Fisheries Centre Research Reports
2006 Volume 14 Number 1

Proceedings of the 2005 North American Association of Fisheries Economists Forum

Fisheries Centre, University of British Columbia, Canada
Proceedings of the 2005 North American Association of Fisheries Economists Forum

edited by
U. Rashid Sumaila and A. Dale Marsden

Fisheries Centre Research Reports 14(1)
220 pages © published 2006 by

The Fisheries Centre,
University of British Columbia

2202 Main Mall
Vancouver, B.C., Canada, V6T 1Z4

ISSN 1198-6727
Fisheries Centre Research Reports 14(1)  
2006

PROCEEDINGS OF THE  
2005 NORTH AMERICAN ASSOCIATION OF FISHERIES ECONOMISTS FORUM

edited by  
U. Rashid Sumaila and A. Dale Marsden

CONTENTS

DIRECTOR’S FOREWORD ...................................................................................................................... 1

EXECUTIVE SUMMARY .................................................................................................................... 2

PART 1: PAPERS ..................................................................................................................................... 3

Prohibited species bycatch in the eastern Bering Sea flatfish fisheries – an analysis of institutions and incentives. Joshua K. Abbott and James E. Wilen ......................................................... 5

Modelling short-term choice behaviour of Danish fishermen in a mixed fishery. Bo S. Andersen and Anne-Sofie Christensen ........................................................................................................ 13

Modeling effects of habitat closures in ocean fisheries. Matthew Berman .................................................................................................................................................................................... 27

High seas fisheries governance: a framework for the future? Stan Crothers and Lindie Nelson ........................................................................................................................................................................ 39

Investing in natural capital – the case of fisheries. Ralf Doering ................................................................ 49

The catch 22 of licensing policy: socio-economic impacts in British Columbia’s commercial ocean fisheries. Danielle N. Edwards, Astrid Scholz, Eric E. Tamm and Charles Steinback ........................................................................................................ 65

The impact of rights-based management regimes on fishery productivity. Stephanie F. McWhinnie ................................................................................................................................................................ 77

Data fouling in marine fisheries: findings and a model for Newfoundland. Kajia I. Metuzals, C. Michael Wernerheim, Richard L. Haedrich, Parzival Copes and Ann Murrin ................................................................................................................................. 87

Early attempts at establishing exclusive rights in the British Columbia salmon fishery. Frank Miller.................................................................................................................................................................................................. 105

Industrial evolution in response to changes in the demand for traceability and assurance: a case study of Chilean salmon aquaculture. Tyler K. Olson and Keith R. Criddle ................................................................................................................................................................................ 123

Optimal location of marine protected areas in an international context. Arjan Ruijs and John Janmaat ........................................................................................................................................................................ 145

An economic analysis of management options in the western rock lobster fishery of Western Australia. Neil Thomson and Nick Caputi .......................................................................................................................... 157

Testing the stability of recreational fishing participation probabilities. Eric M. Thunberg and Charles M. Fulcher ................................................................................................................................................... 165

Improving utilization of the Atlantic sea scallop resource: an analysis of rotational management of fishing grounds. Diego Valderrama and James L. Anderson ........................................................................... 179
Preferences for a buyout program: survey results from U.S. Atlantic shark fishermen.
Charles M. Adams and Sherry L. Larkin........................................................................... 198
Measuring welfare effects of multispecies quota management systems. J. Agar .................. 198
Economic evaluation of marine ecosystem restoration in northern British Columbia.
Cameron H. Ainsworth ........................................................................................................ 198
Valuing U.S. marine habitats: fantasy or fact? Jackie Alder, William Cheung, Gakushi
Ishimura and U. Rashid Sumaila ......................................................................................... 199
Price discovery in laboratory tradable fishing allowance markets with concurrent
leasing. Christopher M. Anderson and Jon G. Sutinen ......................................................... 199
Excessive shares in ITQ fisheries. Lee G. Anderson ................................................................ 200
Framework for the evaluation of socio-economic and environmental indicators of
sustainability in marine ecosystem based fisheries management: The Veracruz
Reef system case. Patricia Arceo, Leonardo Ortiz and Alejandro Granados ......................... 200
Measuring performance in a multi-output industry. Frank Asche, Daniel Gordon and
Carsten Lyng Jensen ............................................................................................................. 200
Experimental analysis of the political economics of fisheries governance. Sam Bwalya,
Christopher M. Anderson and Jon G. Sutinen ...................................................................... 201
Effort response, harvest, and climate in the Gulf of Mexico recreational red snapper
fishery. D.W. Carter and D. Letson ....................................................................................... 201
Socioeconomic impacts of fishery subsidies: a review. Tony Charles .................................. 202
The buyback subsidy problem: time inconsistencies and the ITQ alternative. Colin W.
Clark, Gordon R. Munro and U. Rashid Sumaila ................................................................ 202
Deterrence and compliance in the artisanal Lake Victoria fisheries. H. Eggert and R.
Lokina ........................................................................................................................................ 202
Reconciling the revocable (or impermanent) privilege of IFQs with economic needs of
fishermen. Mark Fina and Joseph Sullivan .......................................................................... 203
Fraser salmon and the species-at-risk act: socio-economic impacts. Gordon S. Gislason......... 203
Genetic resources for fun and profit – the role of the interest rate in natural selection.
Atle G. Guttormsæn, Dadi Kristjófsson and Eric Nævda ..................................................... 204
Bering Sea pollock fisher response to the Steller sea lion conservation area. Alan C.
Haynie and David F. Layton ................................................................................................ 204
Dynamic discrete choice modeling: Monte Carlo analysis. Robert Hicks and Kurt E.
Schnier ...................................................................................................................................... 205
Individual habitat quotas for fisheries: the influences of regulatory scale and spatial
heterogeneity. Daniel S. Holland and Kurt E. Schnier .......................................................... 205
Fisheries cooperatives – varieties and consequences. Daniel D. Huppert and Jennifer
Kassakian .................................................................................................................................. 206
Treadmill effects and capitalization of resource rent in Norwegian fisheries. Gakushi
Ishimura and Rógvaldur Hannesson .................................................................................... 206
Global cost and regional benefit of open ocean aquaculture with ocean nourishment.
Ian S.F. Jones and Ibrahim Al Tarawneh ................................................................................ 206
A dynamic spatial model to predict net distribution of fishing effort in relation to
to changes in fish abundance in the global tuna longline fishery. Heather Keith,
Carl Walters and U. Rashid Sumaila ...................................................................................... 207
Process and policy issues for decentralized fisheries governance in the northeast U.S.
Andrew W. Kitts and Patricia Pinto da Silva .......................................................................... 207
Challenges in restructuring Alaska salmon fisheries. G. Knapp and F. Ulmer .................... 208
Assessing resource and environmental changes: are texts a hazardous product? Jack L.
Knetscb ...................................................................................................................................... 208
High-grading in a quota-regulated fishery, with empirical evidence from the Icelandic
cod fishery. D. Kristjófsson and K. Rickertsen .................................................................. 208
Simulating with ISIS-Fish V2.0 the dynamics of a north-east Atlantic mixed fishery
subject to spatial closures. Stéphanie Mahéva, Dominique Pelletier, Paul
Marchal, Olivier Guyader, Raul Pelleazo and Marina Santurtún ............................................ 208
Entering and exiting a fishery: a strategic choice? S. Mardle and T. Hutton ......................... 209
International trade, fisheries, and Canadian marine ecosystems: an empirical analysis.  
A. Dale Marsden and U. Rashid Sumaila ........................................................................210

Ecosystem of a small lake (Kawahara-ōike, Japan) invaded by two alien species: 
bluegill Lepomis macrochirus and largemouth bass Micropterus salmoides. 
Takashi Matsuishi, Md. Monir Hossain, Akira Goto and Mikio Azuma .......................210

Decision structuring to alleviate embedding in environmental valuation. Timothy L. 
McDaniels, Robin Gregory, Joseph Arvai and Ratana Chuenpagdee ............................... 211

A preliminary look at the Hawai’ian swordfish regulations at reducing sea turtle 
bycatch. Jeffrey K. O’Hara and Theodore Groves ..........................................................211

Importation of tasteless smoke (CO) treated tuna and its impacts to local market and 
fisheries. Minling Pan and Timothy Ming ....................................................................... 211

Risk-shifting in farm-raised catfish marketing channels. K. Quagrainie and I. Neira ........212

Stranded capital and impacts to processors of ITQs. Kate Quigley ....................................212

Modeling economic efficiency in a fishery: the Norwegian cod trawl fishery. Kristin H. 
Roll, Frank Asche and Atle G. Guttormsen ..................................................................213

Protecting marine biodiversity: a comparison of individual habitat quotas (IHQs) and 
the marine protected areas. Kurt E. Schnier and Daniel S. Holland ................................. 213

Outside the realm of economics: what are the implications of environmental ethics for 
fisheries management? Donald M. Schug .......................................................................213

Spatial management of metapopulations in fisheries: the bioeconomic effects of source- 
sink configurations. J.C. Seijo and J. F. Caddy ............................................................... 214

Valuing ecosystem services with fishery rents: a lumped-parameter approach to 
hypoxia in the Neuse River estuary. Martin D. Smith and Larry B. Crowder .................. 214

A hierarchical Bayes approach to discrete choice fisheries modeling: the effect of 
marine reserves on fishing behaviour. Martin D. Smith, Junjie Zhang and 
Felicia C. Coleman ..............................................................................................................215

Amending the Alaska halibut/sablefish IFQ program to address community needs. P.J. 
Smith ....................................................................................................................................215

Ecological and economic analysis of sablefish aquaculture in British Columbia. U. 
Rashid Sumaila, John Volpe and Yajie Liu ......................................................................216

On the economics of fisheries governance: a Presidential address. Jon G. Sutinen .........216

The economic costs of regulation: a bioeconomic comparison of legislative mandates 
for rebuilding fish stocks in the United States and New Zealand. Gil Sylvia, 
Sherry L. Larkin and Michael Harte ................................................................................... 216

Bayesian estimation of technical efficiency in fisheries. D. Tomberlin, X. Irz and G. 
Holloway ................................................................................................................................217

Beyond ITQs: transactions costs and self-governance in New Zealand. Ralph E. 
Townsend ..............................................................................................................................217

The effect of regulatory regimes on productivity development in fisheries: a 
comparative country study. Ragnar Tveteras and Hakan Eggert ......................................... 218

Market power, sharing rule and fishery co-management. H. Uchida and J. Wilen ............218

Moving toward market based management regimes: implementing days at sea leasing 
in the northeast (USA) multispecies fishery. John B. Walden and Charles 
Fulcher .................................................................................................................................. 219

Like counting sheep from a helicopter on a cloudy day: the effects of scientific 
uncertainty on stock assessment and ITQ fisheries management. T. Yandle .......................219

The contribution of fisheries to GDP: underestimating the role of small-scale fisheries. 
Dirk Zeller, Shawn Booth and Daniel Pauly ...................................................................... 220

A Research Report from the Fisheries Centre at UBC

220 pages © Fisheries Centre, University of British Columbia, 2006

Fisheries Centre Research Reports are abstracted in the FAO Aquatic Sciences and Fisheries Abstracts (ASFA) 
ISSN 1198-6727
DIRECTOR’S FOREWORD

As Director of UBC’s Fisheries Centre, it is a pleasure to introduce these proceedings, which document an event, the 3rd Biennial NAAFE Forum, held on May 25-27, 2005 that UBC was proud to host. This was one of the many events that UBC hosts in the course of a year, all proofs of our role as a major research university - although I must admit that it probably helps that UBC is located at the edge of Vancouver, which besides being regularly elected, along with Zurich, as one of the best city in the world to live in, also has the attractions to make it a superb place to visit.

However, it is as researcher and fisheries biologist that I am most pleased with these proceedings. They cover a wide range of topics, documenting, in the process, the enormous variety of conceptual and methodological approaches which economists deploy to study fisheries. To me, this is exhilarating, indicating as it does, that there is, across the disciplinary divide, as much to discover and work with, as on my own multifaceted side of that divide.

In fact, if we could match, or better ‘pair’ each of these concepts and methods with concepts and methods from the discipline across the divide, we would perhaps achieve the understanding and cooperation most of us seek, but mostly fail to achieve because we do not consider the same assumptions realistic and useful, and apply different methods to study the same fisheries.

This would also allow us to make more of the available data, which are often costly to get, especially if they are to be reliable. And, more importantly, this would allow us to see the same fisheries from several angles, with each facet reflecting its own light. Or to use another metaphor, the different disciplinary accounts would ‘jump together’, i.e., lead to ‘consilience’ as defined in E.O. Wilson’s book of the same title.

Consilience between fisheries economics and fisheries biology should not be hard to achieve: we study the same fisheries, and the biological signals from the species being exploited to the fishers, and thence the economic signals to the markets where the catch is sold, and back to the resources that fishers deploy to catch fish, have to be coherent, and reflect the same reality. The distinct accounts of biologists and economists must be consilient if they are to reflect that underlying reality. This offers a powerful, test, independent of, and additional to the disciplinary ‘validation’ that may be undertaken. Such consilience tests, however, are all too rarely performed, and our accounts, rather than jump, or at least stand together, just simply hang together. Perhaps this is one of the many reasons why we – biologists and economists alike - often fail to reach our intended audience, to the detriment of the fisheries which would benefit from our accounts being given more credit than they usually are.

These then, are some of the thoughts I had while reading these proceedings; I hope they inspire other readers to think of consilient, cross-disciplinary, cooperation.

Daniel Pauly
Director, Fisheries Centre, UBC.
EXECUTIVE SUMMARY

This report documents all the presentations given at the North American Association of Fisheries Economists (NAAFE) Forum held at the University of British Columbia in May, 2005. In all, 67 papers were presented at the Forum. The report is divided into two parts. The first contains the 14 full papers that were offered by their authors for publication in the Proceedings. The second part contains abstracts of the remaining papers. The 14 full papers covered topical issues in fisheries economics including the analysis of bycatch economics and management, choice behaviour of fishers, modeling the economic effects of habitat closures, licensing policy, rights-based management regimes, traceability, marine protected areas and the economic analysis of recreational fisheries. In addition to this Proceeding, two other publications are planned from the papers presented at the Forum. These are special issues of (i) Land Economics, and (ii) Marine Resource Economics. These volumes will contain a few out of the 67 papers given at the Forum after the usual review process.

We are grateful to our numerous sponsors, including: the US National Marine Fisheries Service, NOAA; The Sea Around Us Project, UBC; Hampton Research Endowment Fund, UBC; Aquatic Ecosystem Science Section, Province of British Columbia; Canadian Sablefish Association; Octaform Concrete Forming Systems; Faculty of Graduate Studies, UBC; and the Natural Resources Defense Council.

Rashid Sumaila and Dale Marsden
Editors
1 May 2006
PART 1: PAPERS
PROHIBITED SPECIES BYCATCH IN THE EASTERN BERING SEA FLATFISH FISHERIES – AN ANALYSIS OF INSTITUTIONS AND INCENTIVES

Joshua K. Abbott ² and James E. Wilen
Department of Agricultural and Resource Economics
University of California Davis
One Shields Avenue
Davis, CA 95616

ABSTRACT
This paper outlines an ongoing project to examine the prohibited species catch (PSC) avoidance behavior of catcher processor vessels in the Bering Sea flatfish fisheries under the current regulatory system of PSC and target quotas and spatial closures. We describe the history of the fisheries and examine the nature of the incentives provided by the regulatory system. We then develop a random utility model of fishing location choice that allows us to uncover the implicit tradeoffs fishermen make between target and bycatch species and show how this model can be estimated using haul level data provided by the North Pacific Groundfish Observer Program. We then describe how this specification can be extended to shed light on a number of important policy considerations, including the efficacy of a voluntary bycatch avoidance program and the impacts of spatial closures.

INTRODUCTION
The flatfish fisheries of the Eastern Bering Sea (EBS) present a significant challenge to both regulators and fishermen aiming to reduce the bycatch of non-targeted species. The inherent limitations to the selectivity of trawl gear combined with the spatial coexistence of target and non-target species make the avoidance of bycatch very difficult. This has been particularly true for those species designated as prohibited species catch (PSC) – high-value species that may only be retained for sale by particular user groups and/or gear types. PSC bycatch has historically been at such a severe level that regulators are usually forced to close fisheries long before the quotas of target species are taken in order to avoid excessive PSC catch. In an effort to avoid this scenario, many fishermen contracted with a private organization, Sea State Inc., to help them identify and avoid PSC "hot spots".

This paper presents an empirical model to study the nature of fishermen’s incentives to avoid bycatch, the impact of Sea State on these incentives, and the probable impact of regulatory actions (such as spatial closures) on bycatch outcomes. The first section describes the history of the flatfish fisheries, the regulatory strictures meant to address the bycatch problem, and the voluntary measures taken by fishermen to avoid bycatch. Section two enumerates the data that are available for an empirical investigation and describes their strengths and shortcomings. The third section describes the primary research questions and presents an empirical model structure to address these questions. The fourth section briefly discusses the challenges involved in implementing the empirical model and concludes the analysis.

² Email: abbott@primal.ucdavis.edu
³ We do not attempt to summarize the small but growing economic literature on bycatch. For a thorough summary of this literature, see Abbott (2004).
I. THE FLATFISH FISHERIES OF THE EBS

The EBS flatfish complex is composed of four primary species: yellowfin sole (*Limanda aspera*), rock sole (*Lepidopsetta bilineata*), flathead sole (*Hippoglossoides elassodon*), and Alaska plaice (*Pleuronectes quadrituberculatus*). These species spend the vast majority of their time on or near the ocean floor and occupy different depths depending upon the season of the year and oceanographic conditions such as ice cover and water temperature. Generally, in the spring and summer (when most fishing occurs) the fish migrate from their wintering grounds on the outer continental shelf to the more productive waters above the 100m isobath in order to feed and spawn. Although trawl surveys and analyses of fishing data have uncovered variations in the central tendencies of population densities across species, they all overlap to a substantial degree such that a given haul may contain substantial proportions of each species (Spencer, Wilderbuer and Zhang, 2002; Wilderbuer, Bakkala and Walters, 1992).

Of the four species in the flatfish complex, yellowfin sole and rock sole are the most populous and draw the largest fishing effort. Rock sole is targeted both for its roe in the early season and (to a lesser degree) for head and gut product (H&G) in the remainder of the year while yellowfin sole is targeted primarily for H&G production from the spring onward. Flathead sole comprises a relatively small fishery by comparison while Alaska plaice is considered a "trash" species and is rarely landed (Spencer, Walters and Wilderbuer, 2004). Altogether, the EBS flatfish fishery is participated in by a fleet of around 25 vessels of moderate size (between 110-210 feet in length) and many of these vessels participate in other fisheries, such as the trawl fisheries for cod or atka mackerel, at other points in the season.

The bycatch of prohibited species catch (PSC) has a long and contentious history in the flatfish fishery. Due to their high value in targeted fisheries, PSC bycatch is strictly limited by quota allocations to different target fisheries or fishery groups. Three of these species are important to the flatfish fisheries in that their bycatch has frequently limited the ability of vessels to efficiently harvest the target species; these are Pacific halibut, red king crab, and *C. bairdi* Tanner crab. The bycatch of these species is primarily managed by a complex regulatory system of spatial and temporal controls tied to underlying quotas for both PSC and target species. In the case of flatfish, there are two target groups for the division of PSC quota, yellowfin sole and the rock sole/other flatfish group (which includes Alaska plaice and flathead sole). The quotas for the crab species are defined over two large sub-areas which comprise the vast majority of the habitat for these species while that for halibut is defined over the entire Bering Sea/Aleutian Island (BSAI) regulatory area. If at some point in the season regulators perceive that fishermen in one of the two groups are poised to exceed their allocation of a PSC species, the entire fishery will be closed to directed fishing, meaning that only minimal amounts of that species group may be landed.

An undesirable side effect of this regulatory system is that it does little to squelch the individual incentive to participate in the "race for fish". It is largely a foregone conclusion that the avoidance of bycatch is accompanied by a reduction in the harvest of targeted species; therefore, since both target and PSC quotas are common pool resources, it should come as no surprise that PSC quotas have frequently necessitated premature closures of the flatfish fisheries (Gauvin, Haflinger and Nerini, 1995).

By 1995, many of the fishermen in the H&G fleet had grown tired of "leaving money on the table" through premature closures; as a result, the rock sole fishermen contracted with Sea State to provide them with rapid feedback on bycatch rates for all subscribing vessels (the yellowfin fishermen joined later that season). Data from federal observers was relayed to Seattle where Sea State processed the information, performed statistical extrapolations to account for non-sampled hauls, and then either faxed or electronically transmitted to each vessel a spatial display of individual vessel bycatch rates (displayed at a

---

4 Rock sole are an exception in that they are very early spawners, with the majority of spawning activity occurring between December and March. This makes them the source of a short but lucrative roe fishing season between late January and March.
5 Fishing in the BSAI is also heavily constrained by a complex network of spatial closures that have been implemented for a wide variety of (primarily biological) reasons. Many of these closures are permanent in nature and are implemented without reference to the quota status of the fisheries.
6 Another form of bycatch avoidance employed in the BSAI is gear modification. Attempts to reduce bycatch of PSC species while retaining targeted species have met with some limited success (Stone and Buhlitz, 1995; Loverich, 1995); however, when species are similar in size or shape, reductions in bycatch are frequently met by countervailing decreases in fishing efficiency – leaving fishermen little incentive to adopt such technologies when claims to harvest are allocated by the rule of capture.
7 The authors have developed a simple game-theoretic model to explain the bycatch behavior of fishermen in a multispecies fishery with aggregate quotas on both target and bycatch species (Abbott and Wilen, 2005).
resolution of one minute of latitude and longitude) for each PSC species. This mechanism greatly lowered the "search costs" associated with bycatch avoidance in that it pooled in a timely and clear manner a substantial portion of the information possessed by each vessel captain. At a later date (in the early 2000s) participants were also provided with a list of vessels and their weekly bycatch rates so that pressure might be brought to bear on vessels whose catch was more "dirty" than the agreed-upon standard.

The program continues today and its proponents have claimed some major successes, including a sevenfold decrease in red king crab bycatch in the roe rock sole fishery within the program's first year (Gauvin, Haflinger and Nerini, 1995). However, critics have charged that this reduction was largely the result of a concurrent closure of a large area with very high past rates of crab bycatch (Holland and Ginter, 2004). Also, the reduction in crab bycatch was met by an attendant rise in halibut bycatch rates; indeed, the rock sole fishery slightly exceeded its allocation of halibut in 1995 and has exceeded it for all but one year since. The implementation of Sea State's technology in the yellowfin sole fishery in the summer of 1995 appears, on the surface at least, to have yielded disappointing results. The excess of halibut PSC catch over quota has actually increased dramatically since the program's inception. A variety of hypotheses have been advanced to explain this finding, including a dilution of the incentive to cooperate by the refusal of four vessels to participate in the program (Gauvin, Haflinger and Nerini, 1995), strong recruitment of halibut into the fishery in the late 1990s, displacement of effort from areas closed for crab protection, and low yellowfin prices (Holland and Ginter, 2004). Given the large number of confounding factors at play in the data, it is difficult to imagine that the success or failure of the program can be adequately judged by a simple before-and-after analysis of bycatch rates (or even a more sophisticated reduced form econometric approach). What is needed, instead, is a model that allows one to uncover the incentives created by the Sea State program as reflected in the alterations to agents' implicit willingness to trade catch of targeted species for declines in PSC bycatch. However, an understanding of what data are available to construct such a model is paramount.

II. AVAILABLE DATA

The groundfish fisheries of the North Pacific are some of the most heavily monitored fisheries in the world, and thus both the quantity and quality of disaggregated data is unusually high. There are four data sources that together should provide the majority of our dataset:

- Federal observer data;
- State of Alaska fish tickets;
- National Marine Fisheries Service (NMFS) data on vessel characteristics; and
- Private data from Sea State/vessels.

In order to monitor and enforce regulations in the groundfish fisheries, vessels must provide a licensed observer at their own expense. Vessels between 60-125 feet must have an observer onboard for 30% of their trips while vessels 125 feet and larger (which includes the majority of the H&G fleet) must provide an observer 100% of the time. Due to the diversity of duties performed by observers, one can expect around 50% of on-duty hauls to be sampled for species composition — effectively ensuring 50% coverage on large vessels and 15% coverage on smaller vessels. Observers collect a wide array of useful information, but for the purpose of this study the most important variables are those describing the location of gear retrieval (up to a minute of latitude and longitude), the duration of the tow and average speed, and, importantly, estimates of the total weight of each species contained within a haul and a rough approximation of the percentage of the catch of each species that was retained onboard.

The amount of information contained within the observer data is substantial; however, it is far from perfect. First, since not every haul is sampled, there is a possibility that fishermen adjust their fishing behavior according to whether they anticipate a haul will be sampled. On large vessels (where an observer is always present) there may be less cause for concern since observers are instructed to randomly
determine the sampled hauls and not announce beforehand whether a haul will be selected. Small vessels do not always carry observers and so it is safe to assume that their behavior varies dramatically with an observer present. A second concern is that species composition information is the result of observers sampling a portion of the haul, a noisy signal of the actual catch. However, to the extent that the sampling scheme is random – observers do receive extensive training in random sampling techniques – it does provide an unbiased signal. Thirdly, estimates of retained catch are often suspected for the reason that the sampling protocol is primarily designed to ensure that total catch is accurately measured for the purpose of quota tracking. The disposition of catch is something of an afterthought. Despite these shortcomings, observer data is widely believed to be reasonably trustworthy without special statistical manipulation, particularly if the analysis is restricted to vessels with 100% coverage (as we plan to do) and little emphasis is placed on the retained catch data.

Fish ticket data contains information for the landing of fish within the State of Alaska. This information is primarily useful in that it contains information on the quantity and value of each species and derived product landed by vessels that are required to submit fish tickets to the State of Alaska. This information may be useful for developing measures of fishermen’s price expectations. There are some problems with its use, however, in that many vessels (including many of the vessels in this study) are not required to file fish tickets and so the price information they provide is partial at best. Supplementing these data with export price data – much of the H&G and roe product is shipped to Japan and other foreign markets – may be necessary.

Data on vessel characteristics is assembled from both State of Alaska and federal sources, as some fields are considered more reliable from one source than the other. The data is indexed so that it may be linked to vessel identifiers in the observer and fish ticket data and contains a number of useful data fields such as vessel length and tonnage, horsepower, hold and fuel capacity, and the identity of the owning company.

In addition to these official data sources, we possess information, provided by Sea State itself, on the participation status of individual vessels over time in the program. Such information is invaluable in a micro-level model in that it will allow us to test for discernable differences in the preferences of those fishermen that chose to participate in the program versus those that did not.

III. RESEARCH QUESTIONS AND MODEL SPECIFICATION

Given the complexity of the multispecies flatfish fishery and the considerable depth of the data, one may entertain a variety of hypotheses in an empirical model. However, the following questions appear especially interesting and relevant to fisheries policy:

1. To what degree (if at all) do fishermen trade off bycatch for target species under the quota system?

2. How do the implicit values placed by fishermen on PSC species compare to their demonstrated market value in their targeted fisheries?

3. Did participation in the Sea State program strengthen fishermen’s incentives to avoid high bycatch areas?

4. How does bycatch avoidance behavior evolve over the course of the season? Do fishermen exert more care early in the season when much of the PSC quota remains unclaimed than they do later in the season?

5. Did the closure of an area known as the Red King Crab Savings Area (RKCSA) to avoid bycatch of crab do more harm than good by so drastically reducing fishermen’s choice sets that they found themselves unable to effectively avoid the bycatch of halibut?

Providing satisfactory answers to these and other questions requires a model of considerable flexibility that can be employed on a large dataset composed of repeated choices made by several agents over a fine grid of both time and space. One such model, which has the pleasant side effect of a firm grounding in

---

8 However, discarding behavior may very well adjust since at some point during the processing of the catch it becomes obvious whether an observer is actually sampling the catch or not.
economic theory, is the random utility (RUM) model. The application of the random utility modeling framework in studies of fisheries location choice is nothing new. Bockstael and Opaluch (1983) pioneered its use in a simple conditional logit framework in their study of the supply responses of New England fishing firms, and the basic model has been extended in a number of directions since. In its most simple incarnation, the attractiveness of a particular fishing ground, \( n \), is posited to depend upon the expected revenues from choosing to fish at a particular ground at a particular time, \( t \), less the variable costs (such as costs of fuel and the opportunity cost of time spent fishing) associated with the choice. Finally, an additive stochastic term is appended to the model to account for characteristics of the decision maker and location that are unobserved by the analyst but are assumed known to the fishermen. Fishermen then engage in comparisons of fishing ground choices and select the one yielding the maximal expected profit. To account for the fact that captains may also take into consideration the likely bycatch at a fishing ground, the basic model is simply expanded by appending an additive bycatch "penalty function" to the deterministic portion of utility. Mathematically, fishermen solve the following problem over space with each deployment of the net:

\[
\max_n U_{int} = E_i(Revenue_{nt}) - VarCost_{int} + \lambda \cdot E_i(b_{nt}) + \epsilon_{int}
\]

\( E_i(b_{nt}) \) is a vector of expected bycatch amounts for the three PSC species (where expectations are potentially idiosyncratic across vessel captains) while \( \lambda \) is a vector of implicit prices of bycatch that is to be identified by the choice behavior of fishermen. These prices may encapsulate a number of factors including (1) environmental (i.e., bycatch avoiding) preferences, (2) the direct costs of bycatch due to time spent sorting and discarding PSCs, (3) a dynamic shadow value embodying the perceived personal value of a unit of bycatch in allowing increased harvest opportunities in the future, and (4) a fear of retribution from other fishermen in return for increased bycatch. In a fishery with a sizable number of participants – such that an individual fisherman has little chance of benefiting from his own conservation – and little within-group enforcement effort it is reasonable to suppose that \( \lambda \) is either zero or very slightly negative due to the direct costs of PSC discard.

To transform this specification into one that is estimable requires a bit more work. First, it is likely that prices of target species can be treated as known by all fishermen at a given point in time. This allows expected revenues to be decomposed into the product of a vector of prices and a vector of expected catch quantities. Furthermore, given the lack of reliable data on variable costs for this fleet, we hypothesize (as is common in the literature) that the variable costs of choosing to fish in site \( n \) can be written as a nonlinear function of the distance from one’s current location to that site \( dist_n \), a set of observable vessel characteristics \( (char_i) \), such as vessel length and horsepower, and a vector of estimable parameters \( (\alpha_i) \). The random utility function may now be written,

\[
\max_n U_{int} = p \cdot E_i(Catch_{nt}) - VarCost(dist_n, char_i, \alpha) + \lambda \cdot E_i(b_{nt}) + \epsilon_{int}
\]

The first and second research questions may be readily answered by estimating this model on a subsample of the observer data and, for the second question, directly comparing the \( \lambda \)'s (which are in monetary units) with contemporaneous prices for PSC species in their targeted markets. The particular years and fishing seasons employed in the sample depends to a large degree on the particular purpose of the estimation, although care should be taken to avoid applying such a simple model on too long or broad a sample.

---

9 For example, Smith and Wilen (2002) utilized a nested logit to jointly model the participation and site location decision of urchin fishermen. Holland and Sutinen (2000) utilize a nested logit model to capture a two-part process for selecting a fishing ground. Mistiaen and Strand (2000) use a random parameters formulation to account for heterogeneous risk preferences between fishermen. Curtis and Hicks (2000) consider the joint choice of targeted species and fishing location while also accounting for the dynamic attributes of multi-part trips. This is, of course only a partial account of a growing literature.

10 We have assumed, for now at least, that the later decision of how much of each species to discard can be considered independently of the site choice decision. Such a decision may be of questionable realism, but the lack of reliable, haul-level discard data precludes any joint modeling of the location/discard choice process.

11 In practice, interactions of vessel characteristics and distance are frequently linearly inserted into the utility function, although more complex parametric specifications may be used as well.

12 Alternatively, one may allow the parameters to vary over time and/or individuals to broaden the applicability of the model.
Answering the third question (concerning the impact of Sea State) requires that we have a stretch of time in the sample in which nobody belonged to the program as well as a period in which some people belonged while others did not. Fortuitously this is the case as data exists prior to program implementation in 1995 and some yellowfin sole fishermen initially chose not to participate. These facts allow us to specify the elements of $\lambda$ in a traditional difference-in-differences format (see Wooldridge, 2002) as follows:

$$
\lambda_j = \alpha_j + \beta_j SS + \gamma_j PostSS + \delta_j (SS \cdot PostSS)
$$

The effect of Sea State participation on fisherman’s shadow value for PSC species $j$ is captured by $\delta_j$. If these parameters are found to be significant and negative, then this lends support to the hypothesis that Sea State participants were more likely to avoid areas with PSC bycatch than non-participants. If the signs of the $\delta_j$’s differ between species, this may suggest that participation had very different impacts upon incentives depending on the species of concern. Investigating the impact of Sea State in this structural framework is arguably superior to a reduced-form approach based on bycatch outcomes since it is possible in this model for fishermen’s incentives to avoid bycatch to have improved due to Sea State without any discernible lowering in their bycatch rates (due to confounding biological conditions, management actions, etc.).

The fourth question is a potentially complex one. A fisherman’s willingness to trade between bycatch and targeted species throughout a season likely depends on a number of latent factors such as the expected bycatch of one’s competitors and the expected short-term entry/exit of other vessels. Although it is feasible to theoretically model such factors (in, say, an intra-seasonal differential game) it is difficult to directly incorporate them into an empirical specification given that most of the variables of concern will be unobservable. However, it is possible to specify the $\lambda_j$’s as functions of elapsed time within the season or, better yet, as functions of the amount of non-harvested target and PSC quotas at each point in time. It is possible that most fishermen begin a season with every intention of exerting care to avoid bycatch; however, as the season progresses and they begin to receive signals that some of their competitors are fishing less carefully, they may choose to harvest in a more bycatch intensive manner in order to punish noncooperative fishermen or to simply ensure that they receive their share of the quota. Such behavior would be consistent with an upward trend in the $\lambda_j$’s of the empirical model as the season progresses.

The application of RUM models to predict the impacts of spatial closures in fisheries has become increasingly common since Smith and Wilen’s (2002) contribution. Question 5 deviates from the typical case only slightly in that the counterfactual to consider is what would have happened to fishermen’s choices of locations (and thus the composition of bycatch) if the RKCSA had not been implemented. This question may be approached in three steps. First, one must estimate the basic RUM model using a representative sampling of the fleet. Second, one must impute reasonable values for the expectations of target and bycatch variables in the RKCSA closure if it had not been closed during the time in which it was actually closed. This may be done in a variety of ways. For instance, biological survey trawls in the area may be of sufficient temporal and spatial resolution to directly impute the values. Failing this, both catch and non-catch data from before the closure may be used, in either a bioeconomic model or a more ad-hoc projection framework, to provide reasonable estimates. In the third step, one treats these imputed values as data and use them along with the original data to predict the pattern of behavior that was most probable had the RKCSA not been implemented. The bycatch patterns that emerge from this prediction can then be compared to the actual pattern to judge the impact of the closure. It may be that much of the post-1995 reduction in red king crab bycatch was in fact due to the closure rather than anything new in fishermen’s behavior. It may also be that the attendant rise in halibut bycatch was largely attributable to the closure as well.

IV. CONCLUSION

The previous section demonstrates how a variety of empirical questions of significant policy relevance may be addressed within the overarching framework of a random utility model of fishing location choice. The basic architecture of the model is well within the scope of the literature, but, if applied successfully, it should nevertheless contribute some important innovations. First, it will be the first study to the authors’ knowledge to extend the expected profit/utility maximization framework to include the catch of "non-targeted" species in the calculus of where to fish. In doing so we hope to supplement the insights from the economic literature on bycatch by bringing a careful spatial and empirical focus to a topic that has
previously been considered from a largely theoretical and aspatial perspective. Second, unlike previous models of fishing location choice which have largely focused on predicting the micro-level spatial choices of fishermen making short trips or the macro-level spatial decisions of fishermen engaged in longer trips, this model purports to explain the decisions of fishermen engaged in long (two to four week) trips on a very fine spatial and temporal scale. This is made possible by the use of an unusually deep and detailed dataset on the repeated choices of fishermen as represented by the federal observer database.

Undoubtedly there are several challenges that must be dealt with in order to successfully implement this model. A full discussion of these issues is not within the scope of this document; nevertheless, a brief accounting of two primary issues is in order. First, the variables defining the agents’ expectations over target catch and bycatch for individual areas are intrinsically latent and must be specified in a defensible way by the analyst. Past studies have utilized a variety of methods including bioeconomic models (Smith and Wilen, 2002), simple zonal averages of catch and/or revenues (Mistiaen and Strand, 2000; Holland and Sutinen, 1999, 2000), or more complex methods from spatial and time series econometrics (Curtis and McConnell, 2004; Curtis and Hicks, 2000). Some recent work has focused on jointly estimating the expectations variables along with the parameters of the RUM model (Layton, Haynie, and Huppert, 2003). Each of these methods has its unique set of advantages and introduces its own set of biases into the analysis – there is no universally accepted way of addressing this problem.

Secondly, the properties of the errors in the RUM model are very important, particularly since the errors may potentially be correlated over both space and time and the use of an improper distributional assumption in a nonlinear model can easily lead to inconsistent as well as inefficient estimates. Furthermore, the assumptions made on the error distributions may have significant connections to the way in which the spatial cognition of fishermen is represented. For instance, assuming that the errors come from the generalized extreme value family of distributions allows one to view fishermen as sequentially choosing from a nested set of larger and smaller zones. This hierarchical view of spatial choice has considerable intuitive appeal and has been applied in several studies (Eales and Wilen, 1986; Holland and Sutinen, 1999, 2000). The nested logit model also has some ability to capture dynamic aspects of site choice (Curtis and McConnell, 2004; Curtis and Hicks, 2000).

The way in which these and other technical issues are settled in the empirical specification is of great importance to the believability of the final results. However, these concerns are not limited to this particular modeling context; a survey of the literature reveals that they have plagued virtually all work in the empirical spatial modeling of fisheries. Any advances along these fronts will not only reinforce the strength of the empirical results but potentially aid in future research.

ACKNOWLEDGEMENTS

Support for this research was provided by NOAA Grant No. NA07RG0320, project number E/MRE-4.

REFERENCES


*The exact spatial scale of choice has not been specified, but the unit of temporal observation is the individual haul.*


MODELLING SHORT-TERM CHOICE BEHAVIOUR OF DANISH FISHERMEN IN A MIXED FISHERY

Bo Sølgaard Andersen
Danish Institute for Fisheries Research,
Chalottenlund Castle, Dk-2920 Charlottenlund, Denmark

Anne-Sofie Christensen
The Institute for Fisheries Management and Coastal Community Development,
North Sea Centre, PO Box 104, DKK-9850 Hirtshals, Denmark

ABSTRACT

Studying short term choice behaviour in commercial fisheries has mainly been an economic discipline. In this study we apply a more multidisciplinary approach to improve the understanding of how the decision of the fishermen are made on where and how to fish. Information from questionnaires with fishermen is applied to identify important factors influencing short term decision making process. We present a random utility model including the findings from the questionnaires to analyse individual Danish gillnet vessel spatial effort allocation based on information from official logbooks. The model is used to predict the reallocation of fishing effort for the Danish North Sea gillnet fleet before, under and after an area closure.

INTRODUCTION

An issue raised in fisheries science during the past years has been the low precision in predictions of the biological and economic impacts of changes in the technical measures (closed areas, mesh size regulation, etc.). In particular, the concern has been the narrow focus on only the biological analyses, disregarding the responses of the fishermen to changes in resource availability, market conditions and management regulation itself (Hilborn and Walters 1992; Wilen et al. 2002). The importance of including fishermen's behaviour to improve the development of efficient fisheries management has long been realized (Wilen 1979; Hilborn and Walters 1992; Charles 1995), but practical progress towards integrating the issues into the processes of stock assessment and management have been slow. The study of fishermen's behaviour is not a new discipline in fisheries sciences, however, most of these are descriptive work studies of the spatial and temporal effort allocation of selected fisheries whereas only a few studies have attempted to develop predictive models for fleet dynamics and fishermen responses to changes in external factors (see Walters and Martell 2004).

Analysing fishermen's behaviour can be structured in two levels in terms of time response scale: Long and short terms behaviour response (Hilborn 1985; Salas and Gaertner 2004). Long term behaviour (strategies) is year to year changes in the dynamics of the capacity of the fleet (fleet efficiency or number of vessels entering or leaving the fishery due to decommission, investment or attrition). Short term behaviour (tactics) are mainly made on basis of a trip and generated by the decision that fishermen make about when and where to fish (in terms of choice of fishing location, target species or type of gear/rigging) and which fish to land or discard. This paper will focus on the short term behaviour in terms of the spatial and temporal allocation of effort in a mixed fishery.

2 Email: bsa@dfu.min.dk
Economic theories suggested that the distribution of fishing effort would be determined by the expected profit return for individual fishermen from fishing in alternative areas (or fisheries) (Gordon 1953). This means that the fishing effort will be distributed in such a way that the average profit rates equalizes among the alternatives (in the ecological literature this hypothesis is better known as the ‘ideal free distribution’ theory). This hypothesis has been successfully adopted in relatively simple case studies (one or two species, limited number of areas and homogenous vessels in terms of physical characteristics) to analyse and predict the spatial allocation of fishermen (Gillis et al. 1993; Hilborn and Walters 1987; Mangel and Clark 1983; Sampson 1994; Babcock and Pikitch 2000). In latter studies it is assumed that a fisherman has (in most cases perfect) knowledge of other fishermen’s catch success to calculate where he can obtain the highest utility in terms of catch rate in either value or kg landed. In most European fisheries, fishermen have the option to choose among several fishing grounds, where several species can be caught with several types of gear. This complex set of choices makes it more difficult for the fishermen to gain information of his actual profit among the available alternatives at a given time. Then, adding the uncertainty of resources availability (and management regulation), it will be almost impossible for a fisherman to gain knowledge of the actually current profitability among the available alternatives. To obtain information of which alternative a fisherman has to choose to maximise his profit (or catch success) he often makes use of an array of different types of decision factors such as catch expectation, cost, available technology, fishermen past fishing pattern, tradition, availability of the stocks and management regulations (Béné and Tewfik 2001; Hilborn and Walters 1992; Salas and Gaertner 2004). The inclusion of elements from anthropological, biological and economical sciences in fishermen’s short term decision process stresses the need of a more multi-disciplinary approach to improve the understanding of the complex dynamics of fishermen’s short term spatial and temporal allocation of effort (Béné and Tewfik 2001; Charles 1995; Christensen and Nielsen 2005; Wilen 2004).

The main objective for this study is to construct an analytical tool to describe, analyse and model how Danish North Sea gillnetters allocate their effort among a defined number of fisheries (or tactics). First, the information from questionnaires with fishermen is applied to identify important factors influencing short term decision making process. Secondly, the obtained knowledge forms the theoretical background of modelling the behaviour based on quantitative information from commercial fishery (from logbooks, sale slips and vessel register data).

**METHODS AND MATERIALS**

**Danish North Sea gillnet fishery**

The Danish human consumption fishery in the North Sea is characterized by exploiting a wide range of fish stocks (such as cod, haddock, saithe, hake, plaice, sole, turbot and *Nephrops*) with several different types of gears and riggings. One of the larger fleet components in this mixed fishery is the Danish North Sea Gillnet fleet, which, during the last decades, have landed over 50% of the Danish cod quota yearly and contributed to around 30% of the total annual Danish landing (in value) of demersal species in the North Sea (see Table 1). The majority of the vessels in this fleet have their fishing activity in the North Sea, and during the season they shift between different types of fisheries (Ulrich and Andersen 2004).

<table>
<thead>
<tr>
<th></th>
<th>Gillnet/line</th>
<th>Trawl</th>
<th>Danish Seine</th>
<th>Beam trawl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod (kg)</td>
<td>59%</td>
<td>22%</td>
<td>18%</td>
<td>1%</td>
</tr>
<tr>
<td>Plaice (kg)</td>
<td>26%</td>
<td>25%</td>
<td>32%</td>
<td>13%</td>
</tr>
<tr>
<td>Sole (kg)</td>
<td>90%</td>
<td>3%</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Turbot (kg)</td>
<td>59%</td>
<td>25%</td>
<td>3%</td>
<td>10%</td>
</tr>
<tr>
<td>Total landing in kg</td>
<td>34%</td>
<td>33%</td>
<td>16%</td>
<td>4%</td>
</tr>
<tr>
<td>Total landing in value</td>
<td>39%</td>
<td>37%</td>
<td>15%</td>
<td>4%</td>
</tr>
</tbody>
</table>

1 Not included: mackerel, herring, all industrial species, mussels, prawns and shrimps.
Identification of decision factors

To identify important factors influencing on short term the decision making process information from a qualitative study derived from a larger study among all Danish demersal fishermen (Christensen and Nielsen 2005). A qualitative in-depth and semi-structured interview with sixteen fishermen (of which 5 fishermen were gillnetters in the relevant area) was conducted. These fishermen (the respondents) were strategically chosen based on the following background variables: Age, experience in the fisheries, number of days at sea per year, size of vessel, type of gear and active participation in fisheries policy-making. This method was chosen in order to get a thorough and detailed understanding of the situation of each individual fisherman, as this method allows the fishermen as well as the interviewer time to reflect and progress slowly in order to cover all relevant aspects.

In the second step a questionnaire was based on the information obtained from the interviews. The questionnaires were either sent by mail or filled out when visiting the harbours. 789 questionnaires were given/sent out; 271 (of which 44 were gillnetters with home harbours in the North Sea) or 34% of them responded. In the present study the interest was mainly on the part of the questionnaires about the importance of different factors concerning the short term behaviour. From the interview seven factors were identified: (1) the present situation (own experience from recent trips and fish prices); (2) the season/time of the year; (3) weather (wind and currents); (4) regulations; (5) limitation of by-catch; (6) fuel cost or distance; and (7) information from other fishermen. These factors were incorporated in the questionnaire to analyse the importance of the identified factors in the decision making process in terms of choice of fishing ground and choice of target species.

Data for Quantitative Analysis

Data for the quantitative analysis of fishermen’s behaviour were derived from the Danish national fishery database, which was based on commercial fishermen logbooks, sale slips and vessel register data. The database contained information per vessel at trip level, including landing weights and values per species, gear, mesh size, fishing location at a resolution of ICES rectangles and vessel characteristics such as length and tonnages. Data of the North Sea gillnet fleet was extracted from the national fishery database covering the period from 1995 to 2000, where 1995 was only used as an index year to obtain information of individual fishermen past experience for 1996. The Danish demersal fishery in the North Sea is subject to common pool (open access) quota regulation. In the selected time period the TAC for most of the demersal fish species in the North Sea was relatively stable and it was assumed to have minor influence on the choice of target species.

![Figure 1. Map of the North Sea divided into 5 areas.](image)

During the study period a number of vessels within the North Sea gillnet fleet were either inactive or had disappeared from the fleet due to decommission or switch to other fleet groups. Therefore the final data
set was defined to contain vessels which were active during the entire study period and had annual revenue above the minimum revenue criteria that defines a fulltime fisherman set by the Danish Institute of Food Economics. The final data contained 40492 fishing trips, undertaken by 117 vessels. Summary statistics are presented in Table 2.

Table 2. Summary statistics for the Danish North Sea gillnet fleet from 1996 to 2000.

<table>
<thead>
<tr>
<th>Number of trips</th>
<th>Cod</th>
<th>Plaice</th>
<th>Sole</th>
<th>Turbot</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 quarter</td>
<td>5533</td>
<td>1101</td>
<td>110</td>
<td>0</td>
<td>192</td>
</tr>
<tr>
<td>2 quarter</td>
<td>3537</td>
<td>2462</td>
<td>3269</td>
<td>570</td>
<td>306</td>
</tr>
<tr>
<td>3 quarter</td>
<td>4056</td>
<td>810</td>
<td>1211</td>
<td>177</td>
<td>655</td>
</tr>
<tr>
<td>4 quarter</td>
<td>5067</td>
<td>233</td>
<td>71</td>
<td>0</td>
<td>119</td>
</tr>
<tr>
<td>Landing value per unit effort (DKK)</td>
<td>(12898, 12338, 13079, 10599, 11074)</td>
<td>(10341, 10562, 11466, 6938, 8981)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number vessel (per year)</td>
<td>(116, 78, 79, 28, 39)</td>
<td>(0.6, 189.2, 149.0, 92.5, 70.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average vessel length (meter)</td>
<td>(15.5, 14.7, 15.5, 17.4, 14.5)</td>
<td>(3.2, 2.7, 3.0, 3.1, 2.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average vessel horse power</td>
<td>(227.7, 197.2, 233.0, 252.3, 187.6)</td>
<td>(106.8, 83.4, 95.4, 114.0, 94.4)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Standard deviations are given in parentheses.

In the case of complex fisheries, where the fisherman has the opportunity of exploiting different species in several fishing grounds (such as the mixed fishery in the North Sea), the analysis of a fisherman’s fishing activity (on the basis of a trip) has been undertaken through defining types of fishing activities based on main characteristics such as gear used, riggings, fishing grounds and target species. Several approaches have been applied to identify a fishing activity (or fishery/tactic) in mixed fisheries, based on catch and effort data from commercial fishers (Murawski et al. 1983; Lewy and Vinter 1994; Pelletier and Ferraris 2000; Ulrich and Andersen 2004). In a recent study by Ulrich and Andersen (2004) fisheries for the entire Danish fleet were defined, where seven related Danish gillnet fisheries in the North Sea were identified (cod, plaice, sole, turbot and hake, long-line and ‘other’ fishery) based on choice of gear and target species. In the present study the long-line and the hake fishery were grouped in the ‘other’ fishery due to few numbers of trips within the study period. Trips outside the North Sea were not included (<2% of the total number of trips). Based on ad hoc knowledge from historical catch information 5 areas were defined (Fig. 1). In addition, the defined areas were designed to fit the closure of a large fishing area in the North Sea in 2001 (area 2 in Fig. 1). That gave a total of 25 choices (5 target species and 5 areas), however, choices with <100 trips for the entire study period were grouped with nearby fishing areas. The final number combination of fishing area and target species was 16.

**Conceptual framework of empirical model**

In the case where fishermen are confronted with a finite set of alternatives, such as the choice of fishing location, gear, or fishery, a random utility methodology (also better known as RUM) has frequently been applied (e.g., Bockstael and Opaluch 1983; Holland and Sutinen 1999; Wilen, Smith, Lockwood, and Botsford 2002). The basic assumption in the random utility approach relies on the decision makers (fishermen) being assumed to choose the alternative that maximizes his utility, $U_i$. For a given fisherman, $n$, the probability that a particular alternative $i$ is chosen can be expressed as:

$$P_n(Y = i) = P_n(U_{ni} > U_{nj}, \forall j \neq i)$$
where $U$ represents an indirect utility for choice $i$ for a specific fisherman. The utility is expressed by a set of explanatory variables that are summarised to form a systematic component $V_{ni}$ (utility function which is assumed to be linear in the parameters) and a stochastic error component $\varepsilon_{ni}$ (random part):

\[
U_{ni} = V_{ni} + \varepsilon_{ni} = \sum_{s=1}^{S} \beta_s X_{ni} + \varepsilon_{ni}
\]

where $S$ is the number of attributes. The observed utility is based on the findings from the interviews containing the identified decision factors that are involved in the Danish North Sea gillnetters’ decision making process in choice of fishery (or tactic). However, these types of qualitative information are not to be found directly in the fishery database, and proxies were defined for the identified decision factors.

Two types of own experience variables were identified: (1) present knowledge/experiences; and (2) seasonal knowledge/experiences. A Danish gillnetter often makes several trips during a month where he gathers different levels of experiences/knowledge from where he has been fishing. The value of the information a fisherman collects from past knowledge/experience (in terms of catch success) tends to rapidly decline due to the high temporal and spatial availability of the fish stocks (Smith 2000). By assuming the level of recent catch success in a given choice to be proportional with recent effort allocated to that choice, we used the percentage of effort a fisherman has made in each choice during the last month ($\%EFF_{(m-1)}$) as a proxy for attractiveness of fishing in the same choice as in the previous month. The interviews indicated also that Danish gillnetters tend to follow the same fishing patterns as last year due to the seasonal availability of the individual fish stocks. As a proxy for attractiveness of fishing in the same choice as last year, we used the percentage of the effort that the fisherman made in each choice in the same month last year ($\%EFF_{(m-12)}$).

Recent information of other fishermen’s catch success has been a central way to gain information of the expected profit (or revenue) (Bockstael and Opaluch 1983; Smith 2000). To estimate a fisherman’s expected revenue, various types of expectation models have been applied ranging from simple approaches, such as use of total value or average value for the fleet (Bockstael and Opaluch 1983), to the more sophisticated production functions model, where different types of vessel characteristics are taken into account (Holland and Sutinen 1999; Eggert and Tveterås 2004). Similar as for own experiences, the value of catch information from other fishermen is relatively short-lived and very fast becomes unattractive (Smith 2000). In the present study we assume that a fisherman makes use of previous period catch information in terms of value per unit of effort (VPUE) and an information exchange of the average revenue rate on a monthly scale among the vessel within the gillnet fleet. The average VPUE based catch information from the previous month is standardised in terms of individual differences in catchability (or fishing power) among the vessels before it was applied as an explanatory variable in the quantitative behaviour model.

After introduction of electronic equipment it has become easy for fishermen to follow and locate other colleagues’ fishing patterns and spatial aggregation of vessels. Vignaux (1996) observed that the New Zealand purse seine fleet had a tendency to move to areas where other vessels are fishing in terms of expecting higher catch success in those areas. In the present study the total effort from the previous month ($TOT_{EFF_{(m-1)}}$) was used as a proxy for vessel aggregation.

From the in-depth interview the fuel cost was frequently mentioned to influence on the short term decision making process. No information of fuel consumption was available on trip level, instead distances were applied as a proxy for fuel cost. In the questionnaire fuel cost and distance were separated as two distinct decision factors; however, due to the high correlation (Christensen and Nielsen 2005) they were defined as a single factor in the quantitative behaviour analysis. Distance was calculated as the distance from departure harbour to the fishing ground (centre of the ICES rectangle, 1 unit = 30 nautical miles).

The data set was specifically selected for a time period where only moderate changes in the management regulation were enforced. Therefore management regulation was not explicitly included in the utility function. But fishermen may have been under influences of the current management regulations such as mesh size regulation and by-catch limitation. However, these effects were implicitly included in the calculation of the expected revenue rate ($VPUE_{t-1}$). Presently, no applicable proxies for weather and by-
catch have yet been defined (primarily due to lack of information), and therefore not included in current version.

**Behaviour model**

The identified parameters in the utility function can be estimated with different classes of logit models. When the variables in the utility function are estimated they can be used to predict the relative probability of the individual fisherman’s choice among the available alternatives. Assuming the random component, $\varepsilon_{ij}$, in equation (1) and (2) to have an independent type extreme value distribution function (McFadden 1974), the choice probability can after some algebraic manipulation be expressed as the conditional logit model:

$$P_{ni} = \frac{e^{\gamma_{ni}}}{\sum_j e^{\gamma_{nj}}} = \frac{e^{\beta X_{ni}}}{\sum_j e^{\beta X_{nj}}}$$

The simplest way to structure a fisherman’s short term decision processes is by assuming a single level decision structure (or tree). In the first test hypothesis we expect a single level decision making structure by assuming that a fisherman, before he goes fishing, chooses among the 16 choices which are defined as a combination of target species and fishing ground. To estimate the parameters in the utility function, a standard conditional logit model is applied and it takes the following form:

$$U_{ni} = \beta_1 \%EFF_{(m-1)} + \beta_2 \%EFF_{(m-12)} + \beta_3 VPU_{E(m-1)} + \beta_4 TOT\_EFF_{(m-1)} + \beta_5 DISTANCE$$

where $m$ is the month. One of the major restrictive assumptions for the standard logit model is the independences of irrelevant alternatives (IIA) (Train 2003), which means that a change in the attributes of one choice requires proportional changes in the probability associated with alternative choices. Wilen et al. (2002) pointed out that the assumption of IIA is quite often violated in the context of fishery management, as some alternatives share the same unobserved characteristics. To avoid this problem more generalized logit models can be applied to take account for heterogeneity correlation structure among choices and decision makers (Train 2003). In the fisheries literature nested logit models have mainly been used to relax the assumption of IIA for correlation among choices in modelling spatial location choice. In the nested logit models the random error component allows alternatives within a branch to be correlated. For the North Sea gillnetters the choices of target species were observed to be strongly seasonally dependent. In the second test hypothesis we assumed a two level nested logit model for choices of fisheries, where a fisherman first chooses a target species, $k$, and afterwards chooses a fishing area, $i$. The utility for a fisherman to choose a given alternative $i$ is expressed as: $U_{ni} = W_{nk} + Y_{ni} + \varepsilon_{ni}$, where $W_{nk}$ is the parameters in the first level utility function and $Y_{ni}$ is the parameters in the second level utility function. The probability of choosing fishery $i$ in a nested design can be expressed as the product of two standard logit models (Train 2003):

$$P_{ni} = P_{ni|k} P_{nk}$$

$P_{ni|k}$ is the conditional probability that a fisherman chooses fishery $i$ given that an alternative $i$ is in branch $B_k$, and $P_{nk}$ is the probability that target species $k$ is chosen. The $P_{ni|k}$ is found by using the following expression:

$$P_{nk} = \frac{e^{W_{nk} + \lambda_k I_{nk}}}{\sum_{j=1}^{K} e^{W_{nj} + \lambda_j I_{nj}}}$$

where $I_{nk}$ is the inclusive value of branch (target species) $k$. At level 2 the probability of choosing branch $k$ is defined as:
where $k$ is the number of branches (or target species) in the model. The observed utility function for nested logit model was divided into two levels and takes the following forms:

(8) \[ U_{nk} = \%EFF(q-4) \] (q=quarter)

(9) \[ U_{ni} = \beta_1 \%EFF(m-1) + \beta_2 \%EFF(m-12) + \beta_3 \text{VPUE}_{(m-1)} + \beta_4 \text{TOT\_EFF}_{(m-1)} + \beta_5 \text{DISTANCE} \]

The utility in the first level is the percentage of effort that a given fisherman had made in each choice in the previous year in the same quarter (%EFF$_{(q-4)}$). This explanatory variable is a proxy for the attractiveness of a fisherman choosing the same target species as last year at the same time of the season.

The statistical analyses were performed with PROC MDC in SAS (SAS Institute Inc. 1999) and the parameters for both types of models were estimated using full information maximum likelihood methods (LIML).

Both quantitative behaviour models (the standard conditional and nested logit model) operate at the level of the individual fisherman, however, we are also interested in evaluating how well the applied behaviour models predict allocation of effort among the entire North Sea gillnet fleet and how these models predict management changes such as temporal closure of a fishing area. There are several ways to represent an aggregated output (Train 2003). In the present study we have selected two ways to evaluate the predicted power of the applied behaviour models. First, by comparing the observed aggregated effort with the predicted aggregated effort, where the predicted effort was calculated by multiplying the average probability for each choice by the total observed effort for all choices for each month.

Secondly, we used the estimated parameters to evaluate how the behaviour models predicted the closure of a larger area in the North Sea in 2001\(^3\) (from 15 February to 31 April) due to protection of the spawning cod stock. A part of the closure was placed in an area (area2 in Fig. 1) where the Danish North Sea gillnet fleet in that period normally had their main fishing activity. The estimated coefficients from the behaviour models were applied to predict/forecast the spatial allocation of effort (at a monthly timescale) for the North Sea Gillnet fleet before, under and after the closure. This closure involves all fishing activity, therefore the observed utility for those choices inside the closed area were assumed to be zero. Similar methods as used by Wilen et al. (2002) were applied where the utility for choices inside the closed area was set to -1000 and afterwards calculated the predicted probabilities. Due to the exponential form of the logit model the output will always turn out to be a positive number. Using a very high negative number will force the probability towards zero and in this study the probability was <0.001, which in practice meant non allocation of effort to choices inside the closed area.

RESULTS

Analysis of the questionnaire

The findings from the questionnaires indicated clearly that the present situation, season, weather and regulation were of major importance for the Danish North Sea Gillnet fleet. Whereas information from other fishermen, distance and fuel cost were less important (Fig. 2 and 3). The findings were used to define the explanatory variables expressed in the utility function of the applied quantitative behaviour models.

Quantitative analysis

The result of the estimated coefficients for both the standard logit and nested logit models is presented in Table 3. The global $R^2$ was 0.51 and 0.75 for the standard and nested logit model, respectively, which

---

\(^3\)The European Commission enforce an emergency closure of a large area in the North Sea to protect the spawning cod stock (see full description in the Commission regulation No 259/2001).
indicated that both models fit very well to the observed data. In the first model test: the standard logit model was tested for assumption of IIA with a Hausman test (Hausman and McFadden 1984). The choice of plaice/area1 was eliminated from the data set and re-estimated. The test statistic was \( \chi^2(1) = 55.33 \) and the assumption that the other 15 choices were independent of plaice/area1 was rejected. This implied that the assumption of IIA failed.

The second model test, a log-likelihood ratio test, was used to test for any model reduction in the nested logit model with the test hypothesis for equal inclusive value \( H_0: \tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5 \) and afterwards the inclusive value was set to 1. Both tests were rejected \( H_0: \chi^2(5) = 408, p < 0.01; H_0: \chi^2(5) = 445, p < 0.01 \) and no model reductions were carried out.

**Figure 2.** Choice of fishing ground: result from questionnaires: the level of importance was ranked from 1 to 4, where 1 was categorized as not important, 2 as less important, 3 as important and 4 as very important.

**Figure 3.** Choice of target species: result from questionnaires: the level of importance was ranked from 1 to 4, where 1 was categorized as not important, 2 as less important, 3 as important and 4 as very important.
All the estimated coefficients within the conditional and nested logit model were tested significantly from zero at the level of 1% and no further reduction of the full model was done. Except DISTANCE, all the explanatory variables had a positive sign.

Due to differences in the structure of the utility functions in the two models, no statistical comparison was done.

**Table 3.** Result from standard logit and nested logit model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard logit model</th>
<th>Nested logit model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Error</td>
</tr>
<tr>
<td><strong>Area parameter</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VPUE (1000 Dkr)</td>
<td>0.0390</td>
<td>0.00166</td>
</tr>
<tr>
<td>Total effort (m-1)</td>
<td>0.00103</td>
<td>0.00004</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.1798</td>
<td>0.00608</td>
</tr>
<tr>
<td>% eff (m-12)</td>
<td>0.0198</td>
<td>0.00023</td>
</tr>
<tr>
<td>% eff (m-1)</td>
<td>0.0236</td>
<td>0.00022</td>
</tr>
<tr>
<td><strong>Fishery parameter</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% eff (q-4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Inclusive value</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sole</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log-likelihood</td>
<td>30995</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.49</td>
<td></td>
</tr>
</tbody>
</table>

**Model prediction**

Based on the result from the statistical analysis we would have expected a better fit for the nested logit model compared to the standard logit model, but that was not the case. Both behaviour models had almost similar fit (Fig. 4). For the most abundant target species in terms of total effort, both behaviour models captured the seasonality very well. For plaice and sole both behaviour models had a tendency to respond to the observed seasonal peaks with a lag period of 1-2 months. The lagged response was expected due to high attractiveness for a fisherman to make the same choice as previous months and/or year. For the less frequently choices, in terms of effort, both behaviour models was not able to capture the seasonal dynamic; however, these choices represented only a minor part of the total effort allocated.

Before the closure both models seem to fit very well to the allocation of the observed effort; however, the cod in area 1 and 2 was slightly overestimated (Fig. 5). In the first month of the closure period both models predicted an increase in effort for cod in area 1. However, the observed effort shows that most of the vessel instead shifted to target plaice in area 1 and 3. In the second month of the closure (April) both behaviour models recaptured the "unexpected" changes in the allocation of effort. It should be mentioned that the increased effort in the sole fishery in area 1 and 2 were also observed in the previous years and both models captured this increased effort a month later.
Figure 4. The temporal and spatial distribution of the observed (dotted line) and predicted (nested logit: circle symbol and conditional logit: triangle symbol) fishing effort for the North Sea gillnet fleet targeting cod in five different areas. See area definition in Figure 1.
DISCUSSION AND CONCLUDING REMARKS

The transformation of the information from the questionnaire survey into a useful format for the quantitative behaviour analysis was not a straightforward process as the identified variables were not directly accessible from the fishermen’s logbooks and sale slips information. Unfortunately, the questionnaires were anonymous and the linkage to the individual fishermen in the fishery database was not possible. This anonymity was necessary to attain successfully high feedback and reliability of the answers from the questionnaires (Christensen and Nielsen 2005). In general, the problems of defining explanatory variables (or data information) that go into the utility function in discrete choice models have been given relatively little attention (Smith 2000). This study has made one step towards how to utilize information from questionnaire surveys in a more quantitative approach (based on logbooks information) to analyse fishermen’s behaviour. But it also lightened the need for more interdisciplinary work to improve the fundamental understanding of which and how decision factors influence on fishermen’s short decision making process.

The questionnaire survey was not only designed to identify important decision factors but also to verify the findings of the quantitative behaviour analysis. Except for distance, high similarities were found for all identified decision factors when comparing trends in the level of importance of the decision factors between the questionnaire survey and the quantitative behaviour analysis. Overall this indicated consistency in the definition of applied proxies. The distance factor was in the questionnaires weighted by the gillnetters as minor important, whereas the quantitative analysis found distance to be relatively important. The gillnet vessels were on average relatively small in size and due to unstable weather conditions in a large part of the season, they may have been physically limited to choose offshore fishing areas in the North Sea.

Own experience/knowledge was weighted as the most important decision factor whereas the expected revenue rate (or information from other fishermen) was ranked as minor important. Similar observation was found in those “RUM” studies for commercial fisheries where “own experiences” (or habit or tradition) have been included (Bockstael and Opaluch 1983; Curtis and McConnel 2004; Holland and Sutinen 1999; Hutton et al. 2004). Compared to the latter studies, we have modified the “own experience”
proxy from a simple dummy variable to include the level of recent experiences which the individual fisherman gathered during the previous month of fishing. This has contributed to a more flexible and dynamic description and interpretation of this decision factor. However, the applied definition may only be applicable for vessels with few day trips, where for vessels in multi day trip fisheries, the updating process of own experiences and from other fishermen have been found to be of major importance (Curtis and McConnel 2004). But still the "own experiences" variable does not capture all processes involved in the decision of why a fisherman tends to choose same choice as in previous trips (or period). Bockstael and Opaluch (1983) stated that the decision making process of following same fishing pattern may be quite complex and may often be determined by a number of both economic factors (e.g., opportunity costs) and non-economic related factors (e.g., tradition and inertia).

Information from other fishermen in terms of catch rates or quantity have frequently been applied to calculate proxies for expected revenue, where positive responses have been used to confirm economic rational behaviour (Smith 2000). In the present study we found that gillnetters were positive to alternatives with higher expected revenue rates and that may imply a profit maximizing behaviour among the Danish gillnetters. However, this statement was blurred by the relatively low explanatory power of estimated coefficient compared to the estimated coefficients of own experiences (%EFF(m-1) and %EFF(m-12)). Similar findings have been observed in other mixed fishery case studies (Holland and Sutinen 1999; Curtis and McConnel 2004). The weak response fitted to the findings in the questionnaires (information from other fishermen were in average ranked relatively low).

The findings from the interviews confirmed the complex nature of fishermen's short term decision making process of when and where to fish. This complex matter may blur the theories of economic rational behaviour but on the other hand it also indicated that more socially related factors may influence on a fisherman's short term decision process. This study was not specifically designed for testing the assumption of economic rationality, however, a growing body of literature has questioned this assumption regarding fishermen's short term behaviour in open-access fisheries (Hanna and Smith 1993; Béné and Tewfik 2001; North 1995).

The observed variability among the respondents in the questionnaires indicated some degree of heterogeneity among Danish gillnetters. This heterogeneous responsiveness may be due to differences in choice of strategy, fixed and variable costs, opportunity costs, knowledge and risk attitudes (Christensen and Nielsen 2005; Wilen 2004). This paper was not intended to study the heterogeneity of choice behaviour, however the improvement of computer power in recent years have made it possible to apply classes of discrete choices (mixed logit model) for analyses of heterogeneity among fishermen in large data set (McFadden and Train 2000; Smith 2005). Mixed logit model has in recent studies been applied in fisheries to investigate heterogeneity in risk preferences (Eggert and Tveterås 2004; Mistiaen and Strand 2000) and expected return (or information from fishermen) (Mardle and Pascoe 2004; Smith 2005).

The applied behaviour model was designed to predict the spatial effort distribution in a mixed fishery under the closure of larger area in the North Sea. Overall the model succeeded to predict the redistribution of effort among the defined fishing areas and target species under and after the closure. But the findings illustrated that the level of prediction also depended on both the temporal and spatial accuracy of interest. Modelling spatial choice behaviour in term of effort allocation based on catch and effort information from fishermen logbooks (such as in this study and many other studies of European fisheries) are restricted to spatial resolution of the size the predefined ICES statistical rectangles. As short term closures (e.g., seasonal closure, protections of aggregation of juvenile and spawning fish) are getting more frequently used as a management instrument, the demand for more spatial catch and effort information of individual fishermen are needed (such as satellite data combined with catch data).

The next step is to implement the identified short term behaviour rules into a fisheries management evaluation framework, a framework that includes both biological and economic elements to evaluate how changes in technical measures, such as closed areas, will affect both the dynamic of the fish stocks and profitability of the fleet.

ACKNOWLEDGEMENTS

The authors would like to acknowledge funding made available for this work by the Danish Ministry of food, Agriculture and fishery under the project TEMAS "Technical measure –Development of evaluation
model and application in Danish fisheries” and the European Commission under the project TECTAC “Technical development and tactical adaptations of important EU vessel fleets”.

REFERENCES


MODELING EFFECTS OF HABITAT CLOSURES IN OCEAN FISHERIES

Matthew Berman
Institute of Social and Economic Research
University of Alaska Anchorage
3211 Providence Drive
Anchorage, Alaska 99587 USA

ABSTRACT
Theoretical and practical problems arise when Random Utility Models (RUM) of spatial choice developed for recreational fisheries are applied to model spatial closures in ocean commercial fisheries for creating marine protected areas. The RUM clearly has important advantages. To be consistent with RUM and also be relevant to actual closure decisions for open-ocean fisheries, models of habitat-driven fishery closures should avoid imposing unrealistic assumptions about spatial decision-making while incorporating detailed and flexible geographic scales. I describe an approach that satisfies these criteria and is easily estimated with the type of data commonly available to fisheries managers, and discuss an application to North Pacific groundfish closures.

INTRODUCTION
Resource managers are increasingly requested to make decisions to restrict commercial fishing for the benefit of protected species, with uncertainty about the value of reserved habitat to the fishing industry as well as to the species at risk. Claims of high annual losses by fisheries organizations cannot be independently evaluated in the absence of a scientifically defensible method to estimate the cost of the time and area closures around critical habitat areas. The controversy surrounding these actions suggests that there is an urgent need to develop objective methods to quantify their cost.

Methods exist for estimating the costs of fishery time and area closures, based on extensions of the Random Utility Model (RUM) (McFadden, 1981). RUM has important theoretical advantages for dealing with spatial decision-making under uncertainty, as well as computational advantages for estimating welfare effects. For two decades, studies have relied on RUM to estimate non-market values for recreational fisheries, and the literature on applications to commercial fisheries is now growing rapidly. I argue, however, that theoretical and practical problems arise with traditional applications of RUM to model spatial decisions in ocean fisheries. These problems call into question the utility of the standard RUM approach to quantify the opportunity costs of decisions creating marine protected areas.

In this paper, I discuss the limitations of RUM applications to commercial ocean fisheries, and propose a new approach that solves these problems. The new approach is theoretically consistent with RUM and is easily estimated with the type of data commonly available to fisheries managers. In the next section, I review the standard RUM approach to modeling spatial choice in commercial fisheries, and discuss its limitations for modeling time and area closures in ocean fisheries associated with creation of marine protected areas. I then outline a new empirical approach that extends RUM to address need for detailed and flexible geographic scales relevant to decisions regarding spatial closures in ocean fisheries. Next, I demonstrate the new approach in an application to the North Pacific groundfish fisheries. I conclude with a discussion of potential applications of the model to resource management decisions.

2 Email: matthew.berman@uaa.alaska.edu
RANDOM UTILITY MODELS FOR COMMERCIAL FISHERIES

RUM was initially developed to model transportation mode choice (Ben-Akiva and Lerman, 1985; Domencich and McFadden, 1975). Early applications to natural resources focused on estimating demand for recreational fisheries and associated non-market values (Bockstael et al., 1989). RUM was first extended to commercial fisheries by Bockstael and Opaluch (1983), and has increasingly been used to model spatial economic decisions in fisheries (Dupont 1993; Holland and Sutinen 2000). Its advantages include the ability to model choices among multiple spatial alternatives, straightforward computation using maximum likelihood techniques, and direct derivation of welfare estimates under a reasonable set of assumptions (Small and Rosen, 1981).

RUM has a number of limitations, however, based on restrictions it imposes on modeling agents’ choice structures. Most widely discussed is the problem of independence of irrelevant alternatives (IIA) embedded in the multinomial logit model characteristic of RUM (McFadden, 1981). IIA is a relatively minor issue in commercial fishery location choice, however. In essence, it says that closing or opening one fishing area has no effect on the relative attractiveness of the areas that remain open. Other RUM assumptions about the choice set, though less discussed, are much more problematic for applications RUM to ocean fisheries.

Initial applications of RUM to natural resource management fit into the well-established travel-cost model, where the choice set consisted of a small set of discrete alternatives such as lakes, state parks, or boat launch sites. Extensions to spatial management of coastal commercial fisheries such as salmon and shellfish, where alternatives consist of bays and estuaries (Dupont, 1993; Berman et al., 1997), seem reasonable. But spatial choice in ocean fisheries (Holland and Sutinen, 2000; Curtis and Hicks, 2000) is clearly different. Ocean fishers pursue both resident and migratory fish in large expanses of habitat along continuous geography. The open ocean presents a potentially infinite set of choices – or at least a large number – in which alternatives may theoretically exceed the number of observations in the data set.

Discrete choice models such as RUM apply best when the choice set mimics real decisions. Computational limits of algorithms for maximum likelihood estimates of coefficients of nonlinear equations effectively constrain the number of alternatives that can be considered in an empirical application. Even with advances in computing power, multicollinearity makes it increasingly difficult to invert the matrix of partial derivatives (required for estimates of standard errors) as the number of alternatives rises beyond 40 or 50. This effectively limits evaluations of ocean fisheries to large geographic units, whose boundaries are necessarily arbitrary.

Attempting to match choice set boundaries to the boundaries of proposed marine reserves highlights the contradiction with the standard RUM approach. How can fishers decide whether or not to fish within an area of the ocean whose boundaries have not been identified when they make their choices? Yet to be consistent with theory, the choice set must be known in advance, with alternatives considered by the fleet as independent options. The lack of conformity to realistic decision sets casts doubt on the validity of all empirical research addressing fishery time and area closures that do not conform to established regulatory jurisdictions, especially those whose boundaries were identified after the time interval represented in the data.

A recent paper by Haynie and Layton (2004) illustrates the limits of what can be done with RUM models of habitat closures in ocean fisheries. Haynie and Layton estimated a spatial choice model for pollock trawl fishing in the Bering Sea, assuming a choice set consisting of the 18 statistical reporting areas that accounted for most of the harvest between 1995 and 1998. The Bering Sea groundfish fisheries operate across a region spanning several hundred thousand square kilometers, with a complex coastal and subsurface geography; a realistic choice set for the trawl fleet would contain a much larger set of locations.

Haynie and Layton (2004), despite its flaws, provides a framework from which to estimate a cost for closures of large areas, such as the Steller Sea Lion Conservation Area designated north of Unimak Pass, using the established RUM methods. However, this and other standard RUM applications lack the ability to address costs for the irregular spatial boundaries of designated Steller sea lion critical habitat closures now in effect across the North Pacific, as well as for proposed new marine reserves. Furthermore, existing methods lack the flexibility to be useful in evaluating how adjustments to closure boundaries might affect the fishing industry: decisions resource managers often have to make. To be useful to managers making
decisions that include spatial ecological data, a method of valuing habitat-driven fishery closures should be able to model differences at much finer resolution over a large geographic space than current RUM models allow.

