Improving the management of global and regional tuna fisheries

by

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Abstract

Tuna can travel thousands of kilometers throughout their lifetime, and are often found in the waters of several nations and the high seas. These "straddling stocks" are difficult to manage due to competition between the large number of interested fishing nations, all of which can be asymmetric in their economies, management capacity and conservation concerns. This is compounded by the possibility of new members and free riders. It is no surprise then, that tuna fisheries management has, by and large, been unsuccessful in promoting sustainable fisheries. Populations of several of the world's tuna species are fully or over-exploited. This dissertation identifies and addresses areas where improvements in the management of global and regional tuna fisheries may facilitate the continued contribution of these fisheries to livelihoods and food security.

I analyze private and social resource rent derived from fishing for different tuna species and by different gear types. From these results I identify key management targets. Management efforts are formalized through Regional Fisheries Management Organizations (RFMOs), groups which are mandated to promote cooperative agreements and fair and equitable allocation approaches. Stable cooperative agreements, however, have been hard to come by for tuna RFMOs, in part because the issue of allocations has not been appropriately targeted. I propose a combined socio-economic and ecological approach formulated from the perspective of fisheries benefits, as opposed to just catch, which could facilitate stable cooperative agreements for sustaining tuna stocks into the distant future.

Tuna fisheries in the western and central Pacific provide over half of the world's tuna, but lack of effective management capacity in Indonesia and the Philippines threatens the sustainability of these fisheries. I argue that countries that fish in this region, most specifically Papua New Guinea, would be wise to help facilitate improved management capacity in these countries. One of the major management challenges in this region is the bycatch of juvenile yellowfin and bigeye tuna in the skipjack purse seine fishery. Through applied game-theoretic modelling, I conclude that reduction in juvenile bycatch brought about by cooperative management of these fisheries would provide long-term ecological and economic benefits.

Preface

Apart from thesis Chapters 1 and 7, all of the Chapters in this dissertation have been prepared for publication. Chapters 3 and 5 are published, and Chapter 6 is in press. Chapters 2 and 4 are being prepared for submission. I am the senior author on all of the papers, and I led the design, implementation, analysis and writing of the papers.

Chapter 2 is coauthored by Andrew Dyck, Vicky Lam, and Rashid Sumaila. I formulated the concept and methods for the study, analyzed the data, and prepared the manuscript. Andrew Dyck assisted with use of the subsidies and price databases, while Vicky Lam assisted with use of the cost datebase. Rashid Sumaila provided guidance throughout the development of the paper. A version of this Chapter is in preparation for submission.

Chapter 3 is coauthored by Rashid Sumaila and Marko Lindroos. I identified the need for a contemporary review piece, conducted the research and wrote the manuscript. Marko Lindroos offered his expertise in coalition games to strengthen that section of the paper, while Rashid Sumaila provided guidance throughout. A version of this Chapter was published 2010 in *Fisheries Research*, Volume 102, pages 1-8.

Chapter 4 is coauthored by Gakushi Ishimura, Richard Paisley and Rashid Sumaila. I formulated the concept for this paper, conducted research, and prepared the manuscript. Gakushi Ishimura contributed to the section on climate change, while Richard Paisley provided expertise on international water agreements. Rashid Sumaila provided guidance throughout. A version of this Chapter is in preparation for submission.

Chapter 5 is coauthored by Jimely Flores, Sylvester Pokajam, and Rashid Sumaila. I initiated this study following field work in the Philppines, collated and analyzed information on the countries and wrote the manuscript. Jimley Flores conducted interviews in the Philippines, and commented on the Philippine portion of the analysis. Sylvester Pokajam, who works for the National Fisheries Authority in Papua New Guinea, contributed to the analysis of that country. Rashid Sumaila helped guide what was initially a thorough but chaotic piece into a publishable manuscript. A version of this Chapter was published in 2012 in *Ocean and Coastal Management*, Volume 63, pages 30-42.

Chapter 6 is coauthored by Rashid Sumaila and Steven J.D. Martell. I designed this study, developed the model, conducted the analysis and prepared the manuscript. Rashid

Sumaila provided guidance on the economic analysis, whereas Steve Martell provided guidance on the biological modelling methodology. A version of this Chapter is in press at *Strategic Behavior and the Environment*.

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Chapter 1

Introduction

An estimated 80-90 million tonnes of fish are caught from the world's oceans each year (FAO, 2010). In 2000, this catch was worth an estimated US $80 billion in landed value (Sumaila et al., 2007). The annual catch, which increased steadily throughout the 1950s-1990s, recently stagnated, and is now likely declining (Pauly and Watson, 2001; Mora et al., 2009). Many scientists argue that we are facing a crisis in world fisheries (Clark, 2006). Some researchers have predicted a 90% global removal of predatory fish (Myers and Worm, 2003), and warn that shortfalls in the supply of fish could have devastating consequences for human populations (Pauly et al., 2002). Furthermore, overfishing has ecosystem effects (Worm et al., 2006), many of which we don't yet understand, but which will undoubtedly affect human populations in the future.

The degree to which our world is facing this crisis in global fisheries is a hotly contested subject today, a debate which eventually took place publicly in Sea Monster (2011). When purely catch-based data are used to analyze the status of global fisheries, it appears that fish stocks are in trouble and that catches are declining as a result (Worm et al., 2006; Kleisner et al., 2012). Assessments based on catch (or catch per unit effort), however, can bias the results towards being more pessimistic (Branch et al., 2011; Carruthers et al., 2011). When single-species stock assessments are analyzed, improvements in fisheries management, and in the status of stocks, can be seen (Worm et al., 2009; Branch et al., 2011). Although stock assessments offer higher-resolution data (Worm et al., 2009), they are not available for many of the world's fisheries, for example, those in developing countries (Kleisner et al., 2012). Most fish stocks that have regular assessments done are highly managed, and often quite valuable. Species that are often caught as bycatch in these fisheries receive less attention from stock assessment scientists, as do species targeted only in developing countries, or that are not seen as particularly valuable from a global perspective. Therefore, those stocks that seem to be doing well, and which lend evidence to the argument that global fisheries are performing well, are precisely those fisheries that are in fact managed.

It is not my intention here to pick one side of the debate, but no matter where we actually fall on the spectrum of poorly- to well-managed global fisheries, common ground can be found in that we are not yet at a place where improvements are unnecessary.

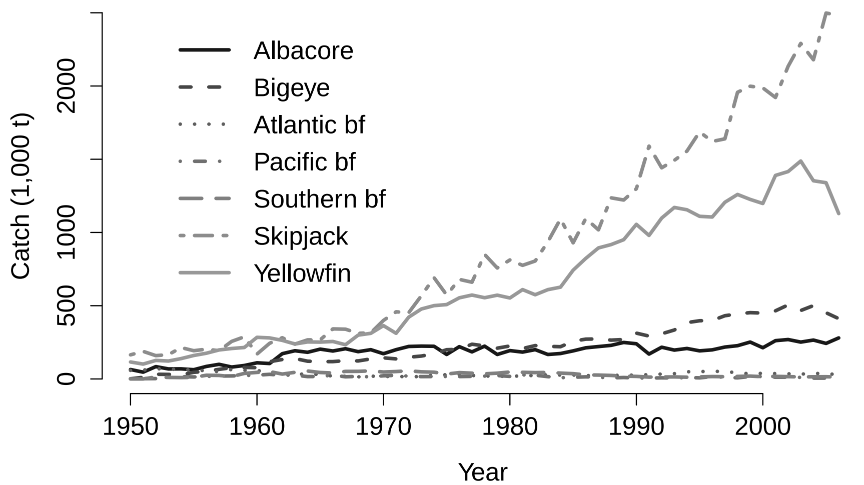

Figure 1.1: Global catches of tuna species since 1950. Data from seaaroundus.org.

With that in mind, this thesis explores the concerns and opportunities with regards to the management of one particular group of species: the tunas.

In recent years, over 4 million tonnes of tuna have been extracted annually from the world's oceans, amounting to about 5% of the global catch total. In 2005, US $17 billion worth of tuna was landed at ports throughout the world (seaaroundus.org). Tuna products are ubiquitous, consumed as everything from smoked skipjack geared towards the domestic market, to low- and medium-grade tuna in cans, to high-priced bluefin sashimi exports, served in Japanese restaurants. Since 1950, over 117 million tonnes of tuna have been removed from the ocean (Figure 1.1 (seaaroundus.org)). Further to their role in global food supply, the world's tuna fisheries also support the livelihoods of fishers in over half of all maritime countries, providing employment and revenue. The importance of tuna fisheries to regional and global economies has been well articulated (Majkowski, 2007; Williams and Terawasi, 2009; Pala, 2011; McKenna, 2008; Collette et al., 2011; Sumaila and Huang, 2012).

There are seven large species of tuna fished throughout the world's oceans. In this thesis, I focus on the management of these seven species, which include the three bluefin species (Atlantic *(Thunnus thynnus)*, southern (*T. maccoyi*) and Pacific *(T. orientalis)*, yellowfin (*T. albacares*), bigeye (*T. obesus*), albacore (*T. alalunga*), and skipjack (*Ketsuwonis pelamis*). Figures 1.2 and 1.3 show the 2005 catches by ocean area of non-bluefin and bluefin species, respectively. Information on how these species are targeted, the markets

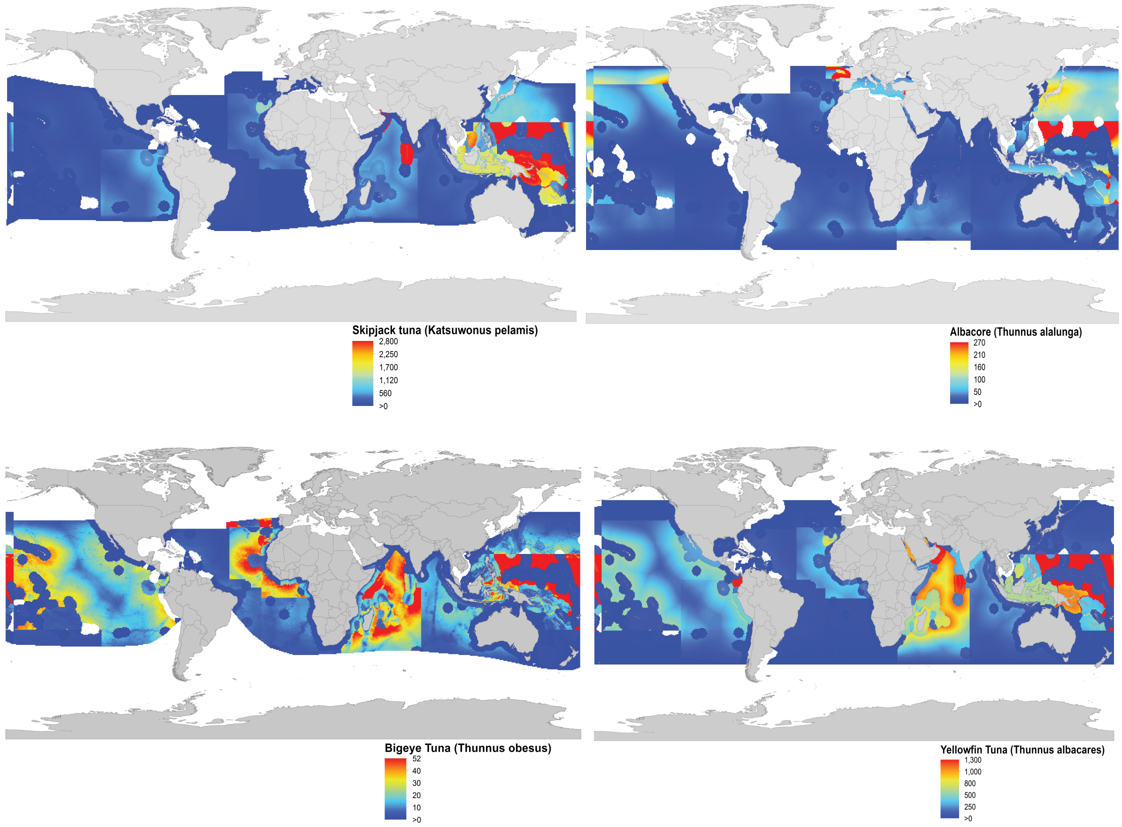

Figure 1.2: 2005 catches, in tonnes, of skipjack, albacore, bigeye and yellowfin tuna (seaaroundus.org).

they supply, 2010 catches and their conservation status is summarized in Table 1.1.

Tuna are highly migratory fish: throughout their lifetime they can travel thousands of kilometers. This often means that one population of fish will spend part of its life in the waters of different countries, and in the waters of the high seas. In management jargon, this behaviour makes tuna populations known as "straddling" stocks. In 1982, the United Nations Convention on the Law of the Sea (UNCLOS) (United Nations, 1982) was convened to address some of the problems leading to overexploitation of shared fish stocks. At that time, however, issues surrounding straddling stocks were not seen as a big problem, as it was thought that catches from the high seas were a minor concern (Alexander and Hodgson, 1975; Lodge et al., 2007). With UNCLOS came the 200 nautical mile exclusive economic zone (EEZ), which resulted in the redistribution of fishing effort targeting straddling stocks from EEZs to the high seas. Today, the management of straddling stocks, which is no easy task (Bjorndal et al., 2000), is considered one of the biggest challenges to sustainable global fisheries, as they may represent as much as a third of fisheries catches

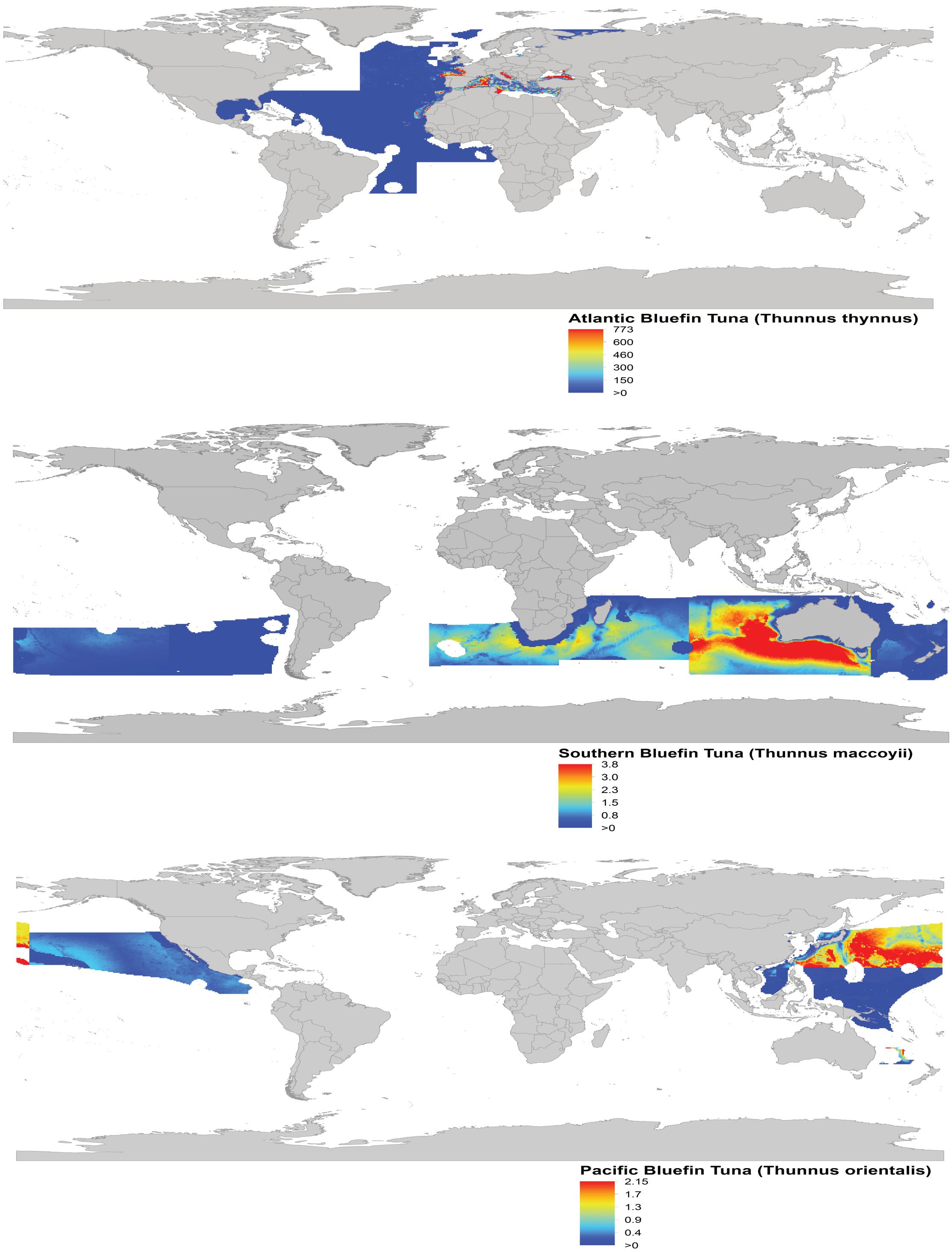

Figure 1.3: 2005 catches, in tonnes, of Atlantic, southern and Pacific bluefin tuna (seaaroundus.org).

Table 1.1: Information on tuna species, fishing gears, markets supplied, 2010 catches (FAO, 2012), and conservation status (iucn.org).

Common name	Scientific name	Number of stocks	Gears used	Markets supplied	2010 catch (1,000 t)	IUCN status
Albacore	*Thunnus alalunga*	6	Longline and pole and line	Canned/ frozen	255.3	Near threatened
Bigeye	*Thunnus obesus*	4	Longline	Sashimi	358.7	Vulnerable
-			Purse seine	Canned		
Atlantic bluefin	*Thunnus thynnus*	2	Longline	Sashimi	13.0	Endangered
Pacific bluefin	*Thunnus orientalis*	1	Longline	Sashimi	12.2	Least concern
Southern bluefin	*Thunnus maccoyii*	1	Longline	Sashimi	9.2	Endangered
Skipjack	*Katsuwonus pelamis*	5	Purse seine	Canned	2,523	Least concern
-			Handline and pole and line	Domestic		
Yellowfin	*Thunnus albacares*	4	Longline	Frozen	1,165	Near threatened
-			Purse seine	Canned		

(Munro et al., 2004).

The existence of dynamic externality leads to competition among fishing countries or sectors (Levhari and Mirman, 1980). According to several sources, many of the world's tuna stocks are either fully exploited or overexploited (Table 1.1) (Collette et al., 2011; FAO, 2010; ISSF, 2012; Miyake et al., 2010). This raises questions about the ability of these populations to continue supporting the livelihoods of millions of fishers, and to continue contributing to global food security. Management systems that take into consideration ecological and economic arguments, capacity concerns, strategic behaviour and fisher decisions are necessary to promote productive global tuna fisheries. In this thesis, I address these necessities through the development of five core papers, which provide information and options that can help improve tuna fisheries management.

We know from biological studies focussing on stock abundance and distribution that the populations of most tuna species are reaching the point where increased catches will not be possible in the future. In fact, for some species, such as Atlantic and southern bluefin, we have known for decades that populations were overfished. Biological arguments, however, have not resulted in major shifts towards improved management of overfished tuna stocks, nor have they prevented the subsequent overexploitation of other tuna stocks, for example Pacific bigeye. Can an understanding of the economics of global tuna fisheries contribute to a shift in tuna management?

In Chapter 2, I explore if and how information about the profitability of tuna fishing can inform management. By combining several global databases created by the*Sea Around Us* Project and the Fisheries Economics Research Unit, both at the Fisheries Centre, I analyze the rent generated by fishing for different tuna species, fishing gear types and fishing nations. We expect that those fisheries where positive rents are being generated are likely to attract more fishing effort in the future, whereas, those fisheries generating negative rents, might be places that management should target for effort reductions.

In this Chapter, I also analyze the difference between the private rent obtained by fishing companies, more conventionally called profit, and the resource rent accruing to society, i.e., the net benefits from the fishery once corrected for distortions. This comparison is possible by incorporating national subsidies into the calculations. Market distortions, for example subsidies that artificially inflate ex-vessel prices or deflate fishing costs, can make fisheries appear profitable to fishers. Yet, once these distortions are identified, these same fisheries may seem less attractive to society as a whole. The aim here is to provide information to managers about where effort is likely to increase or decrease in the future. Furthermore, this Chapter asks whether or not the gap between private rent, as the fishers see it, and the social resource rent perceived by society as a whole is an issue from society's point of view.

Even if, based on economic (or ecological) arguments, we know where and how to target management efforts, we need to understand how management of global tuna fisheries is actually institutionalized. In 1995, the United Nations convened a special session to address this very question. The UN Fish Stocks Agreement (FSA) formalized the management of tuna stocks (and other shared fish stocks) through groups called Regional Fisheries Management Organizations (RFMOs) (UN, 1995). The earlier UNCLOS Agreement, directs coastal states sharing a resource to cooperate in its management, but does not require states to actually reach an agreement (United Nations, 1982). This essentially allows for non-cooperation to be the default option (Munro et al., 2004). Unfortunately, with very few exceptions, cooperation between the states targeting tuna stocks is essential for sustainable fisheries management (Lodge et al., 2007; Munro, 2006). The theory of cooperative games may provide a particularly useful lens through which to view the formation and stability of cooperation within RFMOs.

In Chapter 3, I provide a literature review of the use of game theory in our field since its first application to fisheries by Munro (1979). What insights has the application of this tool provided to the management of joint fisheries resources? I explore the scope for cooperation in the management of highly migratory stocks (i.e., tunas), and speculate on where game-theoretic considerations should be targeted to improve tuna management in the future. How should we tackle the possibility of catch privileges (or allocation) in shared fisheries? And how will changes in climate affect cooperative solutions?

As part of their mandate, RFMOs are required to perform the function of agreeing "on participatory rights such as allocations of allowable catch or levels of fishing effort" in internationally-shared fisheries (UN, 1995). Issues of shared fisheries allocation are some of the most challenging in fisheries management (MRAG, 2006), however, most RFMOs have attempted some type of sharing program in the past, or are in the process of formulating one in the present. Five tuna RFMOs exist, managing tuna in different global oceans. The effectiveness of these RFMOs has been questioned, however, as tuna stocks have continued to decline. A recent report analyzed the performance of all RFMOs in meeting best practices criteria both in theory (as evidenced through RFMO mandates) and in practice (as evidenced by stock status reports) (Cullis-Suzuki and Pauly, 2010). On average, tuna RFMOs met best practices criteria only 59% of the time in theory, and 43% of the time in practice, meaning that their mandates are not strong enough to fully effect conservation of their target tuna stocks (Cullis-Suzuki and Pauly, 2010). We could thus conclude that there is definite room for improvement in how tuna fisheries are managed through RFMOs.

In Chapter 4, I discuss the current approaches taken by the world's tuna RFMOs to allocate benefits to member nations. These allocation approaches are often based on historical catches, stock abundance estimates, and distribution information. The current approach has failed to truly address declining stocks, and thus, a new approach is warranted. Some RFMOs, for example, the Western and Central Pacific Fisheries Commission (WCPFC) (MRAG, 2006) and the International Commission for the Conservation of Atlantic Tuna (ICCAT) (Cox, 2009), have discussed incorporating more than just biological criteria into their allocation programs, but neither have documented how they would quantitatively do that. Interestingly, Hardin (1968) called for multiple weighted criteria to address the Tragedy of the Commons almost fifty years ago. RFMOs are in a position now to answer this call. In Chapter 4, I ask if a new approach, where the socio-economics of interested parties are also considered, could improve global tuna management.