**A Discrete Choice Model With a Large Choice Set**

I start with the assumptions of a Random Utility Model for spatial choice in commercial fisheries. Suppose \( n_k \) identical fishers seek operating profit \( V_{jk} \) from a set of geographic areas \( J_k \) available at choice occasion \( k \). The probability \( \pi_{jk} \) that a vessel chooses area \( j \in J_k \) is given by:

\[
\log \pi_{jk} = \alpha V_{jk} - \gamma_k,
\]

where \( \alpha = 1/\sigma \) is a scaling parameter, \( \sum_{j \in J_k} = n_k \), and

\[
\gamma_k = \log \sum_{j \in J_k} e^{\alpha V_{jk}}.
\]

The probabilistic choice model given by equations (1) and (2) is simply a logarithmic parameterization of the standard RUM model. The motivation for the somewhat unusual specification will become clear in a moment. As specified, the scale factor \( \gamma_k \) represents the "inclusive value" in the RUM context. It varies across choice occasions, \( k \), but is constant across areas during any given choice occasion.

Now suppose that the choice set, \( J_k \), contains a very large number of choices, so that the probability that a fisher selects any particular alternative \( j \) at choice occasion \( k \) approaches zero. Also suppose that we observe a large number of vessels, \( n_k \), so that it is reasonable to anticipate observing at least one vessel selecting area \( j \) during at least one occasion \( k \) within the scope of the empirical investigation. Under these assumptions, the number of vessels \( y_{jk} \) observed harvesting in area \( j \) during occasion \( k \) may be approximated by a poisson distribution. That is, if \( \lambda_k = n_k \pi_{jk} \),

\[
\text{prob}(y_{jk} = y) = \frac{\lambda_k^y e^{-\lambda_k}}{y!}.
\]

The model summarized above extends RUM in a manner not yet attempted for commercial fisheries. It is analogous, though, to the approach proposed by Guimaraes et al. (2003) to model decisions to locate industrial facilities among a large set of geographic choices. As Guimaraes et al. originally proposed it, the scale factor \( \gamma \) was a constant, corresponding to a single choice occasion. In this case, estimating the parameters of equation (3) is a straightforward application of poisson regression. In most RUM applications to natural resources, however, resource abundance may vary over time, and agents based in different locations may have different travel costs. The inclusive value may vary over time and place, and may even vary among individuals if agents have individual-specific preferences or cost differences (such as different opportunity costs of time).

In this case, \( \gamma_k \), would differ for every case in the dataset. It is still possible to estimate equation (3) with standard maximum likelihood techniques, preserving the necessary parameter restrictions embedded in equations (1) and (2). But if the number of choice occasions is not too large -- for example, if the inclusive value varies only over time and place -- then the estimation may be dramatically simplified.

Suppose one specifies \( \alpha V_{jk} \) as a linear function of a vector of variables \( x_{jk} \) and associated parameters \( \beta \), and hypothesizes a poisson probability with a mean of

\[
\mu_k = n_k \exp(x_{jk} \beta + g_k),
\]

or,

\[
\log(\mu_k) = \log(n_k) + x_{jk} \beta + g_k.
\]
where $g_k$ is a vector of $k$ parameters to be estimated. Then poisson log-likelihood is:

$$L = \sum_k \sum_j (-\mu_k + y_{jk}\log(\mu_{jk}) - \log(y_{jk!}))$$

(4)   $$= \sum_k \sum_j \left\{y_{jk}[\log(n_k) + x_{jk}\beta + g_k] - n_k\exp(x_{jk}\beta + g_k) - \log(y_{jk!})\right\}.$$

Since by definition $\sum_{j \in J_k} y_{jk} = n_k$, we may rewrite equation (4) as

$$L = \sum_k \left\{n_k[\log(n_k) + g_k]\right\} + \sum_k \sum_j \left\{y_{jk}x_{jk}\beta - n_k\exp(x_{jk}\beta + g_k) - \log(y_{jk!})\right\}.$$

(5)

At the maximum of $L$ with respect to the parameter vector $g_k$,

$$\frac{\partial L}{\partial g_k} = 0 = n_k[1 - \sum_j \exp(x_{jk}\beta + g_k)]$$

(6)

The solution to equation (6) is

$$g_k = -\log\sum_j \exp(x_{jk}\beta) = -\gamma_k.$$

So by including a set of fixed-effect dummy variables for each choice occasion $k$, a standard maximum likelihood estimate for a poisson regression of $y_{jk}$ on $x_{jk}\beta + g_k + \log(n_k)$, with the coefficient on $\log(n_k)$ restricted to 1, will estimate the coefficients of the RUM model.

In summary, I have shown how one can estimate a poisson approximation to a RUM model with an arbitrarily large number of alternatives. The advantage of the poisson approximation is that it dramatically reduces the size of the data set needed to estimate the model. The method is straightforward to model and easy to estimate if the number of different choice occasions is not too large. Another advantage of the poisson approximation is that one can include information on areas that were available to be selected and could have been chosen, but were not selected during the observation period. These alternatives must drop out of the multinomial logit equation, because there is no variation across cases. The poisson approximation can therefore address incremental spatial effects such as the opportunity cost of closing small areas to fishing. Because it is entirely consistent with RUM's theoretical properties, it provides a closed-form estimate of willingness to pay. In fact, all the RUM advantages and limitations continue to apply.

**APPLICATION TO NORTH PACIFIC GROUNDFISH FISHERY**

I now illustrate how the method would work in practice with an application to a large and diverse ocean fishery: the groundfish fisheries of the North Pacific. First, I review the status of the fishery. Next, I discuss the detailed specification of the empirical application. Then, I discuss data sources, before presenting statistical results and estimating the implied spatial values.

**Habitat closures and the North Pacific groundfish fishery**

The North Pacific Groundfish Fishery is the largest fishery in the United States and one of the largest industrial fisheries in the world. The region is divided between large management regions: Bering Sea and Aleutian Islands (BSAI) region and Gulf of Alaska (GOA) region. Walleye pollock (*Thera gra chalcogramma*) is by far the most important species, accounting for more than half of all groundfish ex-vessel value. Annual catches in U.S. waters in the eastern Bering Sea average around 1 million metric tons, and up to 100,000 tons in the Gulf of Alaska. (Alaska Fisheries Science Center, 2003). Pacific cod (*Gadus macrocephalus*) is the next most important species, with annual harvests from both regions exceeding 200,000 tons. As much as 100,000 tons of Atka mackerel (*Pleurogrammus monopterygius*) has been harvested annually in the Aleutian Islands area of the BSAI region. Other important commercial groundfish species include a variety of flatfish species (other than halibut, which is managed separately), and rockfish (*Sebastes* and *Sebastolobus* sp.).
Nearly all directed fishing for pollock is with trawl gear. Trawl vessels share Pacific cod and other groundfish fisheries with fixed gear (primarily longline) vessels. Under rules recommended by the North Pacific Fishery Management Council, annual harvest allocations in the BSAI region are divided roughly evenly between catcher vessels delivering to shore-based processing plants and the offshore fleet. Most of the GOA groundfish harvests, including all pollock, are reserved for the shore-based fleet.

Critical Habitat designations for Steller sea lions (SSLs) (*Eumetopias jubatus*) since 2000 in the Gulf of Alaska and Bering Sea (50 CFR 679) have been especially disruptive to North Pacific groundfish fisheries. Pending proposals to close additional areas to fishing in the North Pacific in order to create marine reserves under the guise of "essential fish habitat" or "habitat areas of particular concern," and possible future closures to protect other marine species could further reduce the area open for fishing.

The main official study documenting the economic impact of SSL critical habitat designation (National Marine Fishery Service 2001) contains only qualitative analyses of the effect on industry profits. Quantitative economic analyses of North Pacific habitat closures have largely been limited to describing the what has become known as revenue at risk (National Marine Fishery Service 2001; Tetra Tech 2004; North Pacific Fishery Management Council 2004). Revenue at risk represents an estimate of the ex-vessel gross revenue that was expected to be derived from fishing in the areas proposed for closure, based on historic catches when the area was open to fishing. This is a completely inadequate measure of the losses that the industry – and society – would endure from such closures. Under fisheries regulated by Total Allowable Catch (TAC), fishing effort generally moves from closed areas to areas that remain open. Total harvest and gross revenue will remain the same as before unless the restrictions are so severe that some TAC remains uncaught, an unlikely outcome for overcapitalized fisheries like those of the North Pacific. True ex-vessel gross revenue losses are probably close to zero in many cases.

Although most habitat closures are unlikely to affect total harvests, market value, and gross revenues substantially, the expansion of time and area closures on the fishery nevertheless imposes real costs on the industry. Such costs may include higher travel costs to reach open areas, higher operating costs from lower catch rates and interrupted trawls, search costs and costs of learning how to fish profitably in new areas, etc. They are described qualitatively in regulatory review documents (National Marine Fishery Service 2001; Tetra Tech 2004; North Pacific Fishery Management Council 2004). These industry costs represent losses to society, but they are not closely related to the so-called revenue at risk.

**Empirical specification**

I start with the following general assumptions, based on the model presented above:

1. The probability of use of each alternative (when it is open to fishing) is based on the RUM;
2. Modeled alternatives are small geographic units with similar fish habitat;
3. Expected catch in each unit depends on local geographic features such as bathymetry, and can therefore be predicted based on variables exogenous to the fishery;
4. Because alternatives are very small in relation to the total fishery area, the probability that any vessel uses a given area during each fishing day is small (generally < 1%);
5. One observes a large number of vessel-days per month in each modeled fishery (generally > 100).

I represent expected profits from choice $j$ on occasion $k$, $V_{jk}$, as:

$$V_{jk} = pq(X_{jk}) - \beta d_j,$$

where $p$ represents ex-vessel price, $q$ stands for expected catch -- a function of area characteristics, $X_{jk}$, $d$ represents distance, and $\beta$ represents unit travel cost. The probability, $\pi_{jk}$, that a fishing vessel selects area $j$ on occasion $k$ is given by
(9) \[ \log \pi_{jk} = \alpha V_{jk} - \gamma_k = \delta d_j + \alpha l_j + g_k, \]

where \( \delta = \alpha p \) and \( \varepsilon = -\alpha \beta \). Aggregating to the fleet with \( n_k \) participating boats, the expected number of landings in area \( j \) is \( n_k \pi_{jk} \). Distance to a given area varies only by port and not over time, while expected catch for a given area varies only over time (but not by port). This means that coefficients on a set of dummy variables for time and port will automatically estimate the set of \( g_k \) with the appropriate restrictions, as described in the previous section.

Since the underlying choice probabilities conform to the assumptions of RUM, we may invoke RUM to estimate the value of an area from the estimated parameters \( \delta, \varepsilon \), and \( g_k \) following Small and Rosen (1981). Given the ex-vessel price and the relevant geographical information, the value of keeping area \( j \) open to fishing during choice occasion \( k \) is:

(10) \[-n_k \log(1-\pi_{jk})/(\alpha).\]

**Data sources**

The basic data for this application consist of publicly accessible information taken from groundfish fish tickets provided by the Alaska Department of Fish and Game, for the 1998 calendar year. Starting in 1999, time-area closures related to SSL critical habitat withdrawals, confounded by legislated management changes in the American Fisheries Act, greatly complicate analyses of spatial choice in North Pacific groundfish fisheries. Fish tickets contain harvest amounts by species coded to statistical areas (statareas). In offshore (federal) waters, statareas are one degree of longitude by one-half degree of latitude (a roughly 50-60 km grid). Within 3 miles of shore, the statareas are further subdivided, and are much smaller. Figure 1 shows the geographic centroid of each groundfish statarea, computed by ArcGIS. In 1998, 678 statareas, out of a total of about 1,700 groundfish statareas, reported some harvest activity.

**Figure 1.** Alaska Department of Fish and Game groundfish statistical areas. Each point represents the geographic midpoint.

Data consist of the number of vessels by gear type making landings in each statarea by species each month and delivering to each port, along with harvest by species in each statarea each month. Harvest amounts are confidential if the number of vessels represented is less than four. Four species are represented in the data: pollock, Pacific cod, Atka mackerel, and all other groundfish combined. While all vessels delivering to shore-based plants (or to processing vessels anchored in state waters) must report harvest on fish tickets, reporting of offshore deliveries to the state of Alaska is voluntary. Based on NMFS total harvest levels, it appears that as much as 40 percent of offshore catch appears on fish tickets. Statistical reporting of harvests at a finer spatial and temporal resolution is possible using NOAA observer data. However
access to these data is restricted to NOAA researchers, and many participating smaller vessels do not have observer coverage.

The empirical application discussed here represents what is possible to achieve with publicly available data. In conducting exploratory research with the data, it was clear that the geographic distribution of Atka mackerel harvests was too concentrated to permit a spatial analysis of that fishery with statarea as the geographic unit. Although habitat closures clearly have had a significant effect on this fishery -- in particular, the Sequam Conservation Area (50 CFR 679) -- analysis of the effects on this fishery require a data set with finer spatial resolution. The empirical analyses therefore focuses on pollock, Pacific cod, and other groundfish.

I used ArcGIS to compute distances from the statarea centroid to each port. Four ports – Dutch Harbor, Akutan, King Cove, and Sand Point – received nearly all Bering Sea groundfish deliveries in 1998, but dozens of small ports received some Gulf of Alaska harvests. In order to simplify the analysis, I recoded the remaining ports to the closest port among the six communities – Kodiak, Kenai, Seward, Cordova, Hoonah, and Sitka – that received most of the Gulf of Alaska deliveries. Ed Gregr and Ryan Coatta of the University of British Columbia Fisheries Centre kindly provided NOAA data on bathymetry of the North Pacific on a 1 km$^2$ grid. I used ArcGIS to compute a number of summary statistics for the statarea, including mean, standard deviation, maximum and range of water depth, as well as the spatial extent of the statarea.

Finally, I derived ex-vessel prices from Bering Sea and Gulf of Alaska Stock Assessment and Fishery Evaluation reports (Alaska Fisheries Science Center, 2003).

**Results**

The first step is to estimate equations that explain the spatial and temporal distribution of fish harvests by species. Table 1 shows ordinary least squares equations that estimate harvest per boat in a statarea in a month as a function of statarea characteristics. Because of confidentiality rules limiting disclosure of harvests, these equations use only statarea-species-month combinations that include four or more participating vessels. In order to reduce the number of confidential cells, the data points include both trawl and fixed-gear vessels, and offshore as well as onshore vessels.

Despite these limitations of the data set, the equations explain quite a bit of the variation in harvests. For all fisheries except GOA pollock, the bathymetry measures significantly predict harvest. The overall fit varies widely, however, with $R^2$ ranging from 0.26 for BSAI other groundfish, to 0.75 for BSAI pollock.

The harvest equations shown in Table 2 provide two options for the harvest variable in spatial choice equations. One can construct a predicted harvest from the fitted values of the equation for all observations. The predicted harvest is based on variables exogenous to the fishery (except for the trawl percentage, which in the case of pollock, is near 1.0). For statareas, species, and months with at least four vessels harvesting, one can also compute an “average harvest” by adjusting the actual harvests per boat only by the trawl percentage. For observations with one to three vessels, only the predicted harvest is available. I therefore construct two measures: the first based on predicted harvests, and the second substituting average harvests, where available, for predicted harvests. The former measure has preferable large sample properties. But the latter is a more efficient, especially for GOA pollock, where the bathymetry variables are insignificant, and for GOA other groundfish, where the equation poorly fits this highly diverse fishery.

Spatial choice equations are potentially available for six fisheries – two regions by three species by two gear groups. However, pollock harvest by fixed gear is basically limited to bycatch, and there is very little shore-based fixed-gear harvesting of other groundfish in the BSAI region. Of the nine remaining fisheries, all except the BSAI pollock and Pacific cod trawl fisheries harvested in more than 100 statareas. These two large trawl fisheries harvested in 45 and 42 areas, respectively. For the BSAI pollock and Pacific cod trawl fisheries, it is computationally feasible to estimate a standard RUM spatial choice model to compare to the poisson approximation.
Table 1. Spatial harvest equations for Bering Sea and Gulf of Alaska groundfish fisheries (Statareas with four or more boats harvesting in a month). t statistics are shown below coefficients. Ordinary least squares, monthly fixed effects not shown. Dependent variable: natural log of monthly pounds per boat harvested in a statarea.

<table>
<thead>
<tr>
<th>Walleye Pollock</th>
<th>Pacific Cod</th>
<th>Other Groundfish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BSAI</td>
<td>Gulf of Alaska</td>
</tr>
<tr>
<td>Trawl % of total harvest</td>
<td>4.272857</td>
<td>3.36618</td>
</tr>
<tr>
<td></td>
<td>5.914</td>
<td>6.115</td>
</tr>
<tr>
<td>Log of area (sq. km)</td>
<td>0.393591</td>
<td>-0.4714</td>
</tr>
<tr>
<td></td>
<td>2.211</td>
<td>-2.615</td>
</tr>
<tr>
<td>Log of mean depth (m)</td>
<td>0.037752</td>
<td>0.46606</td>
</tr>
<tr>
<td></td>
<td>0.139</td>
<td>1.584</td>
</tr>
<tr>
<td>Log of depth range (m)</td>
<td>-0.976627</td>
<td>0.37554</td>
</tr>
<tr>
<td></td>
<td>-1.844</td>
<td>0.897</td>
</tr>
<tr>
<td>Log of depth std. dev.</td>
<td>1.016074</td>
<td>-0.56187</td>
</tr>
<tr>
<td></td>
<td>2.032</td>
<td>-1.247</td>
</tr>
<tr>
<td>Log of maximum depth</td>
<td>-0.200594</td>
<td>-0.08061</td>
</tr>
<tr>
<td></td>
<td>-1.884</td>
<td>-0.782</td>
</tr>
<tr>
<td>Constant</td>
<td>7.866084</td>
<td>9.96464</td>
</tr>
<tr>
<td></td>
<td>5.112</td>
<td>7.275</td>
</tr>
<tr>
<td>R Square</td>
<td>0.74564</td>
<td>0.70832</td>
</tr>
<tr>
<td>Standard Error</td>
<td>1.03521</td>
<td>1.54781</td>
</tr>
<tr>
<td>Observations</td>
<td>118</td>
<td>156</td>
</tr>
</tbody>
</table>

Table 2 compares maximum likelihood estimates of multinomial logit equations with the corresponding poisson regression for spatial choice in shore-based Bering Sea pollock and Pacific cod trawl fisheries. In the logit equations, statareas drop out of the estimation in months for which no boats reported landings. Consequently, the number of alternatives varies by month, but not among the four ports. Nevertheless, the number of observations – number of boats harvesting in a given month times alternatives – totals over 30,000. With only two variables, however, the maximum likelihood estimates quickly converge. They show a good fit, with highly significant, positive coefficients on predicted harvest, and highly significant, negative coefficients on distance to port. In Table 2, I show the equations that use predicted harvest as the measure of $q$. The corresponding equations using average harvest are quite similar. Management of the pollock fishery is divided into a winter A (roe) season and a summer-fall B (no-roe) season, with separate total harvest quotas for each season. I tested a specification allowing different coefficients on A and B season harvests, but the two coefficients did not differ significantly, despite the small standard errors.

The analogous poisson equations have far fewer observations: fewer by roughly a factor of 50. This is due partly to the aggregation of boats in the same port harvesting in the same area in the same month. But a much more important contribution comes from avoiding the need to create an observation for each choice not selected for each case. Table 2 shows that the differences between the logit and poisson coefficients on harvest and distance are remarkably small. The differences show up only in the third significant digit. In these two instances, the accuracy of the poisson approximation is 99 percent or greater. As Guimaraes et al. showed, the accuracy of the poisson approximation increases as the number of alternatives grows. The
number of alternatives for the seven remaining fisheries is larger than for the two shown in Table 2. Poisson equations are therefore likely to be even closer approximations to the multinomial logit equations, if it were feasible to estimate them.


<table>
<thead>
<tr>
<th></th>
<th>Walleye pollock</th>
<th>Pacific cod</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45 areas</td>
<td>42 areas</td>
</tr>
<tr>
<td></td>
<td>Logit</td>
<td>Poisson</td>
</tr>
<tr>
<td>Predicted harvest (tons/month)</td>
<td>2.177E-03</td>
<td>2.177E-03</td>
</tr>
<tr>
<td></td>
<td>6.73</td>
<td>6.72</td>
</tr>
<tr>
<td>One-way distance to port (km)</td>
<td>-3.967E-03</td>
<td>-3.960E-03</td>
</tr>
<tr>
<td></td>
<td>-15.80</td>
<td>-15.80</td>
</tr>
<tr>
<td>Initial Log likelihood</td>
<td>-4015.4</td>
<td>-2136.1</td>
</tr>
<tr>
<td>Log L. at convergence</td>
<td>-3841.4</td>
<td>-1436.9</td>
</tr>
<tr>
<td>L.R. statistic</td>
<td>348.0</td>
<td>596.4</td>
</tr>
<tr>
<td>Observations</td>
<td>32,929</td>
<td>552</td>
</tr>
</tbody>
</table>

Table 2 shows maximum likelihood estimates of poisson regressions for spatial choice for all nine BSAI and GOA groundfish fisheries. The BSAI pollock and Pacific cod equations are repeated from Table 2. As in Table 2, I show the equations that use predicted harvest as the measure of \( q \) in all cases except GOA pollock trawl, for which I show the equation using "average" harvest. As indicated in Table 1, the harvest equation for GOA pollock trawl included no significant coefficients on oceanographic variables, so the predicted values are not reliable. Coefficients for the corresponding equations using average harvest differ significantly from those shown in Table 3 that use predicted harvest only for the BSAI other groundfish trawl fishery, which is a mix of several diverse directed fisheries. The coefficients on harvest and distance are of the expected signs and statistically significant, except for the positive but insignificant coefficient on harvest for the BSAI fixed-gear Pacific cod fishery. This fishery has a large spatial dispersion with a relatively small sample.

Table 3. Poisson equations for spatial choice in Bering Sea and Gulf of Alaska shore-based groundfish fisheries. Maximum likelihood estimates. Fixed effects for month and port not shown.

<table>
<thead>
<tr>
<th>Fishery</th>
<th>Region</th>
<th>Predicted harvest (tons/month)</th>
<th>One-way distance to port (km)</th>
<th>Log L</th>
<th>Observ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollock trawl</td>
<td>BSAI</td>
<td>2.177E-03</td>
<td>6.72</td>
<td>-4015.4</td>
<td>552</td>
</tr>
<tr>
<td></td>
<td>GOA*</td>
<td>9.963E-04</td>
<td>3.97</td>
<td>-3841.4</td>
<td>1,727</td>
</tr>
<tr>
<td>P. cod trawl</td>
<td>BSAI</td>
<td>2.877E-02</td>
<td>15.60</td>
<td>-3574.9</td>
<td>688</td>
</tr>
<tr>
<td></td>
<td>GOA</td>
<td>2.484E-02</td>
<td>9.16</td>
<td>-3574.9</td>
<td>3,988</td>
</tr>
<tr>
<td>Other trawl</td>
<td>BSAI</td>
<td>1.943E-02</td>
<td>7.05</td>
<td>-3277.3</td>
<td>3,755</td>
</tr>
<tr>
<td></td>
<td>GOA</td>
<td>1.372E-03</td>
<td>7.023E-03</td>
<td>-3277.3</td>
<td>3,755</td>
</tr>
<tr>
<td>P. cod fixed</td>
<td>BSAI</td>
<td>1.233E-02</td>
<td>2.21</td>
<td>-5082.8</td>
<td>14,097</td>
</tr>
<tr>
<td></td>
<td>GOA</td>
<td>0.162E-02</td>
<td>2.21</td>
<td>-5082.8</td>
<td>14,097</td>
</tr>
<tr>
<td>Other fixed</td>
<td>GOA</td>
<td>0.162E-02</td>
<td>27.12</td>
<td>-7917.7</td>
<td>16,467</td>
</tr>
</tbody>
</table>

*GOA pollock trawl equation uses average harvest instead of predicted harvest.
Relative Spatial Value

Using equation (10), the coefficients in Table 3, and average ex-vessel prices, one may estimate the opportunity cost of a one-month closure of a fishery in each statarea to boats from a given port. Table 4 summarizes the results of such hypothetical one-month closures, for each of the nine shore-based groundfish fisheries. All estimates are derived from the equations for the corresponding fishery in Table 3, except for the BSAI fixed-gear Pacific cod estimate. As noted above, the coefficient on harvest in Table 3 is not significant for that fishery. Instead, I used the coefficient on harvest from the GOA fixed-gear Pacific cod equation to estimate the opportunity costs for both regions.

Table 4. Descriptive statistics for estimated annual opportunity cost of closing Alaska Department of Fish and Game statistical areas to fishing by shore-based boats, using 1998 data.

<table>
<thead>
<tr>
<th>Fishery</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Data points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bering Sea-Aleutian Islands</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollock trawl</td>
<td>$226,350</td>
<td>$309,260</td>
<td>$115</td>
<td>$2,340,385</td>
<td>552</td>
</tr>
<tr>
<td>P. cod trawl</td>
<td>29,426</td>
<td>58,033</td>
<td>6</td>
<td>451,983</td>
<td>688</td>
</tr>
<tr>
<td>Other trawl</td>
<td>1,522</td>
<td>2,804</td>
<td>0</td>
<td>24,003</td>
<td>711</td>
</tr>
<tr>
<td>P. cod fixed gear</td>
<td>25,761</td>
<td>42,586</td>
<td>5</td>
<td>224,703</td>
<td>326</td>
</tr>
<tr>
<td><strong>Gulf of Alaska</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollock trawl</td>
<td>152,662</td>
<td>339,567</td>
<td>9</td>
<td>2,263,531</td>
<td>1,727</td>
</tr>
<tr>
<td>P. cod trawl</td>
<td>11,961</td>
<td>27,170</td>
<td>0</td>
<td>299,831</td>
<td>3,988</td>
</tr>
<tr>
<td>Other trawl</td>
<td>7,915</td>
<td>19,806</td>
<td>0</td>
<td>179,791</td>
<td>3,755</td>
</tr>
<tr>
<td>P. cod fixed gear</td>
<td>37,451</td>
<td>146,253</td>
<td>0</td>
<td>2,416,489</td>
<td>14,097</td>
</tr>
<tr>
<td>Other fixed gear</td>
<td>2,882</td>
<td>8,408</td>
<td>0</td>
<td>119,930</td>
<td>16,467</td>
</tr>
</tbody>
</table>

Note: Data points refer to the number of statistical areas used by that fishery in each month, times ports reporting landings. A total of 678 statareas reported groundfish landings in 1998 in at least one groundfish fishery in at least one month.

The estimated values show enormous variation, ranging from less than $0.50 for most port-area combinations, to several million dollars. The largest values are associated with closing some eastern Bering Sea statareas to the Dutch Harbor fleet. The number of data points in the last column refers to the number of statistical areas used by that fishery in 1998, times months fished, times ports reporting landings. This number is used to compute the standard deviations shown in the table. A total of 678 statareas reported groundfish landings in 1998 in at least one fishery, although, as mentioned above, some fisheries were restricted to fewer than 50 areas. Of course, the fisheries that are the most spatially concentrated – pollock trawl fisheries – show the greatest vulnerability to closures of key areas.

The values of individual statareas are spatially correlated among the fisheries. That is, a statarea that is highly valued by one fishery is more likely to be highly valued by another. Figure 2 illustrates the spatial distribution of value per unit area to all the shore-based groundfish fisheries combined. To create the data points in the figure, I added up the value estimates summarized in Table 4 by month, port, and fishery, and then divided the sum by the square kilometers of the statarea. Figure 2 reveals interesting ecological-economic "hot spots" for the North Pacific groundfish fisheries surrounding Kodiak Island, and around Unimak Pass. Many of these areas with high fisheries values per square kilometer are located near Steller sea lion rookeries where fishing was subsequently restricted. The highest density of values comes from a statarea in the eastern Bering Sea near Dutch Harbor, with an estimated value of approximately $150,000 per km$^2$.

Conclusions

In this paper, I have argued that the standard RUM approach to discrete choice modeling of commercial fisheries needs to be modified to apply realistically to ocean fisheries. I outlined a new approach based on poisson approximation that is theoretically consistent with RUM and permits flexible specification of a choice set of almost unlimited size and detail. In an application to North Pacific groundfish fisheries, I demonstrate that estimates of discrete choice models with the new approach provide nearly identical results to what would be achieved by estimating a standard RUM model, were it feasible to do so.
The ability of the new approach to accommodate detailed spatial modeling greatly enhances the utility of discrete choice methods for addressing management issues. In particular, it provides a scientifically defensible method of quantifying the economic cost of relatively small habitat closures and other conservation measures that involve incremental time and area closures to fisheries. Because the method can flexibly evaluate incremental changes in the spatial extent of habitat closures, it can help managers adjust closure boundaries in ways that minimize costs to fisheries while meeting conservation objectives. Application of the new approach to the North Pacific groundfish fisheries produced a map showing detailed spatial distribution of economic value estimated over a large region, illustrating the potential contribution to management decisions about marine protected areas. Future research can identify values on an even finer scale in order to answer specific questions about adjustment to individual protected area boundaries.

REFERENCES


North Pacific Fishery Management Council, 2004. Regulatory Impact Review/Regulatory Flexibility Analysis for Amendments 84/76/19/11/8 to the BSAI Groundfish FMP (#84), GOA Groundfish FMP (#76), BSAI Crab FMP (#19), Scallop FMP (#11), and the Salmon FMP (#8) and Regulatory Amendments to Provide Habitat Areas of Particular Concern. Initial Draft, September.


HIGH SEAS FISHERIES GOVERNANCE: A FRAMEWORK FOR THE FUTURE?  

G. T. (Stan) Crothers  and Lindie Nelson  

Ministry of Fisheries, New Zealand

ABSTRACT

This paper proposes a redefinition of the rights and responsibilities of states in relation to high seas fishing, and a model for governance of high seas fisheries that would ensure accountability for fisheries management performance. Current international initiatives to improve the management of high seas fisheries are, broadly, extensions of the regime established under UNCLOS for management of EEZs. States have rights to exploit high seas fisheries and obligations to cooperate and manage these resources sustainably. Experience to date provides limited evidence of effective governance arrangements for managing high seas fisheries. Most high seas fisheries remain prone to overexploitation and underinvestment in fisheries management. We propose that the high seas freedom to fish be transformed to a right to share in the net wealth generated from sustainable harvest of high seas fisheries. The features of this right would be: (i) all nations have a right to benefit from high seas fisheries; (ii) all harvesting should be environmentally sustainable; and (iii) management agencies should be accountable. New governance arrangements are needed to enable fisheries to be managed to maximise wealth creation within environmental constraints, and to ensure that fisheries managers have authority and adequate resources to manage fisheries, and can be held accountable for their management performance. Rather than relying on the cooperation of nations through regional fisheries management organisations, we suggest the establishment of a management organisation in which nations are beneficial owners. The proposed governance model specifies and separates the roles and responsibilities of owners, directors, managers, harvesters, the environmental standard setter, and auditors. The paper is put forward as a 'think piece' to prompt discussion and further research on alternative governance arrangements to manage high seas fisheries.

INTRODUCTION

Over the last 40 years there has been a very rapid worldwide expansion in fishing, a growing acknowledgement that marine fisheries need to be managed, and a corresponding proliferation of international agreements to try to address the problem of orderly—and sustainable—development of fisheries.

Before the mid 1970s, oceans outside the territorial seas were mostly open to fishing by anyone, at least in terms of international law. Much of the open access ocean was enclosed during the late 1970s and 1980s in the lead-up to the 1982 United Nations Convention on the Law of the Sea (UNCLOS). Article 56 gave coastal states sovereign rights to harvest and manage the fisheries resources within their 200-mile Exclusive Economic Zones (EEZs). In the high seas, the rights and responsibilities of states were defined in Part VII of UNCLOS: all states have freedom to fish in the high seas (Articles 87 and 116) and all states have a duty to take measures to conserve high seas fisheries and an obligation to cooperate in the management of high seas fisheries (Articles 117 and 118).

The creation of EEZs led to the displacement of many distant-water fishing fleets that turned their effort to high seas fisheries. The high-profile depletion of high seas fisheries in the Bering Strait Donut Hole

---

2 Email: crothers@fish.govt.nz
3 The views expressed in this paper are those of the authors, and do not represent the views of the Ministry of Fisheries or the New Zealand Government.
(Alaskan pollock) and the Newfoundland Grand Banks (cod) prompted a call at the 1992 Rio Summit (UNCED, 1992) for a UN conference on the management of highly migratory and straddling stocks, giving rise to the 1995 United Nations Fish Stocks Agreement (UNFSA).

These international initiatives sought to give coastal states and flag states defined rights and responsibilities in relation to fisheries management, yet there continues to be evidence of serious problems (see Garcia and de Leiva, 2001, for an overview). Global fisheries resources are being biologically depleted and, according to Pauly et al. (2002), marine ecosystems are being simplified and made less resilient to disturbance by fishing down the food chain. In addition, over-capitalisation has resulted in inefficient harvesting and dissipation of global wealth. The current use of fisheries resources is, in general, neither biologically sustainable nor economically sustainable.

CAUSES OF OVERFISHING

At one level—on the water—overcapitalisation causes overfishing: the harvesting capacity of the global fishing fleet exceeds the productive capacity of global fisheries. Put simply, there are too many boats pursuing the available fish. But, as Munro (2000) observes, overcapitalisation itself is not sufficient to explain the crisis—there is also a management failure to address overcapitalisation and its effects.

UNFSA has enabled better definition of the rights and responsibilities of coastal and distant water fishing nations, through the establishment of regional fisheries management organisations (RFMOs). However, RFMOs still face difficulties in achieving sustainable fishing. In general the definition of rights and responsibilities under UNFSA has not secured adequate investment in fisheries management by RFMOs or member states: insufficient resources are devoted to setting, monitoring and enforcing rules to ensure that fishing is sustainable. UNFSA does not specifically provide for RFMOs to be held accountable for their fisheries management performance, so there is no incentive for RFMOs to create governance frameworks that ensure member states are held to account.

As noted above, nations have a responsibility to cooperate in the management of high seas fisheries. Economic models (Munro, 2000; Bjorndal et al., 2000; and Munro et al., 2004) demonstrate that a cooperative solution is only possible when the cooperative outcome is better for all parties than the non-cooperative outcome, and when the agreement is binding in a manner that deters non-compliance. Current RFMOs have problems on both counts.

Under UNFSA, coastal states and states fishing on the high seas are required to give effect to their duty to cooperate by becoming members of relevant RFMOs. Other states with a 'real interest' in the fishery may become members. In practice, many RFMOs are established by a subset of the nations fishing the resources. While Article 11 lists matters to be taken into account when determining the nature and extent of participatory rights for new members, Article 8(3) states that the terms of participation must not preclude membership.

The effect of these requirements is that existing members of an RFMO must accommodate the interests of any state with a real interest that wishes to join. The need to accommodate newcomers acts as a disincentive for members to adopt tough management measures to rebuild or conserve stocks, since it is likely that benefits must be shared with new members who have not contributed to the cost (and may have established their 'real interest' in the fishery by fishing contrary to the RFMO management measures).

In addition, RFMO agreements seldom include adequate penalties or dispute settlement regimes. States can sign up to regional agreements, but are not held accountable for failing to control their vessels or their nationals in a manner that meets the state's responsibilities. UNCLOS accords states the high seas freedom to fish but provides no specific means to hold states accountable for their high seas duties and responsibilities.

Overfishing in the high seas is therefore a result of a lack of incentives for states to act responsibly in dealing with the effects of an overcapitalised fishing sector. Free-riding and non-cooperation appear to be better choices for both fishers and states, and there is little reward for investing in fisheries management.
CHALLENGE

In our view, overfishing of high seas fisheries is attributable to the nature of existing rights and the resultant institutional arrangements that do not align the self-interest of nations with sustainable management of fisheries. We see the challenge as one of defining rights that generate a governance framework aligning the interests of nations with sustainable management of high seas fisheries. However we do not propose to resolve this challenge through the allocation of harvesting shares among fishing nations.

The Preamble of UNCLOS says that the development of the law of the sea 'will promote the economic and social advancement of all peoples of the world'. High seas fisheries should be treated as global resources to be managed for the benefit of all peoples of the world. However, the current rights are defined in a way that allows states to derive unilateral benefit and does not provide the means for accountability to be imposed on states for any fishing that does not accord with their responsibilities.

We propose that specification of rights for high seas fisheries should ensure that (i) all nations have a right to benefit from high seas fisheries, regardless of whether they participate in fishing, (ii) all harvesting is environmentally sustainable, and (iii) management agencies are accountable.

For all nations to benefit the wealth created from sustainable fishing should be maximised and the net benefits distributed to nations. To maximise the net wealth generated from high seas fisheries it is necessary to shift from an open access regime to a regime with the characteristics of a 'sole owner' (Scott, 1955), that is, an entity capable of co-ordinating—and minimising the transaction costs of—the processes of information collection, harvest right allocation, and enforcement for an entire stock or series of stocks (see Hanna, 1998). Consequently the governance arrangements must ensure that the exclusive management rights for a stock, or a complex of related stocks, are vested in a single entity. To ensure that the entity manages fisheries sustainably over the long term, environmental performance standards should be set independently.

To distribute the benefits of the wealth created, an organisational structure is needed that unambiguously specifies the beneficial interest of individual nations. Organisational structures that could distribute the wealth generated include trusts, cooperatives, and corporate models.

One further feature is critical to the choice of organisational structure: the ability to secure investment. Effective fisheries management will require investment, especially to rebuild stocks, with benefits that accrue over the longer term. Townsend (1995) notes the benefits of corporate governance over cooperative governance particularly in terms of long-term investment decisions. Corporate shareholders have certainty in relation to the allocation of costs and benefits of such investment whereas under a cooperative structure the distribution of benefits is not directly related to the distribution of costs, creating reluctance to invest except in circumstances where everyone invests and benefits equally.

Governance rules for trusts and cooperatives could be established in a manner that unambiguously specifies nations' obligations and beneficial interests, however these would in essence be based on a corporate ownership model. A corporate organisational model, consistent with the OECD principles for corporate governance (OECD, 2004), can accommodate dispersed ownership and provide the necessary security of beneficial interest to elicit long-term investment.

COMPONENTS OF THE PROPOSAL

We propose that high seas fisheries be managed by organisations jointly owned by nations. A necessary pre-requisite for this is the transformation of the high seas freedom to fish into a right to share in the wealth generated from the sustainable harvest of high seas fisheries. All nations would be allocated a share in each of the organisations established ('one nation one share'). Each organisation would have explicit and exclusive authority to manage the high seas fisheries within its portfolio.

This proposal would not create an allocation of state rights to harvest high seas fisheries – instead the allocation would be of state shares in the proposed organisation. Nor does the proposal suggest any changes to the high seas freedom of navigation provided for under Article 90 of UNCLOS.
A core feature is that states could not exercise their right to benefit unless a governance arrangement was in place that was capable of ensuring that fisheries management resulted in the generation of wealth on a sustainable basis. This would remove the current ability of states to act for unilateral benefit and to avoid meaningful accountability for the exercise of their rights. In addition, all nations would receive a return from sustainable management of high seas fisheries, rather than benefits only accruing to nations with the capacity to invest in fishing fleets.

The management organisation would have a corporate ownership structure. Its shares would be held by nations on behalf of their citizens. For the purpose of this paper we call the proposed organisation 'Marco' and refer to it as a single entity, although we envisage that several organisations would be established.

The aim of Marco would be to maximise shareholder wealth by managing the high seas fisheries in the relevant ocean, subject to meeting externally set environmental standards. The governance structure proposed is based on the specification—and separation—of the roles and responsibilities of shareholders, directors, managers, harvesters, the environmental standard setter, and auditors.

**Shareholders** are the owners of Marco. Shares would be held only by nations that acceded to the enabling international agreement. The shareholders would appoint Marco directors and receive dividends, and would have to report to their citizens.

**Directors** are responsible for setting the strategic direction of Marco, monitoring its performance, and appointing the chief executive of Marco. The strategic direction would encompass maximising shareholder wealth as well as 'ownership' issues that ensured the ongoing viability and integrity of Marco. Directors would be appointed by shareholders, however we suggest that the nominees should be competency-based. All directors would be required to disclose any direct or indirect interests that related to Marco activities.

**Managers** are responsible for managing Marco to maximise shareholder wealth. Marco would have the exclusive rights to allocate and control access to high seas fisheries.

**Harvesters** are those with rights—granted by Marco—to participate in fisheries managed by Marco. They would have to comply with the conditions set for their access. Certain governments might be harvesters (as well as shareholders), for instance by operating state-owned fishing vessels, but their harvesting responsibilities would be specified, and enforced, in the same way as any other harvester.

The **environmental standard setter** is an external, scientific body specifying the performance standards (i.e., outcomes or limits) that must be met with respect to the harvested stocks and the direct and indirect impact of fishing on the marine environment. The environmental standard setter should define the standards, set a timeline to achieve the standards, and have an open process to review and revise the standards. We suggest the standards be developed to meet Articles 5 and 6 of UNFSA.

**Auditors** are external bodies appointed by Marco directors to provide independent reports on Marco's performance. We propose two types of auditors: financial auditors and environmental auditors. Financial auditors would review, and report on, Marco's financial performance and asset management. Environmental auditors would review, and report on, Marco's performance in relation to meeting the environmental standards.

Governments and non-government organisations (NGOs) would also have important roles within this overall framework. In addition to holding the Marco shares, governments might participate in the process of appointing scientists to the environmental standard setting body, and comment on the proposed standards. Governments of port states would also be likely to have a role in enforcement. NGOs would play an important role in holding Marco and governments accountable. NGOs could comment on Marco performance, campaign for their government (as shareholder) to seek changes, advocate for potential directors, and comment on the environmental standards. The ability of Marco to earn and maintain the confidence of governments, NGOs, and the environmental standard setter would be critical to its success and longevity.
TRANSFERABILITY OF SHARES

We propose that Marco shares should be transferable, allowing nations to rationalise their shareholding according to their particular interests. Share transferability would increase the incentives for nations to join the agreement, by giving them the option of converting their 'high seas fisheries right' to cash for other purposes.

Unfettered transferability could increase the incentives for nations to 'cash in and opt out' by selling their shares and then failing to comply with the agreement. The enabling treaty should therefore specify that a member nation that sold Marco shares could not opt out of the agreement unless it agreed to continue to act in a manner consistent with the agreement. Having benefited from the agreement, all member nations would have to remain bound to the commitment to allow Marco to manage the high seas fisheries.

For oceans where many fisheries are depleted, it might be a long time before the management organisation could declare a dividend to shareholders – creating a disincentive to join the agreement or, alternatively, an incentive to join and immediately sell shares to avoid any liability. To counter this, one option would be to establish, at the outset, a single Marco encompassing all the high seas. However, we are of the view that this would impede the prospects of addressing the legitimate concerns of various states via an ocean-specific establishment negotiation. Instead, we suggest a moratorium on the trading of Marco shares for a period of time – for instance 5 years from the time when a nation acceded to the agreement.

FUNCTIONS OF MARCO

Marco would create wealth for its shareholders by managing the access rights to high seas fisheries. To manage the access rights to high seas fisheries, Marco would need the exclusive right to authorise access to the fisheries it managed, and to enforce any access conditions set.

Since the primary means to maximise shareholder wealth would be to maximise the value of the access rights, Marco would have an incentive to increase the value of the underlying high seas fisheries resources. Marco’s fisheries management costs would be met from its revenue. The difference between revenue (e.g., access fees) and management costs would be the return to shareholders.

In some fisheries, the cost of management might exceed the expected revenue, in which case Marco would determine that shareholder value is maximised by closing the fishery (unless shareholders explicitly decide to continue to inject funds to enable the fishery to operate at a loss).

In managing the access to fisheries, Marco would set conditions for access, allocate access rights, and enforce the access regime. Thus Marco would have three main functions: regulatory, allocative, and enforcement. Underpinning these three functions would be fisheries management services such as stock assessment research, compliance services, and registry services – which Marco would either provide or purchase. Marco could also provide services to harvesters – such as operating a trading house for contracts – on a fee-for-service basis, or provide fisheries management services on contract to other fisheries agencies. These ancillary services would be limited to activities that do not conflict with managing access to high seas fisheries, and would be driven by their scope to increase shareholder value.

Regulatory functions

The regulatory functions of Marco would relate to determining the operational rules for fishing, so that the standards set by the environmental standard setter were met. Operational rules could include catch limits, gear and area restrictions, marine protected areas, and requirements for record keeping, reporting and vessel monitoring. Determining the operational rules would require scientific input on stock abundance, the environmental impacts of fishing, and the effectiveness of alternative management measures. The operational rules would, in turn, determine the terms and conditions of the access rights.

Some high seas fisheries (such as tunas) and bycatch species (such as albatrosses) are distributed across more than one ocean. Marco would be required to ensure that a consistent approach was taken to setting operational rules to meet environmental standards related to fisheries managed by more than one high-seas management organisation.
**Allocative functions**

The allocative functions of Marco would relate to letting the access (harvesting) rights. We suggest that the access rights be specified as a contract between the harvester and Marco. The rights would be let to fishing companies rather than nations, although fishing companies could be state-owned. Depending on the type of fishery and the operational rules set to achieve the environmental standards, the access right contract could be defined in terms of catch limits or area limits.

We do not envisage that Marco would allocate permanent access rights. Instead, Marco would allocate variable term (e.g., 1 to 15 years) access rights to particular high seas fisheries. Letting some long-term access rights would allow for efficient rationalisation of fishing capacity over time. The mix of short, medium and long-term access rights offered would depend on the characteristics of the fishery.

We propose that Marco would allocate most, if not all, of the access rights by auction. Auctions are a means to maximise the revenue gained from sale of access rights, and can increase the openness and transparency of the allocation decisions. Allocating access by auction can also avoid the key problem of providing for newcomers in RFMO models since newcomers are able to bid (see Butterworth and Penney, 2004). Recent experience with quota auctions (Anferova et al., 2004) suggests that it is difficult to pre-specify optimal lots for auction. Trondsen (2004) has suggested dealing with this by auctioning access rights within season and allowing unused rights to be returned and re-auctioned. Alternatively, access rights could be sold using combinatorial auctions, or the access rights could be tradable once purchased.

During the establishment phase it might be appropriate to reserve a portion of the access rights for incumbent fleets - with or without an access fee. If no fee was charged, Marco might have to rely on its shareholders for ‘equity finance’. Alternatively, shareholders might determine that certain bidder groups had preferential access through a first right of refusal. Marco would have an interest in ensuring that the pool of bidders was as wide as possible, to avoid becoming captive to particular fleets.

**Enforcement functions**

Two enforcement issues need to be addressed: non-compliance with the access right and illegal fishing.

**Non-compliance**

If, as suggested above, access rights took the form of a contract, then non-compliance should be enforced using commercial law. In the event of non-compliance, Marco could seek damages in civil courts and/or revoke the contracts. The penalties—both damages and revocation—should aim to establish effective deterrence. To ensure that contracts could be enforced, contracts could be registered only in countries that satisfied minimum jurisprudence standards. The enabling charter for Marco should specify the jurisdictions where contracts could be registered and include provisions for jurisdictions to be added and deleted over time. If necessary, the terms of the auction could limit participation to bidders of ‘good standing’.

Contracts would need to contain a compliance section specifying requirements such as allowed landing ports, record keeping and reporting requirements, product tracking requirements, and obligations to carry observers or allow inspectors on board. The compliance requirements could be tailored to the fishery or the type of access right granted.

**Illegal and unregulated fishing**

Illegal fishing – in this case, fishing without a contract – is a more fraught area of enforcement. Upton and Vitalis (2003) review the measures taken to curb illegal fishing in the high seas, noting the difficulties in imposing treaty-based enforceable obligations on flag states, and the promise of using port states’ authority and catch documentation schemes to prevent landing and marketing of illegal take.

Marco would need to rely on the cooperation of port states to take action against boats landing illegally taken fish—as provided for in Article 23 of UNFSA. Also, it would need to rely on the cooperation of coastal states to manage problems that might arise where fishing boats were operating both in the high seas (under a Marco contract) and in EEZs (under the coastal states’ access regimes). Achieving such
cooperation would depend on the establishment of operational agreements between Marco and coastal states—which might require Marco to pay for coastal state services. The greater the overlap between coastal (and port) states and Marco shareholders, the easier it should be to secure effective agreements, since the coastal states would have a financial interest in sustainable high seas fishing. Agreements could lead to, and expand upon, cooperation between national enforcement agencies, in turn facilitating networking of intelligence and delivery of enforcement services such as inspection, surveillance and investigation.

Building on the UNFSA features allowing boarding and inspection of vessels on the high seas, we suggest that Marco should have rights to board and inspect fishing boats from acceding parties, seize catch and gear if no contract is held, and divert a boat to port. Operational enforcement agreements could result in port states making evidence obtained by Marco in the high seas permissible for the purpose of prosecuting under their national jurisdictions, or allow Marco to contract out enforcement duties to nation states.

Marco could not enforce its regime against boats flying flags of states that have not acceded to the enabling international agreement (i.e., ‘unregulated fishing’). However, Marco and its shareholders would have an interest in disclosing detected fishing by non-parties and highlighting its consequences in terms of fisheries sustainability. Marco could also seek to have member states use WTO-compatible trade measures to prohibit the importation of fish caught by non-parties. Going even further, it may be possible to give Marco – as an entity that is a collective of nations – the power to refer states to the WTO directly rather than relying on referrals by member states.

It is likely that illegal and unregulated fishing can only be deterred through international trade measures such as prohibiting sale of fish unless it can be demonstrated to have been taken legally (that is, under contract to Marco or in accordance with specific EEZ regimes). Catch documentation schemes are already in use and should be encouraged and enhanced. Such measures will become more effective as cost-effective technology allowing traceability continues to emerge.

There will continue to be some non-compliance and illegal and unregulated fishing. The key issue is whether compliance rates are likely to be higher or lower under the proposed arrangement than under the existing arrangements. Under this proposal Marco rather than flag states would be responsible for enforcing the management regime for high seas stocks. Consequently, capacity issues for nations to meet flag state responsibilities would be substantially reduced. As discussed, we do envisage some residual responsibility for nation states in relation to enforcement, but these responsibilities would be negotiated between Marco and port states on a case by case basis, allowing specific capacity issues to be dealt with directly.

**Accountability**

Accountability – that is, being held responsible for one’s duties – is fundamental to this proposal. Clear accountability is important to maintain credibility, make performance transparent, and avoid conflicts of interest.

As a corporate entity, Marco directors would face the standard corporate accountability requirements to shareholders. However, this model proposes additional accountability requirements, discussed below. Without these accountability relationships, performance might be no better than under RFMOs.

**Marco shareholders to citizens**

Governments would hold Marco shares on behalf of their citizens. Marco shareholders would have to report the company’s results back to their citizens. Governments would not need to take the blame directly for bad outcomes – the managers and directors of Marco would be responsible for its fisheries management (and dividend) performance. However, citizens and NGOs could advocate for their government, as a Marco shareholder, to take action to improve Marco performance.

Disclosure by shareholders is an important element of ‘public accountability’. Since Marco shares would be held on behalf of citizens, we propose that states would have to disclose to their citizens (say, once a year) the receipt of Marco dividends, and the sale or purchase of any Marco shares. In addition Marco’s constitution should require it to maintain a share register, accessible to the public, which recorded
changes in share ownership. The disclosure requirements for shareholders would need to be part of the establishment agreement.

Marco directors to shareholders and public

Marco directors would have transparent shareholder reporting requirements including presenting an annual report and holding an annual meeting open to all shareholders. The annual report would include a financial report signed off by the financial auditors, and an environmental report signed off by the environmental auditors. The environmental report would audit Marco's performance with respect to meeting the externally set environmental standards. The annual report would be made available to the public, as is the case for public companies.

If shareholders were dissatisfied with performance they would have to right to make resolutions and to vote on new directors. Directors would play an important role in ensuring that the operational activities of Marco resulted in equitable treatment of shareholders.

In addition to the internal accountability mechanisms, Marco shareholders might need to rely on external accountability mechanisms, particularly to manage issues such as protection of minority shareholder interests or corruption by directors or managers. In this case the shareholders would be relying on the legal institutions of the country in which Marco was incorporated. Marco incorporation should be restricted to countries with robust legal institutions.

Marco to environmental standard setter

As noted above Marco would have its environmental performance audited. The environmental audit report would be distributed to the environmental standard setter (as well as Marco shareholders). We suggest that the environmental standard setter should be able to sanction Marco for failing to meet environmental standards. Sanctions could take the form of 'soft tools' such as the ability to disclose non-performance publicly, so that citizens could lobby their government to ensure that Marco met its performance requirements. The ability to impose financial sanctions for ongoing non-performance would align the interests of Marco shareholders with good environmental performance, since sanctions would decrease the returns to shareholders. However, the standard setter should only have the ability to impose financial sanctions if it is established with appropriate checks and balances.

AN APPROACH TO IMPLEMENTATION

Establishing Marco would require initiatives, and agreement among nations, at the UN level. Under this proposal the UNCLOS high seas freedom to fish would be transformed to a right to share in the wealth generated from sustainable fishing. This would be brought about by creating sovereign rights for states to be the beneficial owners of the management company, while extinguishing the high seas freedom to fish. Shares would be allocated to all states and issued once the state acceded to the enabling international agreement.

Possible avenues for reforming the legal framework are to work toward a new implementation agreement on UNCLOS or to work toward a revision of UNFSA. The new agreement would set governance standards for Marco, public disclosure requirements for shareholders, minimum jurisprudence standards for Marco incorporation and harvest contract registration, as well as establishing the framework for an external environmental standard setter and external auditors.

Initially one management organisation would be established for each ocean. Consistent with the view that high seas resources are global resources, all nations would be entitled to receive a share in each of the organisations. Within the general implementation framework, a series of establishment issues will need to be traversed addressing the legitimate concerns of various states.

We suggest that establishment details should be determined in a negotiating forum specifically set up for each ocean. Issues likely to arise include recognition of the special dependency of certain nations on fisheries resources (e.g., Pacific Island countries), recognition of the existing fishing capacity of certain nations, and recognition of the initial costs (burden) of restoring fisheries. Addressing these issues could result in agreements for preferential access rights or special classes of shares. Munro et al. (2004) have...
noted the importance of allowing for such 'side payments' to broaden the scope for all nations to gain from the agreement to cooperate.

A critical issue in establishment is creating incentives for countries – especially port and coastal states – to join the agreement as early as possible. One option could be a provision for early signatories (say within the first five years) to be eligible for a class of share with early dividend payments.

To maintain the potential for further wealth creation, the management organisations should have as much flexibility as possible in their approach to generating wealth for shareholders. In particular they should be allowed to merge, divide, or specialise over time, provided the latent right for nations to be allocated shares whenever they accede to the agreement is protected. The management organisations could issue shares to raise equity, however shares issued to investors rather than governments would not be voting shares. Issuing voting shares to any entity other than governments would dilute the accountability requirements for shareholders to report to citizens.

Marco should not be allowed to exploit its power to regulate the conditions of access to high seas fisheries to create scarcity and extract monopoly rent for its shareholders. Excess market power would not exist in fisheries where the high seas catch is small relative to the catch within national jurisdictions. However, there are some fisheries, notably tunas, in which Marco would have the potential to exercise monopoly power. To address this concern, the implementing agreement should prohibit Marco from using its regulatory powers to create monopoly rent for its shareholders.

There would be a transition period and process for Marco to assume management responsibilities for high seas fisheries. Discrete high seas fisheries that are currently not managed by RFMOs could be managed by Marco immediately. A transition from the existing arrangements would enable Marco to replace RFMOs for highly migratory stocks. Straddling stocks would require a more complex transition, as Marco would need to work with coastal states to agree on a management regime.

**CONCLUSION**

Under current governance arrangements for high seas fisheries there is overcapitalisation of fishing capacity and under-investment in fisheries management. Resource rent is captured by early fishers and subsequently dissipated. This proposal offers the potential for investment in high seas fisheries to provide ongoing benefit for all shareholders – with all states having a right to be a shareholder.

Transforming the current high seas freedom to fish into a right to share in the net wealth generated from sustainable harvest of high seas fisheries would better reflect the intentions of UNCLOS by enabling states to benefit from sustainable high seas fishing regardless of their fishing capacity. It would also remove the ability of states to derive unilateral benefit from fishing for which they cannot be held accountable.

Vesting explicit authority to manage high seas fisheries in an agency would allow for wealth creation through limited access. Effective management of high seas fisheries would not depend on the capacity and willingness of flag states to meet their responsibilities. A corporate ownership structure for the management agency would enable nations to vote and receive returns in accordance with their shareholding.

Existing fleets would face some short-term loss, as in any fishery that needs rationalisation of harvesting capacity, but this approach would secure the long run future for high seas fisheries. The corporate organisational structure would allow access to capital to increase investment in fisheries management. Setting environmental standards externally would address the risk that shareholders could seek to maximise current returns at the expense of future generations, and provide a benchmark to monitor environmental performance.

Fundamentally, this proposal is about improving fisheries management outcomes through effective accountability for fisheries management performance. Marco would be accountable to its shareholders and to the wider international community for its performance in meeting environmental standards and generating wealth for its shareholders. In the absence of this accountability, no one is responsible for avoiding the environmental and economic loss associated with overfishing high seas fisheries.
The paper is put forward as a 'think piece' to prompt discussion on alternative governance arrangements to manage high seas fisheries. We recognise that implementation of this proposal would raise formidable challenges to reform the international legal framework, to negotiate the establishment issues, and to replace RFMOs. But given the prospects for improved outcomes from this model we believe it is worthwhile to pursue further research on an appropriate international instrument, on operational aspects such as the viability of a contract-based approach to controlling access to high seas fisheries, and, in particular, on aspects of this proposal that could be applied to improve the governance and accountability of existing RFMOs.

ACKNOWLEDGEMENTS

We are grateful for the comments and encouragement received from Jon Sutinen, Carolyn Risk, Alex Edgar, Jonathan Peacey, Mark Edwards, Amanda-Jane Healy, Nick Wyatt, and Jim Sinner.

REFERENCES


INVESTING IN NATURAL CAPITAL – THE CASE OF FISHERIES

Ralf Doering
Department of Land Economics,
Grimmer Str. 88, D-17487 Greifswald, Germany

ABSTRACT

Two main problems can be identified in fisheries currently: overfishing and negative effects on ecosystems (including bycatch). Both result in a reduction in natural capital. In recent years a concept for a theory of sustainability was developed at our institute. Part of the work has been to develop a strategy for fisheries for creating sustainable use systems, which can be considered as "investments in natural capital". The paper starts with a short introduction to a layer model for a sustainability theory, a discussion of problems with the term 'natural capital' in natural resource use systems, and of the concept of safe biological limits, which derives from the precautionary approach in fisheries management. Afterwards the paper outlines a strategy for long-term fisheries management that introduces recovery plans while addressing the economic situation of fishermen. This management strategy also addresses options for reduced impacts of fisheries on marine ecosystems.

1. INTRODUCTION

It was Irving Fisher (1906) who presumably used the term capital for natural resources for the first time. After that, natural resources were mostly referred to with the capital stock (K), which includes everything necessary in the production process. This changed only recently, with the rediscovery of the term sustainability in the environmental discussion of the 1970s and 1980s (especially after the recommendation of 'sustainable development' by the World Commission on Environment and Development (WCED 1987)). The term "natural capital" was then coined (Pearce 1988) to distinguish services and functions of ecosystems from other capital stocks and the renewable resources that are part of the ecosystems.

Because of the loss of biodiversity, the destruction of ecosystems (like coral reefs or tropical rainforests), and the overuse of stocks, ecological economists developed the concept of investing in natural capital. This investment is different from other economic activity because it often results in lower exploitation or a stock recovery period. A special characteristic of natural capital is that it consists of living things that have the ability to recover.

The term sustainability, in Germany originally a forestry concept to guarantee long-term harvest possibilities, is now widely used. However, its use for every political program (e.g., "sustainable communication" or "sustainable retirement system") dilutes its meaning, so that nobody really knows anymore what sustainability is about. A more structured debate is necessary to return to the original meaning of sustainable use of renewable resources or natural capital as a whole.

Part of this redefinition was done at the University of Greifswald's departments of land economics and environmental ethics with the development of a "theory of sustainability" (Ott and Doering 2004). The contents of this theory alongside the use of a layer model are discussed in section two of this paper; the description of the term natural capital follows in section three. This is important because of the multiple definitions of the term capital in economic theory with respect to nature or natural resources. Section three also includes a short overview of the precautionary and ecosystem approaches in fisheries management.

2 Email: doering@uni-greifswald.de
Afterwards the main aim of this paper is to discuss why investments in natural capital (in this case fish stocks) are necessary, the theoretical background to date and why such investments did not take place in the past. In section four, I therefore try to apply the theoretical concepts to fisheries management. Section four also outlines the current understanding of a fish stock as a capital good in fisheries economics, the situation in fisheries and fisheries management, and the question of investments in natural capital. This is followed by the qualification of the layer model for the fisheries case. Section six focuses on the recommendations for change in fisheries management.

2. CONTENTS OF 'A THEORY OF SUSTAINABILITY'

The following layer model (Ott and Doering 2004, p. 38) was used as the foundation for the sustainability theory, which combines three basic theoretical layers as the core (layers 1 to 3) via bridge principles (layers 4 + 5) with applications (layers 6 to 8).

1. Idea (theory of inter- and intragenerational distributive justice);
2. Concepts ("strong" or "weak" sustainability, intermediate concepts) – including an understanding of natural capital;
3. Guidelines (resilience, sufficiency, efficiency);
4. Dimensions (environment and nature, social systems, economy, education, culture etc.);
5. Management Rules for Certain Dimensions;
6. Objectives (targets, time frames, set of instruments);
7. Set of Indicators;
8. Implementation, Monitoring, etc.

Every definition of the term sustainability assumes an understanding of intra- or intergenerational justice. Therefore the first layer is relatively uncontroversial and a more detailed description of different concepts for intergenerational justice is not necessary for the further use of the model in this paper.

But a deeper look at the second level reveals some fundamental differences, which are important for the fisheries case. Proponents of "weak sustainability" define sustainability as "constant utility per capita over time". But this leads to a portfolio perspective on capital stocks and the assumption that natural capital can be fully substituted with manufactured or other capital stocks (Neumayer 2003, p. 22).

Supporters of "strong sustainability" argue that we must "bequeath a highly structured bequest package" of different capital stocks. This allows our descendents a wide variety of choices and the possibility with which to satisfy their needs. A variety of functions and services of natural capital and not only the function as a resource input in production (or consumption) are important. Therefore the overall objective is the "constant natural capital rule (CNCR)" (Neumayer 2003, p. 25).

In our theory we argue in favor of a slightly modified concept of "strong sustainability". The main difference is the acceptance of the ideas of substitution of parts of natural capital with other natural capital, which allows us to use non-renewable resources if investments in substitutes take place, and the preservation of critical stocks (because of our dependence on functions and services of ecosystems). Although we allow some substitution (mainly within natural capital and of non-renewable resources), the acceptance of the CNCR is also the main background of the concept.

Following this theory fish stocks should not fall under a certain limit. Additionally, the ecosystems sustaining the stocks should be kept intact, meaning their regeneration capacity should not be decreased.

---
3 Others may claim that this can be the case with a very unfair distribution of income.
4 In some cases a substitution with "cultivated natural capital" (like fish farms) seems appropriate because cultivated natural capital is able to deliver some of the functions and services as well. But this is clearly limited.
As part of the debate on the right sustainability concept we see the discussion on natural capital and the use of the capital concept for "nature". After a concept is chosen, guidelines must be followed. Our layer model includes basically three: Resilience, Sufficiency, and Efficiency.

With these three theoretical layers in mind, the next step is to have a closer look at a certain dimension, in this case fisheries management, and to discuss sustainable use systems. An examination and clarification of the term natural capital is an important precursor to the discussion.

3. THE TERM NATURAL CAPITAL

Capital theory is basically characterized as "allocation and distribution theory over time" (Stephan 1995). It has to do, therefore, with decisions on investment, also an important debate in fisheries because of the overcapitalization of parts of the fleet and the overuse of stocks.

There is an ongoing debate about how to use the term capital in economic theory. Two main definitions can be distinguished: First, capital is a material object that generates a stream of goods and services. Second, capital is a monetary value of future goods and services provided by a capital stock. Irving Fisher (1906) differentiated the definitions for capital, distinguishing capital-goods and capital-value.

Clark and Munro (1975, see also Scott 1955) then discussed a fish stock as capital. They argued that a fish stock generates a usable amount of fish and the reproduction rate can be seen to correspond in some sense to the rate of return on capital. Later Clark and Munro also discussed the case of an ‘investment in natural capital’ applied to fisheries (Clark and Munro 1994).

The main problem in the history of the term ‘capital’ was its use as a homogenizing category. As Fisher declared all stocks, which create a stream of wealth, as capital, later all capital stocks were covered under capital (K) in the production function in economic growth models. This implies only one rate of return exists in the whole economy. There is in principle no difference between the material world of machines and the use of a fish stock in the ocean. Both have to generate a certain rate of return; otherwise, it is better to invest capital in a different business.

With the debate on sustainability, this assumption, which also means that within the capital stock everything is substitutable, was partly abandoned. The concept of strong sustainability assumes that natural capital is not or nearly not substitutable. In contrast to manufactured capital, natural capital must be characterized with some peculiarities:

1. That it consists of living things in most parts;
2. That it is not only a deliverer of goods and services but that living things are part of complex ecosystems; and
3. That it is multifunctional.

To include the service dimension of the living biomass into the existing theory Pearce (1988) and Daly (1996) divide capital into different groups. The categories of importance to fisheries economics are manufactured and natural capital. But in principle, supporters of strong sustainability then use a similar definition for capital. "The concept of natural capital is an extension of the traditional economic notion of capital. ... What natural and manufactured capital have in common is that they both confirm to the working definition of capital as a stock (collection, aggregate) of something that produces a flow (periodic yield) of valuable goods and services" (Prugh et al. 1995, p. 51, very similar Daly 1996).

Investing in natural capital opposed to traditional capital goods means lower or no-use for some time. During this time natural capital can be renewed with its own capacity for reproduction, restocking, etc. But this is not an option for non-renewable resources because of their very slow regeneration rate (at least millions of years). They must be substituted at some point by renewable resources (biomass, wind or solar energy). This can also be seen as an acceptance of substitution within natural capital and agreement that natural capital can’t be seen as one homogenized category that covers everything either (like "natural capital (...) is the totality of nature" (Neumayer 2003, p. 8)).
One possible interpretation of the particular characteristics of natural capital is the theory of funds proposed by Faber and Manstetten (1998, also Faber et al. 1996). In their view funds are entities that provide material goods or immaterial services, or both. Living funds have the ability to reproduce, but they also require services of non-living funds for survival (e.g., fish need clean water to live in). Moreover, in the very long-run living funds can increase the stock of non-living funds. The growth of coral reefs over thousands of years provides a good example for this replenishing effect. Non-living funds in contrast, are characterized by their services to living funds as well as their potential to be consumed (Figure 1).

![Diagram](image)

**Figure 1.** Theory of funds.

In the case of the human economy the theory introduces stocks. Stocks consist in this case of renewable resources (fish). In the overall concept also non-renewable resources are part of the stocks. Flows from living funds can increase or decrease stocks.

In general, Faber and Manstetten define withdrawals as elements of flows influenced by organisms, the individual unit of a fund. For Faber and Manstetten, the use of stocks is not the main problem; the form of use of living funds as if they are non-living funds is more problematic. Normally funds have an indefinite lifespan. Although, organisms, as small parts of living funds, die, their ability to reproduce normally keeps the funds in balance. The devastation of the tropical coral reefs and mangrove forests are very good examples of overuse of living funds. The reproductive capacity of these ecosystems is very low. Figure 1 illustrates this definition of natural capital.

So, capital can be separated into stocks and funds. Natural capital consists of stocks, non-living and living funds. Stocks are unavoidably consumed while using them. The important point is how much we use compared to the potential to rebuild the stocks out of living funds. The renewal may take so much time that we must speak of constant stocks (non-renewable resources). This form of use can lead to more or less damage, as we can see in the case of fishermen using dynamite in the tropics. Living funds regenerate themselves. Sustainable use must therefore not exceed the rate of regeneration.

In fisheries management the ‘precautionary approach’ is widely accepted but not widely implemented. The basic concept is to use a fish stock ‘within safe biological limits’, therefore not to exceed the rate of regeneration. To define the limits, fisheries biologists developed the indicators shown in Figure 2.

---

5 Some supporters of the neoclassical position agree with this analysis. They accept in the meantime that sustainability constraints are violated (Solow 1997, Dasgupta 1995).
The precautionary approach demands that certain measurements are introduced if a stock falls under a certain limit. These limits are defined as follows:

**$B_{lim}$**: At this limit the biomass of the stock is so low that biologists can no longer predict a recovery. The possibility of a total breakdown of the stock is very high. Therefore the fishery must be closed completely.

**$B_{pa}$**: The reaching of this ‘precautionary approach (pa)’ level of the biomass should automatically lead to measures to rebuild the stock. These measures are predetermined. One measure could be to reduce the quotas substantially, for example.

**$F_{lim}$, $F_{pa}$**: Above a fishing level of $F_{lim}$ the fisheries must be closed. At the level of $F_{pa}$ certain measures have to be implemented.

The problem of the precautionary approach is that it is based on a single-stock-approach, not addressing the role of fish stocks in marine ecosystems and the role of ecosystems for stock development. The ecosystem approach has therefore begun to replace the single-stock precautionary approach as a new basis for fisheries management. Fishing operations influence habitats and ecosystems negatively which leads to long-term costs in the sense of lower fish stocks (destruction of feeding grounds, etc.). The ecosystem approach was defined as follows:

The ecosystem approach is "an approach that takes major ecosystem components and services – both structural and functional – into account in managing fisheries... It values habitats, embraces a multispecies perspective, and is committed to understanding ecosystem processes... Its goal is to rebuild and sustain populations, species, biological communities and marine ecosystems at high levels of productivity and biological diversity so as not to jeopardize a wide range of goods and services from marine ecosystems which providing food, revenues and recreation for humans" (US National Research Council 1998, cited in FAO 2003, p. 4).

With the description of the theory of funds, the concept of safe biological limits, and the ecosystem approach in fisheries, two basic characteristics seem important for further analysis: on one side the concrete, sustainable use systems of stocks (or living funds), on the other side the fish stock as part of an
ecosystem (sometimes living funds but in some cases non-living funds), which sustains the stock with its functions and services. Not only the resource character of fish stocks is essential. Fish stocks are often more than just renewable resources (for example, some stocks are not only edible for humans but also food for predators, mussel stocks are edible but also clean the water). We now move on to the concrete situation of fisheries.

4. FISHERIES ECONOMICS AND MANAGEMENT

4.1 Theoretical background in Fisheries Economics

In order to describe the use of capital theory in Fisheries Economics it is necessary to put aside the debate on natural capital for a moment. As Clark and Munro (1994, p. 346 f.) explained, there is theoretically no difference between investments in fish stocks, if we define them only as normal capital goods, and other investment decisions. Clark (1990) assumed a sole owner in possession of the fish stock. In fact an individual property right of a whole stock does not exist, yet, a sole owner is, theoretically, not very different from a social planner also searching for the highest present value from the harvest. The time spans are different, as we will see later.

The sole owner is not a monopolist but a price taker who solves the following maximization problem:

\[
\begin{align*}
(1) & \quad PV = \int e^{-\delta t} R(N,E) \, dt \\
(2) & \quad = \int e^{-\delta t} \left\{ p - c[N(t)] \right\} h(t) \, dt ,
\end{align*}
\]

where \( R(\cdot) \) denotes the owner’s profit function, \( N(t) \) the fish stock biomass, and \( E(t) \) the fishing effort at time \( t \); and \( p \) refers to the harvest’s market price, \( c(\cdot) \) to the cost of production (as a linear function of \( N(t) \)), \( h(\cdot) \) to the catch function, and \( \delta \) to the discount rate.

Defining the catch function \( h(\cdot) \) as \( h(t) = F(N) - \dot{N} \), where \( F(\cdot) \) is a logistic growth function describing the natural growth rate of the fish stock and \( \dot{N} \) the change in biomass in that period. Clark’s (1990) optimal solution requires:

\[
(3) \quad F'(N) - \frac{c'(N)F(N)}{p-c(N)} = \delta
\]

Equation 3 states that if the actual fish stock level \( N(t) \) is above the optimal fish biomass \( N^*(t) \) at time \( t \), fishing effort should be increased (divestment in the fish stock), and if \( N(t) \) is below the optimal fish biomass \( N^*(t) \), fishing effort should be reduced (investment in the fish stock). The discount rate \( \delta \) represents the opportunity costs of alternative capital investments. This rate is equal to the rate of return on capital in the entire economy (Clark 1990, Clark and Munro 1994). The sole owner is also able to invest in his fishing operation to influence the costs of its operation.

What are now the reasons to invest in a fish stock? If we return to our original definition of natural capital and take into account that the fish stocks are in the possession of national governments, not sole owners, then an investment decision based not only on a single stock approach can be reasonable because:

1. The fish stock is on a lower level than its potential and an investment (e.g., starting a recovery program) will lead to a higher catch and higher revenues for fishermen (or societies as owner of the stocks, see below), which results in a positive rate of return on investment.

2. Some fish stocks in the ecosystem have crucial functions (e.g., as prey for predator stocks) which makes it necessary to increase stock levels, although these increased levels may not result in a direct ‘rate of return’ due to the difficulty of valuing functions in monetary terms.
3. Fishing operations reduce the living funds and reduce the ability of the living funds to generate high stocks of usable fish (including other species not used originally in the fishery). Society has a possible interest (e.g., intrinsic values) in preserving habitats and ecosystems for future generations (layer 1 of our model).

All three arguments seem to demand an investment decision today.

4.2 Situation in fisheries and fisheries management (especially the European Union)

The FAO (2004) classified 75% of fish stocks of commercial interest as overused, collapsed, or in a state of recovery. The European Commission published a very similar number in its analysis of the Common Fisheries Policy in 2001 (European Commission 2001). The main reason is the over-capitalization of the fleet. There is an inefficient use of capital in the fishing industry because the fishing capacity, and the fishing effort, is far above the use potential of the stocks at their current level. But the capacity is not the only reason; another point is the efficiency of the fishing operation itself. Modern search technology and increasingly larger nets allow fishermen to find easily usable assemblies of fish and catch them effectively.

Investments in modern technology and larger fishing vessels were possible due to subsidies. The European Union in particular invested heavily in modernizing the fleet. As long as the possibility to move to other fishing grounds exists - and today the EU is still buying fishing rights all over the world - fishermen were able to increase catches. There was no discussion of using the money to invest in natural capital. Only recently, with the introduction of the new Common Fisheries Policy in 2002, is it possible to give fishermen financial assistance to invest in more selective fishing gear in an effort to develop a more sustainable resource use system. To summarize, the investment model of the European Union was not to preserve living funds or stocks as part of the funds, but to give fishermen the ability to fish more at a lower cost level. These payments, which "generate 'profits' even when resources are overfished" (Pauly et al. 2002) should improve the standard of living of fishermen and provide the markets with cheap fish. As we now know, this investment in manufactured capital instead of natural capital resulted in low stocks and high external effects.

In this case we define external effects as bycatches (juveniles, non-target fish species, birds, marine mammals, etc.) and destruction of habitats. Table 1 gives an overview of fishing methods used in Baltic Sea fisheries and their consequences for the ecosystem.

The table shows that static gear creates fewer environmental problems than active gear. But normally active gear is more efficient in a pure economic sense (landing of fish with lower costs).

Two other important considerations have only been discussed recently:

1. A genetic selection process due to date's practice to fish for the minimum length. Mesh sizes are adjusted to allow undersized individuals to escape and to fish more or less all individuals having the minimum size. This prefers early spawning and small individuals because of their higher chances to escape the net and to spawn at least one time. Small individuals may therefore dominate the stocks in the future.

2. 'Fishing down marine foodwebs' (Christensen et al. 2003). Because of the higher market value, stocks on a high trophic level (mostly the predator stocks) dominated the catches and are now overfished. It is now necessary to switch to small fish species, which are used for fishmeal production to feed salmon or other predators in aquaculture.6

To slow down or stop these processes, stocks must again include larger and older individuals and predator stocks must recover. This means a less strict size selection. Additionally, special programs for the recovery of the predator stocks as a whole are necessary. This could also lead to lower catches of their prey species by humans (theoretically leading to higher catch possibilities of predators in the future).