There are other global resources that are shared between nations, for example, fresh water. In Chapter 4, I also draw on the relevant literature from internationally-shared water agreements, particularly a new approach in this field, called the "Mutual Gains Approach" (Grzybowski et al., 2010). This Approach also draws on the issues of strategic interaction between users and the need for cooperation (i.e., game theory), but does so from the perspective of the interests of a nation, as opposed to its political position (Grzybowski et al., 2010). To what extent can we learn from this in fisheries, and move away from merely thinking about allocation from a catch perspective, to thinking about it in terms of other mutual benefits, such as rent, employment, or domestic consumption?

Asymmetry in players, that is, difference in perspectives and interests (e.g., differences in rates of discount and costs of fishing), can affect the outcome arrived at in game theoretic models of fishing (Munro, 1979; Sumaila, 2005), as can incomplete information (Jensen and Vestergaard, 2002). When we consider tuna fisheries management, we are often dealing with ten, twenty or thirty fishing states, all of whom have different preferences, economies, management capacities and objectives. In the Western and Central Pacific Ocean (WCPO), over thirty countries exploit four main tuna stocks: albacore, bigeye, skipjack and yellowfin. Some industrial fishing nations, such as Japan, Taiwan and Spain, have powerful fishing fleets that pay for access to fish in the waters of small Pacific Island Countries (PICs) such as Samoa and Palau. These groups of nations have obvious asymmetries. Cooperation among these fishing nations is formalized through the WCPFC, one of the RFMOs considering socio-economics in the development of their allocation scheme mentioned above.

The Coral Triangle (CT) is in the western end of the WCPO, and contains parts or all of the waters of Indonesia, the Philippines, Malaysia, Papua New Guinea, Solomon Islands and Timor Leste (Figure 1.4). Over 150 million people live in the area, and an estimated 2.25 million fishers depend on marine resources for their livelihood (The Nature Conservancy, 2004). Recent figures suggest that as much as a third of all tuna catch from the western and central Pacific Ocean can be attributed to the fleets of Indonesia, the Philippines and Papua New Guinea (SPC, 2010), the three major tuna fishing nations in the CT. Despite their regional and global importance, however, few papers have focused on confronting the challenges these countries face with regards to tuna management. Rather, emphasis has primarily been placed on analyzing asymmetries and challenges that PICs face in obtaining adequate rents from their fisheries (Bertignac et al., 2000; Gillett et al., 2001; Parris and Grafton, 2006; Petersen, 2006; Campling et al., 2007; Walmsley et al., 2007).

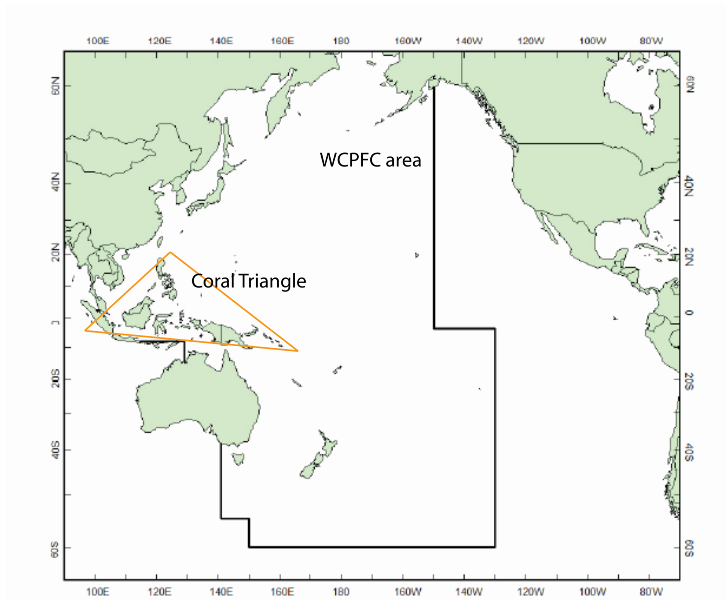

Figure 1.4: Map of the Coral Triangle, shown within the WCPFC Convention area. Convention area map © WCPFC, used with permission.

Indonesia, the Philippines and Papua New Guinea all face socio-economic, institutional and management circumstances that differ from one another, and from the other larger and smaller fishing nations in the region. Tagging studies have demonstrated a high degree of interaction between CT tuna fisheries and those to the east (Vera and Hipolito, 2006; Ingles et al., 2008), while a recent stock assessment for yellowfin reports that the domestic fisheries of the Philippines and Indonesia are in part responsible for stock depletion (Langley et al., 2009b). Tuna fisheries and their management in these countries, therefore, impacts other nations fishing for tuna in the WCPO. How are fisheries managed in these countries? Are there programs in place that have been particularly effective at promoting sustainable fisheries in the region? In this Chapter, I compare and contrast tuna fisheries in the three countries, as well as their management regimes and current management challenges. This analysis is aimed at improving CT management capacity, in hopes of facilitating improved regional management of a valuable transboundary resource.

One of the major management challenges facing the WCPFC is the bycatch of juvenile yellowfin and bigeye tuna in the purse seine skipjack fishery. The regional purse seine fishery has increased its reliance on fish aggregating devices (FADs), essentially floating objects that attract adult skipjack and yellowfin, along with juvenile yellowfin, bigeye and other non-tuna species such as dolphinfish and marlin. Much of the juvenile tuna bycatch occurs in the waters of the Coral Triangle countries. Adult yellowfin and bigeye are targeted by countries inside and outside the Coral Triangle, and thus there is a very intriguing and important conflict of interest between the two groups that needs to be explored.

Chapter 6 addresses this conflict by estimating the potential benefits of cooperative management of tuna fisheries in the WCPO. Fisheries in the region currently operate in a non-cooperative, or competitive way, whereby each fishing group makes decisions based on its own self-interest. I develop a bioeconomic game-theoretic model to determine if, at equilibrium, moving away from non-cooperation through the elimination of juvenile fishing could bring economic benefits to the region. Specifically, I examine non-cooperative and cooperative outcomes for a three player game: purse seine; longline; and handline, and incorporate skipjack, yellowfin and bigeye as target species. Given a long-term perspective, what would be the optimal effort allocation between different fishing gears if we seek to maximize cooperative rent? How does this compare with the current effort allocations we see in the WCPO? I hypothesize that reductions in juvenile bycatch will, in fact, have a positive impact on resource rent from the fisheries, as it will eliminate (or at least reduce) growth overfishing, whereby fish are harvested when they are too small. This will probably require a decrease in effort by purse seine vessels.

Chapters 2 through 4 of this dissertation highlight broad issues worth tackling in the quest for more effective management of global tuna fisheries. The objectives here are to improve our understanding of how rent, cooperation and allocation approaches can facilitate the move towards sustainability. Chapters 5 and 6 tackle issues associated the world's most important tuna-producing region, the Western and Central Pacific Ocean. The objectives of these Chapters are to analyze the management systems of Indonesia, the Philippines and Papua New Guinea, to provide some recommendations for improved regional management, and to estimate the possible economic gains to the region from cooperative management. Over half of the world's tuna supply comes from this region, so improving tuna management here could help move the majority of the world's tuna supply to a more sustainable model. Such improvements could also help to inform and improve tuna management in other regions.

Fisheries management is complex, and requires ecological, economic, social and institutional perspectives to facilitate adequate and effective management. Current management of global tuna fisheries is falling short of promoting a sustainable resource base, long-term employment, a steady revenue stream, and a reliable supply of food. The aim of this thesis is to use economic tools, arguments and methods to increase our understanding of the current issues in, and barriers to, sustainability in the tuna fishing sector, and to provide inputs that can help us move toward improved management of global and regional tuna fisheries.

Chapter 2

Informing global tuna fisheries management: Private versus social resource rent

2.1 Introduction

Fisheries are a global economic sector, providing both income and food for virtually every country on earth. In 2000, the landed value of the world's marine capture fisheries was estimated at about US $80 billion (Sumaila et al., 2007). One particular group of fish, the tunas, is of immense global economic importance, with various species being fished by 82 countries, or 56% of all maritime states, and having a landed value of US $17 billion in 2005 (seaaroundus.org). Tuna products are consumed all over the world, including everything from smoked skipjack consumed domestically, to low- and medium-grade tuna in cans to high-priced bluefin sashimi served in Japanese restaurants. Since 1950, over 117 million tonnes of tuna have been removed from the ocean (Figure 1.1), averaging about 2.06 million tonnes per year (seaaroundus.org).

The importance of tuna fisheries to regional and global economies has been stated several times in diverse places, everywhere from management reports (Majkowski, 2007; Williams and Terawasi, 2009), media and outreach pieces (Pala, 2011; McKenna, 2008; Bailey, 2012), to scientific literature (Collette et al., 2011; Sumaila and Huang, 2012). Often times, however, economic value is viewed solely from the perspective of the "landed value", that is, the gross revenue attained for landing the fish at port. With few exceptions (Sumaila and Huang, 2012), the costs associated with fishing these species are generally not reported on, and as such, net revenue, or resource rent, is not discussed. In light of this, I provide the first estimate of the net economic rent of global tuna fisheries in this Chapter. Rent is calculated in two ways. Firstly, private rent is calculated from the perspective of fishers or fishing companies. This is the difference between revenues obtained and costs incurred through harvesting, and is in fact producer surplus. Secondly, the social resource rent is calculated from the perspective of fishing countries (i.e., society). This estimate includes national subsidies, and thus better represents what society is gaining (or losing) through the global tuna sector. In this paper, I also demonstrate the method of utilizing large global databases to infer economic realities about fisheries.

2.2 Global tuna fisheries

There are seven large tuna species targeted globally, split into 23 stocks (ISSF, 2012). The seven large species, all members of the Scombridae family, include albacore *(Thunnus alalunga)*, yellowfin *(T. albacares)*, bigeye *(T. obesus)*, southern bluefin *(T. maccoyii)*, Atlantic bluefin *(T. thynnus)*, Pacific bluefin *(T. orientalis)* and skipjack *(Katsuwonus pelamis)*. Tuna are considered a straddling stock in that they are found in the exclusive economic zones (EEZs) of more than one country, and also in the high seas. But they are a special type of straddling stock, namely, "highly migratory species", a term which became prominent in the literature after the 1995 United Nations Straddling Fish Stocks Agreement (UN, 1995). The Agreement was primarily an attempt to facilitate cooperation between fishing nations exploiting a common pool resource, as cooperative management is generally preferred to non-cooperation if sustainable use is the goal (Singh and Ballabh, 1996; Ostrom et al., 1999; Sumaila, 1999; Bailey et al., 2010).

Generally speaking, the state of global tuna stocks is worrisome. Of the seven species reported on in this paper, the International Union for Conservation of Nature (IUCN) lists Atlantic and southern bluefin as endangered, bigeye as vulnerable, albacore and yellowfin as near threatened, and (only) Pacific bluefin and skipjack as of least conservation concern (Table 1.1) (IUCN, 2011). All three bluefin species exhibit life history traits that make them particularly vulnerable to over exploitation, including slow growth and late maturity (De Roos and Persson, 2002), compared to their smaller con-specifics. Furthermore, they are temperate water species, which are generally less productive than tropical species (Majkowski, 2007). For species such as bigeye and yellowfin, their association with skipjack around floating objects, specifically in the Pacific, makes them susceptible to growth overfishing[1] due to juvenile bycatch (Miyake et al., 2010; Bailey et al., In press; Langley et al., 2009a,b). Skipjack stocks in the Pacific are probably underexploited, and so planned future increases in fishing effort for this target species are likely to have a negative impact on yellowfin and bigeye stocks in the region if today's fishing practices continue. Albacore stocks are considered near threatened. Table 1.1 gives the number of separately managed stocks for each tuna species.

Several gear types are used to fish for tuna, depending on the species being targeted

[1]Growth overfishing occurs when fish are harvested before the point at which individuals reach the maximum yield per recruit.

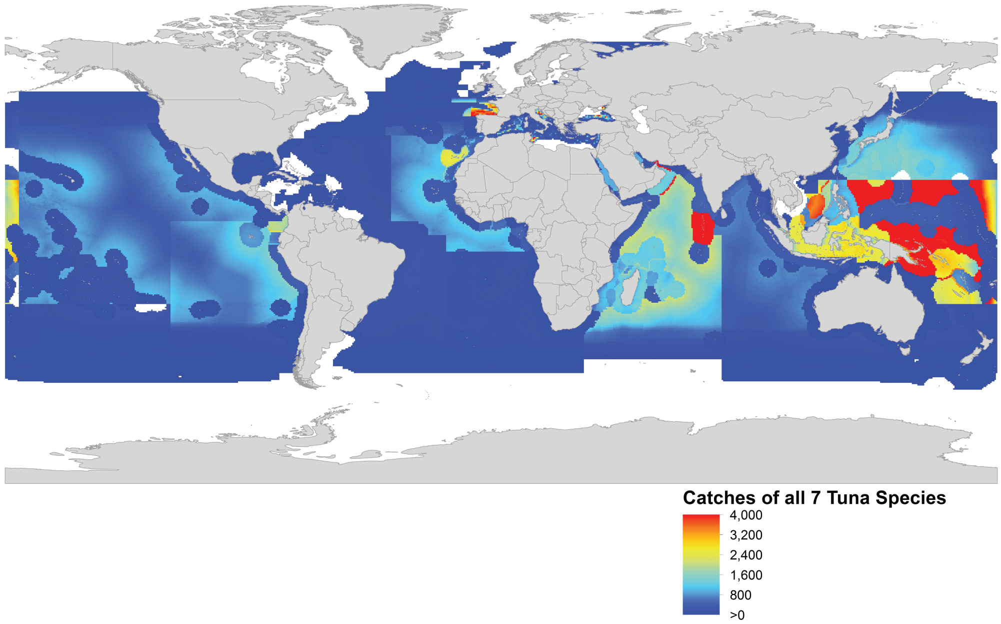

Figure 2.1: 2005 tuna catches (in tonnes) from the world's oceans (Data from seaaroundus.org).

and the markets being supplied (Table 1.1). Purse seines target mostly skipjack tuna and adult yellowfin, often taking advantage of tuna's propensity to aggregate around floating objects. Most purse-seine caught skipjack and yellowfin are sent to canneries, providing 'light' tuna. Pole and line, troll, and longline are used to target albacore, which supplies both the canned tuna market (sold as 'white' tuna) and the frozen tuna steak market. Longlines are usually the gear of choice to catch bigeye and bluefin species, which supply the sashimi market. Artisanal gears are also utilized to catch tuna, such as ringnet, gillnet and handline. Figure 2.1 shows the catches of aggregated tuna species by ocean area in 2005.

Effective management of shared fish stocks often requires cooperation by several fishing nations (Chapter 3). This essential cooperation is facilitated by Regional Fisheries Management Organizations (RFMOs) (UN, 1995). Five tuna RFMOs exist (see Figure 4.1), managing tuna in different global oceans. The effectiveness of these RFMOs has been questioned, however, as tuna stocks have continued to decline. A recent report analyzed the performance of all RFMOs in meeting best practices criteria (set out by Chatham House in Lodge et al. (2007)) both in theory, as evidenced through RFMO mandates, and in practice, as evidenced by stock status reports (Cullis-Suzuki and Pauly, 2010). On average, tuna RFMOs met best practices criteria only 59% of the time in theory, and 43%

of the time in practice, meaning that their mandates are not strong enough to facilitate conservation of their target tuna stocks (Cullis-Suzuki and Pauly, 2010). The main tuna RFMOs are reviewed in Table 2.1, along with their performance in meeting these best practices criteria.

2.3 Subsidies, welfare economics and the fishery

Fisheries economists have generally focused on tackling the issues of inefficiency in global fisheries, for example overcapacity, and have, by and large, ignored issues of distribution and equity (Bromley, 1977; Charles, 1988; Weninger and McConnell, 2003; Tietze et al., 2005; Beddington et al., 2007). That being said, any fisheries management decision or policy tool will have some impact on the distribution of resources, be they in the form of labor and employment, or in the form of food security. While the focus in fisheries economics has largely been placed on judging a policy tool based on its economic efficiency, welfare economics allows us to judge a policy tool based on how it changes the utility (or value) of the resource to members of society. Instead of maximizing profit to one small subset of society (fishers), incorporating the concepts of welfare economics would have us maximizing benefits to society as a whole (Arrow, 1963). Put simply, welfare economics allows us to evaluate the economic well-being within a society resulting from the allocation of resources.

Subsidies are any direct, or indirect, transfer from a public entity (such as the government), to a fishing sector, which essentially gives the fishing sector an economic advantage, encouraging fishers to fish more than they otherwise would (Sumaila et al., 2010). In this way, government subsidies to the fishing sector are a choice on the allocation of public resources to a small fraction of society. Plainly stated, fisheries subsidies exacerbate the problems of overcapacity and overfishing (Arnason, 1998; Clark et al., 2005; Clark, 2006). Two studies in the 1990s estimated that between US $14-54 billion were being transferred to the global fishing sector annually (FAO, 1992; Milazzo, 1998). The World Bank, Organization for Economic Cooperation and Development (OECD), FAO, and conservation groups such as Pew and World Wide Fund for Nature (WWF) have all focused in on fisheries subsidies as an issue to be tackled.

A more recent estimate of global fisheries subsidies was calculated by the *Sea Around Us* Project and the Fisheries Economics Research Unit through the development of a subsidies database containing information on 148 maritime countries for the year 2003 (Sumaila et al., 2010). This updated subsidies database estimated global fisheries subsidies to be between US $25-29 billion, with fuel subsidies making up about 15-30% (Sumaila et al., 2010). In this paper, I consider the benefits from fishing that accrue to the fishing

Table 2.1: Tuna RFMOs, species managed, and performance at meeting best practices criteria.

RFMO	Full title	Year of entry	Tuna species covered	Performance (%) (theory, practice)*
CCSBT	Commission for the Conservation of Southern Bluefin Tuna	1994	Southern bluefin	44, 0
IATTC	Inter-American Tropical Tuna Commission	1949	Albacore, skipjack, yellowfin, bigeye and Pacific bluefin	60, 33
ICCAT	International Commission for the Conservation of Atlantic Tunas	1969	Albacore, skipjack, yellowfin, bigeye and Atlantic bluefin	57, 38
IOTC	Indian Ocean Tuna Commission	1996	Albacore, skipjack, yellowfin, bigeye, Southern bluefin	58, 78
WCPFC	Western and Central Pacific Fisheries Commission	2004	Albacore, skipjack, yellowfin and bigeye	74, 67

*Cullis-Suzuki and Pauly (2010)

sector itself as private resource rent, also known as profit. Unfortunately, this private rent contains market distortions resulting from subsidies, and consequently yields an incomplete understanding of the benefits of global tuna fisheries to society as a whole.

Subsidies can be divided into those that positively affect stock sustainability ("good"), negatively affect stock sustainability ("bad"), and those whose impact is not always clear ("ugly") (Sumaila et al., 2010). Bad subsidies include things that increase capacity, such as fuel subsidies, or processing and storage infrastructure support. Although we often think of subsidies as lowering the cost of fishing, it is also important to remember that they can act through increasing revenue instead, for example through elevated prices due to favourable trade conditions. In this paper, I subsequently incorporate subsidies into the resource rent calculation, thus accounting for these market distortions. Viewing the economic benefits derived from the fishery from the perspective of social resource rent, as opposed to private rent, is better-aligned with the concepts of welfare economics and speaks to the broader benefits (or lack thereof) of fisheries as common pool resources.

2.4 Methods

For over a decade, the *Sea Around Us* Project and the Fisheries Economics Research Unit at the University of British Columbia have been collecting and aggregating fisheries data for most commercially targeted fish species and maritime countries. Here, I combine catch, price, cost and subsidies databases to construct a picture of the current economic condition of global tuna fisheries. Particular emphasis is given to the difference between private and social rent originating from global tuna fisheries.

Catches

The global catch database is based on data provided by the Food and Agriculture Organization of the United Nations (FAO), which are then supplemented by unreported and unregulated catch reconstruction data (Zeller et al., 2006). Catches are assigned to geophysical marine areas either through the existence of direct data of where a catch occurred, or through a rules-based allocation algorithm taking into account which countries have access to what species, and where and how species are distributed throughout the oceans (Watson, 2004; Watson et al., 2005). The catch database begins reporting catches in 1950, and, at the time of writing, contains estimates of catches by country, fish species, and fishing gear up to the year 2006. Catches *(h)* of species *(s)* by gear type *(g)* and maritime country *(m)* for the 2005 year are used in this study.

Table 2.2: Mean price per tonne by species (weighted by catch) and number of observations used for calculations.

Species	Mean price (USD/t)	Number of observations
Skipjack	3,818	265
Albacore	4,003	220
Yellowfin	4,341	355
Southern bluefin	15,684	28
Bigeye	4,533	224
Atlantic bluefin	3,929	111
Pacific bluefin	6,307	23

Prices

Although the FAO publishes information on the price of processed fish products, data on ex-vessel prices (i.e., first-hand prices that fishers receive when they land their fish) are not always easy to come by. To fill this information gap, an ex-vessel price database was constructed in 2007 as a way of turning ecological information, catches, into economic information, landed values (Sumaila et al., 2007). This combination of prices and catches allows users to attach landed values to species in time and in space. In developing the database, prices were entered either directly from sources such as governmental agencies, national websites, expert knowledge, published literature, or, if records on prices could not be found, they were calculated from a rules-based algorithm (Sumaila et al., 2007). The algorithm allowed weighted means to be applied within years, countries and/or taxa, with the quality of the data being tracked along the way (Sumaila et al., 2007). The mean ex-vessel prices (weighted by catch tonnage) used in this analysis are shown for each tuna species in Table 2.2.

Price *(p)*, and the catch volume *(h)*, determine the landed value of the catch, or the gross revenue *(TR)* a fisher (or country) attains from a given fishing trip. The 2005 landed value is computed for each of our seven tuna species of interest *(s)* and for each maritime country *(m)*. Thus, the total revenue country m receives for fishing species s with gear g is calculated as:

$$TR_{m,s,g} = p_{m,s} h_{m,s,g} \quad \forall m, s, g \tag{2.1}$$

The total revenue to country m is then simply the sum of the total revenues for each tuna species harvested and for each gear type used.

$$TR_m = \Sigma_{s,g} TR_{m,s,g}, \quad \forall m \tag{2.2}$$

Similarly, total or mean revenue by species or gear can be calculated by summing across all maritime countries for each gear and species.

Costs

Fishing costs play a major role in determining the behaviour of fishers and thus fishing fleets. Up until 2011, however, reliable estimates on the cost of fishing were not consistently published or adequately summarized. There are several reasons for the lack of data, including the extensive amount of effort required to collect cost information and the lack of reporting requirements for this type of information by government agencies (Lam et al., 2011). Therefore, a fishing cost database was developed in 2011, aimed at quantifying costs for various types of fishing gears in all maritime countries for the 2005 year (Lam et al., 2011). Data were gathered from secondary sources such as grey literature, and government, FAO and consultant reports, along with requests for information from global partners (Lam et al., 2011). The authors were able to source information on, or interpolate data for, countries that made up 98% of the global fisheries catch (Lam et al., 2011).

Fishers face two main types of costs, fixed and variable. The former are costs not dependent on fishing operations directly, often called sunk costs, for example, the cost of the vessel itself. Variable costs are those that vary with the level of fishing activity, for example, fuel, gear maintenance and labour costs. Costs reported in the Lam et al. (2011) database, and used in this analysis, include a normal profit estimate, and are thus economic costs of fishing, as opposed to accounting costs.

For the purposes of this paper, cost estimates for purse seine, pole and line, longline, gillnet and hook and line are of particular interest, as they combined for over 96% of all tuna catches in 2005. Unit costs *(c)* are expressed on a per tonne basis for each gear type g. The lowest costs of fishing, US $259/t as published in (Lam et al., 2011), were for purse seining in some South American and Caribbean countries. The highest unit cost of fishing, US $7,092/t, were for longlining by South Pacific Island countries (Lam et al., 2011). Where cost data were missing for a particular geo-political entity for which I had catch and price data, mean unit costs, weighted by catch tonnage, were used. This occurred for territories of certain countries. For example, a cost estimate for tuna fishing in American Samoa did not exist because it is a United States entity. To avoid making a judgement between whether U.S. costs or costs similar to other Pacific Island nations were more representative of American Samoa, the weighted means were used for the gears utilized. Countries for which weighted means were applied are indicated with an asterisk in Appendix A.

The total cost *(TC)* for country m fishing with gear g in 2005 is thus given as:

$$TC_{m,g} = c_{m,g} h_{m,g}, \quad \forall m, g \tag{2.3}$$

The total cost of fishing to country m is then calculated by summing over all gears and species.

Subsidies

In addition to specific subsidies estimates, the subsidies database (Sumaila et al., 2010) contains the computed subsidy intensity (λ), or the proportion of a country's total landed value that is subsidized (all subsidy categories combined). Because it is not currently known what amount (absolute or relative) of a nation's subsidies go directly to supporting the tuna fishing sector, I use the intensity as a proxy and apply it to the landed value of fishing for tuna species. For example, if a country had a reported subsidy intensity of 0.25 in Sumaila et al. (2010), and its landed value of all tuna species combined in 2005 was US $1 million (based on the price and catch databases), then we would conclude that subsidies amounting to US $250,000 were transferred by that country's government to the tuna fishing sector.

The subsidy intensity ranged from 0 to 2.92, with a mean value of 0.405 (Sumaila et al., 2010). This intensity is applied to the estimated landed value (or TR, as defined above) for the 2005 year for each country and as follows:

$$TS_m = \lambda_m TR_m, \quad \forall m \tag{2.4}$$

Rent estimates

Resource rent as applied to fisheries is formally defined as the difference between the total revenue and the total cost of fishing (Clark, 2006). It is important to note that for this to be true, the total cost estimate must incorporate the opportunity cost of a country (or gear type) using its resources in some other sector, thus allowing for normal profit (Clark, 2006). This is true for the cost estimates developed in Lam et al. (2011), and used in this analysis. In this paper, I calculate rent in two different ways. Firstly, private rent is computed from the simple definition of subtracting total costs from total revenues. This is done for the 2005 year for each country and species caught with each gear as such:

$$\pi_{m,g,s} = TR_{m,g,s} - TC_{m,g,s}, \quad \forall m, g, s \tag{2.5}$$

Secondly, the subsidies-adjusted resource rent (π^{λ}) for each country in 2005 is computed. This is what I consider the social resource rent:

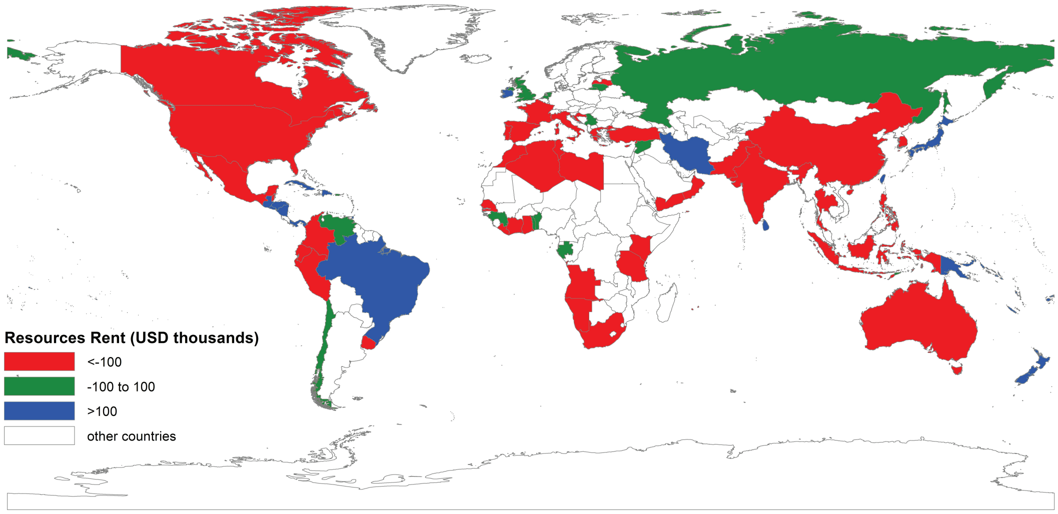

Figure 2.2: Social rent by country.

$$\pi_m^\lambda = \pi_m - TS_m, \quad \forall m \tag{2.6}$$

2.5 Results

The private rent generated from global tuna fisheries, or that which is perceived by the fishing industry, was an estimated US $4.70 billion in 2005. This ranged from a maximum private rent of US $1.62 billion (Japan) to a low of US -$816 million (South Korea). This private rent is the difference between the total revenues generated by fishing for the seven key tuna species of interest (all gears combined) and the total costs incurred through these fishing operations (again, all gears combined).

When subsidies are accounted for, the social rent is an estimated US -$951 million. Japan and South Korea generate the most and least social resource rent, respectively. The difference between the private and the social rent can be thought of as a social opportunity cost, essentially the amount of money that society could choose to put elsewhere, into its 'next best option'. The sum of the opportunity cost over all countries amounted to US $5.63 billion in 2005. Table 2.3 shows the private (before subsidies) and social (after subsidies) resource rent each country derives from the fishing of specifically bluefin tuna species, while Figure 2.2 shows countries generating positive, zero and negative social rent from fishing all tuna species combined. Only Japan, Italy, New Zealand and Croatia derive substantial positive social rents from fishing for bluefin tuna, with Ireland and the U.S. also having positive social rents, although to a lesser extent.

Table 2.3: Private and social rent (USD) for bluefin fishing nations (all bluefin species combined).

Country	Private rent (USD)	Social rent (USD)
Spain	-2,885,881	-6,830,267
France	-532,373	-3,709,356
Morocco	-2,456,061	-2,664,997
Tunisia	-1,453,750	-1,617,400
Malta	-92,536	-798,714
Mexico	-666,347	-729,192
Algeria	-424,065	-445,313
Indonesia	-296,140	-384,296
Taiwan	12,035	-360,456
Portugal	-62,395	-79,143
Cyprus	24,649	-22,509
Greece	359	-1,247
Denmark	-265	-284
Uruguay	-47	-49
USA	20	12
Ireland	430	170
Croatia	323,792	242,810
New Zealand	852,044	800,795
Italy	7,666,626	4,142,360
Japan	94,125,476	56,645,033

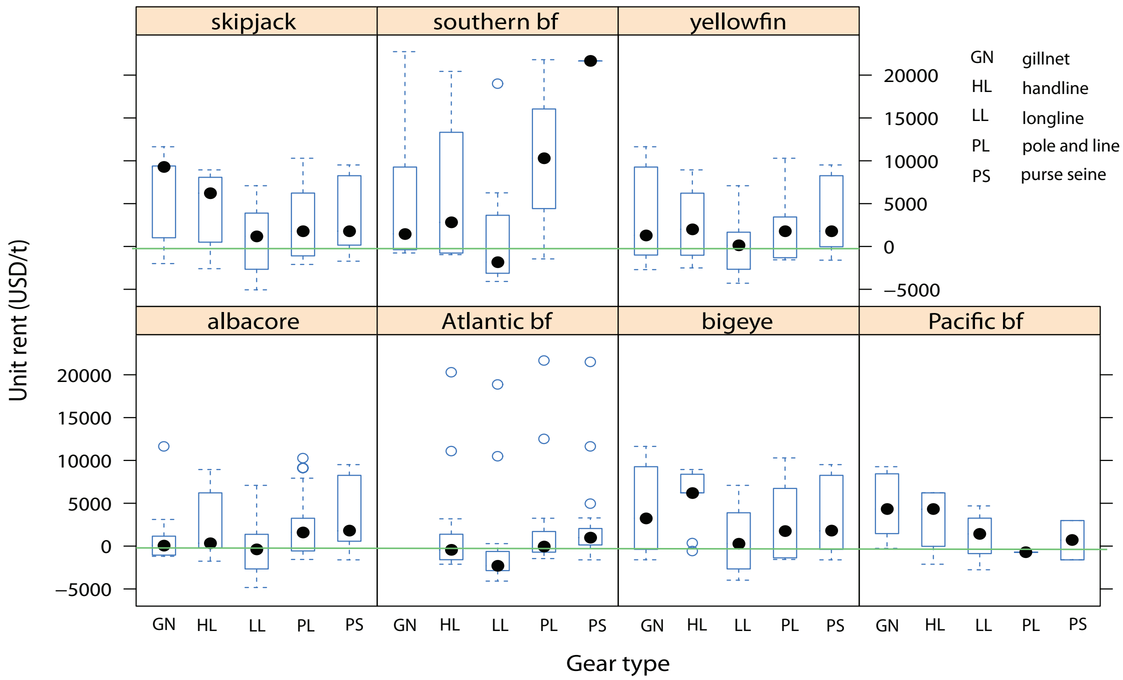

Figure 2.3: Private rent per tonne (difference in price per tonne and cost per tonne) by tuna species and gear type, aggregated over all fishing nations. bf refers to bluefin.

Complete disaggregated results can be found in the Appendix (A.1). Private rent estimates by species and by gear type are summarized below.

Species and gears

I calculated the mean rent per tonne, or difference in price and cost per tonne, for each major gear type employed in global commercial tuna fisheries. There is wide variability from fishing the various tuna species with different gears (Figure 2.3). Gillnets have the highest rent per tonne at US $3,859 per tonne, followed by purse seine (US $3,093/t), hook and line (US $3007/t), pole and line (US $2,329/t), and with longline (US $464/t) having the lowest mean rent per tonne. Note that these means are aggregated across all species caught.

While fishing for Atlantic bluefin offers the highest possible individual rent per tonne (Figure 2.3), the mean is actually the lowest of all of the species at US $981/t (Table 2.4). The highest mean unit rent is for southern bluefin tuna (Table 2.4). The total private and social rents, as discussed above, were disaggregated by species, shown in Table 2.4. From a species perspective, only fishing for yellowfin appears to be bad business, as this species contributes negatively to overall private rent (Table 2.4). Once subsidies are included, however, fishing for albacore, skipjack, yellowfin, and Atlantic bluefin yields negative social rents. This suggests that, with the exception of southern and Pacific bluefin and skipjack, subsidies are making unprofitable fisheries seem otherwise profitable to fishers.

Table 2.4: Species summary: mean unit rent, private and social rent.

Species	Mean rent (USD/t)	Total private rent (million USD)	Total social rent (million USD)
Albacore	2,116	125	-183
Bigeye	2,510	633	-77
Skipjack	2,829	4,057	792
Yellowfin	2,153	-371	-1,562
Atlantic bf	981	46	-6.2
Southern bf	5,865	170	76
Pacific bf	3,533	20	9.5
	Total	4,681	-951

2.6 Discussion

No doubt tuna fisheries provide substantial revenues in the form of landed value for fishing nations. Once costs and subsidies are accounted for, however, the net social rent from global tuna fisheries is negative. There are vast differences in the distribution of rent by country, species, and by fishing gear. Furthermore, there is a substantial difference in the private and social resource rent. Currently, subsidies amounting to over US $5 billion are being transferred to the tuna fishing sector from national governments. This is money that countries are choosing to put into various fishing sectors that may not be providing positive economic returns for the country, and may be fueling overexploitation of tuna stocks.

Bluefin

Fishing for bluefin tuna still remains a potentially profitable endeavor, with the private mean rent per tonne (difference in per tonne revenues and costs) for southern and Pacific bluefin species being higher than for non-bluefin species. Atlantic bluefin, however, offers the lowest unit rent of all tuna species analyzed in this study. Both Atlantic and southern bluefin tuna are overfished (MacKenzie et al., 2009; Collette et al., 2011; ISSF, 2012), yet remain, to varying degrees, profitable. This is especially true with regards to private rent, or the subsidized amount perceived by fishers. Once subsidies have been accounted for and social rent estimated, however, fishing for Atlantic bluefin is no longer profitable. This should offer even more impetus to follow rebuilding plans as suggested in MacKenzie et al. (2009), to reduce subsidies that are probably encouraging overexploitation, and to remove capacity that is not generating positive rent. The results here suggesting that profitability is not for high for Atlantic bluefin fisheries agrees with work conducted by Bjorndal and Brasao (2009), which concluded that profits could be much higher for those involved in fishing for Atlantic bluefin in the Eastern Atlantic and Mediterranean if an increase in stock size resulted from a recovery program. The authors make the case that allowing overexploitation to continue has large economic costs in terms of forgone future income, and make a solid case for rebuilding (Bjorndal and Brasao , 2009).

Some fishing nations (notably Italy, Japan and New Zealand) still stand to have positive social rents from fishing bluefin tuna, while other countries, such as Spain and France, collect only negative rents. Many other fishing nations are fishing right around the zero social resource rent point. Policy recommendations based on decreasing effort (and catch), like those argued for in Bjorndal and Brasao (2009), could be targeted at those countries whose subsidies are negating any positive rents. This may prove to be more effective than targeting those countries that are seeing positive economic benefits. If, as the Bjorndal and Brasao (2009) paper argues, substantial increases in rent are possible by reducing effort and allowing stock rebuilding to take place, then there may in fact be a strong case for exploring the notion of side payments to facilitate this process (see Chapter 3 for more on side payments).

Albacore, skipjack, yellowfin and bigeye

Fishing for albacore and yellowfin, species that are considered near threatened by the IUCN and reported as fully exploited by scientists (ISSF, 2012; Langley et al., 2009b; IUCN, 2011; Collette et al., 2011), still offers positive private rents, albeit lower than most of the other species. The sum of the private rents from yellowfin fishing, however, is negative, despite the positive unit mean. Overall, therefore, fishing for yellowfin tuna is a losing endeavor, even before subsidies have been considered. Fishing for skipjack tuna, an underexploited species, and bigeye, which is of conservation concern (Harley et al., 2010; ISSF, 2012), also have positive mean private rents per tonne. Once subsidies are considered, however, fishing for bigeye contributes negative social rent.

Skipjack tuna make up over half of all global catches (ISSF, 2012). That fishing for this species offers positive social rent does suggest that increasing effort in these fisheries is likely. Some of the cost savings from skipjack fishing comes from the use of fish aggregating devices (FADs) used by purse seiners, which reduces fuel consumption (Miyake et al., 2010). Conservation measures put in place by the Western and Central Pacific Fisheries Commission to limit the use of FADs (due to the issue of juvenile tuna bycatch) (WCPFC, 2009), could result in increased costs to purse seiners in this region, and a decrease in the private and social rents generated by this fishery in the future. This in turn would most likely result in less effort or capacity moving into this particular fishery than would otherwise be predicted.

Conclusion

This analysis finds that the mean unit rents through fishing for all tuna species offers potential positive returns, from the fishers' point of view. This could suggest that effort will continue moving into these fisheries, even though several of the stocks are in danger of overexploitation. It is important to note, however, that the data used here, specifically the cost estimates, are based on fuel costs prior to the large increases occurring since 2008. It is likely that the costs of fuel have been increasing more quickly than the ex-vessel price of fish, and thus the unit rent in 2005, as estimated here, might be higher than what we would calculate based on current costs. Cost data are equally as important as revenue data in determining resource rent, yet to date, the cost database used here is the only publicly available global reference. Improvements in cost estimates of all components of fishing operations will likely lead to improved estimates of fisheries rents, from tuna stocks and others, in the future.

Subsidies can alter the perceived rent possibilities, encouraging overcapitalization (Arnason, 1998; Clark, 2006; Sumaila et al., 2010). For fish populations that are fully or overexploited, increased effort resulting from overcapitalization can lead to decreased stock size, as well as reduced resource rent for all fishing nations. Furthermore, excess capacity in global tuna fisheries is thought to contribute to management challenges and hinder effectiveness of RFMOs (Miyake et al., 2010). In this analysis, national subsidies to global tuna fisheries amounted to US $5.63 billion in 2005. Due to the fact that, besides skipjack and Pacific bluefin, the world's tuna species are fully or overexploited, these subsidies are essentially society's contribution to depletion of its tuna stocks. To what extent is society benefiting from this disinvestment in fisheries capital? This is a question that should be tackled through a better incorporation of welfare economics into decisions about tuna management. It seems for many countries that positive social rents are not being generated by fishing for tuna. Society's support for this disinvestment is therefore leading to economic losses, in addition to ecological losses. More national accountability, coupled with improved management by RFMOs is going to be necessary to reduce the gap between private and social resource rents generated from global tuna stocks.

Chapter 3

Application of game theory to fisheries over three decades

3.1 Introduction

Background

Game theory is a tool for explaining and analyzing problems of strategic interaction (Eatwell et al., 1989). Essentially, it uses mathematics to describe player strategies in sources of conflict and common interest, and predicts what rational players *should* do (Luce and Raiffa, 1957). A game consists of a set of players, a set of strategies available to those players, and a set of possible payoffs for each combination of strategies. A strategy refers to any option that a player can take and it must specify what action will happen in each contingent state of the game (i.e., if player A chooses strategy x, player B will choose strategy y or z). Modern approaches to game theory are usually attributed to von Neumann and Morgenstern (1947), although Luce and Raiffa (1957) point out that there are earlier contributions. Following the von Neumann and Morgenstern work, game theory was expanded on by John Nash, who is probably best known for his work on non-cooperative (Nash, 1951) and cooperative (Nash, 1953) solutions (for which he was awarded the Nobel Prize in economics in 1994). Subsequently, game theory has been used in a number of worldwide applications, including political science, evolutionary biology, military strategies, economics, including natural resource and environmental economics, and computer science (Eatwell et al., 1989).

Game theory deals with the strategies decision makers choose, as individuals or in some forms of collusion, to maximize their outcome in a given situation (Luce and Raiffa, 1957). We can see that the issues of fisheries management fit well within this game-theoretic framework as fishers and/or managers seek to maximize the benefits from a given fishery. Games are structured around players, the constraints they face, the information sets they possess, and the possible outcomes players expect. The players in game-theoretic analyses are assumed to be rational, essentially each player seeks to maximize their potential outcome through an understanding that all other players are seeking the same goal (Luce and

Raiffa, 1957). The rationality assumption helps us to identify preferred outcomes among a set of possible outcomes (Davis, 1997).

The value of an outcome is usually expressed as 'utility' in game theory (Luce and Raiffa, 1957). In a game, utility represents the motivations of a player. A utility function is a value assigned to each player for each possible outcome of the game. As the utility function increases, the respective outcome is viewed as more desirable. For example, a player will prefer outcome L_1 to outcome L_2 if and only if the expected utility of L_1 is greater than that of L_2.

Game theory and fisheries

From society's point of view, overfishing is wasteful, both biologically and economically, yet it happens often (Clark, 2006). The theory of games offers some insights into why fishers may be driven to adopt strategies that seem to be irrational; why overfishing may in fact be an economically rational action (Kaitala and Lindroos, 2007). Game theory is particularly applicable to the study of resource management, such as fisheries, as many of the world's natural resources are common pool in nature (Sumaila, 1999). We can divide shared fisheries resources into four main categories:

1. Domestic shared stocks: those stocks fished by more than one entity within a coastal state's exclusive economic zones (EEZ);
2. Transboundary resources: those occurring in the EEZs of 2 (or more) coastal states;
3. Straddling stocks: those occurring in the EEZs of at least one coastal state and the high seas (including highly migratory species, i.e., tuna);
4. Discrete high seas stocks: those occurring only in the high seas.

Generally speaking, the list above is in increasing order of the level of management difficulty.

The first relevant paper analyzing fisheries in a game-theoretic context was authored by Munro (1979). The author was motivated to write his seminal paper by the increasing acceptance of extended fisheries jurisdiction which he believed would, and in fact did, lead to increased management of fisheries by individual coastal states (Munro, 1979)[2]. He argued that the issue of managing transboundary fish stocks, those that moved between

[2]Munro also credits the inspiration for this paper to Hnyilicza and Pindyck (1976), a report analyzing cooperative behaviour in pricing policies by the Organization of Petroleum Exporting Countries (OPEC). The majority of game theoretic work in economics had focused on non-cooperative or competitive games, and this report was one of the first to start viewing world situations in a cooperative way (Munro, personal communication).

two or more EEZs, would require a joint approach, and as such, he applied the theory of bargaining, or cooperative games, to the problem (Munro, 1979). Interestingly, the United Nations Convention on the Law of the Seas, a result of which was the 200 nautical mile EEZ, suggested that although coastal states sharing a resource must seek to cooperate, they are not required to reach an agreement (United Nations, 1982). This essentially allows for non-cooperation to be the default option (Munro et al., 2004). This outcome is often referred to as the Prisoner's Dilemma, where players are driven to adopt sub-optimal strategies, from the perspective of the group. Note, however, that non-cooperation does not automatically imply a negative situation. Cooperation is a more flexible outcome because players could, of course, choose the non-cooperative payoff as their solution, so a point could exist where cooperation and non-cooperation result in the same outcome. Munro et al. (2004) point to the North Atlantic scallop fishery off the east coast of Canada and the U.S. as an example where non-cooperation puts players in no worse state than cooperation would. In this example, there is limited interaction between the fleets of the two countries, primarily because adult scallop are fairly sedentary.

It has been thirty years since Munro's work was published. We can now reflect on three decades worth of academic and practical applications of game theory to fisheries and ask how influential this paper has been in terms of shaping fisheries management today. In the following section, I summarize the earlier game-theoretic analyses, which involved mostly two-player approaches. The last decade has produced major gains in the theory of games as applied to fisheries, specifically with the incorporation of coalition theory into the analyses, which allows for the development of game-theoretic models with greater than two players. These gains are discussed in Section 3.3. By drawing on current issues in international fisheries, and international environmental issues as a whole, Section 3.4 highlights where fisheries economists are directing their focus today, with respect to game-theoretic applications, and where that focus is likely headed in the next decade.

3.2 Early years: The two-player game

Munro (1979) investigated how asymmetry in players, for example, players facing different rates of discount and costs of fishing, can impact the cooperative solution when considering a fishery resource that is shared between two coastal states. One of the most relevant conclusions in Munro's analysis is that, given that players often have different preferences and perspectives, joint management of a resource is greatly simplified with the possibility of side payments, or what is also called transferable utility (Munro, 1979). Transferable utility is a term used in cooperative game theory and in economics. Utility is transferable if one player can 'costlessly' transfer part of its utility to another player. Such transfers are possible if the players have a common currency that is valued equally by all. Interestingly, the term 'side payment' has been met with scepticism by the international fisheries management community. Fisheries economists may be well advised to rename this policy tool if it is, in fact, going to be a valuable aide in reaching cooperative agreements[3].

Dynamic externality

Levhari and Mirman (1980) published their influential paper on 'fish wars' a year after Munro (1979). In their two-player analysis, the authors highlight two important game-theoretic features of fisheries management: that the underlying stock is affected by both players' decisions; and that each player must take into account the other players' actions (Levhari and Mirman, 1980). These two features create what is known as 'dynamic externality' (Levhari and Mirman, 1980) and it is this fundamental situation that allows game theory, the study of strategic interaction, to be applied to fisheries (Sumaila, 1999). That same year, Clark (1980) published a game-theoretic paper exploring restricted access to common property resources. Clark was motivated to apply game theory to the fishery problem due to the increase in limited entry programs being initiated by fishing countries. This insightful analytical work demonstrated that, for a limited entry system with at least two players, the competitive (or non-cooperative) game results in overfishing, which is in fact what we readily observe in reality.