---

6 This keeps the world catch nearly at the same level as before but with a totally different mixture than 10-20 years ago. Some of the predator species with a very low reproduction rate, like sharks, are threatened with extinction because of their vulnerability as bycatch in other fisheries. In the European waters, this is the case with the spiny dogfish stock in the North Sea.
Table 1. External effects of different gear types in Baltic Sea fisheries.

<table>
<thead>
<tr>
<th>Gear type</th>
<th>Bycatch of Undersized specimen of target species</th>
<th>Non-target species</th>
<th>Birds and marine mammals</th>
<th>Negative consequences for the whole ecosystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gill net</td>
<td>Low</td>
<td>Low, if good fishing places chosen</td>
<td>Partially high – use of pinger hardly successful</td>
<td>Low, because in the open water</td>
</tr>
<tr>
<td>Trap net</td>
<td>Low, but higher than with gill nets</td>
<td>No real problem because bycatch survives</td>
<td>Traps must be covered, little information about bycatch of marine mammals</td>
<td>Low, because of fixed position</td>
</tr>
<tr>
<td>Long lines</td>
<td>Low</td>
<td>Low in most cases</td>
<td>In some fisheries a great problem</td>
<td>Low</td>
</tr>
<tr>
<td>Pelagic Trawl</td>
<td>Depends on mesh sizes, problems with survival rate of escaped fishes</td>
<td>Great problem in some areas, e.g., cod bycatch in the Baltic Sea</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Bottom Trawl</td>
<td>High, because escape windows or mesh sizes are not adequate to avoid bycatch</td>
<td>High, because all fishes in front of the ground rope were startled (up to 95%)</td>
<td>Low</td>
<td>High, destruction of seabeds, plowing of ocean floors, levelling of structural elements, etc.</td>
</tr>
</tbody>
</table>

This table is a translated and shortened version of a table originally in Doering (2001).

The problem is that recovery programs (low quotas) and technical measures (to avoid a strict size selection and external effects) create high short-term costs for the fishing enterprises. The fishing effort is lowered drastically and therefore landings drop. In the long run, if overused stocks recover, more resources will be available, and with a different type of fishing method (with fewer external effects), high revenues may be possible. It is a typical investment decision with costs at the beginning and revenues coming in over a period of time. In fisheries, because of the problematic economic situation of most of the fishermen, the critical time is the transition period and the challenge is how to cover the short-term costs of investments in 'natural capital' (Doering 2003, Doering and Laforet 2004).

The main recommendation by fisheries economists at the moment to deal with the present crisis and to reduce the overcapacity of the fleet, and this is also important for the investment issue, is an introduction of individual property rights, mostly ITQs (Anderson 1997). Although these are individual rights they differ from the sole owner situation in Clark's investment model. The fishermen are only owners of a share of the fishing rights, not of a whole stock.

This ‘privatization’ of fishing rights is only realized in a few fisheries (mostly in New Zealand and Iceland (situation there Gudmundsson 2004)) and is not very popular among fishermen in the EU (in The Netherlands one fishery is regulated with an ITQ-system (Hoefnagel 2003)). Nevertheless, this seems to be a solution to the fishing crisis: private rights will increase interest in long-term gains (and therefore investments in the stocks). Fishermen who can fish with lower costs are able to buy fishing rights from colleagues. They may be then afterwards in favor of an increase in stock biomass because this allows more catches in the future.

This type of fishing rights is very new in the history of fisheries management. Over thousands of years, fishing communities used the fish stocks in their locations. Many of these fishing communities developed specific rules to deal with the threat of overuse of stocks and destruction of habitats. To be able to fish within the community waters every member had to obey the rules or face restrictions. This kind of management, the so-called community-based-management, is today still a very common management system, even in the so-called developed world (see the lobster fishery in Maine, USA (Acheson 2003)). The main characteristic of this type of management is the development of rules for the amount of use and the allowed fishing gear types.
In most European coastal areas, the fishing rights historically belonged to the regional landowners, in Germany the princes, who regulated the fishery. In most cases their regulation limited the amount of use, and because of technical restrictions, the kind of fishing method (Doering 2001). But we can assume that avoiding destruction of habitats on which fish stocks depend was also behind the regulation.

With technical improvements, fishermen were able to fish farther offshore. In the middle of the last century, fishing vessels were fishing around the globe. Then fishing capacity increased dramatically and forced Iceland to declare a 200-mile zone as its exclusive economic zone 7, which is now international law for all countries. National governments became owners of the fishing rights up to 200 miles, which includes nearly 95% of the commercially interesting stocks. Governments were forced to implement a fisheries management system to provide fishermen with certain fishing rights and keep fishermen from other nations out or force them to pay for access to the national waters. In the EU, the European Commission regulates fisheries and the "Common Fisheries Policy" introduced. Upon recommendation for possible catch quotas from the International Council for the Exploration of the Sea, fisheries ministers of the member states decide on the Total Allowable Catch in each of the regulated fisheries. Additionally they introduced more and more technical measures (minimum length for landings, mesh sizes, etc.) to reduce overfishing and external effects. The results of this policy are more or less disastrous. Many stocks in European waters are overused, ecosystems devastated, and many fishermen have lost their jobs, despite high subsidies to the sector from the EU.

The main problem of the EU fisheries policy, and of many more or less similar regulations, is the extreme short perspective for the fishermen. In a community-based-management system, tough regulation exists because of the dependence of the community on long-term gains. The system of one-year catch quotas in the EU is very short-term. No company really plans operations and investments only for one year, and fishermen are not able to plan because they do not even know if they will receive a share of the quota or able to use their equipment beyond the current year. Additionally, new technical measures increase costs.

An ITQ-system seems to create some incentives for longer-term gains. Fishermen know that they still would have a specific share of the catch quota in 5 years. Politicians may be able to plan on the possibility of lowering the catch quotas temporarily to rebuild stocks. As one predicted effect, fishermen with higher costs sell their share to more 'efficient' ones, lowering the capacities in the fleet. In the end only enterprises that are able to catch fish on a competitive cost level will survive. To catch the quota with the lowest costs possible is then the criteria to characterize this system as 'economically efficient'.

The question of whether such a use system fulfils the third criteria for investments in natural capital, the preservation of functions and services of habitats and ecosystems, remains. Currently, fishing enterprises with low costs are often using fishing methods with the highest level of external effects. 8 One strategy for limiting external effects may be to switch from a capital-intensive active fishing method to a static, labor-intensive fishing method. However, this can lead to high short-term costs. The preservation of ecosystems will not generate immediately, if ever, 'a rate of return' to cover the costs.

Nevertheless, in most of the small-scale, coastal fisheries the use of labor-intensive fishing methods is still common, primarily because certain fishing methods are banned in shallow areas or simply because owners cannot afford to invest in larger vessels. But because they have higher costs, and are not paid for preserving living funds, small-scale fishery operations are often in a bad economic situation. So if we decide that this type of fishery is the future of the business, as Daniel Pauly recommended (in a presentation in Stralsund, Germany (November 2004)), we must find a way to improve their economic situation and to encourage investments in this kind of fishing gear. The really interesting point is that fishing communities, as part of a community-based-management system, work with mostly static fishing gear. Obviously a long-term use system creates incentives for fishermen to preserve ecosystems because of their capacity to sustain fish biomass.

In the case of an ITQ-system, only a government seems able to restrict the use of destructive fishing methods. However, while governments introduce an "efficient" use system for the catch quotas, they also have to increase the costs of the operation to lower external effects (and all governments must do this in a

---

7 This was mainly because of the dependence of Iceland’s economy on fish exports, Iceland’s most important export product.

8 This is nevertheless typical in all sectors of the economy if only the production costs and not the external costs are measured. Environmental regulation was introduced to limit external effects.
concerted action!). How to enforce these measures is another important question (not very successful in the EU, see European Commission 2001). The enforcement of the rules is also important in such a system because individual ITQ-holders depend on all other users obeying the rules. This may keep the enforcement and management costs, if not covered by the ITQ-holders, more or less at the same level.

This is different if the ITQ-holders work together as a group to manage the fishery. If they enforce the rules themselves, the government is able to pull out of the system. But then we have a community-based-management system and not a system based on individual rights tradable on markets in a framework set by governments. Such a system can be introduced directly, as we have seen on the west coast of Canada with the introduction of community-development-quotas (Northern Economics 2002).

There are various reasons to invest in natural capital, in this case increasing fish stocks and lowering external effects. However, fisheries management bodies and the fisheries economics field as a whole are not yet reaching this conclusion.

5. **INTEGRATION OF THE CASE OF FISHERIES IN THE THEORY**

With this description of concrete fisheries and fisheries management in mind, it is now possible to supplement the layer model:

1. **Idea:** distributive justice
2. **Concept:** strong sustainability
3. **Guidelines:** resilience (low negative impact on ecosystems), sufficiency, efficiency (efficient use of capital)
4. **Dimension:** fisheries management
5. **Management Rules:** CNCR (stocks and ecosystems), M(aximum) S(ustainable) Y(ield), investment strategy for overused stocks
6. **Objectives:** stocks within safe biological limits, few external effects, community-based-management
7. **Set of Indicators:** \( B_{\text{lim}} \), \( B_{\text{pa}} \), \( F_{\text{lim}} \), \( F_{\text{pa}} \), Rate of bycatch
8. **Implementation, Monitoring:** recovery plans, fleet structure, etc.

The model we can conclude fits very well for fisheries. We are able to assign qualifications to every layer, and the description of concrete measures demonstrates improvement towards sustainable resource use systems.

6. **FISHERIES MANAGEMENT AND APPLICATION TO THE BALTIC SEA COD FISHERY**

Due to unfavourable environmental conditions (low salinity and oxygen content) in the spawning areas, cod reproduction rates have remained low throughout the Baltic Sea since the early 80’s. Annual fishing limits however, were set at levels above those recommended by fisheries biologists (Hammer and Zimmermann 2003) because fishermen were fiercely resisting any cuts. Moreover, Baltic cod fishermen are using trawl nets that cause significant external effects in the form of bycatch of juveniles and non-target species (Table 1). As a result of excessive catches and the low spawning rates, cod stocks decreased substantially over the past 25 years and remain significantly below the precautionary limit \( B_{\text{pa}} \) (Figure 3).

With this situation as a starting point, how can policy-makers accomplish a transition to the proposed ecosystem-based management approach? The first step in this process is to introduce an adjustment period that allows the cod stock to recover. During this period, regulators allow only reduced landings and more selective fishing gear. Biologists of the Federal Research Center for Fisheries (BFAFI) in Germany

---

9 This happens more or less in New Zealand as Dietz et al. (2004) showed.
predict, for example, that using more selective trawl nets with special exit windows for smaller-sized cod allows stocks to begin to recover in as early as three years. With the fourth year, possible cod landings and economic returns start to increase (Ernst et al. 2000). Even under more restrictive assumptions than in Ernst et al. (2000), Bethke (2005) predicts that cod stocks will show signs of recovery within five years.

![Figure 3](image-url)

**Figure 3.** Cod spawning stock biomass (solid line) and total landings (dashed line) in the Baltic Sea from 1981 to 2003 and precautionary biomass limit $B_{pr}$ (WGBFAS 2004).

Hence, after an initial reduction of cod landings, fishermen can be expected to catch more fish and to report increased profits. The following analysis shows the economic effects of an investment in natural capital for Baltic cod fishermen. Assuming a 50-year time horizon, I evaluate four alternative scenarios:

1. **Status quo** – Baltic Sea fisheries continue to catch cod at present rates of 50,000 tonnes per year.
2. **Recovery program I** – Reduction to 25,000 tonnes per year during the first 5 years, 50,000 tonnes in year 6, 5,000 tonnes per year increase for the next 20 years, and 150,000 tonnes per year thereafter. In year 25, switch to longlines.
3. **Recovery program II** – Reduction to 25,000 tonnes per year during the first 5 years, 50,000 tonnes in year 6, 10,000 tonnes per year increase for the next 10 years, and 150,000 tonnes thereafter. In year 15, switch to longlines.
4. **A hypothesized continuously sustainable catch of 150,000 tonnes per year by using longlines only.**

In scenarios 2 and 3, five years of reduced catches at the beginning of the recovery period are followed by 45 years of higher landings. These landings are below the possible landings predicted by Ernst et al. (2000) and Bethke (2005), and thus a conservative assumption. Using the average cod price of $p=1,500$ Euro/tonne in 2004\(^\text{10}\) and the above annual harvests $h(t)$, I compute the net present value of future cod landings as

$$NPV = \sum_{t=1}^{45} e^{-\delta t} \left( p - c [N(t)] \right) h(t)$$

\(^{10}\) The prices of cod in 2004 were the lowest real prices ever recorded for Baltic Sea cod. For the future, white fish prices are expected to increase due to increased demand (Delgado *et al.* 2003). Hence, the 2004 cod price level in our analysis represents a very cautious assumption.
The fishing costs $c(.)$ in Equation 4 are based on Doering et al. (2005, p. 218) and reported in Table 2.

**Table 2.** Fishing costs for Baltic Sea cod fisheries (Doering et al. 2005).

<table>
<thead>
<tr>
<th>Fishing Gear</th>
<th>Annual Landings (tonnes)</th>
<th>Fishing Costs (Euros per tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom trawl</td>
<td>25,000</td>
<td>1,700</td>
</tr>
<tr>
<td></td>
<td>50,000</td>
<td>1,200</td>
</tr>
<tr>
<td>Long lines</td>
<td>150,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>

The results in Table 3 show that scenarios 2-4 substantially outperform the status quo (scenario 1) for real discount rates similar to those of other industrial and agricultural sectors.

**Table 3.** Net present values of alternative fishing scenarios over a 50 year time horizon and different real discount rates.

<table>
<thead>
<tr>
<th>Discount Rate (%)</th>
<th>Scenario 1 Net Present Value (Million Euros)</th>
<th>Scenario 2 Net Present Value (Million Euros)</th>
<th>Scenario 3 Net Present Value (Million Euros)</th>
<th>Scenario 4 Net Present Value (Million Euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>750</td>
<td>2,768</td>
<td>3,077</td>
<td>3,750</td>
</tr>
<tr>
<td>2</td>
<td>469</td>
<td>1,503</td>
<td>1,737</td>
<td>2,347</td>
</tr>
<tr>
<td>4</td>
<td>318</td>
<td>857</td>
<td>1,036</td>
<td>1,589</td>
</tr>
<tr>
<td>13.4</td>
<td>105</td>
<td>105</td>
<td>155</td>
<td>679</td>
</tr>
</tbody>
</table>

Their net present values exceed those in scenario 1 when applying discount rates of 0%, 2%, and 4%. In these cases, Baltic cod fishermen economically benefit from an investment in natural capital. Only for real discount rates of 13.4% and larger, efforts to recover cod stocks begin to become less profitable.

Evidence from Ireland shows that such large discount rates are rather typical for fishermen (Hillis and Wheelan 1994). These rates, combined with high per tonne costs and fear of economic losses in the initial years of any adjustment period, subsequently prevent fishermen to implement measures that would increase cod stocks and landings in the long-run. Yet, Hillis and Wheelan (1994) also found that the large magnitude of fishermen's discount rates (rates range from 25% to 40%) was mainly due to the great uncertainty fishers perceive about future landings. If this uncertainty is reduced by assuring economic help during the early years of a possible recovery program and fixed percentages of future catches thereafter; discount rates can be expected to drop to levels comparable to those of other sectors in the economy (i.e., the risk-adjusted interest rate).

Two important policy implications follow directly from the above. First, Baltic fishermen must be given incentives to lower their cod landings during the initial 3-5 years of the adjustment period. Possible alternatives include direct payments, governmental loan guarantees, and other measures designed to reduce fishermen's financial hardship. In the example above, which requires a conservative 5-year reduction of cod landings by 50% (50,000 tonnes to 25,000 tonnes), direct payments of Baltic countries would total at most 187.5 million Euros (real discount rate of 0%). This amount is small when compared to the economic value created by recovery programs. But even without any cash payments and only loan guarantees, conservation efforts remain economically viable as reported in Table 3. These results are consistent with Rechlin (1999) who shows that a more careful use of cod stocks in the late 80's and early 90's would have resulted in higher biomass in subsequent years.

The second crucial policy task is to reduce fishermen's long-term uncertainty by promising shares of future landings. Regulators must restrict the number of cod fishing licences in the Baltic to current levels (a limited entry system) in order to assure that fishermen will indeed benefit from greater subsequent catches. Because this measure further reduces uncertainty about the future, fishermen's discount rates decrease. As the recovery program becomes increasingly sustainable, EU regulations may be successively replaced by decisions from regional management councils that include – to some degree similar to the Maine lobster fishing communities – composed of cod fishermen, biologists and other stakeholders.

The long-term benefits of a potential cod recovery and policy program, however, extend beyond greater sustainable fishing quotas. At high stock levels, the most efficient fishing gear with also the greatest
negative external effects, the trawl net (Table 1), no longer becomes an economic necessity. More cod and larger specimens will increase the viability of longlines in the Baltic Sea (as assumed in scenarios 2-4), a fishing method with substantially fewer negative externalities (Table 1). The less destructive nature of longlines keeps the Baltic’s floor environment in its natural state and reduces bycatch of non-target species. Hence, more selective fishing methods substantially lessen the impact of cod fisheries on the overall Baltic ecosystem.

Doering et al. (2005) estimated that longline costs decrease to approximately 1,000 Euros/tonne when cod stocks reach levels that sustain annual landings of 150,000 tonnes or more. These costs are only slightly greater than the 850 Euros/tonne estimated for trawl nets. Moreover, if fishermen in management councils determine licences and approved fishing gear appropriately, overfishing of cod stocks becomes almost impossible. Minimum hook and bait sizes on longlines only target cod specimens above a particular size, bycatch is low, and the number of long lines (i.e., the number of fishing licenses) keeps the overall fishing effort within sustainable limits.

The example of the Baltic Sea cod fishery shows that an ecosystem-based approach to stock management is economically and ecologically viable. While policy-makers must assist and educate fishermen during the early years of a potential recovery program, fishermen will enjoy greater landings and profits in subsequent years. The approach minimizes negative externalities and protects the functions and services of cod in the Baltic marine ecosystem.

7. SUMMARY

The aim of this paper is to present a ‘theory of sustainability’ and to explore investment in natural capital with respect to the use of fish stocks. The layer model demonstrates that fisheries as a use system for renewable resources adapts well to the theory, which argues for the acceptance of the constant natural capital rule and makes the case for the necessity, especially in fisheries, to invest in natural capital. For fisheries this means the use of stocks at a sustainable level, which fisheries biologists define as within ‘safe biological limits’, and the avoidance of external effects (bycatches, destroying of seabeds etc.), which reduce the restocking ability of fish stocks.

The described strategy for the establishment of long-term management systems to rebuild overused stocks requires a short-term reduction in fishing effort and lower catches. Loans or sureties to avoid bankruptcies of many fishermen could ameliorate economic losses. Payment of this type (preferably possible without direct payments to the fishermen) can be interpreted as ‘investments in natural capital.’ After the recovery period fishermen are able to use less damaging fishing methods, in the case of the Baltic Sea cod fishery longlines instead of bottom trawls.

The main goal is to rebuild fish stocks avoiding bankruptcies among fishermen (although the capacity reduction may lead to some exit). All recovery programs to date lack a long-term strategy to address the economic and environmental complexities and therefore fishermen do not support or comply with the plans. At the end of this process a limited entry system (in cooperations) may be introduced, fixing the number and type of fishing gear. This would be a very similar system as those used over centuries in many areas, especially around the Baltic Sea.

Only with an overall strategy, which we will call ‘an ecosystem approach’, can the tendency of fishing down marine foodwebs, select only small individuals and overfishing of nearly 75% of all commercially interesting stocks be halted. But therefore a clear new political agenda is necessary.11

REFERENCES


11 See also Sterner and Svedang (2005) for recommendations for the Swedish cod fishery.
Investing in natural capital, R. Doering


THE CATCH 22 OF LICENSING POLICY: SOCIO-ECONOMIC IMPACTS IN
BRITISH COLUMBIA'S COMMERCIAL OCEAN FISHERIES

Danielle N. Edwards
PO Box 586, Ucluelet, BC, V0R 3A0

Astrid Scholz
Ecotrust,
721 NW 9th Avenue, Suite 200, Portland, OR 97209

Eric Enno Tamm
Ecotrust Canada,
200 - 1238 Homer Street, Vancouver, BC V6B 2Y5

Charles Steinback
Ecotrust,
721 NW 9th Avenue, Suite 200, Portland, OR 97209

ABSTRACT

Fisheries policy and the privatization of the fish resources in BC have netted a catch 22. Policies intended to improve the economic, social and ecological effects of fisheries often have had the opposite effect from the stated goals. Recent fishing policy, namely the salmon licence buybacks and quota implementation, have negatively impacted the fishing dependent coastal communities of BC. Licences have been disproportionately lost from rural coastal communities as the purchase price of licences has increased and licences are consolidated into fewer and fewer hands in urban centres. Hampered by reduced access to financial capital, rural communities, First Nations and the next generation of fishermen have been shut out, seriously undermining the long term viability of BC’s fisheries, small coastal communities and small boat fishing fleet.

INTRODUCTION

The current landscape of fisheries licensing and policy can be traced to the implementation of limited licensing in 1969. The plan intended to promote the conservation of salmon stocks and provide a better income for the remaining boats (Meggs 1991). This constituted the first move from public to private property rights in the BC ocean fisheries. Licences were issued by the government of Canada and could be sold and transferred between individuals and boats. Unlike on the east coast of Canada, no comprehensive owner operator policy was established. During this period it was the aim of the Department of Fisheries and Oceans (DFO) to actively promote regional development in small, fishing dependent coastal communities (DFO 1989), by making the fishing fleets more economically viable. From 1967 to 1984 there was a gradual decentralization of the BC fishing industry away from the metropolitan region, and the number of active vessels in the coastal region shifted from 42% of all active fishing vessels in BC to 50% (DFO 1989).

In response to increasing utilization of non-salmon species and growing stewardship concerns, the 1970s saw the start of the “alphabet soup” of licences in BC, with fisheries taken off the base licence and given their own separate licence, beginning with abalone (E), herring (H), trawl (T) and halibut (L) licences. This continued through the 1980s and 1990s, resulting in more than 20 different fisheries licences in BC.

---


Email: dnedwards@telus.net
Following licence limitations and the increasing use of area and time closures, individual transferable quotas began to be utilized beginning with the abalone fishery in 1979. The late 1980s and 1990s saw the introduction of quotas in a number of groundfish and shellfish fisheries, citing inefficiencies and overcapacity with the fleets and high catches over short periods of time that negatively impacted markets and led to unsafe work conditions (CIC 2005, CSA 2005, UHA 2005). Licence buybacks and area licensing regimes were implemented in the salmon industry in 1996 with the stated rationale that it would revitalize the industry and increase earnings for fishermen (DFO 1996).

The current period is marked by proposed expansion of the quota program (McRae and Pearse 2004), despite many concerns about the impact of quotas and other fisheries policies on communities (FN Panel on Fisheries 2004). There are now proposals for quota systems in four more groundfish fisheries (CIC 2005), the prawn fishery (CPIC 2004) and efforts to move salmon and all other commercial ocean fisheries in BC to quotas (McRae and Pearse 2004, BC Seafood Alliance 2005). Pilot quota projects began in the north coast troll salmon fishery in 2005 despite strong opposition from many licence holders (The Fisherman 2005) and the long recognized difficulties implementing quotas in the salmon fishery (Senate Report 2005, Sproat 1996, FRC 1982).

In addition to the socio-economic impacts of recent policy, including an aging fleet, aging participants and widespread leasing activity – the average age of licence owners is 55 years (CCPFH 2005) and temporary transfers of halibut quota increased from 19% in 1993 to 74% in 2003 (DFO 1994, DFO 2003) – ecological concerns continue to exist. It has been recognized that quotas are not a conservation tool, but an economic one (NRC 1999). While quotas can be used to effectively keep landings within total allowable catch levels, bycatch discard, highgrading and poaching problems can be exacerbated (Copes 1999, 1986) and habitat issues remain unaddressed. To address the ecological concerns increased by quota, fishermen-funded comprehensive dockside and vessel monitoring is being implemented (CIC 2005). There has been little done to address the combined fee and debt effects of additional costs associated with quota fisheries in BC, but the increasing debt load due to fees has been recognized as an issue that could threaten the viability of certain fleets given that the DFO-mandated user fees are not tied to the ability of a fleet to pay (GPCEL et al. 1999), unlike in Australia where there is a link between fees paid and benefits received (Industry Commission 1992). The multitude of issues threatening the viability of BC fisheries and coastal communities, arising from previous policy initiatives, are a caution that we must consider all impacts of policy: social, economic and ecological.

**METHODOLOGY**

Our primary mode of research was the collection and analysis of DFO licence records for 1994 and 2002. These years corresponded to the period just prior to major shifts in licensing, most notably the Mifflin Plan, and to the current period. We compiled market values of licences and quota over a fifteen year period ending with 2004 from prices advertised in local trade magazines. The landed value of select fisheries during that same time period was obtained from DFO. Landed catch assigned to statistical areas was obtained from DFO for salmon and shellfish species and derived from International Pacific Halibut Commission (IPHC) documents for the halibut fishery (IPHC 2005).

To analyze the spatial distribution of licence ownership we used the contact city for the licence on record with DFO. The contact city represents the region of ownership and refers to the business address for the primary owner of record. For the majority of licences owned by individuals, business address is synonymous with residential address. Of the 4,939 licences considered, 39% had a company listed as the primary or contact owner, 9% were First Nation communal licences and the remainder had an individual listed as primary owner.

The spatial analysis of licence ownership was limited to vessel based licences or vessel associated licences. Party based licences without attached vessels did not have contact city data available and were excluded from the analysis for this reason. This included herring gillnet, intertidal clam, smelt and a number of small and experimental licences such as goose barnacles, eulachon and herring bait. For the vessel based licences, a small percentage of licences (3.3% in 1994, 6.3% in 2002) did not have contact city available due to difficulties accessing the data from DFO. For a portion of the analysis, only major fisheries for which full data was available were considered, namely: salmon (AG, AS, AT), schedule II (C), geoduck (G), halibut (L), sablefish (K), crab (R), prawn (S), sea cucumber (ZD), urchins (ZA, ZC), hook and line rockfish (ZN) and trawl groundfish (T).
We divided areas into rural and urban based on the population size of census consolidated subdivisions (du Plessis et al. 2001) and into coastal, interior and outside of BC. Subdivisions with populations less than 10,000 were designated rural and all others were designated urban. All subdivisions within 80 km of a marine port were designated coastal. Coastal BC was further divided into 5 regions corresponding to political, ecological and licensing boundaries, consisting of Northern and Central BC, Northern Vancouver Island, West Coast Vancouver Island, Central East Coast Vancouver Island, and Metropolitan Vancouver Island and the Lower Mainland.

All values are reported in Canadian dollars and were corrected to real value using the Consumer Price Index (Statistics Canada Cansim II table 326-0002) for all items Canada-wide.

**THE RESULTS**

Coastal rural communities have lost 45% of major fishery licences, 28% when salmon is excluded. The coastal urban areas have lost 30% of major fishery licences, 5% when salmon is excluded. The overall loss in licences from the coast has been due to licence retirement and the movement of licences to areas in the interior of BC and outside of BC. The loss of licences during this time period has been more pronounced in some of the small fishing dependent coastal communities than in others, but all have experienced loss of licences (Fig. 1).

![Figure 1](image-url)

**Figure 1.** The number of major fishing licences owned in rural fishing dependent coastal communities in 1994 and in 2002.

Most licences are now owned in the metropolitan regions of BC — Vancouver, Victoria and the central East Coast Vancouver Island region (Fig. 2). The regions with the fewest licences, especially quota licences, are the north coast of BC and the north and west coast regions of Vancouver Island.

Concurrent with the loss of licences from remote regions has been the increase in the purchase price of licences irrespective of the landed value of the licence. In the salmon gillnet and troll licences over the last 10 years there has been a continuous rise in market values despite a drastic drop in the average landed values (Fig. 3).

In halibut and sablefish quota, the market values for quota have risen sharply over the last fifteen years, from $9-36 and $8-45 respectively. For halibut, when compared to the ex-vessel price per pound, the increases in the market value of the quota are clearly increasing irrespective of the actual ex-vessel price which has been relatively stable (Fig. 4). The purchase price for quota has steadily increased from twice the landed value per pound to ten times the landed value from the time quota was implemented to 2004.

With the movement of licences out of the region, there is a corresponding loss of adjacency between where the resource is harvested and where ownership resides. For the Area G (west coast Vancouver Island) salmon troll licences, despite large losses from the coastal communities, 21% ownership still resides in
Figure 2. Ownership of the major commercial fishing licences, quota and non-quota licences, in the coastal regions of BC in 2002.
Figure 3. The difference between the purchase price (sale value) of a licence and the average landed catch value per licence for gillnet (AG) and troll (AT) salmon fisheries for the years 1994, 1998 and 2002. In 1994, salmon troll and gillnet licences were the same licence, but were split into separate licence types and licence areas in 1996. The sale values per licence were calculated using advertised licence prices per foot multiplied by the average licence length in each year. The catch value was taken from DFO catch statistics, from the overall landed catch value divided by the number of licences in each year. The overall number of licences dropped by half between 1994 and 2002.

Figure 4. The landed value of halibut for the years 1951-2004 represented as real value per lb dressed weight and the purchase price of halibut quota for the years 1990-2004 represented as real value per lb round weight.

areas adjacent to harvest areas on the west coast of Vancouver Island (Fig. 5). For the salmon gillnet in the north and central coast, ownership resides in the region for 50% of the licences (Fig. 6), with the Northern Native Fishing Corporation owning 254 of the 351 gillnet licences in the region. By contrast, the majority of the catch in the geoduck fishery comes out of the north coast, but licence ownership is centred on the east coast of Vancouver Island and the Lower Mainland (Fig. 7). For the quota halibut fishery which has 84% of catch coming from the north and central coast, only 8.7% of quota holdings are owned in the adjacent region (Table 1).
Table 1. The 2002 commercial BC halibut licence ownership and adjacent landings by region. Licence and quota ownership is based on primary owner contact city, excluding First Nation communal licences totalling 26 licences (6% of licences) and 5% of quota. The landings are based on the IPHC recorded landings for regulatory area 2B (British Columbia) based on IPHC statistical areas. The statistical areas are aligned with regional boundaries with the exception of the division between the North Vancouver Island and the Central Coast boundary, for which statistical areas 091 and 092 cross over. The landings for these areas represent a small portion of total landings and were assigned to the North Vancouver Island region.

<table>
<thead>
<tr>
<th>Region</th>
<th># of Licences</th>
<th>% of All Licences</th>
<th>% Quota Holdings</th>
<th>% of landings caught in adjacent waters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metro Vancouver Island/Mainland</td>
<td>176</td>
<td>42.72</td>
<td>44.21</td>
<td>0</td>
</tr>
<tr>
<td>Central Vancouver Island/Mainland</td>
<td>148</td>
<td>35.92</td>
<td>35.21</td>
<td>0</td>
</tr>
<tr>
<td>North Vancouver Island/Mainland</td>
<td>17</td>
<td>4.13</td>
<td>3.06</td>
<td>3.9</td>
</tr>
<tr>
<td>West Coast Vancouver Island</td>
<td>4</td>
<td>0.97</td>
<td>0.64</td>
<td>12.1</td>
</tr>
<tr>
<td>North/Central Coast</td>
<td>52</td>
<td>12.62</td>
<td>8.69</td>
<td>84.0</td>
</tr>
<tr>
<td>Interior BC</td>
<td>12</td>
<td>2.91</td>
<td>2.31</td>
<td>0</td>
</tr>
<tr>
<td>Outside BC</td>
<td>1</td>
<td>0.24</td>
<td>0.13</td>
<td>0</td>
</tr>
<tr>
<td>Unknown</td>
<td>2</td>
<td>0.49</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

The trawl industry is in a similar position with nearly 40% of its 2002 catch in the north/central coast and over 40% off the west coast Vancouver Island, totalling over 80% of the trawl catch. Ownership of trawl licences resides in these regions totalling 6.3% and 1.4% respectively. The trawl fishery is the only major fishery currently with comprehensive, though not 100%, catch discard data. Discard of non-directed catch in the trawl fishery varied from 7,800 up to 19,900 tonnes per year in the 8 years (1996-2003) for which on-board observer data was available, as determined using DFO obtained landed and on-board observer catch data. Discard ranged from 8% to 20% of total catch by weight.

DISCUSSION AND CONCLUDING REMARKS

There has been little consideration of the effects of licensing policy and quota on coastal communities in BC that have long depended on the fishing resource. With a clear direction for moving all of BC's fisheries to quota (McRae and Pearse 2004), most fisheries are experiencing increasing licence capitalization. There are few limits on concentration, no owner operator provisions and leasing is common.

The problem with open access and limited entry fisheries management approaches has been summed up to be the "race for the fish", coupled with "overcapitalization" in boats and equipment as fishermen try to obtain a competitive advantage. While we have seen a drop in the number of vessels participating in fisheries, capitalization in boats, equipment, licences and quota continues. Two large trawl boats from Europe have been added to the BC fleet in the 2004/2005 season. These are two of the largest boats to be brought into the BC fleet. We have also seen a shift in capitalization as the competitive advantage is now gained through licence holdings. The more holdings an individual or company has, the greater ability they have to execute their fishery. This has led to a "race for the fish" before the fish have even come out of the water. The race is for quota, for the ownership of the fish in perpetuity as they swim about in the ocean.

Prices for a licence and quota often exceed a million dollars in today's market. This suggests that there is now too much money chasing too few fish. As prices climb, access in rural coastal communities falls. To explain this loss in licences we need only look at who has access to the capital needed to buy these licences to see why there is this shift towards the urban centres. Lower annual incomes compared to urban communities (Alessandro et al. 2003), fewer job opportunities and housing values often less than half that of metro Vancouver (Statistics Canada 2001) all contribute.

For aboriginal communities, the situation is even worse, with 35% lower annual incomes in rural regions, unemployment rates double that of the general population (Armstrong 1999) and no home equity for those living on reserve. This has considerable impacts on access to capital, diminishing the ability to weather bad fishing seasons and hold on to existing licences, as well as to be able to invest in additional licences to diversify fishing opportunities.
Figure 5. Ownership of salmon troll licences and landed catch in the coastal regions of BC in 2002.
Figure 6. Ownership of salmon gillnet licences and landed catch in the coastal regions of BC in 2002.
While the high market value of quota is often attributed to improved financial performance of the fishery, this clearly is not the main determining factor of market value. Windfall profits have been an important factor for licence holders. Quota can quickly gain in value and provide a significant source of ongoing income from leasing, sold for profit or used as collateral. This puts more money in the hands of those granted quota to further capitalize in the industry. This is compounded by the tax system. There are tax incentives for reinvesting in the fishing industry, promoting the accumulation of licences into the hands of wealthy licence and quota holders who already are heavily invested and profiting from the fishing industry.

Furthermore, there are few licensing rules in BC fisheries. Halibut quota is typically leased with 70% of the landed value going to the licence holders in the absence of owner operator provisions. Most of the existing rules actually encourage consolidation, including licence stacking provisions and the development of
multi-species fishery culminating in the current groundfish integration discussions. In addition to this, there is increased demand. Speculation in fishing licences prior to quota implementation and First Nation’s treaty settlements have driven demand and consequently prices higher.

Crewmen, often the children of fishermen, have traditionally been the ones that are mentored into the industry and who eventually buy a boat and licence, but the price of a licence today is far out of reach of the average deckhand. A number of First Nations communities have acquired communal licences in recent years as part of pre-treaty settlements through a federal licence buyback program. This has brought back a small number of quota licences, accounting for ~15% of the rural held licences and ~2.5% of the urban held licences. This has offset some of the losses of licences, but only partially and has not had a significant impact on the centralization and consolidation of licences. In competitive fisheries, the picture is somewhat better in the north coast where the Northern Native Fishing Corporation provided considerable protection to this region against licence loss that other regions on the coast did not have through communal, dedicated First Nation salmon gillnet licence ownership. These benefits do not extend to other fisheries or to the non-First Nation residents of the rural north coast.

Efforts to examine the ecological consequences of fisheries policy have been hampered by DFO’s data sharing policy, especially with regard to quota fisheries, but some work has been completed with the trawl fishery. A recently completed analysis of discard rates in the trawl fishery found that fishermen were able to influence their discard species and amounts and that there was a noticeable change in catches of rockfish species for which the fishery was limited by individual quotas and total allowable catch (Branch 2004). Quotas are cited as promoting the reduction of discard by introducing individual incentive to fish cleanly (Branch et al. 2005), but this is only effective when there is enforcement and actual individual incentive to reduce or eliminate discard (Clucas 1997). There is 100% on board observer coverage for the outside bottom trawl fleet, but only 10% coverage for the mid-water trawl and inside (Queen Charlotte Strait, Johnston Strait, Strait of Georgia, and Juan de Fuca Strait) bottom trawl fisheries (FOC 2004). The individual incentive only applies to those species which have limiting total allowable catches. Many species do not have any catch limits including sponges and corals and traditional area closures (FOC 2004) have been used to control for high rates of discard of these species (Ardron 2005). Juveniles and sub-adults of many species are not counted against quota including sablefish and dogfish, resulting in no incentive to avoid. Other species have catch limits which are never reached or have low assessed mortality on discard that does not take into account mortality due to large tow size, all reducing the incentive to avoid discard and the effectiveness of using quota to accomplish ecological goals.

The health of the fisheries resource is being compromised by the large capitalization of the industry resulting in undue pressure by investors to keep catches high regardless of fish health and using industry funded science to back up claims of healthy stocks. Those who purchase licences in today’s market must pay off the debt, this leads to increased pressure to keep catch levels high. Science is increasingly being funded by industry and the data consequently owned by industry. Data from science and from landings is becoming harder to obtain. The health of the resource is expressed in terms of maintaining existing catch levels with little recognition of the overall health of our ocean environment separate from fisheries.

There is increasing recognition of the role of communities in the stewardship of the resource to not only maximize local benefits from resource use but also to ensure sustainable, long term and respectful use of adjacent resources. The negative impacts of quota allocations on fishing dependent coastal communities are increasing recognized (US GAO 2004). Alternatives are being put forward to the standard approach to allocating quotas to reverse the practice of hampering community involvement in fisheries as they move to quota (Macinko 2005) and to address problems from existing quota systems. The policies as they have been implemented by DFO have led to community and intergenerational disenfranchisement and the loss of adjacency to harvested resources. We must consider which problems must be solved before deciding on the solution. Privatization of the fisheries resource with no owner operator provisions, no corporate concentration restrictions and no adjacency principles creates problems that will not be solved with further entrenchment of private rights.

ACKNOWLEDGEMENTS

The authors would like to thank Don Hall, Peter Fricke, and Chris Newton for their invaluable comments on an early draft of this report, and several colleagues who provided a stimulating discussion at the NAAFE conference in Vancouver, BC, in May 2005. Special thanks go to Jeff Ardron, formerly of the
Living Oceans Society, for providing data, and to the Oak Foundation for providing financial support for this research.

REFERENCES


Fleet Rationalization Committee, 1982. Fleet Rationalization Committee Report. Commissioned by the Minister of Fisheries and Oceans (Romeo LeBlanc). Vancouver, BC.


Standing Senate Committee on Fisheries and Oceans, 2005. Interim Report on Canada’s New and Evolving Policy Framework For Managing Fisheries and Oceans.


Statistics Canada, 2001. 2001 Census Community Profiles. Available at:  
http://www12.statcan.ca/english/profil01/PlaceSearchForm1.cfm


Underwater Harvesters Association, 2005. History of the Geoduck Clam Fishery in British Columbia Available at:  

THE IMPACT OF RIGHTS-BASED MANAGEMENT REGIMES
ON FISHERY PRODUCTIVITY

Stephanie F. McWhinnie

Department of Economics, University of British Columbia
997-1873 East Mall, Vancouver BC, V6T 1Z1, Canada

ABSTRACT

Property rights regimes are increasingly recommended and implemented in fisheries management around the world. While theoretical examination and anecdotal evidence suggest that these regimes are successful at increasing both productivity and sustainability, the empirical evidence on their effects is limited. This paper provides an empirical examination of the effect of a move to a property rights system on productivity in the Norwegian coastal cod fishery. Using a unique vessel-level dataset I conduct a parallel analysis using a traditional productivity approach and an index number decomposition to establish the source of productivity changes. The strength of conducting a parallel analysis is to be comparable with previous studies while exploiting the power of the decomposition to identify the component effects of the policy. Determining the important components of productivity changes allows for the refinement of management to mimic the effect of property rights systems even when their full implementation may not be possible. Results suggest that the introduction of individual vessel quotas in the coastal cod fishery increased productivity.

INTRODUCTION

Property rights regimes have been prescribed as the panacea of fisheries management the world over and are increasingly implemented in a variety of forms. While theoretical examination and anecdotal evidence suggest that these regimes are successful, both economically and biologically, there is limited empirical evidence on the effect of property rights regimes on fisheries productivity. Studying these effects is important for appropriate policy development, industry support and political understanding.

The objective of this paper is to empirically examine the effect of a move to a property rights regime on productivity in the Norwegian coastal cod fishery. I take a parallel approach using a data envelopment analysis to calculate technical efficiency and an index number decomposition to calculate relative productivity. An advantage of the index number decomposition is that it can be used to determine the source of productivity changes. The purpose of the parallel approach is to address the problem that analysis of changes in fisheries management regimes are, by necessity, done at the level to match with management. This means researchers and managers must make empirical predictions about the effects of different types of management from a series of case studies. Unfortunately, if the methodology of the case studies differs for each, the ability to develop a consistent body of evidence is limited.

Fisheries productivity analysis is done using a variety of methods including data envelopment analysis, stochastic production frontiers, and, most recently, index number profit decomposition using the method developed in Fox et al. (2003). However, only two fisheries have had the introduction of property rights analysed with a regime-switch type of analysis. Fox et al. (2003) follow up on the productivity frontier analysis of Grafton et al. (2000) using data on the British Columbia halibut fishery to illustrate the profit decomposition. They find that profitability rises after the change to individual quotas in this single-species fishery and that rises in price due to an extended season of high quality, fresh fish is an important factor. Dupont et al. (2005) extend the decomposition to the Nova Scotia mobile gear multi-species


2 Email: sfmcwhin@interchange.ubc.ca
fishery that had previously been studied using a data envelopment analysis (Dupont et al. 2002) and find, similar to the halibut fishery, profitability rises after the introduction of individual transferable quotas due to a rise in price of species subject to quota.

The limitation of studying these fisheries is that only a small number of vessel-level observations across three years of data are available for each: one year before, the year of, and one year after, the management change for the British Columbia halibut fishery with a total of 105 observations; and two years before, and the year of, the change for the Nova Scotia multi-species fishery for a total of 108 observations. The Norwegian coastal cod fishery, in contrast, 2865 vessel-level observations from 1985-2000, flanking the change in 1990. This is of particular importance for the Norwegian coastal fishery as the individual vessel quotas are non-transferable, suggesting a more limited ability to adapt to the management change. The volume of data is a mixed blessing as it has provided a greater degree of heterogeneity across vessels, necessitating an adaptation of the profit decomposition, outlined in the next section.

The methodological framework section outlines the parallel data envelopment analysis and index number decomposition framework with which I determine productivity change. A discussion of the management of and data on the Norwegian coastal cod fishery follows in Data and Management. The fourth section gives the Productivity Analysis Results. Finally, the conclusion of how property rights management regimes alter productivity is discussed.

**Methodological Framework**

There are a variety of methods with which to analyse changes in productivity. The approach I have chosen is to combine a data envelopment analysis (DEA) with an index number decomposition (IND). The DEA is carried out in two stages: the first is a calculation of an efficiency score for each observation; the second stage uses regression analysis to determine the effect of management change on the efficiency scores. Of great interest to managers and industry alike, however, is where the effect is coming through, that is, does the management change lead to lower costs, higher prices or a combination? Fox et al. (2003) developed an index number profit decomposition specifically to allow a breakdown of these effects. I use a modified version of their approach that is also conducted in two stages: the first stage uses an index to decompose the revenue-cost ratio and hence find productivity ratios; similar to the DEA, the second stage uses regression analysis to determine the effect of management change. Of note is that both approaches allow for the analysis of multiple outputs so examination of both a change of input and output mix in the response to regulation change is possible. The strength of conducting a parallel analysis is to be comparable with previous studies while exploiting the power of the IND to tease out the component effects of the policy.

**Data Envelopment Analysis**

Data envelopment analysis can examine efficiency in a variety of forms, such as, technical, allocative, cost, or profit efficiency. I take the case of technical efficiency, that is, determining by how much inputs could be contracted while producing the same amount of outputs. The methodology is described in detail in Coelli et al. (1998), from where I will draw heavily in this brief outline. The idea can most easily be seen in Figure 1, which shows a two-input (\(x_1\) and \(x_2\)), one-output (\(y\)) production function. Let the curve \(ss\) represent the most technically efficient isoquant. The technical efficiency of a firm depends upon how far beyond \(ss\) a firm’s input combination lies. For example, the technical efficiency of a firm with inputs at point \(P\) is the ratio \(OQ/OP\); the closer to one this ratio is, the more efficient a firm is. In practice the efficient isoquant is estimated from the data using a piece-wise function.

The linear programming problem associated with this measure of technical efficiency for each firm \(b\) with input vector \(\mathbf{x}_b\) and output vector \(\mathbf{y}_b\) is:

\[
\begin{align*}
\text{min}_{\theta, \mathbf{y}_b, \mathbf{X}, \lambda} & \quad \theta \mathbf{y}_b - \mathbf{X} \lambda \geq 0 \\
\text{st} & \quad \mathbf{x}_b \lambda \geq 0 \\
& \quad \lambda \geq 0
\end{align*}
\]

(1)
where $X$ and $Y$ are matrices with column $b$ of each being $x_b$ and $y_b$, respectively, and $\lambda$ is a vector of constants. Equation 1 uses all the observed data to determine the most efficient isoquant as the inner envelope of the data. Then, each firm is taken in turn and the input vector, $x_b$ (OP in Figure 1), is contracted until the efficient isoquant is reached at $(X\lambda, Y\lambda)$ (finding $OQ$ in Figure 1). The comparison of the observed inputs and the efficient solution thus give a value for technical efficiency, $\theta$, for each firm from which a regression analysis of the effect of management change may proceed.

**Index Number Decomposition**

To find the effects of the mix of inputs and outputs, Fox et al. (2003) (hereafter denoted FGKS) develop an index number approach to decompose profits. Their methodology is clearly described but as I implement a modified version I present their method and my adaptation briefly here. Productivity of any firm (firm $b$) is defined in both FGKS and this paper as the ratio of an index of outputs over an index of inputs:

$$\text{(2) Productivity Index } = \frac{O^{ab}}{I^{ab}}$$

where each index is defined relative to the most profitable firm (firm $a$). A firm will be considered to be more productive the higher the ratio of outputs to inputs, compared to the most profitable firm.

FGKS use the concept of "netputs" (inputs are indicated by negative quantities) and Fisher's "weak factor reversal test" (a quantity index multiplied by the price index equals the values index) to define the output index as the profit ratio divided by the netput price index, and define the input index as fixed inputs only to define productivity as:

$$\text{(3) } \varphi^{ab} = \frac{O^{ab}}{I^{ab}} = \frac{\pi^b / P^{ab}}{k^b / f^b \cdot \pi^a / P^{ab} \cdot k^a / f^a}$$
where $\pi$ is variable profits, $k$ is a fixed capital input, $f$ is a fixed fish biomass input, and $T^b$ is the netput price index. The netput price index can be calculated using any index but the authors recommend a Törnqvist index, thus for $n=1,\ldots,N$ netputs:

$$T_{n}^{ab} = \prod_{n=1}^{N} T_{n}^{ab} = \exp \left[ \frac{1}{2} \left( \sum_{n} \frac{t_n^{b} z_n^{b}}{t_n^a z_n^a} + \sum_{n} \frac{t_n^{a} z_n^{a}}{t_n^b z_n^b} \right) \ln \left( \frac{t_n^b}{t_n^a} \right) \right]$$

where $t_n$ and $z_n$ are the price and quantity of netput $n$, and $\sum t_n z_n = \pi$. The advantage of this approach is that a Törnqvist index of netputs can be derived from profit maximisation of a translog profit function with constant returns to scale in variable inputs and capital together. The disadvantage comes in empirical application when there is large heterogeneity of inputs and outputs across firms with possibly non-constant returns to scale, and/or negative profits, both of which are the case in the data I use on Norwegian cod. The problems arise from using profits in the weights on relative prices in Equation 4: large heterogeneity with non-constant returns means that firms with large revenues and costs may have the same profits as firms with small revenues and costs causing the index to explode to an unworkable magnitude; similarly, negative profits can make the weights such that the index explodes.

To address the empirical drawbacks of the FGKS measure of productivity I use a deflated revenues and costs method to calculate productivity. This also uses Fisher’s test to define the output index as total revenues divided by the output price index, and the input index as total costs divided by the input price index. The advantage of weighting outputs by revenues and inputs by costs (rather than both by profits) means the indexes are less susceptible to the non-constant returns problem and profits do not enter, eliminating the negative profits problem. I make a further modification to include capital as a variable input, which implicitly gives all remaining profits to the fish biomass. An advantage of this is that it gives a picture of how well, or poorly, the fishery is doing depending on how much profit, or loss, remains. As such, I define productivity as:

$$\tau^{ab} = \frac{O^{ab}}{I^{ab}} = \frac{TR^b}{TR^a} \left( \frac{P^{ab}}{f^b T^b C^b} \right) \left( \frac{f^a T^a C^a}{W^{ab}} \right)$$

where $TR$ and $TC$ denote total revenues and total costs, $f$ continues to denote fish biomass, and $P^{ab}$ and $W^{ab}$ are indexes for output prices and input costs respectively. In keeping with FGKS, I use Törnqvist indexes for $j=1,\ldots,J$ outputs and $i=1,\ldots,I$ inputs:

$$P^{ab} = \prod_{j=1}^{J} P^{ab}_j = \exp \left[ \frac{1}{2} \left( \sum_{j} \frac{p_j^{b} y_j^{b}}{p_j^a y_j^a} + \sum_{j} \frac{p_j^{a} y_j^{a}}{p_j^b y_j^b} \right) \ln \left( \frac{p_j^b}{p_j^a} \right) \right]$$

$$W^{ab} = \prod_{i=1}^{I} W^{ab}_i = \exp \left[ \frac{1}{2} \left( \sum_{i} \frac{w_i^{b} x_i^{b}}{w_i^a x_i^a} + \sum_{i} \frac{w_i^{a} x_i^{a}}{w_i^b x_i^b} \right) \ln \left( \frac{w_i^b}{w_i^a} \right) \right]$$

where $p_j$ and $y_j$ are the price and quantity of output $j$ with $\sum p_j y_j = TR$, and $w_i$ and $x_i$ are the cost and quantity of input $i$ with $\sum w_i x_i = TC$.

---

3 More than one capital input can be accommodated by using an index in the denominator, I omit this for simplicity and to match the empirical analysis directly.

4 In the empirical analysis I also run a specification where capital is treated as a fixed input with little difference in predicted productivity.
DATA AND MANAGEMENT

Individual vessel quotas (IVQs) were introduced into the Norwegian coastal cod fishery in the 1990 season in response to the previous race for fish that in 1989 had exhausted the total allowable catch (TAC) by April. Each year the managers establish the vessel quotas in dialogue with the fishermen’s’ organisation and always include some overregulation (the sum of all IVQs is greater than the TAC) to account for factors such as vessels not taking part. This overregulation is undertaken to avoid having to adjust the quotas throughout the year but frequently it is too high, in which case seasonal closures are introduced. While this method is effective with respect to restricting catch it reduces the effectiveness of the property rights in terms of fishing when prices are highest or costs are lowest. Throughout the period of my study there was no transferability or divisibility of quotas allowed; a vessel with quota attached was allowed to be sold but the quota was not saleable separate from the vessel, forming another restriction to taking advantage of property rights.

The Norwegian Directorate of Fisheries provided vessel level data from the Annual Profitability Survey from 1985 to 2000. This dataset is ideal for studying the impact of the introduction of IVQs as it flanks the regime switch. The survey includes data on vessels of length 13-27.9 metres that participate in the fishery for at least 30 weeks. These vessels represent 80–85 percent of the total national catch each year and survey samples approximately 25 percent of this fleet.

The unbalanced panel that results from the survey gives 2865 observations in total, 180 per year on average, with detailed output and input information. I remove 67 observations that have incomplete characteristic information and a further 27 observations that are extreme outliers (indexes for $P_{ab} >1000$ or $<0.001$). As the survey is coast-wide and the mix of outputs varies by county, a geographic snapshot of statistics is given in Table 1 with associated map in Figure 2. Full summary statistics are presented in Table 2.

### Table 1. Summary statistics by county.

<table>
<thead>
<tr>
<th>County</th>
<th>Observations</th>
<th>Vessel Length (m)</th>
<th>Operating Profit (NOK)</th>
<th>Cod Share Of TR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finnmark</td>
<td>291</td>
<td>17.58</td>
<td>62,966</td>
<td>0.53</td>
</tr>
<tr>
<td>Troms</td>
<td>538</td>
<td>18.60</td>
<td>129,446</td>
<td>0.44</td>
</tr>
<tr>
<td>Nordland</td>
<td>1095</td>
<td>17.74</td>
<td>80,037</td>
<td>0.53</td>
</tr>
<tr>
<td>Nord-trøndelag</td>
<td>90</td>
<td>15.37</td>
<td>89,354</td>
<td>0.43</td>
</tr>
<tr>
<td>Sør-trøndelag</td>
<td>161</td>
<td>15.92</td>
<td>49,403</td>
<td>0.33</td>
</tr>
<tr>
<td>Møre og Romsdal</td>
<td>390</td>
<td>18.66</td>
<td>156,737</td>
<td>0.31</td>
</tr>
<tr>
<td>Sogn og Fjordane</td>
<td>92</td>
<td>18.95</td>
<td>213,722</td>
<td>0.27</td>
</tr>
<tr>
<td>Hordaland</td>
<td>43</td>
<td>19.77</td>
<td>153,280</td>
<td>0.17</td>
</tr>
<tr>
<td>Rogaland</td>
<td>21</td>
<td>18.76</td>
<td>25,381</td>
<td>0.20</td>
</tr>
<tr>
<td>Vest-agder</td>
<td>44</td>
<td>19.16</td>
<td>355,967</td>
<td>0.33</td>
</tr>
<tr>
<td>Telemark</td>
<td>1</td>
<td>20.12</td>
<td>110,503</td>
<td>0.02</td>
</tr>
<tr>
<td>Østfold</td>
<td>5</td>
<td>15.94</td>
<td>162,364</td>
<td>0.17</td>
</tr>
<tr>
<td>Total</td>
<td>2771</td>
<td>17.94</td>
<td>106,210</td>
<td>0.44</td>
</tr>
</tbody>
</table>

The coastal cod fishery is a multi-species fishery where vessels surveyed report quantity and value of four specific species (Northeast Arctic Cod, Northeast Arctic Haddock, Saithe - divided into north or south of 62°, and Greenland Halibut); other species are reported in an "other" category - also divided into north or south of 62°. Due to the diverse nature of the fishery the mix of outputs varies widely, and the vessels from extremely southern, or northern, ports do not generally harvest north, or south, of the 62° reporting division, thus I focus my analysis on the three species that almost all of the fleet catch (Cod, Haddock and Northern Saithe) and group everything else into an "all other" category. Quantities are in kilograms and values are in real Norwegian Kroner.\(^5\) Prices are calculated as Value/Quantity and will differ to reflect different ports, time of delivery and so forth. Vessels report operating revenues as well as the value of catch for each species; where the sum of catch value is different from operating revenues I create an additional category of "other income". Where this comes from is currently not clear.

\(^5\) All values are converted to real using the consumer price index with base-year 1998. At that time 1 USD = 7.5 NOK.
Effects of rights-based management on productivity, S.F. McWhinnie

Non-biomass inputs are divided into six categories: labour (wages and salaries including crew-shares); labour-related (social security tax, crew assurances and provisions); fuel (fuel and lubrication oil); other variable (bait, ice, salt and packing, gear maintenance and investment, other operating and administrative); quasi-fixed (vessel insurance and maintenance); and capital (estimated depreciation). As the cost of inputs is reported as expenditure on each category I have to determine prices by Value/Quantity, as done with outputs, except for labour and fuel. The price of labour is proxied by the annual earnings for a worker in manufacturing (International Labour Office 2005) while the price of fuel is proxied by the price per litre of autodiesel (Statistics Norway 2003, 2005). The labour-related price is value divided by man-years, the other variable price is value divided by days at sea, and quasi-fixed price is value divided by vessel length. It is interesting to note that 44% of the observations record negative profits and even excluding vessel depreciation (which could be justified given that overcapitalisation is a problem in fisheries the world over) 14% report negative profits. This still means that there is most likely some degree of underreporting of revenues and/or overreporting of costs.

**PRODUCTIVITY ANALYSIS RESULTS**

As outlined in the Methodological Framework section, both the data envelopment analysis and the index number decomposition are a matter of computation. For each firm I calculate the measure of technical efficiency relative to the efficient isoquant ($\theta$) using the DEA and a measure of productivity relative to the most profitable firm ($\gamma$) and decompose the elements of that using the IND. The variable inputs are labour, labour-related, fuel, other variable, quasi-fixed, and capital, with stock biomass included as a fixed input. The outputs are cod, haddock, northern saithe, other fish, and other income. While I chose my species groups to limit the problem of blanks, for the 217 observations that did not catch haddock, northern saithe or other fish, the analysis is done with respect to just the species caught.

Before considering the components, I take the calculated measures of technical efficiency and relative productivity and examine the effect of IVQ management using panel least squares analysis with a spline to allow for a structural break at 1990. The simplest specifications, presented in Columns 1 and 3 of Table 3 just use a constant and the structural break; the specifications presented in Columns 2 and 4 include...

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod (kg)</td>
<td>104,055</td>
<td>98,604</td>
<td>7</td>
<td>952,857</td>
</tr>
<tr>
<td>Haddock (kg)</td>
<td>19,267</td>
<td>36,054</td>
<td>1</td>
<td>328,784</td>
</tr>
<tr>
<td>North Saithe (kg)</td>
<td>66,510</td>
<td>146,870</td>
<td>1</td>
<td>1,701,075</td>
</tr>
<tr>
<td>All Other (kg)</td>
<td>254,878</td>
<td>506,354</td>
<td>2</td>
<td>5,477,409</td>
</tr>
<tr>
<td>Cod (NOK)</td>
<td>929,609</td>
<td>834,594</td>
<td>29</td>
<td>8,001,647</td>
</tr>
<tr>
<td>Haddock (NOK)</td>
<td>119,363</td>
<td>231,601</td>
<td>0</td>
<td>3,259,702</td>
</tr>
<tr>
<td>North Saithe (NOK)</td>
<td>232,779</td>
<td>473,307</td>
<td>0</td>
<td>6,721,887</td>
</tr>
<tr>
<td>Other Fish (NOK)</td>
<td>802,610</td>
<td>1,280,684</td>
<td>0</td>
<td>13,200,000</td>
</tr>
<tr>
<td>Other Income (NOK)</td>
<td>187,421</td>
<td>410,655</td>
<td>-2,539,395</td>
<td>4,712,988</td>
</tr>
<tr>
<td>Vessel Length</td>
<td>17.9</td>
<td>4.0</td>
<td>1.0</td>
<td>12.7</td>
</tr>
<tr>
<td>Man-Years</td>
<td>4.2</td>
<td>1.8</td>
<td>1.0</td>
<td>12.7</td>
</tr>
<tr>
<td>Days in Operation</td>
<td>281</td>
<td>44</td>
<td>62</td>
<td>364</td>
</tr>
<tr>
<td>Wage Costs (NOK)</td>
<td>994,735</td>
<td>864,697</td>
<td>10,462</td>
<td>8,285,785</td>
</tr>
<tr>
<td>Labour Related (NOK)</td>
<td>152,194</td>
<td>135,375</td>
<td>1,514</td>
<td>1,322,988</td>
</tr>
<tr>
<td>Fuel Costs (NOK)</td>
<td>160,719</td>
<td>169,939</td>
<td>0</td>
<td>1,852,319</td>
</tr>
<tr>
<td>Other Variable (NOK)</td>
<td>294,468</td>
<td>327,950</td>
<td>622</td>
<td>7,275,451</td>
</tr>
<tr>
<td>Quasifixed (NOK)</td>
<td>317,458</td>
<td>312,132</td>
<td>14,086</td>
<td>3,326,144</td>
</tr>
<tr>
<td>Depreciation (NOK)</td>
<td>248,430</td>
<td>256,999</td>
<td>33</td>
<td>4,110,051</td>
</tr>
<tr>
<td>Manuf. Wage (NOK/year)</td>
<td>227,826</td>
<td>16,192</td>
<td>199,368</td>
<td>261,591</td>
</tr>
<tr>
<td>Fuel (NOK/litre)</td>
<td>5.18</td>
<td>2.20</td>
<td>2.86</td>
<td>9.25</td>
</tr>
<tr>
<td>Revenues (NOK)</td>
<td>2,278,881</td>
<td>2,041,760</td>
<td>68,539</td>
<td>19,400,000</td>
</tr>
<tr>
<td>Costs (NOK)</td>
<td>2,173,465</td>
<td>1,804,291</td>
<td>154,258</td>
<td>18,500,000</td>
</tr>
<tr>
<td>Profit (NOK)</td>
<td>105,416</td>
<td>486,917</td>
<td>73,135,557</td>
<td>6,153,804</td>
</tr>
<tr>
<td>Cod Stock (000 tonnes)</td>
<td>143,688</td>
<td>34,793</td>
<td>81,971</td>
<td>196,855</td>
</tr>
</tbody>
</table>

All values in real Norwegian Kroner (1USD = 7.5NOK). 2771 Observations

Table 3. Panel regression of management’s effect on technical efficiency and relative productivity.

<table>
<thead>
<tr>
<th></th>
<th>DEA (Simple)</th>
<th>DEA (with Controls)</th>
<th>IND (Simple)</th>
<th>IND (with Controls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.2794***</td>
<td>0.2785***</td>
<td>1.8181***</td>
<td>-0.4974</td>
</tr>
<tr>
<td></td>
<td>(0.011)</td>
<td>(0.044)</td>
<td>(0.114)</td>
<td>(0.431)</td>
</tr>
<tr>
<td>Pre-1990</td>
<td>-0.0013</td>
<td>-0.0005***</td>
<td>-0.1294***</td>
<td>-0.1044***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.027)</td>
<td>(0.025)</td>
</tr>
<tr>
<td>Post-1990</td>
<td>0.0473***</td>
<td>0.0441***</td>
<td>0.5112***</td>
<td>0.4349***</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.003)</td>
<td>(0.036)</td>
<td>(0.034)</td>
</tr>
<tr>
<td>Vessel Length</td>
<td>0.0066***</td>
<td>0.0066***</td>
<td>0.2066***</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
<tr>
<td>Vessel Age</td>
<td>-0.0024***</td>
<td>-0.0024***</td>
<td>-0.0172***</td>
<td>-0.003</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>County Dummies</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Gear-Type Dummies</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Obs. 2771</td>
<td>Wald X²(2) 1482</td>
<td>Wald X²(27) 2141</td>
<td>Wald X²(2) 826</td>
<td>Wald X²(27) 1828</td>
</tr>
<tr>
<td>Groups 851</td>
<td>Overall R² 0.35</td>
<td>Overall R² 0.49</td>
<td>Overall R² 0.25</td>
<td>Overall R² 0.47</td>
</tr>
</tbody>
</table>
controls for vessel length, vessel age, a set of county dummies, and a set of gear type dummies. Using the DEA approach, the coefficients for the Post-1990 effect on technical efficiency (column 1) indicate that observations after 1990 are 4.7 percentage points closer to the efficient isoquant than observations prior to 1990. This effect is slightly smaller (4.4 percentage points) after controlling for vessel size and age, and county and gear-type (column 2). The IND approach supports this conclusion, in the simple case (column 3) the introduction of IVQs raises productivity 51.1 percentage points compared to the previous licensing scheme, while the additional controls reduce this to 43.5 percentage points. The difference in magnitude is due to the DEA approach restricting the measure of efficiency to a maximum of one. In contrast, the IND approach provides no upper bound as it is relative to the most profitable firm; in the data 2300 observations have higher productivity than the most profitable firm.

To get a better sense of when the productivity effects are coming through, I conduct the same regressions but instead of using structural break I use a set of year dummies. The coefficients of these are presented in Figure 3 and tell us how productivity has changed compared to 1985 so we can examine when the management effects took hold. In all specifications there is a statistically significant increase in efficiency or productivity after 1993, compared to 1985. Why the increased productivity we would expect from the introduction of property rights took three years to take effect is unclear. It may be due to the lack of transferability of quota or due to the lack of property rights for the species other than cod. It is interesting to note that 1989 has statistically higher efficiency and productivity than 1985 when this is the year of collapse that led to the introduction of IVQs. However, this is most likely due to the fact that the fishery was actually closed in April thus restricting the season and thus the use of inputs.

To take advantage of the component analysis allowed by the IND I present the decompositions in Tables 4 and 5. To give a sense of how the decompositions differ across vessel size and under different management regimes the results are presented altogether and subsequently divided into small and large vessel sizes under the two management regimes. The columns give geometric means of the six cost categories (Labour, Labour-related, Fuel, Other variable, Quasi-fixed, and Capital) and the five outputs (Cod, Haddock, Northern Saithe, Other Fish, and Other Income). The lower portions of the tables present a series of t-tests of whether the means are different across management regimes and vessel sizes. None of the input or output categories have exhibited change across the time period except for a reduction in the importance of Other Fish for larger vessels. This is despite the increase in profits that can be observed in Table 4. Conducting this decomposition has not, in this fishery, enabled identification of how firms are responding to altered management practices. Input prices have risen, and output prices have not while profits have risen across the time period.

Figure 3. Efficiency and productivity increases over 1985.

---

6 Coefficients are not presented for these dummies; full results may be obtained from the author upon request.
### Table 4. Profits, revenues and costs – arithmetic means by group.

<table>
<thead>
<tr>
<th>Productivity Ratio</th>
<th>Profit Value</th>
<th>Revenues Value</th>
<th>Costs Value</th>
<th>Biomass Ratio</th>
<th>Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Years</td>
<td>1.787</td>
<td>105,416</td>
<td>2,278,881</td>
<td>2,173,465</td>
<td>1.071</td>
</tr>
<tr>
<td>(2.03)</td>
<td>(486,917)</td>
<td>(2,041,760)</td>
<td>(1,804,291)</td>
<td>(0.26)</td>
<td>(34,802)</td>
</tr>
<tr>
<td>Pre-1990</td>
<td>1.430</td>
<td>-21,733</td>
<td>1,786,460</td>
<td>1,808,193</td>
<td>0.928</td>
</tr>
<tr>
<td>920 obs</td>
<td>(1.63)</td>
<td>(464,820)</td>
<td>(1,636,008)</td>
<td>(1,485,198)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Small</td>
<td>1.318</td>
<td>-71,502</td>
<td>1,045,050</td>
<td>1,116,552</td>
<td>0.929</td>
</tr>
<tr>
<td>562 obs</td>
<td>(1.62)</td>
<td>(356,788)</td>
<td>(746,918)</td>
<td>(788,382)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Large</td>
<td>1.461</td>
<td>57,684</td>
<td>1,340,290</td>
<td>1,282,607</td>
<td>1.179</td>
</tr>
<tr>
<td>358 obs</td>
<td>(1.85)</td>
<td>(199,638)</td>
<td>(733,780)</td>
<td>(638,535)</td>
<td>(0.27)</td>
</tr>
<tr>
<td>1990-on</td>
<td>1.430</td>
<td>21,733</td>
<td>1,786,460</td>
<td>1,808,193</td>
<td>0.928</td>
</tr>
<tr>
<td>1863 obs</td>
<td>(1.63)</td>
<td>(464,820)</td>
<td>(1,636,008)</td>
<td>(1,485,198)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Small</td>
<td>1.318</td>
<td>-71,502</td>
<td>1,045,050</td>
<td>1,116,552</td>
<td>0.929</td>
</tr>
<tr>
<td>803 obs</td>
<td>(1.62)</td>
<td>(356,788)</td>
<td>(746,918)</td>
<td>(788,382)</td>
<td>(0.08)</td>
</tr>
</tbody>
</table>

Standard deviations in parentheses.

**t-statistics testing for differences under IVQ management**

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>if small</td>
<td>1.60</td>
<td>7.92</td>
<td>7.60</td>
<td>4.29</td>
<td>28.58</td>
</tr>
<tr>
<td>if large</td>
<td>12.10</td>
<td>6.53</td>
<td>8.34</td>
<td>7.49</td>
<td>14.27</td>
</tr>
</tbody>
</table>

### Table 5. Index number decompositions – geometric means by group.

<table>
<thead>
<tr>
<th></th>
<th>Labour</th>
<th>Labour Related</th>
<th>Fuel</th>
<th>Other Variable</th>
<th>Quasi-fixed</th>
<th>Capital</th>
<th>Biomass</th>
<th>Cod</th>
<th>Had-dock</th>
<th>Nh</th>
<th>Saithe</th>
<th>Other Fish</th>
<th>Other Income</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Years</td>
<td>1.056</td>
<td>0.898</td>
<td>1.042</td>
<td>1.044</td>
<td>0.865</td>
<td>0.823</td>
<td>0.326</td>
<td>1.027</td>
<td>0.995</td>
<td>0.993</td>
<td>0.514</td>
<td>0.865</td>
<td>0.823</td>
<td>1.787</td>
</tr>
<tr>
<td>(1.04)</td>
<td>(1.04)</td>
<td>(1.04)</td>
<td>(1.04)</td>
<td>(1.08)</td>
<td>(1.09)</td>
<td>(1.39)</td>
<td>(1.06)</td>
<td>(1.02)</td>
<td>(1.03)</td>
<td>(1.62)</td>
<td>(2.03)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-1990</td>
<td>1.014</td>
<td>0.888</td>
<td>1.003</td>
<td>1.033</td>
<td>0.847</td>
<td>0.805</td>
<td>0.318</td>
<td>1.023</td>
<td>0.995</td>
<td>0.997</td>
<td>0.573</td>
<td>0.874</td>
<td>0.847</td>
<td>1.430</td>
</tr>
<tr>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.08)</td>
<td>(1.09)</td>
<td>(1.35)</td>
<td>(1.05)</td>
<td>(1.01)</td>
<td>(1.03)</td>
<td>(1.46)</td>
<td>(1.63)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>920 obs</td>
<td>1.013</td>
<td>0.876</td>
<td>1.008</td>
<td>1.008</td>
<td>0.818</td>
<td>0.799</td>
<td>0.280</td>
<td>1.025</td>
<td>0.994</td>
<td>1.002</td>
<td>0.582</td>
<td>0.924</td>
<td>0.811</td>
<td>1.318</td>
</tr>
<tr>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.08)</td>
<td>(1.09)</td>
<td>(1.35)</td>
<td>(1.05)</td>
<td>(1.01)</td>
<td>(1.02)</td>
<td>(1.41)</td>
<td>(1.62)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>1.074</td>
<td>0.890</td>
<td>1.058</td>
<td>1.018</td>
<td>0.841</td>
<td>0.802</td>
<td>0.274</td>
<td>1.031</td>
<td>0.994</td>
<td>0.997</td>
<td>0.583</td>
<td>0.890</td>
<td>0.841</td>
<td>1.461</td>
</tr>
<tr>
<td>562 obs</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.07)</td>
<td>(1.07)</td>
<td>(1.07)</td>
<td>(1.07)</td>
<td>(1.07)</td>
<td>(1.07)</td>
<td>(1.07)</td>
<td>(1.07)</td>
<td>(1.07)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>1.082</td>
<td>0.921</td>
<td>1.066</td>
<td>1.091</td>
<td>0.921</td>
<td>0.874</td>
<td>0.401</td>
<td>1.027</td>
<td>0.996</td>
<td>0.983</td>
<td>0.538</td>
<td>0.921</td>
<td>0.874</td>
<td>3.006</td>
</tr>
<tr>
<td>358 obs</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990-on</td>
<td>1.078</td>
<td>0.903</td>
<td>1.061</td>
<td>1.049</td>
<td>0.875</td>
<td>0.832</td>
<td>0.328</td>
<td>1.029</td>
<td>0.995</td>
<td>0.995</td>
<td>0.487</td>
<td>0.903</td>
<td>0.875</td>
<td>1.995</td>
</tr>
<tr>
<td>1863 obs</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>1.015</td>
<td>0.906</td>
<td>1.003</td>
<td>1.074</td>
<td>0.893</td>
<td>0.848</td>
<td>0.361</td>
<td>1.021</td>
<td>0.997</td>
<td>0.991</td>
<td>0.560</td>
<td>0.906</td>
<td>0.848</td>
<td>1.625</td>
</tr>
<tr>
<td>1060 obs</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td>(1.02)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>1.082</td>
<td>0.921</td>
<td>1.066</td>
<td>1.091</td>
<td>0.921</td>
<td>0.874</td>
<td>0.401</td>
<td>1.027</td>
<td>0.996</td>
<td>0.983</td>
<td>0.538</td>
<td>0.921</td>
<td>0.874</td>
<td>3.006</td>
</tr>
<tr>
<td>803 obs</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Geometric standard deviations in parentheses.

**t-statistics testing for differences under IVQ management**

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre v. Post</td>
<td>1.550</td>
<td>0.366</td>
<td>1.249</td>
<td>0.352</td>
<td>0.637</td>
</tr>
<tr>
<td>if small</td>
<td>1.147</td>
<td>0.249</td>
<td>1.041</td>
<td>0.176</td>
<td>0.403</td>
</tr>
<tr>
<td>if large</td>
<td>1.034</td>
<td>0.227</td>
<td>0.974</td>
<td>0.239</td>
<td>0.405</td>
</tr>
</tbody>
</table>
CONCLUSION

I have used a previously untapped dataset to examine the impact of a change to IVQ management on the productivity in the Norwegian Coastal Cod fishery. The analysis is conducted with two methodologies in a parallel fashion to allow comparison to previous work and to highlight the usefulness of determining the important components allowed by the index number decomposition. The results suggest that management has a positive impact on productivity. Unlike the studies of Canadian fisheries, there is no evidence to suggest a move to attaining higher prices for outputs. This is in part due to the overregulation of the fishery where the total restriction on catch is effective but the property rights are less so. The transferability provisions since 2003 may generate greater profitability in this fishery, as would tightening the property rights by reducing overregulation.

ACKNOWLEDGEMENTS

My particular debt goes to Tove Aasheim of the Norwegian Directorate of Fisheries who prepared the data used here. I would also like to thank Trond Bjørndal and Per Sandberg for answering all my questions about Norwegian fisheries. Continuing advice and encouragement from Brian Copeland, Erwin Diewert, Gordon Munro, Rashid Sumaila and Siwan Anderson is gratefully acknowledged.

REFERENCES


DATA FOULING IN MARINE FISHERIES: FINDINGS AND A MODEL FOR NEWFOUNDLAND

Kaija I. Metuzals, C. Michael Wernerheim, Richard L. Haedrich
Memorial University of Newfoundland,
St John's, NL, Canada

Parzival Copes
Simon Fraser University
Burnaby, BC, Canada

Ann Murrin
Memorial University of Newfoundland,
St John's, NL, Canada

ABSTRACT

One of the most serious problems facing fisheries managers is how to improve estimates of the distortion (‘fouling’) of commercial landings data resulting from misreporting in all its various forms. Data fouling (legal or illegal) drives a wedge between what is caught and killed at sea, and what is landed and reported to the regulator. This can obscure the true state of the stock causing it to appear healthier than it is, resulting in quotas being set too high. Informed by our survey of the reporting practices of 50 Newfoundland fishermen and other evidence, we formulate a simple theoretical model of two types of data fouling in a quota fishery; high-grading and under-reporting of catch. The model is solved analytically for the profit maximizing effort level and the associated number of high-grading operations. A second version is solved for the optimal proportion of the harvest to under-report, given the perceived probability of detection and conviction, and the structure of fines. The models can be used with available empirical data to estimate what we call the ‘data fouling factor.’ Some illustrative policy implications are derived.

1. INTRODUCTION

If misreporting is ignored and catch data is worthless, what you have is an uncontrolled fishery.

— Halifax Herald, 20 January 2003

Sound fisheries management depends on the quality of catch data. Specifically, the estimation of stock abundance and the determination of quotas alike depend in large measure on accurate and precise statistics on commercial landings. One of the most serious problems facing fisheries managers is how to improve estimates of the distortion resulting from 'misreporting.' Failure to obtain an accurate account from harvesters about activities at sea undermines the reliability of catch data, which can in turn introduce an (avoidable) element of uncertainty into the outcomes of fisheries policy: the greater the inaccuracy in

---

2 Email: wern@mun.ca
3 Precision is a measure of the variability of data around its mean value, whereas accuracy is a measure of the closeness of a measured or computed value to its true value (NRC 2000).
the data the wider the confidence intervals around the estimate of stock size. Data fouling causes the stock to appear healthier than it is, which, all else being the same, causes quotas to be set too high.

The problems associated with data fouling have attracted increasing attention in the literature and popular media. There are several reasons for this. Recent resource crises in Canada and elsewhere have raised questions about the reliability of scientific stock abundance estimates, recruitment, and other key population characteristics. There is also growing recognition of the need for better enforcement given the unrelenting pressure on stocks from both domestic and foreign fleets. Finally, it is well-known that activities that distort fisheries statistics occur in virtually all fisheries, and that they can cause entire fisheries to collapse (FAO, 2002 and Corveler, 2002). But are some fisheries policy regimes 'better' than others in terms of the quality of the data made available for management?

The fisheries economics literature on avoidance behaviour and enforcement is rich in theoretical insight but provides very little in the way of empirical findings. Little theoretical work exists in this area, and empirical work has been hampered by the lack of reliable data on activities at sea (legal or illegal) that are unobserved by the regulator. The empirical evidence is therefore scarce, and often indirect or anecdotal. Apart from data on activities that violate the Fisheries Act there appear to have been few attempts to collect in a systematic and comprehensive manner information that can be used to estimate landings data inaccuracy in Canada.

Our paper seeks to address this gap by (a) providing a descriptive analysis of the survey and anecdotal data collected from an interview study with Newfoundland fish harvesters on data fouling, and (b) by developing an analytical model of key elements that drive data fouling practices. By data fouling we mean legal and illegal fishing-related behaviors that distort or 'foul' the statistics that form the basis for fisheries policy. Our larger intent is to design a framework that can be used with empirical data to estimate what we call the 'data fouling factor.' Our overall hypothesis is that data fouling is a much more important problem than fishermen or fisheries management generally appear willing to recognize. Our survey of fishermen in Newfoundland, and our review of the international evidence (statistical and anecdotal) support this hypothesis.

The personal interviews in our survey were structured so as to elicit first-hand information from current and former participants in the fishery about the nature, scope, and determinants of a range of legal activities that (perhaps entirely inadvertently) contribute to data fouling as we define it. The survey also shows an alarming lack of knowledge of conservation practices and protocols amongst respondents. Informed by the findings from this research we draw on the avoidance/enforcement literature to develop a simple analytical model. The model highlights the factors that are the main drivers behind high-grading and misreporting (market conditions), and suggests how they are related to some of the policy parameters controlled by the regulator (surveillance and enforcement). The analytical simplicity allows some key results with policy relevance to emerge, while keeping the assumptions transparent and the data requirement for implementation to a minimum. We formulate a theoretical model of two types of data fouling in a quota fishery; high-grading and under-reporting of catch. The model is solved analytically for the profit maximizing effort level and the associated optimal number of high-grading operations. A second version of the model is solved for the optimal proportion of the harvest to under-report, given the perceived probability of detection and conviction, and the structure of fines for this offence.

Finally, we demonstrate how the model can be applied to address some of the policy-related issues that surfaced in the survey research. Using available data on prices, costs, harvesting technology, and the biology of the resource obtained from independent sources, we parameterize the model and solve it numerically. Sensitivity analysis informed by the survey responses can then be undertaken. For example, we ask by how much must the fine be increased above its base level to bring the level of under-reporting down to a 10 percent 'margin of error' that may be tolerated by the regulator? Given that a 'large' fish fetches a premium price, how many high-grading operations will maximize the profit on the quota in a given season? How sensitive is high-grading to the probability of finding large fish?

---

4 The anecdotal evidence from Canadian print media, and the findings from court records of convictions on fisheries violations cannot be reported fully here for reasons of space, see Murrin (2003).
2. THE CONCEPT OF DATA FOULING

Our definition of data fouling has its origins in the taxonomy of adverse side effects of quotas proposed by Copes (1986, 2000) and elaborated below. Rather than treating data fouling as one such side effect as does Copes, we define the term more broadly to refer to a wide range of fishing-related behaviors, legal and illegal, all of which have one aspect in common; they distort or 'foul' the statistics that form the basis for fisheries policy. These behaviors include over-fishing, high-grading (selective dumping, usually by size), misreporting, discount (or time preference)-driven overfishing, by-catch dumping (of incidental or non-targeted catch because it is of illegal size of a regulated species, or simply a low-value species), price dumping (of lower-valued specimens), quota busting, and the unrecorded dumping of bruised catch. These activities occur in an essentially unobserved environment at sea and leave few traces in the statistics requested by and reported to the regulator. The expression 'illegal, unreported and unregulated fishing' or IUU fishing has been used to describe a wide range of activities occurring on the high seas. The three main IUU categories are: (1) illegal fishing on the high seas including poaching, (2) unregulated fishing whereby vessels operate outside management controls for whatever reason, and (3) unreported or misreported fishing (Bray, 2000). The latter category has been subdivided by Pitcher et al. (2002) to capture categories not covered by the reporting system as follows: (3a) unreported (legal or illegal) discards; (3b) un-mandated catches: catches that the fisheries agency is not mandated to record; and (3c) illegal catch, i.e., catch contravening regulations in that it is unreported, or deliberately misrepresented by species or size usually to conceal quota violations. Treating these categories separately is difficult as they intersect. The only difference between the extended definition of IUU given above and our concept of data fouling is that we do not distinguish between legal and illegal practices: any fishing behaviour that causes a discrepancy between the total mortality and the reported catch fouls the data and is categorized accordingly.

A number of methods have been used to examine 'unreported fishing' for total catches (what happens at sea) versus landings (what is officially reported on land). For example, estimates of discarding can be obtained from observer data. Illegal landings are more difficult to quantify but may be estimated by comparison of reported landings with market sales or interviews with fish harvesters or by tracing techniques (Forrest et al., 2001). Estimates of bycatch and discarding for different fisheries have been obtained using biological models of the fishery (Allard and Chouinard, 1997). Economic approaches have also been used to estimate incentives to discard (Anderson, 1994; Arnason, 1994). In 2003 the European Union, concerned about the widespread accuracy of official statistics, confirmed that inaccurate reporting of catch statistics might have played an important role in the decline of the cod stocks in the North Sea.

Amongst the papers that seek to quantify aspects of data fouling, five stand out. The first is a theoretical analysis by Turner (1997). Second, Hutchings and Ferguson (2000) survey fishermen in an attempt to generate upper and lower bounds on reported landings data in the Newfoundland cod fishery. Third, Pascoe et al. (2001) use Data Envelopment Analysis (DEA) to estimate misreporting in fisheries output data. Fourth, Angel et al. (1994) report that most regulations associated with quota management in the Scotia-Fundy region have not been enforceable, such as reporting by area and species, dumping, discarding, high-grading using correct gear, etc. Finally, Pitcher and Watson (2000) also attempt to estimate the impact of illegal fishing practices in the North Atlantic.

In 2002, over 8,000 serious breaches of rules were recorded by all EU member states; these included falsifying and misreporting of the catch. Evans (2000) argues that fish stocks generally are probably overestimated by 75 percent, and high sea stocks by as much as 100 percent. Although the percentages for specific stocks are necessarily uncertain, it is widely held that not only does IUU fishing account for a large percentage of total catch, but IUU fishing is increasing world wide as harvesters try to avoid the stricter fishing rules that follow declining catches. In response to this the UN Food and Agriculture Organization (FAO) has proposed an international plan of action for dealing with IUU fishing on the high seas (FAO, 2002). Not all misreporting is under-reporting. Watson and Pauly (2001), for example, argue that over-reporting by China (high catches for political reasons) has masked decreases in global catches for more than a decade.

5 See also Alverson (1977); Alverson et al. (1994); Hall et al. (2000).
6 Other terms for dumping used in Atlantic Canada are 'shacking', 'pitching', 'biffing', 'culling' and 'capacity dumping' (Breeze, 1998). In Newfoundland discarding is sometimes known as 'tripping the cod end'.
7 See http://www.Europe.int
In Atlantic Canada there was widespread misreporting, concealment, dumping and discarding long before the 1992 cod moratorium. Maintenance of two sets of logbooks and hidden holds for undersized, illegal catches were common occurrences (see e.g., Anderson, 1972; Harris, 1998; Angel et al., 1994; Palmer and Sinclair, 1997). Fishing pressure on cod was heavy in the 1980s as certain fleet sectors exceeded their quotas twice over (Gough, 2001). Misreporting seems to have declined from the early to mid 1990s but then increased again (Preikshot, 2001) to the extent that it caught the attention of the federal Auditor General, who reported in 1997 that information on fish stocks was considered inaccurate due to misreporting and unsustainable fishing practices (AGC, 1997). The cause was the blatant misreporting, under-the-table sales, and massive discarding of fish in Atlantic Canada (Mason 2002). The FRCC stated recently that briefs received from industry acknowledged that unsustainable fishing practices such as misreporting were indeed widespread, and that anecdotal reports of cheating were increasing (FRCC, 2003). Deep-sea trawler fishermen were often described as 'the biggest bunch of liars!' as under-reporting by skippers typically went uncontested by plant owners who had no incentive to verify skippers' reports (Anderson 1972). As Baum et al. (2003) aptly put it, missing values cannot be distinguished from true zeros in logbooks.

It has been estimated that in fisheries worldwide, fishermen discarded about 25 percent of the catch during the 1980s and the early 1990s, or about 60 billion pounds each year (Alverson et al., 1994; Alverson, 1998). Discarding and dumping are long-standing practices in all Newfoundland fleet sectors as well (Hache, 1989; Harris, 1990). By-catch was just 'dumped over the side' (Martin, 1990; Marshall, 1990; Cashin, 1993), sometimes in protest when there was no demand (Wiseman, 1972). High quantities of small cod were discarded at sea due to the high costs of handling and storing small fish on trawlers (Task Group on Newfoundland Inshore Fisheries, 1987). But by-catch was also dumped in ever greater amounts during the 1980s (Atkinson, 1984; Kulka, 1982, 1984, and 1986). Keats et al. (1986) estimate that discards of cod increased from seven to 24 percent between 1981 and 1986, but decreased somewhat in 1987 due to the use of larger mesh sizes and the introduction of the observer program.

Other major species such as redfish and flatfish were discarded at a rate that doubled in the early 1980s in NAFO region 2J3KL off the northeast coast of Newfoundland and Southern Labrador. Hutchings and Myers (1995) estimate that the inshore fisheries discarded five percent by weight in the early 1980s and 28 percent in 1989. In more recent studies, Hutchings (1996), and Hutchings and Ferguson (2000) estimate that discarded and unreported catches in the inshore fishery actually trebled in the same period. Unreported discards have been directly implicated in the erroneous estimates of fishing mortality on northern cod. Moreover, this high rate of discarding young fish contributed to the rapidity with which the cod stocks eventually collapsed (Hutchings, 1996; Myers et al., 1997; and Hilborn et al., 2003). In 1993 the FRCC agreed that dumping and misreporting have contributed to frequent underestimation of the mortality and hence to an overestimation of the Atlantic groundfish biomass (FRCC, 1993: 9). In 1994 the FRCC reported testimony by fishermen about selective dumping of catch in order to maintain quotas in mixed stock fisheries, a practice said to be tacitly acknowledged by fisheries managers (FRCC, 1994: 2). This is borne out by a study of Scotia-Fundy fisheries in which twenty-three fishermen interviewed admitted to dumping fish that did not match their quotas (Breeze, 1998). It is important to note that although the Fisheries Act stipulates that no discards are allowed in groundfish fisheries, it was only after the moratorium in 1992 that the regulations were enforced. Dwyer (2001) describes an instance where high amounts of deep-sea species were discarded as "garbage fish."

Observer programs covering the offshore fleet have existed in Canada since the early 1980s. Vessels operating within the 200-nm EEZ may be required by law to take an observer onboard. Coverage levels for particular fleets vary between one and 100 percent10. The inshore and nearshore fleet we examined has low coverage, 1 to 2 percent. Interviews with fish harvesters are therefore a valuable source of information (Saila, 1983; Neis et al., 1999). However, fish harvesters' estimates of unreported catch will vary and have a bias toward underestimation (cf. Saila, 1983; Jensen and Vestergaard, 2002).

---

8 See also Finlayson (1994); Harris (1998) and others for analyses of the collapse of the Atlantic ground fishery.
9 Notwithstanding section 33 of the Fishery (General) Regulations, no person who catches groundfish of any species with fishing gear other than a cod trap shall return the groundfish to the water unless the person is authorised by a condition of a licence to return groundfish of that species to the water.
10 D. Kulka, DFO, St. John’s, Personal communication.
3. THE SURVEY

We developed a survey questionnaire to elicit first-hand information about the nature and extent of data fouling fishing practices in the Coasts Under Stress (CUS) east coast study area. We also carried out a search of Newfoundland court records on fisheries violations, along with an extensive search of print media for the purpose of collecting additional anecdotal information from a wider cross-section of fisheries participants than could be reached in our survey (Murrin, 2003). The survey suggested a widespread lack of knowledge of conservation practices and of skills for participatory management. These findings were followed up in a separate pilot study of two communities in the CUS study area (Breen, 2003).

Structured, face-to-face interviews of 30 minutes average duration were undertaken. One interview took three hours. Interviewees were selected using 'snowball sampling,' a method well suited for the study of sensitive issues and one that can increase the accuracy of the information collected (Lopes et al., 1996; Hutchings and Ferguson, 2000). Having started with a list provided by the Fish Harvester's Union, subsequent interviewees were asked to identify other possible contacts. There were 8,675 licensed nearshore vessels in Newfoundland in 2002. A total of 50 fish harvesters were interviewed throughout Newfoundland from April to October 2003. Of these 41 were active and nine retired harvesters. Seventeen fish harvesters owned inshore vessels (<35 feet), 26 owned vessels in the 35-65-foot near-shore sector, and three had vessels > 65 feet. Almost all (96 percent) respondents came from traditional fishing families; only two did not. All but one (a crew member) were full-time skippers. The respondents had an average of 30.6 (± 1.56 SE) years of fishing experience, ranging from 11 to 73 years. Most were first or second generation fish harvesters (80 percent), but some were third (four percent), fourth (ten percent), or fifth generation (four percent) fish harvesters. One respondent was a sixth generation fisherman.

3.1 Results

Thirty-eight percent of interviewees said that misreporting occurs in their respective fisheries. This takes the form of dumping, discarding and other potential data fouling activities that go on daily. Many (51 percent) appeared unaware that this might be in violation of the Code of Responsible Fishing for the simple reason that what appears inconsequential on an individual basis is of no concern. In the crab fishery, 50 percent of harvesters admitted that misreporting occurs. Estimates range from five to 40+ percent by weight. Crab harvesters also report having witnessed the use of more than the allowed number of pots, as well as illegal sales of unreported crab. One person said that, in the past, this was done "quite a bit." Another informant claims that now only "a handful of people are doing it, but it is not worth the risk for me." But the stakes are high. Two respondents alleged that bribes of $20,000 have been given to fisheries observers.

Regarding cod, it was claimed that in the past (pre-moratorium) "landings were never written down and misreporting happened all the time." Although some of the commercial cod fisheries in Newfoundland remain under moratorium, four respondents indicated that the misreporting of cod landings is still "extremely" high. Trucks are reported to off-load unobserved in some instances. In other cases monitoring is lax. One skipper claimed that he could smuggle a boatload past DFO without them seeing a thing. In the limited fisheries still open for Northern cod, in particular the Sentinel and Index Fisheries, fish harvesters indicated that under-reporting of cod and redfish by weight is rampant. As much as 30 percent of cod landings were allegedly never reported according to some harvesters. Turbot landings are also misreported. Adding to the confusion, two skippers said that some redfish landings have been recorded as cod landings. Two respondents noted that mackerel, herring, and capelin landings could have been misreported since they were not monitored by boatloads. Interestingly, one skipper observed that the illegal activity centres on fishing in prohibited zones, concealing rather than misreporting illegal catch. The reasons for this are not hard to discern. Shellfish accounted for 83 percent (or $465.1 million) of landed value in the Newfoundland and Labrador fishery in 2003. This exceeds the landed value of the cod fishery in its heyday in current dollar terms. While income in the cod fishery was relatively widely dispersed (at least in modern times), income in the crab and shrimp fisheries is concentrated in the hands of a comparatively small number of licence holders.

---

**Misreporting, discarding, dumping and by-catch**

Discarding occurs when the crab is below legal size. This poses a problem if the discarded specimens die and the discards remain unreported. Most harvesters use a variety of mesh sizes in their pots. The regulated minimum mesh size is 5 ¼ inches. This is in order to allow escapement of adult males for reproduction (DFO, 2003). A summary of the estimated discards from crab pots obtained from the respondents (Table 1) shows that, on average, a high amount of discarding takes place with 5 ½-inch mesh pots, whatever the season and fishing area. Very little discarding seems to occur with the 6-inch mesh. A number of skippers preferred the 6-inch mesh because it means 'less picking to do'. Only one harvester in our sample used an illegal 5-inch mesh. The average discard estimates are 26.5% for the 5 ½-inch, 15% for 5 ¼-inch, and 10% for the 6-inch mesh. This is considerably lower than a recent DFO estimate according to which almost 50% the crab landings are discarded (Wellman, 2004).

Turning briefly to dumping, it appears that most of the pre-moratorium dumping of cod was due to insufficient demand. Estimates range from 'medium' in the 1970s to 'high' in the 1980s when sometimes "the water was white with small fish" as "boatloads were thrown away since the plants did not take any more." Cod dumping from traps could vary from 1-2 loads per day or up to 50 percent by weight: "the harbour looked like it was covered with ice." The contrary view of others is summed up by a longliner skipper who stated: "No, I don't know anything about dumping ... we never dumped cod." Respondents indicated zero dumping since the beginning of the 1990s.

**Table 1.** Estimated percent crab discarded by weight and mesh size.

<table>
<thead>
<tr>
<th>Estimated crab discards (% by weight)*</th>
<th>Mesh size of crab pot (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% (n=1)</td>
<td>5</td>
</tr>
<tr>
<td>10-20% (n=4), 50% (n=11), high (n=1)</td>
<td>5 ¼</td>
</tr>
<tr>
<td>10-20% (n=10), 20-30% (n=3),</td>
<td>5 ½</td>
</tr>
<tr>
<td>75% (n=1), high (n=1), low (n=2)</td>
<td></td>
</tr>
<tr>
<td>10-20% (n=5)</td>
<td>5 3/4</td>
</tr>
<tr>
<td>0% (n=1), 5% (n=2), 33% (n=1)</td>
<td>6</td>
</tr>
</tbody>
</table>

*sample size in parentheses

Cod by-catch is also an issue. In by-catch fisheries for cod the allowable proportion of cod is managed according to a set percentage of the overall catch. There is no quota monitoring and extensive overfishing still goes on according to one skipper. Another skipper estimated that 30 percent of these by-catch cod were never reported since there was legally no quota. Two other skippers agreed that these catches are often known locally but go largely unreported. One respondent expressed dislike and contempt for the by-catch regulations, calling them "silly." One respondent claimed that the amount of cod sold illegally has increased since the moratorium.

**Other indications of data fouling**

Canadian print media and regional court cases were also sources of information on data fouling. From 1970-1993 only 44 cases were prosecuted in Prince Edward Island and Newfoundland (Table 2).

Violations ranged from illegal possession of undersized fish to failures to record catch. The most frequent offence was keeping undersized catch. From 1994-2002, the print media was examined for instances of overfishing, misreporting, discarding and other fisheries related offences. Although the number of articles recording overfishing activities by foreign fleets predominate, there were many instances where the domestic fleets were said to cheat on catches, keeping undersized fish and high-grading (Murrin, 2003). Other irregularities such as 'bonuses' offered openly by the plants to secure delivery by the fish harvester to a specific plant, paint a complex and dark picture of the fishing industry. Some fish harvesters accused the plants of operating a cartel or a local 'mafia' in order to control the supply and fix prices. Although the majority of crab harvesters in our survey say that they approve of management including the use of

---

12 The harvester claimed not to know the mesh size of his crab pots. Our measurement showed 5 inches. The harvester explained that he had bought them second-hand in an outport 300 km away. The previous day his wife had been contacted by DFO regarding the mesh sizes of the crab pots. When the wife, who is fishing with her husband, said that she did not know the caller responded: "Well, I guess it's 5 ¼ inch mesh, isn't it?" Investigation concluded.
graders, monitors, offshore observers, and 'black boxes' (vessel monitoring systems and satellite monitors), they also say the fishery is fraught with illegal activity. More diligent enforcement makes cheating more difficult, but some respondents say they know that observers are paid off.

**Table 2.** Summary of fisheries violations and convictions, 1970-1993.

<table>
<thead>
<tr>
<th>Violation and Conviction</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overfishing – Catching and Retaining Fish in Excess of Quota</td>
<td>4</td>
</tr>
<tr>
<td>Undersized Catch</td>
<td>9</td>
</tr>
<tr>
<td>Fishing in Closed Season/Waters</td>
<td>3</td>
</tr>
<tr>
<td>Fishing in a Protected Area</td>
<td>3</td>
</tr>
<tr>
<td>Misreporting</td>
<td>4</td>
</tr>
<tr>
<td>Fishing with an Undersized Net/Mesh</td>
<td>3</td>
</tr>
<tr>
<td>Fishing Without a License</td>
<td>5</td>
</tr>
<tr>
<td>Illegal Possession of Fish/Lobster and/or Equipment</td>
<td>2</td>
</tr>
<tr>
<td>Illegally Entering Canadian Waters</td>
<td>7</td>
</tr>
<tr>
<td>Destruction of Fish Habitat</td>
<td>2</td>
</tr>
<tr>
<td>Unlawfully Transporting Fish</td>
<td>1</td>
</tr>
<tr>
<td>Oversized Catch</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>44</strong></td>
</tr>
</tbody>
</table>

Source: Newfoundland and Prince Edward Island Reports – Index

**MANAGEMENT AND THE CANADIAN CODE OF CONDUCT**

Most fish harvesters interviewed (84 percent) said that they like IQs and that they like the way the crab fishery is managed today. But in direct reference to the data fouling problem, ten percent of harvesters disapprove of IQ management, claiming that it destroys the fishery: "That's where the big guy gets the profit; the plants will get it all." The remaining six percent were retired fish harvesters. Some said that ITQs would be acceptable only if the plants/processors were exempted as ITQs are believed to give control to processors. It is instructive that ITQs in particular are disliked primarily for reasons other than the strengthened incentives to high-grade and misreport that they give rise to.

The Canadian Code of Conduct for Responsible Fishing Operations is based on the FAO Code of Conduct established by the UN (FAO, 1995). The Code is provided by DFO with each license. Yet, 51 percent of all fish harvesters (45 percent of active harvesters) interviewed said they were unaware of the Code. Of those who were aware of the Code, 16 percent said they had not read it and were unfamiliar with it. The wife of one harvester said that he should be aware of the Code since she had seen it in his mail.

Fish harvesters were also asked if they are aware of the Marine Stewardship Council (MSC). The MSC is an independent, global, non-profit organization set up to solve the problem of overfishing. Established in 1997 by Unilever, the world’s largest buyer of seafood, and WWF, the international conservation organization, the MSC became fully independent of both organizations in 1999. Today MSC is funded by a wide range of organizations including charitable foundations and corporate entities around the world. The MSC has developed an environmental standard for sustainable and well-managed fisheries following worldwide consultation with scientists, fisheries experts, environmental organizations and other stakeholders with a strong interest in preserving fish stocks for the future. Environmentally responsible practices are rewarded with a distinctive blue product label. There is currently no Canadian affiliation, and only two fish stocks in Canadian waters are undergoing certification. Only 23 percent of the 34 harvesters who responded to this question in the inshore, nearshore and midshore fleets had heard of the MSC. But all agreed with the idea of eco-labeling since it would appear to enhance the value of the product: "Must try to do something, if it is not too late already."

---

13 See http://www.dfo-mpo.gc.ca/communic/fish_man/resp98/index_e.htm
14 See http://eng.msc.org
4. The Model

In this section we formulate a theoretical model of two of the most pernicious forms of data fouling in a quota fishery: high-grading and under-reporting of catch. Stating the issue formally lends a unified interpretation to the data that we have gathered from our field research. Our survey research confirms that it is appropriate to model these collectively irrational activities as the outcome of privately rational (if myopic) action.

We assume that each harvester has a property right to a portion of the catch in the form of a non-transferable individual quota (IQ) in a single-species fishery. The biomass comprises 'small' and 'large' fish, encountered with known probabilities. The IQs are auctioned or reassigned arbitrarily on a seasonal basis, giving rise to myopic fishing behaviour and a desire to maximize the in-season value of the quota. The harvester can affect the returns to fishing the quota in two ways: high-grading or discarding of small fish that would fetch a lower price on the market than larger specimens (legal); and misreporting of catch (illegal). The incentive to high-grade arises from a known market price premium on large fish.

The first problem is to choose the profit maximizing number of high-grading operations. Suppose further that there are incentives to misreport catch, arising from balancing the benefits and costs of under-reporting catch. Misreporting all or part of the catch carries a risk of getting caught, prosecuted and fined according to the gravity of the offence. But misreporting can also increase profit since the catch will not count against the quota if it can be landed unreported and undetected. The undetected (concealed) portion of the quota can thus be caught again. Determining the profit-maximizing proportion of catch to misreport is the second problem considered here. Most often misreporting amounts to understating the catch. It is worth noting that in some cases harvesters may have an incentive to overstake the catch or misrepresent catch location. For example, this has been said to occur in the lucrative snow crab fishery off the east coast of Newfoundland. When commercial catches are low (well below quota levels) or consist mostly of immature crab, harvests in certain locations may be overstated to the regulator so that quotas are less likely to be lowered for the next season.\footnote{The source is an anonymous informant. Personal communication, 9 December 2003.}

We define high-grading as the sorting and selective discarding of the portion of the catch comprising small fish for the purpose of replacing it with higher valued large fish. Assuming that each time a portion of the catch is replaced in this way the probability of catching large fish remains the same, the incentive to high-grade depends on the relative price of large fish, the cost of high-grading, and the cost of replacing the fish
discarded by a new catch. Based on past experience fishers expect to catch large fish and small fish with probabilities $\pi_L$ and $\pi_S = 1 - \pi_L$ respectively. The harvest of large fish $H_L$ and small fish $H_S$ can then be written

$$H_i \equiv H \cdot \pi = q \cdot E \cdot X \cdot \pi_i \quad i = L, S$$

The relationship between the corresponding market prices per unit weight is $p_L = a \cdot p_S$, where $a > 1$ is the mark-up on large fish. Fishing revenue can thus be written: $p_L \cdot H_L + p_S \cdot H_S$. The opportunity cost of high-grading, $C_d(n)$, varies with the number of high-grading operations undertaken. It includes the costs of sorting, handling and storing large fish at sea. But it does not cover the cost of replacing discarded catch. Postulating that $C_d' > 0$ captures the practical aspect that high-grading gets increasingly more expensive (due to on-deck congestion and time factors) the more frequently a portion of the catch is discarded and replaced. The remaining portion of the opportunity cost of fishing $C(E,n; \theta)$ is attributable to fixed, vessel related costs, $f$, such as insurance and licence or quota fees, the variable effort expended, and the number of high grading operations. This function is increasing in its arguments reflecting the increasing costs associated with longer time at sea. Specifically, $C_d' > 0$ since the marginal cost increases with effort even if no high-grading occurs. Also, $C_n' > 0$ since the marginal cost is increasing with the number of high-grading operations as this involves effort to replace discarded small fish with large fish. It stands to reason that if high-grading is profitable, the total effort expended in attempting to fill the quota can be considerably greater than otherwise. Hence,

$$Q \leq H = H_L + H_S.$$

Each replacement catch adds additional weight of large fish $H_L$ to the vessel hold. Suppose for illustrative purposes that $\pi_L = 1/3$ and $\pi_S = 2/3$. Successive replacements of the small catch with large fish will then increase revenue but at a decreasing rate since the size of the replacement catch declines continuously. This is because a portion of it (1/3) is retained with each high-grading whilst the rest is discarded. It follows that fishing revenue increases at a decreasing rate as the size (weight) of the catch continues to decline as the quota is gradually filled. For example, the weight of small fish discarded in the first high-grading operation is $H_S \pi_S$ whereas the value of the fish retained from the $n^{th}$ high-grading is $p_L H \pi^n \pi_L$ (Figure 1).

- Original harvest of small fish: $H_S = H \frac{2}{3}$
- $H_S$ 2/3  $H_S$ 1/3 ( = $H_L$)  1st discard
- $H_S$ (2/3)2/3  $H_S$ (2/3)1/3 ( = $H_L$)  2nd discard
- $H_S$ (2/3)(2/3)(2/3)  $H_S$ (2/3)(2/3)(1/3) ( = $H_L$)  3rd discard
- $H_S$ (2/3)$^n$  $H_S$(2/3)$^{n-1}$ 1/3 ( = $H_L$)  $n^{th}$ discard
- or $H (2/3)^n$ 1/3 ( = $H_L$)

**Figure 1.** Determining the weight of large fish ($H_L$) retained in the $n^{th}$ high-grading operation in which small fish ($H_S$) are discarded. It is assumed here that the probability of catching large fish remains $\pi_L = 1/3$.

If costs were zero, fishing would continue until the entire hold (the full quota) consists of large fish. Since fishing and high-grading operations are both costly, a choice must be made simultaneously about the
number of discarding operations, and the amount of effort to be expended in replacing the discards. When \( n \geq 1 \), profit becomes

\[
\max_{E,s} \Pi = p_L \cdot H \cdot \pi_L + \sum_{s} a \cdot \pi_L \cdot \pi^s \cdot H \cdot \pi_L \cdot \pi^s - C(E,n;\phi) - C_d(n) \\
= p_L H \cdot \left(1 + \frac{\pi^s}{\pi^s - 1}\right) - C(E,n;\phi) - C_d(n)
\]

Using the definition of the harvest from above and dividing through by \( p_s \), the first-order conditions can be expressed as

\[
\frac{\partial \Pi}{\partial E} = \frac{p_L}{p_s} \cdot \pi_L \cdot q \cdot X \cdot \left(1 + \frac{\pi^s}{\pi^s - 1}\right) \cdot \frac{C'_e(E,n;\phi)}{p_s} = 0
\]

and

\[
\frac{\partial \Pi}{\partial n} = \frac{p_L}{p_s} \cdot \pi_L \cdot q \cdot X \cdot \left(\frac{\ln \pi_L \cdot \pi^s}{\pi^s - 1}\right) \cdot \frac{C'_e(E,n;\phi)}{p_s} \cdot \frac{C'_d(n)}{p_s} = 0
\]

Note that the first term in the latter expression is positive for \( n \geq 1 \) since \( \ln(\pi_L) \cdot \pi^s > 0 \). Eqns. (1) and (2), satisfied for \( E^* \) and \( n^* \) respectively, state a simple intuitive result. Use fishing effort to discard the catch of small fish and replace it with large fish until the marginal return (the incremental additions of large fish) equals the marginal cost (the incremental cost of another high-grading and catch replacement operation). It is easy to verify that the second-order conditions \( \partial^2 \Pi/\partial n^2 < 0 \), and \( \partial^2 \Pi/\partial E^2 < 0 \) hold.

4.2 Misreporting

We [DFO] are still catching people, but we don’t seem to be addressing the root problem, that poaching is unacceptable behaviour. There are stiff fines and jail time, but people are still willing to take that risk.

— The Telegram, St. John’s, 14 November 2003

Failure to report all or part of the catch in a quota fishery (poaching) is illegal and if detected will lead to administrative penalties, and prosecution in the case of serious and repeated offences. In the case of the Newfoundland snow crab fishery, administrative penalties are agreed upon by the DFO and representatives of harvesters in an attempt to limit prosecutions in cases where there may not be criminal intent. This amounts to a limited tolerance of errors in the harvester’s measurement of the landed catch. In general, the penalties are related to the extent of the offence: the higher the proportion of the quota over-fished, the higher the penalty. Obviously, if undetected the catch is not counted against the individual’s quota and can therefore be caught once more and be reported legally.

Let \( H_r \) be the reported catch so that if \( H_r = H \) the entire catch is reported. The proportion of the catch unreported \( x \) is then \( 1 - H_r/H \). Assume that the harvester faces a horizontal demand curve for the legal (reported) catch, which is sold at the competitive price \( p \) per unit weight to the processing plant at dockside. But in selling the illegal (unreported) catch the fisherman faces a downward sloping demand curve on the black market. Denote the fisher’s perceived probability of getting caught and convicted for misreporting catch by \( \pi_{dc} \), and the fine for misreporting \( G(x) \), with \( G(0) = 0 \), \( G' > 0 \), and \( G'' > 0 \). Denote harvesting costs by \( C(E,x) \). Let \( C'_e > 0 \) for reasons analogous to those stated in the previous section, and \( C_v > 0 \) since avoidance costs are positive if misreporting occurs. Let \( Q = H \) as before. Profit can then be expressed as

\[
\max_{E,x} \Pi = p \cdot H + (1 - \pi_{dc}) \cdot p \cdot H \cdot \left[1 - \frac{1}{\alpha_x \cdot \exp(\alpha_x \cdot x)}\right] - C(E,x) - \pi_{dc} G(x)
\]

for example,
The first-order conditions are

\( \frac{\partial \Pi}{\partial E} = p \cdot q \cdot x \left( 1 - \frac{1}{\alpha_2 \cdot \exp(\alpha_2 \cdot x)} \right) - C'_E(E, x) = 0 \)

\( \frac{\partial \Pi}{\partial x} = \frac{p \cdot q \cdot x}{\alpha_2 \cdot \exp(\alpha_2 \cdot x)} \cdot \alpha_1 \cdot \ln(\alpha_2 \cdot e) - C'_E(E, x) - \pi_{dc} \cdot G'(x) = 0 \)

Together these first-order conditions give an intuitive result entirely consistent with those familiar from the avoidance/enforcement literature\(^{16}\): it is privately optimal to under-report catch (increase the proportion concealed) until the value of the catch equals the expected fine. Again, it can be verified that

\[ \frac{\partial^2 \Pi}{\partial E^2} < 0, \text{ and } \frac{\partial^2 \Pi}{\partial x^2} < 0 \]

as required.

4.3. Numerical solution: data and functional forms

The parameters estimated on empirical data come from a study of the Pacific Halibut fishery by Cook and Copes (1987) and include the carrying capacity \( K \), the catchability coefficient \( q \), the intrinsic growth rate \( r \), the aggregate effort expended by the fleet, the number of vessels, and actual catch rates. Cook and Copes estimate harvesting costs as a function of a standardized measure of nominal effort in this fishery (skate soaks), and provide a demand function for halibut. We use this demand function with the actual catch rates to determine on an ad hoc basis the relative price of 'large' and 'small' fish. We modify the cost function to account for high-grading, catch replacement, and the interactions between these elements and fishing effort. We posit a high-grading cost function that can be estimated empirically given more detailed data than we have available. The cost parameters relating to high-grading were thus constructed. The functional forms for the cost functions are:

\( C(E, n) = \beta_1 E + \beta_2 nE - \beta_3 E^2 \)

\( C_d(n) = \frac{n^{\delta_1 + 1} \cdot \delta_2}{\delta_1 + 1} \)

\( C(E, x) = \gamma_1 E + \gamma_2 xE - \gamma_3 E^2 \)

\( G(x) = \exp(\alpha \sigma_2) \cdot \frac{\sigma_1 (\alpha \sigma_2 - 1)}{\sigma_2^2} \)

Eqn (5) describes total harvesting costs (including the effort used for catch replacement following discarding). Eqn (6) captures total high-grading costs (the on-deck costs of sorting, handling, and storage using catch quality control). Eqn (7) represents total harvesting costs in the absence of discarding. Eqn (8) captures the fine for misreporting catch. All parameter values are reported in in Table 3.

---

\(^{16}\) See e.g. Anderson and Lee (1986) and Charles et al. (1999).
Table 3. Parameter values used to obtain a numerical solution.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha)</td>
<td>10</td>
<td>(\zeta)</td>
<td>10</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>0.4</td>
<td>(a)</td>
<td>2</td>
</tr>
<tr>
<td>(\beta_1)</td>
<td>38.65</td>
<td>(p_L)</td>
<td>5 ($/kg)</td>
</tr>
<tr>
<td>(\beta_2)</td>
<td>0.1</td>
<td>(p_s)</td>
<td>2.5 ($/kg)</td>
</tr>
<tr>
<td>(\beta_3)</td>
<td>0.45</td>
<td>(\pi_L)</td>
<td>0.333</td>
</tr>
<tr>
<td>(\delta)</td>
<td>1.1</td>
<td>(\pi_s)</td>
<td>0.667</td>
</tr>
<tr>
<td>(\delta)</td>
<td>0.9</td>
<td>(\pi_{Lw})</td>
<td>0.5</td>
</tr>
<tr>
<td>(\gamma)</td>
<td>400</td>
<td>(K)</td>
<td>(1009 \times 10^5) (tonnes)</td>
</tr>
<tr>
<td>(\gamma)</td>
<td>1</td>
<td>(q)</td>
<td>(0.115 \times 10^{-3})</td>
</tr>
<tr>
<td>(\gamma)</td>
<td>0.45</td>
<td>(r)</td>
<td>0.58</td>
</tr>
<tr>
<td>(\sigma)</td>
<td>8000</td>
<td>(X)</td>
<td>(3.66 \times 10^{-7}) (tonnes)</td>
</tr>
</tbody>
</table>

4.4. Simulation results

Numerical solutions are obtained by solving the relevant first-order conditions for each model. Sensitivity analysis can then be undertaken. The following questions are of particular interest to us. What is the extent of data fouling resulting from high-grading? That is, what is the factor by which which reported (observed) landings can be expected to differ from the unobserved actual kill at sea? Given that 'large' fish fetches a premium relative to 'small' fish, how many high-grading operations will maximize the profit on the quota in a given season? How sensitive is high-grading to the probability of finding large fish, to the price premium on large fish and fishing costs? By how much must the fine be increased above its base level to bring the level of under-reporting down to some 'margin of error' that may be tolerated by the regulator? How sensitive is the optimal rate of concealment (under-reporting) to the unit price of fish for various probabilities of detection? What is the minimum viable price of fish at various rates of concealment? We consider the issues pertaining to high-grading first.

Elasticities of the dependent variables in each of the two models were calculated. This allows a quantitative assessment of the sensitivity of the optimal (solution) values to changes in the key parameters of the model (Tables 4 and 6). This is useful for policy analysis since some of these parameters are under the direct control of the regulator, while others can be influenced indirectly by other policy means. For the high-grading model we report elasticity coefficients of effort and high-grading (\(\eta\)), and for the misreporting model we calculate elasticities of effort and concealment (\(\varepsilon\)). A log-linear functional form is used for this purpose, except where changes in the independent variable are best thought of in incremental or unit terms, rather than in percentage terms. In such cases a semi-log functional form is derived by taking logs of the dependent variable. The interpretation of the elasticity coefficient is, of course, affected accordingly.\(^{17}\) The elasticity estimates show that the optimal effort level is much more sensitive to the relative price of fish than to the number of discards. This is consistent with the expected finding that the optimal number of discards is also highly sensitive to the relative price of fish. The optimal effort level is 517,000 skate-soaks (with \(E\) in hundred thousand skate-soaks), and the optimal number of discards is five. The first four estimates (Table 4) refer to the sensitivity or responsiveness of \(E^*\) to each of four key parameters. The remaining two results are measures of the responsiveness of \(n^*\) to two of the same parameters. Several things are worth noting about these estimates. The first is that both \(E^*\) and \(n^*\) are remarkably sensitive to changes in the parameters in question. This is especially true of changes in the relative price of large fish, and interestingly, the opportunity cost of fishing. A one percent increase in the relative price elicits a very large positive response in effort. Similarly, a one percent increase in any fixed cost component, such as the quota fee, causes a disproportionate reduction in effort. Kingsley (2002) reports a similar result, albeit derived under much more restrictive conditions than those that obtain here. Note also that as the probability of catching small fish increases the optimal effort level falls continuously, while the optimal number of high-grading operations increases until most large fish are gone after which it also declines (see also Figure 2). The explanation for this is that high-grading contributes more to profits.

\(^{17}\) Given \(Y_i = \beta_1 + \beta_2X_{it} + \epsilon_i\), if \(Y_i\) and \(X_t\) are both expressed in log form (log-linear), the interpretation of \(\beta_1\) as an elasticity means that if \(X_t\) changes by one percent then \(Y_i\) will change by \(\beta_1\) percent. If only \(Y_i\) is expressed in log form, then if \(X_t\) changes by one unit \(Y_i\) will change by \(\beta_1\) (times 100) percent.
than the required effort expended reduces it. High-grading thus continues, *ceteris paribus*, until the remaining few large fish become too expensive to catch.

**Table 4.** Optimal solution values and elasticity estimates.

<table>
<thead>
<tr>
<th>From eqn.</th>
<th>Elasticity of $E^*$ with respect to:</th>
<th>$\eta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>number of high-grading operations $n$</td>
<td>0.372&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>probability of catching small fish $\pi_S$</td>
<td>-0.734&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>relative price of fish $p_L/p_S$</td>
<td>3.278&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>level of marginal cost $\beta$</td>
<td>-5.279&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Elasticity of $n^*$ with respect to:

| 2         | probability of catching small fish $\pi_S$ | 0.505<sup>b</sup> |
| 2         | the relative price of fish $p_L/p_S$ | 0.317<sup>b</sup> |

<sup>a</sup> calculated from semi-log form  
<sup>b</sup> calculated from log-linear form

**Figure 2.** Optimal effort and discard rates.

This model also allows us to estimate the extent of error in the reported landings statistics as a result of high-grading. The 'data fouling factor', DFF, measures the discarded (unreported) catch as a proportion of the total fishing mortality. To see this, consider a quota set by the regulator (Table 5). Assuming that no high-grading occurs the quota is calculated as the equilibrium harvest using $Q = qXE$ and parameter estimates for the Schaefer model reported in Table 1. The DFF can then be calculated as $\text{DFF} = 1 - \left(\frac{\text{harvest reported}}{\text{total fishing mortality}}\right)$. We calculate the DFF to be 56 percent. Interestingly, this is very close to a recent discard estimate by Canada's fisheries regulator, Department of Fisheries and Oceans, for the Newfoundland Region (Wellman, 2004).
Table 5. Data fouling results.

<table>
<thead>
<tr>
<th>Harvest Measures</th>
<th>tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quota</td>
<td>475.24</td>
</tr>
<tr>
<td>Harvest reported (large fish)</td>
<td>433.39</td>
</tr>
<tr>
<td>Discards (small fish)</td>
<td>551.01</td>
</tr>
<tr>
<td>Total kill</td>
<td>984.49</td>
</tr>
<tr>
<td>Data fouling factor</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Turning next to the misreporting model (Table 6), it is not surprising to find that the effort level and the concealment rate are both sensitive to the price of fish. That is, as the price rises the effort level and concealment rate both increase as intuition would suggest. What is interesting is that the effort level is much more responsive than the concealment rate to a price increase. Moreover, the results suggest that if in a rising-price environment surveillance and enforcement are boosted, the concealment rate will be reduced more sharply than the effort level generally. This is as it should be since if concealment drops off, less effort is required to land the legal catch only.

Table 6. Optimal solution values and elasticity estimates - the misreporting model.

\[ E^* = 63.984 \quad x^* = 0.23 \]

<table>
<thead>
<tr>
<th>From eqn.</th>
<th>Elasticity of ( E^* ) with respect to:</th>
<th>( \varepsilon )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>concealment rate ( x )</td>
<td>0.579b</td>
</tr>
<tr>
<td>3</td>
<td>unit price of fish ( p )</td>
<td>5.623b</td>
</tr>
<tr>
<td>3</td>
<td>probability of detection and conviction ( \pi_{dc} )</td>
<td>-0.565b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>From eqn.</th>
<th>Elasticity of ( x^* ) with respect to:</th>
<th>( \varepsilon )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>effort level ( E )</td>
<td>0.012a</td>
</tr>
<tr>
<td>4</td>
<td>unit price of fish ( p )</td>
<td>0.355b</td>
</tr>
<tr>
<td>4</td>
<td>probability of detection and conviction ( \pi_{dc} )</td>
<td>-0.691b</td>
</tr>
</tbody>
</table>

CONCLUSIONS AND POLICY IMPLICATIONS

The problem of data fouling is probably far greater and more urgent than commonly believed. One reason for this suggests itself immediately. Data fouling is intractable in that existing policy tools are ill-designed to curb most such behaviour. In some cases, the policy instruments in use inadvertently encourage data fouling, or at least tacitly tolerate it. Only in some of the most egregious cases are regulatory effort and enforcement brought to bear in an attempt to limit the outright illegal forms of this behaviour. Surveillance and enforcement are costly in financial as well as political terms. Financially it is difficult to argue for larger enforcement budgets when the benefits and costs are not supported convincingly by statistical evidence. Politically it is problematic because enforcement pits the interest of the present generation against that of future generations. But if our moral obligation to future generations includes a capacity to generate economic well-being from the fishery it requires that decision-makers face squarely the trade-off between poverty-alleviation now and a sustainable fishery for the future.

The tensions in this trade-off are manifest in our survey. Many fishermen are antagonistic to management for sustainability. Despite the FRCC’s warnings, misreporting still appears to be common in Newfoundland. Approximately 40 percent of all fishers interviewed admitted to knowing that misreporting occurs although they themselves would never do it. Nor would they report a buddy. This may be an underestimate since many fishers who initially denied any misreporting, did admit in the ‘verification’ question that ‘some’ cheating and poaching are going on. Fishermen indicated that they knew that cod is being illegally poached and sold from door to door. A recent study comparing attitudes to poaching in fishing communities in Norway and Newfoundland (Gezelius, 2003) found that in Newfoundland, in contrast to Norway, cod poaching for food is not considered morally wrong whereas
commercial poaching is, even though it has been going on for years on a commercial basis. This supports earlier findings for Newfoundland’s west coast (Palmer and Sinclair, 1997).

We conclude from our small survey sample that fisheries management and fish harvesters in Newfoundland have not fully digested the lessons of the cod stock collapse and the socio-economic consequences of the subsequent cod moratoria. The fishery is still not prosecuted on a sustainable basis. Overfishing still occurs on an alarming scale. This not only jeopardizes individual species; it also undermines the benefits that could come from a diversified fishery. Despite the moratorium and increased surveillance and enforcement, reports of deliberate misreporting (of crab and cod landings) are still frequent. Findings from this small sample cannot be generalized to the whole population of harvesters but they are indicative of ongoing problems with discarding, high-grading and other data fouling activities. As indicated by one harvester, "lots of things happen here in St John's that people in Ottawa are not informed about." In the words of another, "They don't have a clue". As Perry and Ommer (2003: 516) describe it: "Failing to comprehend and deal with scale issues like these creates a rich breeding ground for community rebellion against regulations, promoting various kinds of illicit practices that thwart the legitimate practices of fisheries management." We agree with this appraisal. It follows that a better understanding is necessary of what drives these practices and how they distort the information on which management depends. The clearest general indication from this research is that a dedicated effort to improve education in matters of sustainability is urgent. As such this study lends further support to a conclusion drawn in a number of previous studies in Canada and elsewhere. The role of education in changing the long-established habits and practices that undermine the scientific basis for fisheries management cannot be overemphasized. In the long-term only education and proper enforcement can lead to acceptance of the idea that the very practices that are often perceived as privately rational are in fact socially irrational and destructive. The implications for fisheries policy from this research can be summarized as follows:

1. In all but exceptional circumstances IQs and ITQs cannot be expected to resolve the problem of data fouling. IQ and in particular ITQ regimes strengthen incentives to high-grade and under-report in order to maximize the value of the quota. Since ITQs are unpopular with fishermen for yet other reasons, an opportunity may exist to build political capital by reconsidering the ITQ option (Copes, 2000).

2. The Newfoundland groundfish community shows sustained shifts in overall size distribution and declines in average size of commercial species (Martinez, 2001, 2003; Walsh, 2001; Haedrich and Barnes, 1997). The present modeling effort indicates that while the economic incentive to high-grade is weakened as the probability of finding 'large' fish declines, it does not go to zero until large fish are all but gone. This result is driven by the premium on large fish, relative to unit harvesting costs. The higher this ratio, all else being the same, the more highgrading there will be. This is worrisome in light of the fact that harvesting costs trend downward with technological change, while the price premium for large fish in the market can be expected to trend upward as the quality of the remaining resource is degraded. These factors thus combine to drive the price/cost ratio upward, which in turn fuels more highgrading. The damaging effects of this behaviour need to be given much more attention by policy makers. The Norwegian approach with a 'no discard' policy warrants closer examination.

3. Given the probability of being detected and subsequently convicted, a very sizeable increase in fines may be necessary in order to bring under-reporting within tolerable bounds. This may well be a more cost-effective means of controlling under-reporting, at least for low probabilities of detection. Even though we hypothesize that more effort is required to sell under-reported catch (as some avoidance may be necessary) than the reported catch (accepted directly by processing plants), the profitability of under-reporting makes it highly unlikely that moral suasion will curb such behaviour measurably.

4. Few fisheries agencies can field the resources necessary to monitor and prevent illegal fishing (Hilborn et al., 2003). Local co-operation and control (where fishermen patrol themselves) is the appropriate approach. The rationale is that local fishermen know exactly who is doing what, when and where.
5. More research on the factors contributing to misreporting is necessary. We have strong indications of what motivates data fouling. We know much less about the most effective ways of dealing with it.

ACKNOWLEDGMENTS

We are grateful indeed to the many fishers for their participation in his study and for sharing their valuable experiences and insights. Thanks are due to Michael Ryan and Danny Ings who provided helpful research assistance, and Martin Hall for many useful comments on the questionnaire. We gratefully acknowledge the financial support from the Social Sciences and Humanities Research Council of Canada (SSHRC), and the Natural Sciences and Engineering Research Council of Canada (NSERC) who funded the Coasts Under Stress Project through SSHRC’s Major Collaborative Research Initiatives (MCRI) program.

REFERENCES


FAO (Food and Agriculture Organization of the UN), 2002. Stopping illegal, unreported and unregulated fishing. FAO, Rome, 20pp.

Finlayson, A., 1994. Fishing for truth. Institute for Social and Economic Research, ISER Books, Memorial University, St John’s, NL.


EARLY ATTEMPTS AT ESTABLISHING EXCLUSIVE RIGHTS
IN THE BRITISH COLUMBIA SALMON FISHERY 1

Frank Millerd 2
Department of Economics, Wilfrid Laurier University
Waterloo, Ontario, Canada N2L 3C5

ABSTRACT
As the British Columbia salmon fishery expanded in the early twentieth century, resource managers struggled to effectively discharge their responsibilities. With limited capability to manage and enforce regulations on the numerous salmon spawning streams spread over a long and sparsely-populated coastline, various exclusive fishing privileges often appeared to be viable solutions. Local managers, particularly, viewed exclusive rights as an expedient way of facilitating regulation. Exclusive area fishing privileges were often granted for drag and purse seines. The number of processing plants in northern areas was limited and each plant given a fixed number of fishing licences. Traps, an efficient means of capturing salmon, were permitted in certain areas. But, despite the potential for efficient harvesting and other benefits, these exclusive rights allocations did not last. Established to meet short-term needs, not long-term benefits, the rights allocations were flawed. With little assurance of continuing exclusivity, no secure long term tenure, and little transferability the rights were incomplete. Those holding them saw little benefit in taking any responsibility for managing and conserving the resource. Each had the potential to generate rents but little attempt was made to collect rent, despite common knowledge of the profits generated in many cases. The rights allocations were opposed by small boat fishers, often viewed as privileges for a favoured and politically connected few, and barriers to many others eager to enter the industry. The successful establishment of exclusive use rights depends on the objectives and structure of the rights system.

INTRODUCTION
While many studies examine the progression of a fishery from open access to access limited by the creation of property rights, this is a report of the opposite move, from various forms of rights based access to open access. The fishery considered is the British Columbia salmon fishery from the late nineteenth century to the 1930s, an era of rapid development of the industry. The industry moved from reliance on one species, sockeye, and one river, the Fraser, to all species and all areas of the coast. Demand developed for other species and production on the Fraser River was severely curtailed by partial blockage of the river during railroad construction. This era also saw the adoption of new fishing techniques, mechanisation of fishing and processing, and similar expansions in neighbouring parts of the United States. Canning remained the dominant processing method. Not only did resource managers have to contend with a growing industry but also with limited knowledge of the resource, minimal budgets for administration and regulation, increasing conflict with the United States over jointly accessible stocks, and uncertainty about jurisdictional responsibility for fishing. All these elements influenced management.

Jurisdictional uncertainty arose from provincial challenges to the federal government’s assumption of complete authority over fishing after confederation in 1867. Both governments wanted a major role, not always trusting the other and viewing the industry as a source of revenue, a basis of development, and a way of distributing favours. Court decisions in 1882 and 1898 allowed provinces to allocate proprietary rights in fisheries and gave them limited legislative powers, encouraging many provinces to aspire to a

2 Email: fmillerd@wlu.ca
wider role. British Columbia allowed the federal government to take the lead for a time but in 1908 created its own licencing and regulatory system. Both governments then issued cannery and fishing licences, not always agreeing on licencing policy and regulations. The federal government, in particular, was often unsure about its authority and wary of making moves. Finally, in 1913 a court decision limited the provincial role in tidal fisheries and confirmed federal legislative authority over fisheries.

The expansion of the industry to all areas and all species placed considerable pressure on fishery administrators. Initially, in the major sockeye salmon areas, fishing occurred in relatively limited areas and focussed on one species. The expanded fisheries for other species of salmon meant fishing spread to practically all rivers and streams of the remote coast, a much greater regulatory challenge. Management was further complicated by minimal knowledge of the hundreds of individual stocks and lack of research. With limited resources to manage and enforce regulations, various ways of limiting participation by creating exclusive use rights, rather than allowing open access, were often attractive regulatory tools. These rights could restrict effort in a location, define the fishing gear allowed, and clarify access privileges.

The exclusive use rights discussed here all involve some control over the number of participants. With open access, in contrast, the number of participants is not controlled, usually just the total harvest and the rules of participation. Access to the fishery is open resulting in a continuing contest between managers and fishermen and the dissipation of economic rent. With exclusive use rights access may be controlled by giving an individual or individuals the exclusive use of an area or limiting the number of units of fishing gear allowed.

Recently, rights-based management has been advocated for salmon fisheries. Knapp (2001) proposes rights-based management for the survival and future prosperity of the Alaska salmon industry. With rights-based management fishery administrators would decide on escapements and the allocation of the catch to individual rights-holders. Each rights holder would be allowed a given harvest in an area or during a specific time period. The rights holder would choose the harvesting method or methods, including, possibly, fish traps. Each rights holder would have guaranteed landings, not having to compete for the available fish. Schwindt, Vining, and Weimer (2003), in evaluating policy alternatives to the current salmon fishery in British Columbia, rank river-specific exclusive ownership rights the highest. The right to catch all salmon entering a river system, except for the Fraser River, would be allocated to a rights holder for twenty-five years. Here the rights holder would determine escapement. Because of its size the Fraser River arrangement would be similar to that proposed for Alaska; fishery managers would decide on rights holders and allocate the catch among them. Exclusive use rights could potentially yield benefits from efficiency of harvesting through limitation of effort and a continuing incentive to adopt more efficient harvesting technology, the capture of resource rent with lower harvesting costs, stock management improvements since rights holders have incentives to allow adequate escapement, lower public costs as rights holders assume many management and regulatory functions, improvements in product quality as harvesting and processing are coordinated, ease of allocation of subsets of rights for particular groups such as Aboriginals, and greater flexibility in adapting to changing natural and economic conditions.

The rise and fall of several systems of exclusive rights will be reviewed here: granting exclusive area fishing privileges; granting exclusive use of a given type of fishing gear in an area, specifically beach seines and purse seines; the use of fixed fish traps, as opposed to mobile fishing boats; and limiting the number of processors in an area and allowing them to allocate fishing licences. While each had the potential to achieve the benefits of rights-based management all were eventually abandoned due to deficiencies in the rights. The reasons for their demise will be explored.

**IMPLEMENTATION OF EXCLUSIVE RIGHTS**

**Exclusive area fishing privileges**

Before 1903 a small number of exclusive area fishing privileges or leases were awarded by the federal government. Generally these were for specific sections of the British Columbia coast with an annual fee

---

3 Fairley (1980) and Thompson (1974) discuss these and subsequent cases.

4 Johns (1935), 83; Victoria Colonist, 2 May, 1901; Vancouver Province, 8 May 1901; BC Bureau of Provincial Information (1910), 16.
and for periods up to nine years. The leases could be quite extensive, one was for sixty miles of coast line on the east shore of Vancouver Island, granted in 1902 for nine years with an annual fee of $50. The holder of this lease then sub-let these privileges. In 1905 the holder received $1000 for the sub-lease, a nice profit on the $50 fee. Smith's Inlet on the central coast provides another example of the rent available from exclusive fishing privileges. In 1902 the "exclusive right of fishing with nets and other legal gear" at the head of the inlet was awarded for an annual fee of $25 to a co-owner of the only cannery in the inlet. This operation was extremely profitable. The cannery and lease sold for $300,000 in 1911, far more than that paid for any other cannery at that time. These profits did not go unnoticed. In 1916, when an additional cannery licence was issued for the inlet, the BC Deputy Commissioner of Fisheries suggested auctioning the additional cannery licence; "...I see no reason the respective governments should not obtain some advantage if a license is to be granted." But this does not seem to have occurred.

The use of exclusive long-term leases floundered on such abuses. The federal department later characterised the leases as "tentative" and described the experience as "...not such as would prompt it to increase their numbers." After 1903 multi-year leases were no longer issued or renewed and some of the government wanted to cancel. A 1905-1907 investigatory commission, noting abuses of lease privileges with some not used and held for speculation, some offered for sale, and some sub-let, recommended that no further leases be granted. The jurisdictional uncertainty of the time also made the federal government wary of granting long-term leases. In 1903 the department stated that it would not be issuing multi-year leases as it "might complicate matters" with the provincial government. With misuse by some lease holders, public and provincial government opposition, and a predicted unmanageable demand, all exclusive leases for sections of the coast were allowed to expire.

### Beach or drag seines

With the expansion of fishing to the smaller rivers and creeks, new types of fishing gear were needed. Beach or drag seines were more suitable for these smaller rivers and creeks than the gillnets used in the major rivers and inlets. Beach seines had a cork line above and a lead line below the web. One end was fastened on shore and the other set from a boat in a circle around the salmon and brought ashore. The net was then pulled ashore, often manually, with the lower edge dragging on the bottom to trap the fish. Drag seines could be quite effective, sometimes too effective.

Beach seines were always controversial. They were banned in 1890 but, after claims that salmon could not be caught in sufficient quantity in some areas otherwise to support a cannery, some beach seines were allowed in 1894 under special permit. In March 1904 the government announced its intention to more

---

5 National Archives of Canada (hereafter NAC), RG23, vol. 326, file 2780(1), F. Gourdeau, Deputy Minister of Marine and Fisheries, to C. McIntosh, secretary of the Fisheries Commission, 8 December 1905.
6 Ibid., file 2780(1), Deputy Minister of Marine and Fisheries to Secretary, Fisheries Commission, 6 December 1905; Ibid., vol. 354, file 3081(1), R.G. Warton to W.M. Griffin, 2 March 1906.
7 Henry Doyle papers, Explanatory Notes Covering each of the Existing Companies it is Hoped to Secure for the Amalgamation, c. 1925, reproduced in Newell (1989a), 222. The cannery was assessed by a government commission at $10,000.
8 Public Archives of British Columbia (hereafter PABC), GR 435, Box 152, file 1915#2, Deputy Commissioner to Commissioner of Fisheries, 6 October 1915.
9 NAC, RG23, vol. 348, file 3023(2), G. Desbarats, Deputy Minister of Marine and Fisheries, to A. Christie, 4 December 1909.
10 Ibid., file 3081(2), A. Johnston, Deputy Minister of Marine and Fisheries, to J. McRae, 21 October 1911; Ibid., file 3023(2), Memorandum Re Application for the Renewal of the Hickey Lease, 4 January 1910; Vancouver Federal Records Centre (hereafter VFRC), Acc 84-85/278, box 500540, file General Correspondence 1903, J. Prefontaine, Minister of Marine and Fisheries, to Clayquot Sound Canning Company, 22 January 1903.
11 British Columbia Fisheries Commission 1905-1907 (1908): Report and Recommendations. Ottawa: Government Printing Bureau, 31-32. The Commission states a recommendation to end exclusive leases was made in an interim report but the recommendation cannot be found in the published interim reports or the final report's listing of interim recommendations.
12 VFRC, Acc. 84-85/278, box 500540, file General Correspondence 2003, R. Venning, Assistant Commissioner of Fisheries, to C. Sword, Inspector for district 1, 11 September 1903.
13 NAC, RG23, vol. 348, file 3023(1), Memorandum Re Application for a Lease of Fishing Privileges in British Columbia, 22 November 1907; Ibid., J. Williams, Inspector for district 2, to Venning, 13 November 1905. The lease which provoked the most opposition was the April 1907 proposal to grant exclusive fishing privileges for Cowichan Bay. Under pressure the company surrendered the lease in 1909. This lease is cited by the provincial government as one reason for proclaiming their fisheries act.
14 British Columbia Fisheries Commission 1905-1907 (1908), 34.
generally issue seine and trap licences. An order-in-council of May 2, 1904 rescinded the prohibition on nets other than gillnets for catching salmon. Licences for beach seines were now more widely available.

The department granted one licence per area, not considering it "feasible, nor desirable in the public interest, to grant different drag [beach] seine licences for the same area." A beach seine licence gave exclusive fishing privileges for a stretch of coast with at least one creek or small river. In practice, but not part of the regulations, the licence was usually for about fifteen miles of coastline. Exclusive licences were justified on conservation grounds; the deputy minister wrote: "The run of salmon to these small creeks is ... not large and will not admit of a great deal of fishing ... if over-fishing is to be prevented, it is essential that the amount of fishing allowed must be carefully restricted." By 1912, 139 beach seine licences were issued.

Again, however, these privileges were abused. A canner complained about speculation in licences arguing that "in a great many instances these licences are sought after and obtained by parties having no intention of utilizing the privilege for legitimate canning purposes, but with the sole object of selling the use of the license to someone else." The inspector for the northern district complained that "There had been too much speculation in seining privileges in my District of late and I am resolved to stop it...."

**Purse Seines**

Purse seining for salmon was first done in Washington state in the 1880s and was obviously suitable for Canadian waters. Purse seining, where the fish are captured by being encircled, is done from a boat or boats away from shore. In 1903, after a Canadian commission recommended allowing purse seining in BC waters, partly to increase the Canadian share of Fraser River fish, purse seines were permitted. The first purse seine licence was "for fishing in open waters of Barclay Sound, between Cape Beale and Ucluelet, containing conditions protecting approaches to mouths of inlets and rivers and other conditions necessary to such untredied fishing engines. Tentative fee fifty dollars." With no experience with this type of licence, the conditions of this initial licence were regarded as temporary, the local inspector was advised to become informed about this fishing gear so that licences could be issued with appropriate conditions. Initially all purse seining operations were done manually but adaptation of the internal combustion engine to marine use increased these vessels' mobility and efficiency.

With purse seining now permitted and feasible, fisheries administrators faced the problem of how to allocate these licences. Initially, purse seine licences were for limited areas, a restriction imposed primarily for conservation purposes. The northern district inspector, in commenting on a particular licence application, noted that a purse seine licence had already been issued for that area but "...this vast area of water I consider is able to support the operation of two purse seines, without endangering the conservation of the fisheries in this vicinity." Licences were issued for areas such as "the vicinity of the mouth of the Skeena River" or "Esperanza and Nuchatlitz Inlets on the west coast of Vancouver Island" with a limit, sometimes of one or two, on the number of licences in an area. An application could be turned down if, in the opinion of the local inspector, there was already the number of licences appropriate for the area.

Purse and drag seine licences were to be renewed annually. Those who held licences and used them or intended to use them were renewed on application but the federal department would not make any commitment for more than one year. This was not a strong conservation incentive but some licence

---

15 NAC, RG 23, vol. 131, file 222(2), Gourdeau to W.D. Burdis, Secretary, Fraser River Cannners' Association, 25 March 1904.
16 Canada Statutes 1904, vol 1, iii.
17 NAC, RG 23, file 721-4-6(2), Deputy Minister of the Naval Service to G.W. Nickerson, 31 August 1915.
18 University of Washington Libraries, Manuscript Division, Henry Doyle papers, Doyle to R. Prefontaine, Minister of Marine and Fisheries, 24 March 1903.
19 NAC, RG23, vol. 348, file 3023(2), Williams to Venning, 9 June 1909.
21 VFRC, Acc. 84-85/278, box 500540, file General Correspondence 1903, Venning to Sword, 27 August 1903.
22 Ibid.
23 NAC, RG23, vol. 348, file 3023(1), Williams to E. Prince, Commissioner of Fisheries, 27 July 1905.
24 Ibid., file 3023(3), Memorandum Re Certain Drag-Seine Licences in District No. 2, B.C., 15 June 1912.
holders did take a long run view. The chief inspector, in an overview of fishing conditions in 1919, discussed the situation for the Bella Bella area on the central coast where a canner had the exclusive rights for the area, holding eight drag seine and four purse seine licences. The company, having exclusive use of the area, concentrated on the better streams and rivers, allowing the poorer runs to build up. His report was that good catches were made and the stocks increased.25

Traps

Traps were another fishing gear first used in Washington state. For a salmon trap netting is hung on piles set across a migration route to guide the fish to a collection area. Traps have many advantages: well placed traps catch fish at a very low cost, a high quality product can be produced as fish are available fresh and in the needed quantities for processing, and traps are easily regulated. In the 1890s Americans, using fixed traps, increased their harvest of Fraser River sockeye, catching more than Canadians in three of the four years from 1899 to 1902 as the fish migrated through American waters on their return to the river. Canadians felt the American harvest was made unfairly and was a severe threat to the Fraser fishery.26 The cost advantage was regarded as particularly unjust by canners since both countries sold considerable amounts in the British market. Canadian fishermen, however, strongly opposed traps, arguing, quite correctly, that traps would reduce their landings.27

Despite the opposition, in 1904 the federal government rescinded the 1894 ban on all but gillnets, thus permitting trap net licences to be issued.28 There was little attempt to extract any economic rent, a trap net licence was $75.29 Licences were first issued for sites at the southern end of Vancouver Island, along the route followed by the migrating Fraser River salmon before running the gauntlet of the American traps. Only three or four traps operated in 1904, although twenty-five licences were granted and over 100 had applied, some asking for traps at multiple locations.30 A trap licence was usually granted on the basis that it not interfere with other trap locations and, after the provincial government became active in licensing, the concurrence of the provincial government.31 The maximum number of traps operated was never more than twenty. Not all sites were profitable and after 1922 only three to six operated in the area.32 Traps were never responsible for more than a small proportion of total British Columbia landings.33

Later, again in response to traps operating in adjacent American waters, traps were licenced and operated in northern border waters. In 1917 four trap licences were awarded for areas adjacent to the border with Alaska.34 Two to seven northern traps operated until 1920 and from 1924 to 1926, but the licenses were

25 VFRC, Acc 84-85/278, box 500508, file Licence restrictions 1919, Memo Re Fishing Conditions - District No. 2, 28 November 1919.
26 The BC Commissioner of Fisheries wrote in 1903: "... I can positively state ... that the run of sockeye to the Fraser watershed above the great canyon was a failure ... I believe that the decrease in the run absence of fish upon the spawning grounds this year is all attributable to excessive fishing ... [and] the censure for it rests principally a the door of the State of Washington as the unbridled fishing conducted in her waters is indefensible and unjustifiable and, if continued, will wipe out the salmon fishery of the Fraser." (Report of the Commissioner of Fisheries for 1903, F1-F2.)
27 Vancouver Daily World, January 25, 1902; NAC, RG 23, vol. 131, file 222(1), Gourdeau to Secretary, British Columbia Fishermen's Union, 10 October 1901 and 7 May 1903.
28 A few Canadian traps were allowed in 1894 in a location south of the mouth of the Fraser River that supposedly allowed Canadians the first crack at the salmon, but the traps were poorly located and did not make large catches. (NAC, RG 23, vol. 131, file 222(1), Memo re Traps in Boundary Bay, n.d., ca. 1901)
29 Ibid., file 222(2), Gourdeau to Burdis, 25 March 1904; NAC, RG 23, vol. 124, file 164(4) Desbarats to E.L. Newcombe, Deputy Minister of Justice, 2 April 1910.
30 Ibid., vol. 345, file 3005(1), Memorandum Re Salmon Trap Applications in British Columbia for 1905, 10 November 1904; Ibid.,Prefontaine to Templeman, 10 November 1904; Carrothers (1941), 17; Pacific Fisherman, July 1904, p. 8; Vancouver News-Advertiser June 27, 1906; J.H. Todd and Sons, who had vigorously sought trap privileges and done preliminary surveys, was the only company reported as operating traps in 1904. (Pacific Fisherman, June 1904).
33 Between 1925 and 1937, for example, Canadian traps in the Strait of Juan de Fuca annually never caught more than five percent of Fraser River sockeye. (Sooke Harbour Fishing and Packing Co. Ltd. files, J.H. Todd and Sons Ltd. papers, UBC Library Special Collections)
34 Pacific Fisherman, June 1917.
not renewed for 1927 and 1928. A canner pressed for renewal claiming they would not take fish that would otherwise be caught by Canadian fishermen, but fishermen objected. A commissioner, appointed to settle the issue, recommended that traps be permitted in two channels forming part of the border but, due to vigorous opposition to these traps, no further licences were issued for the northern boundary area.

The traps allowed at the northern and southern borders were allowed principally in retaliation for nearby American traps. Initially, trap net applications were refused for other areas. In January 1917, however, with an increased demand for pink and chum salmon, the Minister approved traps for these species. Only six licences were granted, all in waters between northern Vancouver Island and the mainland. These traps were allowed to operate until the end of the 1920 season. In 1918 a trap was reported to have been built on the river at the head of Nitinat Lake which drains on the south-west coast of Vancouver Island.

Limiting the number of fishermen

Initially, most fishing was done with one or two person gillnet boats. As the industry expanded outside the Fraser River canners in the various areas often colluded to limit the total number of gillnet boats in an area and assign a number to each cannery, with the knowledge, acquiescence, and even encouragement of fishery managers. This type of scheme for an area was referred to as a "boat rating." Conservation was often given as the reason for the limitation and, with a limited fishing time per week, there were conservation benefits but, of course, there were economic benefits to canners. Fewer fishermen would have to be transported north, fewer boats outfitted and serviced, and, with fishermen tied to canneries, the pressure to increase the prices paid to fishermen would be restrained.

The earliest instance of "boat rating" was in 1899 when Rivers Inlet canners agreed on a total of 530 boats and their allocation. This agreement held until 1905 when three more canneries were built and a further agreement could not be negotiated. A similar agreement was made in 1903 by Skeena River canners and renewed from 1904 to 1907. The 1905-07 commission encouraged these arrangements, recommending limits on the number of fishing boats in each major northern area for five years starting in 1906, and having the canners allocate these boats among themselves. In 1908, failing to come to an agreement, the

---

35 NAC, RG 23, vol. 765, file 716-15-12(1) Minute of a Meeting of the Committee of the Privy Council, 10 March 1929; Woodward (1948), 14-15; Newell (1989a), 212. The three traps operating near the northern boundary are mentioned in PABC, GR 435, box 45, J.H. Motherwell to J.P. Babcock, 11 April 1927.


38 In 1913 the Minister of Marine and Fisheries, in refusing a trap application for eastern Vancouver Island, stated that it was only because of competition from Americans that traps were allowed in Juan de Fuca Strait and near Point Roberts. Applications away from international waters have been refused. (Ibid., vol. 355, file 3081(3), J. Hazen, Minister of Marine and Fisheries, to H. Clements, member of Parliament, 15 May 1913)

39 Ibid., vol. 930, file 721-4-6(6). Extract from minutes of the Pacific Division of the Fisheries Advisory Board, 16-20 January 1917; Ibid., file 721-4-6(11) Memorandum Re attached letter from H. Bell-Irving, 11 January 1918. These traps may have first operated in 1916, the minute notes that traps for fall fish were first allowed in 1916, a press report states that the Board had recommended traps for fall fish in 1916 (Vancouver World, 22 March 1916). The 1917 Commission later also recommended that traps should be considered where pinks and chums could be taken in good condition for the fresh and frozen market. (p. 45)


42 PABC, GR 435, box 14, Anglo British Columbia Packing Company to Commissioner of Fisheries, 8 March 1910.

43 UBC Special Collections, B.C. Salmon Canners Minute Book, 14 March 1904; Francis Millerd papers, Statement Submitted by Mr. W.A. Found, Superintendent of Fishers, to the Fisheries Commission, July 10th, 1917. Besides agreeing on the number of boats to be fished by each cannery, canners agreed, at least for 1904, on prices to be paid to fishermen, not to pay bonuses to fishermen, and the transportation costs that would be covered.

canners appointed a committee to set a rating for 1908.\textsuperscript{45} The ratings held for 1908 but in 1909 several canners increased their numbers of boats and in 1910 almost every canner threatened to increase their numbers. For the 1910 season the provincial government simply informed all canners of the number of licences that would be issued for each northern cannery.\textsuperscript{46} To provide a more permanent solution the federal and provincial governments appointed a joint commission, based on the reasoning that the impact of limiting canneries was curbed if the number of fishing boats was not also limited. The report in July 1910 recommended the total number of fishing licences for all areas of the north and how these licences were to be divided between canneries, the recommendations to be for five years. The recommendations were based on the capacities of spawning grounds and cannery outputs. In most areas fishing was to be done by gillnets; but some areas had drag seines or purse seines allocated.\textsuperscript{47} The recommended boat rating was made effective by federal order-in-council in December 1910.\textsuperscript{48} The boat ratings, previously only agreements between canners, now had formal government approval and, by dividing the available fishing licences among the established canneries, effectively limited the number of canneries.

The provincial government defended the boat rating, arguing that "the rating was designed, first to insure permanence to fishing in waters that had already been exploited to their limit, and by only such a limitation could the Government secure conditions whereby a sufficient number of seed fish would reach the spawning bed."\textsuperscript{49} The federal view of the 1910 boat rating was more perceptive, recognising that, although the boat rating made controlling fishing easier, the northern boat rating was certainly favourable to the established canners. With all fishing licences attached to the current canneries, entry of new canners was blocked and canners could set prices as fishermen had little choice about where to sell their fish.\textsuperscript{50} The federal Superintendent of Fisheries later commented that "…unless the canners were required to pay into the treasury a large enough amount in the way of licence fees to justify the special privileges thus given them, the limitation of canneries was not desirable and this Department should confine its efforts to prevent over-fishing."\textsuperscript{51}

The federal department wished to end the boat rating but believed that this would place "the fishery almost entirely in the hands of naturalised Japanese fishermen, and this was not regarded as desirable."\textsuperscript{52} Thus, starting in 1913, the boat rating for canneries was eased out by taking increasing numbers of licences from canneries and making them available to "white fishermen" who applied independent of a cannery. The remainder of the licences were granted to "Indian and other applicants" as licences attached to canneries. The "other applicants" would be those of Japanese ethnic origin.\textsuperscript{53} With the licencing of additional canneries in the north after 1912 reallocating a fixed number of boats among an increasing...
number of canneries was practically impossible, thus the total number of boats allowed in some areas increased to accommodate the new canneries.\textsuperscript{54}

\textbf{Limiting the number of canneries}

Although the allocations of the limited number of fishing licences in various areas also limited the number of canneries the number of processors was for a time more directly limited. The first interim report of the 1905-1907 commission recommended "that immediate measures are necessary to limit the number of canneries in ...[northern areas] or the fisheries there will be in danger of depletion".\textsuperscript{55} Limiting the number of canneries in an area would be an indirect resource management tool as fewer processors in an area would at least partially check the pressure to increase the number of fishermen. Of course a limit on the number of canneries in an area would be of benefit to those fortunate to have the privilege to operate there.