Following the Munro, Levhari and Mirman, and Clark papers, many other contributions were published, mostly in the 1990s, applying game theory to highlight several of the most pressing issues in fisheries management, specifically how to manage shared stocks. Generally, these games took the form of cooperative and non-cooperative games, with authors usually illustrating the gains to the system through cooperative management (Sumaila, 1999). Nash defined cooperation as occurring when players in the game are able to discuss and agree upon a joint plan (they can communicate), and that the agreement is 'assumed to be enforceable', or binding (Nash, 1953). It thus follows that non-cooperative games are those in which agreements are non-existent and/or non-binding, and where parties cannot communicate. For a two-player cooperative outcome to be stable, it must meet two conditions, namely, Pareto Optimality (no player can increase their payoff without decreasing the payoff to another player) and the Individual Rationality Constraint (the cooperative payoff to any player must be equal to or greater than the payoff under non-cooperation, essentially the player's threat point). Miller and Munro (2004), in the context of climate change, add a third condition to these two, that of flexibility and resilience of the cooperative solution. This third condition is discussed in Section 3.4.

[3] Recently the term 'negotiation facilitators' has been proposed (Munro, personal communication).

These early contributions, thoroughly reviewed in an article published ten years ago by Sumaila (1999), usually modeled fisheries shared between only two players. Although one could envision several fisheries situations where there are greater than two players, authors can reduce complexity in their models by aggregating players into two groups. This can be done by gear type, as in the case of the Arcto-Norwegian cod fishery where Armstrong and Flaaten (1991) and Sumaila (1995, 1997a) modeled the interaction between offshore trawlers and coastal vessels. Fisheries game-theoretic methods were also applied to study how cannibalism by adult cod on juveniles can affect the optimal catch shares between two entities that fish different age classes (Armstrong and Sumaila, 2000). Similarly, players can be grouped by country, which was the way Munro had originally envisioned the application of game theory when he wrote about the management of transboundary resources (Munro, 1979). Kennedy (1987) developed a two-player game of the fishery between Australia and Japan, targeting Southern bluefin tuna. The author concluded that the optimal outcome is, in fact, joint management, or cooperation, resulting in the total exclusion of Australia from the fishery (compensated through side payments) (Kennedy, 1987). In the case of the industrial pelagic fishery shared by Chile and Peru, Aguero and Gonzalez (1996) also applied a 2-country analysis. The authors also conclude that appropriate joint management can lead to benefits, specifically through eliminating the tendency for overcapitalization and overfishing to occur in open access fisheries (Aguero and Gonzalez, 1996).

The two-player application expanded

In the decade following the Sumaila (1999) review, the two-player framework was expanded upon to analyze more than just catch shares between two entities. Game theory was used to study the efficiency of marine protected areas (MPAs). MPAs are areas of the ocean or inter-tidal regions, which have been reserved by law or other means in an effort to protect the ecosystems within those areas. Sumaila (2002) developed a two-agent bioeconomic game-theoretic model to assess the difference in expected MPA effectiveness under cooperative and non-cooperative management. Not surprisingly, the paper concludes that both cod stock biomass and rent from the fishery are higher under an MPA program that is managed cooperatively by the two players (Sumaila, 2002). A subsequent paper to this addressed the distributional effects of MPAs to different players through a game-theoretic analysis (Sumaila and Armstrong, 2006). The authors conclude that the management plan in place before and after the implementation of an MPA can influence which players may win or lose (Sumaila and Armstrong, 2006). Studies like this can help illustrate to policy makers that simply creating an MPA is not necessarily a sufficient plan to enable sustainable fisheries. Measures may need to be put in place to ensure that the management plan is equitable and honored by all players.

Not only are we interested in the gains to the system through cooperation, but we would also like to understand what factors are likely to aide cooperation. Trisak (2005) attempts to answer this question by analyzing the biological characteristics of a fished stock that affect fishers in a co-management group. The author concludes that the size and the internal growth rate of the stock do in fact influence fishers' decisions to cooperate, but fishers' attitudes toward risk are also highly influential (Trisak, 2005). These conclusions are related to if and when a player chooses to cooperate: essentially the timing of cooperation. This issue of timing of the cooperative agreement has gained attention recently, and is likely to be even more important in the coming years. Kaitala and Lindroos (2004) helped to initiate this conversation within the fisheries game theory realm. Applying game theory in this type of analysis can help policy makers better understand how the biological characteristics of a fishery can help or hinder cooperation.

Stage and sequential games

Most fisheries game-theoretic studies have used a single stage structure. Players make one decision at the beginning of the game, usually based on known states of the future system. There have been a few attempts at multiple-stage games, where players make a decision about inputs in stage one, and in the second stage, the players use those inputs to engage in competitive behaviour. Sumaila (1995) developed a two-stage game, where players decide on the fishing effort to maximize rent in stage one, and in stage two, take their optimal catch shares. In a similar style, Ruseski (1998) formulates a two-player game where players choose the number of allowable firms in the fishery, or a fishery subsidy amount, and then optimize their catch shares in a competitive second stage. Kronbak and Lindroos (2006) take the stage-game further, by combining the idea of coalition formation by fishers with the level of government regulation and enforcement. The authors use a four stage game. In stage one, authorities choose their level of regulation (centralized, decentralized, etc.,). In stage two, authorities choose a level of effort control. Fishers choose their coalition structure in stage three, and in stage four, fishers choose their optimal effort strategy.

In sequential games, one player makes their decision first, followed by the other player(s). This type of structure probably resembles how international agreements are decided in the real world, where often a player may wait to sign onto an agreement until a certain other player has done so. Hannesson (1995) develops a sequential game and considers the possibility of cooperative harvesting being a self-enforcing equilibrium. A two-player game was developed by Laukkanen (2003), where the author allows the catch of agent one to occur first because they target fish in the feeding grounds, followed by agent two determining their catch from the stock in the spawning grounds, as the second decision. McKelvey (1997) also develops a sequential game, but instead of looking at a domestically-shared resource, the author applies the sequential model to a transboundary stock.

These types of stage and sequential games may, in fact, be more realistic, as fishers, nations or management authorities do not necessarily all make one single decision simultaneously. More work of this kind may help to yield insights into the resiliency of cooperation, as discussed later in the paper.

I have explained how the application of game theory to the management of transboundary resources has illuminated some of the issues present in non-cooperative management, and illustrated possible gains from cooperation. After about 20 years of game theoretic work involving mostly two-player games, fisheries economists began to work on the issues present in situations involving greater than two players, particularly as it relates to the management of straddling stocks, specifically tuna.

3.3 Major movement: Coalitions

Coalitions: Characteristic function approach

As stated earlier, both analytical and computational methods are often easier when only two players are considered, and the two-player approach seemed a logical simplification for the first game theoretic applications. At the time of extended fisheries jurisdiction, about 90% of the world's capture fisheries were believed to be located in the EEZs of countries (Alexander and Hodgson, 1975). The creation of EEZs gave management jurisdiction over coastal marine resources to the states themselves, and it was thought that this would make sustainable management more of a reality. The management of internationally shared fish stocks, where interested fishing parties include coastal states, Distant Water Fishing Nations (DWFNs) and high seas fishing fleets, has required models involving greater than two players. And in fact, the issue of the management of straddling stocks, that is, those that migrate between the EEZs of several countries and the high seas, may now be one of the biggest challenges to global sustainable fisheries, as these fisheries represent as much as one third of marine capture fisheries catches (Munro et al., 2004).

The application of game theory to fisheries has recently expanded to allow for this possibility of coalitions in games involving greater than two players (Kaitala and Lindroos, 1998; Arnason et al., 2000; Brasao et al., 2000; Duarte et al., 2000). A coalition framework allows for cooperation among a group that is smaller than the total number of players in the game (Kronbak and Lindroos, 2007). Coalitions are common in the real world. Examples include several countries joining together to form an oil cartel such as OPEC (Organization of the Petroleum Exporting Countries) and the creation of a political unit such as the European Union. The formation of coalitions is a vital part of economic activity (Yi, 2003).

The management of fisheries occurring in both the EEZ of countries and in the high seas can call for a coalition approach due to the potentially large number of interested countries (Lindroos et al., 2007). Following the 1995 United Nations Migratory Fish Stocks Agreement (UNFSA) (UN, 1995), Kaitala and Munro (1997) realized that the two-player analysis would not be sufficient to tackle one of the most pressing of fisheries management issues, namely, management of straddling stocks. The UNFSA effectively mandated the management of straddling stocks to be carried out through regional fisheries management organizations (RFMOs) (UN, 1995). Kaitala and Munro (1997) observed that, while the bargaining process among two players proceeds in a straightforward manner, the standard game-theoretic models that had been developed thus far were not capable of dealing with a larger number of players. The limitations of the 2-player game were also raised by Hannesson (1997), again in relation to the UNFSA. Hannesson (1997) develops a repeated game model of infinite duration (known as a supergame), one of the results of which is that the payoffs to playing non-cooperatively increase as the number of players in the game increases. Thus, there is a large incentive to deviate from cooperation given a sufficiently large group of players. This may be particularly relevant for management of tuna fisheries, as the potential number of interested players can be quite large.

Some of the earliest fisheries studies involving greater than two players found in the literature, no doubt inspired by the Kaitala and Munro (1997) and Hannesson (1997) suggestions, used characteristic-function games, or C-games, to assign a value to a given coalition (Kaitala and Lindroos, 1998; Duarte et al., 2000; Lindroos, 2004). To apply a C-game approach, we first compute and compare the relative payoff of each coalition, with respect to the grand coalition, where the grand coalition is the outcome where all players in the game play cooperatively. The next step, which is the primary function of C-games, is to calculate the sharing imputation - that is, what fraction of the benefits should each player in a coalition receive? There are different methods for assigning sharing rules, and in fisheries, these methods generally include the Shapely value (Shapley, 1953), the nucleolus (Schmeidler, 1969), and the Nash bargaining solution (Nash, 1950). The Shapley value essentially weights players based on their marginal contributions (Shapley, 1953), while the nucleolus is a unique solution that maximizes the benefits of the least-satisfied coalition (Schmeidler, 1969). The Nash bargaining solution is an egalitarian approach, essentially assuming that all players in the coalition are equally important because full cooperation would not succeed without all of them, and thus the payoff should be shared equally (Nash, 1950). Note that there is no guarantee that all or any of these approaches will lead to a stable coalition structure, that is, one that is rational to all players. A review of a coalitional fisheries games was undertaken in Lindroos et al. (2007).

The issue of stability of the cooperative solution soon emerged, with models comparing core and free-rider stability (Kronbak, 2004; Kronbak and Lindroos, 2007). A given coalition is stand-alone stable if and only if no player is better off by leaving the coalition to become a singleton, or free-rider (internal stability), and no player wishes to join the coalition (external stability) (Pintassilgo, 2003). In an early coalitional game of the Baltic Sea fishery, Kronbak (2004) determines that the sum of the players' threat points if operating as singletons is greater than the sum of the grand coalition's payoff. In light of this, Kronbak and Lindroos (2007) apply a novel sharing rule that combines a cooperative and non-cooperative game and considers free-rider threat points, those payoffs that each player would get if deviating from the grand coalition. Their model indicates that there can be a large enough increase in benefits through the formation of the grand coalition to satisfy all players, (Kronbak and Lindroos, 2007), where all players are 'satisfied' if their payoff through cooperation is at least equal to their payoff from free-riding (the individual rationality constraint). This approach, which incorporates the issues of externalities in coalition formation, developed in parallel to a complimentary approach, called the partition-function approach, as discussed in the next section.

Externalities: Partition function approach

One major drawback to the conventional C-game approach, is that a given coalition value is calculated based only on the makeup of that coalition, not on the entire coalition structure of the game. This results in C-games ignoring the influence of group externalities. As Yi (1997) explains, many coalition formations exert positive or negative externalities on other players/coalitions in the game. For example, an oil cartel's decision to limit supply has a positive effect on other oil-producing non-members, as the price they command for their oil will be higher based on the actions of the cartel. Negative externalities can be seen with the example of established trading blocs, whereby non-members may suffer by not joining the bloc coalition.

We can determine if externalities are present by observing whether a merger of coalitions changes the payoff to a player not involved in the merger (Kronbak and Lindroos, 2007). These externalities are considered positive if, upon the merger of coalitions, the payoff to a player not involved in the merger increases (Yi, 2003). The term 'free-rider' has been given to describe a player benefiting from coalition formation but not involved in the merger.

The issue of these group externalities in fisheries has been tackled by Pintassilgo (2003) and, as described above, by Kronbak and Lindroos (2007). Pintassilgo (2003) applies a partition-function game to the management of Northern Atlantic bluefin tuna, stating that fair sharing rules on their own can't guarantee stability of cooperation, but rather suggests that legal frameworks need to be in place. This is in fact quite an important conclusion that policy makers may benefit from understanding. Taken together, the Pintassilgo (2003) and Kronbak and Lindroos (2007) papers illustrate that full cooperation is not always an economically rational decision at the level of an individual player, and may help us to understand why in fact so much non-cooperative behaviour exists in internationally shared fish stocks management.

Highly migratory stocks

The application of game theory has proved useful in understanding some of the management issues concerning a specific group of straddling stocks, namely, highly migratory stocks (Duarte et al., 2000; Pintassilgo, 2003). The term 'highly migratory stock' pertains "to all intents and purposes, to tuna" (Kaitala and Munro, 1997). As highly migratory stocks, tuna tend to occur in the exclusive economic zones of multiple countries, and in the high seas, resulting in substantial management challenges (Bjorndal et al., 2000). The ability to model multi-player games is essential for joint management. This is particularly the case, as Kaitala and Munro (1997) revealed, given the UN mandate encouraging countries exploiting these highly migratory species to cooperate in their management by the initiation of RFMOs (UN, 1995)[4].

RFMOs are formed by groups of countries with relevant interest in fishing shared stocks, be they coastal states or DWFNs. Resolution of negotiations between different groups can be studied through the use of coalition theory (Lindroos et al., 2007). However, the major problem that remains is that even if an international cooperative agreement is reached, it is not binding or enforceable (Bjorndal et al., 2000), which contradicts one of the main requirements for the existence of cooperative solutions (Nash, 1953). However, Munro (2006) specifically states that, with very few exceptions, cooperation between the states targeting highly migratory fish stocks is essential for sustainable fisheries management. Game theory may provide a particularly useful lens through which to view the formation and stability of RFMOs. Recent work by Pintassilgo et al. (2008) illustrates that, although higher cooperative gains can be expected from RFMOs with a large num-

[4]Note that RFMOs exist to manage numerous fish stocks, and were not created solely for tuna management.

ber of members, the likelihood of cooperative stability decreases as number of members increases.

Two of the main issues in the management of highly migratory stocks are unregulated fishing, or free riders, and what has been termed the 'New Member Problem' (Kaitala and Munro, 1993). Fishing nations that are not party to the RFMO agreement (and therefore probably not abiding by RFMO guidelines), but fishing on the high seas, can be said to be engaging in unregulated fishing. Currently, there is very little RFMO member countries can do to address this issue. Unfortunately, it seems cooperation is not likely if unregulated fishing, and thus free-riding, is allowed to persist (Pintassilgo and Lindroos, 2008). The second issue arises from the fact that the RFMO is not justified in excluding any interested party from joining the organization (UN, 1995). As such, possible entrants may participate in unregulated fishing (or no fishing) until the state of the stock is rebuilt to such a level that they choose to join the RFMO. This new entrant is free-riding, essentially benefiting from the stock rebuilding program without bearing any of the management costs (Munro, 2006). In order for RFMOs to be effective in managing stocks sustainably, as they are mandated to do, these two issues will need to be addressed. The next section discusses the current ideas being formulated to tackle these issues, the resolution of which may come through the application of game theory to fisheries.

3.4 Looking forward: Catch privileges and resilience

Catch privileges and the principal-agent problem

Although game-theoretic models of shared stocks have been somewhat successful in elucidating the benefits of joint management, actually obtaining this cooperation is another question. There are two levels of cooperation, as identified by Gulland (1980). The primary level is scientific cooperation, where players in the game communicate and share research information (Gulland, 1980). Even this first level can be hard to achieve because some players may suspect that their 'rivals' may use that information against them (Munro et al., 2004). In fact, McKelvey et al. (2003) demonstrate that if non-cooperation, which is often the default option in shared stocks management, prevails, more information can actually be harmful to the sustainability of the resource. The authors suggest side payments as a way to encourage cooperation in asymmetrical information situations (McKelvey et al., 2003). Gulland (1980) describes the secondary level as cooperation in active management, which is, in effect, the formation of joint management arrangements, such as RFMOs. One of the possible underlying challenges in creating effective cooperative regimes, even at the primary level, is the lack of 'property rights' bestowed on fishing nations. Without property rights, if one country agrees to actively cooperate in management, what guarantee do they have that they will, in fact, be the ones to benefit from that cooperation?

With so many vested interests in a straddling stock fishery, unregulated fishing and cheating are bound to occur. Unregulated fishing can lead to an underestimate of catch and effort in the fishery (Pitcher et al., 2002), and can severely undermine management programs (FAO, 2002). It has been suggested that *de facto* property rights granted to member countries (including for catch on the high seas) would effectively change unregulated to illegal fishing (Kaitala and Munro, 1997; Munro, 2008), thus allowing RFMO member countries to take action against such illegal fishers. Perhaps game-theoretic modeling could be used to illustrate the differences in optimal outcomes between 'open access' and 'privatized' fisheries. Of course, the granting of access rights, or catch privileges, comes with a suite of its own challenges, including distribution and equity arguments (Clark, 2006). In this case, allocation of catch privileges could be seen as just one of several tools that would bestow greater ownership to, and hence possibly greater likelihood of cooperation by, RFMO member countries. Munro (2007) points out, however, that development of state property rights in straddling stock fisheries is far less straightforward than in transboundary fisheries, but stresses that private fishery access rights *should* enhance cooperative management. In Chapter 4, I examine the challenges of current allocation schemes in shared fisheries, and propose a way forward for RFMOs.

A branch of game theory, called principal-agent analysis[5], could possibly be applied to address these issues. The majority of game theoretic applications in fisheries rely on the assumption of perfect information (Jensen and Vestergaard, 2002). However, this assumption is not met in many circumstances, as Nash (1953) himself admitted. Principal-agent analysis, part of a class of games called incomplete or asymmetric games, is applied in systems of imperfect information and uneven power (Clarke and Munro, 1987). This type of analysis focuses on the problem of devising compensation rules (incentives) that induce an agent to act in the best interest of a principal (Sappington, 1991). To my knowledge, there are only a handful of principal-agent analyses applied to fisheries in the literature. The first two were analytical pieces by Clarke and Munro (1987, 1991) that analyze the optimal catch and effort tax scheme to be employed by coastal states on DWFNs. Jensen and Vestergaard (2002) analyze a tax on the effort of EU member states (agents) to be enforced by the EU (principal) in an attempt to correct for imperfect information in the system. An empirical piece analyzing illegal fishing in Indonesia has been conducted by Bailey and Sumaila (2008b), where the authors use principal agent analysis to devise a

[5]This is also sometimes referred to as a Stackelberg or leader-follower game (Mesterton-Gibbons, 1993).

penalty scheme to discourage illegal fishing. Given that these are the only analyses to date, there appears to be more scope for incorporation of principal-agent analyses into fisheries modeling. It has been suggested that in the context of principal-agent analysis, granting of catch privileges may in fact strengthen the information and control that a principal has over the agents in the system (Munro et al., 2009). This may mean that implementing a catch privileges/allocation scheme within the context of RFMO fisheries may lead to RFMO member states having more control over the management of the resource (Chapter 4).

Although catch privileges have been suggested as a way of helping reduce or eliminate the occurrence of unregulated fishing, to my knowledge, this has not been modelled in a game-theoretic framework. Collective catch privileges have also been suggested as a way of increasing stability of a cooperative agreement in light of the new member problem. This was addressed by Pintassilgo and Duarte (2001). The authors explore three possible solutions to deal with new members, including transferable membership, a waiting period, and a fair sharing rule. They point out that in a quota or allocation scheme, transferable memberships in the cooperative group can take on the attributes of individual transferable quotas (Pintassilgo and Duarte, 2001). However, the authors are quick to point out that, at the time of writing their paper, international quota markets, were not common in fisheries. This condition does not appear to have changed much over the past few years. The new member problem falls under the bigger issue of resilience of the cooperative solution.

Resilience of the cooperative solution

As Kaitala and Lindroos (2004) point out, the timing of international agreements can either facilitate or destabilize cooperation. The costs players face, and how players in the game perceive the size of the stock biomass, among other variables, can affect whether or not and when they choose to cooperate (Kaitala and Lindroos, 2004). Similarly, one can imagine that changes in the future state of the system, such as new members or shifting climate regimes, can hinder a cooperative agreement created today. With regard to the new member problem, as discussed above, this might involve a potential fishing nation waiting until the stock has been rebuilt to join the cooperative agreement. The immediate response by the RFMO may be then to keep the stock at such a level to discourage new entrants, as suggested by McKelvey et al. (2002). However, the authors are quick to explain that this is perhaps a desperate action, which may entail large economic and ecological losses to RFMO members (McKelvey et al., 2002). They conclude that instead of trying to deal aggressively with non-RFMO fishers by discouraging them to join the RFMO or to engage in unregulated fishing, (what they call ‘interlopers’), working out a cooperative solution would probably be the optimal action (McKelvey et al., 2002). As such, there seems to be even more impetus on reaching a cooperative solution in the present day that is resilient to changes in the future. One way may be to develop a better understanding of how to negotiate the reallocation of property rights to new RFMO entrants in the future, as called for by Bjorndal et al. (2000), but I are unaware of any studies to date that have analyzed this issue.

The issue of 'resilience' to shocks in the system in the cooperative solution was raised by Kaitala and Pohjola (1988) twenty years ago, and reiterated by Munro (1990). However, it has not yet been tackled properly either in theory or in practice (Munro, 2008). Deterministic models, such as Kaitala and Pohjola (1988), illustrate how changes in the system can lead to an unstable equilibrium. Game-theoretic stochastic models, such as those developed in Sumaila (2002), Laukkanen (2003), and McKelvey et al. (2003), although rare, are insightful and can help policy makers anticipate how shocks in the system *may* affect the cooperative solution. However, practical evidence suggests that predicting these shocks is difficult, both in magnitude and direction (Munro, 2008). If, however, cooperation is to succeed, for example in RFMOs, then stochasticity in models should be the norm (where it is currently the exception), and our time frame must be increased in an attempt to incorporate future conditions. The issue of future states of the ocean, biomass, and economy, brings up the issues of discounting, where we prefer benefits to be received today, over benefits to be received in the future. In conventional discounting, often the benefit of a fishery in 50 years is negligible to the decision-making of today. This means that we are essentially unable to predict how future changes could affect cooperation. New methods for discounting, including those by Sumaila and Walters (2005) and Weitzman (2001), are worthwhile attempts to address the discounting issue.