Before 1908 neither the federal nor provincial government required a licence to operate a salmon cannery but in 1908 the provincial government passed legislation requiring licences for canneries.\textsuperscript{56} The provincial policy was to "limit the number of canneries in an area to make sure that those operating can make a profit and to protect fish. ... [If] the canneries are operating at a loss they will evade your regulations and they will make inroads upon your capital stock of fish."\textsuperscript{57} Justifying their action by conservation, the provincial government was clearly protecting operating canners. The provincial government claimed that they waited for the federal government to act on the recommendation of the 1905-07 commission to limit canneries in the north before they acted.\textsuperscript{58} A federal order-in-council requiring canneries to be licenced and pay a fee was passed in 1908, an action doubtless stimulated by provincial action. These same regulations stated that no additional canneries would be licenced in the north.\textsuperscript{59} The two governments coordinated the issuing of cannery licences in the north between 1908 and 1913, although the federal government contended they wanted to licence additional canneries while the province did not.\textsuperscript{60}

The dual jurisdiction continued until the 1913 Privy Council decision established exclusive federal authority over fishing in tidal waters. The federal department believed, in licencing new canneries, that it should not limit the number of canneries in an area but should concentrate on preventing over-fishing.\textsuperscript{61} The federal government realized there were benefits to the limited number of canners, one reason for increasing the number of canneries. The minister later stated that "In earlier years it did not seem feasible to attach fees to the salmon canning and fishing privileges, which this department felt were commensurate with the value of these privileges. Hence, in 1913 the Department embarked on the policy of gradually increasing the number of canneries...."\textsuperscript{62}

\textbf{ENDING EXCLUSIVE RIGHTS}

Many objected to the restrictions in the north. Fishermen objected to licences attached to canneries and exclusive seining privileges.\textsuperscript{63} In Prince Rupert, a northern city heavily dependent on the fishing industry,
the local newspaper asserted in 1916 that "the breaking of the salmon fishing and canning monopoly is the most important question in British Columbia. ... [T]he business of canning is in the hands of a few, who control the salmon fisheries of the northern waters in such a way that the white fisherman has no chance to make a living by fishing for salmon...." A delegation from the city went to Ottawa to protest against the "cannery monopoly" and ask that the exclusive rights of canneries at the mouths of streams, the beach seine licences, be abolished and purse seines be allowed to fish in these areas.

In 1917 the federal government moved to deal with some of the festering issues. Beginning in 1918, the practice of attaching fishing licences to canneries was to end and all fishing licences issued independent of a cannery. The number of licences issued for each area would still be limited. Removal of restrictions on the number of cannery licences was also announced. Canners, as expected, objected arguing that limiting the number of boats and not the number of canneries discriminated against canners and that there were few true independent fishermen in the north, as most fishermen were supported by canners. Canners successfully advocated for the appointment of a commission to investigate the industry, even agreeing, after departmental pressure, to an investigation of their profits.

**The 1917 Commission**

The Special Fishery Commission 1917 was appointed by federal order-in-council on July 2, 1917. The commissioners were neither public servants nor politicians; an economist was chairman, the other two members were businessmen. On the question of whether the number of salmon canneries now operating in the northern district be limited, the commission recommended that the number of cannery licences not be increased for five years. The commission regarded the existing plants as more than adequate for the current supply of salmon but also recommended that licence duties on canneries be increased on the basis of the number of fish canned and profits made "so that while enjoying an adequate return the canneries may contribute to the public treasury, for the propagation and conservation of the salmon or for other proper public purposes, due compensation for the privileges conferred."

The Commission also recommended that there be no increase in the number of boats in the northern district, as there were adequate for the available fish, and only licences with no connection to a cannery should be issued. The Commission claimed this would provide fishermen with a more competitive market for their fish. Although not using the term "common property", the consequences of the common property nature of the salmon fishery were clearly recognized and dealt with. The commission realized that the use of more capital and labour than necessary in either fishing or processing cannot increase output but dissipates profits or the rent available from the fishery. With limitations on inputs, any excess profits should go to the government to pay for management of the resource and for the privilege of fishing. This was a very perceptive analysis and one on which the Commission's recommendations were built.

**After the 1917 Commission**

For 1919 the department proposed that the recommendations of the 1917 commission be put into effect. Fishing licences would be limited, but none attached to canneries. The number of canneries would also be limited and fishing and cannery licence fees raised to be "commensurate with the value of the privilege" so that "the revenue should be sufficient to at least cover the cost of administration, protection, and development of the industry by this Department." The fee increases recommended were considerable, trap net licences were to go from $75 to $500 plus a half cent per fish taken, purse seine licences from $50 to $300 plus a half cent per fish, drag seine licences from $25 to $150 plus a half cent per fish, gill net licences from $5 to $10, trolling licences from $1 to $5, and cannery licences from $50 to $500 plus four

---

66 Francis Millerd papers, Statement Submitted by Mr. W.A. Found, Superintendent of Fisheries to the Fisheries Commission, 10 July 1917; Pacific Fisherman, July 1917, 34. Also, motor gillnet boats, then banned in the northern district, were to be allowed.
68 NAC, RG 23, vol. 930, file 721-4-6(6) Secretary, BC Salmon Canners Association to Minister of Naval Service, 20 February 1917.
69 Ibid., Memorandum Re British Columbia Delegation, 28 May 1917.
70 Special Fishery Commission, 1917, 24.
71 Ibid., 19.
Early exclusive rights in the BC salmon fishery, F. Millerd

cents per case of sockeye and three cents per case of other species. Although the 1917 Commission only considered the northern district, the licence limitations and increases in fees were to apply to the whole province. The basic principles of the 1917 Commission were applied throughout the fishery. The Minister announced changes in policy for 1919; no further canneries would be licenced for five years, except in areas with an over-supply of fish, and all licence fees were to be raised as proposed.

Just as the policy changes were proposed, however, World War I finally ended and the Department now faced demands to provide fishing licences for veterans. Employment opportunities in other industries were limited. With the end of the war the economy staggered; manufacturing employment fell, agricultural prices were down, and real GNP declined. The dilemma for the department was how to provide for the veterans while restricting licences and raising cannery licence fees. A department official wrote that "While it is the earnest desire and endeavour of this Department to do everything it feasibly can ... to facilitate procuring employment for returned soldiers it must not be forgotten that the existing policy specifically states that one of its objects is to enable those engaging in the canning industry to operate as economically as possible and in return for giving them large and comparatively exclusive fishing privileges, they are required to compensate the public by adequately paying into the public treasury for the privileges they receive."

Despite the announced policy that those benefiting from restricted licences should pay for the privilege, public and political pressure was building to end restrictions. Members of Parliament favoured removal of restrictions on the number of cannery and fishing licences and using other ways to protect the runs, with first consideration for licences given to "returned soldiers", a phrase used to describe all veterans. For 1919 the department attempted to accommodate this wish. All applications from veterans for gillnet licences would be granted. Where the number of licences was limited, a proportion of licences would be reserved for veterans until a month before the season started. Additional seine licences would only be issued to "bona fide" veterans.

While restrictions were loosened for 1919, many, including the British Columbia members of Parliament, however, wanted complete abolition of all restrictions on fishing and cannery licences. One issue, however, on which the members had difficulty was the effect of removing limitations on the number of fishermen of Japanese ethnic origin in the industry. Some members and some groups of "white fishermen" advocated limiting and gradually eliminating fishermen of Japanese ethnic origin.

In the Department's view, many of the licences allocated to veterans were not properly used. Some veterans given licences were reported to have sold or leased them to others; others were reported to have asked canners for payments over and above the price of fish. The department predicted this problem would become worse in the future leading to an investigation such that "those in charge of the administration of the fisheries will be condemned on practically all hands."
Given the political wish to end restrictions and the unsatisfactory experience with partial restrictions, the Superintendent of Fisheries now proposed returning to pre-1917 recommendations, an "open door" policy with no limitations on the numbers of fishing and cannery licences. Runs would be protected by restricting fishing time and hiring more fishery officers. The northern area, with its limits on fishing and cannery licences, would be the most affected. While unlimited gillnet licences were not expected to cause management difficulties, the district inspector predicted that the "purse and drag-seine question has practically insurmountable difficulties." With no limit on the number of seiners "depletion of these fisheries will inevitably follow, all licensees would flock to the good sockeye creeks," areas would have to be closed and a "regiment of officers" needed to enforce the closures.

In January 1920 the "open door" policy was announced. There would be no limit on the number of gillnet, purse seine, trolling, and cannery licences, but only for "white British subjects." Bowing to public pressure, there were racial restrictions on licences. The number of gillnet, purse seine and troll licences issued to "other than white men or native Indians" was not to exceed the number issued in 1919. Those of Japanese ethnic origin were not to have more licences than they had in the previous year. The total number of licenses in an area would be limited. Beach seines were to be replaced with purse seines where possible but if no other fishing method was feasible in a location the beach seine licence could continue to be issued. Only existing trap licences were to continue. Other forms of regulation were now needed: fishing boundaries were placed at the mouths of rivers, weekly closed times extended, and the fishing season curtailed in some areas.

In justifying the "open door" policy the Minister stated that the industry was "almost a monopoly and the fisheries belong to all the people." The department wrote that it had felt for years that the "open door" policy was the appropriate one but held off implementing the policy because of the difficulties in properly protecting all areas, difficulties which are certainly less if "undue competition is prevented." Now the department feels it has greater ability to protect the salmon runs and can allow increased numbers of fishermen. The previous limitation of fishing and canning licences in the north no doubt made regulation of fishing easier but now the department felt it had the capacity to protect stocks even with more fishermen.

Canners were unhappy with the results of the significant increase in fishing and canning fees in 1919 and then the lifting of restrictions on the numbers of licences in 1920. In 1920 canned salmon prices were high and fish plentiful, canners could absorb the higher fees. In 1921, however, prices fell and the increased fees were now having an impact. As well, according to the department, other issues needed to be addressed, including protecting and enhancing stocks and the whether or not fresh pink and chum salmon could be exported. A major fishermen's organisation was advocating the elimination of beach seines and traps and

---

81 Ibid., Memorandum Re Policy for British Columbia Fishery, 11 November 1919. The memo stated that, with no limitations, "naturalized Japanese" would become more significant in the fishery. But It seems impracticable to exclude them-many of them being returned soldiers-in the absence of any general Governmental policy dealing with the Japanese situation. This difficulty is recognized by the Prince Rupert agitators for an open door policy, but they...say that the proper thing to do in the circumstances is to give such Japanese licences.

82 VFRC, Acc. 84-85/278, Box 500508, file: Licence restrictions 1919, Williams to Cunningham, 11 October 1919.

83 NAC, RG 23, v. 931, file 721-4-6(21) Found to Cunningham, 31 December 1919; New Westminster Columbian, January 3, 1920; NAC, RG 23, vol. 932, file 721-4-6(23), B.C. Canners' Association, Memo re 1920 policy, January 2, 1920; Ibid., vol. 931, file 721-4-6(21), Re Policy in Connection with the B.C. Salmon Canning and Salmon Fishing Industries, December 18, 1919. Although it does not appear to have been announced the departmental memo stated "That from the nature of the industry, it is undesirable that Asians should engage therein, whether they are naturalized British subjects or not. Therefore there should be no increase in the fishing privileges available to such naturalized subjects, and a process for their gradual elimination from the industry should be started, by annually decreasing the number of gill-net licences that may be available to them."

84 Annual Report of the Fisheries Branch, Department of the Naval Service for the year ending December 31, 1920, 9, p.48; NAC, RG23, vol 934, file 721-4-6(44), Re Salmon Purse-Seining Licences, March 1924.

85 Vancouver Sun, 28 August 1920.


87 NAC, RG23, vol. 933, file 721-4-6(32), Memorandum Re British Columbia Salmon Fishing and Canning Industries, 9 February 1922. The export of raw sockeye salmon was already prohibited but now American Puget Sound canners were buying Canadian caught pink and chum salmon.
that licences be valid for the whole coast, not just district they were issued for. A number of issues were simmering, ripe conditions for the appointment of another commission.

**The 1922 Commission**

This time the commission, appointed in 1922, consisted of members of Parliament. The Commission had its own priorities, recommending that motor boats be permitted in the north for gillnetting, that a joint commission with the state of Washington be established for the restoration of Fraser River sockeye and that various measures be undertaken for the protection of runs. The commission also recommended a substantial reduction in fishing, trap, and cannery fees, to levels considerably below those in 1918 before the last increase. The recommendations of the Commission were put into force by the department.

Perhaps the most significant recommendations of the Commission dealt with restricting Japanese-Canadian access to licences. After 1919 no increase had been allowed in the number of fishing licences awarded to citizens of Japanese ethnic origin. Starting in 1922, following the recommendation of the commission, the number of licences to those of Japanese ethnic origin was to be gradually reduced and their licences to remain attached to the northern canneries. For others access was open and licences unattached with the payment of nominal fees. In 1932 the department finally completely did away with the system of attached licences. Practically all early efforts to allocate property rights had now ended; the only remaining were the few traps allowed near the southern border.

**WHY RIGHTS WERE USED**

The exclusive use rights considered here were established for a variety of reasons: limited resource management capacity and experience, lack of knowledge of the resource, the primitive technology then used in fishing and processing, competition from the United States, and political and stakeholder pressure. Although there was wide knowledge of the profits that many rights holders enjoyed there was little attempt to generate the benefits of exclusive use rights that are now proposed.

Convenience and expediency were primary reasons for the exclusive use rights discussed here. With local fishery managers having limited resources to manage and enforce regulations, various ways of limiting participation through creation of exclusive use rights, rather than allowing open access, were attractive regulatory tools. As the industry expanded and beach and purse seines were introduced managers faced new and difficult challenges in conserving stocks. Managers had little experience with the new fishing techniques operating in remote areas and little knowledge of the stocks being exploited. Exclusive use rights simplified management by restricting effort in a particular location, defining the fishing gear allowed, and clarifying access privileges.

The inspector for the northern district put a high priority on assigning licence holders to an area and knowing their whereabouts, commenting that "if I lose touch with them [purse seiners], they immediately proceed with their illegal work, fishing during close seasons, barricading, etc." He was also concerned about his ability to enforce regulations warning that if licences are not restricted to an area additional patrol boats will be required. When beach and purse seines were first permitted each licence was for a particular area and the number of licences in each area limited to that estimated to be appropriate for the size of the run. Especially for beach seines often only one licence was allowed in a given location. The primitive and relatively immobile fishing techniques then in use facilitated limiting each licence to a specific location.

While local federal department officials favoured restricting the area in which a beach or purse seine operated and limiting the number in a location, department headquarters officials, were more concerned about the legal implications of allowing exclusivity. They informed local officials in 1906 that purse seine

---

88 Vancouver Sun, 20 August 1920.
89 The department stated that the original limitation was at the urging of B.C. Members of Parliament and "returned soldier organizations." In 1922 the number of salmon trolling licences was reduced but after this the department only made further reductions on the recommendation of the Select Standing Committee of the House [of Commons] on Marine and Fisheries. (NAC, RG 23, vol. 933, file 712-6-8(1), Memorandum re Policy of Placing the Fishing Industry in the Hands of Whites and Canadian Indians, 14 April 1927.)
90 Pacific Fisherman, January 1932
91 NAC, RG23, vol. 348, file 3023, part 1, Williams to Venning, 26 January 1906.
licences were "to convey no privileges of an essentially exclusive character such as would prevent the issue of licences for any reasonable number of similar or other fishing engines in the same vicinity. ... the Department reserves to itself the right to limit or extend the number of such licences in any given locality." A licence should have a vague description of the area to which it applies, reducing the implication that the licence gives exclusive privileges. But local officials tended to limit licences for particular areas. In 1908 the officer in charge of the northern coast commented that usually only one purse seine licence was issued for each 20 miles of coast and one drag seine licence for each 15 miles of coast. Since at that time all seine licences had to be approved in Ottawa, it appears that Ottawa at least concurred with this policy.

When canners devised the "boat rating" scheme for limiting and assigning fishing boats in each area, they were no doubt doing this primarily for their own benefit. For them costs were reduced and entrants discouraged. But the scheme also eased regulatory responsibilities for fishery managers as effort in each area would be limited. Thus government managers not only acquiesced to the scheme but encouraged it. Eventually the scheme was formally approved by the government. These exclusive use rights were certainly a convenient management tool.

The primitive fishing technology of the time limited the fishing techniques available for harvesting certain stocks and forced situations where gear numbers had to be limited. Gillnets had limited mobility and were best used in rivers and inlets. Thus beach and purse seines were the only gear types for the smaller streams and rivers and, without close supervision, their numbers had to be strictly controlled.

Not only was the fishing industry expanding at this time but agriculture and other natural resource industries were growing through the allocation of access rights. Exclusive use rights for a fishery may not have appeared much different than homesteading, the allotment of land free to those who clear and farm it, a policy widely used to settle western Canada. The provincial government regarded a limit on the number of canneries in an area as "no more a monopoly that occurs when all the land in a district is allocated."

One objective of the time was to offset American catches of Canada-bound fish. For this purpose traps, which implied exclusive rights, were used. Traps were then only feasible for the northern and southern border areas. The major motivation for permitting traps was retaliation for American harvesting of joint stocks, although many canners pressed for the use of traps because of their low costs of harvesting. Traps were first permitted near the southern border to try and land a bigger proportion of the Fraser River fish then heavily harvested by American traps. Later a similar situation developed along the northern boundary and traps were permitted for a time there. The traps in the Johnstone Strait area were only used for a short period of time to assist with the harvesting of pink and chum salmon. No attempt was made to capture any economic rent from traps. Auctioning trap sites was suggested but not carried out. In any case when traps were first introduced into British Columbia it was not clear which sites, if any, would be profitable; some trial and error was necessary.

As was no doubt true with other privileges granted by governments of that time, the awarding of trap, purse seine, and drag seine licences was subject to political influence. Licences in good locations were valuable, particularly when the licences in an area were limited. Politicians were likely not averse to having the power to influence the awarding of these rights. A 1904 internal department memo reminded the Minister that "nothing in connection with Fisheries matters in British Columbia was to be decided without first consulting the Honourable Mr. Templeman." Templeman was a Liberal Senator from Victoria who had earlier informed the Minister that he would advise with reference to the granting of trap-net licences. In 1906 a note appears in the department's file on licences for district 3 (Vancouver Island) that "Mr. Sloan [Liberal Member of Parliament for Comox-Atlin] is to be consulted as to applications for new

---

92 Ibid., vol. 345, file 3005, part 2, Venning to E. Taylor, Inspector for district 3, 6 February 1906. As an example of keeping the licence area vague, the purse seine licence for Esperanza and Nuchatlitz Inlets was not to specify the various tributaries to these inlets, as had originally been suggested by the local inspector.
93 Ibid., vol. 348, file 3023, part 1, Williams to Venning, 19 May 1908.
94 PABC, GR435, box 65, file 608, Memo Re Boat Rating, 12 February 1912
licences.” Canners, who benefited from many of these rights, no doubt exploited their political connections to encourage continuance of many of these rights.

**REASONS FOR THE DEMISE OF EXCLUSIVE RIGHTS**

The question is why these early attempts to use of exclusive harvesting rights, now regarded as potentially having useful properties, had such a short life time. Why did policy for the fishery evolve towards open access, rather than towards greater use of various forms of use rights? Although the rights as then devised were flawed and needed improvement they had potential benefits, but still gave way to a policy of open fishing.

Three categories of reasons may be suggested for the discontinuance of these early use rights. The first is that the specific reasons for establishing the rights decreased in importance and new objectives for management of the fishery evolved. The early rights were not established to capture the benefits now proposed for exclusive use rights but were a response to the conditions of the day. Secondly, the rights as then structured were flawed, lacking the characteristics of exclusivity, continuance, and transferability, which provide rights holders with incentives to operate efficiently and responsibly. The flaws in the rights were compounded by uncertainty about the relative jurisdictional responsibilities of the federal and provincial governments. Lastly, the various forms of exclusive access were opposed by other fishermen, elected representatives, members of the public, and many government managers. The benefits of the rights mostly went to the holders, others were excluded. Practically no attempt was made by either the provincial or federal government to capture any economic rent generated as a result of issuing these exclusive use rights.

*Change in reasons for the rights*

Over time the reasons for establishing these rights were no longer applicable. Developed and used to deal with that era’s problems, the rights were not structured to capture the benefits, such as efficiency, rent capture, improved management, lower public costs, quality improvements, and equity that would encourage their continuance. The exclusive use rights established in the era considered here were established because of the issues and circumstances of the time: competition from the United States, limited resource management capacity and experience, lack of knowledge of the resource, the primitive technology then used in fishing and processing, and political and stakeholder pressure. When these reasons were less urgent or no longer valid then the perceived need for the use of these exclusive rights diminished. Changing management goals and capability meant changes in management methods. Initially the primary focus was conservation and, with limited management capability and experience, the exclusive use rights were attractive management tools. The opening of new fishing areas, the primitive and immobile harvesting technology, and the siting of processing plants near the fishing grounds facilitated the use of exclusive use rights. Later, when more focus was placed on providing employment and with greater competition for access to the resource, improved and strengthened management capability allowed open access with stricter regulation of effort.

Assigning exclusive or near-exclusive use rights appeared to be a viable management tool as the fishery expanded away from the Fraser River area and new stocks and species were exploited. With this expansion managers, particularly those in the field, struggled to effectively discharge their responsibilities. The resources to manage fishing effort and enforce regulations for numerous salmon spawning streams and rivers spread over a long and sparsely-populated coastline were limited. Outside the Fraser River, any form of real time management where fishing time would be adjusted according to landings was impossible. Open times and the permitted maximum amount of fishing gear had to be set at the beginning of the season, with the hope that the size of the run was adequate to support the permitted effort and allow an adequate escapement. Resource managers searched for techniques which would fulfil these objectives and could be enforced with the available staff. Local managers were particularly in favour of granting exclusive or semi-exclusive rights for an area. They viewed exclusive rights as an expedient way of facilitating regulation and limiting effort.

Traps were only licenced for specific and limited locations, thus easy to supervise. Various other exclusive fishing rights, where one or a few were allowed to use a particular type of gear in an area, were workable

---

96 Ibid., vol. 354, file 3081(1)
solutions. Purse seines and drag seines were licensed for specific locations, easing the monitoring of their activities. Fishery managers were wary of the use of seines but, given the fishing technology of the era, drag or purse seines were often the only method possible in certain areas or for certain species.

Limiting the number of canneries and the number of gillnet licences for each cannery in an area also appeared to be a practicable and cost-effective way of regulating fishing in an area. These limits on numbers would be easy to monitor. In the northern area and on Vancouver Island canners developed cannery sites and transported fishermen and supplies to and from the sites. Fishermen had to rely on canners for transportation, boats, and nets. This infrastructure provided by the canners was used by fishery managers in regulating effort by limiting the number of canneries and assigning a fixed number of fishermen to each.

**Effective rights need property characteristics**

Capturing the benefits now seen for exclusive use rights in the salmon fishery requires that the rights be properly structured. The rights should have the characteristics of property; holders of the rights must view the rights as secure. This requires that the rights possess exclusivity, a lack of interference from others and protection from interference; continuance, validity for a time period in which investments in the resource would provide a return; and transferability, the ability to sell or lease the right. Use rights with these characteristics will encourage the holders to act responsibly as if they are owners of the resource; efficiency and conservation are promoted. Lack of these property characteristics or uncertainty about them mean that the rights are defective without full incentives for efficiency and conservation. At the extreme, holders of defective rights will act no differently than those exploiting an open access resource. Any system of exclusive use rights instituted today should be established to capture as many of the currently appreciated benefits as possible. These potential benefits justify the use of exclusive use rights and offset opposition to them.

Unfortunately the use rights awarded in the earlier era did not have the characteristics of exclusivity, continuance, and transferability. The rights were incomplete; they were use or access rights, not ownership rights. Exclusivity was lacking as there was always a threat that others would be allowed to operate in an area. Drag seine licence holders were threatened with the emergence of purse seines and the federal department’s wish to do away with drag seines. For purse seines there was no exclusive granting of rights, particularly from Ottawa’s point of view. Even though a purse seine may have been the only one allowed in an area, this exclusivity was not guaranteed.

Few had any form of secure long term tenure, and there was little assurance of continuing exclusivity. Licences were granted only on an annual basis, although usually renewed. With the lack of any long-term tenure and the issuing of most licences to individuals or companies there was practically no opportunity to transfer the licences. Thus, although the licences often gave exclusive or limited access to a fishing area or ground they were deficient in the other characteristics, continuance and transferability, which would make them true property rights. One result was that neither the holders of the rights nor the issuing authorities acted as if they were property rights.

The rights were also flawed by jurisdictional uncertainty between the federal and provincial governments. The security of an award of harvesting rights depends on the legitimacy of the institution awarding the rights. If the institution awarding the rights does not legitimately hold the rights to start with then those receiving the rights will not have security of tenure. If there is uncertainty about an institution’s jurisdictional powers then its actions will be subject to question. Throughout most of the period jurisdictional issues were unsettled, diminishing the security and value of any rights allocations made by these governments.

The consequence of the flaws and uncertainties about the rights was that the rights holders did not act as if they had secure long-term tenure. Northern canners, in particular, did not act as if they had exclusive use rights. In the earliest days of fishing in the north canners colluded to limit the number of gillnet fishermen allocated to each, with the acquiescence of authorities. This was followed by the federal and provincial governments limiting the number of canneries in each of the northern areas. Canners could have taken advantage of these privileges and seized many of the benefits of exclusivity, particularly efficiency of harvesting and, possibly, conservation through limitation of effort. Canners’ opportunities could have been
further exploited by continuing to limit the number of fishermen or perhaps even shrinking the number allocated to each, thus reducing their costs.

But the opposite occurred, some canners broke the agreement by increasing their numbers of fishermen, others threatened to increase their numbers. The government then had to set the allocation of fishermen among the canners. As a group canners failed to continue to take advantage of the use rights awarded to them; rights holders did not act as if they had exclusive continuing ownership rights. Those who had joint access to the resource competed instead of cooperating. Even though the potential and actual profits were known, only late in the era did the federal government make an effort to capture the rent generated. Similarly those who were individually given exclusive rights for an area appeared to regard this primarily as a potential profit making or speculative opportunity. Those with privileges did not act responsibly.

A voluntary agreement among canners may be expecting too much. Scott (1993), in his review of fisheries self-government, states that self-governing groups can regulate how fishing is done but have not been successful in regulating the size of the total catch. Regulating the size of the total catch requires information on individual catches and an agreement on distribution, both of which are difficult to attain. Ostrom (1992) lists the beliefs that each member of a group must have in order to develop a common and jointly beneficial plan to use a common property resource: a belief that cooperation is better than individual action, a belief that there are known alternatives to individual action, a belief that other members of the group can be trusted to do what they say they will do, and a belief that the cost of joint decision making does not exceed the benefits. Canners, each voluntarily limiting the number of boats for a period of time, appear to have held these beliefs but not firmly enough for joint action to continue. Probably some did not believe that all would continue to do as they said. Leal (1996) has enumerated the characteristics of long-enduring community management systems: clearly defined boundaries for the resource and participants, established and binding rules, rules based on local conditions, resources for monitoring and enforcing the rules, mechanisms to resolve conflicts available, and rules not subject to change by government. For the northern canners in each district boundaries and rules were known and fit local conditions but within the group the resources for monitoring and enforcing the rules were inadequate and no mechanisms for resolving conflicts were available. There was also the threat that government would change the overall environment.

The lack of secure continuing property rights could be offset by providing fishermen and canners with alternative sources of supply. Having to rely on a single stream without security could tempt a rights holder to heavily discount future returns and increase current harvests to provide an adequate income or supply of fish. Providing several possible sources of supply would allow a fisherman or canner to provide for conservation while still acquiring an adequate supply of fish. The canner in the Bella Bella area, holding drag seine rights to a number of streams, fishing the stronger runs, allowing the weaker to increase, provides an example of the benefits of providing rights holders with alternatives.

Opposition to the rights

A third reason for the demise of the exclusive use privileges was the strong opposition of many to the rights. Gillnet fishermen were opposed to traps, arguing that the traps meant fewer fish for them. This argument had validity since, although the traps were established to compete with Americans for fish, the traps were no doubt taking some fish that would have been otherwise caught by Canadian fishermen. Gillnetters were successful in having traps on the northern boundary banned. Many of these rights were viewed as privileges for a favoured and politically connected few, a valid observation. Department officials were often asked to seek the approval of politicians before awarding trap and seine licences. In many cases these rights were valuable and the profits they generated were well-known and often viewed as unjustifiable, but little attempt was made to capture this resource rent. In some cases the rights were obtained for speculative purposes or to sub-let, with the possibility of profit for the holder of the rights.

SUMMARY AND CONCLUSIONS

As the salmon fishery expanded on the west coast of Canada fishery administrators searched for ways to effectively manage the fishery. Limited by the resources available to them, a lack of experience with new fishing methods and fishing dispersed over a remote coastline, little knowledge of the hundreds of stocks in their area, relatively primitive fishing techniques, and pressure from many in the industry, various forms of exclusive use rights were sometimes the only management instruments available. Exclusive area
privileges, limiting fishing licences in an area, and limiting the number of processing plants were among the types of exclusive use rights tried.

But the rights only lasted for a short time. The specific reasons for establishing the rights decreased in importance and new objectives for management of the fishery emerged. The early rights were not established to capture the benefits now suggested for exclusive use rights but were a response to the conditions of the day. Managers saw the allocation of certain exclusive use rights as a convenient and expedient way of discharging their responsibilities. Unfortunately, although the benefits to rights holders were known, little attempt was made to capture these benefits. Later, conservation goals were joined by the objective of providing employment, with the result that access to the fishery could not continue to be limited.

Also, the rights as then structured were flawed, lacking the characteristics of exclusivity, continuance, and transferability, which provide rights holders with incentives to operate efficiently and responsibly. Rights holders had little inducement to conserve the resource. The flaws in the rights were compounded by uncertainty about the relative jurisdictional responsibilities of the federal and provincial governments. Furthermore, the various forms of exclusive access were opposed by other fishermen, elected representatives, members of the public, and many government managers. The benefits mostly went to the rights holders, others were excluded. Practically no attempt was made by either the provincial or federal government to capture any economic rent generated as a result of issuing these exclusive use rights.

The continuance of any system of exclusive use rights is facilitated by the objectives and structure of the rights. Use rights structured with the principles of efficiency and equity will be more likely to continue than those not so structured.

REFERENCES
British Columbia Commissioner of Fisheries Report, 1902-1930.
Department of Marine and Fisheries and Department of Naval Service. 1900-1930. Annual Reports of the Fisheries Branch.
INDUSTRIAL EVOLUTION IN RESPONSE TO CHANGES IN THE DEMAND FOR
TRACEABILITY AND ASSURANCE:
A CASE STUDY OF CHILEAN SALMON AQUACULTURE

Tyler K. Olson and Keith R. Criddle
Utah State University,
Department of Economics, Logan UT 84322

ABSTRACT

The structure and organization of industries evolves over time in response to changes in the price and availability of inputs, changes in the demand for outputs and output attributes, and changes in technology. The growing demand for traceability and assurance is a change in the demand for credence attributes. Firms that are able to organize to provide traceability and assurance at low cost will, ceteris paribus, have an advantage. In recent years, many segments of the food and agribusiness industry have become more concentrated through horizontal or vertical integration within firms or within associations of firms (cooperatives). This paper explores changes to the relative competitiveness of vertically integrated firms and horizontally and vertically aligned cooperative associations in response to demand for traceability and assurance with respect to food safety, product quality, and credence attributes. The Chilean salmon aquaculture industry is used as a contextual example.

INTRODUCTION

Increased demand for traceability and assurance will affect the relative competitiveness of firms in markets such as the U.S., Japan, and E.U., which are evermore conscious of food safety, quality, and credence attributes related to labor, capital, and resource inputs to production, and the impact of production processes on the physical, biological, and human environment. Given the nature of tracing products or product attributes through the food chain, transaction costs will differ depending on industry and company structures and the nature of the information being transmitted. Thus, the effect of traceability on the relative competitiveness of firms will depend on their ability to efficiently organize and transfer information through the supply chain. Large vertically integrated firms that transfer information internally may or may not have a cost advantage over smaller non-integrated firms that bundle information and goods in market transactions.

As recently as 1995, the salmon aquaculture industry was, to a large degree, composed of many small independent firms: small farms, small feed suppliers, and small processors (Anderson 1995). Since then, salmon aquaculture has increasingly become the domain of horizontally and vertically integrated multinational firms (Tveterås 2004). Consolidation has been driven by increasing returns to scale in feed production, hatchery operations, grow-out facilities, processing, and distribution. In addition, total output has increased both in response to cost–savings associated with efficiencies of scale, cost savings associated with technology advances (Asche 1997), and cost savings associated with efficiencies of scope. In Chile, increased scope has come about through ownership, cooperation, and contracts. Positive agglomeration externalities often arise in regions where production is localized in the form of a cluster of interdependent firms (Tveterås 2002). For the past decade, the Chilean salmon industry has actively encouraged the development of just such a cluster.

2 Email: tko.olson@gmail.com
Chilean Salmon Aquaculture Industry

It is only in the last decade that Chile has emerged as a major supplier of farmed salmon and trout (Bjørndal and Aarland 1999). The Chilean salmon industry is concentrated in southern Chile, with hatchery operations in and around Lake Llanquihue, feed production in and around the cities of Osorno and Puerto Montt, grow-out operations around Chiloé Island, and processing facilities around the city of Puerto Montt and on Chiloé Island. Recently, grow-out and processing operations have extended increasingly into regions that are more southerly. The long coastal strip—approximately 1,700 kilometers—running from Region X through Region XII provides several natural advantages for hatcheries and salmon farms: abundant clean freshwater, cool clean seawater, low salinity, moderate currents, and fjords and inlets that shelter net-pens and associated farm structures from storm surges. Production by region for 2003 was 83% for Region X, 16% in Region XI, and 1% in Region XII (Sernapesca 2005).

The four salmonids farmed in Chile are Atlantic salmon, coho salmon, chinook salmon, and rainbow trout. Production of Atlantic salmon represents over 57% of harvest, nearly 50% of export volume, and near 60% of export value (Table 1).

Table 1. Harvest by species (metric tons).

<table>
<thead>
<tr>
<th>Year</th>
<th>Atlantic salmon</th>
<th>Coho salmon</th>
<th>Chinook salmon</th>
<th>Rainbow trout</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>29,182</td>
<td>25,177</td>
<td>859</td>
<td>22,257</td>
<td>77,475</td>
</tr>
<tr>
<td>1994</td>
<td>34,175</td>
<td>34,538</td>
<td>379</td>
<td>32,866</td>
<td>101,958</td>
</tr>
<tr>
<td>1995</td>
<td>54,250</td>
<td>44,037</td>
<td>371</td>
<td>42,719</td>
<td>141,377</td>
</tr>
<tr>
<td>1996</td>
<td>77,327</td>
<td>66,988</td>
<td>341</td>
<td>54,429</td>
<td>199,085</td>
</tr>
<tr>
<td>1997</td>
<td>96,675</td>
<td>73,408</td>
<td>738</td>
<td>77,110</td>
<td>247,931</td>
</tr>
<tr>
<td>1998</td>
<td>107,066</td>
<td>76,954</td>
<td>108</td>
<td>75,108</td>
<td>259,236</td>
</tr>
<tr>
<td>1999</td>
<td>103,242</td>
<td>76,324</td>
<td>208</td>
<td>50,414</td>
<td>230,188</td>
</tr>
<tr>
<td>2000</td>
<td>166,897</td>
<td>93,419</td>
<td>2,524</td>
<td>79,566</td>
<td>342,406</td>
</tr>
<tr>
<td>2001</td>
<td>253,850</td>
<td>136,870</td>
<td>3,807</td>
<td>109,895</td>
<td>504,422</td>
</tr>
<tr>
<td>2002</td>
<td>248,407</td>
<td>94,927</td>
<td>2,248</td>
<td>105,410</td>
<td>450,992</td>
</tr>
<tr>
<td>2003</td>
<td>280,301</td>
<td>91,797</td>
<td>1,526</td>
<td>114,607</td>
<td>488,231</td>
</tr>
</tbody>
</table>

Source: Sernapesca (2005).

Although initially comprised of small independent firms with heavy reliance on foreign technology and production inputs, the Chilean salmon aquaculture industry has evolved into a complex cluster of interdependent suppliers, producers, processors, distributors, and supporting entities. Clusters are regional concentrations of companies and institutions that compete but also cooperate (Porter 1990, 1998). The Chilean salmon cluster presents multiple levels of competition and cooperation. The cluster consists of a mix of small, medium, and large firms; some integrated vertically, horizontally, or in cooperatives; all interacting under the auspices of one encompassing association, SalmonChile.

Over half of all firms who participate in the nucleus of the value chain, from hatchery to processing, are forward or backward integrated. Feed inputs are the only source of supply that is integrated mainly within the largest salmon producers. Consolidation in feed production has resulted in a decline from 23 factories in 1992 to seven in 2003. Of those seven, two—Salmones Antártica S.A. and Cultivos Marinos Chiloé Ltda—are wholly vertically integrated with coordinated management (SalmonChile 2004). While Skretting Chile S.A., Ewos Chile S.A., and Salmofood S.A share ownership interests with particular farm operators, they, along with Biomar Chile and Alitec, also produce and sell feed to independent farm operators.

Over the past few years, consolidation has left 39.5% of export value concentrated among the top three producers and 70.3% of export value concentrated among the top nine producers (Table 2). These trends indicate increasing returns to scale; being big seems to offer advantages with respect to production, logistics, and marketing in the global salmon market.
Table 2. Main producers in the Chilean salmon industry.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Harvest Chile S.A./</td>
<td>216 $ million &amp; 15.0%</td>
<td>Vertically integrated, Dutch owned (Nutreco)</td>
</tr>
<tr>
<td>Stolt Sea Farm Chile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AquaChile / Aguas Claras S.A.</td>
<td>190 $ million &amp; 13.2%</td>
<td>Vertically integrated, Chilean owned</td>
</tr>
<tr>
<td>Salmons Mainstream S.A./</td>
<td>164 $ million &amp; 11.3%</td>
<td>Vertically integrated, Norwegian owned (Cermaq &amp; Fjord Seafood, merger pending)</td>
</tr>
<tr>
<td>Fjord Seafood Chile S.A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pesquera Camanchaca S.A.</td>
<td>100 $ million &amp; 6.9%</td>
<td>Vertically integrated, Chilean owned</td>
</tr>
<tr>
<td>Salmons Multiexport Ltda.</td>
<td>95 $ million &amp; 6.6%</td>
<td>Vertically integrated, Chilean owned</td>
</tr>
<tr>
<td>Cultivos Marinos Chiloé S.A.</td>
<td>75 $ million &amp; 5.2%</td>
<td>Vertically integrated with coordinated management, Chilean owned</td>
</tr>
<tr>
<td>Pesquera Los Fiordos Ltda.</td>
<td>66 $ million &amp; 4.6%</td>
<td>Vertically integrated, Chilean owned (Agrosuper)</td>
</tr>
<tr>
<td>Salmons Antártica S.A.</td>
<td>64 $ million &amp; 4.4%</td>
<td>Vertically integrated with coordinated management, Japanese owned (Nippon Suisan)</td>
</tr>
<tr>
<td>Pesca Chile S.A.</td>
<td>44 $ million &amp; 3.1%</td>
<td>Vertically integrated, Spanish owned (Pescanova)</td>
</tr>
<tr>
<td>Other Exporters</td>
<td>427 $ million &amp; 29.7%</td>
<td></td>
</tr>
</tbody>
</table>

Sources: Revista Aqua (2005); Montero (2004); Aqua al Día (2005).

Information Transfer through the Production Chain

The amount, accuracy, and verifiability of information recorded are choices for producers trying to satisfy demands of food safety and traceability; more information allows for more detailed traceability, but can be costly to maintain and could be an asset or liability in the event of legal action against the firm. Information costs increase when it becomes necessary to maintain a verifiable trail of information about the genetic characteristic of broodstock or the use of organic feeds. These types of attributes are difficult to detect through sampling the fish and must instead be verified by auditable records that document that batches with differing attributes are not co-mingled or provided inappropriate feeds or pharmaceuticals at anytime from egg-production through grow-out.

The credibility of a traceability system could depend on whether assurance is provided by the firm, by a government agency, or by an independent for-profit firm or nonprofit association. Compromising the integrity of a traceability system for credence attributes could be as simple as the inadvertent mixing of fish from different cages, inaccuracies in information transferred from the hatchery, or mislabeling of feeds or human error in the application of feeds and pharmaceuticals. Implementing traceability systems means solving a variety of complex problems that differ depending on company structure (vertically integrated, etc.), market requirements, and resources available. Any credible traceability system must address the transfer of information through the three stages of production (hatchery/nursery, grow-out, and processing) and the transfer of information regarding feed and other inputs used in each of the production stages. In the next sections, we will discuss the three stages of fish production and feed production to illustrate the type of information that would need to be transferred and potential vulnerabilities that could compromise the integrity of a traceability system.

Hatchery/Nursery Operations

The first stage of production—spawning, egg fertilization, incubation, and development and growth from egg to smolt is carried out in hatchery facilities located in or adjacent to a source of high-quality fresh water. Two production systems and three modes of operation are currently used for hatchery/nursery operations in Chile. The two production systems are lake-based tank and pen systems, and stream-based tank systems. The three operation modes are smolt production from hatchery-provided eggs for farms owned by the same company; smolt production from hatchery-provided eggs for farms owned by unrelated companies; and, smolt production for farms owned by unrelated companies, using eggs provided by those farms.
Piscicultura Rió de la Plata, located near Tegualda, about 30 miles northwest of Puerto Montt, Chile is a typical of stream-based tank system hatchery. The hatchery is designed for batch production in independent tanks. Because each tank is independent, it is relatively simple to isolate disease and to produce multiple verifiably distinct genetic strains or feed regimes. Piscicultura Rió de la Plata produces about 600 million smolts per year. Of these, 93% are produced for farms owned by its parent, the Camanchaca Fishing Company. The remaining smolts are produced for sale to farms owned by other companies. While most of the smolts sold to other farms are grown from eggs produced by the Camanchaca Fishing Company, some smolts are produced using eggs provided from broodstock maintained by contracting farms. In November 2004, about 10% of the smolts in production at Piscicultura Rió de la Plata were being maintained on certified organic feeds. In March 2005, Camanchaca Inc. introduced "Pier 33 Organic Salmon," certified by Naturland, a leading organic certifier (The Wave 2005a).

Phase I begins with broodstock whose eggs and roe are stripped and mixed together for fertilization. Eyed eggs (245-510 degree days for Atlantic salmon and 175-370 degree days for rainbow trout) are very resistant to handling stress and can be shipped great distances. Consequently, although Chilean-spawned eggs were available as early as 1980, Chilean hatcheries remained largely dependent on fertilized eggs from Norwegian broodstock through the 1990s. Since 2000, Chilean egg production has increased dramatically; as of September 2004, over 90% of all eggs used in Chilean hatcheries were produced from local broodstock (Aqua al Día 2004). The increase in local egg production has resulted from improved understanding of the role of light (photoperiod) and temperature (thermal) in the timing and rate of egg development and growth rates in fry. This knowledge has permitted greater control over growth rates and allows smolts to be produced in any month (Mundo Acuícola 2004). The Atlantic salmon eggs hatch after about 510 degree days (approximately 64 days at 8°C) as alevins or sac-fry. After 290 degree days (approximately 36 days at 8°C), the sac-fry begin feeding and are referred to as fry or parr (Edwards 1978). Rainbow trout eggs hatch after about 370 degree days (approximately 46 days at 8°C) months and begin feeding after 150 degree days (approximately 19 days at 8°C) after which they are referred to as fry or fingerlings (Edwards 1978). Once Atlantic salmon parr reach 30-60 g, they undergo physiological changes, smoltification, that prepares them for entering seawater. Rainbow trout fingerlings can be transferred to saltwater at about 50 g.

The principle environmental concern with hatchery facilities is nutrient enrichment of effluent water. While water re-circulation systems are increasingly common in developed nations, they are not yet common in Chile. Indeed, effluents are often discharged without treatment in lake-based tank and pen systems and in some stream-based systems. The Piscicultura Rió de la Plata facility represents one of the newer hatcheries that are being held to effluent discharge quality standards. The standards require that tailwaters not exceed the level of BOD (biological oxygen demand) of the source water and that dissolved oxygen levels in the tailwaters match or exceed levels in the source water. At the Piscicultura Rió de la Plata facility, these effluent standards are met with a combination of physical screens, biofiltration, and paddlewheel aeration.

Information that may be important for traceability and assurance regarding this stage of production includes information about broodstock genetics, information about feed and prophylactic regimens applied to broodstock, eggs, sac-fry, fry, parr, and fingerlings. Information about the quality of water inflow and effluent discharges, the status of native aquatic fauna in source and receiving waters may be needed to demonstrate environmental sustainability and information about employee work-conditions, compensation and demographics may be needed to demonstrate social responsibility.

Grow-out

In the second stage of production, smolts are transferred to marine cultivation centers for grow-out. The grow-out phase takes 8 to 18 months depending on species and water temperature. Water temperatures vary by season, with cooler winter (June, July, and August) temperatures slowing the rate of growth. The time required for grow-out is also dependent on feeding rates and target slaughter size. The Chilean government regulates the size and placement of fish farm sites and requires concession owners to report monthly stock and harvest volumes. Long-term leases for farm sites are allocated on a first-come first-serve basis.
The cultivation phase accounts for 51.6% of the total cost of bringing salmon to the market, with feed costs, alone, accounting for 60% and 70% of farm level costs (SalmonChile 2004). High feed cost are due to dependence on high cost inputs (medications, vitamins, pigments, fishmeal and other proteins, fish oil and fats, etc.). Recent cost savings have arisen from the substitution of vegetable fats and proteins for higher-cost fish-based fats and proteins. Feed is delivered to each pen using hopper-blower systems, similar to systems used in the installation of loose cellulose insulation. Some farms use a portable hopper-blower system and carry the bags of feed to the hopper. Other farms have a system of valved plastic pipes that distribute feed from a central hopper/blower in the feed shed. In either case, feed delivery to individual pens is varied according to the number and average size of fish, season, and water temperature. Feeding is monitored using underwater cameras to ensure that feed is only delivered if the fish are actively feeding and that feed delivery is continued until active feeding has ceased.

Farmed salmon are subject to viral, fungal, and bacterial diseases. Until recently, most of these diseases were treated with antibiotics. However, some of the most effective antibiotics for fish diseases are not approved for human consumption. Nevertheless, many of these antibiotics continue to be used in Chile and elsewhere. In recent years, importing nations have become more rigorous in testing for the presence of prohibited antibiotics and rejecting shipments found to exceed established limits. Fish farmers have developed better understanding of the rate at which traces of antibiotics are cleared from fish and labs have proliferated in salmon-producing regions to test the level of antibiotics in samples before harvesting and shipment. While these measures have reduced the number of shipments found to exceed established limits, there remain concerns about the heavy use of antibiotics in finfish aquaculture in general and salmon/trout culture in particular. These concerns have spurred interest in the development of vaccines. For example, in 2003, the majority of on-farm mortality resulted from rickettsia, a bacterial liver disease that makes the fish lethargic and slows growth. A vaccine for rickettsia was developed in late 2003 and became widely available in 2004. Fish are siphoned from the pen, defective fish are culled, and the remaining fish are segregated by size, anesthetized, and vaccinated.

To reduce the incidence of disease and to ensure that penned fish receive sufficient oxygen, farm managers must maintain good environmental conditions. Excessive feeding or stock rates that exceed site capacity could lead to a concentration of organic wastes and localized eutrophication that could reduce the concentration of dissolved oxygen and increase the density of undesirable microorganisms. Even with careful feed management, net pens must be cleaned of algae and fouling organisms about once every ten days to avoid reductions in water exchange that increase the risk of oxygen deprivation.

Another suite of issues arise in organic production. Without pharmaceuticals and feed supplements, it is necessary to reduce stocking densities and increase monitoring and handling of fish, thus the cost of organic production is higher than the cost of traditional production. The premium consumers are willing to pay for organic salmon would have to be substantial to offset the cost of higher mortality, more expensive feed, and increased labor (Sutherland 2001). Although Chern et al. (2002) find that consumers in the United States, Norway, Japan, and Taiwan are willing to pay premiums of up to 50% for non-GM salmon, their estimate should be viewed with caution because it does not reflect differences in the relationship between marginal willingness-to-pay and the volume of certified non-GM salmon made available to the market. It should be noted that organic producers may pose adverse externalities for other producers by increasing the reservoir of un-immunized fish that may increase the likelihood of disease throughout a region.

In addition to carrying forward information from hatchery/nursery operations (broodstock genetics, feed and prophylactic regimens applied to broodstock, eggs, sac-fry, fry, parr, and fingerlings, etc.), traceability and assurance systems must document feed and prophylactic regimens applied during the grow-out phase, demonstration that there in no mixing of fish undergoing different regimens or mixing of feeds, medications, or colorants delivered fish being grown under different regimens. Information about the quality of water inflow and effluent discharges, the status of native aquatic fauna in source and receiving waters may be needed to demonstrate environmental sustainability and information about employee work-conditions, compensation and demographics may be needed to demonstrate social responsibility.

Processing and Distribution

When the salmon or trout reach market size—usually 1 kilo for pan size trout, 2.8-3 kilo for whole trout or coho salmon, and 4 to 5 kilos for salmon and trout to be cut into steaks or filleted—they are readied for
processing. Although growth rates can be influenced by feeding rates and feed composition, and harvest size is a choice variable, in practice, the harvest window is dictated by broodstock genetics and the date that smolts are stocked in the net-pens. While a continuous product flow from hatchery to cultivation center and on to processing and distribution would be ideal, the vagaries of supply and demand can upset this delicate balance, sometimes leaving seawater pens empty or filled with aged and oversized fish. In Chile, the production of Atlantic salmon and rainbow trout has been stabilized to yield near constant output throughout the year. In contrast, production of coho and chinook salmon remains highly seasonal with peak output in November through January, a season in which there is very little wild production to compete against.

Chile's distance from North American, European, and Asian markets and the perishable character of salmon and trout are disadvantageous. However, Chile's productive capacity and low production costs offset this disadvantage and have allowed Chile to position itself as the foremost producer of value-added salmon and trout products. In 2003, Chilean salmon and trout exports exceeded one billion dollars, 67% of those exports were value-added products (SalmonChile 2004). One of the limits to profitability and market development lies in the difficulty of pairing airfreight imports with airfreight exports. Because most Chilean farmed salmon is transported to market by air, there is relatively high payload for outbound freight. Chile has a relative advantage in foreign markets that produce high volume exports for airfreight into Chilean markets. In foreign markets that do not produce goods that are in high demand in Chile, the transportation costs for salmon include the cost of deadhead return flights.

Several channels are used in the distribution of Chilean salmon: sales to wholesale distributors; sales to institutional buyers, retailers and food service establishments; and direct sales to end consumers. Each of these channels may require unique traceability and assurance information. Barcodes and tracking numbers provide for rapid and transparent access to information for food safety recalls or for accessing production information. The principle challenges for traceability and assurance at the processing and distribution stages have to do with conservation of information from the hatchery and grow-out stages. There must be a verifiable flow of information with the fish as it is processed for consumption and distributed to end markets. In addition, there may be demand for information about the environmental impacts of processing operations and waste discharges and about employee work-conditions, compensation and demographics.

**Feed Industry**

Because feed is the largest component of farm level production costs for salmon and trout, many producers coordinate with corporate owned yet separately managed feed companies, or are part of a fully integrated feed manufacturing—fish farming operation. Variable supplies of key inputs, fishmeal and fish oil also create incentive for further upstream coordination. Feed production is highly concentrated, both vertically and horizontally. Consolidation in feed production has resulted in a decline from 23 factories in 1992 to seven in 2003. Of those seven, two—Salmones Antártica S.A. and Cultivos Marinos Chiloé Ltda—are wholly vertically integrated with coordinated management (SalmonChile 2004). While Skretting Chile S.A., Ewos Chile S.A., and Salmofood S.A share ownership interests with particular farm operators, they, along with Biomar Chile and Alitec also produce and sell feed to independent farm operators.

The seven factories produce different sizes of pelletized feeds formulated to meet the dietary requirements of trout and salmon fry, smolts, and maturing fish, medicated feeds, organic feeds, feeds with and without colorants. Because nutrients and vitamins included in the feeds are not stable for extended periods at ambient temperatures, most feed is produced near the fish farms where it will be used and very little feed is shipped over long distances. The high cost of feed results from dependence on high cost inputs (medications, vitamins, pigments, fishmeal and other proteins, fish oil and fats, etc.).

Fishmeal prices are highly volatile and futures markets are not well established, so it is difficult for feed producers to secure long-term contracts for fishmeal. The volatility of fishmeal prices is largely due to fluctuations in fishmeal supply that arise from natural variation in the abundance of wild stocks of the fish species harvested as inputs into fishmeal. The primary sources of fishmeal are the capture-fisheries for herrings, sardines, and anchovies. The largest of these fisheries is the Peruvian-Ecuadorian-Chilean fishery for anchoveta (Engraulis ringens). While this fishery is often the world's largest in capture fishery with landings in excess of 10 million metric tons, population fluctuations driven by changes in nutrient availability associated with El Niño-Southern Oscillation can lead to order-of-magnitude swings in
abundance and landings. Thus, even though Chilean feed producers have an advantage of being close to a key source of fishmeal, volatility in the availability and price of fishmeal has provided strong incentive to develop feed formulations that are less dependent on fishmeal. However, diversifying towards vegetable proteins would mean increased difficulty and complexity of providing traceability and assurance. The more inputs used in feed production, the more breadth and depth of information will be required. Extending traceability to include feed inputs (fishmeal, fish oil, nutritional supplements, medications, grains, or vegetable proteins) will increase the complexity and cost of ensuring traceable product and quality assurance. Based on this, firms may choose to organize production (e.g., integrate upstream into vegetable production) in different ways to achieve a desired level of traceability and assurance.

Markets for Salmon

Chilean salmon and trout exports for 2004 have increased in volume and value when compared to exports for the same period in 2003 (Table 3). In terms of value, the largest markets for Chilean salmon are the U.S. and Japan. Other important markets include Germany, Brazil, France and Thailand. Improved trade relations with developing markets have helped increase the share of Chilean salmon sold in China, Israel, Russia, South Korea, Singapore and other nations.

Table 3. Main markets, export quantity and value (2003 and 2004).

<table>
<thead>
<tr>
<th>Market</th>
<th>Quantity (net tons)</th>
<th>Value (millions $U.S. FOB)</th>
<th>Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>117,142</td>
<td>124,052</td>
<td>543,690</td>
</tr>
<tr>
<td>Japan</td>
<td>119,075</td>
<td>154,283</td>
<td>427,066</td>
</tr>
<tr>
<td>European Union</td>
<td>15,340</td>
<td>24,084</td>
<td>60,574</td>
</tr>
<tr>
<td>Latin America</td>
<td>16,840</td>
<td>22,957</td>
<td>55,926</td>
</tr>
<tr>
<td>Other</td>
<td>17,449</td>
<td>29,360</td>
<td>60,172</td>
</tr>
<tr>
<td>Total</td>
<td>285,846</td>
<td>354,736</td>
<td>1,147,428</td>
</tr>
</tbody>
</table>


Asche, Bjørndal, and Young (2001) note that increases in production volume have depressed prices in most markets. While technology has allowed production cost savings to keep pace with declining product prices, Guttormsen (2002) reports that salmon farms, especially in Norway, have reached a point where there is limited potential for additional substitution among inputs. Because exchange rates fluctuate through time and because inputs are purchased in local markets while products are sold in foreign markets, FOB prices in U.S. dollars do not accurately reflect the actual value of revenues received by Chilean producers. It becomes evident that when prices are expressed in Chilean pesos, Chilean producers have benefited from an average 3.4% depreciation over the past 15 years. To understand changes in the value of revenues over time, it is important to adjust for inflation. Over the past 15 years, annual wholesale price inflation has averaged 10.5% in Chile. From 1990 through 2004, the average real price of Chilean Atlantic salmon has declined by an average of 4% per year; the average real price of Chilean rainbow trout has declined by an average of 4.8% per year; and, the average real price of Chilean coho salmon has declined by average of 7.9% per year. Average real FOB prices for Chilean salmon and trout (pesos/kg) are represented in Figure 1.


---

3 The 95% confidence interval for the estimated average rate of depreciation is 3.4%±0.55%.
4 The 95% confidence interval for the estimated average rate of wholesale price inflation is 10.5%±2.1%.
5 The 95% confidence interval for the estimated decline in the average real price is 4.0%±1.6% for Chilean Atlantic salmon, 4.8%±4.5% for Chilean rainbow trout, and 7.9%±4.4% for Chilean coho salmon.
Atlantic and coho salmon are close substitutes in fresh and frozen markets in the United States, E.U., and Japan. As world prices for salmon have declined with the expansion of farmed production, the capture fisheries have been thrown into financial disarray that has led to bankruptcy and cessation of fishing by those least able to restructure to reduce their harvesting costs.

![Graph showing average real FOB prices for Chilean salmon and trout (pesos/kg), 2004 base year.](image)

**Figure 1.** Average real FOB prices for Chilean salmon and trout (pesos/kg), 2004 base year.

**Production Costs**

Salmon producers have generally separated their activities into fresh water or smolt production, sea farming operations, processing, and sales. The most recent estimates of the cost share of each of these production stages are reported in Table 4.

Activities generating the most significant costs for farming operations are feed and feed pigments (69.7%) and labor to administer feed (11.6%). The most costly activities for processing operations are labor (63.5%) and packaging (21.2%). Processing labor costs are high primarily because pin bones are too fine for machine removal. It is surprising that marketing costs (sales costs) are such a small share (0.5%) of total production and distribution costs. In contrast, the U.S. broiler industry (e.g., Tyson Foods, Pilgrims Pride, Perdue, Foster, Gold Kist, etc.), which like integrated salmon aquaculture operations in Chile, controls the entire value-chain from feed input through end-consumer brands, spends substantially more.6

Increased consolidation among vertically integrated salmon producers could increase the resources available for as well as potential benefits of investment in own-brand development and marketing to end-consumers. Implementation of traceability and assurance systems capable of documenting assertions about measurable characteristics of end products and credence attributes regarding production inputs and processes will create the opportunity for marketing to consumers who are willing to pay a premium for particular quality characteristics and credence attributes. One advantage for larger producers with multiple farms is that natural variations in their output caused by lags in the production process can be smoothed by staggering production across multiple farms. For large producers, fluctuations in output can be a small percentage of their total output and it is relatively easy to maintain brand awareness. For small producers, the production cycle results in intervals when product is available and intervals when it is not; maintaining brand awareness becomes difficult in such an environment (Tveterås and Asche 2004). As a whole, the industry should benefit from increased emphasis on understanding the end-consumer and establishing an international presence through foreign sales offices (Hernández 2004). However, part of the problem with advertising expenditures for salmon is that advertising benefits all producers whether

---

6 In August 2004, Tyson Foods launched a $75 million campaign for poultry, beef, and pork (Tyson Foods 2004). Although the largest private label poultry producer, Gold Kist, does little consumer advertising, their total marketing budget is over $2 million (Moore 2005).
they do or do not help pay the cost (Kinnucan and Myrland 2001, 2002, 2003; Myrland and Kinnucan 2001; Myrland et al. 2004).

**INDUSTRIAL EVOLUTION AND INDUSTRY STRUCTURE**

The structure and organization of industries change over time in response to changes in input and output markets and changes in technology. Firms can thrive or founder as circumstances change, either because they had the good fortune to be pre-adapted to the new circumstances or because they have chosen to position themselves strategically in anticipation of the new circumstances. That is, firms and industries may evolve through time under the influence of "Darwinian" natural selection—survival of the fittest, or "Lamarkian" transferal of acquired characteristics. When consumer preferences change, when new physical or organizational technologies emerge, when the cost of inputs change, firms and industries will thrive or fail because of the suitability of pre-existent inherent characteristics or because of their adaptive capabilities. In other words, a firm or industry may evolve consciously or randomly.

**Table 4.** Cost components for Chilean salmon production (2003).

<table>
<thead>
<tr>
<th>Hatchery/Nursery Operations</th>
<th>% of Total Cost</th>
<th>% of Cost by Stage</th>
<th>Farming Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Feed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pigments</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Manual labor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External services</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Other costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Other costs of grow-out</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Subtotal of Farming Operations</strong></td>
</tr>
</tbody>
</table>

| Processing Plant            |                |                  | Manual labor       |
|                             |                |                  | 12.0               |
|                             |                |                  | Packaging materials|
|                             |                |                  | 4.0                |
|                             |                |                  | Energy             |
|                             |                |                  | 0.9                |
|                             |                |                  | Maintenance and other costs |
|                             |                |                  | 2.0                |
|                             |                |                  | **Subtotal of Processing Cost** | 18.9 | 100.0 |

| Transport and Sales         |                |                  | Ground freight     |
|                             |                |                  | 1.5                |
|                             |                |                  | International airfreight |
|                             |                |                  | 13.0               |
|                             |                |                  | International ocean freight |
|                             |                |                  | 3.0                |
|                             |                |                  | Cool and frozen storage |
|                             |                |                  | 0.5                |
|                             |                |                  | Sales costs        |
|                             |                |                  | 0.5                |
|                             |                |                  | **Subtotal of Transport and Sales Costs** | 18.5 | 100.0 |

<table>
<thead>
<tr>
<th>Administrative and Financing Costs</th>
<th>8.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Production Cost</td>
<td>100.0</td>
</tr>
</tbody>
</table>


The rise of consumer and political demand for traceability and assurance with respect to food safety, product quality, and credence attributes represents a new competitive pressure on firms and industries. Some firms and organizational structures, by happenstance or foresight, are pre-adapted to satisfy the demand for traceability and assurance. Firms that are not pre-adapted must either acquire infrastructure and organization to support traceability and assurance or surrender real and potential market share in markets that demand traceability and assurance. Out of rational self-interest, firm owners can be expected to maximize some objective: maximizing profits, manager-utility, market share, growth rate, shareholder value, etc. Other goals of the firm may include minimizing transaction costs (Coase 1937), or the cost of principal-agent incentives (Alchian and Demsetz, 1972). Firms or organizations that are successful further the collective interest of their members—benefiting from the synergies created.
Recent Evolution in the Meat Industries

In recent years, many segments of the food and agribusiness industry have become more concentrated through horizontal or vertical integration within firms or through the formation of cooperatives or other associations. The vertical and horizontal consolidation taking place in the salmon aquaculture industry resembles changes that have already taken place in the poultry and pork industries, and to a lesser degree in beef. Tvetenás and Kvaløy (2004) assert that potential incentives for increased consolidation in the salmon aquaculture industry are in part due to food safety, food quality, and environmental effects. Consequently, an examination of the evolution of poultry, pork, and beef industries and their experience in adapting to heightened concerns about food safety, and demands for traceability and assurance may provide insight into the types of organizational structures that are likely to be successful for the salmon aquaculture industry.

The U.S. pork industry has recently undergone a transformation in its structural organization from 11% of production under contract or vertical integration in 1993 to 64% in 1999 (Preckel et al. 2004). Preckel et al. (2004) suggest that a primary reason for the emergence of vertical integration in the pork industry is that vertical integration provides improved communication to suppliers about animal characteristics valued by the market. The demand for traceability and assurance can be motivated as a demand for information about latent product attributes; information that some, but not necessarily all, consumers want. Implementing traceability systems may provide a mechanism for improved signaling of these product attributes. Reimer (2004) suggests that with increased demand for traceability and assurance, packers are more likely to integrate upstream if producers exhibit low investment productivity. Producers with low investment productivity are less able to access capital needed to invest in new technologies or traceability software and assurance systems. In addition, given their proximity to and need to communicate with consumers and retailers, packers are on the front line with respect to liability for food safety, environmental, and animal welfare concerns. Exercising direct control of upstream production is one of managing risk associated with liability for food safety, environmental, and animal welfare concerns. In addition, if packers consolidate horizontally, producers will lose market power and have even less ability to access capital needed to invest in traceability software and assurance systems.

The recent evolution of the pork industry suggests some possible changes in the Chilean salmon industry. For example, it can be expected that independent salmon farmers are at a relative disadvantage in negotiations with processors because processors are relatively few in number and control some production capacity through ownership or contract. Similarly, it can be expected that independent salmon farmers are at a relative disadvantage in negotiations with feed-suppliers because feed-suppliers are relatively few in number and control some production capacity through ownership or contract. Moreover, because many of the processors and feed-suppliers are controlled by the same parent firms, and because those parent firms also control production facilities, it can be expected that independent farmers have relatively little power. The perishable nature of feed inputs and farm output also shift market power to feed-suppliers who have many customers and away from independent farmers who cannot stockpile feeds, and to processors who can rely on their own farms and many other independent farmers for process-ready fish and away from farmers who have a perishable product and a limited ability to transport their product to any but the closest processors.

Producers would be likely to integrate upstream when hatcheries show low investment productivity and if liability is high. In the case of producers, it is expected that horizontal integration will be used as a risk management strategy because it is unlikely that multiple geographically distributed production facilities would suffer simultaneous "crop" failures. Indeed, the strategy of horizontal consolidation and geographical diversification is evidenced by recent mergers and acquisitions. Under Nutreco's ownership, Marine Harvest and Stolt Sea Farms produce upwards of 20% of global farmed salmon with facilities in Norway, Chile, Canada, the Faroe Islands and other locations. As supply relationships increasingly bypass the middleman, it becomes evermore costly to fail to deliver product at an expected time; processors can increase the likelihood of satisfying contractual obligations to wholesalers and retailers by taking steps to ensure that supply from producers is not interrupted. Although processors could ensure the scheduling of deliveries through ownership or contract, the advantage of ownership is that it reduces the possibility that a producer might renege on the contract.

Like the pork industry, most poultry slaughter firms (e.g., Tyson Foods or Perdue) have integrated ownership throughout the chain and detailed contracts with growers. Ollinger, MacDonald, and Madison
(2005) analyzed structural change in poultry industries and found that from 1967-1992 the mean plant size increased sixfold for turkey processors and nearly tripled for chicken processors. However, they suggest that the presence of negative cost externalities places limits on further expansion of processing scale economies. As processing capacity has increased, processors have faced increased transportation costs because of limitations placed on the scale and density of poultry production facilities due to concerns about manure disposal and animal and human health. Food safety is also an issue, if authorities purposefully limit plant size for accurate inspections, or in one case, insufficient water supply for washing carcass-restrained plant size (Ollinger, McDonald and Madison 2005).

These types of constraints also apply to processors and producers of Chilean salmon. For instance, environmental regulations limit the size and concentration of farm sites. It is important to locate processing facilities near concentrated producer areas to exploit economies of scale and scope. Processors can increase the number of products, increase further processing, expand product mix to include other fish or seafood, and expand the number of international markets into which they sell. With greater consolidation, the ability to control food safety would likely increase, but increasing plant size and product mix might increase the cost of traceability and assurance due to differing product requirements and the number distant/distinct suppliers.

In a recent review of the effects the United State's National Animal Identification (NAIS) will have on the cattle market structure, Mark (2004) suggests that competitive effects will depend on a firm's size and position in the marketing chain; smaller cow-calf producers, stockers, and feed yards will likely be exposed to the greatest structural changes as economies of size, price discounts/premiums relayed from downstream feed yards and packers, liability protection, and possible gains with increased management information influence adaptive capability. Productivity or marketing gains could come from improved genetic tracking where consumers demand characteristics verifiable through genetics.

In the case of salmon, if traits such as "not genetically modified" (non-GM) are valued by retailers, or consumers, traceability and assurance systems which trace and verify breeding and genetics could be important for maintaining market share. With increased costs of transferring this additional information, it is advantageous to reduce the number of transactions between input sources, producers, processors, and customers. Producers and processors who can minimize the number of intermediate transactions will have lower costs for animal identification and traceback.

The NAIS system has received considerable debate over whether it should be voluntary or mandatory. Imposing a traceability system through political processes rather than allowing it to emerge in response to consumer demand expressed through the market, imposes costs on those who do not value traceability and subsidizes those who do. While debate over whether implementation of traceability and assurance programs could or should be left to the market or mandated by government may be interesting, it is, in large measure, moot; requirements for traceability and assurance are being implemented by governments in Chile's principal export markets. Tothova and Oehmke (2004) note that cross-country differences in consumer preferences and regulatory approaches have polarized markets into clubs (e.g., those such as the United States, that accept GM foods and those such as the E.U. that do not). The polarization of markets increases the challenges that firms and industries face. Should they specialize in serving the consumer preferences and regulations of a single trade partner or generalize to meet the divergent consumer preferences and regulations of multiple partners? In order to participate in multiple markets, producers may need to implement parallel production and traceability systems—to be used for example in simultaneously servicing separate GM and GM-free markets.

Cooperation vs. Competition

The Chilean salmon industry exhibits diverse patterns of governance and ownership. Ownership within the Chilean salmon industry includes large multinational firms, a large number of medium-to-large-sized domestic firms, and a few smaller firms. The initial success of the Chilean salmon industry came from small producers emerging in response to international demand. As the scale of production increased, firms increased their size and began to integrate. Under the umbrella of SalmonChile, these fragmented producers began to share information, input sources, and output markets, consciously evolving into an industrial cluster. The current pattern of inter-business relations is quasi-hierarchic, with cooperative efforts in research and development, foodstuffs, vaccines, etc., and hierarchic relations between large
firms and the small and medium sized suppliers. As vertical and horizontal consolidation takes place, the benefits of cooperation may decline.

Bontems and Fulton (2004) note that "privately held information is valuable to those that posses it, while it imposes a cost on those that do not." This, they suggest, can provide cooperatives with an organizational cost advantage over for-profit firms when privately held information is important to the success of the organization. If a Chilean cooperative held private information—related to traceability and assurance—that was important to the objectives of its members, it could have an organizational and cost advantage over the independent firms operating outside that cooperative. For instance, a cooperative in the Chilean salmon industry could share the cost of knowledge intensive software requisite to ensuring traceable product. One positive externality might be the development of consumer trust towards the firm or cooperative able to meet requirements of either regulation or consumer preferences for credence attributes.

Weaver and Chin (2004) suggest that collective bargaining can increase producer profits when they face individual processors that might exercise monopsony power. Collective bargaining through producer cooperatives enables farmers to capture margins that otherwise would go to processors and can maximize total surplus. If market power is held by one intermediate stage, e.g., processing, coordination through supply contracts may be better than coordination through open markets (Asirvatham and Bhuyan 2004).

Tveterås (2004) suggests that long-term contracts could be a viable alternative to vertical integration for salmon farmers and processors. Similarly, it may be advantageous for independent farm operators to organize as an input-buying cooperative to offset the market power associated with the high degree of concentration in feed production. To date, feed manufacturers have exercised considerable power over smaller salmon producers, who often enter loan contracts to be repaid after harvest, and by so doing, give feed suppliers partial influence over production and marketing. Because implementation of a traceability system requires transmission of information from each stage of production to the next, and because the development and transmission of information is costly, it can be anticipated that the burden of the cost of traceability systems will be distributed between stages of production according to their relative market power.

With respect to food safety, or product recalls, the collective industry image is at stake; therefore, a cooperative effort would be expected largely focused on painting a picture of transparency and quality assurance to buyers and consumers. This effort is evident with SalmonChile’s new Integrated Management System (SIGES) created in response to emerging international requirements for safety, security, social responsibility, and sustainable production. Fourteen companies, including several of the largest multinationals, have enrolled so far. In order to obtain the SalmonChile-SIGES certification, companies must commit to adhere to otherwise voluntary protocols (e.g., information system software, ISO, OSHA, HACCP, best practice guidelines, etc.). A software package from Chilessoft S.A. is available for tracking records and product, but is not required for SIGES certification; companies can employ other electronic record systems. Although feed inputs have not yet been included in SIGES, efforts are underway to expand SIGES to include feed inputs. One problem, which has been identified in other production processes (e.g., pork, beef, etc.), is maintaining traceability to the farm level (Bailey, Jones, and Dickinson 2002). It appears that the depth of traceability required by SIGES addresses this problem.

These collective efforts are not limited to one industry; a workshop organized by SOTA brought representatives from the Chilean and Canadian salmon industries and from the U.S. Food Marketing Institute (FMI) to discuss harmonization of standards. The plan is to integrate the Chilean (SIGES) and Canadian systems with the Safe Quality Food (SQF) program from FMI. Interestingly, this system would not include Norwegian, U.K., and Faroe Island producers. This materializes into using the attributes certified by SQF (including quality, environment, safety, and sustainability) to benefit SOTA member producers. By using common standards and certification schemes, SOTA members (Chile, United States, and Canada) should be able to benefit by promoting a clean, dependable, and sustainable industry while also intensifying advertising for additional certified attributes.

If some firms wish to convey additional information about quality or credence attributes beyond the basic information conveyed through SIGES it may be advantageous to develop a stand-alone alternative rather than support SIGES and a parallel system for these other attributes. For example, a retailer in the United States selling organic salmon from Chile could not rely on SIGES to verify that inputs and processes complied with organic production standards. Since SalmonChile does not certify organic, a separate or
A combination traceability chain would need to be used to ensure that certified organic product is not mingled with uncertified product between being shipped from the producer and arriving at the retailer. Thus, a producer seeking to differentiate a product based on credence attributes would likely incur costs greater than costs incurred by participants in SIGES. If several producers desired to market the same attribute, they might be able to cooperatively arrange and share the cost of certification, inspections, etc. Unless premiums are sufficiently high, producers might be discouraged from creating differentiated products and investing in separate traceability systems. The size and type of firm could also influence this decision. Where vertically integrated firms are responsible for several stages of recordkeeping and information transfer, single stage firms are less so and could have lower transaction costs. Furthermore, the largest integrated and single stage firms should have larger capital resources for investment and specialization of traceability and assurance systems from which information management can exploit gains to productivity and marketing.

TRACEABILITY AND ASSURANCE

While traceability in the E.U. and United States is driven by consumer demand and food safety concerns, traceability in Chile is driven by a desire to maintain access to the E.U. and North American markets. While the idea of traceability is rather simple, execution and implementation is complex. The seafood industry—including the salmon aquaculture industry—has not yet achieved the level of traceability and assurance that is characteristic of beef, poultry, pork, and other protein industries. However, with recent advancements in the seafood and salmon industries, the disparity is shrinking. Improvements in traceability are originating from stricter governmental oversight, industry association involvement with supply and production-chain traceability systems, and individual producer investments in software for tracking and database integration.

Definitions

There are many definitions and terms used to describe traceability: trace, traceback or tracing, traceforward or tracking, product tracing, or simply recordkeeping. Although we use traceability as a catchall term, it is important to acknowledge that specific terms and specific definitions have specific meaning in law and regulation. ISO 9000:2000 (ISO 2004) guidelines define traceability as: the ability to trace the history, application or location of that which is under consideration. E.U. (2002, 2004) define traceability within the food chain as: the ability to trace and follow a food, feed, food-producing animal or substance intended to be or expected to be incorporated into a food or feed, through all stages of production, processing and distribution. Codex (2004) defines traceability as: the ability to follow the movement of a food through specified stage(s) of production, processing and distribution. Farm Foundation (2004) defines traceability as: the efficient and rapid tracking of physical product and traits from and to critical points of origin or destination in the food chain necessary to achieve specific food safety and, or, assurance goals. SalmonChile specifies traceability or tracking systems as a method of exact and opportune identification of products, in any part of the supply chain, by means of a bar code with an incorporated database of information leading to its origin. It may also be helpful to define traceability by what it does not do—it does not assure food quality or safety, rather it provides useful information for decision-making. As it implies, traceability tracks the product, its inputs, attributes or other processes. Traceability is an information system, which provides information about the extent to which quality assurance systems such as HACCP, ISO, SQF, etc., are functioning.

Differences in traceability systems may lead to inefficiencies and confusion (Dickinson and Bailey 2005). Resolving these differences has been one of the aims of several international (e.g., CIES7, EAN.UCC, Codex, OIE), national (e.g., British Retail Consortium, Farm Foundation), and aquaculture specific organizations (e.g., Tracefish/SeafoodPlus8, Global Aquaculture Alliance9). These, along with other government, associations, and private sector organizations have endeavored to accurately define traceability and make the sharing of traceability information more flexible and useful. The objectives of traceability systems differ; therefore, each should be defined by those characteristics that drive the system.

---

7 CIES—The Food Business Forum includes over two thirds of the world’s largest retailers and suppliers.
8 TraceFish is a European Commission initiative to establish a common position for recording traceability information in the farmed and captured fish supply chains (EAN 2002). SeaFoodPlus is an implementation of Tracefish.
9 Global Aquaculture Alliance (GAA) is a nongovernmental organization that has established best aquaculture practices and standards. GAA runs a nonprofit certifying body (Aquaculture Certification Council) that verifies adherence to mandatory requirements for food safety and traceability.
Golan et al. (2004) and Souza-Monteiro and Caswell (2004) classify traceability systems according to: breadth—the amount of information recorded; depth—how far backwards or forwards the system tracks information; and, precision—the degree of assurance to which the system can pinpoint or isolate a product's movement or characteristics. The breath, depth, and precision of a traceability system will depend on the product and the incentives for adopting a traceability system.

**What is Driving Traceability?**

Interest in implementing traceability in the food chain was initially set in motion by high profile food safety scares—bovine spongiform encephalopathy (BSE), foot and mouth disease, and dioxin and PCB contaminants. For example, in January 1999, dioxins and PCBs contaminated animal feed in Belgium, affecting an array of agricultural products, disrupting trade, and costing the country millions of euros. Without proper records to identify and trace contaminated feed, blanket recalls were issued, imposing a cost on products which in hindsight may have been perfectly safe (Buzby 2003). In 2001, an outbreak of foot and mouth disease in the United Kingdom cost the U.K. cattle industry about $13 billion. Similarly, the 2003 discovery of BSE in a small number of Canadian cattle cost the Canadian industry billions of dollars and led the Canadian government to outlay over $400 million in aid to affected ranchers. The discovery of a BSE infected dairy cow in eastern Washington, in 2003, effectively halted U.S. beef exports to Asian and other markets, costing U.S. producers over $180 per head in reduced sales value; a loss of over $6 billion for the U.S. cattle industry as a whole (FoodOrigins 2004).

FAO (2004) suggests that traceability systems could be useful as an effective protocol for administering food safety, quality assurance, and biosecurity, while also enhancing management of production, distribution, and marketing. The motives and objectives for traceability and assurance systems are diverse and specifically tailored to meet the needs of consumers and food chain participants from retail to production. Golan et al. (2004) suggest that firms will benefit from implementing and maintaining traceability systems when used as a tool for supply management. Firms may also use traceability systems to limit liability in case of recall and to complement HACCP, good management practices (GMP), and other assurance systems for ensuring food safety and quality assurance. Additional benefits may arise from using traceability systems as a means of verifying authenticity of differentiated products with credence attributes. In addition, using traceability as a business management tool to maintain contractual quality, develop commercial partnerships, optimize production, distribution, and marketing, and to facilitate horizontal and vertical integration (FAO 2004). Beyond the firm, governments also have incentive to use traceability as a security device for protecting the food supply from terrorist actions (e.g., contamination of food or feedstuffs with pathogens or toxins).

The standards and requirement for traceability are in large part driven by domestic and foreign government regulation and the downstream power of large retailers. The most relevant and significant legislation on traceability has come from the E.U., United States, and Japan. The E.U. has passed comprehensive regulations covering several foods including beef, fish, and GM products (E.U. 2002, 2004). Effective January 1, 2005, the E.U. began requiring mandatory traceability for the entire food chain; under E.U. regulations, this means that firms must be able to track all suppliers and buyers of food or feed and store the information for inspection. The E.U. regulations also require country of origin identification. In the U.S., the National Animal Identification System (NAIS) and the Public Health Security Bioterrorism Preparedness and Response Act of 2002 are in the initial stages of implementation with final requirements still in development. The goal of these regulations is to protect food supply from tampering and fully trace food products to their source of origin in the event of a safety related incident. The USDA's National Organic Standards Board (NOSB) will also present standards for handling and labeling organic seafood products in the fall of 2005 (The Wave 2005b). Japan's Ministry of Agriculture, Forestry, and Fisheries has implemented mandatory traceability requirements for beef and is updating requirements for other products in the food chain.

While governments have taken a prominent role in mandating traceability, firms have also taken a key role. For example, in 2004, Wal-Mart and Sam's Club in cooperation with several manufacturers (The Gillette Company, HP, Johnson and Johnson, Kimberly-Clark, Kraft Foods, Nestle-Purina PetCare

---

10 Credence attributes may be either content or process attributes. Content attributes are related to the physical properties of a product and in some cases may be hard for consumers to detect. For example, the level of healthy omega-3 fatty acids in salmon cannot be discerned by tasting it. Process attributes refer to the characteristics of the production process. These include country-of-origin, free-range, shade-grown, dolphin-safe, fair trade, earth-friendly, and organic (Golan et al. 2004).
Company, Procter and Gamble, and Unilever) started tracking cases and pallets using electronic product codes (EPC) and radio frequency identification (RFID) technology. Wal-Mart's top 100 suppliers were expected to have RFID tags by January 2005. Similarly, McDonald's had a goal of tracking 10% of its beef before the end of 2004 (Gjerde et al. 2004). Wal-Mart and McDonald’s are asking suppliers to go beyond government regulation and use traceability systems to add value and reduce liability.

In evaluating the desirability of implementing traceability and assurance systems, it is important to consider the trade-offs between mandatory and voluntary systems and between public and private implementation. Because traceability and assurance have characteristics of public and private goods, it is difficult to decide who should administer, enforce, or certify such systems—governments or firms. Goldsmith (2004) indicates that for public food safety problems, such as disease outbreaks or bioterrorism, it may be more effective to incentivize public-private partnerships rather than wholly devolve responsibility to private firms. However, in open markets, private industry innovation and investment will usually precede government involvement. For proprietary or private goods, such as, differentiated credence attributes or management information firms have opportunity to secure competitive advantages with market position and/or product price, and thus have private incentive to develop traceability and assurance systems (Farm Foundation 2004). Even so, in certifying traceability and assurance systems or resultant product attributes, information asymmetries or dishonesty could diminish consumer trust in government, third party, or producer certifications (Christensen et al. 2003; Ward, Hunnicutt, and Keith 2004). Certification preferences for safety, quality, organic, sustainability and social responsibility attributes, etc., vary across products, industries, and nations. Given these tradeoffs, it is evident that "one size does not fit all"; flexibility and customization should be considered depending on the traceability capabilities and goals of specific industries (Farm Foundation 2004).

One consequence of mandatory or voluntary traceability is the potential for increased accountability and liability. Indeed, increased liability is a primary concern of many who oppose the implementation of mandatory traceability programs. With movement towards full chain traceability in the E.U. and stricter tracing of products in the U.S., increased depth of traceability will place greater liability on producers (Liddell and Bailey 2001). With this pressure, producers face a dilemma of whether to falsify information or improve production and processing methods. Given the choice, producers may reduce risk and preserve reputation and consumer trust by responsibly providing transparent information (Souza-Monteiro and Caswell 2004).

It can be anticipated that the costs and benefits of traceability and assurance will vary according to size and market or chain position of businesses, and on consumer's willingness-to-pay (WTP) or demand for particular product attributes. Two examples cited by Gjerde et al. (2004) indicate a general willingness to pay for quality attributes and origin. In the first example, Gjerde et al. (2004) report that research by two U.S. retailers, suggested that consumers are willing to pay 12-15% more for source-verified products with identifiable positive attributes. In the second example, Gjerde et al. (2004) report that a recent E.U. survey suggests that 52% of European consumers would be willing to pay more for their meats and vegetables if they were provided with information about the country of origin and assured of a 5-10% increase in product quality. Results from willingness-to-pay experiments conducted for red meats (beef and pork) in the United States, Canada, United Kingdom, and Japan indicate that nontrivial premiums exist for traceability with even higher WTP for specific attributes such as safety and animal treatment (Dickinson and Bailey 2005). However, a significant portion of consumers in these countries also indicated that they would not pay for traceability attributes. A broader observation highlighted by Dickinson and Bailey (2005) is that irrespective of product, results indicate that consumers are willing to pay for environmental and food safety related attributes. Indeed, there is a growing interest, among some consumers, for goods associated with attributes related to the choice of inputs, source of inputs, origin, or production processes employed in manufacturing the good—attributes such as "organic," "fair labor," "GMO-free," "sustainable," "Made in the U.K," etc. Huffman et al. (2003) estimate consumers are willing to pay a 14% premium for food perceived as non-GM.

In the case of salmon, Chern et al. (2002) find that consumers in the United States, Norway, Japan, and Taiwan are willing to pay premiums of up to 50% for non-GM salmon. Nevertheless, their estimate should be viewed with caution because it does not reflect differences in the relationship between marginal willingness-to-pay and the volume of certified non-GM salmon made available to the market. Kaneko and
Chern (2003) also found that some U.S. consumers were willing to pay 40.9% and 52.5% above base price to avoid farmed GM-fed salmon and GM salmon. In a survey of U.S. consumers, Wessells and Holland (1998) and Holland and Wessells (1998) suggest that for retail purchases of salmon, consumers prefer farmed to wild, and federally inspected as the means of seafood safety inspection.

The issue of GM-fed and GM salmon draws into focus the concern over sustainability. Some NGOs have decried the use of fish meal derived from capture fisheries and the use of GM-soy in fish feeds. One response has been to promote sustainable fisheries with ecolabels (e.g., MSC). Gudmundsson and Wessells (2000) use bioeconomic modeling to discuss the effectiveness of ecolabels on sustainable fisheries management. They report that ecolabels could increase sustainable fisheries management if there is a price premium for ecolabels and if the label is trusted and unique from other labels. An ecolabeling survey conducted by Wessells, Johnston, and Donath (1999) found that consumers with larger weekly seafood budgets where more likely to choose certified seafood. However, a difference is reported between those with larger budgets and those purchasing a particular species more often. Those purchasing salmon at least once a month, were less likely to choose certified salmon compared to those purchasing salmon less frequently, and those involved with environmental groups were more likely to choose ecolabels. Wessells (2002) cautions that with a proliferation of labels there is potential for confusion and disinterest from consumers and the possibility of eroding the market for credence attributes. Mariojouls and Wessells (2002) indicate that the French market for seafood shows significant creation of market segmentation through labeling. They believe the French market could be the best predictor of the success of labeling for other countries. Johnston et al. (2001) address the design of international seafood ecolabeling programs by comparing consumer acceptance of ecolabels in the United States and Norway. They indicate that acceptance of ecolabels depends on many factors, including the country, the characteristics of consumers, trust in the labeling agency, and the species chosen for labeling. They suggest that consumers who generally eat fresh seafood are more likely to select certified seafood, compared with other consumers who generally purchase frozen seafood.

When it comes to product origin, Lusk and Anderson (2004) estimate that the welfare effects and costs to producers from mandatory country-of-origin labeling (COOL) legislation will largely depend on the consumers’ reaction. They estimate that aggregate consumer demand would need to increase by 2% to 3% to offset increased production costs. Krisoff et al. (2004) find little evidence to suggest that mandatory labeling will increase consumer surplus; they argue that the market is already meeting the preferences of consumers for country-of-origin information and labels. Loureiro and Umberger (2003) estimate that U.S. consumers are willing to pay a premium of 38% to 58% for “U.S. Certified” steak and hamburger. Nevertheless, it remains unclear whether or not premiums would exist for COOL at the supermarket (Umberger 2004). As it relates to Chilean salmon, further investigation is needed to identify the actual or likely impacts to Chilean salmon producers of COOL labeling requirements, and certification of attributes such as “organic” or “environmentally sustainable”. While most studies suggest that consumers are willing to pay for traceability and the attributes it certifies, consumers might instead insist on discount prices for products without desired traceability characteristics.

**Traceability and Assurance in Chilean Salmon Aquaculture**

Unlike the mandatory government policies used in some countries, Chile has allowed for voluntary implementation of traceability and quality assurance systems. This has allowed the private sector time to plan for and adapt to export requirements and develop systems without imposed financial pressure or deadlines. To a large degree, Chile has allowed large export markets to define traceability requirements for Chilean products. Because these markets (United States, E.U., and Japan) are in a phase of rapidly updating regulations and deadlines for exporters, and because information requirements and standards vary between these markets, Chile has hesitated to endorse and adopt a specific traceability system. One of the first, TrazaChile, was started with funds from Fundación Chile and the National Chamber of Commerce in June 2004 and is now available to both animal and fish producers (Lewis 2004). The depth of traceability envisioned for capture or aquaculture production is full chain traceability from input providers to the end-consumer.

---

11 Salmon fed with genetically modified inputs (e.g., GM soybeans) would be characterized as GM-fed salmon. Gene modification of the fish itself would be characterized as GM salmon.
Traceability solutions for the salmon industry can be out-sourced to a variety of third-party providers. Maritech, Akvsmart, TraceTracker, Intentia, C-Trace, and others offer a variety of IT, ERP, and traceability solutions covering fish from either vessel or farm through the chain. Being touted as the first automated global traceability chain, a new tracing project, TELOP (Technology Development for Profitable Fish Farming), should provide high levels of breadth, depth, and precision for traceability in the salmon supply chain. TELOP uses the GTN (Global Traceability Network) provided by TraceTracker. This decentralized, platform-independent network, links internal traceability systems to an on-line hub where accredited users may access information. GTN subscribers control their own data with security certificates and access-controlled mechanisms. The implementation of automatic information exchange will greatly reduce costs of demonstrating traceability and related certifications. With TELOP, retailers can label and communicate information that is required by regulation or desired by consumers.

The significance of transparency and trust to Chilean salmon producers is evidenced by the traceability information found on company websites. Salmones Multiexport claims to have full chain traceability from production to consumer based on the TrazaChile software. Ventisqueros, provides customers with access to an online extranet, which provides information about the entire life cycle of its products. Inverttec provides traceability from feed and broodstock to harvest and processing. It allows for online product tracing through its extranet. Los Fiordos, provides consumers with the ability to view specific product information by entering tracing codes included on their product labels. Nutreco uses a proprietary system, NuTrace, as a comprehensive tool for tracing its feed and fish products. Nutreco's feed company, Skretting, is part of the previously mentioned TELOP project.

CONCLUSIONS

Implementing traceability systems means solving a variety of complex problems that differ depending on the structure of firms, their incentive to cooperate, the nature of the attribute to be traced, the character of the assurance and verification process, and market requirements. Recouping the cost of these systems may or may not be possible. Overall, estimates suggest consumers are willing to pay for traceability and the assurance it provides for measurable and credence attributes; however, consumers have diverse preferences and many may prefer paying lower prices for products that lack traceability characteristics. There is a need for additional market analysis of the demand for quality and credence attributes and analyses of the potential that traceability could serve as a tool for cost savings as an element of supply chain management. In the past, goods flowed from producers to consumers and payments flowed from consumers to producers, and there were competitive advantages to firms and industries that were able to minimize the transaction costs in these flows. With the demand for traceability, goods and information flow from the producer to the consumer and payments and requests for information flow from the consumers to the producers, and there are competitive advantages to firms and industries that can minimize the transaction costs of these flows.

Chile has adapted slowly to international demands for food safety and requirements for traceability; to a large degree, Chile has allowed large export markets to define traceability requirements for Chilean products. Some important factors that the industry must address include: cost distribution, means of conveying information (e.g., RFID, tags, etc.), liability distribution, system design for divergent performance requirements by different countries, training personnel to monitor, inspect and implement the system and carry out recalls, and developing a high level of transparency, trust, and credible certification. Individual firms must also assess their relative size and position in the supply chain. With increasing costs of transferring additional information, supply chains will tend to reduce the number of transactions between input sources, producers, processors, and customers. One implication is that those producers and processors who are able to bypass wholesalers and sell directly to retailers will tend to have lower costs of implementing and maintaining traceability and assurance systems. In addition, firms that have already created cooperative alliances with integrated information systems should enjoy an advantage.

With respect to food safety, or product recalls, the collective industry image is at stake; therefore, the industry as a whole could benefit from a cooperative effort to emphasize transparency and quality assurance to buyers and consumers. Efforts toward this end are observed with SalmonChile's new SIGES program and the recent SQF program. If some firms wish to convey additional information about quality or credence attributes beyond the basic information conveyed through, for example, SIGES, rather than maintain dual information systems, they may find it advantageous to disengage from the traceability system adopted within the cluster and instead develop single information system that would support both
food safety information flows and the flow of information about credence attributes. If a Chilean cooperative holds private information—related to traceability and assurance—that is important to the objectives of its members, it could have an organizational and cost advantage over the independent firms operating outside that cooperative. For instance, a cooperative in the Chilean salmon industry could share the cost of knowledge intensive software requisite to ensuring traceable product. If several producers desired to market the same attribute, they might be able to cooperatively arrange and share the cost of certification, inspections, etc. Unless premiums are sufficiently high, producers might be discouraged from creating differentiated products and investing in separate traceability systems. The size and type of firm could also influence this decision. Because traceability systems require forward and backward transmission of information from each stage of production to the next, and because the development and transmission of information is costly, it can be anticipated that the burden of the cost of traceability systems will be distributed between stages of production according to their relative market power. Where vertically integrated firms are responsible for several stages of record keeping and information transfer, single stage firms are less so and may face lower prices for their product to induce processors to undertake responsibility for maintaining traceability information. In addition, large vertically or horizontally integrated firms have larger capital resources for investment in traceability and assurance systems.

While there are trade-offs among types of industry structure, it can be expected that independent salmon farmers will be at a relative disadvantage in negotiations with processors because processors are relatively few in number and control some production capacity through ownership or contract. Similarly, it can be expected that independent salmon farmers are at a relative disadvantage in negotiations with feed-suppliers because feed-suppliers are relatively few in number and control some production capacity through ownership or contract. The perishable nature of feed inputs and farm output also shift market power to feed-suppliers who have many customers and away from independent farmers who cannot stockpile feeds, and to processors who can rely on their own farms and many other independent farmers for process-ready fish and away from farmers who have a perishable product and a limited ability to transport their product to any but the closest processors. Moreover, because many of the processors and feed-suppliers are controlled by the same parent firms, and because those parent firms also control hatchery and farming facilities, it can be expected that independent farmers will have relatively little power. Under these circumstances, it can be expected that independent farmers will also be burdened with a large share of the costs of transferring information required for traceability, that is, traceability requirements can be expected to further reduce the competitiveness of independent farmers. While Tvetenås (2004) suggests that long-term contracts could be a viable alternative to vertical integration for salmon farmers and processors, long-term contracts between stages of production is not characteristic of the emerging industrial structure of the poultry, pork, or beef industries, or of the Chilean salmon industry. Similarly, although there would appear to be advantages for independent farm operators to organize as an input-buying cooperative to offset the market power associated with the high degree of concentration in feed production or as output-selling cooperatives to offset the market power associated with the high degree of concentration in processing and distribution, producer cooperatives have not emerged.

Overall, it appears that the vertically integrated or coordinated firms possess competitive advantage over independent firms in the Chilean salmon industry. Competitiveness depends more and more on the size and position of firms. Independent producers carry heavy cost burdens while vertically integrated firms appear to be pre-adapted to cope with demand for traceability. The initial response to traceability is to integrate; however, small independent firms may be able to exploit niche markets and benefit where cooperative cluster resources are available. Coordination along the supply chain between retailers, manufacturers, and producers can also be carried out through long-term contracts. Organizing the costs of traceability through alternative industrial and firm structures requires extensive market intelligence, investment in human capital and technology, and strategic foresight.

ACKNOWLEDGEMENTS

Support for this project was provided, in part, by the Utah Agricultural Experiment Station.

REFERENCES


OPTIMAL LOCATION OF MARINE PROTECTED AREAS IN AN INTERNATIONAL CONTEXT 1, 2

Arjan Ruijs 3
Environmental Economics and Natural Resources Group, Wageningen University, P.O. Box 8130, 6700 EW Wageningen, The Netherlands

John Janmaat
Department of Economics, Acadia University, Wolfville, NS B4P 2R6

ABSTRACT

Marine protected areas (MPAs) can have positive impacts on marine biodiversity as well as the fisheries sector. Increased fish densities inside the MPA will, through dispersal, have positive effects on fish catches outside the area. This paper considers how MPA location choice in an inter-national context differs from the social optimum and examines factors which affect location choice. A differential game is used to analyze strategic behavior in MPA location choice and long term effects on catch and stock size in two neighboring nations. A metapopulation model is used to describe dispersion and densities of fish. Non-cooperation between national governments results in a prisoners’ dilemma in MPA location choice and in the fish harvest levels adopted. Strategic interactions lead to a divergence between socially or ecologically optimal MPAs and those chosen by national governments. Results imply that international agreements on marine biodiversity should take into account possible strategic considerations of the partners.

INTRODUCTION

There is an increasing call for the expansion of marine protected areas (MPAs) with no-take zones in order to protect fish stocks and make fisheries sectors more sustainable. Because of the spillover effects, or positive externality effects, of protected areas on adjacent areas, creating an MPA might result in improved biodiversity in the closed area and increased fish stocks inside and outside the area. The recent UN Millennium Ecosystem Assessment Synthesis Report advises creating networks of MPAs (Millennium Ecosystem Assessment, 2005). This would both protect fisheries sectors and contribute to sustaining marine biodiversity. With the increasing recognition that limited entry fisheries and individual transferable quota (ITQ) may not be the answer to overfishing (Townsend, 1990; Fujita et al., 1998; Pauly et al., 2002), temporary or full closure of fishing grounds promises to be a superior way of managing fish stocks (Brown, 1974; Clark, 1999). MPAs are said to provide multiple benefits including: "protection of habitats, conservation of biodiversity, protection or enhancement of ecosystem services, recovery of depleted stocks, export of individuals to fished areas, insurance against environmental or management uncertainty and sites for scientific investigation, baseline information, education, recreation and inspiration" (Lubchenco et al., 2003). In contrast to ITQs and other species specific management approaches, the use of MPAs is directed towards ecosystem functioning. Where ecosystems are easily disrupted by fishing efforts, reserves may be a more appropriate option (Botsford et al., 2003). Halpern (2003) argues that MPAs are better able to address the anthropogenic impacts like over-fishing, certain fishing methods, pollution, coastal development, etc.

2 We would like to thank Hans Peter Weikard for his valuable comments and suggestions in the methodology and results.
3 Email: Arjan.Ruijs@wur.nl
So far, few networks of MPA have been implemented. An example may be the set of MPAs in the Caribbean Sea. Unfortunately, the initiative has largely resulted in isolated actions by each of the participating nations, without much emphasis on the ecological connectivity of the regions and joint multinational governance of the network (Milon, 2000). Also in Europe, the EU-Habitat and Bird Directives will result in a network of MPA in European waters. In the Baltic Sea, the Helsinki Commission (HELCOM) aims to protect the marine environment of the nine participating countries. In 1994, 62 protected areas have been designated to protect sensitive environments. However, to date, required legal changes and monitoring systems have hardly been implemented in any of the participating countries. Likewise, the 1992 OSPAR Convention guides international cooperation on the protection of the marine environment of the North-East Atlantic. This also includes establishing a number of marine reserves, some of which are shared by two or more nations. For example, the Doggersbank, a shallow sand wall in the North Sea that is an important breeding ground for many fish species, is shared by Great Britain, Denmark, Germany and the Netherlands. By the year 2010, the areas designated as important in the EU Habitat Directive are to be managed as marine reserve. However, international negotiations on selection and delimitation of the protected areas are still in their early stages.4

This raises the question how multi-national management of MPA networks should best be arranged. Specifically, can self-sustaining networks, where nations do have the incentive to enforce their own MPA, be designed. This paper concentrates on the optimal location of MPA in a multi-national setting. It is argued that a cooperative system, where nations decide on MPA location on the basis of joint fisheries benefits, is not self-sustaining. A self-sustaining network set up is possible, however, at the expense of biomass densities and total fisheries benefits. This problem will be analyzed by setting up a differential game using a bioeconomic model in which a metapopulation model describes biomass growth and dispersal over space. Different from many fishery economics models, we do not consider an open access or limited entry fisheries sector but consider a social planner who decides on MPA location and optimal effort. By implicitly assuming that appropriate policies can be introduced to prevent entry exceeding optimal effort levels, we can concentrate on the question of location choice. In Sanchirico (2003), it is shown that patch closure can not increase net revenues if a resource manager can fully control effort and decide on the location choice. Therefore, we can not analyze whether patch closure is superior to other policies.

To our knowledge, nothing has been written to date on a multiple nation situation in which the biological and economic effects of location choice and the difference between cooperative and non-cooperative harvest and MPA management are analyzed. An increasing number of papers analyze the spatial interactions and the combined biological and economic effects of closing fishing grounds. Among marine scientists, there is more or less a consensus on the potential conservation and fishery-enhancement benefits of marine reserves (Sanchirico, 2005). Increased fisheries and improved biodiversity conservation are not necessarily in conflict (Hastings and Botsford, 2003) and the effect of reserves on yields is similar to reducing effort whereas the effect on biodiversity is positive (Hastings and Botsford, 2003; Botsford et al., 2003). Several modeling studies, however, sketch a more nuanced picture. In one of the first modeling studies, Polacheck (1990) considers exogenous larval recruitment and exogenous fishing effort to analyze the effect of spatial closure on an exploited fishery. He concludes that effects on fishing yields are ambiguous. Sanchirico (2003, 2005) and Sanchirico and Wilen (2001a,b, 2005) set up a spatially explicit bioeconomic model to analyze location choice of marine protected areas and effects of MPA on biodiversity and fisheries. They concentrate on open-access fisheries and limited entry fisheries to analyze the factors that contribute to resource exploitation patterns over space and time. The effects of reserve creation for different dispersal processes are investigated and it is concluded that for some specific biological and economic preconditions a win-win situation can be attained in which both aggregate biomass and fish harvests increase. Moreover, under certain circumstances, closing two low value patches is superior to closing one high value patch both in terms of biodiversity and political acceptability.

This is confirmed by Smith and Wilen (2003), who conclude on the basis of a multiple patch bioeconomic model using a richer and empirically estimated model for fishermen behavior that gains from MPA are far from certain. They show that making simplifying assumptions on economic behavior has severe implications for the predicted positive impact of reserves. Treating reserves as the optimal fisheries policy is more ambivalent than concluded in many papers. Moreover, Watson et al. (1993) conclude on the basis

---
4 See www.helcom.fi and www.ospar.com for more information on the status of the marine protected areas in the Baltic Sea and North-East Atlantic Ocean.
of a spatial and temporal model that closures can protect biomass habitat and increase overall harvest levels, but that these effects may vanish with violation of closure rules. This is corroborated by Kritzer (2004), who concludes that enforcement of no-take zones is an essential element of assigning protected areas as non-compliance will undoubtedly result in lower benefits for both conservation and fisheries.

Beattie et al. (2002) also analyze optimal size and location of MPA using a dynamic spatial bioeconomic model in which much emphasis is put on multiple species, multiple types of fleet, trophic interactions and multiple goals. In order to show interactions between fishing fleet and fishery managers, a game theoretic model is used in which managers decide about their policies to regulate the fisheries sector and conserve marine biodiversity and the fishing fleet decides where and how to fish given the policies adopted. They conclude that the assumption that MPA provide benefits to marine biodiversity no matter where they are located is wrong. Moreover, in most situations considered, fishing industries are negatively affected by implementing an MPA. Finally, Janmaat (2005) analyzes optimal stock size and resource use in a situation where the resource can disperse between zones whereas economic agents own property rights to only one zone. Using a dynamic bioeconomic model based on a metapopulation model it is shown that individual agents’ stock sizes are inversely related to dispersal and that socially optimal stock sizes in each zone are in most cases larger than individual stocks. Dispersal is shown to create a tragedy of the commons if joint management is not possible.

The next section describes the bioeconomic model and the differential game. Subsequently, a number of numerical examples are discussed, representing different biomass dispersal and growth systems. For all cases, the socially optimal location choices are compared to the non-cooperative situation. Finally, we draw some conclusions on ways to improve cooperation on designing MPA networks.

MODEL DESCRIPTION

In order to analyze optimal choice on the location of marine protected areas in a multi-national setting, consider an island which is divided into a number of nations. Each nation has within its boundaries a portion of the shoreline of the island. Suppose that each nation has a fishing fleet which catches fish only within its territorial waters. This fleet is managed to expend only the efficient effort, with respect to maximizing the present value of harvest from its territorial waters. Each nation is small, and the fish are sold in an international market, making each nation a price taker. Further, the fish population surrounding the island is isolated from other fish populations in the ocean, such that the only migration of interest occurs within the territorial waters of the island nations. Fish do migrate around the island, and that migration can be represented by considering each nation’s territorial waters as composed of a number of connected patches. Define \( I = \{1, 2, \ldots, n\} \) as the set of patches surrounding the island. See Figure 1 for a two nation example.

![Figure 1](image)

**Figure 1.** Schematic representation of a two nation island with three MPA locations per nation.

Each nation makes two types of decisions. First, a one-time choice on MPA location is made. Secondly, they choose optimal fishing effort in each patch, for given levels of effort of the neighboring nation. Each
nation $k$ can then be considered to maximize the present value returns generated from the patches in its territorial waters subject to the evolution of the stock of biomass within all patches.

\[
\begin{align*}
(1) & \quad \max_{\gamma_k} \left\{ \max_{\gamma} e^{-\rho t} \sum_{i \in I} \gamma_i \rho_i (e_i(x_i)) \right\} \\
(2) & \quad \text{s.t.} \quad \dot{x}_i = g_i(x_i) + \sum_{j \in I} d_{ij} x_j - \gamma_i f_i(e_i(x_i)), \quad i \in I
\end{align*}
\]

where $I^k$ is the set of patches within the territorial waters of nation $k$, $\rho$ is the discount rate, $\gamma$ is a binary variable indicating which patch is closed for fishing, with a value of 1 for patches open for fishing and 0 for patches that are protected areas, and $\rho_i(e_i(x_i))$ is the function measuring the rent generated in each patch as a function of the effort level $e_i$ and the stock $x_i$ within patch $i$. For a two nation situation with six patches, $I^1 = \{1,2,3\}$ for nation 1 and $I^2 = \{4,5,6\}$ for nation 2. Decision variables are closure decisions and effort levels, where $\gamma$ and $e_k$ are vectors with elements $\gamma_i$ and $e_i$ for $i \in I$. Decisions made depend on the location and effort choices by all nations, as shown in metapopulation model (2). In this model, $g_i(x_i)$ measures the growth in each patch and $\gamma f_i(e_i(x_i))$ is the catch.\footnote{For a review of metapopulation models used in marine biology see, e.g., Levin (1976) and Hastings and Harrison (1994). See also e.g., Sanchirico and Wilen (1999) and Janmaat (2003) for applications of this type of metapopulation model.} Dispersal term $d_{ij}$ describes the dispersal between patches. Dispersal $d_{ij}$ is the share of the stock in patch $i$ that leaves, $d_{ij} \leq 0$, while $d_{ij}$ is the share of the stock in patch $i$ that disperses to patch $j$, $d_{ij} \geq 0$ for $i \neq j, i, j \in I$. By assuming that the fishery is isolated, it follows that $\sum_{j \in I} d_{ij} = 0$. Net dispersal depends upon biomass in all patches and the direction of dispersal is endogenous to the model, depending on relative density differences between the different patches. The value of $d_{ij}$ determines the nature of the fish dispersal, and thereby defines the strategic relationship between the nations. As will be shown, the optimal location of MPA depends on the type of dispersal process considered and the spatial connectivity of patches. The regular restrictions, $e_i \geq 0$ and $x_i \geq 0$ for $i \in I$ apply.

In a cooperative situation, nations jointly maximize total net revenues subject to metapopulation model (2). The non-cooperative problem, in which each nation individually optimizes its own net revenues, given effort levels of the other nation, can be solved using a two-step procedure. In the first step, for each possible choice of vector $\gamma = [\gamma_1, \gamma_2, \ldots, \gamma_6]$, the Nash equilibrium of optimal effort for the open patches is determined. Second, given the Nash equilibria for the different choices of $\gamma$, the Nash equilibrium for location choice is determined. The Hamiltonian for nation $k$ for the optimization problem of the first step is

\[
(3) \quad H_k (e_k, x) | \gamma, e_k = \sum_{i \in I^k} \gamma_i \rho_i (e_i(x_i)) + \sum_{i \in I} \mu_i e_i(x_i) + \sum_{j \in I} d_{ij} x_j - \gamma_i f_i(e_i(x_i))
\]

with the costate variables $\mu_i$, the location choices fixed at $\gamma$ and effort levels for nations other than $k$ assumed fixed at $e_k$, where $e_k$ is a vector of effort levels by the nations other than nation $k$. This latter assumption implies that the solution paths identified may not be subgame perfect, as they will be open loop solutions. In general, requiring subgame perfection will result in a greater divergence between the socially optimal result and equilibrium behavior, so that we interpret our solutions as a best case. The optimization conditions are

\[
(4) \quad \frac{\partial H_i}{\partial e_i} = \gamma_i \left[ \frac{\partial \rho_i}{\partial e_i} - \mu_i \frac{\partial f_i}{\partial e_i} \right], \quad i \in I^k
\]

\[
(5) \quad \frac{\partial H_i}{\partial x_i} = \alpha_i \gamma_i \frac{\partial \rho_i}{\partial x_i} + \mu_i \frac{\partial g_i}{\partial x_i} + \sum_{j \in I} \mu_j d_{ij} - \mu_i \gamma_i \frac{\partial f_i}{\partial x_i} = \rho \mu_i - \mu_i, \quad i \in I
\]
and \( \partial H_k / \partial \mu_i^k = x_i \) for \( i \in I \). In (5), \( \omega_i^k \) is a binary variable indicating whether a patch is owned by nation \( k \). For example, \( \omega_i^k = [\omega_1^k, \omega_2^k, \ldots, \omega_n^k] = [1 1 0 0 0 0]. \) At the steady state, \( \dot{x}_i = 0 \) and \( \dot{\mu}_i^k = 0 \) for \( i \in I \) and \( \partial H_k / \partial \epsilon_i = 0 \) for \( i \in I \). In equilibrium, these conditions hold for all \( k \). Note that for each patch, the \( \mu_i^k \) are different for the different nations \( k \).

The first-order conditions show that optimal effort in each patch depends on biomass densities in all patches in the system. The dispersal of biomass over the neighboring patches means that a change in one patch has effects on all other patches and therefore on optimal effort levels of each nation. This creates a strategic relationship between the nations. For example, equation (2) shows that in the steady state, harvests in each patch equal net growth, which depends on own growth and dispersal from and to other patches. This implies that in the steady state, the patches closed for fisheries (i.e., when \( \gamma = 0 \)) show a net growth of zero. It also implies that higher catches in one nation result in less biomass dispersal to the other nations, and correspondingly lower catches in those nations. Moreover, (4) shows that at the optimum, marginal net revenues from an extra unit of effort are equal to the shadow value of the corresponding additional catch. This shadow price \( \mu_i^k \) considers effects of current effort on future potential catches. Furthermore, (5) governs the behavior over time of the shadow price of the biomass stock, which implicitly determines the optimal catch rate.

The optimization results can be interpreted in line with classic fisheries models by rearranging the steady state version of equation (5) as

\[
(6) \quad \rho = \gamma \left( \frac{1}{\mu_i^k} \omega_i^k \frac{\partial r_i^k}{\partial x_i} - \frac{\partial q_i^k}{\partial x_i} \right) + \frac{1}{\mu_i^k} \sum_{j \in I} \mu_i^j d_{ij}, \quad i \in I
\]

If there is only one patch, which is fished (\( \gamma = 1 \)), then this generates the standard result that at the steady state optimum, the impact on the rate of return of a marginal increase in the fish stock is equal to the discount rate. The marginal impact is made up of the impact on rents \( \partial r_i^k / \partial x_i \), scaled by the shadow price of a unit of stock \( \mu_i^k \), the impact on the growth rate \( \partial q_i^k / \partial x_i \), and the stock externality impact on harvest \( \partial f_i^k / \partial x_i \). When there is dispersion and there are multiple patch owners, stock in every patch, even those not owned, must satisfy a rate of return relationship. That stock can affect via dispersion the rents of all owners, even though it can not be directly fished. In particular, the last term in equation (6) is the marginal value of the dispersing stock, which is the net return generated to nation \( k \) by a marginal increase in \( x_i \) as it affects stocks in all patches \( j \in I \). For an unowned and/or unished patch, the marginal rate of return of a unit of stock at the steady state is the sum of the growth rate and the marginal value of the dispersing stock. The higher the dispersal value, the lower the growth rate, implying a larger equilibrium stock in the unished patches.

**Numerical Example**

Solving model (1)-(2) analytically becomes infeasible even for very simple functional forms and dispersal parameters. Only for closed patches in which dispersal between patches is absent \( (d_{ij} = 0 \) for all \( i, j \in I \)) can an analytical solution be easily derived. For that reason, we discuss a numerical example with two nations and three patches per nation (so that \( I = \{1, \ldots, 6\} \)). For different values of growth rates and dispersal patterns we compare optimal location choice, effort and biomass levels in the cooperative and non-cooperative models. In order to exemplify a situation in which all countries engage in marine protection, for both models it is assumed that each nation has to close one patch within its own territorial waters, even if no ecologically valuable locations are present. This corresponds to the World Conservation Union convention that in order to set up a network of protected areas, each nation should protect 10% to 12% of its surface (Rodrigues et al., 2004).

In this analysis, we adopt a Schaefer production function, \( f_i(e_i, x_i) = q_i e x_i \), with \( q_i \) a catchability coefficient. Revenues are \( r_i(e_i, x_i) = pf_i(e_i, x_i) - c_i(e_i) \) in which cost function \( c_i(e_i) = c_i e_i \), with costs \( c_i \) per unit of effort and price \( p \) for a unit of harvest. For the growth function, we adopt a logistic growth function in which biomass is delimited by carrying capacity \( x_{max} \), \( g(x) = g x(1-x/x_{max}) \) with \( g \) the intrinsic growth rate. Carrying capacity parameter \( x_{max} \) is scaled to one, so that \( x_i \) represents biomass densities instead of quantities. Parameter values are chosen in such a way that model (1)-(2) has an interior solution.
For the functional forms adopted, it can immediately be seen that effort levels in both nations are interrelated. For the steady state, it can be derived from equation (2) that \( \frac{\partial x_i}{\partial e_i} < 0 \) and \( \frac{\partial x_j}{\partial e_j} > 0 \). An increase in effort by one nation results in a lower biomass density in both nations. Moreover, from equation (4) it can be derived that \( \mu_i = p c_i/x_i \), so that a higher effort in one nation results, for fixed prices, in a decrease of the shadow price for all patches.

To determine the cooperative solution, effort levels are chosen for both nations to maximize joint benefits. All possible combinations of one MPA in each nation are then examined to identify the one that maximizes total benefits. Similarly, for the non-cooperative case, for each possible combination of MPA locations, the Nash equilibrium of effort levels is determined iteratively. This is done by iterating through both nations' optimization problems for given effort levels of the other nation and updating fixed effort until the effort levels are unchanging for both nations' optimizations. This converges to a Nash equilibrium in which both nations choose their optimal effort \( (e_k) \) for given effort levels of the other nation \( (e_x) \) and in which they both do not have the incentive to adopt another strategy. Once the equilibrium effort levels and optimal net revenues for both nations are determined for each combination of MPA locations, the Nash location choice can be determined in which each nation chooses the optimum location \( (y_k) \) for given MPA location of the other nation \( (y_x) \).

We consider location choice for a single integrated dispersal system while varying patch specific growth rates. In the integrated dispersal system, biomass can flow from each patch to (almost) all other patches and they can flow in all directions \( (d_{ij} \geq 0 \text{ for } i \neq j) \). Four scenarios of biomass growth systems are considered. First, a homogenous system in which growth is equal in all patches. Secondly, a heterogeneous system in which growth is positive in all patches, but in which a few patches are more productive, for example due to oceanographic or marine biodiversity characteristics. In the third system, growth is positive in only one patch whereas it is zero \( (g_x = 0) \) in the other patches. In the last system, growth is positive in one patch per nation and zero in the other patches. These last two systems reflect a situation with one or a few spawning grounds from which juveniles disperse to the other patches, or it reflects a system in which biological and ecological characteristics of patches differ so that only some are suitable as spawning grounds. For all four systems, we consider four sub-scenarios, depending on whether growth rates are low \( (g_i = 0.3) \) or high \( (g_i = 0.8) \) and on whether dispersal is low or high. In Table 1, dispersal values adopted are presented. Furthermore, \( p = 20 \), \( c_i = 1 \) and \( q_i = 1 \) for \( i \in I \). Table 2 presents the scenarios and the optimal non-cooperative and cooperative MPA location choices.

### Table 1. Dispersal matrix D for the low dispersal scenario. Parameter values in the high dispersal scenario are the double of those given here.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.30</td>
<td>0.10</td>
<td>0.05</td>
<td>0</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>2</td>
<td>0.10</td>
<td>-0.30</td>
<td>0.10</td>
<td>0.05</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>3</td>
<td>0.05</td>
<td>0.10</td>
<td>-0.30</td>
<td>0.10</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0.05</td>
<td>0.10</td>
<td>-0.30</td>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td>5</td>
<td>0.05</td>
<td>0</td>
<td>0.05</td>
<td>0.10</td>
<td>-0.30</td>
<td>0.10</td>
</tr>
<tr>
<td>6</td>
<td>0.10</td>
<td>0.05</td>
<td>0</td>
<td>0.05</td>
<td>0.10</td>
<td>-0.30</td>
</tr>
</tbody>
</table>

For the first scenario, the homogenous system, results show that for all four sub-scenarios of growth rates and dispersal, the cooperative optimum is to locate the MPA on opposite sites of the island (so adopt \{1,4\}, \{2,5\} or \{3,6\} as MPA, see Figure 1). In the non-cooperative situation, both nations have a dominant strategy in all four sub-scenarios; choose the middle patch (patch 2 for nation 1 and patch 5 for nation 2). So, the Nash equilibrium is to close patches \{2,5\}, which is also one of the optimal cooperative location options. Table 3 shows that in the Nash location choice, the nations are in a prisoners' dilemma. For both nations, it is better to close \{1,4\} or \{3,6\}. However, for this MPA combination, each nation can increase its gain from its rival’s MPA and profit the most from its own MPA by moving its own MPA to the middle patch. However, once one nation moves, the other is best off by moving its MPA away from the border. At the Nash location choice biomass densities are at their lowest level. For biomass it is optimal to make one large reserve at the border of both nations, i.e., close \{1,6\} or \{3,4\}. This strategy, however, results in lowest net revenues, illustrating a trade off between biomass and rent maximization.
Table 2. Scenarios considered and optimal MPA location choices for country 1 and 2 in the non-cooperative and cooperative situation, respectively. For low dispersal data see Table 1.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Low Dispersal</th>
<th>High Dispersal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g_i = 0.3</td>
<td>(2,5)</td>
<td>(1,4),(2,5) or (3,6)</td>
</tr>
<tr>
<td>g_i = 0.8</td>
<td>(2,5)</td>
<td>(1,4),(2,5) or (3,6)</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g_i = g_i^a</td>
<td>(2,5)</td>
<td>(2,5)</td>
</tr>
<tr>
<td>g_i = g_i^b</td>
<td>(3,4)</td>
<td>(3,4)</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g_i = g_i^c</td>
<td>(2,5)</td>
<td>(2,5)</td>
</tr>
<tr>
<td>g_i = g_i^d</td>
<td>(3,4)</td>
<td>(3,4)</td>
</tr>
<tr>
<td>g_i = g_i^e</td>
<td>(2,5)</td>
<td>(2,5)</td>
</tr>
<tr>
<td>g_i = g_i^f</td>
<td>(3,4)</td>
<td>(3,4)</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g_i = g_i^g</td>
<td>(2,5)</td>
<td>(2,5)</td>
</tr>
<tr>
<td>g_i = g_i^h</td>
<td>(3,4)</td>
<td>(3,4)</td>
</tr>
<tr>
<td>g_i = g_i^i</td>
<td>(2,5)</td>
<td>(2,5)</td>
</tr>
<tr>
<td>g_i = g_i^j</td>
<td>(3,4)</td>
<td>(3,4)</td>
</tr>
</tbody>
</table>

Notes: a) g_i = [0.3 0.3 0.8 0.8 0.3 0.3]; b) g_i = [0.8 0.8 0.3 0.3 0.8 0.8]; c) for the other patches g_i = 0.

The failure to internalize the dispersion spillovers, leads to the non-cooperative rents being less than the cooperative rents for all MPA combinations. In the non-cooperative situation, effort levels are higher and biomass levels are lower than in the cooperative situation. Especially if growth is low and dispersal high, biomass may be 30% lower and revenues per nation 15% lower if nations do not cooperatively manage their fishing grounds. For high growth and low dispersal, these differences are smaller, but non-cooperation still results in a loss of biomass of 7% and of revenues of 2% compared to cooperation. These results show that for a homogeneous growth system with integrated dispersal, reaching an agreement on location choice and cooperative management of fishing grounds will result in a win-win situation in which both net revenues (an increase of 2%-19% compared to the Nash equilibrium) and biomass densities (an increase of 7%-39%) will improve. Simply reaching an agreement to close {1,4} or {3,6} will result in a win-win situation (revenues increase with 1% to 3% and biomass with 2% to 5% compared to the Nash equilibrium), even if joint cooperative management of harvesting effort is not agreed on.

Table 3. Pay-off matrix for an integrated system with low growth (g_i=0.3 for i ∈ {1,...,6}) and high dispersal (see Table 1). Entries are the net revenues for nation 1 and 2 respectively and aggregate biomass x at the non-cooperative and cooperative effort levels, respectively. Entries in bold correspond to the Nash or cooperative location choice.

<table>
<thead>
<tr>
<th></th>
<th>Non-cooperative</th>
<th>Cooperative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>(3.35, 3.35)</td>
<td>(3.07, 3.44)</td>
</tr>
<tr>
<td></td>
<td>x=2.08</td>
<td>x=2.08</td>
</tr>
<tr>
<td>2</td>
<td>(3.44, 3.07)</td>
<td>(3.26, 3.26)</td>
</tr>
<tr>
<td></td>
<td>x=2.03</td>
<td>x=1.99</td>
</tr>
<tr>
<td>3</td>
<td>(3.23, 3.23)</td>
<td>(3.07, 3.44)</td>
</tr>
<tr>
<td></td>
<td>x=2.08</td>
<td>x=2.03</td>
</tr>
</tbody>
</table>

For the second system, the heterogeneous growth system with higher growth levels in some patches, non-cooperative and cooperative closure decisions are the same for the parameter values adopted. Patch closed are the low growth patches and, if it is not a high growth patch, the middle patch. The most productive patches are not closed, not even when dispersal is high. Closing those patches results in most cases in a loss in harvest for the owner which may reach 30% compared to the Nash location choice if growth rates and dispersal are low. It is interesting to observe that, compared to the biomass levels in the

---

6 For this scenario we calculated optimal strategies for high and low dispersal and for g_i = [0.3 0.3 0.8 0.8 0.3 0.3] and g_i = [0.8 0.8 0.3 0.3 0.8 0.8].
Nash location choice, when four patches have high growth rates, closing two productive patches results in a decline of overall biomass from 2% to 10%, whereas it results in an increase of biomass from 3% to 7% if only two patches have high growth rates. In the latter case, not closing the more productive patches leads to intensive harvesting in these patches, leaving less biomass to disperse to the less productive patches. For such a system, we are not in a prisoners’ dilemma for the location choice, but still encounter a prisoners’ dilemma for the chosen effort levels. Also in this situation, jointly managing harvesting effort will result in a win-win situation. In the cooperative compared to the non-cooperative case, revenues increase from 2% to 11% and biomass from 8% to 30%. Higher dispersal leads to higher economic and ecological gains from cooperation. However, the more patches have high growth rates, the lower the gains from cooperation.

For the third and fourth scenarios, the spawning ground systems in which only one or two patches have a positive growth rate and dispersal is integrated, the optimal cooperative location choices are not stable. For all parameter scenarios and all spawning ground locations, Nash location choices differ from the cooperative location choices. Also for this system, nations are in a prisoners’ dilemma for the effort levels they adopt but encounter a prisoners’ dilemma for their MPA location choices only in some situations. In the third scenario, with only one productive patch, location choice is a prisoners’ dilemma only if the growth rate is low and the spawning ground is in one of the border patches. If only patch 1 is productive, the Nash location choice is \( \{4,4\} \) (see Table 4), whereas the cooperative optimum is to close the spawning ground and the adjacent patch, i.e., close \( \{1,6\} \) (see Figure 2). The cooperative strategy is not only optimal from an economic point of view, but also from a biomass point of view. The gain in biomass if the cooperative instead of the non-cooperative strategy is adopted is 63% and the gain in revenues 56%. In the Nash location choice, patches are as far away from the spawning ground as possible. This results in low steady state biomass levels and also relatively low revenues. Note that closing the spawning grounds is optimal for nation 1 if nation 2 agrees on closing patch 6 instead of patch 4, which is his dominant strategy. In that case, for both nations the situation improves. Moreover, it is also optimal in terms of biomass. However, the additional revenues for nation 1 if \( \{1,6\} \) is closed instead of \( \{3,4\} \) are not enough to prevent nation 2 from breaking the agreement. In the cooperative situation, it is no longer optimal to close the spawning ground if growth rates are higher (see Table 2). In that case, the cooperative optimum is to close \( \{2,6\} \) and harvest especially in patch 1 and to a lesser extent in 3 and 5. If in the low growth case the spawning ground is not closed, catches in the spawning ground are so high that not much biomass remains for the other patches. In the high growth case, growth is high enough to prevent this. This is the case for the low as well as for the high dispersal situation.

<table>
<thead>
<tr>
<th></th>
<th>4</th>
<th>5</th>
<th>6</th>
<th></th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When patch 2 is the spawning ground, revenues for nation 1 are considerably higher than for nation 2. Moreover, there is no prisoners’ dilemma in location choice in this situation. In a cooperative situation, the optimal choice will be to close the spawning ground only if growth and dispersal are low. For high growth it is optimal to close two adjacent patches, i.e., \( \{3,4\} \) or \( \{1,6\} \). Closing two adjacent patches is better for biomass than closing two remote patches. Moreover, it has a larger effect on the other patches due to dispersal. In the non-cooperative situation, patches \( \{2,5\} \) are closed if growth is low and \( \{1,5\} \) or \( \{3,5\} \) if growth is high. In the low growth case, fishing patch 2 results in much lower dispersal to the adjacent patches which leads to lower overall catches for nation 1. If growth is higher, this is not the case anymore.

\[ \text{Note that similar to the situation with a spawning ground in patch 1, it will be optimal in the cooperative case to close patch 2 and one of the adjacent patches. However, we assume that each nation has to close one patch in their own territorial waters.} \]
In the non-cooperative case, both nations can earn more profits if side payments are possible. If the cooperative location choice is adopted but effort is not managed cooperatively, the additional revenues for nation 1 are enough to compensate the loss in revenues from nation 2. However, this is worse for biomass levels. Also in this situation, revenues and biomass can be considerably higher for both nations if they cooperatively manage marine reserves and fishing effort.

These results show that, under cooperative management of fishing grounds, closing the more productive areas is optimal from an economic point of view only under specific circumstances, i.e., if growth rates are low. If there is no cooperation, the nation owning the spawning ground only has an economic incentive to close the spawning grounds if it is not a border patch and if growth is low, i.e., if he can capture most of the spillover benefits. Moreover, reaching agreements on closing the patches that yield maximum overall revenues is possible only under specific circumstances. In particular, if spawning grounds are in the border patches and growth rates are low, a prisoners’ dilemma prevents nations from reaching a stable agreement.

Also in the fourth scenario considered, one spawning ground in each nation, nations are in a prisoners' dilemma for location choice only if the spawning grounds are in one of the border patches. This occurs both with adjacent spawning grounds (i.e., \{1,6\} or \{3,4\}) and with spawning grounds opposite to each other (i.e., \{1,4\} or \{3,6\}). If they are in the patches 1 and 6, both for low and high growth and both for low and high dispersal, the Nash solution is to close the patches as far away from the productive areas as possible, i.e., close patches \{3,4\}. The cooperative optimum is to close the patches adjacent to the spawning grounds, i.e., close \{2,5\}, see Table 5. It is interesting to see that if nations do not cooperate and for low growth rates, closing \{2,5\} is the strategy yielding the lowest total net revenues. So, nations will consider closing those patches only if full cooperative effort management is possible. Reaching at the same time agreements on MPA location and effort restrictions is, however, likely to be difficult. Note that for this system, in a non-cooperative situation, effort levels are 15% to 50% higher than in a cooperative situation, biomass levels 10% to 40% lower and revenues 5% to 40% lower. So, cooperation results in a win-win situation with considerably less effort. Moreover, in the non-cooperative situation, if growth is low, closing the spawning grounds yields maximum total net revenues, whereas in the high growth situation it results in minimum total net revenues. In a cooperative situation, in which nations jointly manage effort, closing the spawning grounds is from an economic point of view the worst choice. Therefore, growth rates and the likelihood of reaching an agreement on cooperative effort management are important in deciding whether or not closing the spawning grounds should be a goal. This contrasts sharply with the ecological perspective, where closing the spawning grounds is preferable.

If the spawning grounds are opposite of each other in the middle patches (i.e., \{2,5\}), it is a Nash equilibrium to close them when growth is low. However, in that case, closing \{1,4\} or \{3,6\} are also Nash solutions. If growth is high or if spawning grounds are opposite of each other at one of the border patches
\[\{(1,4) \text{ or } (3,6)\}\] closing the spawning grounds is not a Nash solution and for the high growth situation even results in the lowest net revenues. In case patches \(\{2,5\}\) are the only productive patches, the cooperative location choice is to close two adjacent patches \(\{3,4\}\) or \(\{1,6\}\). For this system, closing the productive patches \(\{2,5\}\) results in minimum net revenues, and for the high growth situation in minimum biomass levels. Again, cooperation on location choice and effort management results in considerable ecological and economic gains which may exceed 50% compared to the non-cooperative situation.

To conclude, the question whether it is better to have one large or several small protected areas can not be answered unambiguously. It depends very much on growth rates per patch and dispersal whether one large MPA that is two patches in size is preferable to two smaller MPAs that are not adjacent. If all patches have equal growth rates or if spawning grounds are in the border patches, one large MPA is in terms of biomass preferable over two smaller patches. For revenues, however, two smaller MPAs are in most situations better than one large. Only in specific spawning ground systems with low dispersal, one large MPA may also in economic terms be preferable.

### Conclusions

In this paper, we analyze which factors affect MPA location choice in an international context. If two nations decide to create marine protected areas in their territorial waters, dispersal of fish across the territorial borders adds a strategic dimension to location choice. By using a differential game in which each nation maximizes its present value returns from its territorial waters and in which the evolution of the stock of biomass is governed by a metapopulation model, optimal effort and location choice can be determined for each nation. The results show a prisoners’ dilemma in harvesting effort if nations do not jointly manage their fishing fleet. Gains from cooperation are substantial, both from an economic and biomass perspective. Full cooperation and effort management will result in a win-win situation for both nations. Reaching agreements on the location of no-fishing areas and on effort levels is, however, difficult for many systems of biomass growth. Only under specific circumstances, cooperative and non-cooperative location choice is the same. If joint effort management is not possible but agreements on MPA locations are within reach, closing the cooperatively optimal MPA locations may be suboptimal and result in lower revenues and biomass levels than when the Nash location choices are adopted. This is particularly true when only one or a few patches are spawning grounds, from which fish disperse to the other patches. Moreover, for many situations, a prisoners’ dilemma in MPA location choice prevents nations from reaching stable agreements on location choice, effort levels and side payments. In those situations, additional revenues from cooperation are not enough to overcome the incentive to adopt the non-cooperative optimum. Only for some scenarios, especially when the more productive patches are not bordering the other nations’ territorial waters, side payments may result in stable agreements optimizing joint net revenues. An interesting result is that closing the more productive areas or closing the spawning grounds may, for some circumstances, be suboptimal from both an economic and biomass perspective. Even in a cooperative situation, closing the spawning grounds is in many situations non-optimal. Closing them may be optimal economically only if growth rates are low. In that case, keeping them open would lead to heavily fished spawning grounds and low dispersal to the other patches resulting in low harvests and low overall biomass levels. The results show that nations must not overlook the difficulties of agreeing on jointly managing fishing grounds and that the economic effects of location choice can not be ignored.

<table>
<thead>
<tr>
<th></th>
<th>Non-cooperative</th>
<th></th>
<th>Cooperate</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>(0.698, 1.164)</td>
<td>(0.693, 1.147)</td>
<td>(0.948, 0.948)</td>
<td>(0.896, 1.361)</td>
</tr>
<tr>
<td>x=1.261</td>
<td>x=1.301</td>
<td>x=1.560</td>
<td>x=1.648</td>
<td>x=1.707</td>
</tr>
<tr>
<td>2</td>
<td>(0.879, 0.884)</td>
<td>(0.880, 0.880)</td>
<td>(1.147, 0.693)</td>
<td>(1.155, 1.615)</td>
</tr>
<tr>
<td>x=1.174</td>
<td>x=1.175</td>
<td>x=1.301</td>
<td>x=1.690</td>
<td>x=1.696</td>
</tr>
<tr>
<td>3 (0.883, 0.883)</td>
<td>(0.884, 0.879)</td>
<td>(1.164, 0.698)</td>
<td>(1.159, 1.159)</td>
<td>(1.165, 1.155)</td>
</tr>
<tr>
<td>x=1.174</td>
<td>x=1.174</td>
<td>x=1.261</td>
<td>x=1.680</td>
<td>x=1.690</td>
</tr>
</tbody>
</table>
Negotiations have to start in early phases of network creation, and linking negotiations with other issues for which cooperation is desirable may result in more stable agreements than single-issue agreements on fisheries management alone. Moreover, agreeing on location choice, without jointly managing harvesting effort, may result in suboptimal situations. Incentives to reach overall agreements are, however, in most situations high as potential gains of cooperative management are substantial.

Although the model simplifies fishermen behavior and ecosystem functioning, the results show strong evidence that cooperative reserve and effort management will lead to a substantial improvement in revenues and biomass for all participants. More realistic behavioral and ecological representations, for example dealing with limited entry fisheries, multi-species systems, fish-age, fish mortality and other biological and ecological issues, are likely to show even larger effects of cooperation. In particular, a richer ecosystem model would allow measures of biodiversity and/or ecosystem quality to play a role in productivity and dispersal. This would allow effects of fisheries management on patch health and productivity to be explicitly considered. Furthermore, although we concentrate in this paper only on marine reserves, similar result are expected for terrestrial ecosystem reserves to protect for example bird species, insects or other animals who disperse over large areas. For that reason, mechanisms and conclusions presented here are more widely applicable than for fisheries management alone.

REFERENCES


AN ECONOMIC ANALYSIS OF MANAGEMENT OPTIONS IN THE WESTERN ROCK LOBSTER FISHERY OF WESTERN AUSTRALIA

Neil Thomson
Department of Fisheries, Western Australia
168 St George’s Terrace, Perth, Western Australia 6000 Australia

Nick Caputi
Department of Fisheries, Western Australia,
Western Australian Fisheries and Marine Research Laboratories, PO Box 20 North Beach, Western Australia 6920 Australia

ABSTRACT

The Western Rock Lobster Fishery, which is located on the lower west coast of Western Australia, is the largest rock lobster fishery in any county. It supports about 550 lobster fishing boats and has an average annual catch of 11,000 tonnes valued at about $AUD250 million. The sustainability of the fishery is maintained by limiting total allowable effort (TAE), managed through an individually transferable effort (ITE) system.

Ongoing improvements in the effectiveness of rock lobster fishing, have placed increased pressure on the fishery and an assessment of the estimated ‘sustainability index’ has indicated that an effort reduction of about 15% is required in one of the three management zones of the fishery, to ensure there is an adequate breeding stock for continued sustainability.

Management options (such as reductions in the number of traps allowed to be used in the fishery, seasonal closures and changes to the maximum size of lobsters taken) to achieve the 15% TAE reduction for the zone vary in the way they could impact on the fishers’ financial position because they have different impacts on the value of both the income and expenses.

The expected annual net revenue (average revenue net of average fixed and variable costs) of fishers, under different management scenarios, is modeled to determine which has the least negative impact (or as occurs in some cases, the most positive impact) on the net revenue of fishers. The results of the study (which assessed both Year 1 and Year 2 impacts) were provided to the rock lobster industry and the Western Australian Government’s industry advisory group in order to assist in the decision making process. The assumptions used in the analysis were also provided to fishers so that feedback could be garnered in order to gauge the veracity of the results.

The analysis showed that the most efficient management options were those that involved closing the fishery during periods when the catch rate of rock lobsters is low. These periods (ranked from the most efficient to the least efficient in Year 1), included: (a) 21 days from 15 January to 10 February; (b) 16 days from 15 November to 30 November; (c) late season closures for 3 to 7 days around the full moon; (d) June closure; and (e) early season closures for 3 to 7 days around the full moon. By the second year all of these closures resulted in increased net revenue due to the cost savings and the reduced negative impact on catch.

2 Email: nthomson@fish.wa.gov.au
Uniform trap reductions (which could be imposed on a proportional basis against fishers existing unit entitlements for all or part of the season) were shown to be the least efficient in the short-term, however this assessment does not account for any long-term benefits arising from a reduction in fleet size as was observed in previous trap reductions in 1993/94. The results of the study provided input into the decision making process.

INTRODUCTION

The Western Rock Lobster Fishery, which is located on the lower west coast of Western Australia, is the largest rock lobster fishery in any county. It supports about 550 lobster fishing boats and about 1500 fishers. Many more are employed in the processing sector. The industry has an average annual catch of about 11,000 tonnes with a gross value of production of about $AUD250 million per annum (based on the ex-vessel price of lobsters paid to fishers).

The sustainability of the fishery is maintained by limiting total allowable effort (TAE), managed through an individually transferable effort (ITE) system. This system has provided a sound basis for management since 1963, when limits on the TAE were introduced. A series of management changes (eg closed seasons, trap reductions) have been made over the years with the objective to remove latent effort within the fishery and reduce the TAE in order to maintain the fishery's sustainability (Caputi et al., 1997).

In the fishery, trends in rock lobster stock are monitored by means of a comprehensive survey of the recruitment and spawning stock and an assessment of voluntary and mandatory reports (on catch and effort) provided by fishers. The abundance of the settlement of the post-larval stage (puerulus) has been monitored for over 35 years and provides a reliable basis for catch prediction which is utilised in the management of the fishery (Caputi et al., 1995). The breeding stock is monitored from catch rates of commercial vessels and since the early 1990's from fishery-independent breeding stock surveys.

Increased efficiencies in the operations of rock lobster fishers has increased the exploitation (Wright et al., 2006) and placed pressure on the breeding stock. The fishery is currently managed on the basis of a biological reference point (BRP) based on the breeding stock. Latest surveys indicate that the breeding stock in one of the zones (the North Coastal Zone, otherwise referred to as Zone B3) is declining and is close to breaching the BRP. An updated analysis from the Hall and Chubb (2001) Rock Lobster Model indicated that an effort reduction of about 15% was required to ensure that the breeding stock in Zone B was maintained above the BRP over the next few years. A similar assessment has been made for the other rock lobster fishing zones where the sustainability concerns are not as vexed, therefore this study focuses on the results of the Zone B analysis.

While industry generally agreed about the need for effort reduction, there was extensive debate about which management method should be adopted in order to achieve the required effort reduction and the subsequent improvement in the breeding stock. Management options such as reductions in the number of traps fished, seasonal closures, and maximum size (of rock lobsters kept) changes, were considered and these vary in the way they impacted on a fishers' financial position because they had different impacts on the catch and value of rock lobsters and also impacted in varying ways on fishers operating costs (eg labour, bait and fuel). Ideally the management method chosen would achieve the required management outcome but minimise any negative impact on the earnings (net of costs) of fishers.

This study estimated the expected impact of different management options on fishers' gross margins by modelling the average revenue and fixed and variable costs of fishers and assessed how these would be affected by different management options.

The most significant impact of a new management measure on catch is likely to be felt in the first year after the management is implemented. The reason for the lessened negative impact on catch in Year 2 is that any lobsters left behind as a result of the management measures in the first year will grow in size and be available for capture in Year 2 and subsequent years. This was demonstrated by the 1993/94 management package when an 18% trap reduction was imposed along with other management measures.

---

3 Zone B encompasses Western Australian coastal waters north of latitude 30° South, excluding waters surrounding the Abrolhos Islands, which lie 60 kilometres west of the coast.
The results of the analysis of Year 1 and Year 2 impacts on expected gross margins were provided to industry and the Western Australian Government’s industry advisory group on rock lobsters to assist in deciding what combination of management options for effort reduction to adopt.

**Management Options Considered**

There were three types of management options that were considered to achieve the required 15% reduction in TAE, being: (a) trap reductions for part or all of the season; (b) seasonal or time closures; and (c) female maximum size change. All of these have their advantages and disadvantages from a biological, economic, marketing and social perspective and will affect fishers differently, depending on their circumstances and the way they fish.

A trap reduction over the whole season will also achieve the required reduction in TAE, resulting in a saving in the cost of traps and bait, but the number of days fished would stay the same so that there is little (if any) saving in fuel costs. Previous experience has shown that trap reductions have probably accelerated the decline in the number vessels in the fishery as some fishers sell their trap entitlements to others and exit the industry. While this is likely to lead to a long-term improvement in the economic efficiency of effort, there are also likely to be substantial transitional costs, as capital is made redundant.

A trap reduction for part of the season was another management option considered, as it may be used to reduce the catch during the peak catch periods in December and March and hence allow for a more orderly processing and marketing of the lobsters. The industry is of the view that such an option could result in improved prices at peak periods of catch, although prices used in the study were based on past observations, of trends within the season, and current average prices.

Time closures, particularly during periods of low catch rates, have the advantage of reducing bait and fuel costs with a relatively minimal impact on catch. The time closures considered were November, January, June and during periods of full moon. The full moon closures were considered over periods from the early and later parts of the fishing season, which is November to February and March to June, respectively. The full moon period has a negative impact on catch rates of about 20%, particularly in the later part of the season (Srisurichan et al., 2005).

Time closures may have positive social benefits in providing fishers with a rest break during the 7.5-month season (15 November to 30 June). However, they may not promote any long-term fleet rationalisation, over and above that which has been occurring as technology and fishing practices have changed.

The option to lower the maximum allowable size of female rock lobsters caught from 105 mm carapace length to 100 mm (which is aimed at providing direct protection to mature females) has the advantage of targeting the breeding stock directly and has the least impact on catch. However it has no social or economic advantages in that it does not reduce operating costs.

**THE MODEL**

**The Impact of Various Effort Reduction Proposals**

A comparison of the various management options was undertaken so that the net biological effect of effort reduction options could be determined. An estimate was made of the percent effort reductions that would be achieved by implementing each of the options so that the options could be compared. For example, the 15% reduction in TAE could be achieved simply by imposing a 15% trap reduction for the whole year. However, effort reduction options covering only part of the year (for example a 15% trap reduction in November and December), were scaled for the proportion of annual catch caught in the period for which an effort reduction was applied.

A similar assessment was done to evaluate the time closures. For example, January was being considered for closure because it is a period of low catch rate with a poor economic return taking into account the cost of fishing. During January about 13% of the annual trap lifts occur and so the estimated savings in trap lifts (and hence in bait and fuel expenses) for the year is assumed to be about 13%. However because this is a low catch rate period, a January closure does not equate to a 13% reduction in fishing effort. During January about 6% of the Zone B catch is taken and so a January closure was assumed to represent the
same effective effort reduction as a 6% trap reduction for the whole year. Other time closures were considered in the same way so that a comparison against different effort reduction options could be made. Throughout the paper, the term ‘effective effort reduction’ is used to describe how various options are equated.

The change to the female maximum size does not have any savings in trap lifts so the impact of a maximum size change was compared to that of a trap reduction on the basis of their expected long term (say 5 years) impact on the breeding stock. Thus for Zone B, the output from the Hall and Chubb (2001) model indicated that a change in the maximum size from the current maximum of 105 mm to 100 or 95 mm resulted in an effective effort reduction of 3.5% or 7.8% respectively.

**Rock Lobster Prices**

The average price for rock lobsters was set at the current season average price, which is $20 per kilogram, but weighted each month, by the average monthly variation, calculated from a ten-year data set, noting that in real terms, the average price is higher but trending downwards.

**Rock Lobsters Fishing Costs**

The Western Rock Lobster Fishery is characteristically fished by small modern craft having a length of about 20 metres. They are generally crewed by a skipper and two deck-hands, although there are some that are crewed by one, two or four crew. Recently, data were collected in a survey of the operating costs of rock-lobster fishers as part of a broader economic consultancy on the merits of input controls versus output controls. Data from that survey has been used to provide an indication of both fixed and variable costs of fishing. The assumptions about costs have been validated on an informal basis, as they have been reviewed by the rock lobster fishing industry.

The estimated annual fixed costs for a fishing vessels were as follows:

- the capital cost of a rock lobster fishing vessel is $AUD500,000, annualised at 12% per annum in order to approximate both for the cost of capital and boat depreciation;
- the cost of an annual overhaul is $AUD15,000 per year;
- the cost of administration is $AUD15,000 per year; and
- the cost of running the licensees office is $AUD11,880 per year (including the cost of bookkeeping, office consumables, insurance and depreciation on office equipment).

No consideration was given to the costs of servicing capital associated with rock lobster trap licences. While this capital is considerable, with traps trading at between $AUD20,000 and $AUD25,000 per trap, their inclusion in the cost base was not considered necessary in order to compare management options.

Estimates were made about the variable costs of labour (which were based on the well established industry norms which include a revenue sharing agreement with crew), fuel and bait costs. Fuel and bait costs have been converted into an average cost per trap lift basis, noting that the average annual fuel bill for fishers is approximately $45,000 per annum, after the Australian Federal Government’s fuel tax rebate which is provided to primary producers is accounted for.

The average variable cost per trap lift was used to estimate savings where the number of trap lifts was assumed to be reduced due to the implementation of time closures. This assumption was central to the estimated saving that time closures were shown to produce.

**Treatment of Costs and Revenues**

Under the time closure scenarios, whether they were seasonal or other periods of low catch, it was assumed that variable costs were not consumed during the period of the time closure, whereas fixed costs were unchanged.

In the case of trap reductions, bait costs were reduced in proportion to the trap reduction that was considered. With fewer traps, it was assumed that fishers would continue to fish in the same fishing grounds, so fuel costs were assumed to be unchanged. Because of the revenue sharing arrangements,
labour costs are proportional to the revenues from rock lobsters caught, except for a retainer payment for skippers.

It was estimated using the Hall and Chubb (2001) model that a 15% effective effort reduction would result in a reduction in catch of 9% in the first year and 3% in the subsequent year. The reason for the lessened negative impact on catch in Year 2 is that any lobsters left behind as a result of the management measures in the first year will, despite suffering some natural mortality, the survivors will grow in size and be available for capture in Year 2 and subsequent years.

The assessment of the Zone B fishery is complicated by the fact that in the last 3.5 months of the fishery (15 March to 30 June) about half of the 280 vessels move to fish another zone of the fishery, the Abrolhos Islands (also known as Zone A). Thus effort reductions during the first four months of the fishery (15 November to 14 March) are borne by all fishers while those in the last 3.5 months are only borne by those remaining in Zone B. The economic assessment present in this study focuses only on those fishers who fish in Zone B for the whole season.

THE RESULTS

The results of the analysis are presented (below) showing the net revenue impact of effort reduction options in the first year after it is introduced (Year 1) and in the following year (Year 2). Different options were considered up to a 15% effective effort reduction. Zone B is currently considered to be the least profitable of the rock lobster zones in Western Australia as a result of a recent low catches with expected gross margins of $AUD34,400 per boat (Fig. 1).

Figure 1 shows that as the fishery effort is reduced in the first year, so are the short-term returns to fishers. However, not all options have the same impact on fisher revenues and costs, therefore the aim is to identify those options that provide the greatest effective effort reduction but cause the least negative impact on short term net revenue. The second year shows a similar trend however the impact on catch is much less (see discussion above) but the cost savings are maintained (Fig. 2).

![Figure 1. Expected gross margin in year 1 versus the effective effort reduction.](image-url)
Figure 2. Expected gross margin in year 2 versus the effective effort reduction.

**Time Closures**

The analysis showed that the most economically efficient option in Year 1 would be to close the season between 15 January and 10 February and this could result in a net improvement in the expected gross margin (from $34,400 per annum to $37,000 in the first year), for an effective effort reduction of about 5%. Note that other January closure options were also tested (by extending or shortening the period of the closure), with this option being the most efficient.

The expected net improvement in average gross margins does not necessarily mean that all fishers are currently losing money when they undertake fishing activity in this period. It does, however, suggest that gross margins are very limited in that period. Some fishers also operate during this period to maintain cash flow. A net benefit is likely to arise only if all fishers are barred from fishing in this period because it is assumed that 40% of the catch foregone (that would otherwise be caught in the period of closure) will be caught later in the season for no additional cost.

This conclusion and treatment of revenues was broadly supported by the anecdotal views of individual fishers. Incidentally, some fishers voluntarily cease fishing over the late January period in order to take holidays over the summer season and to minimise costs during the low catch period.

The November closure is another period that appears to provide an effective effort reduction of about 7% with minimal reduction in gross margin. November, which is at the start of the fishing season, is a period with relatively low catch rates and hence the ratio of catch loss to cost savings is low if there is a delayed start to the fishing season.

The Zone B fishery is shared by fishers who fish around the Abrolhos Islands, from the opening of the season in November to 14 March. This means that in Year 1 (Fig. 1), insofar as those fishers that exclusively fish in Zone B are concerned, effort reduction strategies that occur during the shared period 15 November to 14 March, are likely to have a lesser relative negative impact on their gross margin than those options that occur only in the period from 15 March through to the end of June when the season closes. In Year 2, (Fig. 2) the relative difference between early season and late season time closures was eliminated. These outcomes highlighted the potential different interests of fisher stakeholders involved in the decision making process.
Similar to the Year 1 analysis, the results of the Year 2 analysis (Fig. 2) indicate that most efficient options appear to be time closures during low catch periods. In the second and subsequent seasons the cost savings are maintained, however the reduction in catch is lessened because fishers catch many of those lobsters left behind in the first year of effort reduction. Thus all the time closures result in a net benefit in gross margin while still maintaining an effort reduction.

The January closure could provide benefits of approximately $7,000 per annum (20% increase) to fishers in the second and following seasons. The foregone catch in the January period is higher in Year 1, but in Year 2, it is assumed that catches throughout the year will increase more substantially as a result of the January closure.

**Maximum size**

The maximum size change for females has a small reduction in the gross margin in Year 1 (Fig. 1) and is estimated to have the equivalent impact on breeding stock of a 3% to 4% effort reduction. However there are no cost savings associated with this measure and hence in the second and subsequent years there is a similar reduction in gross margins as there is no carryover of stock available for capture (Fig. 2).

**Trap Reductions**

The trap reductions of 5% to 15% are assumed to result in the same effective effort reduction as the proportion of traps reduced. Trap reductions are also likely to result in some savings in the cost of bait used but no significant savings in terms of fuel as it is assumed that fishers will fish the same number of days and travel to similar fishing locations even if their total number of traps are reduced proportionally. Hence there are likely to be substantially fewer cost savings than those likely to arise for equivalent effort reductions where time closures are implemented. Therefore a significant reduction in gross margin is apparent in Year 1 (Fig. 1). In the second year most of the catch foregone in the first year is available for capture and the net impact on the gross margin is negligible, even with a 15% trap reduction (Fig. 2).