Shifting climate

Recent work has illustrated how shifts in climate may affect fish, and thus fishing, distribution globally (Cheung et al., 2009). One of the major suggestions is that many fish populations will move away from the equator and toward the poles (Cheung et al., 2009), which would almost certainly result in losses of benefits to tropical countries. Furthermore, species naturally occurring in northern regions are quite sensitive to temperature changes, rendering them susceptible to shocks from climate shifts (Cheung et al., 2009), which could result in economic losses to northern fisheries. A recent publication by Brandt and Kronbak (2010) analyzes how changes in climate could impact Baltic Sea fisheries. The authors determine that if changes in climate result in decreases in future payoffs to the fishery, stability of the cooperative solution is not guaranteed. Hopefully, similar studies can be undertaken to address implications for both domestic and internationally-shared fish stocks as a result of possible climate shifts. What is also necessary is a move away from just modelling of these scenarios to a real solutions-based discussion of how to get to where we want to be.

The impact of climate shifts on the stability of the cooperative agreement between Canada and the United States, formed to manage the Pacific salmon transboundary resource, was summarized by Miller and Munro (2004). The authors describe how warming of coastal waters on the west coast of North America in 1977 led to an increase in the abundance of salmon in Alaskan waters, and a sharp decrease in abundance in salmon found in California, Oregon, Washington and southern Canada (Miller and Munro, 2004). The benefits expected by the southern players at the outset of the cooperative agreement did not materialize, and non-cooperative behaviour ensued (Miller and Munro, 2004). One major criticism to the Canada-US Pacific Salmon treaty was that it did not explicitly include the scope for side payments (Munro, 1990). This retrospective analysis helps to illustrate why resiliency in a cooperative agreement is important for stability, however, testing the resiliency of straddling stock cooperative agreements, such as those through RFMOs, to changing circumstances has yet to be adequately addressed in the fisheries game theory literature (Munro, 2008).

One further development that should begin to surface is the use of game theory in a broader, ecosystem-based context. The majority of game-theoretic analyses in fisheries have been applied to single stocks. There are a few exceptions, for example, the predatory-prey piece analyzed by Sumaila (1997b), where the author looks at the optimal exploitation for cod and capelin in the Barents Sea. Chapter 6 in this dissertation develops a multi-species model that addresses bycatch and growth overfishing in an effort to address this gap in modelling.

Game theory is also being applied in many other environmental contexts, notably the possibility for cooperation in international environmental agreements geared towards mitigating the impacts of climate change. Interestingly, the progress that has occurred recently in fisheries coalitions has paralleled the developments in coalitional models to address the issue of climate change negotiations. Finus et al. (2008) discuss new developments in coalition theory as applied to this issue. The authors model heterogeneity in players (i.e., asymmetric players) and explore the issues of open and restricted membership (where fisheries coalition models are generally developed as open membership games) (Finus et al., 2008) and transferability (broadly paralleled to side payments in fisheries). In addition to their predictable result that gains through the cooperative solution are large, one of the key outcomes in their study is that it may be more beneficial to have the most important players (those whose marginal contributions to cooperation are largest) within the cooperative agreement than to insist on full cooperation by all members (Finus et al., 2008). Work on this front may offer interesting new angles that should be addressed by fisheries economists in the next few years. It seems that these approaches are being merged, as evidenced by the recent joint work of Finus, Pintassilgo, Lindroos, and Munro (Pintassilgo et al., 2008).

3.5 Conclusion

It seems fair to conclude, given the extensive literature available on the application of game theory to fisheries, that indeed, Munro's 1979 paper was influential in directing attention to how fisheries can be modeled as strategic dynamic interaction between fishing entities. The impetus for publishing the paper was the issue of extended jurisdiction and transboundary resources. These issues were tackled for fisheries in Norway and Russia (Sumaila, 1997a), Canada and the US (Miller and Munro, 2004), Australia and Japan (Kennedy, 1987), among others. However, it is equally, or perhaps even more useful, to view the management of straddling stocks, such as tuna, through the lens of game theory. It is in this realm that much of the work over the past decade has focused, beginning with applying game theory to the management of North Atlantic bluefin tuna (Duarte et al., 2000; Pintassilgo, 2003). The recent work on coalition theory through the partition function approach has illuminated many challenges in achieving cooperation (both primary and secondary) in straddling stocks management (Pintassilgo and Lindroos, 2008). Recent work in fostering cooperation in international climate change agreements may help inform future game-theoretic models, and may help facilitate cooperation by fishing states. One further detail that may need better incorporation in game theoretic models to facilitate cooperative management is improved cost functions. The costs of achieving cooperation, be they institutional, technical, or other, are generally not properly factored into the fisheries game-theoretic analyses that have been developed to date.

The application of game theory to fisheries has provided insightful predictions about stability of cooperation in internationally shared fish stocks management. This has been shown both in theory and in practice (Munro, 1990). As Munro (2008) points out, the continued broadening of game theory from the theoretical to the applied may go a long way in aiding cooperation in the management of the world's shared fish stocks.

Chapter 4

Present and future allocation approaches for shared tuna fisheries

4.1 Introduction

Shared fisheries resources are susceptible to the "tragedy of the commons" (Hardin, 1968). Although Hardin (1968) formally explored the impact of individual shepherds increasing their heads of cattle on a shared pasture, his thesis is just as relevant to shared marine pastures, or the global ocean commons. Fish stocks are common pool resources that face the problem of overuse (i.e., overfishing) due to dynamic (Munro, 1979; Levhari and Mirman, 1980), market (Dockner et al., 1989; Sumaila, 1999; Datta and Mirman, 1999) and stock (Koenig, 1984; Fischer and Mirman, 1992; Sumaila, 1997b) externalities. This challenge to economically and ecologically viable common pool fisheries was identified as early as the 1950s (Gordon , 1954), even though the idea was better-popularized by Hardin. Economists took up the challenge by analyzing the difference between noncooperative and cooperative management of these shared fish stocks (see Chapter 3), concluding that cooperation could alleviate some of the problems of the overuse of common pool resources as it seeks to find the optimum solution (Munro, 1979; Clark, 1980; Levhari and Mirman, 1980).

In the case of fisheries shared by several fishing nations, a race to the fish fueled by national interests has historically ensued, leading to both biological and economic losses. Some countries recognized the sub-optimal nature of such interactions and formed joint management arrangements to facilitate cooperation and improved fishing strategies. Canada and the United States, for example, formed a joint committee as early as 1923 to improve management of Pacific halibut. The United Nations Convention on the Law of the Sea (United Nations, 1982) admonished fishing states to seek regional or sub-regional organizational groups to improve management of transboundary and straddling stocks. In 1995, the United Nations Fish Stocks Agreement (UNFSA) furthered this sentiment, and formalized these joint arrangements into what are called Regional Fisheries Management Organizations (RFMOs) (UN, 1995).

Among other responsibilities, RFMOs are required to perform the function of agreeing “on participatory rights such as allocations of allowable catch or levels of fishing effort” in internationally-shared fisheries (UN, 1995). And, although the degree to which an allocation program is seen as equitable and effective can have a large impact on all other effectiveness measures of an RFMO, it is often one of the least structured elements of RFMO activities (Lodge et al., 2007). In order for cooperative management to succeed, parties must be confident that they are better off through cooperation than through non-cooperation: known as the individual rationality constraint as described in Chapter 3. The allocation of catches (or other benefits) can largely influence whether or not cooperation is rational.

Issues surrounding the allocation of shared fisheries resources are some of the most challenging in fisheries management (MRAG, 2006; Metzner et al., 2010). While RFMOs have often relied only on biological information, economists have been using the theory of games to derive the conditions under which fishing states sharing a resource would be encouraged to cooperate in management, including how effort or catches should be allocated. Most applied game-theoretic analyses, which usually focus on maximizing economic rent from the shared fishery, have concluded that cooperative agreements between fishing nations bring benefits above and beyond non-cooperative management (Chapter 3). Two of the formidable barriers that impede international cooperative agreements are the new member problem, by which a new country seeks access to the shared resources (Kaitala and Munro, 1997; Munro et al., 2004), and issues related to free-riding, whereby a country not engaging in the cooperative agreement benefits from the conservation measures of compliant countries. Such issues are usually present in fisheries that involve a substantial catch from the high seas, in addition to EEZ catches, such as fisheries for tuna species. Cooperation in such systems is inherently difficult to reach (Pintassilgo, 2003; Pintassilgo et al., 2008).

In this Chapter, I summarize how the current allocation programs for the tuna RFMOs came to be. These results are summarized in Table 4.1. In Section 4.3, I speculate on future considerations for allocation programs, both for new schemes and those schemes that may need to be renegotiated in the near future. The issues present in the management of shared fish stocks are also present in the management of internationally-shared water resources. I therefore draw on various parallels with, and conclusions from, international water agreements. By highlighting current allocation practices, criteria to be considered in the future, and allocation programs present in sharing other natural resources, I propose a way forward for tuna RFMOs with regard to their responsibilities for allocation schemes.

4.2 Allocation by tuna RFMOs

Due to their migratory nature, managing tuna stocks in a cooperative manner is remarkably difficult. Several RFMOs exist to do just that, although according to Cullis-Suzuki and Pauly (2010), they have had variable degrees of success in meeting management objectives, be they catch limits or otherwise. This could be partly due to the lack of quantifiable guiding principles on which RFMOs can draw for their allocation decisions (Lodge et al., 2007). Figure 4.1 shows the RFMOs that are charged with the management of tuna (and tuna-like) species (Lodge et al., 2007).

Most tuna RFMOs currently have some type of catch allocation or apportionment scheme in place. Although RFMO members are under a legal obligation to cooperate as per the UNFSA (UN, 1995), groups have often failed to reach agreement on the allocation of catches, and overages have been common (Lodge et al., 2007). Current allocation schemes fall short in their ability to address the problem of new member allocations, of adequately considering the needs of developing states, and of limiting non-compliance with catch allocations (MRAG, 2006; Lodge et al., 2007).

ICCAT: Atlantic bluefin tuna

The RFMO in charge of Atlantic bluefin is the International Commission for the Conservation of Atlantic Tuna (ICCAT). In the early 1970s, tuna fishing nations in the Atlantic began to worry about overexploitation of Atlantic (northern) bluefin tuna. In 1974, minimum size limits were implemented, but by 1981, it was evident that more drastic conservation measures would be required (Palma, 2010). The United States proposed allowable catches be allocated based on 1970-1974 catch histories, but this was not agreed upon. Further delegations resulted in the TAC being divided among Canada, Japan, and the U.S., with Brazil and Cuba having no catch restrictions. Reportedly, allocations were determined by a combination of historical catches, economic factors, and monitoring needs (Palma, 2010). These initial bluefin delegations paved the way for further TAC allocation schemes to be developed for other North Atlantic species, such as swordfish and albacore tuna. For these latter schemes, instead of catches being explicitly allocated, management instead suggested to set the allowable fishing mortality (Palma, 2010). This resulted in an implicit sharing arrangement. However, problems with uncertainty in mortality estimates and the inability to enforce this measure, meant that catch allocations were eventually favoured. Similar to earlier allocation schemes, sharing was based on historical catches. Pathological underreporting of catches, however, has occurred (Lodge et al., 2007).

Today, ICCAT has developed an extensive set of criteria to inform allocation schemes of individual stocks. The inclusive nature, however, makes consensus difficult, and leaves

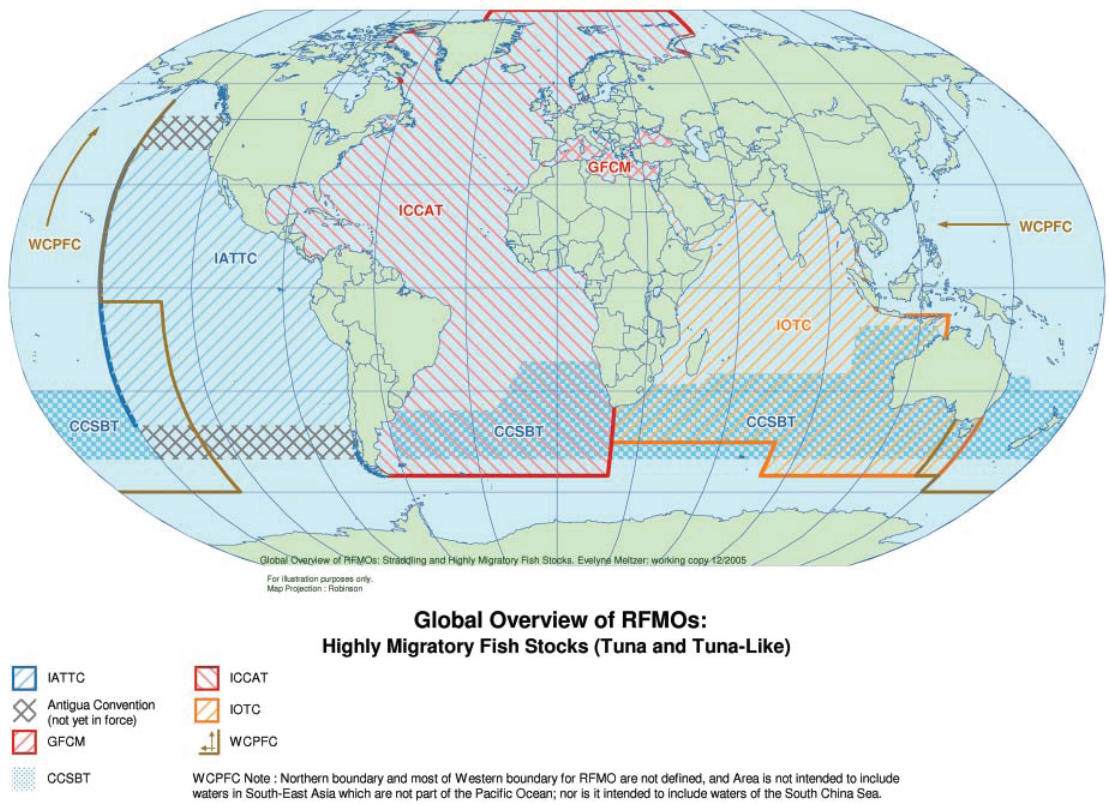

Figure 4.1: Map of tuna RFMOs (Lodge et al., 2007). © Chatham House, used with permission.

room for various concessions and opportunities for ineffective management (Cox, 2009). One of their more questionable allocation criteria is based on aspirations. For example, in 2002, ICCAT allocated 25 tonnes of bluefin tuna to Mexico and various amounts of swordfish to Morocco, Mexico, Barbados, Venezuela and China, among others, because of the aspirations of these countries (MRAG, 2006; Cox, 2009). Unfortunately, such practice resulted in the 2002 allocated TAC for bluefin being significantly higher than the scientifically-recommended TAC (MRAG, 2006). ICCAT outlines the conditions for applying their allocation criteria as follows (Cox, 2009):

1. Applied in a fair and equitable manner;
2. Applied by relevant panels on a stock by stock basis;
3. Applied to all stocks in gradual manner;
4. Takes into account contributions to conservation;

5. Applied consistent with international instruments in a manner to prevent overfishing;
6. Applied so as to not legitimize illegal, unreported and unregulated catches (IUU);
7. Applied in a manner that encourages cooperating non-members to become contracting parties;
8. Applied in a manner that encourages cooperation between developing states;
9. No qualifying participant shall trade or sell allocated quota.

Some of these criteria appear to be at odds with one another. For example, to apply an allocation program to stocks in a gradual manner (3), may in fact not be consistent with preventing overfishing (5). Interestingly, ICCAT does not assign area-specific TAC allocations, rather, allocation of a TAC to a party allows that party to fish throughout the whole convention area (access to foreign EEZs has to be applied for) (MRAG, 2006). This is due to the migratory nature or tuna (and tuna-like species) and is something for other tuna RFMOs to consider. Agreed-upon ICCAT allocations are valid for three years (IOTC, 2011).

WCPFC: Western Pacific tuna

The Western and Central Pacific Fisheries Commission (WCPFC) is the RFMO responsible for tuna management in the western Pacific. The Commission was established under the Convention on the Conservation and Management of the Highly Migratory Fish Stocks of the Western and Central Pacific Ocean in 2000, in an effort to more effectively manage fish stocks in the area. It came into being in 2004, after both UNCLOS and FSA, and thus their guidelines are more considerate of the the issues around straddling stocks management, including issues of allocation. The WCPFC has a strong sub-coalition within its membership through the Nauru Group, made up of Pacific Island Countries (PICs) with plentiful tuna resources within their EEZs. They have had success in bargaining together as a group (Lodge et al., 2007), and influence the development and direction of the WCPFC (Munro et al., 2004).

The WCPFC does not presently allocate specific tuna catches to member states, however, they recognize the future need for such a program, and have therefore developed a list of criteria to consider upon development of an allocation program (MRAG, 2006):

1. Stock status;
2. Past and present fishing patterns and practices of participants, extent to which catch is used for domestic consumption;
3. Historical catch in an area;
4. Needs of small island states with highly fisheries-dependent economies;
5. Contributions by participants to conservation and management;
6. Record of compliance;
7. Needs of coastal communities;
8. EEZ size, with special consideration for states with limited EEZs due to proximity of neighbours;
9. Geographical situations of island states;
10. Fishing interests and aspirations of coastal states.

Although these practical criteria exist, there does not appear to be any indication of how they would be weighted in an effort to calculate and distribute allocations. The sub-coalition mentioned above, the Parties to the Nauru Agreement (PNA), use the vessel day scheme (VDS), which is an effort allocation program. VDS was adopted by the PNA under the Palau Arrangement for the Management of the Western Pacific Purse Seine Fishery (the Palau Arrangement), to regulate purse seine fishing days in the waters of PNA countries. VDS came into effect in December 2007, and was implemented as a way to provide for effective management in the face of declining fish stocks, and in an attempt to improve economic returns by creating a limit on the number of fishing days. Fishing days are allocated to all bilateral fishing partners, and these days are monitored using Vessel Monitoring System (VMS) technology. Effort allocation is based on equal weighting of historical effort levels and the level of estimated biomass in different EEZs (MRAG, 2006).

Work within the WCPFC is ongoing in an effort to develop an allocation approach that will be accepted by its members. A recent analysis outlined four possible allocation schemes for WCPFC tuna (Parris and Lee, 2009):

1. Effort model: calculate allocated shares based on historical effort;
2. Harvest model: calculate relative allocations based on historical harvest data;

3. Biomass model: calculate allocations based on biomass distribution data;

4. Spatial model: calculate relative allocations based on size of EEZs.

Unfortunately, no combination model was analyzed and socio-economic factors were not suitably incorporated. One important element for WCPFC to note, and other RFMOs who are currently contemplating initiation of allocation programs, is that it is easier to meet the needs of members through allocation when the stock status is considered healthy, i.e., prior to overexploitation (Lodge et al., 2007) (or perhaps after rebuilding). In this regard, setting up catch quotas for skipjack, yellowfin and albacore should proceed quickly, as reaching agreement in the future may be harder if conservation measures are not put in force today.

CCSBT: Southern bluefin tuna

Southern bluefin tuna is managed under the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), which came into force in 1994. Prior to the Commission, southern bluefin was managed through a voluntary cooperative agreement between Australia, Japan and New Zealand, but this agreement failed to adequately conserve the resource.[6] Kennedy (1987) developed an applied two-player game of the fishery between Australia and Japan, targeting Southern bluefin. Due to the heterogenous markets for sashimi (Japan) and canned (Australia) products, the optimal outcome in the early 1980s was joint management whereby Australia was totally excluded from the fishery (compensated through side payments) (Kennedy, 1987). In reality, of course, no country was excluded and membership increased instead of decreased. CCSBT was faced with the new member problem when South Korea and Chinese Taipei wanted access to the resource. CCSBT simply increased the total allowable catch for southern bluefin, despite concerns about the health of the stocks (Lodge et al., 2007).

CCSBT originally inherited the allocation scheme that the three founding fishing nations had developed in 1986, but there is no record of how that allocation program was decided upon (MRAG, 2006). In 2005, CCSBT initiated a changing TAC procedure, but this did not change national TAC shares that were initially negotiated in 1986 (MRAG, 2006). However, in 2009, members agreed on a proportional allocation program based on catches and distribution (CCSBT, 2011). Like ICCAT, fishing nations can fish their allocated TAC throughout the convention area (Harwood, 1997). CCSBT is in the process of redefining their national allocation approach, which currently allocates based on proportions of the TAC (CCSBT, 2011). Upon any increase in the calculated TAC, those

[6] $http : //www.ccsbt.org/site/origins_of_the_convention.php$

countries who took voluntary decreases in allocation (New Zealand and Australia) will have the difference in their TAC returned to them, providing a system with some type of incentive for voluntary conservation (CCSBT, 2011). Any decrease in TAC will result in a decrease in national allocation consistent with allocation proportions (CCSBT, 2011). CCSBT allows for nations to carry forward any unused TAC in the subsequent year, however it does not allow for transfers between nations.

IATTC: Eastern Pacific tuna

Tuna and tuna-like species in the eastern Pacific have been managed through the Inter-American Tropical Tuna Commission (IATTC) since 1969. Original allocations were based on historical catches, with disregard for the migratory nature of tuna and stock distribution information (MRAG, 2006). This original program collapsed in the mid 1970s. IATTC has since promoted management measures supplementary to allocations, such as area closures.

IATTC manages its purse seine and longline fisheries differently. The purse seine fishery is managed through capacity (effort) allocations using four main criteria (MRAG, 2006; IATTC, 2007):

1. Catch history of national fleets (1985-1998);
2. Amount of catch taken from zones where nations have jurisdiction;
3. Landings of tuna in each nation;
4. Contribution of each nation to the IATTC conservation program.

The longline fishery is managed through a catch limit program. The benefit to allocating catches instead of capacity is that IATTC found some fleets were manipulating their vessel capacity and this resulted in capacity allocation being ineffective (MRAG, 2006). National catch allocations are based on stock abundance and distribution, as well as historical catches during the 2000-2002 period (MRAG, 2006).

IOTC: Indian Ocean tuna

In 1996, the Indian Ocean Tuna Commission was formed and today, consists of 30 Member states. Its stated objective is to promote cooperation among its Members, and to use appropriate management to encourage the conservation and sustainable use of tuna stocks. A total of sixteen tuna and tuna-like species are managed by the IOTC, including southern bluefin, yellowfin, skipjack and bigeye tuna, among others. Similar to IATTC, IOTC has tried to use restrictions on vessel capacity (through measurement of gross registered tonnage) as their allocation program, however the restrictions are reportedly not binding

(MRAG, 2006). A resolution was passed in 2006 encouraging members to limit their capacity, but allows for much flexibility in meeting capacity targets (MRAG, 2006). IOTC has, however, produced a report documenting allocation approaches by other RFMOs in an attempt to begin their allocation process (Indian Ocean Tuna Commission, 2007). The report documents their struggles with using capacity limits to impact conservation, and discusses the possibility for allocations based on historical catch (Indian Ocean Tuna Commission, 2007).

In 2012, some IOTC Members submitted reports with their suggested allocation approaches in response to IOTC Resoultion 10/01, requiring the adoption of a quota allocation program (or other suitable approach) (Indian Ocean Tuna Commission: Japan, 2012; Indian Ocean Tuna Commission: EU, 2012; Indian Ocean Tuna Commission: Seychelles, 2012). The proposal put forth by the Republic of Seychelles suggests historical catches and catches per area be used as the basis for allocation, but they make note that for some developing coastal states, catch records have not been consistently collected and this could negatively impact their catch allocations (Indian Ocean Tuna Commission: Seychelles, 2012). Thus, the proposal suggests that, where catch records are not of good quality, socio-economic factors be incorporated (Indian Ocean Tuna Commission: Seychelles, 2012). The EU proposal is also firmly attached to the idea that historical catches should form the basis of the allocation program, but it suggests that a percentage of the TAC be put aside to be redistributed to developing coastal states and new members (Indian Ocean Tuna Commission: EU, 2012). Similarly, the third proposal, put forth by Japan, states that allocation should initially be based on historical catches, specifically over the past 10 years (Indian Ocean Tuna Commission: Japan, 2012). These base allocations are subsequently altered using different mathematical relationships, based on criteria such as if the Member has contributed financially to the IOTC, or has had any occurrences of non-compliance (Indian Ocean Tuna Commission: Japan, 2012). These proposals all use catch histories as their basis, but also recognize, in different ways, that this singular criteria is not the most effective and equitable strategy.