**DISCUSSION AND CONCLUDING REMARKS**

The analysis of the different impacts of effort reduction options provided timely input into the decision making process of the Western Australian Government's rock lobster industry advisory committee. This committee was tasked with providing advice to the Western Australian Minister for Fisheries on how to achieve an effective effort reduction of 15% in Zone B and lesser effective effort reductions in other zones of the Western Rock Lobster Fishery. This effort reduction was required, particularly in Zone B, to achieve an improvement in the breeding stock.

This study allowed industry and managers to assess the short-term economic impact of the proposed management changes as well as the assessment of the biological consequences of the changes on the stock undertaken by the Hall and Chubb (2001) rock lobster model.

The analysis showed that the most economically efficient options in the short term were targeted seasonal closures, including closures for periods during November, January or June and 3-day to 7-day closures over the full moon period. These are all periods of relatively low catch rates. The analysis showed trap reductions were effective and efficient for the two years. The closures for the 3 months specified each contributed about 5% to 7% in effective effort reduction and by the second year they all had a positive impact on the gross margin.

It is acknowledged that the study is limited in that it only examines the impact of effort reductions for two years and does not include an assessment of how longer term structural changes in the fleet could improve the relative efficiency of trap reduction options, if they were to be introduced. Trap reductions could have a long-term economic advantage if they promote further fleet rationalization, arising when some fishers sell their trap entitlements to others and leave the industry.

The analysis also simplifies the dynamic and inter-temporal relationship between fishing effort and catch at different times of the year and for different periods during moon cycle. For example, fishers may modify their behaviour to adjust for new management rules in order to try and minimise their impact; an assessment of this behaviour would require some form of optimisation. However this adjustment of
behave would apply to all the potential management rule changes to some extent so that the relative impacts should still be relevant.

Notwithstanding the simplification, if the basic premise that an effective effort reduction of 15% will result in catch reductions of 9% and 3% in years 1 and 2 respectively, then there is likely to be a benefit to fishers from the effort reductions, particularly if it brings about a reduction in expenditure required to fish (e.g., the cost of labour, fuel and bait).

The information from this study was a significant contribution to the decision-making process of determining the new management package. The package recommended for Zone B consisted of a 15 January to 10 February closure, a 10% trap reduction from 15 November to 14 March and Sundays off from 15 March to 30 June. (It is noted that the Sunday off scenario was not examined in this study, but was included after discussions with fishers who requested it.) The 'Sundays off' option, during the latter part of the season, was supported by the Zone B fishers in order to overcome potential occupational health and safety issues associated with fishing that is occurring continuously for 7.5 months.

In Zone C (which is south of the Zone A and B fisheries), fishers opted for a later start to the season opening on 25 November and they will be trialling 3-day moon closures from February to June. Zone A fishers who also fish in Zone B until the 14 March will have 10% trap reductions until the 15 April. The trap reductions have been recommended to cover the peak catch period of December on the coast and March-April at the Abrolhos Islands. (Zone A).

ACKNOWLEDGEMENTS

Authors thank the economic consultants, Economic Research Associates (Perth, Western Australia) for access to economic data and Rhys Brown and Dr Jim Penn, Department of Fisheries (Western Australia) for remarks provided on this paper.

REFERENCES


TESTING THE STABILITY OF RECREATIONAL FISHING PARTICIPATION PROBABILITIES ¹

Eric M. Thunberg ² and Charles M. Fulcher
Social Science Branch
Northeast Fisheries Science Center
NOAA Fisheries Service
Woods Hole, Massachusetts

ABSTRACT
Forecasts of recreational fishing participation provide managers with a planning tool to anticipate changes in numbers of anglers that may affect future demand for fishing opportunities. Projections of recreational fishing participation have typically been accomplished by estimating participation probabilities for cohorts of a given population and then applying these probabilities to forecasted changes in population size and demographic composition. As such, the resulting predictions rely on the assumption that estimated participation probabilities within each demographic cohort are constant over time. This assumption was tested using replicated surveys of marine recreational fishing participation conducted in 1994 and again in 2002-2003 for the Northeast, United States coastal population from Maine to Virginia. Participation probabilities and forecasts obtained from the 1994 were compared to both actual participation rates and the estimated participation probabilities in the 2002-2003 survey. Results suggest that participation probabilities among demographic cohorts are not stable over time. Additional avenues for research are identified that could improve predictions of changing demand for recreational fishing resources.

INTRODUCTION
Forecasts of recreational fishing participation provide managers with a planning tool to anticipate changes in numbers of anglers that may affect future demand for fishery resources. Although it is well recognized that a variety of factors influence participation decisions (see for example Searle and Jackson, 1985; Kay and Jackson, 1991; and Aas, 1995) projections of recreational fishing participation have typically been accomplished by first estimating participation probabilities for demographic cohorts of a given population. These probabilities are then applied to forecasted changes in population size and demographic composition to estimate future participation and participation rates.

Loomis and Ditton (1988) were among the first to develop participation forecasts for saltwater recreational anglers in Texas. Their approach involves estimation of participation proportions for demographic cohorts based on age, race, and gender. Using a similar approach Murdock et al. (1992) provided National estimates of fishing participation to the year 2050 based on demographic trends. Milon (2000) also used methods based on population proportions to develop forecasts of saltwater participation in the Southeastern U.S. coastal states. Edwards (1989), Milon and Thunberg (1993), and Thunberg et al. (1999) developed statistical models to estimate participation probabilities and forecasts of marine recreational fishing for the U.S. Atlantic seaboard, Florida resident anglers, and the U.S. Northeast region respectively³.

In each one of the above studies, initial participation probabilities were based on survey data. Further, the resulting forecasts of fishing participation were based on the assumption that the estimated participation probabilities by demographic cohorts would remain constant. This means that in addition to potential

² Email: Eric.Thunberg@noaa.gov
³ Other than Edwards (1989) all of these studies were based on one of two methods. For an overview of these methods and their advantages/disadvantages, see Thunberg and Milon (2002).
forecast error associated with demographic change, the reliability of participation estimates critically depends on the assumption that the likelihood that a 25-year old female will participate in fishing in the year 2025 is the same as it is today. The present study is the first to test the validity of this assumption by replicating the survey conducted in 1994 (reported in Thunberg et al., 1999) during calendar years 2002/2003.

The remainder of the paper is divided into four sections. In the first section, a brief description of the two surveys is provided including a summary of response rates and a brief description of the survey vehicle; the National Marine Fisheries Service (NMFS) Marine Recreational Fishing Statistics Survey (MRFSS). The second section describes the statistical methods used to estimate participation probabilities and the methods used to forecast future saltwater marine recreational fishing participation. The third section presents the results of the test of the null hypothesis that participation probabilities remained constant. Participation forecasts are also compared. The final section offers conclusions and recommendations for further research.

PARTICIPATION SURVEY

Participation data were collected as a component of the National Marine Fisheries Service (NMFS) Marine Recreational Fishing Statistics Survey (MRFSS)\(^4\). The primary purpose of the MRFSS is to provide annual estimates of marine recreational catch and effort through a combination of a household telephone survey (to estimate fishing effort) and a field intercept survey (to estimate catch). Since the telephone survey is based on a stratified random design where the sample frame is all households in coastal counties it was used as the survey vehicle for both the 1994 and the 2002/2003 surveys.

The MRFSS telephone survey is administered to residents of coastal counties (generally defined as counties within 25 or 50 miles of ocean coastline). Strata are the coastal counties and sample size for each strata is proportional to the square root of the county population. The survey is conducted in six two-month waves beginning with wave 1 (January/February) and ending with wave 6 (November/December). Interviewing is conducted during a two-week period beginning the last week of the wave and continuing into the first week of the next wave.

The MRFSS household survey is designed to acquire information on all fishing trips taken within each two-month wave. For each trip, detailed data are collected on fishing mode (shore, party or charter, and private or rental boat) and primary fishing location (estuary, bay, sound, and distance from shore). Since the primary purpose of the MRFSS is to obtain information on fishing trips, data are not normally collected on individuals or households that have not fished during a given wave, and demographic or economic data are not collected in the base survey.

The participation survey was administered in the following manner. In accord with the MRFSS survey protocol described above, the individual answering the telephone call was asked whether any member of the household had participated in a saltwater recreational fishing trip at any time within the past two months. If a negative response is provided, the MRFSS interview is normally terminated. However, for the participation survey, each respondent was queried as to whether he/she had never fished; not fished in past 12 months; or had fished at least once in past 12 months but not during the past two months. The interview was continued for all individuals in the latter two categories to collect data on age, ethnicity, education, gender, income, and employment status. Demographic data were also collected for a sample of individuals that had never fished. For individuals that had fished in the past two months, the standard MRFSS data were collected for each fishing trip taken in the past two months in addition to demographic data. This survey protocol was followed for all coastal states from Maine to Virginia. The 1994 survey was implemented over waves 3 through 6 during the 1994 calendar year. The 2002/03 survey was originally scheduled to be conducted in waves 2 through 6 of calendar year 2002, but data collected in waves 2 through 4 of that year were unusable due to contractor error. This error was subsequently corrected and the survey was continued in waves 5 and 6 of 2002 and carried over into waves 2 through 4 of calendar year 2003. The resulting data cover the approximate 12-month time frame originally anticipated.

In 1994, 53,553 households for potential inclusion in the base MRFSS and participation survey were screened whereas in 2002/03, 154,958 households were screened (Table 1). The large difference in

\(^4\) A detailed description of the MRFSS can be found at www.st.nmfs.gov/st1/recreational/index.html
sample size between the two different surveys is due to an enlarged sample size for the base MRFSS and the fact that the 2002/03 survey was administered for five of six MRFSS waves whereas the 1994 survey was implemented over four waves.

Table 1. Summary of response rates and sampling rates for participation survey by year and angler category.

<table>
<thead>
<tr>
<th></th>
<th>Total Households</th>
<th>Never Fished</th>
<th>No Fishing in Past 12 Months</th>
<th>Fished in Past 12 Months, Not in Past 2 Months</th>
<th>Two-Month Angler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Households Screened</td>
<td>53,553</td>
<td>154,958</td>
<td>44,714</td>
<td>127,006</td>
<td>2,081</td>
</tr>
<tr>
<td>Interviews Initiated</td>
<td>11,060</td>
<td>42,226</td>
<td>3,109</td>
<td>14,274</td>
<td>1,618</td>
</tr>
<tr>
<td>Completed Interviews</td>
<td>8,621</td>
<td>27,766</td>
<td>2,781</td>
<td>9,241</td>
<td>968</td>
</tr>
<tr>
<td>Percent Initiated</td>
<td>20.7</td>
<td>27.2</td>
<td>7.0</td>
<td>11.2</td>
<td>77.8</td>
</tr>
<tr>
<td>Percent Complete</td>
<td>77.9</td>
<td>65.8</td>
<td>89.4</td>
<td>64.7</td>
<td>59.8</td>
</tr>
</tbody>
</table>

Sampling Rates (%)

North Atlantic

<table>
<thead>
<tr>
<th>Wave</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave 2</td>
<td>7.2</td>
<td></td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Wave 3</td>
<td>10.0</td>
<td>8.4</td>
<td>34.6</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Wave 4</td>
<td>9.8</td>
<td>10.0</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Wave 5</td>
<td>9.9</td>
<td>11.6</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Wave 6</td>
<td>10.2</td>
<td>7.0</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Mid-Atlantic

<table>
<thead>
<tr>
<th>Wave</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave 2</td>
<td>4.9</td>
<td></td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Wave 3</td>
<td>5.2</td>
<td>4.7</td>
<td>25.2</td>
<td>100</td>
<td>76.3</td>
</tr>
<tr>
<td>Wave 4</td>
<td>5.8</td>
<td>5.2</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Wave 5</td>
<td>5.5</td>
<td>9.0</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Wave 6</td>
<td>6.8</td>
<td>7.6</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Since a large proportion of the Northeast region population does not fish at all, different sampling rates were assigned to different categories of anglers. Overall, the participation survey was initiated for about 21% of the total households in 1994 with nearly 78% of respondents completing the survey. In 2002/03, the participation survey was initiated with a higher proportion of screened households (27%) but a lower completion rate (66%) was achieved. Nevertheless, because the sample size was much larger in 2002/03, the number of completed surveys (27,766) was nearly three times as great. Relative to the 1994 survey, completion rates for the 2002/03 survey were generally lower but followed a similar pattern. That is, completion rates were highest for two-month anglers and lower in all other angler categories.

Based on experience gained from the 1994 survey, sampling rates in the 2002/03 for anyone that had ever fished in saltwater or had fished in the either the past year or the past two months were set at 100%. Target sampling rates for individuals that had never fished were initially set at approximately 10% in the North Atlantic states (Maine to Connecticut) and at 5% in the Mid-Atlantic (New York to Virginia). Not surprisingly realized sampling rates deviated from these targets although the realized rates for the 1994 survey were much closer to the targets than those for the 2002/03 survey. Sampling rates in the 1994 survey were initially set to less than 100% for anglers that had not fished in the past twelve months and for anglers that had fished in the past twelve months but not in the past two months. However, after finding the incidence of these two angler categories in the sampled population to be lower than expected, these sampling rates were adjusted to 100%.
STATISTICAL METHODS

Estimation of population parameters from samples drawn from a stratified random design must be weighted according to strata characteristics and related survey procedures (Cochran, 1977). The statistical weights were also used to estimate participation probabilities using a logit model. A more detailed treatment of the specifics of the statistical weighting procedures is reported in Thunberg et al. (1999) and the reader is referred to Pindyck and Rubinfeld, (1981) for a treatment of the logit model. The following provides a brief summary of the steps taken in this study.

Weights

The sampling design requires that three weights be applied to each observation; a population weight, a wave weight, and a sampling rate weight. Thus, for any given stratum (h), wave (w) and individual observation (i), the following weight was assigned:

$$\gamma_{hwi} = \frac{\alpha_h m_{hi}}{b_{hw}}$$

where $\alpha_h$ is the proportion of total coastal county population in stratum h to the population across all strata (L), $m_{hi}$ is the inverse of the sampling rate by angler category (1 to 4) (see Table 1), and $b_{hw}$ is the wave weight for stratum h. Since the realized sampling rates differed across waves, the minimum variance wave weights were calculated as:

$$b_{hw} = \sqrt{\frac{n_{hwi}}{\sum_{w=1}^{W} n_{hwi}}}$$

where $n_{hwi}$ is the total number of observations in stratum h in wave w, and W is the total number of waves. Given these weights, the post-stratified population estimator for a sample proportion for a demographic characteristic j is:

$$P_j = \sum_{h=1}^{H} \sum_{w=1}^{W} \alpha_h b_{hwj} p_{hwj}$$

and

$$p_{hwj} = \frac{\sum_{i=1}^{I} m_{hi} y_{hi}}{\sum_{i=1}^{I} m_{hi} n_{hi}}$$

Finally, the variance for a proportion is:

$$V[P] = \sum_{w=1}^{W} b_{hw}^2 \sum_{i=1}^{I} \alpha_h^2 \frac{p_h q_h}{n_h}$$

where $p_h$ is the proportion in stratum h and $q_h = 1 - p_h$. Note that since the denominator is $n_h - 1$ the sample size in any given stratum must be greater than 1. This meant that some strata had to be combined with strata in adjacent counties of the same state. Appropriate adjustments to the stratum and wave weights were also necessary.

$^5$ Note that since the MRFSS is not conducted in Maine or New Hampshire during waves 2 or 6, the population sum across all strata had to be adjusted accordingly.
Logit Model

The logit model was used to estimate participation probabilities. The logit model is appropriate in cases where the dependent variable represents a dichotomous choice. In this study prediction of annual participation in marine recreational fishing is of interest. Therefore, individuals that never fished or who had not fished in the past year were defined as non-participants and all others were defined as participants. The logit model is based on the cumulative probability density function for the logistic function of the form

\[ P_i = F(Z_i) = F(\alpha + \beta X_i) = \frac{1}{1 + e^{-(\alpha + \beta X_i)}} \]

(6)

The form of the logit model ensures that predicted values will be bounded between 0 and 1. The logit model is estimated as

\[ \log \frac{P_i}{1 - P_i} = \alpha + \beta X_i \]

(7)

where the independent variables were the demographic variables collected on both surveys. These characteristics were household income, age, gender, education, and ethnicity.

Hypothesis Test

Hypotheses about parameters in the logit models can be tested using likelihood ratio tests (Fox, 1997). In this case, we were interested in determining if the estimated parameters of the logit models using 1994 and 2002/3 data respectively were different in a statistically significant sense. Performing the test required estimation of the unrestricted models and of a pooled model restricting the coefficients to be the same for both groups. This test provides considerable flexibility in that particular parameters may be allowed to vary between the regressions, permitting tests on the stability of subsets of parameters in addition to testing the hypothesis that all of the parameters are the same.

The test statistic was calculated as:

\[ LR = -2(\ln(L_C) - \ln(L_U)) \]

(8)

where, \( \ln(L_C) \) is the value of the maximized log-likelihood function from the constrained (pooled) regression and \( \ln(L_U) \) is the sum of the values of the maximized log-likelihood functions from the unconstrained (individual) regressions. This test statistic is distributed as \( \chi^2 \), where \( i \) indicates the number of restrictions being imposed. If the test statistic exceeds the \( \chi^2 \) critical value for \( i \) degrees of freedom, then the hypothesis that the estimated parameters are identical for the two groups is rejected.

RESULTS

The post-stratified estimates for the population sampled in the two surveys differed across nearly every demographic category. In 1994, the sampled population consisted of 48.7% males and 51.3% females (Table 2). In 2002/03, the proportion of males and females was nearly identical (49.9% male and 50.1% female). These point estimates from the two surveys are statistically different. The same is true of the estimates by age groups and household income categories. Compared to 1994, the 2002/03 sample population was older and proportionally more individuals had higher household income. The latter may be a reflection of increasing per capita incomes in nominal terms. That is, as incomes increase an increase is expected in the proportion of individuals in higher income categories. Of the remaining demographic categories, there was some overlap between the two surveys in the estimated confidence intervals for the proportion of whites and Hispanics and the proportion of individuals with a college degree. Otherwise,

---

6 The age groups in the 2002/03 survey were offset one year compared to the 1994 survey while the household income categories were offset by $1. This change in age and household income categories was implemented in 2002/03 to correspond to age and income groups used by the U.S. Census Bureau.
the ethnic composition and the level of educational attainment of the 2002/03 sample population differed from that of the 1994 survey.

Table 2. Summary of post-stratified estimates of descriptive statistics for 1994 and 2002/03 samples. All values are percentages.

<table>
<thead>
<tr>
<th>Demographic Variable</th>
<th>1994 Survey</th>
<th>2002 Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Point Estimate (Standard Deviation)</td>
<td>95% Confidence Interval</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>48.7 (0.0039)</td>
<td>47.9 - 49.5</td>
</tr>
<tr>
<td>Female</td>
<td>51.3 (0.0039)</td>
<td>50.5 - 52.1</td>
</tr>
<tr>
<td>Age Groupa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 to 24 [16 to 25]</td>
<td>14.8 (0.0029)</td>
<td>14.2 - 15.3</td>
</tr>
<tr>
<td>25 to 34 [25 to 35]</td>
<td>24.2 (0.0035)</td>
<td>23.5 - 24.9</td>
</tr>
<tr>
<td>35 to 44 [36 to 45]</td>
<td>20.9 (0.0033)</td>
<td>20.3 - 21.6</td>
</tr>
<tr>
<td>45 to 54 [46 to 55]</td>
<td>16.5 (0.0032)</td>
<td>15.9 - 17.1</td>
</tr>
<tr>
<td>55 to 64 [56 to 65]</td>
<td>10.7 (0.0024)</td>
<td>10.2 - 11.1</td>
</tr>
<tr>
<td>65+ [66+]</td>
<td>13.0 (0.0023)</td>
<td>12.5 - 13.4</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>73.7 (0.0031)</td>
<td>73.1 - 74.3</td>
</tr>
<tr>
<td>Black or African American</td>
<td>13.6 (0.0024)</td>
<td>13.1 - 14.1</td>
</tr>
<tr>
<td>Hispanic</td>
<td>7.5 (0.0019)</td>
<td>7.1 - 7.9</td>
</tr>
<tr>
<td>Asian</td>
<td>1.0 (0.0007)</td>
<td>0.9 - 1.2</td>
</tr>
<tr>
<td>American Indian</td>
<td>0.9 (0.0004)</td>
<td>0.8 - 1.0</td>
</tr>
<tr>
<td>Other</td>
<td>4.2 (0.0018)</td>
<td>3.8 - 4.5</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than High School</td>
<td>9.5 (0.0021)</td>
<td>9.1 - 10.0</td>
</tr>
<tr>
<td>High School Graduate</td>
<td>30.5 (0.0039)</td>
<td>29.8 - 31.3</td>
</tr>
<tr>
<td>Vocational or Associate</td>
<td>4.2 (0.0017)</td>
<td>3.9 - 4.6</td>
</tr>
<tr>
<td>Some College</td>
<td>20.9 (0.0033)</td>
<td>20.3 - 21.6</td>
</tr>
<tr>
<td>College Graduate</td>
<td>24.3 (0.0036)</td>
<td>23.6 - 25.0</td>
</tr>
<tr>
<td>Post-Graduate or Professional Degree</td>
<td>10.5 (0.0023)</td>
<td>10.1 - 11.0</td>
</tr>
<tr>
<td>Household Incomea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than $15,000</td>
<td>12.1 (0.0023)</td>
<td>11.6 - 12.5</td>
</tr>
<tr>
<td>$15,000 to $29,999</td>
<td>23.4 (0.0032)</td>
<td>22.8 - 24.1</td>
</tr>
<tr>
<td>$30,000 to $44,999</td>
<td>22.2 (0.0033)</td>
<td>21.6 - 22.9</td>
</tr>
<tr>
<td>$45,000 to $59,999</td>
<td>18.6 (0.0031)</td>
<td>18.0 - 19.2</td>
</tr>
<tr>
<td>$60,000 to $84,999</td>
<td>12.3 (0.0030)</td>
<td>11.7 - 12.9</td>
</tr>
<tr>
<td>$85,000 or more</td>
<td>11.3 (0.0029)</td>
<td>10.7 - 11.9</td>
</tr>
</tbody>
</table>

a Categories in brackets denote age and income categories used in the 1994 survey.

Differences in the sample populations do not necessarily mean that estimated participation probabilities will be different. However, estimates of demographic characteristics among fishing participants differed across survey years. For example, the proportion of female recreational anglers increased from 18.8% in
1994 to 21.0% in 2002/03 (Table 3). Similarly, the proportion of non-white recreational anglers increased from 11.2% to 14.6% in 2002/03.

**Table 3.** Estimates of demographic composition of marine recreational participants. All values are percentages.

<table>
<thead>
<tr>
<th></th>
<th>1994 Survey</th>
<th>2002/03 Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>81.2</td>
<td>79.0</td>
</tr>
<tr>
<td>Females</td>
<td>18.8</td>
<td>21.0</td>
</tr>
<tr>
<td>Age Group(^a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 to 24 [16 to 25]</td>
<td>11.8</td>
<td>7.2</td>
</tr>
<tr>
<td>25 to 34 [25 to 35]</td>
<td>25.9</td>
<td>15.9</td>
</tr>
<tr>
<td>35 to 44 [36 to 45]</td>
<td>26.1</td>
<td>27.5</td>
</tr>
<tr>
<td>45 to 54 [46 to 55]</td>
<td>18.5</td>
<td>25.1</td>
</tr>
<tr>
<td>55 to 64 [56 to 65]</td>
<td>11.7</td>
<td>15.4</td>
</tr>
<tr>
<td>65+ [66+]</td>
<td>6.1</td>
<td>8.9</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>88.8</td>
<td>85.4</td>
</tr>
<tr>
<td>Black or African American</td>
<td>5.7</td>
<td>7.8</td>
</tr>
<tr>
<td>Hispanic</td>
<td>2.1</td>
<td>3.9</td>
</tr>
<tr>
<td>Asian</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>American Indian</td>
<td>-</td>
<td>1.1</td>
</tr>
<tr>
<td>Other</td>
<td>2.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than High School</td>
<td>6.0</td>
<td>5.1</td>
</tr>
<tr>
<td>High School Graduate</td>
<td>33.8</td>
<td>30.0</td>
</tr>
<tr>
<td>Vocational or Associate</td>
<td>4.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Some College</td>
<td>23.2</td>
<td>15.3</td>
</tr>
<tr>
<td>College Graduate</td>
<td>23.8</td>
<td>23.6</td>
</tr>
<tr>
<td>Post-Graduate or Professional Degree</td>
<td>8.6</td>
<td>17.3</td>
</tr>
<tr>
<td>Household Income(^a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than $15,000 [Less than $14,999]</td>
<td>5.2</td>
<td>3.1</td>
</tr>
<tr>
<td>$15,000 to $29,999 [$15,001 to $30,000]</td>
<td>16.6</td>
<td>8.0</td>
</tr>
<tr>
<td>$30,000 to $44,999 [$30,001 to $45,000]</td>
<td>21.3</td>
<td>15.8</td>
</tr>
<tr>
<td>$45,000 to $59,999 [$45,001 to $60,000]</td>
<td>22.4</td>
<td>18.6</td>
</tr>
<tr>
<td>$60,000 to $84,999 [$60,001 to $85,000]</td>
<td>18.5</td>
<td>20.5</td>
</tr>
<tr>
<td>$85,000 or more [$85,001 or more]</td>
<td>16.0</td>
<td>34.1</td>
</tr>
</tbody>
</table>

\(^a\) Categories in brackets denote age and income categories used in the 1994 survey.

Compared to 1994, proportionally more anglers had either a vocational or associates degree or had some post-graduate or professional degree in 2002/03. However, the cumulative percent of individuals with at least an associates or vocational degree was similar between 2002/03 (43.7%) and 1994 (44.4%). The cumulative percent of anglers between the ages of 25 to 54 was also not appreciably different (70.5% in 1994 as compared to 68.5% in 2002/03).

\(^7\) Demographic statistics are ratio estimators calculated as the weighted number of individuals in subgroup i (participant/non-participant) and demographic category j to the total weighted number of individuals in demographic category j.
Closer inspection of the estimated proportions across age groups between surveys reveals an interesting pattern. Even though the surveys were not quite a decade apart, a substantial number of individuals that were less than 25 in 1994 would have been between the ages of 25 and 34 in 2002/03. Similarly, many individuals that were between 25 and 34 in 1994 would be in the next higher age group in 2002/03, and so on. Aligning the proportion of participants in the age groups (cohort 1) from the 1994 survey with the next highest age groups from the 2002/03 survey shows a potentially strong age cohort effect (Figure 1). These results suggest that recreational fishing preferences are formed at an early age, and once formed, follow a life cycle process where participation increases and then declines as individuals grow older. This pattern also suggests that a lower participation rate among individuals less than 24 years of age may translate into lower participation rates overall as this cohort ages. Of particular relevance to this particular study, is that participation probabilities are would not to be constant. The likelihood ratio test provides a formal basis for testing the hypothesis that participation probabilities are constant.

![Figure 1. Participation by age cohort 1994 and 2002/03.](image)

The likelihood ratio test first requires estimation of the two participation models separately. For each survey year, household and income were specified as detailed in Table 3. Dummy variables were used for gender (1 = male, 0 = female), ethnicity (1 = non-white, 0 = white), individuals less than 25 years of age (1 = < 25, 0 otherwise), for individuals 65 and above (1 >= 65, 0 otherwise), and region (1 = household residence in New Jersey, Delaware, Maryland, or Virginia, 0 otherwise). The reference group was white females between 25 and 64 years of age living from in a coastal state from New York to Maine. Results from both survey years were consistent in terms of sign, were all statistically significant except for the regional dummy variable in the 2002/03 model (Table 4). However, since the dependent variable in the logit model is the logarithm of the odds of choice the parameter estimates themselves cannot be interpreted as probabilities. For continuous variables, the marginal probabilities can be calculated as:

\[
\Delta P_i = \beta_i [P_i(1-P_i)]
\]

where, \( P_i \) was calculated at the median values for household income and education for the reference group. Marginal probabilities for dummy variables were calculated as the difference between the participation probability for the reference group and the participation probability with the dummy variable set to one.

Compared to the estimated marginal probabilities for 1994, the change in the marginal probability for male participation in saltwater recreational fishing is pronounced. In 2002/03 the marginal participation probability for males was 11.8%, a decline of almost 5% from 16.7% in 1994. For all other demographic variables, the marginal probabilities between 1994 and 2002/03 differed by no more then 0.5%.
Table 4. Coefficient estimates for northeast region saltwater recreational fishing participation model for 1994 and 2002/03.

| Variable     | 1994 Survey | | | 2002/03 Survey | | |
|--------------|-------------|----------------------|----------------------|----------------------|----------------------|
|              | Estimated Coefficient | Standard Error | Marginal Probability (%) | Estimated Coefficient | Standard Error | Marginal Probability (%) |
| Intercept    | -2.9101* | 0.1124 | | -3.2575* | 0.2084 | |
| Household Income | 0.1414* | 0.0234 | 0.7 | 0.1640* | 0.0376 | 0.7 |
| Education Non-White | -0.1288* | 0.0214 | -0.5 | -0.1336* | 0.0343 | -0.5 |
| Male | 1.6981* | 0.0754 | 16.7 | 1.4797* | 0.1176 | 11.8 |
| Age <= 24 | -0.2916* | 0.1036 | -1.1 | -0.3811* | 0.1890 | -1.3 |
| Age >= 65 | -0.5045* | 0.1095 | -1.8 | -0.5317* | 0.1730 | -1.7 |
| Mid-Atlantic | 0.1977* | 0.0625 | 1.0 | 0.1263 | 0.0996 | 0.5 |

* Denotes statistically significant at the 0.05 level or greater.

The likelihood ratio test provides a means of testing the hypothesis that the estimated parameters of the full model are equivalent in both survey years. The likelihood ratio test also permits testing hypotheses about specific variables or combinations of variables to identify whether the effect on participation probabilities for specific demographic components is constant. Since eight parameters are estimated in the individual models, there are 255 possible combinations of restrictions. For this study, each of these possible combinations was estimated and a likelihood ratio test performed. The hypothesis test that all 8 estimated parameters (8 constraints) are equivalent was rejected (Table 5). However, the parameter restrictions were not rejected in nearly 80% of the cases. This indicates that at least some of the parameters were stable between the two survey years. To understand what restrictions caused the null hypothesis to be rejected in the other cases, the individual variables and the number of the rejected constraints are summarized in Table 6. The only two parameters appearing in each of the rejected constraints are the intercept and the coefficient on the male dummy variable, seemingly indicating that a difference in the male participation coefficient that is driving the rejections. It is possible to constrain either the intercept or the male coefficient separately, but constraining both simultaneously typically leads to a rejection. There are only 10 cases where both the intercept and male coefficient were constrained and the constraint was not rejected. Unfortunately the coefficients that are allowed to differ in those cases vary, possibly indicating subtle interplays between the variables that are impossible to discern. Nonetheless, each of these 10 cases yields a likelihood ratio test statistic within 10% of the $\chi^2$ critical value, with 7 lying within 5% of the critical value. Thus, these cases may be viewed as near rejections.

The likelihood ratio tests indicate that no one demographic variable (alone or in combination with others) may be conclusively determined to have had no influence on participation probabilities between the 1994 and 2002/03 surveys. Furthermore, even though the differences in marginal probabilities were quite small for all variables other than the male dummy variable, even small differences can produce large changes in forecasted numbers of recreational fishing participants when applied to the entire coastal county population. Even if all other variables were stable compared to the 1994 survey, the change in the male participation probability alone from the 2002/03 survey is large enough to result in an overestimate of forecasted marine recreation fishing participants of between 800 and 900 thousand from 2005 to 2025 (Figure 2). In addition to producing a higher estimate of total participants, forecasts based on the 1994 survey also generate differing estimates of the demographic composition of fishing participants.
Table 5. Summary of results of likelihood ratio tests.

<table>
<thead>
<tr>
<th>Number of Constraints</th>
<th>Number of Tests</th>
<th>Rejections</th>
<th>% Rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>70</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>56</td>
<td>15</td>
<td>27</td>
</tr>
<tr>
<td>6</td>
<td>28</td>
<td>12</td>
<td>43</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>5</td>
<td>63</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>255</td>
<td>54</td>
<td>21</td>
</tr>
</tbody>
</table>

Table 6. Summary of parameters appearing in rejected constraints.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rejections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>54</td>
</tr>
<tr>
<td>Household Income</td>
<td>30</td>
</tr>
<tr>
<td>Education</td>
<td>27</td>
</tr>
<tr>
<td>Non-White</td>
<td>23</td>
</tr>
<tr>
<td>Male</td>
<td>54</td>
</tr>
<tr>
<td>Age &lt;= 24</td>
<td>25</td>
</tr>
<tr>
<td>Age &gt;= 65</td>
<td>22</td>
</tr>
<tr>
<td>Mid-Atlantic</td>
<td>30</td>
</tr>
</tbody>
</table>

Figure 2. Difference in projected marine recreational anglers in the northeast region (1994 - 2002/03).

The largest discrepancy between the 1994 and 2002/03 participation probabilities occurs in the proportion of females in the fishing population. That is, even though the female participation probabilities declined in 2002/03 (Table 7) this reduction was proportionally less than the reduction in the male participation probability. As such, forecasts based on the 2002/03 survey will result in proportionally more females in the fishing population than predicted using the 1994 survey. Additionally, the marginal participation probability for non-whites was slightly higher (i.e., less negative), the marginal probability for individuals less than 24 years of age was lower (more negative), and the marginal probability for
individuals 65 or older was higher (less negative). Thus, compared to predictions using the 2002/03 survey, the 1994 survey predicted composition of the marine recreational fishing public in 2025 would under-represent the proportion of females, non-whites, and individuals 65 years of age or older while overstating the proportion of individuals less than 25 years of age (Figure 3).

**Table 7.** Predicted participation probabilities by demographic cohort for 1994 and 2002/03 surveys.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>White Female</th>
<th>White Male</th>
<th>Non-White Female</th>
<th>Non-White Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME to NY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 to 24</td>
<td>3.6</td>
<td>2.9</td>
<td>16.9</td>
<td>11.5</td>
</tr>
<tr>
<td>25 to 64</td>
<td>4.7</td>
<td>4.2</td>
<td>21.4</td>
<td>16.0</td>
</tr>
<tr>
<td>65+</td>
<td>2.9</td>
<td>2.5</td>
<td>14.1</td>
<td>10.1</td>
</tr>
<tr>
<td>NJ to VA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 to 24</td>
<td>4.3</td>
<td>3.3</td>
<td>19.8</td>
<td>12.9</td>
</tr>
<tr>
<td>25 to 64</td>
<td>5.7</td>
<td>4.7</td>
<td>24.9</td>
<td>17.8</td>
</tr>
<tr>
<td>65+</td>
<td>3.5</td>
<td>2.8</td>
<td>16.7</td>
<td>11.3</td>
</tr>
</tbody>
</table>

**Figure 3.** Difference in demographic composition of fishing participants in 2025 (1994 minus 2002/03).

Although the forecasts of recreational fishing participation in 2025 differ considerably between the two survey years, the predicted participation in both survey years was quite close to that estimated from the base MRFSS survey in the years the surveys were initiated (black bars in Figure 4). Short term forecasts using the 1994 participation probabilities remained within the range of observed annual estimates of participation through 2003 but were consistently on the high side. By contrast, compared to the independent MRFSS estimate of participation, the participation probabilities based on the 2002/03 survey provided a precise estimate of participation in calendar year 2002 but would have consistently underestimated participation in most other years. What seems apparent is that the methods employed herein produce estimates of participation that are a reflection of conditions that existed at the time the survey was conducted. As such, they provide a reasonable understanding of what components of the coastal county population fished in any given year but are not likely to provide a reliable estimate of either future numbers of participants or their demographic profile.
CONCLUSIONS
The study findings do not support the hypothesis that participation probabilities are stable over time. Hence, forecasting recreational fishing participation will not provide a reliable estimate of future numbers of fishing participants. Even subtle changes in participation probabilities among demographic cohorts can lead to an unreliable understanding of the composition of the fishing public. This can compromise strategic planning based on anticipated demand for recreation fishing opportunities.

These conclusions should be tempered by acknowledging that the participation modeling was limited by consideration of demographic variables alone. Reliance on demographic information alone is insufficient for understanding motivations for fishing and the social factors that influence participation decisions. What is needed is a more comprehensive approach to participation modeling that includes the multifaceted social dimensions of recreational fishing participation including availability of substitute recreational activities.

REFERENCES


IMPROVING UTILIZATION OF THE ATLANTIC SEA SCALLOP RESOURCE: AN ANALYSIS OF ROTATIONAL MANAGEMENT OF FISHING GROUNDS

Diego Valderrama and James L. Anderson

Department of Environmental and Natural Resource Economics, University of Rhode Island, 205 Kingston Coastal Institute, 1 Greenhouse Road, Kingston, RI 02881, USA

ABSTRACT

An age-structured bioeconomic model was constructed to determine optimal patterns of exploitation for the U.S. Atlantic sea scallop fishery. Results indicated that economic rents are maximized by engaging in pulse fishing strategies, whereby fishing only occurs following a multi-year closure period. Closures allow biomass to accumulate undisturbed for several years in a row, leading to the harvest of premium-size scallops upon reopening of the fishing grounds. Closures also result in substantial reductions in operating fishing costs. The rotational harvesting strategy was found to be robust with respect to a number of assumptions in the model. Policy implications are discussed.

INTRODUCTION

The Atlantic sea scallop, Placopecten magellanicus, is a bivalve mollusk that occurs on the eastern North American continental shelf. Major aggregations are found in the Mid-Atlantic from Virginia to Long Island, on Georges Bank, in the Great South Channel, and in the Gulf of Maine (Figure 1). U.S. meat landings in 2003 exceeded 25,000 metric tons (MT), a historical record, with ex-vessel revenues reaching almost $230 million, making the sea scallop fishery one of the most valuable in the northeastern United States (second only to lobster).

Captures from the U.S. fishery have fluctuated considerably over the years. Landings increased substantially after the mid-1940's, with peaks occurring around 1960, 1978, 1990, and in the most recent period (2001-2004). The U.S. portion of Georges Bank witnessed a dramatic decline in productivity during 1993, with landings remaining low until 1998 (Figure 2). Historically, the Mid-Atlantic Bight area has been less productive than Georges Bank; however, there has been an upward trend in both recruitment and landings in the area since the mid-eighties (NEFSC 2004). Scientists agree that unusually strong recruitment in the Mid-Atlantic Bight has been a key contributor to the record landings achieved in the most recent years.

Sea scallop fisheries in the U.S. Exclusive Economic Zone (EEZ) are managed under the Atlantic Sea Scallop Fishery Management Plan (FMP), initially implemented in May 1982. During the initial years regulation was primarily based on a minimum average meat weight requirement for landings. The near-collapse of the fishery in Georges Bank during the mid-1990s prompted drastic changes in management philosophy. The Amendment #4 to the FMP (NEFMC 1993), implemented in 1994, shifted management away from meat count regulations to effort control measures, including incrementally increasing restrictions on days-at-sea (DAS), minimum ring size, and crew limits. In addition, approximately one-half of the productive scallop grounds on Georges Bank were closed in December 1994. In the Mid-Atlantic, two areas were closed for three years starting in 1998 to protect aggregations of small scallops (Figure 1). Area closures had an immediate effect on scallop abundance and biomass; for example, it is estimated that over 80% of the sea scallop biomass in the U.S. portion of Georges Bank is currently in areas closed to fishing (NEFSC 2004). Portions of Georges Bank closed areas were temporarily opened for

---


2 Email: dval3623@postoffice.uri.edu
limited scallop fishing during 1999-2001, resulting in the capture of exceptional amounts of very large scallops. Remarkable landings have also been achieved from controlled-access programs to the closed areas in the Mid-Atlantic Bight since 2001.

![Figure 1](image_url)

**Figure 1.** Major regions for Atlantic sea scallop fishing in the U.S. The most important aggregations are found in Georges Bank and the Mid-Atlantic Bight. The Mid-Atlantic closed areas have been managed under special access programs since 2001.

The success of the temporary access programs led to the formulation of a new set of regulations, Amendment #10, implemented in 2004 (NEFMC 2004a). This amendment proposes a spatially-based management system, with provisions and criteria for new rotational closures, and separate days-at-sea allocations for reopened closed areas and general open areas. Under this amendment, restricted access to portions of two of the Georges Bank closed areas during the fall of 2004 was approved. Preliminary reports indicate that the reopened areas have again yielded large amounts of "frisbee-sized" scallops (McGovern 2004). Amendment #10 also introduced new gear regulations to improve selectivity towards larger scallops and to reduce the amount of associated bycatch.

**Sea scallops and rotational management**

There is already considerable evidence that rebuilding of sea scallop biomass in heavily overfished areas can be conducted much more efficiently through area closures than with effort control regulations such as meat count requirements or limited crew sizes. For example, biological surveys conducted in 1998 indicated that total and harvestable scallop biomasses were 9 and 14 times denser, respectively, in closed than in adjacent open areas in Georges Bank (Murawski et al. 2000). Evidence clearly suggests that the sea scallop fishery would benefit greatly from a formal "area rotation" scheme of fishing grounds. This same approach has been proposed or is being used for other sedentary species such as sea urchins, sea cucumbers, corals, and abalone (Lai and Bradbury 1998; Heizer 1993; Caddy 1993; Botsford et al. 1993; Sluczanowski 1984). Sea scallops appear to be ideal candidates for rotational fishing because 1) they have low mobility, moving at most a few miles per year; 2) they grow quickly and are relatively long-lived; and 3) they exhibit low natural mortality (around 10% per year).
In its simplest form, the concept of rotational management proposed by Amendment 10 mandates the closure of areas containing beds of small sea scallops before they experience fishing mortality and the reopening of areas for fishing when the scallops are larger, boosting meat yield. In practice, this simple concept will prove difficult to apply because it will require consideration of the smallest practical areas to close, the duration of the closures, and the fishing mortality to be applied when the areas re-open. Despite the information gaps, the New England Fishery Management Council (NEFMC) has proposed a fully-adaptive rotation system of flexible-boundary areas. Based on the results from government- and industry-supported resource surveys, the NEFMC would consider areas for closure when the expected increase in exploitable biomass in the absence of fishing mortality exceeds 30% per year, and re-open to fishing when the annual biomass increase in the absence of fishing mortality is less than 15% per year. This strategy would protect areas with young, fast-growing scallops, and re-direct fishing pressure to areas with older, slower growing scallops. The NEFMC has proposed to use ten-minute squares (each about 75 square nautical miles) as the basis for the evaluation of contiguous blocks that may close to protect young scallops. A ten-minute square implies a high resolution level for management that is currently not possible to achieve with the existing government surveys. It is still unclear whether industry-supported surveys will provide sufficient information for final implementation of this fully-adaptive rotation system.

Given the complexity of the rotation system contemplated by Amendment 10, the NEFMC proposed a simpler scheme of mechanical rotation via Framework Adjustment (FA) 16 (NEFMC 2004b) for portions of three closed areas in Georges Bank. Under this strategy, access was allowed to the Nantucket Lightship Area and Closed Area II in the fall of 2004. In 2005, the Nantucket Lightship Area would close, while Closed Areas I and II would become accessible for scallop fishing. The general idea is to implement a three-year rotation cycle that would open access to scallops in two of three groundfish closed areas each year. Thus, in 2006 Closed Area II would close, while the Nantucket Lightship Area and Closed Area I would become accessible. This three-year cycle might be reinitiated in 2007. The order of rotation and target mortality rates specified in FA 16 are given in Table 1.

The simplicity of the rotation scheme proposed in FA 16 suggests that research efforts should be directed first at the improvement of strategies for mechanical rotation before engaging in ambitious (and difficult to implement) rotation systems based on fully-adaptive flexible boundaries. There is little doubt that the latter system would lead to a more rational utilization of the resource, but its complex logistics may ultimately render this approach infeasible. Optimization of mechanical rotation strategies might serve as a basis for the design of simple but highly effective rotational systems that are much easier to administer.
**Table 1.** Fishing mortality targets for a mechanical area rotation strategy proposed in Framework Adjustment 16. $F = 0.2$ is approximately the continuous (i.e., every year) fishing mortality that maximizes yield-per-recruit, or $F_{\text{max}}$.

<table>
<thead>
<tr>
<th>Fishing Year</th>
<th>Closed Area I</th>
<th>Closed Area II</th>
<th>Nantucket Lightship Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Closed</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>2005</td>
<td>0.2</td>
<td>0.2</td>
<td>Closed</td>
</tr>
<tr>
<td>2006</td>
<td>0.2</td>
<td>Closed</td>
<td>0.2</td>
</tr>
<tr>
<td>2007</td>
<td>Same as 2004</td>
<td>Same as 2004</td>
<td>Same as 2004</td>
</tr>
</tbody>
</table>


With this idea in mind, the goal of this paper is to develop a bioeconomic model of Atlantic sea scallops aimed at the identification of optimal patterns of exploitation based on the essential biological features of the resource. The model seeks to describe the population dynamics of a plot of sea scallops in both Georges Bank and the Mid-Atlantic Bight regions and determine the optimal levels of annual exploitation rates leading to maximization of the Net Present Value of the fishery for a period of 30 years ($\text{NPV}_{30}$).

Evidence from the temporary access programs to closed areas suggests that rotational management is linked to improved efficiencies in the fishery; therefore, it is anticipated that the simulation model will specify a staggered schedule of closures and reopenings for the plot of sea scallops. One of the most important insights to be obtained from the model is related to the optimal duration of closures for the fishery. This result would provide an important benchmark to evaluate the effectiveness of the three-year cycles contemplated by FA 16.

The following section of this paper explains the bioeconomic model for Atlantic sea scallops. Most of the model parameters were obtained from a number of studies conducted by scientists at the Northeast Fisheries Science Center, National Marine Fisheries Service (NMFS/NEFSC). This section will be followed by a discussion of the results of various model simulations. Particular emphasis will be given to the implications of our empirical results with respect to the rotation systems proposed in Amendment 10 and FA 16.

**The Model**

Our modeling approach is similar to that used in population dynamics models developed by scientists at the NMFS/NEFSC. These models have been successful in forecasting the increases in sea scallop abundance, landings, and catch rates that have been observed in the last several years (NEFMC 2004a).

Briefly, the objective of the model is to keep track of the number, size composition, and biomass of two hypothetical stocks of scallops – placed in Georges Bank and the Mid-Atlantic Bight, respectively – for a period of 30 years. The main processes affecting the standing biomass are natural recruitment, natural mortality, and fishery exploitation. The model distributes the population of fully-recruited scallops across 5-mm size classes, or bins (size refers to the height of the shell in mm). The smallest size class is the 40-45-mm bin, corresponding to young adults (about 2.2 and 2.5 years-old in Georges Bank and the Mid-Atlantic Bight, respectively). The largest size class is the 145-150-mm bin, occupied by the oldest scallops. Scientists at the NEFSC routinely model recruitment as a stochastic process\(^3\), assuming a log-normal distribution for each management sub-area. In our model, recruitment of new members into the adult population is assumed to occur at an annual constant rate $R$, corresponding to a weighed average of the historical time series between 1992 and 2000 for both Georges Bank and the Mid-Atlantic Bight (NEFSC 2001). We assumed a constant rate of recruitment to keep the model within tractable proportions for the optimization process. In a subsequent stage, Monte Carlo simulation analyses were conducted to evaluate the effect of stochastic variation in recruitment rates on the baseline results.

The model uses a difference equation approach where time is partitioned into discrete time steps $t_i, t_i, ...$, with a time step of length $\Delta t = t_{i+1} - t_i = 0.083$ years (approximately 1 month). Population is tracked at

\(^3\) Studies have repeatedly indicated that a stock-recruitment relationship is difficult to establish in either Georges Bank or the Mid-Atlantic (NEFSC 2004).
each time $t$ by population vectors $\mathbf{p}(t) = (p_1, p_2, \ldots, p_n)$, where $p_j$ represents the density of scallops in the $j$th size class at time $t$. Catches at each size class at each $k$th time step are represented by a landings vector $\mathbf{h}(t_k)$ calculated as

$$h(t_k) = [I - e^{\lambda M(t_k)}] \mathbf{p}(t_k)$$

where $I$ is the identity matrix and $H$ is a diagonal matrix whose $j$th diagonal entry $h_{jj}$ is given by

$$h_{jj} = \begin{cases} 0, & \text{if } s(j) \leq s_d \\ -F_c(t_k) \frac{[s(j) - s_{\text{min}}]}{(s_{\text{full}} - s_{\text{min}})}, & \text{if } s_d < s(j) < s_{\text{full}} \\ -F_e(t_k), & \text{if } s(j) \geq s_{\text{full}} \end{cases}$$

where $s_{\text{min}}$ is the minimum size at which a scallop is vulnerable to the gear, $s_{\text{full}}$ is the size at which a scallop is fully vulnerable to the gear, $s_d$ is the cull size ($\leq s_{\text{min}}$) below which scallops are discarded, and $F_c(t_k)$ denotes the capture fishing mortality rate suffered by a full recruit at time $t_k$ (NEFSCH 2001).

Conversion parameters are used to estimate the vector of meat weights $\mathbf{m}$ (representing the meat weights at shell height $s$) by means of the following shell-height meat-weight relationship:

$$W = e^{a + bs_{\text{in}}(s)}$$

where $W$ is the meat weight of a scallop of shell height $s$.

Thus, the landings $L(t_k)$ for the $k$th time step can be calculated as

$$L(t_k) = A \mathbf{h}(t_k) \cdot \frac{\mathbf{m}}{(W e)}$$

where $A$ denotes the total area of the plot of scallops (in square nautical miles, nm$^2$), $e$ represents the dredge efficiency, and $w$ is the tow path area of the dredge (estimated as 8/6080 nm$^2$ – see footnote 4).

Captured scallops of shell height less than a minimum size $s_d$ are assumed to be discarded and suffer a discard mortality rate of $d$ estimated at 20% in NEFSCH (2001). Some scallops not actually landed may suffer additional mortality due to incidental damage from the dredge. Incidental fishing mortality was modeled as $F_I = 0.175 F_c$ in Georges Bank and $F_I = 0.03 F_c$ in the Mid-Atlantic Bight (NEFMC 2003).

Growth of scallops is modeled with a von Bertalanffy equation:

$$s(t) = L_m [1 - e^{(-K[t-t_0])}]$$

where $s(t)$ is shell height at age $t$ (in years), $K$ is the growth parameter, and $L_m$ represents the maximum shell height.

Equation [5] can be used to construct a matrix $G$ specifying the fractions of each size class that remains in that size class, or grows to other size classes, in any given time interval $\Delta t$. The population dynamics of the stock of scallops can be summarized with the equation

$$\mathbf{p}(t_{k+1}) = \mathbf{p}(t_k) e^{(-\lambda M \Delta t)}$$

4 The standard area unit used in the NEFSC biological surveys is the "tow", which corresponds approximately to 8/6080 nm$^2$=0.0013 nm$^2$. Therefore the population vectors $\mathbf{p}(t)$ denote the total number of scallops per tow in the population.
where $\rho$ denotes recruitment occurring at time $t$ and $M$ is a matrix containing the natural mortality, discard fishing mortality, and incidental fishing mortality parameters.

Landings per unit of effort (LPUE) were estimated using an empirical function based on the observed relationship between annual landing rates and survey exploitable numbers per tow (NEFMC 2004a). A modified Holling Type-II model was used so that the landings per unit of effort (number of scallops landed per day at sea) $L$ will depend on scallop exploitable biomass $B$ according to the formula:

$$L = \frac{\alpha B}{\sqrt{\beta^2 + B^2}}$$

where $\alpha$ and $\beta$ are constants.

Table 2 summarizes the parameters used in the model. Most values were taken directly from the 32nd Northeast Regional Stock Assessment Workshop report (NEFS 2001) and the Amendment 10 document (NEFMC 2004a).

**Table 2.** Parameters of the age-structured model for Atlantic sea scallops in Georges Bank and the Mid-Atlantic Bight stock areas.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta t$</td>
<td>Simulation time step</td>
<td>0.083 years</td>
</tr>
<tr>
<td>$L_\infty$</td>
<td>Maximum shell height</td>
<td>152.46 mm (GB), 151.84 (MAB)</td>
</tr>
<tr>
<td>$K$</td>
<td>Growth parameter*</td>
<td>0.4 y$^{-1}$ (GB), 0.23 y$^{-1}$ (MAB)</td>
</tr>
<tr>
<td>$m$</td>
<td>Natural mortality rate</td>
<td>0.1 y$^{-1}$ across all size classes</td>
</tr>
<tr>
<td>$R$</td>
<td>Annual number of recruits per tow</td>
<td>129 y$^{-1}$ (GB), 58 y$^{-1}$ (MAB)</td>
</tr>
<tr>
<td>$a$</td>
<td>Shell height/meat weight parameter</td>
<td>-11.6038 (GB), -12.2484 (MAB)</td>
</tr>
<tr>
<td>$b$</td>
<td>Shell height/meat weight parameter</td>
<td>3.1221 (GB), 3.2641 (MAB)</td>
</tr>
<tr>
<td>$s_o$</td>
<td>Initial shell height of recruit</td>
<td>40 mm</td>
</tr>
<tr>
<td>$s_{\text{min}}$</td>
<td>Minimum size retained by gear</td>
<td>65 mm</td>
</tr>
<tr>
<td>$s_{\text{full}}$</td>
<td>Size for full retention by gear</td>
<td>88 mm</td>
</tr>
<tr>
<td>$s_d$</td>
<td>Maximum size discarded</td>
<td>80 mm</td>
</tr>
<tr>
<td>$d$</td>
<td>Mortality of discards</td>
<td>0.2</td>
</tr>
<tr>
<td>$e$</td>
<td>Dredge efficiency</td>
<td>0.5 (GB), 0.7 (MAB)</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>LPUE/biomass relationship (seven-man crew)</td>
<td>49.056</td>
</tr>
<tr>
<td>$\beta$</td>
<td>LPUE/biomass relationship (seven-man crew)</td>
<td>102.8</td>
</tr>
</tbody>
</table>

Sources: NEFSC(2001); NEFMC (2004a).

The parameters $K$ were originally estimated by Serchuk et al. (1979). These parameters were subsequently revised by the 32nd SAW. We used the revised values in our simulations.

**Economic sub-model**

The economic analyses conducted by the NEFMC (e.g., NEFMC 2004a; 2003) routinely include pricing models to obtain more accurate estimates of the impact of regulatory measures on the profitability of the fishery. Pricing equations were not used in our analysis because the model was concerned only with the population dynamics of a relatively small plot of scallops, i.e., we assume fishermen behave as price takers. We also assume that a different price is received for each of the following size categories: under 10, 11-20, 21-30, 31-40, 41-50, 51-60, and 61+ counts. Monthly landings data (1998-2003) provided by the NMFS/NEFSC were used to compute ex-vessel nominal prices for each size category, which were subsequently expressed in their equivalent 1996 constant prices. The averages of the time series of constant prices were used as representative values for each size category (Table 3). A consistent premium was assumed across meat counts, i.e., higher prices are paid for larger scallops.

---

8 The parameters $\alpha$ and $\beta$ are reduced by a factor $\sqrt{20/g}$ if the mean meat weight of the scallops caught, $g$, is more than 20 g. This correction is introduced as large scallops tend to require slightly longer shucking times (NEFMC 2004a).

6 Counts refer to the number of meats per pound.
Table 3. 1996 constant ex-vessel prices assigned to six different size categories in the bioeconomic model of the Atlantic sea scallop fishery. Based on monthly landings data (1998-2003) provided by the NMFS/NEFSC.

<table>
<thead>
<tr>
<th>Size category</th>
<th>Price ($/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 10</td>
<td>5.91</td>
</tr>
<tr>
<td>11-20</td>
<td>4.69</td>
</tr>
<tr>
<td>21-30</td>
<td>4.36</td>
</tr>
<tr>
<td>31-40</td>
<td>4.27</td>
</tr>
<tr>
<td>41-50</td>
<td>4.05</td>
</tr>
<tr>
<td>51-60</td>
<td>3.80</td>
</tr>
<tr>
<td>61+</td>
<td>3.65</td>
</tr>
</tbody>
</table>

Variable costs of fishing were estimated using a cost equation developed by the NMFS/NEFSC (Gautam and Kitts 1996; Edwards 1997). Per-vessel annual operating costs (OPC) in 1996 constant prices were postulated to be a function of vessel crew size (CREW), vessel size in gross tons (GRT), and vessel days at sea (DAS). The equation is

\[
\log(\text{OPC}) = 4.6130 + 0.2531 \times \log(\text{CREW}) + 0.2743 \times \log(\text{GRT}) + 1.1134 \times \log(\text{DAS})
\]

(6.31) (3.34) (3.46) (8.79)

\[n = 69, \text{adj } R^2 = 0.58, D-W = 1.97, t\text{-value in parentheses.}\]

Crew size was assumed to be seven, the maximum allowed under Amendment 4. Vessel size was specified to be 166.2 gross tons, which is an average vessel tonnage in this fishery. The number of days at sea is directly related to landings per unit of effort. An important feature of the model is that vessels capture a greater number of scallops per unit of time when the biomass of the resource is at a high level, thereby reducing the harvesting cost per scallop (see [7]).

The model assumes scallop plots are 680 nm² each, and the fishing fleet is composed of 20 vessels in each stock area. These parameters are arbitrary as they do not affect the qualitative character of the results, only the scale of payoffs to the fishery.

In summary, increases in the population of scallops are driven by natural recruitment and declines are caused by natural mortality and fishery exploitation. The objective is to maximize the stream of annual net revenues (gross revenues minus operating costs) over the 30-year period. The control variable is the target level of fishing pressure \( F_T \) that is selected at the beginning of each year. The variable \( F_T \) is the summation of two different types of mortality: the capture mortality rate \( F_c \) that applies to scallops actually landed (see [2]), and the incidental fishing mortality \( F_I \) caused by contact with the gear.

MATLAB codes were specifically developed for these simulations. Biomass and shell height composition data from the NEFSC scallop biological surveys for Closed Area I (Georges Bank) in 1990 (NEFSC 2001) were used as initial conditions for the simulations in both Georges Bank and the Mid-Atlantic Bight (Figure 3). The \textit{fmincon} solver was used to find a global maximum for the NPV of the fishery (a "real" discount rate of 5% was assumed) in both stock areas. Given the complexity of the model, upper and lower bounds were imposed on the control variable \( F_T \) to facilitate the optimization process. Exploitation rates were restricted to fluctuate between zero (closure of the fishery) and one (maximum fishing pressure allowed in the model)\(^8\).

It is noted that the model was designed with simplifying assumptions on aspects such as recruitment, pricing, and composition of the fleet, because our primary interest was to focus the optimization process on crucial biological characteristics such as scallop growth, gear selectivity, incidental fishing mortality,

---

\(^7\) Because prices and costs are expressed as 1996 constant prices, the discount rate is assumed to be unadjusted for inflation.

\(^8\) It is recalled that the fishery exploitation rate \( F_T \) corresponds to the exponent in a model of exponential decay. Thus, a exploitation rate \( F_T = 1 \) implies that approximately 65% of the harvestable biomass is extracted every year.
and the effect of higher biomass on LPUE. Our intuition suggested that these were the key features in the search for optimal patterns of exploitation.

![Graph](image)

**Figure 3.** Shell height composition data from NEFSC sea scallop surveys illustrating the state of the resource for Closed Area I in the Georges Bank stock area during 1990. These data were used as initial conditions for simulations in both Georges Bank and Mid-Atlantic Bight stock areas. Source: NEFSC (2001).

**RESULTS AND DISCUSSION**

**Georges Bank**

Table 4 presents the selection of annual fishing mortality rates ($F_T$) for the plot of scallops in Georges Bank. A quick glance at the results reveals the evidence for rotational fishing. The low level of beginning biomass in Year 1 (2.33 kg/tow), with a large proportion of small scallops (Figure 3), reflects the depleted state of the resource in Closed Area I during 1990 as reported by the 32nd SAW (NEFSC 2001). Given these poor conditions, the model proceeds to close down the fishery from Year 1 through Year 5. The fishery is reopened in Years 6, 7, and 8. Fishing occurs at a moderate rate in Year 6 ($F_T = 0.268$), but intense exploitation takes place in Years 7 and 8 ($F_T = 1$). A second cycle is initiated in Year 9 and extends through Year 16. The fishery is closed for six years to let biomass rebuild and intense harvesting at $F_T = 1$ occurs in the last two years of the cycle (Years 15 and 16). A third cycle extends from Years 17 to 23 (with a five-year closure and two years of intense exploitation) while the fourth and final cycle begins with a four-year closure (Years 24 through 27) and ends with three years of intense harvesting ($F_T = 1$ in the last two years).

<table>
<thead>
<tr>
<th>Year</th>
<th>$F_T$</th>
<th>Year</th>
<th>$F_T$</th>
<th>Year</th>
<th>$F_T$</th>
<th>Year</th>
<th>$F_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>18</td>
<td>0</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>19</td>
<td>0</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>13</td>
<td>0</td>
<td>21</td>
<td>0</td>
<td>28</td>
<td>0.527</td>
</tr>
<tr>
<td>6</td>
<td>0.268</td>
<td>14</td>
<td>0.074</td>
<td>22</td>
<td>1</td>
<td>29</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>15</td>
<td>1</td>
<td>23</td>
<td>1</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The first and second production cycles (from Years 1 through 8 and 9 through 16) suggest an optimal pattern of rotational harvesting for Georges Bank consisting of a 6-year closure period followed by two
years of intense harvesting. The slightly shorter closure periods identified in the third and fourth production cycles (Years 17 through 23 and 24 through 30) reflect the need to accommodate these two cycles within the 30-year time frame of the simulation.

These results are important not only because they specify the optimal duration of closures and re-opening periods in the Georges Bank fishery, but also because they clearly reveal that the pattern of pulse fishing is better suited to the characteristics of the resource than exploitation at a constant fishing rate. Our results support the general assertion that rotational harvesting is a more sensible management strategy for sedentary species as compared to continuous exploitation under open-access conditions (Caddy and Seijo 1998; Caddy 1993). The estimated NPV$_{30}$ obtained from a 680-nm$^2$ plot is approximately $324$ million under the rotational harvesting schedule shown in Table 4. In contrast, the NPV$_{30}$ of the fishery is only $278$ million (-14%) if the stock is exploited under a constant annual rate $F_T = 0.2$. The latter number is recommended by the NEFMC as the target fishery mortality rate that maximizes yield-per-recruit for the Atlantic sea scallop fishery in Georges Bank (NEFSC 2001).

As one of several alternatives considered in their analysis of rotational management, Amendment 10 has proposed a ramped rotation approach whereby a fishing area is closed for three years and subsequently reopened for three years at exploitation rates $F_T = 0.32, 0.40,$ and $0.48$, respectively. One important property of this approach is that the time-averaged fishing mortality is precisely 0.2, the target rate. In our simulation, this ramped rotation scheme leads to an NPV$_{30}$ of $294$ million, which is 9% less than the maximized NPV$_{30}$. It should be noted that the time-averaged fishing mortality rate is 0.3 under the optimal rotational schedule of Table 4.

Three main factors drive the selection of rotational harvesting strategies in our simulations:

1. The life-cycle characteristics of scallops are clearly well-suited for rotational fishing. There is continuous and rapid growth of biomass during the first years and natural mortality remains low throughout the life cycle. These factors, along with the low mobility of scallops, clearly point toward pulse fishing as the optimal way to exploit the resource.

2. Fishery closures and subsequent reopenings lead to the harvest of larger scallops, which have a price premium advantage over smaller counts. Our results indicate that over 80% of landings in each harvesting cycle are composed of the largest two size categories of scallops (under 10 and 11-20) (Table 5).

3. Fishing costs per pound decline significantly when biomass has been allowed to accumulate. This is directly related to the empirical relationship between landings per unit of effort and exploitable numbers per tow demonstrated in [7] and further illustrated in Figure 4. A higher LPUE leads to a reduction in the number of fishing days required to land a given quantity of scallops, which in turn results in considerable savings in operating costs. For example, setting $F_T = 0.2$ from Year 1 through Year 6 results in a total of 311 DAS for any given vessel during this six-year period. The same poundage can be landed by setting $F_T = 0$ from Year 1 through Year 5, and having $F_c = 0.52$ in Year 6. In the last case, however, only 253 DAS per vessel are required.

Figure 5 compares biomass at the end of the year (kg/tow) as predicted by the model to the average of survey biomass data reported by the 32nd SAW (NEFSC 2001) for Closed Area I in Georges Bank. It is reminded that the model was initialized with the 32nd SAW data corresponding to 1990. While the model recommends closing the fishery immediately, the actual resource was heavily exploited during the early 1990s, with survey biomass routinely under 5 kg/tow. The area closure in December 1994 led to substantial increases in survey biomass almost immediately. Sampling conducted in 2000 indicated biomass in Closed Area I was over 15 kg/tow. On the other hand, the biomass series predicted by the model clearly illustrates the selected pattern of pulse fishing, with only four major harvest events during the 30-year period and area closures within harvests. Biomass in the model is allowed to fluctuate between 4 and 20 kg/tow.
Table 5. Size composition of landings (percentage) in each harvesting cycle of the bioeconomic model of Atlantic sea scallops in the Georges Bank region.

<table>
<thead>
<tr>
<th>Size category</th>
<th>Cycle 1 (Years 6, 7, 8)a</th>
<th>Cycle 2 (Years 15, 16)</th>
<th>Cycle 3 (Years 22, 23)</th>
<th>Cycle 4 (Years 28, 29, 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 10</td>
<td>47 %</td>
<td>47 %</td>
<td>41 %</td>
<td>35 %</td>
</tr>
<tr>
<td>11-20</td>
<td>39 %</td>
<td>41 %</td>
<td>45 %</td>
<td>48 %</td>
</tr>
<tr>
<td>21-30</td>
<td>7 %</td>
<td>7 %</td>
<td>7 %</td>
<td>9 %</td>
</tr>
<tr>
<td>31-40</td>
<td>4 %</td>
<td>4 %</td>
<td>4 %</td>
<td>5 %</td>
</tr>
<tr>
<td>41-50</td>
<td>2 %</td>
<td>2 %</td>
<td>2 %</td>
<td>2 %</td>
</tr>
<tr>
<td>51-60</td>
<td>1 %</td>
<td>1 %</td>
<td>1 %</td>
<td>1 %</td>
</tr>
<tr>
<td>61+</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
<tr>
<td>Total</td>
<td>100 %</td>
<td>100 %</td>
<td>100 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>

a The numbers in parenthesis indicate the years in which harvesting takes place. Numbers may not add up due to rounding.

Figure 4. Empirical relationship between landing rates, expressed as number of scallops caught per day (NLPUE), and survey exploitable numbers per tow. Source: NEFMC (2004a).

Figure 5. Comparison of time series of biomass (kg/tow). The starred line corresponds to the average of survey trend data for Closed Area 1 in Georges Bank (1990-2000) as reported by the 32nd SAW (NEFSC 2001). The dotted line represents biomass at the end of the year as simulated by the model.

Several researchers had already pointed out the potential benefits of rotational fishing for Atlantic sea scallops. Myers et al. (2000) and Hart (2003) concluded that rotational fishing had the potential to
generate increased yield and biomass-per-recruit for sea scallops compared to nonrotational fishing. In addition, Myers et al. (2000) indicated that rotational harvesting might contribute to reduce the effects of uncertainty over indirect fishing mortality. Both studies, however, focused on the biological implications of rotational management, giving no consideration to the economic advantages inherent to rotation of fishing areas. Both studies, therefore, probably undervalued the full potential of rotation as a fisheries management strategy.

These two studies recommended rotational cycles for Georges Bank that are two years shorter compared to our results. Myers et al. (2000) argued that a rotational period close to 6 years (consisting of a 5-year closure with a one-year reopening, during which fishing mortality is around 0.5), would result in a close to maximum average yield per recruit and would maintain spawning biomass at acceptable levels. Our results indicate that the fast growth of scallops in Georges Bank support higher fishing rates upon re-opening of areas ($F_T = 1$ for two years). It is reminded that our results are based on the assumption that recruitment remains close to the historical average. As mentioned previously, there is yet no clear evidence of a spawning stock – recruitment relationship for Atlantic sea scallops (NEFSC 2004); therefore, we did not assume a strong adverse effect on recruitment due to the reopenings of fishing grounds. Even if such effect existed, the subsequent multi-year closure would contribute to boost recruitment in the fishery.

Hart (2003) also suggested that, under rotational management, a harvesting cycle of 6 years (a five-year closure followed by one year of harvesting) would optimize discounted yield-per-recruit for the sea scallop fishery in Georges Bank. However, she found that maximal yield-per-recruit is obtained by fishing uniformly. She also mentioned that gains from rotation would be modest unless the closure was timed to optimally exploit an unusually large class. As explained previously, Hart’s (2003) analysis most likely underestimated the benefits of rotation because no consideration was given to premiums paid for larger scallops or the savings in fishing costs resulting from extraction at larger biomasses. Nevertheless, Hart (2003) recommended rotational management as part of a precautionary strategy to help alleviate the effects of growth and recruitment overfishing.

**Mid-Atlantic Bight**

Table 6 presents the selection of annual fishing mortality rates for the plot of scallops in the Mid-Atlantic Bight. The pattern of rotational fishing is also evident here, with three production cycles clearly recognizable within the 30-year time frame. The initial conditions are the same as those assumed for Georges Bank, but the initial closure in the Mid-Atlantic runs for seven years as opposed to only five years in Georges Bank. The second cycle consists of an eight-year closure period followed by two years of intense harvesting (Years 19 and 20). Some exploitation also occurs in Year 21 ($F_T = 0.145$) and the fishery closes again from Year 22 through 27. Intensive harvesting is scheduled for the last three years of the simulation.

<table>
<thead>
<tr>
<th>Year</th>
<th>FT</th>
<th>Year</th>
<th>FT</th>
<th>Year</th>
<th>FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>21</td>
<td>0.145</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>13</td>
<td>0</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>14</td>
<td>0</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>18</td>
<td>0</td>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>19</td>
<td>1</td>
<td>29</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>20</td>
<td>1</td>
<td>30</td>
<td>1</td>
</tr>
</tbody>
</table>

* Hart (2003) analysis assumed a 10% discount rate. A lower discount rate would have probably resulted in a longer rotation period.*
Table 7 shows the size composition of landings for each major harvesting event. It is clear that the function of the closures is to provide sufficient time for scallop growth such that harvests are primarily composed of the larger meat counts (under 10 and 11-20), just as was observed in Georges Bank. The longer closure periods in the Mid-Atlantic are necessary to compensate for the slower growth of scallops (see Table 2 and Figure 6).

Table 7. Size composition of landings (percentage) in each harvesting cycle of the bioeconomic model of Atlantic sea scallops in the Mid-Atlantic Bight region.

<table>
<thead>
<tr>
<th>Size category</th>
<th>Cycle 1 (Years 8, 9, 10)</th>
<th>Cycle 2 (Years 19, 20)</th>
<th>Cycle 3 (Years 28, 29, 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 10</td>
<td>39%</td>
<td>33%</td>
<td>27%</td>
</tr>
<tr>
<td>11-20</td>
<td>43%</td>
<td>47%</td>
<td>49%</td>
</tr>
<tr>
<td>21-30</td>
<td>9%</td>
<td>11%</td>
<td>12%</td>
</tr>
<tr>
<td>31-40</td>
<td>4%</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>41-50</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>51-60</td>
<td>1%</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>61+</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*The numbers in parenthesis indicate the years in which harvesting takes place. Numbers may not add up due to rounding.*

Figure 6. Comparative growth of Atlantic sea scallops in Georges Bank and the Mid-Atlantic Bight.

Figure 7 illustrates the effect of closures and harvestings on biomass of the plot of scallops in the Mid-Atlantic Bight. Biomass is allowed to fluctuate between 2 and 11 kg/tow. Because both growth and recruitment rates\(^{10}\) are lower in the Mid-Atlantic (see Table 2), biomass does not accumulate to the levels seen in Georges Bank (Figure 5). The estimated NPV\(_{30}\) for a 680-nm\(^2\) plot under rotational fishing was $94 million. Comparatively, a constant fishing rate \(F_T = 0.2\) leads to an NPV\(_{30}\) = $81 million (a 14% decline). The 6-year ramped rotation approach with \(F_T = 0.2\) as target fishing mortality rate (i.e., \(F_T = 0\) for the first three years and \(F_T = 0.32, 0.40,\) and 0.48 in the ensuing three years) results in an NPV\(_{30}\) = $86 million (a 9% decline). The time averaged fishing mortality of the optimal harvesting schedule (Table 6) is 0.27.

\(^{10}\) It is recalled that the recruitment rates used in the model correspond to weighed averages of the 1992-2000 time series (NEFSC 2001), calculated separately for each stock area.
Figure 7. Biomass at the end of the year (kg/tow) as simulated in the bioeconomic model of the Atlantic sea scallop fishery in the Mid-Atlantic Bight region.

Effect of variability in annual recruitment rates

As explained previously, constant recruitment rates were assumed to facilitate the optimization of harvesting schedules. However, recruitment processes are stochastic, greatly influenced by environmental conditions, and with large variations normally occurring from year to year. To incorporate the stochastic effect of recruitment in our analysis, we conducted a series of Monte Carlo simulations comparing different patterns of exploitation for the fishery while allowing variation in annual recruitment rates. To this end, annual recruitment was modeled using lognormal distributions in each stock area (Georges Bank and the Mid-Atlantic Bight). The assumed mean and variances were estimated from the historical time series between 1992 and 2000 (NEFSC 2001) and are shown in Table 8.

Table 8. Mean and standard deviation of recruitment time series between 1992–2000 used in the Monte Carlo simulation of the Atlantic sea scallop fishery. Recruitment is expressed as annual number of recruits per tow.

<table>
<thead>
<tr>
<th>Stock area</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georges Bank</td>
<td>129.2</td>
<td>204.3</td>
</tr>
<tr>
<td>Mid-Atlantic Bight</td>
<td>58.5</td>
<td>55.67</td>
</tr>
</tbody>
</table>


Four patterns of exploitation were compared in the Monte Carlo analysis: (1) constant fishing at $F_T = 0.20$; (2) a three-year rotation with $F_T = 0, 0.2, 0.2$, which is the rotation program recommended by FA 16 for Closed Areas I, II and the Nantucket Lightship Area in Georges Bank; (3) a six-year ramped rotation with $F_T = 0, 0, 0, 0.32, 0.4, 0.48$ (i.e., target fishing mortality rate is 0.2); and (4) the optimal harvesting schedules from Tables 4 and 6. Each Monte Carlo simulation was conducted for 400 trials.

The mean and standard deviation of the NPV$_{30}$ outcomes from the Monte Carlo simulations are shown in Table 9. The results are qualitatively the same as those obtained under the constant recruitment assumption. The highest expected NPV$_{30}$ values are achieved with the optimal rotation schedules from Tables 4 and 6. These schedules are clearly superior to the strategy of continuous fishing at $F_T = 0.2$ and the three year rotation proposed in FA 16 for the closed areas of Georges Bank. Excluding the optimal rotation schedule, the best results are achieved with the six-year ramped rotation. Dispersion of NPV$_{30}$ values was very similar across exploitation strategies. The greater variability observed in Georges Bank is connected with unusually strong recruitment events that were documented in some of the closed areas in the late 1990s.
Table 9. Mean and standard deviation (in 1996 million dollars) of the distribution of NPV<sub>30</sub> outcomes resulting from the Monte Carlo simulation (400 trials) of annual recruitment rates.

<table>
<thead>
<tr>
<th>Stock area</th>
<th>( F_T = 0.2 ), continuous</th>
<th>( F_T = 0, 0.2, 0.2 )</th>
<th>Ramped rotation&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Optimal rotation&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Georges Bank</td>
<td>274</td>
<td>76</td>
<td>254</td>
<td>62</td>
</tr>
<tr>
<td>Mid-Atlantic Bight</td>
<td>80</td>
<td>11</td>
<td>76</td>
<td>10</td>
</tr>
</tbody>
</table>

<sup>a</sup>This is a six-year rotation with \( FT = 0, 0, 0.32, 0.4, 0.48 \), respectively.

<sup>b</sup>See Tables 4 and 6.

In summary, the Monte Carlo simulations indicate that the optimal rotation cycles will generate greater expected net revenues given uncertainty in annual recruitment patterns. This has the important implication that closures need not coincide with the emergence of a large recruitment class in order to obtain measurable gains from rotational management.