4.3 The future of allocation schemes

Table 4.1 summarizes the major tuna RFMOs and their various approaches to allocation programs. The table also includes references to several non-tuna RFMOs. More detailed information about the allocation approaches of these specific RFMOs is included in Appendix B. A recent report analyzed the performance of all RFMOs in meeting best practices criteria in theory (based on written mandates) and in practice (based on stock status reports) (Cullis-Suzuki and Pauly, 2010). These rankings are included in

Table 4.1: Summary of RFMO allocation information

RFMO	Species	Data for allocation	What is allocated	Penalties for non-compliance	Transferability	Ranking (theory, practice)
NAFO (ICNAF)	Groundfish	Stock assessment and historical catch	Catch	Yes	Allowed	52,53
NEAFC	Herring, mackerel, blue whiting	Zonal attachment principle and historical catch	Catch	Yes	Allowed	52,72
ICCAT	Tuna species	Stock assessment, historical catch, bycatch	Catch and effort	Yes	No sale, exchange ok	57,38
CCSBT	Southern bluefin	Stock assessment and historical catch	Catch	Yes	None	44,0
IOTC	Tuna species	Gross registered tonnage (plus historical catch in future)	Effort	Yes	None	58,78
IATTC	Tuna and tuna-like species	Vessel carrying capacity	Catch and effort	Yes	None	60,33
WCPFC	Tuna and tuna-like species	Stock assessments and historical catches, distribution, economic dependence	No current regional allocation, but sub-regional effort program (VDS)	Yes	Currently being discussed	74,67
PSC	Pacific salmon	Historical catch, bilateral negotiations	Percentage of TAC	Unknown	None	43,NA
IPHC	Pacific halibut	Stock abundance and distribution	Catch	Unknown	None	52, 33

Sources: MRAG (2006); Cox (2009); Cullis-Suzuki and Pauly (2010)

Table 4.1 to relate the allocation schemes in place with one measure effective or ineffective management.

The first question to be addressed in developing an allocation approach is what, in fact, is to be allocated. There is an obvious precedent in internationally shared fish stocks management for historical catches (by proportion) to provide the basis for allocation. The assumption here is that a fair way to distribute shares is based on historical participation, with the added benefit of catches being a relatively easily measured and quantified reference (Cox, 2009). The PNA countries (a WCPFC sub-coalition) employ an effort allocation scheme, instead of allocating catches, called the vessel day scheme. But apart from this, allocation schemes for existing RFMOs are based on catch tonnage. Using catch histories is not always the most ecologically-sound method (Caddy, 1996), and gives an incentive for members to block allocation agreements until they have built up their capacity and catches (Lodge et al., 2007). Furthermore, the allocation schemes that have been put in place so far, based on catch histories or abundances, have been unsuccessful in facilitating sustainable fisheries.

It may be time to start reconsidering what is being allocated. Perhaps potential rent can be allocated, or some other benefit. One way to do this would be to try to put different types of benefits into equivalent units. This has been suggested several times with regards to the Pacific Salmon Commission, the RFMO put in place to manage Pacific salmon between Canada and the U.S.. Sockeye are the most valuable of the five Pacific salmon species harvested. It was argued that "sockeye" equivalents could be used so that catches, overages and interceptions are measured in a similar fashion, and could perhaps facilitate trading. This type of relativity would allow the two countries to compare apples to oranges, that is, to put all salmon species in the same currency. Unfortunately, this scheme has never been realized because groups within both countries were unable to agree on a way forward.[7] As discussed later in the paper, some international water allocation agreements have explicitly allowed each interested party to develop their own apples- or oranges-based utility function (Sanderson, 2009).

Currently, no program for internationally-shared tuna stocks is based on revenue or rent allocations. The addition of socio-economic factors into allocation decision-making was argued for as early as 1996 (Caddy, 1996). Several tuna RFMOs have begun using qualitative criteria in assisting with the allocation process, for example economic dependence and domestic consumption. How to explicitly incorporate these into some type of allocation algorithm is a challenging next step. One possible way to incorporate other criteria would be to develop objective functions of resource use for each country and then

[7]Sandy Argue, Argus Bioresources Ltd., personal communication.

test possible allocation schemes in their ability to most closely meet both (all) countries' needs. For example, if employment is an important target, then incorporating a layer of fishery dynamics into allocation modelling could suggest employment outcomes for various schemes. Optimization approaches could be used to calculate the weighting system that best meets nations' objectives. Some possible factors to consider including are: historical catches; species distribution within EEZs; spawning and nursery areas; contribution to habitat and environmental health; contribution to research and monitoring; amount of catch for domestic consumption; and interactions between catch and employment in the fisheries and processing sectors. Currently most RFMOs produce some type of annual report that summarizes stock dynamics, catches, and sometimes effort, for the fishery. Producing an annual report that includes social, environmental and economic assessments of RFMO-managed fisheries, in addition to these biological reports, could help highlight the broader benefits of reaching an optimal sharing agreement (Bjorndal, 2009).

One of the first papers in the literature to start theorizing about the future of allocation schemes suggested an objective framework where national allocations depend on multiple factors which are given different weights by individual parties (Caddy, 1996). One important point to note in developing an allocation criteria based on multiple factors is the fact that for every new factor introduced into the negotiations, the importance of all other factors goes down. For example, if biomass distribution is the sole factor, then only it has importance. However, when economic considerations are entered, the importance of biomass must be less than 1. As per the Caddy (Caddy, 1996) approach, allocation negotiations essentially break down into three parts:

1. What factors are relevant (catch histories, domestic consumption, biomass distribution, employment, etc.)?
2. How do we calculate/measure values for each factor for each interested party?
3. How do we weight the different factors?

One of the drawbacks associated with solely using catch as a way of measuring fleet performance and stock sustainability is that it explicitly ignores human drivers of fishing behaviour and does nothing to illustrate tradeoffs in policy decisions (allocations) with community well-being. This is of course an argument that can be made across many forms of fisheries management and is not at all exclusive to the challenges of internationally-shared stocks, but it is worth mentioning here. Importantly, the incorporation of short-term social, economic and political criteria can also pave the way for opportunities to overexploit and ignore conservation goals (Lane, 2008). Many allocation schemes do utilize penalties for lack of compliance to discourage TAC overages (Cox, 2009). For example, NAFO and CCSBT reduce the quotas in the subsequent year of members who overfish their allocation. If countries cooperate in defining their objectives in participating in the joint fishery (above and beyond catch), that could help in developing some sort of tradeoff matrix. What mix of targets is optimal? What costs and amount of risk are communities and governments willing take to promote economically viable fisheries?

Although no tuna RFMOs have taken seriously the task of developing a multi-criteria allocation algorithm, academic studies have been discussing this issue. One such study involving NAFO fisheries, developed a model linking catches to processing and community livelihoods in Canadian maritime regions, taking into account fleet dynamics of Spanish and Portuguese fisheries (Lane, 2008). The schematic developed, shown in Figure 4.2, displays how the annual catch scenario (or allocation rule) feeds into the socio-economics of the communities (Lane, 2008). In this way, allocations are directly linked with their outcomes to the community at large, and are thus representative of benefits above and beyond catches.

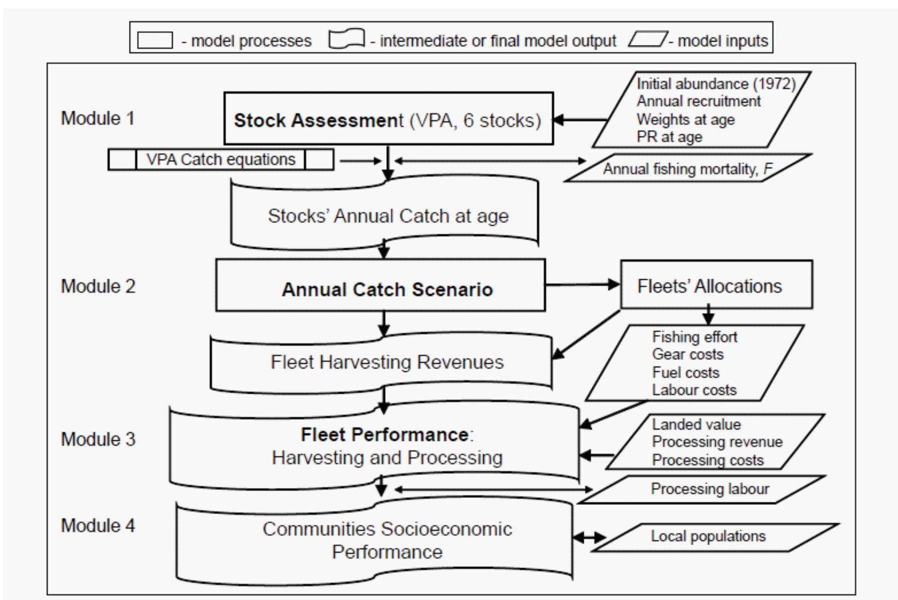

Figure 4.2: Grand Banks fishery model schematic (Lane, 2008). © Journal of Northwest Atlantic Fisheries Science, with permission through Creative Commons Attribution-Non Commercial 2.5 Canada.

Rationality, flexibility and reviews

In order for members to agree on a cooperative management solution, they must be better off in doing so than by continuing in a non-cooperative manner, the so-called rationality assumption. Ensuring equitable distribution is an essential component of an agreement, as agreements perceived as inequitable often lead to non-compliance (Lodge et al., 2007; Cox, 2009). Having flexibility built into the cooperative agreement, often called resilience (Miller and Munro, 2004; Munro, 2008), is of paramount importance to ensure the rationality constraint continues to be met through time.

One of the major impediments to long-term stability of allocation agreements is the new member problem. A stipulation in the UNFSA (Articles 10 and 11) states that any party with genuine interests in a fishery can seek to join the RFMO (and thus have access to the resource) at a later date. How to deal with these new members is something that RFMOs to date have not adequately addressed. Most RFMOs have chosen to accommodate new members by increasing the total allowable catch instead of reallocating from within the catch limits (Lodge et al., 2007). This has been done with disregard to the conservation status of the resource (for example, the case with CCSBT), and thus is at obvious odds with RFMO mandates for conservation.

The scope for bargaining and renegotiation of allocations needs to be widened, and access rights should certainly stop trumping conservation concerns. Both conservation and access are part of RMFO mandates so novel ways of trading them off against each other resulting in the best outcomes are necessary. One possible option would be to put aside part of the total catch allowance, say 5%, for new members. Each year, if no new members have been added to the RFMO, that 5% gets redistributed to existing members, but it should be seen as a bonus, not as a right. An additional, or supplemental, mechanism would be to relax the ban on trading of quota that most RFMOs have in place and allow existing members to lease out or sell part of the allocation to new members (MRAG, 2006; Lodge et al., 2007). If these methods were combined, new members would be afforded initial allocation (from the 5% surplus) with the chance to increase their share through trading.

As discussed in Chapter 3, this was addressed by Pintassilgo and Duarte (2001). The authors explore three possible solutions to deal with new members, including transferable membership, a waiting period, and a fair sharing rule. They point out that in a quota or allocation scheme, transferable memberships in the cooperative group can take on the attributes of individual transferable quotas (Pintassilgo and Duarte, 2001). One way may be to develop a better understanding of how to negotiate the reallocation of property rights to new RFMO entrants in the future, as called for by Bjorndal et al. (2000). Renegotiation of the allocation scheme should take place, and an appeals process should be developed (Caddy, 1996), if one is not already in place. It has been suggested that renegotiation should be considered on a medium to long term basis, for example, every 10 years (MRAG, 2006).

Currently, no RFMO has any type of independent review panel in place to assess suitability of catch allocations (Cox, 2009), even though this can be a useful measure (Caddy, 1996) and has even been outlined in the UNFSA (UN, 1995). NAFO does, however, have an appeals process in place, whereby a contracting party is able to file an objection to any conservation or management measure, along with an explanation for the objective and an alternative policy. This objection can then go to an independent ad-hoc panel, who will make a subsequent recommendation to NAFO. Ad-hoc panels made up of external experts should be a more frequently-used tool.

Anticipated and unanticipated climate shifts can change local fish distributions. If the allocation scheme is fixed and based on fish distributions, such changes can affect the viability of national fisheries and can give participating countries an incentive to deviate from cooperative agreements. For example, climate shifts impacted the stability of the cooperative agreement formed between Canada and the U.S. to manage Pacific salmon (Miller and Munro, 2004). Warming of coastal waters on the west coast of North America in 1977 led to an increase in the abundance of salmon in Alaskan waters, and a sharp decrease in abundance in salmon found in California, Oregon, Washington and southern Canada (Miller and Munro, 2004). The benefits expected by the southern players at the outset of the cooperative agreement did not materialize, and non-cooperative behaviour ensued (Miller and Munro, 2004). One major criticism to the Canada-US Pacific Salmon Treaty was that it did not explicitly include the scope for side payments (Munro, 1990), which would have been a way to compensate the losing party subsequent to any unforeseen shifts in abundance. This retrospective analysis helps to illustrate why resiliency and flexibility in a cooperative agreement is important for stability. This is becoming of increasing importance as climate forecasts coupled with models of fish stock distributions suggests there could be major shifts in terms of future access to shared resources (Cheung et al., 2009).

Efficiency and transferability

Economic efficiency does not seem to play into allocation decisions for any tuna RFMO (Cox, 2009). This is probably because most efficiency gains from allocation programs are seen to derive from some loss in equity (Pinkerton and Edwards, 2009).[8] Ex-vessel prices, fishing costs, and fleet capacity are rarely mentioned in stock assessment reports describing allocation. One argument that has been put forth in the literature is the possibility for

[8] A tradeoff between efficiency and equity does not have to occur. A lack of dialogue between economists and non-economists about efficiency and equity has bred continued confusion about this apparent tradeoff. Economists have continually suggested that side payments be utilized to facilitate cooperation. This is one way that equity could be strengthened, while at the same time improving efficiency.

auctioning quota or allocation shares (Copes and Charles, 2004) to increase efficiency. This has not been taken seriously to date. Given that cooperation must bring benefits above and beyond non-cooperation, the added economic burden of paying for allocation shares could result in non-cooperation being the more economically-sound decision for some states (Cox, 2009). Most RFMOs do not allow trading or selling of quota among participating members. This is inefficient from an economic perspective, however, as transferability allows for the most efficient vessels or nations to harvest fish (Gibbs, 2009). Efficiency gains have been seen through allowing a secondary market for transferring quota (Morgan, 1995), and some RFMOs have recognized the future need for transferability of allocated quota (IATTC, 2007).

The issues around limiting greenhouse gas emissions parallel those around sharing fisheries resources. Allocated quota and trading programs for greenhouse gas emissions were initiated based on setting national targets. A market for international trading has emerged as the primary policy tool to promote efficiency and benefit those who choose to lower their contribution to the problem, although improvements in the system are still being sought. The allocation schemes in place to deal with greenhouse gas emissions have incorporated economic efficiency as a major objective in their design. There will likely be lessons learned about the international quota markets for carbon trading that could help guide the way towards an international trading mechanism for catches or revenues from shared fisheries.

Allocation and shared water agreements

Like the United Nations Convention on the Law of the Sea, the United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses exists to provide a framework for allocating water resources that are shared internationally (United Nations, 1997). The Convention states three main rules that govern the conduct of states who share a watercourse (United Nations, 1997):

1. The watercourse is to be used in an equitable and reasonable manner;
2. States are to take appropriate measures to prevent significant harm to another state;
3. States are to consult with, and provide timely notification to, other states about any possible adverse effects resulting from new policies or a change in policy.

A novel approach to negotiations between states sharing watercourse, called the "Mutual Gains Approach", has been proposed by Grzybowski et al. (2010). The authors outline two possible negotiation scenarios, one in which the *position* of the states is the primary driver of negotiations, and one in which states negotiate based on their *interests*. The conclusions reached suggest that when institutional egos can be left off the bargaining table, mutual gains to all cooperating parties are attainable based on the interests they represent (Grzybowski et al., 2010). The authors draw on historical examples of successful cooperative agreements, writing in length about the Columbia River Basin, a watercourse shared by Canada and the U.S.. One of the more interesting, and important, parts of the Columbia River Treaty, is that the responsibility for calculating the benefits and costs of non-cooperative and cooperative management lies with each individual country (Sanderson, 2009). In this way, each country calculates and communicates what it is likely to gain through cooperation, but these perceived benefits, or utility functions, need not be comparable between states (Sanderson, 2009). Rather, each country lays out what it hopes to get from cooperation, and as long as those hopes are met, cooperation can ensue.

The Columbia Treaty suggests a 50/50 sharing of the benefits of cooperation, but in the event that one party would end up being worse off than through non-cooperation, a renegotiation of the sharing rules takes place (Sanderson, 2009). In a more applied assessment not related to the Columbia, van der Zaag et al. (2002) suggested three alternative allocation algorithms: equal sharing; shared in proportion to each country's area in the water basin; and equal sharing per capita. The authors report that once equitable allocation has been reached, parties should be free to trade or transfer their allocated water amongst themselves (van der Zaag et al., 2002).

In terms of allocation of shared water *within* a nation, historical usage patterns have been a common starting for allocation programs, although this is as much for political reasons as for any other (Cox, 2009). Market-based approaches have been employed in Australia, South Africa, the western states of the U.S. and Chile (Cox, 2009), but it's hard to imagine that these can be at all equitable. A two-tiered approach has, however, reportedly been successful in the U.S. and Australia, whereby some amount of reliability or security of the entitlement is combined with the actual allocated amount (Peterson et al., 2004). In this way, allocations that are highly secure (or can be met 96-99 times out of 100) have priority before general secure allocations are met (those that are to be met 75 times out of 100) (Peterson et al., 2004). Efficiency is achieved through market-based trading allowances. The implications for fisheries would be as follows: one proportion of the TAC is allocated to nations as fixed, with the remaining quota classified as flexible, distributed on an annual basis to members either through auction or some other mechanism (Cox, 2009).

4.4 Conclusion

This study has provided a review of tuna allocation approaches used by groups managing internationally-shared fisheries resources. Many RFMOs have found it a tedious and tiring process to formulate allocation programs that are agreed-upon by all members, or have avoided making explicit allocation decisions all together (Metzner et al., 2010). In most cases, allocation has generally been decided based on historical catches, and more recently, combining historical catches with current biomass distribution trends (MRAG, 2006). Most current programs are based solely on biomass and catch information, without consideration of economic or social factors in allocation decisions. Socio-economic factors can include such items as economic dependency on the fisheries stock, and national economic wealth (Palma, 2010). Incorporating these may offer alternative allocation possibilities that could increase the scope for cooperation in internationally-shared fish stocks management. And although the United Nations Fish Stocks Agreement states that there should be development of transparent allocation criteria (UN, 1995), transparency has not been a priority to date (Lodge et al., 2007).

The "Mutual Gains Approach" (Grzybowski et al., 2010) for shared international watercourses, offers some insights into the future of fisheries management. The authors suggest that the *interests* of nations sharing a resource should be the central tenant that drives negotiations (Grzybowski et al., 2010). This is akin to states moving away from "how much" of the resource they should be allowed to extract, to "what" they hope to gain from participating in a sharing system. Allocation in shared fisheries has invariably been based on a political process (Lodge et al., 2007), something that has not served sustainability well. In the Grzybowski et al. (2010) paper, the authors draw on historical examples of side payments (or negotiation facilitators) in shared watercourses, whereby the party who stands to gain the most through cooperation compensates those parties who may not be better off under cooperation. One of the earliest such schemes was contained within the Treaty of Versailles in 1919 (Carnegie Endowment for International Peace, 1924), one of the post-World War I treaties. Article 358 of the Treaty gives France "the exclusive right to the power derived from works of regulation on the river, subject to the payment to Germany of the value of half the power actually produced" (Carnegie Endowment for International Peace, 1924).

A more relatable example is the 1911 agreement between the the U.S., Russia, Canada and Japan, all of whom targeted fur seals. In the early 1900s, the fur seal population had declined to the point that the economic benefits from the fishery were brought into question. While the U.S. and Russia harvested seals from land, Canada and Japan targeted individuals at sea. To maximize economic returns, all harvesting was to take place from land, essentially removing Canada and Japan from the harvest (Barrett, 2003). All of the catch was taken by the U.S. and Russia, with Canada and Japan compensated, through side payments, with a fixed percentage of the annual sealskins (Barrett, 2003). The need for side payments to factor more heavily in cooperative fisheries schemes is evident today, and has been raised before (Munro, 1979; Lodge et al., 2007; Bailey et al., 2010).

Although Hardin's most memorable contribution to our understanding of the problems associated with shared resources is the idea that self-interest almost always trumps collective interest,[9] he also explored briefly the fact that incommensurable goods could in fact be compared, simply through subjective judgement and a weighting system (Hardin, 1968). In this regard, he was encouraging us to combine different objectives with different measurements in a joint utility function to improve the management of common pool resources. His challenge to the future was to "work out an acceptable theory of weighting" (Hardin, 1968). That challenge needs to be taken up and applied to the ocean commons. Allocation models with multiple weighted criteria would be a good starting point.

Further to this, economic efficiency has not routinely been a component of international allocation schemes. Socio-economics have been largely ignored in allocation formulations in part because, although RFMO members are required to report some biological and catch statistics, there is no requirement to report statistics related to fishing costs, employment, or subsidies. In the very least, developing a bioeconomic allocation approach with which to compare the strictly ecological program currently in place would provide an interesting starting point for dialogue among RFMOs.

Clearly, the allocation programs developed thus far have not provided the right incentive structure to promote sustainable fisheries. Most RFMOs, especially those tasked with managing highly migratory fish like tunas, face problems of illegal, unregulated and unreported fishing (IUU), TAC overages, competing sector interests, and challenges associated with multi-species and multi-gear fisheries, such as juvenile bycatch. Perhaps a de-politicized incentive structure whereby allocations are afforded based on more than just catch histories and abundance estimates is required to address these problems and improve RFMO management of shared fisheries resources.

[9]It has been argued that Hardin had it wrong (Feeny et al., 1996), and that groups could in fact be counted upon to manage shared resources well (Ostrom, 1990). Although it is probably true that Hardin's argument does not always hold its ground, the fact that so many shared resources are mismanaged and overexploited certainly gives credence to his insights.

Chapter 5

Towards better management of Coral Triangle tuna

5.1 Introduction

The western and central Pacific Ocean (WCPO) encompasses over 94 million km^2 (Molony, 2008), and is home to an incredible amount of marine biomass. In 2010, tuna catches from the area provided 59% of the global tuna supply (SPC, 2010), with 2008 catches having an estimated gross value of almost US $5 billion (Williams and Terawasi, 2009). The four main species targeted in the WCPO are albacore (*Thunnus alalunga*), skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*Thunnus obesus*). These four species are highly migratory, resulting in their biomass being present in the exclusive economic zones (EEZs) of many different countries, as well as in the high seas. There are numerous challenges associated with managing these types of resources in a cooperative manner, including asymmetry in national objectives and economic conditions, new members, and the tendency to default to the prisoner's dilemma, among others (Aguero and Gonzalez, 1996; Munro, 1990, 2007; Munro et al., 2004; Bailey et al., 2010). Despite all of the challenges, the need for cooperation among states in managing shared resources is paramount (Chapter 3).

The Coral Triangle (CT) is located in the western part of the WCPO (Figure 1.4); its name resulting from the region's coral reef biodiversity. This area, approximately 5.7 million km^2 in size, spans all or part of the waters of Indonesia, the Philippines, Malaysia, Papua New Guinea, Solomon Islands and Timor Leste. It is considered the world's most biodiverse marine environment (The Nature Conservancy, 2004), and also one of the most threatened, due to population and poverty pressures faced by the communities that depend on its resources (Allen and Werner, 2002). Over 150 million people live in the area, and an estimated 2.25 million fishers depend on marine resources for their livelihood (The Nature Conservancy, 2004).

Although named for its species-rich reefs, it is the Coral Triangle's tuna stocks that are of immense importance to food security and economic production in the region. Tuna fisheries in the CT range from small-scale subsistence and artisanal fishing to large-scale commercial operations. In 2010, about a third of the reported tuna catch in the WCPO was taken by the combined fleets of the Philippines, Indonesia and Papua New Guinea, equating to over 97% of tuna removals by CT countries (SPC, 2010). Tagging studies have demonstrated a high degree of interaction between CT tuna fisheries and those to the east (Vera and Hipolito, 2006; Ingles et al., 2008). The most recent stock assessment for yellowfin reports that the domestic fisheries of the Philippines and Indonesia are in part responsible for stock depletion (Langley et al., 2009b). Despite their regional and global importance, however, few papers have focused on confronting the challenges these countries face with regards to tuna management. Rather, emphasis has primarily been placed on analyzing the challenges that the small Pacific Island Countries (PICs) face in obtaining adequate rents from their fisheries, for example Bertignac et al. (2000), Gillett et al. (2001), Parris and Grafton (2006), Petersen (2006), Campling et al. (2007) and Walmsley et al. (2007). Reporting on the status and management challenges of CT fisheries will fill this information gap, improve tuna management in the CT, and hopefully facilitate better management in the WCPO as a whole.

5.2 Coral Triangle tuna

Tuna species

Skipjack, yellowfin and bigeye are the three main tuna species targeted in the Coral Triangle, with skipjack making up almost 75% of the catch by weight (SPC, 2010). Skipjack are often caught by attracting the schools using either drifting or anchored fish aggregating devices (FADs), and then collected with a purse seine or by handline. The skipjack stock in the WCPO is thought to be underexploited (Majkowski, 2007), with the fisheries considered sustainable (Langley and Hampton, 2008). Skipjack catch is primarily sent to canneries, either exported to Thailand, or processed directly in the Philippines, Indonesia or Papua New Guinea. Some skipjack is smoked, or processed into 'ham', for domestic consumption. Table 5.1 summarizes the main CT tuna species fished.

The biological diversity of the CT, along with the shelter of the archipelagic region, make this area prime nursery habitat for juvenile yellowfin and bigeye. These small juveniles are often captured as bycatch in the skipjack fishery, due to their association with skipjack stocks around FADs, and subsequently sent to canneries. Juvenile fish make up a high percentage of the standing stock biomass for all three species in CT waters, especially in the Philippines (Vera and Hipolito, 2006). As adults, yellowfin and bigeye are targeted by U.S., European (Spain, Portugal, etc.) and Asian (Taiwan, Japan, Korea etc.) longlin-

Table 5.1: Summary of main tuna species fished in the Coral Triangle, along with the gears used, markets supplied and status of the stocks.

Species	Age	Gears	Markets	Stock status
Skipjack	Adult	Purse seine, pole and line	Canned, domestic	Underexploited
Yellowfin	Juvenile	Purse seine (bycatch)	Canned, domestic	Fully exploited
	Adult	Purse seine, handline, longline, pole and line	Sashimi, steaks, loins	
Bigeye	Juvenile	Purse seine (bycatch)	Canned, domestic	Overfishing occurring
	Adult	Handline, longline, pole and line	Sashimi	

ers, as well as by domestic fisheries in Pacific Island Countries. Juvenile bycatch reduces the possible catch to these other fishing groups due to growth overfishing (see Chapter 6). This results in a conflict of interest between purse seine fisheries in the CT, who would prefer to exploit juveniles now, with longline fisheries outside the CT, who would benefit from reduced juvenile bycatch (Bailey et al., In press; Sumaila and Bailey, 2011; Hanich, 2012). Stock assessments report that yellowfin are fully exploited (Langley et al., 2009b), and that there has been significant depletion of yellowfin in the WCPO due to fishing "by the domestic fisheries of the Philippines and Indonesia and the combined purse seine fishery" (Hampton, 2002c). Yellowfin mature at about one and a half to two years of age, however, juvenile yellowfin are encountered in commercial fisheries in the Philippines and eastern Indonesia when they are only a few months old (Langley et al., 2007).

Bigeye purse seine catch is almost exclusively juveniles, and because bigeye is often misidentified as yellowfin in its juvenile years, catch estimates are significantly underestimated (Lawson, 2008a; Reid et al., 2003; Lawson, 2007). As illustrated in Figure 5.1, there has been a rapid increase in purse seine catches of bigeye since the early 1980s, mostly due to the increased use of FADs (Hampton, 2002a; Langley et al., 2009a). Currently, stock assessments indicate that overfishing is occurring on the bigeye population (Harley et al., 2010) (Table 5.1).

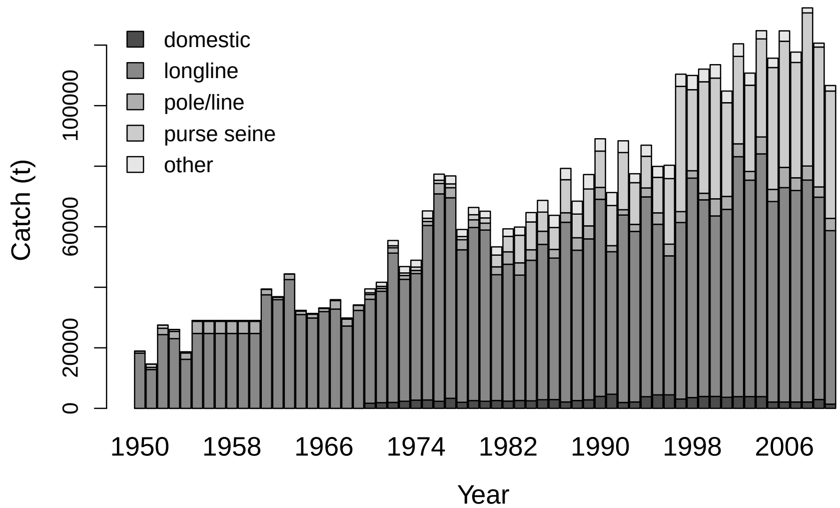

Figure 5.1: Total bigeye catch by gear, compiled from SPC (2010).

Tuna management

Tuna stocks in the region are managed by the Western and Central Pacific Fisheries Commission (WCPFC), a regional fisheries management organization (RFMO). Figure 5.2 shows the statistical area of the WCPFC (solid straight lines), which, at the time of writing, has 25 participating members. Both the Philippines and Papua New Guinea are members, while Indonesia is considered a cooperating non-member. The Commission is a multi-lateral regime that includes PICs, large coastal states, and distant water fishing nations (DWFNs), and has been viewed as an impressive achievement (Parris and Grafton, 2006). The WCPFC received the highest ranking in a recent analysis scoring 18 different RFMOs against best-practices criteria (Cullis-Suzuki and Pauly, 2010). As sustainability issues with regional bigeye and yellowfin fisheries are abundant, however, there is still much room for improvement (Langley et al., 2009c; Cullis-Suzuki and Pauly, 2010; Hanich, 2012).

The Secretariat of the Pacific Community (SPC) is another international organization in the area that represents about 8 million people in 22 PICs (Figure 5.2). The SPC has been in existence, in one form or another, for about 60 years, and works to provide technical and policy advice, along with training and research services to PICs. The SPC deals with a variety of issues relevant to its members, including health, human development, agriculture, forestry and fisheries, and contributes substantially to the scientific program of the WCPFC. Of the three countries highlighted in this Chapter, only Papua New Guinea

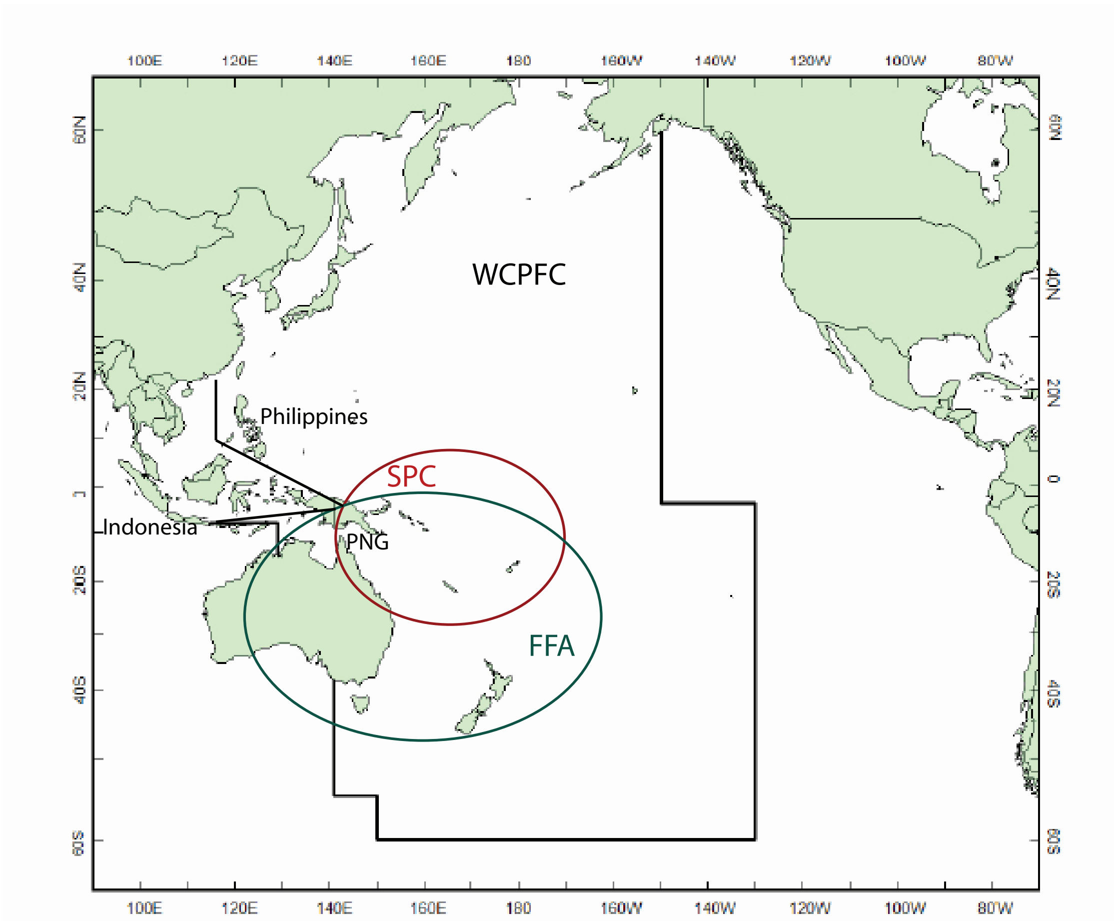

Figure 5.2: Map of the statistical area of the Western and Central Pacific Fisheries Commission (© WCPFC, used with permission), shown by solid lines, and regional coverage of SPC (small circle) and FFA (large circle).

is a member of the SPC (Figure 5.2).

Finally, the Forum Fisheries Agency (FFA) is a third player in the region. The FFA has 17 members, mostly PICs, but members also include Australia and New Zealand (Figure 5.2). It is essentially a coalition of countries with interest in Pacific tuna stocks. The FFA works to help facilitate effective management of tuna by its member countries through the sharing of information and expertise. Indonesia and the Philippines are not members.

Given the existence of these three organizations, it would seem fair to conclude that tuna management in the WCPO is well-institutionalized. In reality, however, availability of information and data in the region, particularly in the Coral Triangle, is limited, and subsequently, the validity of scientific assessments is compromised. This then results in the WCPFC having difficulty setting informed management recommendations, let alone having those recommendations followed. That being said, it is argued here that affiliation with these regional organizations can lead to better management.

5.3 Indonesia

Indonesia is the world's largest archipelagic nation, comprised of about 17,000 islands. It also has one of the most biodiverse and productive marine areas (Tomascik et al., 1997), making fisheries an important sector economically and culturally, and also in terms of food security. Indonesia catches more tuna in its waters than any other country in the world (Ingles et al., 2008). In 2006, Indonesian fishery exports totalled US $2.1 billion, 12% of which were tuna and tuna products, mostly fresh or frozen (Ministry of Marine Affairs and Fisheries, 2007). About 44% of all Indonesian tuna exports go to Japan, and about 27% go to the USA (Ministry of Marine Affairs and Fisheries, 2007). The current availability of information regarding tuna fishing and fisheries in Indonesia falls short of the information available for neighbouring countries. Catch and effort statistics have not been consistently reported, leading to regional uncertainty in stock assessment reports. The most recent year of catch data reported by the WCPFC for Indonesia's distant water purse seine fleet is 1989. At the time of writing, Indonesia is not a full member of the WCPFC.

Tuna fisheries

Indonesian fishers employ a variety of gears to harvest tuna. A pole and line skipjack fishery has existed in Indonesia since at least the 1940s (Ishida et al., 1994). A major expansion began in 1977, with catches of yellowfin and bigeye (collectively reported as "tunas") increasing at an average of 10.6% per year, from 1977, to 1989 (Ishida et al., 1994). The majority of tuna fishing gears used in Indonesia also target other pelagic species and these include Danish and purse seines, four varieties of gillnets, troll and simple handlines. Tuna longlines and tuna handlines are the only two gear types that specifically target large tunas (yellowfin and bigeye) in Indonesia (Ingles et al., 2008). All gears apparently fish only within Indonesian waters, as catch statistics available from the WCPFC suggest that there were no distant water fisheries after 1990 (Lawson, 2008b). However, some Indonesian handliners catch and offload their tuna in the Philippines (Ingles et al., 2008), and it is unclear how these catches are reported.

Purse seine

In Indonesia, the use of purse seines to catch tuna and other pelagic fish began in the 1960s. After trawling was banned in much of the country, many trawl vessels were converted to seine operations, which resulted in three times the amount of purse seines operating between 1976 and 1983 (Ingles et al., 2008). This exemplifies what is likely to happen when well-intended policies are not broadly considered. Small- and medium-sized purse seine fleets catch tuna seasonally, often targeting other small pelagic species throughout the year. There is also a fleet of large purse seine vessels ($>$ 100 gross registered tonnes, GRT) that works in tandem with several catcher, carrier, skiff and light boats to operate. This fleet uses about 20-30 FADs per catcher vessel, and is not authorized to operate in archipelagic waters, but vessels often violate this law, leading to higher juvenile catches (Ingles et al., 2008).

Longline

The Indonesian longline sector originated in the 1980s, when the ban on trawling, combined with a government loan scheme (subsidy), created an ideal situation for the development and expansion of a tuna longline fleet (Ishida et al., 1994). Recently, the longline fishery in Indonesia has decreased in terms of its importance in the fisheries sector, which can be attributed to a decline in the availability of bait fish, as well as increasing fuel costs (Ingles et al., 2008). Effort has shifted to smaller-scale fishing gears, such as troll and tuna handline, which can provide high quality fish to the ever-growing sashimi market at a lower cost (Ingles et al., 2008).

Processing

The hygienic conditions of the landing facilities in Indonesia are far below international standards (Ingles et al., 2008). This, along with poor post-harvest handling practices, generally results in a lower-quality product going to market, and means that Indonesia is unable to supply to those markets willing to pay for high-quality fish. The government has, however, initiated plans to increase and improve the processing sector in an effort to facilitate all tuna caught in their EEZ to be landed and processed directly (Anon., 2007). The new regulations, scheduled to take place in December of 2011, will require all foreign fleets fishing in Indonesian waters to comply (PNA and U.S. News Agency / Asian, 2011). If this plan is to be successful, Indonesia is going to have to improve its processing facilities to remain competitive in the global market. Requiring landed fish to be processed domestically will not only increase activity of the processing sector, but should lead to better catch accounting, as currently tuna caught in the Indonesian EEZ but transhipped elsewhere are not always reported. Possibly due to this underreporting of catches, managers seem to believe that some of their tuna fisheries are underexploited, and are thus increasing their joint-venture relationships with foreign fleet owners (Anon., 2007).

Management measures and challenges

In 2004, the Indonesian government enacted Fisheries Act No. 31, resulting in the management of tuna fisheries being segmented into 9 Fisheries Management Areas (FMA), overseen by the Ministry of Marine Affairs and Fisheries (MMAF). In 2009, the number of FMAs was increased to 11 by Ministerial Decree No. 1/2009 (Anon., 2009). FMAs refer to a particular body of water or fishing area, and are thus based on ecological boundaries, not political ones. Although this is relevant from a fisheries point of view, it can make management difficult. Often times several provincial and regency governments must cooperate in one FMA, or one province or district may have to participate in the management of various FMAs. These recent changes make analyzing trends over time difficult because catch statistics, now collected according to FMA, cannot easily be compared to statistics reported prior to institutional re-organization.

The 2009 Ministerial Decree committed Indonesia to implementing a vessel monitoring system (VMS) (Anon., 2009), even though the government issued a similar decree in 2003 which did not lead to any changes (Directorate General of Catch Fishery, 2003). The year 2009 also saw Indonesia ratify the UN Fish Stocks Agreement (Anon., 2009). Indonesia's prior refusal to ratify the Agreement was seen as a major barrier to international conservation efforts. As previously stated, tagging studies have shown a high degree of mixing between tuna found in Indonesia, and those found in the Indian Ocean, and further east in the WCPO (Ingles et al., 2008). Tuna management in Indonesia, therefore, greatly affects tuna fisheries in other countries.

Indonesia does not have effective regulations to limit the size of tuna removed from its waters (Ingles et al., 2008). They do, however, issue licenses that can technically be revoked if fishers are caught fishing in areas for which they are not licensed, and for misreporting their catches (Anon., 2008b). New laws and regulations introduced in the mid 2000s to combat illegal, unreported and unregulated (IUU) fishing allow Indonesia to meet its international obligations for fisheries management on paper (Agoes, 2005). However, they fall drastically short in actually promoting conservation, in part because enforcement is so weak.

Subsidies

Since the late 1960s, the Indonesian government has been encouraging development of its tuna fleet for export-oriented markets (Ishida et al., 1994). The country currently uses subsidies to promote several different parts of their fishing sector. For example, trollers in the Ambon region (FMA-V Banda Sea) have received free boats and motors to enter the fishery (Ingles et al., 2008). The government also provides fishers with materials free of charge to build FADs, thus exacerbating the issues of juvenile bycatch (see below) (Ingles et al., 2008). Furthermore, investments in the processing sector, funded in part by joint-ventures, is also a type of subsidy, which may encourage more fishing than is currently profitable. The MMAF has stated that the country will strive to be the world's biggest producer of fish, with the goal of increasing its fisheries sector by 300% by 2012 The Jakarta Post (2009). Government-driven fisheries expansion almost always involves subsidies. In 2003, the Indonesian government was estimated to have provided harmful subsidies amounting to almost US $800 million (Sumaila et al., 2010).

Data

One of the major challenges of fisheries management in Indonesia arises from the grouping of landed fish into categories useful for trade or for sale, not according to biology. For example, the category for landed 'tuna' includes both bigeye and yellowfin tuna, and could also include southern bluefin, albacore and long tail tuna (Ingles et al., 2008). Similarly, the 'skipjack' category probably includes juvenile yellowfin and bigeye tuna because they are sold together (Ingles et al., 2008). This problem was recognized as early as 1994 (Ishida et al., 1994), but species identification seems to vary within FMA, often due to local language differences. Discrepancies in the tuna species found in abundance at the market, with those recorded as the catch, have been noted (Ingles et al., 2008). In 2004, the national fisheries statistics system began recording catches by species, but this change was not uniformly made in all FMAs. Catch statistics prior to 2004 may not be particularly accurate, and thus the country does not have accurate catch statistics from which to draw management recommendations.

The WCPFC reports that a total of 182,476 tonnes of skipjack were caught by Indonesia in 2004 (Lawson, 2008b), however, based on MMAF data, fisher interviews and independent port sampling, it was reported that as much as 288,353 tonnes were caught (Ingles et al., 2008). Similarly, the WCPFC reports that officially 52,042 and 31,160 tonnes of yellowfin and bigeye were caught, respectively (Lawson, 2008b), while Ingles et al. (2008) report that the combined landings for these two species was 237,753 tonnes in 2004. A study initiated in eastern Indonesia (Papua province) also found substantial under-reporting of tuna catches, with the authors stating reduced taxes as the major economic incentive driving under-reporting (Varkey et al., 2010). Reported catch figures for 2009 were 210,590 t of skipjack, 94,141 t of yellowfin and 11,568 t of bigeye (SPC, 2009). The WCPFC is apparently working with grossly underestimated catches, leading to management difficulty on a regional scale (ACIAR, 2003). These removals should thus be reformulated to incorporate better catch estimates. Development of data collection and reporting 'standard operating procedures' would go a long way in improving the fisheries statistics system in Indonesia. Indonesia and the Philippines have developed a joint data collection program that is a good start to improving Indonesia's data system.

FADs and juvenile bycatch

Of the nine FMAs visited by Ingles et al. (2008), the authors found evidence of FAD fishing in all of them, with some (FMAs 6 and 7) having extensive FAD use for multiple gears. The government's choice to actively subsidize the construction of FADs is worrisome. The increased use of FADs in Indonesia, in part due to these subsidies and the rising cost of fuel, has resulted in increased catches of juvenile yellowfin and bigeye by the purse seine fleet, with these species now making up between 18% and 90% of the total catch weight Ingles et al. (2008). If there are spatial and seasonal differences in these percentages, then it might be worthwhile to limit FAD use during those times, or in those areas, where juvenile bycatch is the highest. Unfortunately, this will most likely result in short term losses for fishers, and require substantial monitoring and enforcement resources.

5.4 Philippines

As an island nation with an EEZ of about 2.2 million km^2, the Philippines is a country highly-dependent on fisheries resources (Barut and Garvilles, 2005). Fisheries contribute about 4% to the country's Gross Domestic Product (GDP), with tuna fisheries comprising about 20% of marine fisheries production (Barut and Garvilles, 2005). Commercial tuna

Table 5.2: Summary of Indonesia's tuna fisheries and management.

Fisheries	Purse seine, longline, handline, gillnet, pole and line, small seines, troll
Processing	Below industry standards, but economically important
Challenges	Unregulated FADs, juvenile bycatch (making up 18-90% of purse seine catch by weight), under-reporting, directed subsidies for FADs, inconsistent data collection
Management measures	No size limits, no FADs plan, no unified data collection program, some closed areas

fisheries initially developed in the Philippines during Japanese occupation in the early 1940s (Vera and Hipolito, 2006), where catches were supplied to the local market (Barut and Garvilles, 2005), or delivered to smoking plants for the Japanese market (called 'katsuobushi'). As catches started to decrease in the Philippine EEZ, and as American and Japanese demand for tuna increased, effort moved into the waters of Indonesia, Papua New Guinea and the high seas (Barut and Garvilles, 2005). Philippine fisheries now supply to both domestic and foreign markets.