**Additional implications for management**

All simulations conducted in this analysis provide substantial evidence that the Atlantic sea scallop resource can be more efficiently managed under rotational harvesting than under any other management scheme involving continuous fishing activity. This pattern of pulse fishing is highly suggestive of the classic Faustmann theory of forest rotation (for a review, see Reed 1986). There is an important difference, however. The basic problem in forest rotation is concerned exclusively with the determination of an optimal cutting time for a stand of trees. With sea scallops, in contrast, there is always the possibility to engage in partial harvests, or "thinning", of the resource. In this regard, our results are very powerful as rotation is selected first as the optimal exploitation strategy, and then an optimal rotation period is established.

A prominent feature of rotation is that the net present value of the fishery is maximized even if (and more precisely, because) no fishing at all occurs for several years in a row. This, of course, does not imply that the entirety of the fishing grounds in Georges Bank and the Mid-Atlantic Bight should be closed down simultaneously for several years to let biomass accumulate. Given that our results suggest optimal closure periods of six and eight years followed by two years of harvesting, a sensible proposal would be to subdivide the stock areas in both Georges Bank and the Mid-Atlantic into eight and 10 sub-areas, respectively, and implement a program of rotational harvesting of these sub-areas. Because re-opened sections can support exploitation for two years in a row, fishing could take place in two sub-areas within Georges Bank and the Mid-Atlantic during any given year.

It is obvious that many other details would need to be addressed before implementing rotation of fishing grounds for sea scallops (e.g., harmonization with the fishery management plans for other species) but the important point is to recognize that rotation should be the underlying management paradigm for this resource. In other words, allowing fishermen to roam freely in open areas at all times clearly leads to a sub-utilization of the resource. The difference in growth rates between Georges Bank and the Mid-Atlantic indicate that the strategy of rotational harvesting is robust to uncertainty in the true values of these parameters. This is important because the growth parameters of the Von Bertalanffy growth equations (Equation [5]) have been subjected to revisions based on the results of recent biological surveys (NEFSC 2001).

Spatial management of rotational areas at a high resolution level as set forth in Amendment 10 is a praiseworthy initiative but full-scale implementation may impose an overwhelming administrative burden on management agencies. Flexible boundaries might also generate confusion among fishermen. A simple scheme of mechanical rotation (that includes all fishing grounds) based on 6-year and 8-year closure periods in Georges Bank and the Mid-Atlantic Bight may be a much more effective way towards sustainable management of the resource and improved profitability for the fishery. The mechanical rotation strategy proposed in FA 16 (Table 1) is an important step forward; however, the one-year closure period falls short if the objective is to rebuild biomass in a previously open area or to maximize economic returns from the fishery.
Logically, rotational schemes could be adjusted if new information becomes available, such as the identification of "nursery" areas with high production of recruits. Also, our model considered $F_T = 1$ as an upper bound for fishery mortality. Rotational strategies could be designed with a lower cap on fishing pressure if the objective is to maintain biomass at every moment above a specified level. However, our simulations for Georges Bank showed that setting $F_T = 1$ as an upper bound keeps biomass above the critical levels observed during the early 1990’s for Closed Area I (Figure 5).

An important result from our research is the confirmation that economic factors, such as the existence of price premiums for larger scallops, play an influential role in the determination of optimal harvest strategies for biological resources. In this regard, our study adds to the growing literature emphasizing the relevance of market considerations in the management of fishery resources. For example, in their analysis of the blacktip shark fishery, Fong and Anderson (2002) recommended the harvest of large individuals exceeding the maturation age of the species for about 2.75 years. While this recommendation contributed to the biological sustainability of the fishery, it also ensured the harvesting of high-quality, larger-sized shark fins preferred by the end-users in the Hong Kong market. Fong and Anderson’s findings strongly parallel our own results.

There are some other benefits associated with rotational management that were not addressed in this analysis. In addition to reductions in DAS, rotational management also leads to reductions in contact time between scallop gear and the ocean bottom. This has the important implication that amounts of bycatch should be lower under rotational fishing, a desirable management goal from any perspective. Another interesting aspect is that, while no definitive stock-recruitment relationship has been verified for Atlantic sea scallops due to the great influence of environmental factors on recruitment, recent evidence from the Mid-Atlantic suggests that area closures may contribute to boost recruitment. This additional effect appears to be likely and would further the case for rotational management.

CONCLUDING REMARKS

The bioeconomic model presented in this paper provided compelling evidence that optimal exploitation of a resource with the life-history characteristics of Atlantic sea scallops (a sedentary species with fast growth and low natural mortality) involves rotation of fishing grounds. The traditional management approach of open areas with unrestricted access which ruled the fishery for decades is not appropriate for sea scallops; such an approach is bound to dissipate economic rents and ultimately sets the stage for overexploitation of the resource.

The rotational management strategy appears to be robust to a number of assumptions regarding the life history of the resource, such as growth rates and uncertainty in recruitment rates. The essential idea for management of the resource is to institute closure periods that are sufficiently long to create a harvestable biomass composed primarily of large scallops, which demand a premium price in the marketplace. Extraction at high standing biomasses is also advantageous because it leads to reduction in operating days at sea and decreased contact time with the ocean bottom. The gains derived from closures of the fishery in the initial years largely outweigh the initial loss of revenue.

Fishery management agencies should be commended for redirecting their attention to rotation as the new paradigm for management of the resource. However, the mechanical rotation strategies proposed so far involve closure periods that are too short relative to what is recommended by our model. Our results also indicate that the resource can support more intense exploitation upon re-opening of the closed areas. In other words, re-opened areas can be harvested at fishery mortalities larger than 0.20, the target fishing mortality rate typically recommended to maximize yield-per-recruit in models of continuous exploitation.

Our recommendations imply a thorough re-thinking of the way scallop fisheries have been normally conducted. Our main tenet is that scallops should not be managed in the same way as mobile resources such as pelagic, free-swimming species. Scallop lend themselves to be managed in the same manner as forests or terrestrial crops. The success of the temporary access programs to the closed areas provides strong support to our recommendations. We are aware that full-scale rotational management of Atlantic sea scallops would limit the ability of fishermen to decide where and when to fish. But it must also be reminded that the traditional ways of fishing, with unrestricted access to the scallop beds, was what initially placed the resource under so much stress during the early 1990s. Rotation of fishing grounds as a management tool is the safest strategy to avoid the recurrence of such conditions.
ACKNOWLEDGEMENTS

The authors would like to thank Steve Edwards (NMFS/NEFSC) for providing detailed landing statistics for the period 1998–2003. They are also indebted to Deborah Hart (NMFS/NEFSC) for offering important insights on the application of Holling predation models to the Atlantic sea scallop fishery. The assistance from Kurt Schnier (University of Rhode Island) in the development of the MATLAB codes is also greatly appreciated. Financial support for this research was provided by the Saltonstall-Kennedy Grant Program / National Marine Fisheries Service.

REFERENCES


PART 2: ABSTRACTS
PREFERENCES FOR A BUYOUT PROGRAM: SURVEY RESULTS FROM U.S. ATLANTIC SHARK FISHERMEN

Charles M. Adams and Sherry L. Larkin

Presented by Dr Sherry L Larkin, University of Florida, Gainesville, USA
Session 17: Subsidies

The U.S. shark fishery in the Atlantic Ocean and Gulf of Mexico has experienced a significant reduction in quotas and fishing areas due to concerns over stock status. In response, the industry has expressed interest in a buyback program. Of the 605 license holders in 2004, only 474 reported landing any species and only 303 reported landing any shark. Collectively, the 605 commercial shark fishermen held 2,792 additional federal permits. An examination of landings profiles reveals that the majority of fishermen are not dependent on shark revenues. To determine the preferences of shark fishermen regarding a buyback program, a questionnaire was sent to all license holders. Fishermen were queried about past and future shark fishing behavior, reasons for that behavior, preferences for various components of a buyback program, and demographic information. Questions pertaining to a potential buyback program also included a contingent valuation scenario. The scenario required fishermen to select between selling their vessel with or without all licenses at 50% below to 50% above the estimated fair market value based on landings in 2003, or not selling. Scenarios were also presented to capture the willingness to pay for the buyback program with a loan.

Keywords: excess capacity, latent effort, capacity reduction programs

MEASURING WELFARE EFFECTS OF MULTISPECIES QUOTA MANAGEMENT SYSTEMS

J. Agar

NOAA, Miami, USA
Session 12: Economic Performance 1: Measuring Performance and Welfare Effects

This paper investigates the welfare effects of regulatory proposals for the South Atlantic black sea bass trap fishery, including transferable and non-transferable quotas. The multi-product, joint-in-inputs nature of the technology employed implies that regulations to control catch rates of one species may have spill-over effects on other species. By accounting for these spill-over effects, improved welfare estimates can be obtained.

Keywords: multiproduct, welfare, jointness-in-inputs, black sea bass

ECONOMIC EVALUATION OF MARINE ECOSYSTEM RESTORATION IN NORTHERN BRITISH COLUMBIA

Cameron H. Ainsworth

University of British Columbia, Vancouver, Canada
Session 14: Ecosystem Issues 3: Restoration, MPAs, Bycatch

Using Ecopath with Ecosim (EwE) marine ecosystem modelling software, we draft whole ecosystem restoration plans for Northern British Columbia that would return biomass, biodiversity and production potential to historic levels. A new EwE algorithm is developed to estimate optimal levels of fishing mortality per gear sector that will, over time, manipulate the ecosystem into a desired configuration - in this case, a species-biomass composition based on the northern BC marine ecosystem at various points in history: 1750, 1900, 1950 and 2000. Varying the speed of restoration, and the end-goal ecosystem state, we perform cost-benefit analysis on the candidate restoration plans to evaluate the net economic benefit of restoration. Plans for quick restoration entail large immediate sacrifices in catch, but more moderate plans allow for some continued level of exploitation. The trade-off between restoration and continued income
from harvesting is described and an optimal rate of restoration, one that maximizes net present value of the plan, is identified. Restoration plans designed to return the ecosystem to a high level of productivity potential, such as seen prior to European contact (1750) or before industrial fishing (1900) are difficult to achieve, requiring a long period of reduced harvesting, while restoration to a more recent condition (1950 or 2000) is less costly by comparison. Cost-benefit analysis determines which restoration goal maximizes net present value of the restoration plan. This work offers a new methodology to guide strategic ecosystem restoration efforts, and makes trade-offs explicit between the costs and benefits of restoration in market and non-market terms.

Keywords: Ecopath with Ecosim, ecosystem restoration, British Columbia

VALUING U.S. MARINE HABITATS: FANTASY OR FACT?

Jackie Alder, William Cheung, Gakushi Ishimura and U. Rashid Sumaila

Presented by Dr Jackie Alder, University of British Columbia, Vancouver, Canada

Session 7: Ecosystem Issues 2: Values and Valuation, Biodiversity

Data generated by a direct choice experiment with over 1000 US residents was used to estimate their mean willingness to pay for maintaining or enhancing future use, existence and indirect use value, which we term the ‘fantasy value’ of marine habitats, to mimic what some consider these values to be. Iconic fish species were used as proxies to represent coral reef, seamount, estuarine and other marine habitats so that the mean willingness to pay could be apportioned to the various habitats. Participants were willing to accept a mean increase in the price of fish of between $1.31 per pound for salmon to $8.58 per pound for shrimp. The resulting total ‘fantasy values’ for each of the habitats, based on the mean willingness to pay, ranged from $511 per km$^2$ for seamounts to $5695 per km$^2$ for estuaries. These values are of the same order of magnitude as the direct use values that were estimated as part of a larger study, and they provide further justification for careful management of these habitats.

Keywords: choice experiment, contingent valuation, habitat values

PRICE DISCOVERY IN LABORATORY TRADABLE FISHING ALLOWANCE MARKETS WITH CONCURRENT LEASING

Christopher M. Anderson and Jon G. Sutinen

Presented by Dr Chris Anderson, University of Rhode Island, Kingston, USA

Session 5: Rights-Based Fisheries 2: Transferable Quotas

When a new tradable allowance system is implemented, a new asset is created about which little price information is available. In the field, this often leads to high volatility in the first four to six years of market-based management. During this time, many fishers make investment and capitalization decisions, including whether to exit the fishery. Poor price signals can lead to inefficient capitalization, and fishers who purchase at market highs, or sell, or sell out, at market lows can become frustrated with the system.

In previous experiments, we have replicated this volatility in a controlled laboratory environment based on the most commonly used rules of trade and which allows only permanent transactions at the beginning of the program. Subsequent experiments showed that volatility is significantly reduced by an initial lease period, or a period during which only single-year transfers are permitted. This lease market generates a common knowledge price signal that reduces opportunity for speculation when permanent trading is introduced. In the field, it is more common for both permanent trade and lease markets at the outset of the program. The lease market may serve to censor high, speculative prices in the permanent trade market by providing a substitute for fishers purchasing based on fundamental value, or it may aggravate price uncertainty in the permanent market during its own price discovery process. In this paper, we will report the results of experiments, currently in the design phase, which evaluate the effect of these concurrent lease markets on price discovery.

Keywords: ITQs, tradable fishing rights, transferable allowances, experiments, asset markets
EXCESSIVE SHARES IN ITQ FISHERIES

Lee G. Anderson

University of Delaware, Newark, USA

Session 5: Rights-Based Fisheries 2: Transferable Quotas

One of the issues in designing an ITQ program is the necessity of implementing excessive share limits or ownership caps on what percentage of the quota can be controlled by a single entity. The purpose of this paper is to discuss the issue as it pertains to the potential for monopoly power and to constraints on efficient production. It is shown that it is possible to calculate a value for the maximum percentage that can be controlled by a single entity without creating incentives for monopoly output restrictions. The parameters used in the calculations are the price and marginal cost at the TAC level of production and the elasticities of demand and supply. The potential for overly restrictive limits to blunt short and long run incentives for efficient production are also discussed.

Keywords: ITQ, ownership caps, excessive share

FRAMEWORK FOR THE EVALUATION OF SOCIO-ECONOMIC AND ENVIRONMENTAL INDICATORS OF SUSTAINABILITY IN MARINE ECOSYSTEM BASED FISHERIES MANAGEMENT: THE VERACRUZ REEF SYSTEM CASE

Patricia Arceo, Leonardo Ortiz and Alejandro Granados

Presented by Dr Patricia Arceo, Universias Veracruzana, Boca del Río, Mexico

Session 14: Ecosystem Issues 3: Restoration, MPAs, Bycatch

The purpose of this paper is to present a methodology to make operational the concept of sustainability when applying to marine fisheries management. The sustainability debate and some of the assumptions and considerations related to the management of marine resources are presented. Following that is a section on the set of characteristics that marine resources should present in order to achieve sustainable use. This is accomplished by considering the methodology used by Masera et al, (1999) called Framework for the Evaluation of Natural Resource Systems Management, Incorporating Sustainability Indicators (MESMIS by their Spanish name). A brief description of some of the methodologies using socio-economic and environmental indicators is presented as well as an alternative way to select indicators using the cited methodology. The resulting graphical representation to compare fisheries management actions by sustainability indicators is suggested and discussed. The consequences of implementing management closures in the Veracruz Reef System National Park (PNSAV) are analyzed in light of this methodology.

Keywords: sustainability, fisheries management, socio-economic indicators

MEASURING PERFORMANCE IN A MULTI-OUTPUT INDUSTRY

Frank Asche, Daniel Gordon and Carsten Lynge Jensen

Presented by Dr Frank Asche, University of Stavanger, Stavanger, Norway

Session 12: Economic Performance 1: Measuring Performance and Welfare Effects

Many regulated industries are multi-output production process with some outputs restricted to fixed levels. Efficient regulation requires that the multi-output structure of the industry is accounted for. In this paper we use a constrained profit function to investigate the structure of production for a multi-output industry where some but not all outputs are restricted to fixed levels. In natural resource industries like fisheries, these structural issues are important because regulations are necessary to protect the stock and to prevent full rent dissipation. However, with quota restrictions on some species there is a risk of increased fishing effort directed towards unregulated species. An empirical application is provided based on data for the Norwegian purse seine fleet, a fishery regulated with individual vessel quotas for their main target species, but which also targets a number of unregulated species.
**EXPERIMENTAL ANALYSIS OF THE POLITICAL ECONOMICS OF FISHERIES GOVERNANCE**

_Sam Bwalya, Christopher M. Anderson and Jon G. Sutinen_

_Presented by Jon G. Sutinen, University of Rhode Island_

_Session 13: Fisheries Governance 2: Politics, Policy, ITQ Fisheries Management_

This paper analyses how fishing firms attempt to influence fisheries policymaking in an experimental fisheries governance institution. An experimental fisheries governance institution was designed and economic experiments performed to test the predictions derived from a formal model. The political and common pool resource (CPR) institutions are combined in a game-theoretic model of fisheries decision-making. Firms are assumed to have homogenous policy preferences and to make voluntary contributions toward efforts to influence fishery regulations and management. The cost of lobbying is private but benefits from influencing fisheries regulations are common to the industry. In other words, a firm’s lobbying effort yields collective rents that are shared equally across all firms in the industry. Experiments were conducted with undergraduate student subjects to analyze lobbying, fishing behavior, and the effect of lobbying on the economic performance of the fishery. During the experiment, student subjects played a two-stage game. In the voluntary contribution game, subjects made voluntary contributions to lobbying efforts to change the cap on fishing effort, which applies to the group in the subsequent CPR decision game. We found that voluntary contributions are generally below sub-game perfection, and decrease with subject experience. For instance, the experimental evidence indicates that sub-game perfect lobbying occurred only 25% of the time in experiments with twice experienced subjects. In addition, no significant voluntary contribution lobbying was observed at initial caps above the social optimum in all the experiments performed. The implication is that free riding leads to suboptimal investment in efforts to influence political outcomes aimed to improve economic rents in the fishery.

**EFFORT RESPONSE, HARVEST, AND CLIMATE IN THE GULF OF MEXICO RECREATIONAL RED SNAPPER FISHERY**

_D.W. Carter and D. Letson_

_Presented by Dr David W. Carter, NOAA, Miami, USA_

_Session 10: Subsistence, Small-scale, Recreational Fisheries_

Analyses of fisheries rebuilding plans require predictions of effort and harvest. Structural biological and economic models can be used to forecast changes in aggregate fishing trips and harvest over time. However, the timing and direction of causality between these aggregate variables is often unclear, especially for recreational fisheries. For example, when do changes in recreational harvest cause changes in effort and vice versa? Exogenous economic and climatic influences should be controlled for when attempting to isolate the empirical relationships among aggregate fisheries variables. Climate conditions are of special interest in evaluating the effects of climate change on regional fisheries. For example, does angler effort respond to changes in climate conditions (El Nino, hurricanes, etc.)? Are there seasonal or inter-annual patterns in recreational fishing effort and harvest? We examine the above issues using results from a vector autoregression analysis of aggregate effort, harvest, economic, and climatic variables in the Gulf of Mexico recreational red snapper fishery.

Keywords: recreational fishing, climate, effort response, time series
SOCIOECONOMIC IMPACTS OF FISHERY SUBSIDIES: A REVIEW

Tony Charles
Saint Mary’s University, Halifax, Canada
Session 17: Subsidies

This paper explores socioeconomic aspects of fishery subsidies and approaches to their analysis. A sustainable development framework is followed, addressing sustainability across the fishery, from fish stocks and ecosystems, to social and economic structures, to the fishing communities and management institutions. Within this integrated perspective, the paper explores the various positive and negative impacts of subsidies on the social, economic, ecological and institutional components of fishery sustainability, dependent on the form of subsidy, the fishery context, the manner of implementation, and the spatial scale of the fishery. Particular attention is paid to distributional effects – who benefits from the subsidy, who does not, and over what time frame. In this regard, an attempt is made to categorize potential socioeconomic impacts of subsidies into three groupings: those targeted on a specific fishery component, those of universal benefit to all in the fishery, and those with benefits aimed at the fishery but also beyond. A parallel analysis examines how particular types of subsidies impact on each fishery component – fishers, the post-harvest sector, fishing communities, and the socioeconomic environment surrounding the fishery. Finally, a preliminary assessment is undertaken of interactions between subsidies and fishery management and policy, in particular in regard to the potential for subsidies to shift the fishery toward improved achievement of sustainable development goals.

Keywords: subsidies, socioeconomic impacts, distributional effects, fishery management, sustainable development

THE BUYBACK SUBSIDY PROBLEM: TIME INCONSISTENCIES AND THE ITQ ALTERNATIVE

Colin W. Clark, Gordon R. Munro and U. Rashid Sumaila
Presented by Dr Gordon Munro, UBC Economics and Fisheries Centre, Vancouver, Canada
Session 17: Subsidies

The question of buybacks, and their accompanying subsidies, continues to be vigorously debated. A Special Session on buybacks, at IIFET 2004 Japan, concluded that, on balance, there was still a strong case to be made for buybacks. "...[B]uybacks provide a valuable option for management of fisheries..." given that they are "...used as a part of a transition from an ineffective management regime to one that is more effective...." It is now argued, however, that, even if used, as prescribed, as a part of a transition package, the buybacks option can lead to a serious time inconsistency problem. This paper will review the nature of the time inconsistency problem, and then go on to ask whether excess fleet capacity can be dealt with by the alternative of implementing a full fledged ITQ system (or the equivalent thereof), unaccompanied by a subsidized buyback scheme. It will be argued that, while this alternative approach is certainly superior to the standard buyback option, the threat of a potential time inconsistency problem yet remains.

Keywords: buybacks, ITQs, time inconsistency

DETERRENCE AND COMPLIANCE IN THE ARTISANAL LAKE VICTORIA FISHERIES

H. Eggert and R. Lokina
Presented by Dr Håkan Eggert, Goteborg University, Göteborg, Sweden
Session 9: Illegal Unreported and Unregulated (IUU) Fishing

This paper analyzes the causes for regulatory compliance using traditional deterrence variables and potential moral and social variables. We use self-reported data from 450 Tanzanian artisanal fishers in Lake Victoria, which use gill-nets, small open wooden boats with or without engines. The results give
support to the traditional economics of crime model, but also show that the extension of the basic deterrence model which includes moral development, legitimacy, and considerations about the behavior of others in the fishery leads to a richer model with substantially higher explanatory power for the decision between being purely honest or maybe violate. For those who sometimes violate the moral and legitimacy variables have less impact, i.e., once you break the rule these factors are less important in mitigating the violation rate, but the social and legitimacy variables significantly explain the behavior of this group too. In the Lake Victoria fishery, as indicated by previous studies on fishery compliance, there is a small group of systematic violators which violate all the time irrespective of either deterrence variables or legitimacy and social variables.

Keywords: compliance, artisanal fishery, Lake Victoria

RECONCILING THE REVOCABLE (OR IMPERMANENT) PRIVILEGE OF IFQs WITH ECONOMIC NEEDS OF FISHERMEN

Mark Fina and Joseph Sullivan

Presented by Mark Fina, North Pacific Fishery Management Council, Anchorage, USA
Session 16: Rights-Based Fisheries 3: Communities, Conservation, North Pacific Fisheries

Under the public trust doctrine, the U.S. government maintains ownership of its fisheries and manages those fisheries in the public interest. To meet this public trust mandate, laws and regulations governing existing IFQ and other “rights-based” management programs in U.S. fisheries contain provisions that clearly state any fishing privileges held under these programs are not permanent and that the revocation of fishing privileges is not a compensable taking. Notwithstanding these statements, all “rights-based” management programs contain somewhat contradictory elements that suggest an uncertain degree of permanence to those fishing privileges. For example, long term interests under the programs all create a privilege to receive an annual allocation in a fishery. Managers administer systems of compensated transfers in the various fishing privileges. In some programs, government sponsored long-term loans fund these transfers. This paper explores legal and economic foundations for determining an appropriate tenure for the interests created under “rights-based” management programs. The paper first examines an equitable approach that could be employed to determine an appropriate notice period for a revocation of fishing privileges, if policymakers were to decide that it is in the public interest to revoke privileges under an existing program. The paper goes on to suggest that in developing future “rights-based” management programs a more predictable tenure of reasonable length could benefit both participants in the fisheries and the public interest.

Keywords: IFQs, property rights, public trust

FRASER SALMON AND THE SPECIES-AT-RISK ACT: SOCIO-ECONOMIC IMPACTS

Gordon S. Gislason

GSGislason & Associates Ltd., Vancouver, Canada
Session 2: Ecosystem Issues 1: Species-at-Risk, Genetic Resources and Valuation

The federal Species-At-Risk Act (SARA) could have profound implications for people, businesses and communities dependent on the salmon resources of the Fraser River. This paper develops a Multiple Account Evaluation framework for analyzing the impacts of the Act. The framework has three Environmental Accounts (Biological, Ecosystem, Science) and eight Socio-Economic Accounts (First Nations, Business, Government, Regional Development, Social/Community, etc.). The framework is applied to two candidates for SARA-listing, Cultus Lake sockeye and Interior Fraser coho. Impacts vary between the short term and long term and depend critically on future marine survival. The framework can help informed decision-making through making tradeoffs between environmental benefits and business compliance costs more transparent.

Keywords: endangered species, socio-economic impacts, analytical framework
GENETIC RESOURCES FOR FUN AND PROFIT – THE ROLE OF THE INTEREST RATE IN NATURAL SELECTION

Atle G. Guttormsen, Dadi Kristofersson and Eric Nævdal

Presented by Dr Atle G. Guttormsen, Norwegian University of Life Sciences, Ås, Norway
Session 2: Ecosystem Issues 1: Species-at-Risk, Genetic Resources and Valuation

It has become clear that exploitation of some natural resources may result in evolutionary selection pressure on some species. This has the potential consequence that species may undergo significant morphological changes over time. The potential adverse effects should be taken into account when regulating such resources. In this paper we present a bioeconomic model where we analyze the effect of selective harvesting on genetic frequency for one specific gene in terms of the socially optimal long term management of the resource. It is assumed that nature selects for the gene while harvesting selects against it, i.e., the individuals carrying it have a lower natural mortality rate but are also more valuable to catch. The model is based on a standard logistic growth model with mortality combined with a model for genetic dynamics. Optimal regulation is then examined, assuming that a regulator wants to maximize the discounted profits from harvesting the resource. The complexity of the genetics makes an explicit solution of the problem very difficult. However, the model has a structure that enables the identification of a steady state solution with relative ease. The solution indicates that it is optimal to conserve as long as the stocks own rate of return for conservation exceeds the discount rate. The stocks own rate of return in this simple model is the difference in natural mortality rate between individuals carrying the gene and those that do not.

Keywords: bioeconomics, selective harvesting, genetics, biodiversity

BERING SEA POLLOCK FISHER RESPONSE TO THE STELLER SEA LION CONSERVATION AREA

Alan C. Haynie and David F. Layton

Presented by Mr Alan C. Haynie, NOAA Fisheries, Seattle, USA

Marine protected areas (MPAs) have become a primary tool for marine preservation and management. Despite the extensive research that has been conducted on MPAs, a limited amount of work has addressed how commercial fishers adjust their behavior in response to marine protected areas. How do fishers respond to the closure of key portions of their fishing grounds? An extensive network of protected areas has been developed in the Bering Sea to protect the foraging grounds of the endangered Steller sea lion. These closures affect many Alaskan fisheries, including the pollock fishery, which is by volume the largest fishery in the United States. In 1999 and 2000, fisher cooperatives were developed in the pollock fishery which ended the race for fish and provided quota rights based on historical catch in the fishery. In previous work, we model how fishers respond to these area closures and develop a new methodology to calculate the welfare impacts of area closures. In this current work, we extend our previous work to model how fishers make location choices now that the race for fish has ended. The benefits of economic restructuring have far outweighed the costs of introducing protected areas, resulting in a fishery that is more profitable and more sustainable. We discuss the benefits of combining economic restructuring with the introduction of marine protected areas.

Keywords: marine protected areas, Alaska, discrete choice models, cooperatives, spatial effort dynamics
DYNAMIC DISCRETE CHOICE MODELING: MONTE CARLO ANALYSIS

Robert Hicks and Kurt E. Schnier

Presented by Dr Kurt E. Schnier, University of Rhode Island, Kingston, USA
Session 11: Spatial Decision-Making 1: Discrete Choice

Recent work on spatial models of commercial fishing has provided insights into how spatial regulatory policies (i.e. Marine Protected Areas) are likely to alter the fishing location choices of commercial fishermen and the efficiency of these policies. The applied studies have spanned a diverse range of fisheries from sedentary to highly migratory species. This literature has largely ignored the inter-temporal aspects of commercial fishing site choice at the cruise level. Therefore, these models depict fishermen as if they are ignoring the fact that a location choice on the first day of a cruise may have potentially important consequences for the rest of the cruise. For many fisheries, particularly highly migratory fisheries, fishermen might choose a dynamically optimal cruise trajectory rather than myopic day-by-day strategies. An econometric model that ignores these inter-temporal aspects of location choice will likely lead to erroneous conclusions regarding a vessel’s response to spatial regulatory policies. A dynamic discrete choice model is developed herein that utilizes the same information conventionally used in static models which is entrenched in the principles of dynamic optimization (Bellman’s principle). Using Monte Carlo analysis, we evaluate the relative performance of this estimator as compared to the conventional static model for a variety of conditions that mimic different fishery types.

Keywords: location choice, dynamic spatial choice modeling

INDIVIDUAL HABITAT QUOTAS FOR FISHERIES: THE INFLUENCES OF REGULATORY SCALE AND SPATIAL HETEROGENEITY

Daniel S. Holland and Kurt E. Schnier

Presented by Dr. Daniel S. Holland, New Zealand Seafood Industry Council, Wellington, NZ
Session 11: Spatial Decision-Making 1: Discrete Choice

Limiting adverse consequences of fishing on essential fish habitat has emerged as a key fishery management objective. The conventional approach to providing habitat protection is to create MPAs or marine reserves that prohibit all or certain types of fishing in specific areas. However, there may be more cost-effective and flexible ways to provide habitat protection. We propose an individual habitat quota (IHQ) system for habitat conservation that would utilize economic incentives to achieve habitat conservation goals cost-effectively. Individual quotas of habitat impact units (HIU) would be distributed to fishers with an aggregate quota set to maintain a target habitat “stock”. HIU use would be based on a proxy for marginal habitat damage. We use a dynamic, explicitly spatial fishery and habitat simulation model to explore how such a system might work. We examine how outcomes are affected by spatial heterogeneity in the fishery and the scale of habitat regulation. We find that the IHQ system is a highly cost-effective means of ensuring a given level of habitat protection, but that spatial heterogeneity and the scale of regulation can have significant effects on the distribution of habitat protection. Heterogeneity in cost can lead to distinct spatial patterns of habitat protection associated with higher cost areas. If cost heterogeneity is associated with different habitat types, it may be necessary to create separate quotas for different habitat types. Coarse scale habitat regulation can lead to a divergence of the actual level of habitat quality from its regulated proxy and a loss in efficiency.

Keywords: MPAs, habitat conservation, individual habitat quotas
FISHERIES COOPERATIVES – VARIETIES AND CONSEQUENCES

Daniel D. Huppert and Jennifer Kassakian

Presented by Dr Daniel D. Huppert, University of Washington, Seattle, USA
Session 3: Rights-Based Fisheries 1: Co-Management

Many fishing cooperatives that have been organized in U.S. north Pacific fisheries in the past decade. The fisheries affected include at least Pacific whiting, Alaska weathervane scallop, Chignik sockeye salmon, Bering Sea pollock. This presentation will review the rationale and organization of these cooperatives. Then we assess the economic consequences for cooperative members. Finally, we speculate about the future of cooperatives in other fisheries, such as the Bering Sea crab fishery.

Keywords: cooperatives, U.S. north Pacific

TREADMILL EFFECTS AND CAPITALIZATION OF RESOURCE RENT IN NORWEGIAN FISHERIES

Gakushi Ishimura and Rögnvaldur Hannesson

Presented by Mr Gakushi Ishimura, Fisheries Centre, UBC, Vancouver, Canada
Session 18: Efficiency and Productivity of Fisheries

Improved fish stock management in Norway has achieved sustainable production of marine capture fisheries in the 1990s. In 2002 the Norwegian fishery harvested 2.6 million metric tons of fish. The value of total marine captures has also increased through rising unit ex-vessel prices of the main species. In addition, a considerable reduction in the number of boats have improved revenue per fisherman significantly. Although short-run profits per vessel from such fisheries would be expected to be improved, the annual average profits in Norwegian fishing vessel accounts did not indicate an increase in profits corresponding to the increase in revenue. In contrast, annual average long-term debt, which reflects new investments in vessels and fishing gear, as well as fish quotas under the Transferable Quota (Individual Vessel Quota) system, has grown dramatically. This situation of Norwegian fisheries strongly suggests the existence of treadmill effects in profits, whereby investment in fishing capital prevents fishers from materializing potential profits by adapting cost-reducing strategies and acquiring more quota toward a larger scale of operation.

Keywords: quota, profitability, treadmill effect

GLOBAL COST AND REGIONAL BENEFIT OF OPEN OCEAN AQUACULTURE WITH OCEAN NOURISHMENT

Ian S.F. Jones and Ibrahem Al Tarawneh

Presented by Dr Ian S.F. Jones, University of Sydney, Sydney, Australia
Session 21: Aquaculture

The impact on the global economy of a shift in wild fisheries to fish ranching has been investigated by using DICE, a computerized, dynamic, general equilibrium model of the economy developed at Yale University. It is assumed that Ocean Nourishment, the purposeful introduction of nutrients into the surface ocean, is widely adopted over the next 50 years to increase the production of fish biomass. Using the fish stock response predicted in Jones (2004) to the addition of urea (and other nutrients) to the ocean, the change in GDP per person can be calculated. There is an empirical relationship between the birthrate and the GDP per capita. This relationship has been estimated from UNICEF data for 2003 and used to predict the future population of low income countries. With the extra GDP assumed to be available as a result of ocean nourishment focused on low income countries, the population in 2105 is predicted to be half a billion less than if Ocean Nourishment is not practiced. The low income peoples would enjoy an 18% increase in GDP per person.
Keywords: Ocean Nourishment, ranching, fisheries, population

A DYNAMIC SPATIAL MODEL TO PREDICT NET DISTRIBUTION OF FISHING EFFORT IN RELATION TO CHANGES IN FISH ABUNDANCE IN THE GLOBAL TUNA LONGLINE FISHERY

H. Keith, C. Walters and U. Rashid Sumaila

Presented by Ms Heather M Keith, University of British Columbia, Vancouver, Canada
Session 20: Spatial Decision-Making 3: MPAs, Tuna, Recreational Fisheries

The complexity of a multispecies, multifleet fishery makes it difficult to predict the allocation of fishing effort among areas and alternative target species, rendering large limitations on fisheries management. With a better understanding of fleet dynamics in large commercial fisheries, management policies will be able to predict fishing effort changes when fish abundance and market prices fluctuate. Effective spatial management depends on the knowledge of fisher behaviour and choice of fishing location. Fisher choice behaviour will depend on economic and environmental indicators such as perceived economic opportunity, market conditions and relative fish abundance, which will govern decisions between alternative fishing areas. A bioeconomic model that combines an age structured population model with a fishing effort distribution model was developed from historical catch, effort, and price data for the global longline tuna fisheries in order to predict long term trends in fishing effort and fish population response. Total fishing effort is distributed each year based on the changes in relative profit and fish abundance in each area. Expected profitability for each 5º by 5º cell is calculated for the aggregated global tuna fleet. Predicted fishing effort will be distributed to each cell as a weighted proportion of the total fishing effort dependent on the expected catch and profit in that cell. In an attempt to assess the behaviour of a fishing fleet in a relatively simple model, spatial movement can be explained in order to implement appropriate management policies.

Keywords: tuna longline fishery, fishing effort dynamics, bionomic equilibrium

PROCESS AND POLICY ISSUES FOR DECENTRALIZED FISHERIES GOVERNANCE IN THE NORTHEAST U.S.

Andrew W. Kitts and Patricia Pinto da Silva

Presented by Mr Andrew W Kitts, NOAA Fisheries Service, Woods Hole, USA.
Session 1: Fisheries Governance 1: High Seas, Regional Fisheries Organizations

The recent introduction of sector allocations in the Northeast Multispecies Groundfish fishery represents a new and innovative management option for fisheries in the Northeast U.S. Interest in less centralized stewardship of marine resources is evident from a diversity of stakeholders including industry representatives, NGOs, community representatives and others. While important steps have been taken towards less centralized fisheries management in the Northeast, an overall policy has not been established to guide further developments and strengthen existing ones. This paper expands upon the model of co-management arrangements formulated by Sen and Neilson (1966) by developing a framework for identifying degrees of government involvement and control. Categories are defined for government involvement and control in: (a) conducting research and providing information; (b) crafting and implementing fishery regulations; and (c) establishing property rights. The framework is then used to characterize recent initiatives, using data obtained from informal interviews of key personnel involved in a variety of case studies. Use of the expanded framework provides a method for more clearly defining policy issues. We present and discuss several unresolved policy issues in the Northeast that will become much more obvious as NOAA Fisheries Service and other stakeholders begin to undertake their respective roles in less centralized fisheries governance arrangements.

Keywords: decentralized governance, sector allocation, co-management
CHALLENGES IN RESTRUCTURING ALASKA SALMON FISHERIES

G. Knapp and F. Ulmer

Presented by Dr Gunnar Knapp, University of Alaska Anchorage, Anchorage, USA

Session 8: Fishery Management 1: Restructuring, Buyback Control, ITQs

Over the past fifteen years, Alaska’s salmon industry has experienced a dramatic decrease in value as a result of competition from farmed salmon and other factors. The resulting economic crisis in the salmon industry has led to calls for improved quality, new products, and better marketing. However, there has been relatively little discussion of restructuring the management of Alaska’s limited entry salmon fisheries to reduce costs and increase value. This paper examines why Alaska’s salmon management has remained essentially unchanged as the economic challenges facing the salmon industry have worsened (with the significant exception of the Chignik salmon fishery). One reason is that restructuring is difficult. Changes to salmon management would affect fishermen and communities in different and complex ways, and the industry is deeply divided about what kinds of changes are needed—or whether changes are needed at all. Unfished or “latent” permits add to the difficulty of restructuring, to the extent that the benefits of restructuring must be shared with these permit-holders. However, the fundamental obstacle to restructuring is the ambiguity of responsibility and authority within state government for the economic success of Alaska’s fisheries. The Legislature—which has ultimate authority for Alaska’s fisheries management—has neither assumed nor delegated responsibility and authority to restructure Alaska salmon management for the purpose of strengthening the economic viability of the industry. Unless and until this responsibility and authority is clearly established, it will be difficult for restructuring to succeed.

Keywords: Alaska, salmon, fishery management, restructuring

ASSESSING RESOURCE AND ENVIRONMENTAL CHANGES: ARE TEXTS A HAZARDOUS PRODUCT?

Jack L. Knetsch

Simon Fraser University, Burnaby, Canada

Session 4: Behaviour, Ethics and Natural Capital

On present evidence the short answer is an almost unqualified yes. Most current texts and manuals remain consistent with conventional mainstream environmental economics, and however well-intentioned, they, among other things, ignore insights provided by findings of recent behavioural economics research.

Keywords: behavioural economics, endowment effect, understate losses

HIGH-GRADING IN A QUOTA-REGULATED FISHERY, WITH EMPIRICAL EVIDENCE FROM THE ICELANDIC COD FISHERY

D. Kristofersson and K. Rickertsen

Presented by Dr Dadi Kristofersson, Norwegian University of Life Sciences, Aas, Norway

Session 9: Illegal Unreported and Unregulated (IUU) Fishing

Fishers in quota-regulated fisheries find it to their advantage to discard less valuable fish at sea to increase the value of their catch. A theoretical model describing the high-grading behavior of fishers is presented, and an empirical model is derived as well as a testing strategy to test for high-grading and to estimate the discarded amount of each grade. The model is applied to data for the Icelandic quota regulated cod fishery during the period September 1998 to June 2001. The results indicate that high-grading occurs in the Icelandic cod fishery for both long-line and net vessels. However, the discard rates are small, and the results clearly suggest that the ban on discards in Iceland has effectively dealt with high-grading. The estimated discard rates are consistent with existing estimates of high-grading for the same types of vessel.
in the same fishery. This suggests that the modeling of discarding decisions based purely on incentives is a useful alternative to classical biometric methods.

Keywords: ITQs, highgrading, estimation

SIMULATING WITH ISIS-FISH V2.0 THE DYNAMICS OF A NORTH-EAST ATLANTIC MIXED FISHERY SUBJECT TO SPATIAL CLOSURES

Stéphanie Mahévas, Dominique Pelletier, Paul Marchal, Olivier Guyader, Raul Prellezo and Marina Santurtún

Presented by Dr Stéphanie Mahévas, IFREMER, Nantes, France
Session 15: Spatial Decision-Making 2: Metapopulation, Spatial Closures

The purpose of this study is to test and compare the impact of management scenarios, including spatial closures, on both resources and fishing activity of the main demersal mixed fishery of the Bay of Biscay (located in the North Atlantic western of France). This fishery is actually managed through mono-specific-TAC, minimum landing sizes, mesh size, and fishing ban for large boats within the 12 miles area. All these management measures are inefficient to protect the main target species, Nephrops, Hake, Anglerfish and Megrim. Since several years, spatial closures of the nephrops area and the hake nursery have been envisaged. We propose to assess this management measure and to compare it to traditional ones. The simulations were performed with ISIS-Fish V2.0, a simulation tool aimed at evaluating the impact of spatial and seasonal management measures on the dynamics of mixed fisheries. ISIS-Fish V2.0, a generic software which elaborates on the previous version by explicitly considering and modelling the short-term economics dynamics of mixed fisheries. The model includes the already existing structural components of fishing activities, namely metiers and strategies. Metiers and strategies describe the spatial and seasonal allocation of standardised fishing effort. Effort allocation may be altered through fishers behaviours, which depend on economic conditions, management options implemented, and other factors influencing fishers decisions. Economic conditions are modelled through short-term cost and revenues. Decision rules and other endogeneous behaviours may be modelled through a Script language that is integrated in ISIS-Fish. The study required first to parametrize the spatio-seasonal dynamics of the populations mentioned above, and of fishing activity. Then management scenarios were evaluated using a statistical simulation design coupled to linear models.

Keywords: fleet dynamics, mixed fishery, simulation, marine protected area, fishermen reactions

ENTERING AND EXITING A FISHERY: A STRATEGIC CHOICE?

S. Mardle and T. Hutton

Presented by Dr Simon Mardle, University of Portsmouth, Portsmouth, United Kingdom

It could be expected that the decision of fishers to enter, stay or exit a fishery in a given year is related to profits in that year. Due to the lack of trip level cost data, catch rates, revenues or some weighted value per unit effort are used as a proxy for profit. Thus, poor catch rates could force fishers to leave the fishery and high catch rates could attract new entrants. There may be several reasons for a vessel exiting the fleet, including decommissioning and selling. However, exiting a fishery (i.e. acquiring rights to fish elsewhere), either permanently or temporarily, is more difficult to track. Movement to other fisheries is somewhat restricted by issues of licensing, however there is generally some scope to modify strategy towards more than one “fishery”. Hence, modelling the behaviour of fishers with respect to their entering and exiting strategy can affect the success of policy, such as closed areas or quota restrictions, aimed at a fishery substantially. In this paper, we consider the behaviour of the English North Sea beam trawl fleet principally targeting quota species such as plaice and sole between 1989 and 2003. Results show that the age of the vessel, revenues achieved and status of the plaice stock have an effect on vessels leaving the fishery. In addition to these factors, vessels entering the fishery are affected significantly by the number of vessels operating in the fishery at the time.
INTERNATIONAL TRADE, FISHERIES, AND CANADIAN MARINE ECOSYSTEMS: AN EMPIRICAL ANALYSIS

A. Dale Marsden and U. Rashid Sumaila

Presented by Mr Dale Marsden, University of British Columbia, Vancouver, Canada
Session 6: Trade, Traceability, and Marketing

We examine how international trade in fisheries products has affected Canadian marine ecosystems. Canada currently exports more than half of its fisheries landings, an increase from one-third in the late 1980s. International trade is thus likely to influence the incentives that steer Canadian fishing effort and fisheries management. There is concern that trade might exacerbate the depletion of fisheries resources, especially in contexts where management is weak, ineffective or absent, and our preliminary analysis showed a negative relationship between fish exports and fish biomass. In the current study, we quantify the empirical relationship between fish biomass in Canadian marine ecosystems and the volume of trade and landings using a panel of data on eight major fishery species since 1980. We found that increases in exports were associated with increased landings and decreased biomass after controlling for other variables, but encountered difficulties in assigning causative roles. This study is an intermediate phase of a project that aims to assess how trade liberalization affects fisheries and, indirectly, marine ecosystems.

Keywords: international trade, ecosystems, biomass, empirical analysis

ECOSYSTEM OF A SMALL LAKE (KAWAHARA-OIKE, JAPAN) INVADED BY TWO ALIEN SPECIES: BLUEGILL (LEPOMIS MACROCHIRUS) AND LARGEMOUTH BASS (MICROPTERUS SALMOIDES)

Takashi Matsuishi, Md. Monir Hossain, Akira Goto and Mikio Azuma

Presented by Mr Md. Monir Hossain, Hokkaido University, Japan.
Session 10: Subsistence, Small-scale, Recreational fisheries

In Japan, many ponds, lakes and rivers have been invaded by largemouth bass and bluegill and the consequences have been frequently reported. Despite the difficulties in predicting the impacts of invasive species, the present study has been carried out to determine the mechanisms of such consequences and the desired fishing effort rate which will maintain the stability and integrity of the ecosystem. By using ECOPATH software, an energy budget model was developed for an invaded small lake (Kawahara-oike) of Nagasaki Peninsula, western part of Japan as a case study. The input parameters were estimated from the length-frequency analysis and from the literature. The balanced Ecopath model of the lake consisted of 11 compartments and a total biomass of 1.364 t/km². The mean trophic level was 26.80, with catches being highest on bluegill (0.440 t/km²), paradise goby (0.318 t/km²) and Trident goby (0.241 t/km²). Each species appears as a predator on several different trophic levels. The prey items of largemouth bass and bluegill were quite different; however, largemouth bass are included in the prey of bluegill. As a predator, the largemouth bass has the highest trophic level (3.9) and has direct trophic relations with paradise goby, Trident goby, stone moroka and zooplankton. As prey, bluegills have a direct trophic relation with detritus, prawn and aquatic vegetations. The result shows that the largemouth bass forage on two abundant gobies, paradise goby and Trident goby, not the bluegill, which will help to stabilize the population of largemouth bass if one prey item becomes scarce.
DECISION STRUCTURING TO ALLEVIATE EMBEDDING IN ENVIRONMENTAL VALUATION

Timothy L. McDaniels, Robin Gregory, Joseph Arvai and Ratana Chuenpagdee
Presented by Dr Tim L. McDaniels, University of British Columbia, Vancouver, Canada
Session 2: Ecosystem Issues 1: Species-at-Risk, Genetic Resources and Valuation

Embedding is the widely-observed phenomenon that a good is assigned a higher value if evaluated on its own rather than as part of a more inclusive set. Embedding is considered a serious problem affecting the quality of many environmental management and health risk policy judgments. This paper presents the results of an experiment involving a structured, small-group approach for conducting environmental policy evaluations. It focuses on eliciting problem-specific values and discussion among participants about the pros and cons of multiple project alternatives, in the context of tradeoffs between fisheries production and electricity generation from dams. Study results show a significant reduction in embedding, which is viewed as an improvement in the quality of the preference judgments compared with a standard contingent valuation (CV) approach.

Keywords: Embedding, value, electricity, power

A PRELIMINARY LOOK AT THE HAWAI’IAN SWORDFISH REGULATIONS AT REDUCING SEA TURTLE BYCATCH

Jeffrey K. O’Hara and Theodore Groves
Presented by Mr Jeffrey K. O’Hara, University of California, San Diego, La Jolla, USA
Session 14: Ecosystem Issues 3: Restoration, MPAs, Bycatch

The first year of the reopening of the Hawaii swordfish longline industry terminated on December 31, 2004. A moratorium had been placed on swordfish longlining in Hawaii due to excessive sea turtle bycatch. The fishery was reopened in 2004 by replacing j-hooks and squid bait with circle hooks and mackerel bait; 100% observer coverage on every swordfish vessel; a quota on the number of allowed trips (half of their historical effort is the maximum allowed); and a cap on the number of interactions permitted with sea turtles. We have observer data for every swordfish vessel that lets us know where, when, and how many sea turtle interactions occur, how many swordfish are caught, and gives us insight into how these new regulations will impact the swordfish industry. We will specifically be looking at the decision of longliners to switch from targeting tuna to swordfish. We will explain how this decision can depict risk preferences of fishermen and how this information can be used in the formulation of future regulatory schemes. Although the Hawaii experiment is in its infancy, its novel features and unique design make the fishery compelling to analyze. The results of this experiment could play a large role in shaping future policy decisions about the compatibility of longlining and sea turtle population recovery.

Keywords: sea turtles, swordfish, Hawaii, longline, bycatch

IMPORTATION OF TASTELESS SMOKE (CO) TREATED TUNA AND ITS IMPACTS TO LOCAL MARKET AND FISHERIES

Minling Pan and Timothy Ming
Presented by Dr Minling Pan, NOAA Fisheries, Honolulu, USA
Session 6: Trade, Traceability, and Marketing

To investigate the impact of imported frozen tuna to the local market and fisheries, a study is conducted to test the assumptions that (1) local consumers of fresh raw tuna (ahi poke) exhibit an ignorance towards the imported Tasteless Smoke (CO) treated product, and (2) local consumers value the quality of fresh local ahi poke over previously frozen Tasteless Smoke (CO) treated ahi and are willing to pay a higher price for the former. This paper presents some important findings from this study.
RISK-SHIFTING IN FARM-RAISED CATFISH MARKETING CHANNELS

K. Quagrainie and I. Neira

Presented by Dr Kwamena K Quagrainie, University of Arkansas at Pine Bluff, Pine Bluff, USA
Session 21: Aquaculture

Over 93 percent of farm-raised catfish are sold through fish processing companies, with processors largely dictating the terms of trade, particularly size requirements, and spot prices. If catfish processors are facing price risk in their terms of trade from retailers, they are more likely to pass that risk on to producers. Catfish processors may dictate the terms of transactions for the purpose of profit maximization. Some processors of late have been willing to bear some market risks through selling delivery rights. To fully understand the development of catfish markets, it is necessary to understand whether catfish processors are more risk averse and/or have less ability to absorb risks from producers. This relationship in terms of risk aversion between processors and producers would imply that catfish processors are more likely to offer terms of trade that do not shift risk from producers. Catfish producers face input market risk and output market risk. The study examined the extent income risk is borne by the processors to make inferences relating to risk transfer back to producers. The classic principal-agent model was used to examine the risk behavior of processors using secondary market data. Theoretical models, limited personal contacts, and other data were used to parameterize the simulation models of alternative contract structures and their impacts on producers and processors. Results suggest that processors transfer risk because of higher risk-bearing costs associated with marketing aquaculture products. Optimal solutions occur when farmers are given more incentives to meet the delivery conditions that enable processors to increase the production of consumer-oriented aquaculture products.

Keywords: catfish, risk shifting, marketing channel

STRANDED CAPITAL AND IMPACTS TO PROCESSORS OF ITQS

Kate Quigley

National Marine Fisheries Service, Seattle, USA
Session 3: Rights-Based Fisheries 1: Co-Management

Analyzing the potential impacts to buyers and processors resulting from implementation of an individual transferable quota system is an important task for management agencies to tackle. An individual transferable quota (ITQ) system is being considered for the Pacific Groundfish trawl fishery. Implementation and acceptance of the program will hinge in part on how potential impacts to processors and other stakeholders are perceived. However, estimation of potential impacts is not straightforward. The data necessary for impact estimation is often unavailable or scarce. Efforts to gather data are not always successful due to processor limitations regarding sensitive data. This presentation reviews the conceptual issues surrounding ITQ impacts to processors, summarizes the theoretical and analytical approaches used by others to estimate impacts, discusses the empirical difficulties these approaches entail, summarizes the pre and post-ITQ experiences of other fisheries with regards to impacts on processors and discusses the potential approaches that could be used to more adequately assess potential impacts.

Keywords: ITQs, Pacific groundfish, seafood processing, stranded capital
MODELING ECONOMIC EFFICIENCY IN A FISHERY: THE NORWEGIAN COD TRAWL FISHERY

Kristin H. Roll, Frank Asche and Atle G. Guttormsen

Presented by Miss Kristin Helen Roll, University of Stavanger, Stavanger, Norway

Session 19: Economic Performance 2: Efficiency, Productivity and Welfare Effects

We are in this paper using a shadow revenue model to decompose economic inefficiency into its technical and allocative components, since revenue maximisation subject to a single quasi-fixed input appears to be a reasonable assumption for a fishery. In a fishery, efficiency is traditionally modeled through a production function. However by using a production function to describe the underlying technology, it is only possible to get estimates of technical efficiency. Based on a dual approach, all types of inefficiencies can be estimated through additional parameters, and firm-specific technical inefficiency as well as output and firm-specific allocative inefficiency, can be identified. Traditionally the literature is concerned with the development of econometric techniques for the cost efficiency (and profit efficiency), whereas very little attention is paid to the revenue efficiency. The common known technique used to estimate cost efficiency might to a certain point be modified to estimate revenue efficiency, but there are several differences between the estimation of input-oriented cost efficiency and output-oriented revenue efficiency.

Keywords: multispecies fishery, technical efficiency, allocative efficiency, revenue function

PROTECTING MARINE BIODIVERSITY: A COMPARISON OF INDIVIDUAL HABITAT QUOTAS (IHQs) AND MARINE PROTECTED AREAS

Kurt E. Schnier and Daniel S. Holland

Presented by Dr Kurt E. Schnier, University of Rhode Island, Kingston, USA

Session 7: Ecosystem Issues 2: Values and Valuation, Biodiversity

Fisheries managers in the United States are required to identify and mitigate the adverse impacts of fishing activity on essential fish habitat (EFH). There are additional concerns that the viability of noncommercial species, animals that are habitat dependent and/or are themselves constituents of fishery habitat may still be threatened. We consider a cap-and-trade system for habitat conservation, individual habitat quotas for fisheries, to achieve habitat conservation and species protection goals cost effectively. Individual quotas of habitat impact units (HIUs) would be distributed to fishers with an aggregate quota set to maintain a target habitat “stock” of EFH conservation. Using a dynamic, spatially explicit fishery simulation model we explore the efficiency and cost effectiveness of an IHQ policy versus alternative marine protected area (MPA) configurations, at reducing the risk of extinguishing a habitat dependent species of unknown spatial distribution. Our findings indicate that an IHQ policy with a conservatively established habitat target is better suited to the protection of non-target species than a rotating or fixed MPA policy.

Keywords: essential fish habitat, habitat units, cost effectiveness

OUTSIDE THE REALM OF ECONOMICS: WHAT ARE THE IMPLICATIONS OF ENVIRONMENTAL ETHICS FOR FISHERIES MANAGEMENT?

Donald M. Schug

Northern Economics, Inc., Anchorage, USA

Session 4: Behaviour, Ethics and Natural Capital

This working paper explores the possible technical and institutional implications of the notion of intrinsic value for fisheries management. Intrinsic value in environmental assets is inconsistent with the economic paradigm of trade-offs between income changes and species or ecosystems because it presents individuals with the moral imperative that we ought to preserve nature (i.e., it reflects a lexicographic decision rule). Analysts employing contingent valuation method surveys to place a monetary value on various aspects of
the environment have endeavored to eliminate the bias caused by intrinsic value through survey redesign and data manipulation. However, the question of how and to what extent intrinsic value and ethical concerns in general should inform and guide the process of making public choices has received relatively little attention. In the specific area of fisheries management, the public discourse surrounding such prevalent issues as endangered species interactions, bycatch and habitat effects suggests that ethical concerns may be an important aspect of these issues for a segment of the U.S. citizenry. Yet, few NEPA analyses of proposed fishery conservation measures discuss this possibility. Moreover, some observers have raised questions about the capacity of current decision-making tools and participatory and deliberative mechanisms (e.g., MSA-created fishery management councils) to be adequately responsive to different ethical values.

Keywords: fisheries management, valuation, environmental ethics

SPATIAL MANAGEMENT OF METAPOPULATIONS IN FISHERIES: THE BIOECONOMIC EFFECTS OF SOURCE-SINK CONFIGURATIONS

J.C. Seijo and J.F. Caddy

Presented by Dr Juan Carlos Seijo, Universidad Marista de Mérida, Merida, Mexico

Session 15: Spatial Decision-Making 2: Metapopulation, Spatial Closures

A dynamic spatial age-structured bioeconomic model was built to represent source-sink resource dynamics of metapopulations and the resulting spatial allocation of fishing intensity over time. This study explores a specific situation, namely the consequence of management not taking into account a source-sink population configuration where one exists, and in contrast, considers what management approaches would be appropriate where a source-sink configuration applies. A source-sink configuration is where a stock occurring in two or more areas is genetically homogeneous but due to a sub-optimal sink environment and/or its hydrography, if spawned from a sink or peripheral area either larvae have a low probability of return to home range, or population fragmentation does not allow spawning migrations of part of the adult population to a favorable spawning location. The study focuses specifically on the dynamic biologic and economic consequences of a differentiation in reproductive potential through the species range not being usually recognized in stock assessment and management. Alternative spatial management strategies for fisheries with source-sink attributes are also explored.

Keywords: spatial bioeconomic simulation, metapopulations, source-sink populations, spatial allocation of fishing intensity

VALUING ECOSYSTEM SERVICES WITH FISHERY RENTS: A LUMPED-PARAMETER APPROACH TO HYPOXIA IN THE NEUSE RIVER ESTUARY

Martin D. Smith and Larry B. Crowder

Presented by Dr. Martin D. Smith, Duke University, Durham, USA

Session 7: Ecosystem Issues 2: Values and Valuation, Biodiversity

Valuing ecosystem services with microeconomic underpinnings presents enormous challenges because these services typically constitute nonmarket values and contribute to human welfare indirectly through a series of ecological pathways that are dynamic, nonlinear, and difficult to quantify and link to appropriate economic spatial and temporal scales. This paper develops and demonstrates a method to value a portion of ecosystem services when a commercial fishery is dependent on the quality of estuarine habitat. Using a lumped-parameter, dynamic open access bioeconomic model that is spatially explicit and includes predator-prey interactions, this paper quantifies part of the value of improved ecosystem function in the Neuse River Estuary when nutrient pollution is reduced. Specifically, it traces the effects of nitrogen loading on the North Carolina commercial blue crab fishery by modeling the response of primary production and the subsequent impact on hypoxia (low dissolved oxygen). Hypoxia, in turn, affects blue crabs and their preferred prey. The discounted present value fishery rent increase from a 30% reduction in
nitrogen loadings in the Neuse is $2.04 million, though this welfare estimate is fairly sensitive to some parameter values. Surprisingly, this number is not sensitive to initial conditions.

Keywords: ecosystem services, open access, fishery rents, estuarine pollution, hypoxia, blue crab

A HIERARCHICAL BAYES APPROACH TO DISCRETE CHOICE FISHERIES MODELING: THE EFFECT OF MARINE RESERVES ON FISHING BEHAVIOUR

Martin D. Smith, Junjie Zhang and Felicia C. Coleman

Presented by Dr Martin D. Smith, Duke University, Durham, USA
Session 11: Spatial Decision-Making 1: Discrete Choice

The dominant paradigm in fisheries policy is undergoing a transformation from one that views regional fish stocks as single entities towards one that increasingly acknowledges the importance of spatial heterogeneity and spatial processes in management. This transformation has led to intense interest in establishing marine reserves around the world not only for conservation but also explicitly for commercial fisheries management. Yet, we know almost nothing about how reserves perform empirically. A key aspect of evaluating reserves for fisheries management is understanding the behavioral responses of fishermen. In June of 2000, two marine reserves were established in the Gulf of Mexico reef fish fishery. In this paper, we examine species targets, participation, and fishing location choices for the reef fish fishery in the Gulf of Mexico using a discrete choice model. We use a Hierarchical Bayes framework that allows for unobserved heterogeneity through random parameters, and we estimate the model using Markov Chain Monte Carlo simulation. The data set combines vessel-level logbook data from 1993-2002, NOAA weather buoy data, landings ticket data, and NOAA Fisheries permit records. Since we have data before and after the policy change, we test for structural breaks in responsiveness to prices, abundance, and weather conditions when the reserve goes into effect.

Keywords: fisheries policy, heterogeneity, spatial processes

AMENDING THE ALASKA HALIBUT/SABLEFISH IFQ PROGRAM TO ADDRESS COMMUNITY NEEDS

P. J. Smith

NOAA Fisheries Service, Alaska Region, Juneau, USA
Session 16: Rights-Based Fisheries 3: Communities, Conservation, North Pacific Fisheries

The 1995 implementation of the Individual Fishing Quota (IFQ) program in the Pacific halibut and sablefish fisheries off Alaska transformed those fisheries. Fishing seasons, which had been short, intense, derby-style exercises in racing for fish were extended to more than 8 full months. Ex-vessel prices rose, safety at sea was improved, and a variety of other benefits were realized. However, the experiences of small, coastal communities on the Gulf of Alaska were not as positive. In most such communities, the amount of individual quota that was initially issued was small and, once issued and transferable, a number of community quota holders opted to transfer (sell) their quota to recipients from other places. As a result, the aggregate "fishing power" in those communities has declined. In 2002, the North Pacific Fishery Management Council recommended a change in the program to authorize small communities to form non-profit corporations to petition for the ability to obtain quota and to hold it on behalf of community residents. A final rule to implement the changes was effective on June 1, 2004. Several communities have taken advantage of the opportunity and have submitted applications to be recognized as authorized to purchase quota. The State of Alaska has amended its fishery loan program to authorize loans to these qualifying entities.

Keywords: IFQs, Alaska, communities
ECOLOGICAL AND ECONOMIC ANALYSIS OF SABLEFISH AQUACULTURE IN BRITISH COLUMBIA

U. Rashid Sumaila, John Volpe and Yajie Liu

Presented by Dr. U. Rashid Sumaila, University of British Columbia, Vancouver, Canada
Session 21: Aquaculture

The goal of this study is to undertake an assessment of the potential ecological and economic effects of sablefish Anoplopoma fimbria farming in British Columbia (BC). Sablefish aquaculture is a topical issue in BC due to the prospect of a major sablefish hatchery planned for Salt Spring Island, which would produce juveniles for the intended BC industry. This paper analyzes available information in an effort to inform if and how development should proceed. If a common thread can be found in the published works on this issue so far, it is that empirical data are in short supply. Ecological data regarding wild sablefish are rudimentary at best, and of course aquaculture data are non-existent. As a result, authors, us included, rely to a great extent on the BC salmon aquaculture experience to frame the sablefish issues. Two preliminary results from the study are (i) at low aquaculture production levels, small economic gains are possible if BC engages in sablefish farming under different ecological externality (impact) assumptions. However, gains quickly disappear as production increases towards anticipated levels, and (ii) a decrease in the price of sablefish will ultimately follow an increase in sablefish supply to the market from aquaculture. This decrease will be at the expense of both sablefish farmers and fishers in Canada but beneficial to sablefish fish consumers, which in this case are mainly Japanese. Thus, benefits are exported while costs are entirely absorbed within Canada.

Keywords: ecological risk, price effects, added value

ON THE ECONOMICS OF FISHERIES GOVERNANCE: A PRESIDENTIAL ADDRESS

Jon G. Sutinen

University of Rhode Island, Kingston, USA
Session: Opening of the Forum

The Presidential address to the 2005 NAAFE Forum focused on recent concerns with, and developments in, fisheries governance. The address reviewed some of the recommendations on fisheries governance contained in the recent reports by US Ocean Commission and the Pew Ocean Commission, reviewed recent published research on the governance of environmental and natural resources, and outlined for fisheries economists a research agenda for this critical set of issues.

THE ECONOMIC COSTS OF REGULATION: A BIOECONOMIC COMPARISON OF LEGISLATIVE MANDATES FOR REBUILDING FISH STOCKS IN THE UNITED STATES AND NEW ZEALAND

Gil Sylvia, Sherry L. Larkin and Michael Harte

Presented by Dr. Gil Sylvia, Oregon State University, Newport, USA
Session 19: Economic Performance 2: Efficiency, Productivity and Welfare Effects

Implicit in many national fishery laws – for example the United States MSFCMA and the New Zealand Fisheries Act – is the concept of an optimal rebuilding rate or trajectory for overfished stocks. For New Zealand fisheries the law provides for flexibility in designing a rebuilding process in order to meet economic, social, and cultural needs. In the United States, however, the fisheries manager is constrained by the requirement that, where biologically feasible, stocks must be rebuilt within 10 years. Thus, the U.S. fisheries manager may sacrifice economic and social benefits in order to meet this legal mandate. Using bioeconomic models, fisheries managers can evaluate the tradeoffs associated with alternative rebuilding horizons, discount rates, and regulations for fisheries characterized by moderate- or long-lived species. As modeled in this paper, high discount rates delayed rebuilding trajectories under some scenarios. Alternative rebuilding horizons for the longer-lived stock produced significantly larger changes in the value of the fishery even though the rebuilding horizon was shorter relative to the longevity of the species.
In addition, the effect of the discount rate was larger with the longer-lived species. The effects on the average annual quotas of alternative rebuilding horizons were also different at the highest discount rate. Specifically, a delayed rebuilding horizon for the long- (moderately-) lived species would increase (decrease) the average annual harvest quota.

Keywords: rebuilding, fisheries management, long-lived species, bioeconomic modeling

BAYESIAN ESTIMATION OF TECHNICAL EFFICIENCY IN FISHERIES

D. Tomberlin, X. Irz and G. Holloway

Presented by Dr David Tomberlin, National Marine Fisheries Service (USA), Santa Cruz, USA
Session 18: Efficiency and Productivity of Fisheries

Analysis of technical efficiency in fisheries provides a framework for studying issues such as regulatory impacts and the relative importance of skill versus luck in fishing success. Technical efficiency in fisheries has been most often investigated using data envelopment analysis or stochastic production functions, the latter usually estimated by maximum likelihood methods. This paper describes an alternative, Bayesian approach to estimating stochastic production frontiers in fisheries. Through an application to Washington’s groundfish fishery, we demonstrate the relevance of Bayesian methods to technical efficiency analysis and highlight some particular strengths of the approach that may appeal to fisheries economists. In addition, we assess heterogeneity in the sample and suggest ways of modelling it robustly in fisheries efficiency analysis, with supporting model selection diagnostics.

Keywords: technical efficiency, stochastic production frontier, Bayesian estimation

BEYOND ITQs: TRANSACTIONS COSTS AND SELF-GOVERNANCE IN NEW ZEALAND

Ralph E. Townsend

University of Maine, Orono, USA
Session 13: Fisheries Governance 2: Politics, Policy, ITQ Fisheries Management

New Zealand has made a well-known commitment to ITQs. Less appreciated has been the government interest in self-governance as the next management phase. The most comprehensive example has been the Challenger Scallop Enhancement Company, but self-governance organizations have emerged in orange roughy, hoki/squid, rock lobsters, and oysters. The Ministry of Fisheries has promoted self-governance, but industry interest has been tepid. Transactions cost analysis may (1) explain the limited industry interest in self-governance, and (2) suggest government steps that would promote self-governance. First, because transactions costs increase with the number of participants, most self-governance institutions (both in New Zealand and elsewhere) have involved small numbers of players. Second, absent a constitution for self-governance, there is a de facto requirement for unanimous agreement, which raises transactions costs exponentially with the number of participants. Government can lower these transactions costs by specifying non-unanimous decision structures, such as one-share, one-vote mechanisms. Third, the government has failed to specify the terms under which it would agree to devolve its management authority to self-governance institutions. Uncertainty over obtaining requisite government approval raises negotiation costs and reduces the expected benefits. Fourth, the government has suggested that approval of self-governance agreements might be contingent on concurrent agreements with other stakeholders, such as environmentalists. This would require negotiation with organizations that have no incentive to reduce transactions costs and that might well increase transactions costs intentionally as part of their bargaining strategy.

Keywords: self-governance, transactions costs, New Zealand
THE EFFECT OF REGULATORY REGIMES ON PRODUCTIVITY DEVELOPMENT IN FISHERIES: A COMPARATIVE COUNTRY STUDY

Ragnar Tveteras and Hakan Eggert

Presented by Dr Ragnar Tveteras, University of Stavanger, Stavanger, Norway
Session 19: Economic Performance 2: Efficiency, Productivity and Welfare Effects

Several factors contribute to the productivity of nations' fisheries: (1) The biophysical conditions that determine the abundance of fish stocks, (2) government regulation of fisheries, and (3) innovation and adoption of (i.e. investments in) new fishing technologies. This paper analyzes the long-run productivity performance of two leading European fisheries nations, Iceland and Norway. Relative to other European nations the regulatory regime in Iceland and Norway has been more successful in sustaining stocks levels for important fish species. However, there are also significant differences in policy objectives towards the industry in these two countries. For example, Norwegian policies towards the fisheries sector have been more focused on income distribution. This has affected fleet structure, and subsequently productivity in a negative way relative to Iceland. Our paper analyzes the evolution of the industry's productive performance in light of industry structure and government policies towards the fisheries sector in these two countries. The analysis is supported by econometric productivity estimates of these countries performance using annual data from 1960 to 2003 for several competing production model specifications. Our econometric production models provide estimates of such measures as technical progress, labor productivity growth and total factor productivity growth. This analysis allows us to draw conclusions on the long-run evolution of economic performance without undue influence of shorter biological cycles in important fish stocks and other type of shocks. We find a productivity gap between the two countries according to several productivity measures we employ, and discuss the evolution and sources of this.

Keywords: regulation, productivity

MARKET POWER, SHARING RULE AND FISHERY CO-MANAGEMENT

H. Uchida and J. Wilen

Presented by Mr Hirotsugu Uchida, University of California, Davis, Davis, USA
Session 3: Rights-Based Fisheries 1: Co-Management

A successful fishery co-management, where the resource is collectively managed by local well-defined but limited group of fishermen, requires sufficient coordination of their fishing effort. Achieving and maintaining such collective action is no easy task. But anecdotal evidence shows that once fishermen experience the benefit of collective action it is more likely to sustain, and such benefits often come from new marketing opportunities, i.e., supply and/or quality control. This paper develops a model that illustrates such anecdotal evidence by linking so-called proceeds-sharing rule, where some or all individual proceeds are pooled and then equally redistributed among member-fishermen, and collusion in aim to exert market power. Many fisheries potentially have a certain degree of market power in local ex-vessel markets since the product is perishable, or fishermen can differentiate their product by quality control. This paper's main question is thus: Does a sharing rule induce fishermen to coordinate their fishing effort through exploitation of market power? The model shows that outcomes from non-cooperative behavior under the sharing rule and collusive oligopoly is essentially identical; a sharing rule can induce fishermen to non-cooperatively realize a collusive outcome, thereby making them realize the benefit of coordination. This could encourage fishermen to actively coordinate their fishing effort in aim to further increase the benefit, effectively fine-tuning the resource co-management.

Keywords: fishery co-management, sharing rule, market power
MOVING TOWARD MARKET BASED MANAGEMENT REGIMES: IMPLEMENTING DAYS AT SEA LEASING IN THE NORTHEAST (USA) MULTISPECIES FISHERY

John B. Walden and Charles Fulcher

Presented by Mr. John B. Walden, NOAA Fisheries Service, Woods Hole, USA
Session 5: Rights-Based Fisheries 2: Transferable Quotas

Amendment 13 to the Northeast (USA) Multispecies Fishery Management Plan, implemented on May 1, 2004, seeks to rebuild important groundfish fish stocks. The primary management tool used in the plan is effort control which reduced allowable fishing time – measured as days-at-sea (DAS) – for each vessel. At the suggestion of industry, a sector allocation program was established for certain fishermen, along with a DAS leasing program, and a DAS transfer program. It was hoped that the leasing and transfer programs would provide some regulatory relief for the industry. The primary focus of this paper is to present information about the DAS leasing program, and preliminary data on leases that have occurred. We then analyze spatial patterns in the lease data using GIS tools. Results show that leasing between vessels may be influenced in part by “social networks” based on homeport. While this result may be intuitive, an implication is that the DAS leasing market may not operate efficiently if this trend persists through time. Future extensions of the DAS leasing program need to consider the implications of social networks and how they may be influencing this market.

Keywords: days-at-sea leasing, social networks

LIKE COUNTING SHEEP FROM A HELICOPTER ON A CLOUDY DAY: THE EFFECTS OF SCIENTIFIC UNCERTAINTY ON STOCK ASSESSMENT AND ITQ FISHERIES MANAGEMENT

T. Yandle

Emory University, Atlanta, USA
Session 13: Fisheries Governance 2: Politics, Policy, ITQ Fisheries Management

A key underpinning of Individual Tradable Quota (ITQ) management is that once the Total Allowable Catch (TAC) is set correctly, ITQs result in an economically efficient harvest. However, critics argue that TAC setting requires sound understanding of fishery population dynamics, leading to high information costs and scientific uncertainty. If the TAC is set incorrectly for several seasons, there can be severe overfishing before the error is discovered and corrected. (Mace 1993; Loayza 1994). Furthermore, ITQ systems manage fisheries as individual species, rather than ecosystem (Duncan, 1993) and treat fisheries as extremely large areas, rather than localized resources (Wilson et al, 1999). Furthermore, the TAC setting process is subject to political pressures when decision makers are confronted with scientific uncertainty. Accordingly, fisheries managers are subject to capture and other forms of rent-seeking behavior. Since New Zealand has one of the longest histories of ITQ management, it provides an excellent case to study whether these critiques of science under ITQ management are valid. I examine the robustness of the TAC setting process in New Zealand from multiple perspectives. These include: the state of the science, the perception of participant, spending on stock assessment, and the transparency of the stock assessment process. Results suggest that fisheries science in New Zealand is the best or close to the best science there is – especially for high profile fisheries. But there are high degrees of uncertainty; and there are serious equity and transparency issues surrounding the administrative process through which stock assessment decisions are made.

Keywords: Scientific uncertainty, individual tradable quotas, ITQs, New Zealand, stock assessment
The Contribution of Fisheries to GDP: Underestimating the Role of Small-Scale Fisheries

Dirk Zeller, Shawn Booth and Daniel Pauly

Presented by Dr Dirk Zeller, University of British Columbia, Vancouver, Canada
Session 10: Subsistence, Small-scale, Recreational Fisheries

Official statistics, national accounts and economic development initiatives, including foreign aid, have often focused on commercial fisheries in Pacific islands, such as the large-scale tuna fisheries, which are perceived to be of major economic importance to these countries, and in the case of American Samoa have increased significantly in recent years. In contrast, while small-scale coastal fisheries, especially subsistence fisheries on coral reefs, have been recognized as fundamental for social, cultural and food security reasons, their catches are seldom accounted for in official statistics (despite suggestions that catches were high historically), and hence their contribution to GDP of a country are often not taken into consideration. We undertook catch reconstructions for American Samoa for 1950-2002, providing estimates of the non-commercial, subsistence catches that do not form part of the officially reported fisheries statistics. Our reconstruction suggests a large discrepancy between official statistics as reported by American Samoa (representing the artisanal commercial sector) and our reconstructed scenario (artisanal plus subsistence sectors), for the time period considered. Significantly, our reconstruction suggests a decline in total catches over the time period of interest, driven by declines in subsistence catches on the major inhabited island, likely caused by overfishing due to a very high population growth rate. For the more recent years, this is masked by large increases in catches of pelagic species by increasingly large-scale long-line vessels moving into the American Samoa pelagic fisheries. Evidence points towards the non-sustainability of this trend. We applied our reconstructed data to an approach used by the Manila-based Asian Development Bank to account for all fisheries contributions to national GDP, using value-added estimators for each fisheries sector in combination with market prices for the period 1982-2002. This suggests that the national contributions of fisheries to GDP have been substantially underestimated in American Samoa over the last 50 years. This indicates that subsistence fisheries have played a considerably more important role in national accounts as contributors to GDP than currently assumed. This should challenge our perspective with regards to the importance of various fisheries sectors to the economies of Pacific islands, and should give international development agencies, as well as local governments, pause to re-think their prioritization of development support.

Keywords: American Samoa, artisanal fisheries, coral reef fisheries, subsistence fisheries, small-scale fisheries, national accounts, GDP, catch reconstruction