Capture fisheries are divided into two main sectors: municipal and commercial. Tuna vessels are usually classified as commercial because fishing occurs outside of municipal waters, using vessels larger than 3 GRT (Vera and Hipolito, 2006). Census data from 2002 estimated that the fisheries sector employed almost 1.8 million municipal fishers and about 8,000 commercial fishers[10] (Vera and Hipolito, 2006).

Tuna fisheries

The Philippines domestic fleets caught about 266,600 t in 2009 (SPC, 2009). Gillnets were used in Philippine tuna fisheries until 1997, and today, purse seines, ringnet, longline and handlines are all used. Lower-value fish, like skipjack or smaller yellowfin, are generally consumed domestically, or sent to the canneries, whereas higher-value fish, such as adult yellowfin and bigeye, are destined for the frozen loin or sashimi market. The main gears used include purse seine and longline, both considered commercial gears, and handline, considered a municipal gear. Because of this designation, handline vessels are not required to report their catches outside of Philippine waters, even though they also fish in Indonesia, Palau, Papua New Guinea and the high seas (Vera and Hipolito, 2006). The only vessels allowed to fish in Philippine waters are those flagged to the country. However, in 1995

[10] To avoid double counting, any fisher engaging in both municipal and commercial fishing was counted as only a municipal fisher, and thus commercial fisher numbers are most likely underestimated.

as much as 10,000 t of tuna, 40% of which was yellowfin, were caught by longline vessels illegally fishing in Philippine waters (Barut and Garvilles, 2005)

Purse seine

The domestic and distant water purse seine fleets target mostly skipjack and some adult yellowfin, but also catch juvenile yellowfin and bigeye. Skipjack caught in purse seines average 27-35 cm in length, with juvenile tunas being around 15-50 cm, and, although the proportions vary by season, the domestic purse seine tuna catch is generally composed of about 60-70% skipjack, 20-30% yellowfin, and 10% bigeye[11]. In 1995, as much as 90% of purse seine catch from commercial fishers in the area of Mindanao (in the southeastern region of the country, where much of the tuna catch is landed) was found to be less than 12 months of age (Aprieto, 1995). The use of FADs has only increased since then, so it is probably safe to assume that juvenile catch composition is not any better today. Purse seiners fish throughout Philippine waters, and the waters of Indonesia, Papua New Guinea and the high seas. An area of water between the Philippines and Indonesia is disputed territory that both countries claim as their own, but it is recognized internationally as Indonesian waters. This catch is treated as 'domestic' by the Philippines. There was evidence that large catches by Philippine fleets in these waters has adversely affected smaller-scale tuna operations in northern Indonesia (Naamin et al., 1995). About 60% of purse seine-caught tuna goes directly to the cannery for processing (Vera and Hipolito, 2006).

We spoke with TSP Industries, a company owning a sizeable fleet of small, medium and large purse seine vessels, about their operations. The following lists some generalities:

- For small- and medium-sized vessels, labour is paid via profit sharing. The boat owner finances the boat, while the master fisher hires the crew. Fishers continue fishing until they have reached the point where their catch volume is enough to cover costs. The owner takes 50% of the gross revenue, and the fishers split the remaining 50%, which could be considered the cost of labour;

- TSP has 20-30 large purse seine vessel groups that spend their time catching fish in waters of the high seas and Papua New Guinea; one 'group' consists of one catcher boat, 2 carriers with ice, and 3-4 light boats, and employs 70-80 crew members;

- About 70% of the vessels are active at any given time, but require dry-docking every 2 years;

[11] Glennville Castrence, NSAP, personal communication.

- Six to seven years ago, larger vessels faced operating costs of US $400/t and they were selling fish for US $550-600/t. In late 2008, costs were about US $1,200/t, while the ex-vessel price was around US $1,625/t. Profitability has therefore increased about twofold;
- TSP uses about 30 FADs per catcher vessel, 90% of which are anchored. Each FAD costs about US $3-4,000, and lasts 6-12 months;
- The initial cost to using FADs is more than compensated for by the saving on fuel costs (especially following the elimination of fuel subsidies);
- Costs are made up of 50% fuel, 14% labour, 18% maintenance, 8% FADs, 4% each to insurance and corruption (such as pilferage at sea), and 2% overhead;
- TSP expects on average 4,000 t of tuna to be caught per catcher vessel per year.

Handline

Handline fishers are the primary Philippine producers of high-grade sashimi fish. They target adult skipjack, yellowfin and bigeye, as well as other species. There are two classifications of handlines: the *palaran* vessel, which is confined to municipal waters, and the *pamariles*, which can venture into deep Philippine and international waters (Vera and Hipolito, 2006), fishing as far away as Palau. Although there is uncertainty around the numbers, an estimated three to four thousand handline vessels, probably employing about ten times as many fishers, are active in the Philippines (Vera and Hipolito, 2006). Municipal handline fishers are opportunistic, in that they catch a large variety of species, depending on what is abundant at the time of fishing. On average, a *palaran* fisher catches about four tuna per week (Vera and Hipolito, 2006). The quality of the fish is of primary importance, and as such, industry and government began discussing a possible subsidy that would help handline fishers on very small vessels, with limited space for ice, maintain a fresh product by providing refrigeration vessels in municipal waters (Vera and Hipolito, 2006). Further to this, World Wide Fund for Nature Philippines has helped facilitate a public-private partnership aimed at promoting handline-caught yellowfin tuna as a more sustainable food choice for consumers[12].

Pamariles fishers target only tuna. A mother-boat will carry auxiliary vessels and head out to fish on anchored FADs, known as *payaos*. Handline-caught tuna, although often fished with FADs, is usually adult-sized therefore the problems of juvenile bycatch

[12] http://wwf.panda.org/?199811/Small-scale-fishers-in-the-Coral-Triangle-get-big-break-in-global-market

associated with fishing on FADs are less relevant in the *pamariles* fishery. Most FADs in Philippine waters are owned by purse seiners, but handliners are allowed to fish on these FADs given that the purse seine fleet has fishing priority. Furthermore, allowing handliners to fish on FADs can give purse seine owners a good idea of the possible catch composition of the school aggregating around the *payao*. A new handlining mother-boat costs between about US $10-30,000, while used ones are sold for about half of that (Vera and Hipolito, 2006). Operational considerations such as labour can cost up to US $1,900 per fishing trip (Vera and Hipolito, 2006). Profit sharing is employed, with fishers getting a percentage of the value of their catch, which amounts to about US $95 - $150 on average per month for a *pamariles* fisher (Vera and Hipolito, 2006).

Longline

The Philippine distant water longline fleet targets adult yellowfin and bigeye in the waters of Papua New Guinea and the high seas. The catch is exclusively landed in the city of Davao, in the province of Mindanao. Landed catch includes Philippine-caught tuna, and catch taken by other countries (mostly Japanese, Taiwanese and Korean vessels) in and around Philippine waters. There is a high degree of vertical integration in this sector - with industries owning both fleets and processing plants.

Far East Seafood, Inc., shared information about the structure of their longline operations. The following are their generalities:

- Trips last about 20 days, with vessels fishing about 200 miles from the shore;
- Average vessel catches about 12-15 tonnes of tuna per trip, the majority of which is yellowfin;
- Nine workers are employed on one vessel, eight of whom take home about US $250 per trip, with the captain receiving about US $2,000 (unless he is Japanese, then he will earn up to US $5,000);
- Fuel accounts for about 50% of the operating costs, with a longline vessel using about 2,000 litres per trip;
- Vessels are, almost without exception, second-hand, costing about US $500,000. Vessels are dry-docked for one year (every couple of years), at a cost of about US $10,000;
- The longline catch is composed of about 30% Grade B (commanding about US$3.25/kg), 45% Grade A (commanding about US$6/kg), and 25% Highest Quality fish (commanding about US$7.50/kg).

Processing

The catch value, itself substantial, is only part of the economic benefit that tuna fisheries provide to the Philippines. There is a large value-added sector for tuna products, with about 80% of all tuna caught in the Philippines going to the cannery to be processed domestically[13]. General Santos City, in the southern part of the province of South Cotabato, is a city founded on the cannery business. In fact, the City hosts an annual 'Tuna Festival' to promote its industry. Philippine purse seine vessels and Indonesian handline vessels land their catch here. For the Indonesian fishers, this port is closer for them, based on where they fish, and therefore is a more economical landing site. Compared to Indonesia, the Philippine cannery sector is also more economically efficient. In Indonesia, 3,000 workers, on average, are needed to can every 150 tonnes of tuna, whereas 1,500 are required in the Philippines. This is, in part, due to more holidays and shorter work days in Indonesia to facilitate daily prayers and religious holidays. The average daily wage in the Philippines is US $6.32, compared to US $2.20 in Indonesia (Anon., 2010).

The port in General Santos City is managed by the Fisheries Development Authority (FDA, see below). There are about 30,000 direct cannery jobs, and an estimated 100,000 indirect jobs provided by the canning sector. Consequently, there is concern here about the implications that management may have on catch levels, and thus supply and processing[14]. Both locally-caught and imported tuna is processed here. The tuna is generally bought at a lower price by the canneries, then sold at a higher price once canned. As such, although the Philippines is a net importer of fish, the total trade earning is positive, an estimated US $445 million in 2003 (Vera and Hipolito, 2006). The Philippines is currently working on internal reforms so that the processing sector better-meets EU health and safety standards.

In addition to the large canning industry, some of the domestic skipjack and yellowfin catch is smoked, dried, salted, or processed into sausages and ham (Barut and Garvilles, 2005). Larger yellowfin are often sold as fresh or frozen loins, or exported as lower-grade sashimi.

Management measures and challenges

Two national laws provide the fisheries policy framework in the Philippines: the Fisheries Code of 1998, and the Agriculture and Fisheries Modernization Act of 1997 (Vera and Hipolito, 2006). The Fisheries Code outlines policies regarding the development and utilization of fisheries resources, which include measures to control commercial fishing in

[13]Benjamin Tobias, BFAR, personal communication.
[14]Miguel Lamberte, FDA, personal communication.

municipal waters, managing fisheries with regard to maximum sustainable yield (MSY), implementation of user fees, gear regulations, such as limiting the use of active fishing gears in municipal waters, and policies toward decentralization of fisheries management (Vera and Hipolito, 2006). Interestingly, the 1997 Act is focused on modernizing the fisheries sector, and thus sometimes promotes development-based measures that are in direct conflict with the more conservation-based measures promoted by the Fisheries Code of 1998 (Vera and Hipolito, 2006).

There are several different organizations overseeing tuna management in the Philippines. The Bureau of Fisheries and Aquatic Resources (BFAR; www.bfar.gov.ph) is the highest federal entity in charge of fisheries management. BFAR tuna management functions include: monitoring and review of international fishing agreements; authorization of Philippine vessels fishing in international waters; regulation of transhipped products; and enforcement of fisheries laws and rules, except in municipal waters.

Licenses are required to fish and are good for three years. The annual revenue from all fisheries licenses is quite low, about 1-3 million Pesos (US $6,000 - $18,000) in 2006 and 2007 [15]. Licensing is given locally for fishing in municipal waters, or federally for fishing access in national waters. The municipal licenses are inexpensive, and often granted to commercial vessels through bribery. In total, about 1.3 billion Pesos (US $7.8 million) are spent on fisheries management annually in the Philippines, with about 500 million (US $3 million) of those being directed to tuna management[16].

In addition to BFAR at the federal level, there is also the National Stock Assessment Program (NSAP). NSAP provides observers at port to take length and age samples of landed fish and its scientists are responsible for conducting stock assessments for domestic fisheries. NSAP has currently entered into a joint agreement with Indonesia called the Indonesia-Philippine Data Collection Project (IPDCP), which is aimed at improving reported catch statistics from the two countries (NFRDI, 2008). Although the Philippines has its own system for management of domestic tuna fisheries, it also participates in management through its membership in the WCPFC. In 2008, the Philippines paid about US $83,000 to the WCPFC as part of its membership obligations, and in return for this, received US $150,000 for management (primarily for data collection and tagging programs)[17].

Overseeing of the fishing ports is done by the Fisheries Development Authority (FDA). Throughout the Philippines there are 12 FDA government ports. Some of these have been built with subsidies from Japan. The FDA is currently working on improving product

[15]Augusto Natividad, BFAR, personal communication.
[16]Benjamin Tobias, BFAR, personal communication.
[17]Benjamin Tobias, BFAR, personal communication.

quality and implementing measures to improve traceability, both in order to facilitate better market access. The Bureau of Statistics does its own port sampling, and interviews fishers and dockside observers. The FDA port in General Santos City, home to the country's canning industry, has invited the private sector to invest in an on-site testing laboratory to check histamine levels in the fish. Histamine is a byproduct of bacterial action and can build up in the muscle tissue of fish if it is not kept at near-frozen temperatures. When consumed by humans, it can cause histamine poisoning, the symptoms of which mimic allergic reactions or other types of food poisoning.

Industry is very much involved in tuna management in the Philippines. The National Tuna Industry Council (NTIC) is a coalition of actors, including academic, industry (purse seine and handline producers), non-government and government members. NTIC deals with trade and access issues, and reviews recommended management. The industry representatives serve as liaisons in an effort to ensure that the interests of industry are accounted for in management decision-making, and to help the industry as a whole cope with those decisions.

Mesh size

The Philippines has put into law a 3.5 inch minimum mesh size requirement for net fisheries (Table 5.3), however, many vessels still use 1 inch meshes for three reasons. Firstly, many fishers in the Philippines use second-hand nets because they are cheaper. They buy these from Japan and Taiwan, where stronger enforcement of measures in place for minimum mesh size requirements mean fishers there can no longer use their 1 inch meshes. And secondly, for Philippine companies who can afford to purchase new nets, they often have to be custom-ordered, sometimes taking more than 2 years to arrive. The third, more perverse, reason is due to demand. Many people rely on fish as a main source of protein, but most residents can only afford cheaper fish, which often means small juveniles. Consequently, there is high domestic demand for juvenile tuna sold at the markets. To this end, the government has issued fish rulers to people frequenting fish markets to discourage them from buying juvenile fish. The Philippines has instituted a management measure reportedly setting 10% as the maximum proportion of the catch that can be made up of small tunas (under 500 g) (Anon., 2008a). For yellowfin and bigeye, however, fish of this size are still juvenile. A proposed "net amnesty" program would allow fishers to trade in their smaller meshed nets in exchange for regulations size mesh.

Subsidies

The Philippines used to subsidize fuel for fishers, but currently domestic fishers pay the full cost of about $1/litre. Commercial distant water fleets (fishing outside the Philippine EEZ), however, can avoid paying federal fuel tax by requesting direct importation of fuel. The removal of fuel subsidies and the increase in fuel prices in early 2008 had two major ramifications. Firstly, fishing effort and landings decreased in the Philippines, and elsewhere in the world. Skipjack catch was down an estimated 60%, and Philippine canneries were seeing an overall decrease in supply by about 50-300 t/day[18]. The global supply of tuna decreased and thus the price skyrocketed, with skipjack prices reaching almost $2,000/t (Williams and Terawasi, 2009). Secondly, fishers who were able to fish, used their gear closer to shore where more juvenile fish are found. The removal of fuel subsidies therefore contributed to an increase in the by-catch of juvenile fish. Any policy reform is likely to alter fisher behaviour in ways other than originally intended by the reform. Subsequent enforcement, for example in not allowing purse seines to operate in juvenile tuna habitat, should have been in place to help mitigate undesirable consequences. In 2003, the Philippine government was estimated to have provided harmful subsidies amounting to US $610 million (Sumaila et al., 2010). Their joint-venture relationship with Japan for landing and processing fish, for example, is a form of subsidy.

Juvenile catch

The catching of juvenile yellowfin and bigeye tuna is recognized by both government and industry as a sustainability issue. Juvenile by-catch in the Philippines tends to involve very young and small fish, for example, bigeye and yellowfin of about 15 cm in length. In Indonesia, juvenile's are also caught, but they tend to be a bit larger, 20-30 cm in length. In Papua New Guinea, as the tuna have started migrating out of the Coral Triangle area, those caught in purse seines are larger, about 50+ cm in length, but still juvenile. This makes it difficult to enact sweeping management recommendations regarding juvenile by-catch by the WCPFC, because the catch varies so much between countries, and management measures would adversely affect some countries more than others. In the Philippines, juvenile by-catch is highest in coastal waters, with oceanic waters having a smaller catch proportion of juveniles.

A recent summary of NSAP data concluded that 100% of the yellowfin and bigeye captured by purse seines in Philippine archipelagic waters were juveniles (Ingles and Pet-Soede, 2010). In 2009, this resulted in a total of over 61,000 t of juvenile fish, of all three species combined, being removed from the ecosystem (Ingles et al., 2008). The use of

[18] Bayani Fredeluces, NTIC, personal communication.

FADs in Philippine waters should be monitored, if not controlled. FADs tend to decrease the costs (particularly fuel) associated with fishing, and thus can lead to both overfishing and an overcapitalized fishery. Up to 150 FADs are currently being used per purse seine vessel in the Philippines[19]. Many individuals in government and industry thought that a limit of about 25-30 FADs per catcher vessel might be reasonable. Effective enforcement of such a limit is obviously a substantial subsequent issue, however, making fishers register and be accountable for their FADs, may help regulators. One way to do this would be to require documentation on FADs, as suggested by the WCPFC (2009).

Table 5.3: Summary of the Philippine's tuna fisheries and management.

Fisheries	Purse seine, longline, handline, ringnet
Processing	Very important economically, undergoing improvements to secure EU accessibility, more efficient than Indonesia
Challenges	Unregulated FADs, juvenile bycatch (averaging 15-50 cm in length), subsidies, ineffective controls
Management measures	Mesh size limits (3.5 inch, but ineffective), no FADs plan, juvenile catch limits (10% by weight)

5.5 Papua New Guinea

Papua New Guinea (PNG), home to about 6 million people, shares its land mass with the province of Papua, Indonesia. The PNG EEZ is about 2.4 million km^2, and borders the EEZs of Australia, Solomon Islands, Indonesia and Federated States of Micronesia (FSM). The major fisheries in PNG include tuna, prawns, sea cucumber (or bêche-de-mer), lobster, trochus shells and shark. PNG is one of the Parties to the Nauru Agreement (PNA), along with Palau, FSM, Marshall Islands, Nauru, Kiribati, Tuvalu and Solomon Islands. The PNA formed a coalition specifically to facilitate multi-lateral cooperation in regional purse seining. In February of 2010, they undertook measures to have skipjack tuna eco-certified as sustainable by the Marine Stewardship Council (MSC). Their request specifies that only tuna caught by purse seines setting on free schools (that is, without the use of FADs or any floating object) in PNA country EEZs should be considered for certification (Marine Stewardship Council, 2010). After going through the MSC appeals process, the fishery was officially declared MSC-certified in December, 2011. .

[19]Benjamin Tobias, BFAR, personal communication.

Tuna fisheries

The tuna fisheries of PNG are the fishing sector's biggest and most valuable. The tuna sector includes domestic longline, handline, pole and line (although the WCPFC (Lawson, 2008b) only reports pole and line catches up 1985) and purse seine fleets, as well as a locally-based foreign purse seine fleet, and a foreign access purse seine fleet. Of 194 licensed vessels in 2008, 9 were PNG-flagged, 30 were locally-based foreign vessels, and the other 155 were foreign access distant water fishing vessels. Over 80% of the landed catch is skipjack, with about 20% being yellowfin and less than 1% bigeye. Figure 5.3 shows the catch trends for Papua New Guinea's fisheries over the past 40 years. Since the late 1990s, the country has seen a major increase in catches of all species, due mostly to the increased use of purse seines.

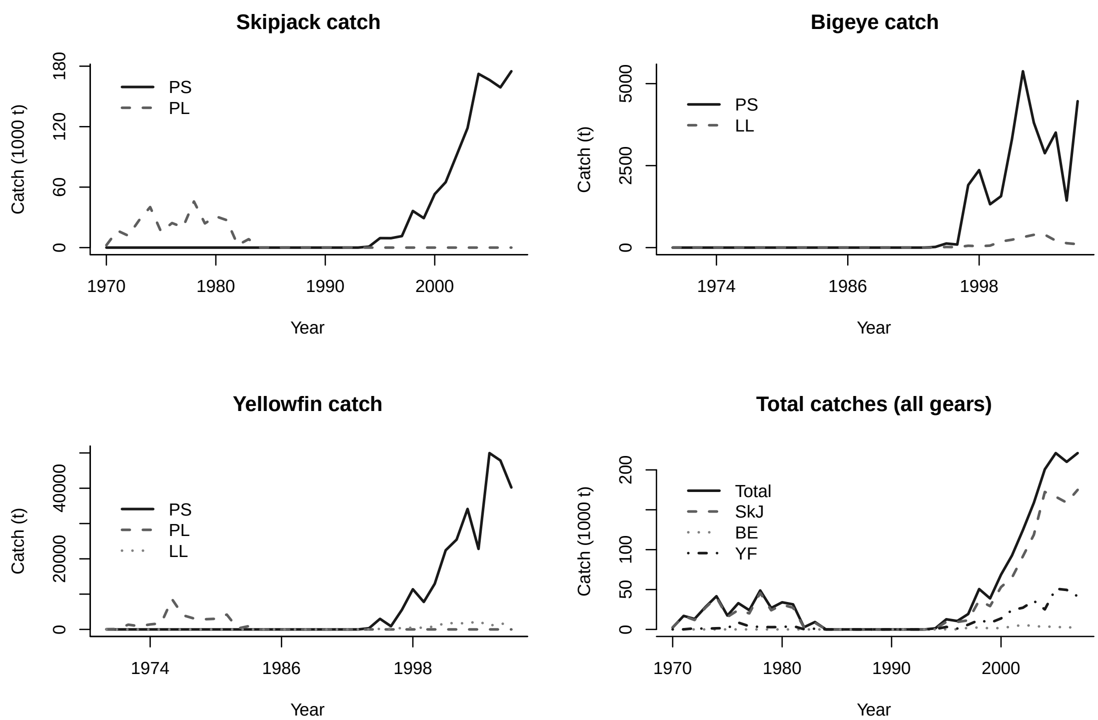

Figure 5.3: Papau New Guinea catch trends, compiled from SPC (2009). PS: purse seine; PL: pole and line; LL: longline; HL: handline.

Processing

The importance of the processing sector is also factored into national policy decisions. PNG has many processing plants in place now, and plans further development. When the European Union, PNG's major tuna export destination, required that imported tuna meet certain food safety standards, PNG undertook measures to be designated a Seafood Competent Authority. Competency for PNG was awarded as a result of the availability of legal instruments empowering the development and implementation of the PNG Standards for Fish and Fishery Products. Furthermore, the system allows for continuous updates on compliance of EU food laws by the National Fisheries Authority, in terms of sanitary control processes, and procedures based on risk application and monitoring mechanisms, such as official controls and laboratory services. The agreement with the EU allows for duty free status of all tuna processed in PNG, and exported to the EU (essentially, a subsidy).

Management measures and challenges

The fisheries sector is governed and regulated by two federal initiatives: the Fisheries Management Act of 1998 and the Fisheries Management Regulation of 2000. These initiatives specifically mandate that PNG fisheries resources be managed in a sustainable and equitable way for current and future generations. Under the 1998 Act, the National Fisheries Authority (NFA) is responsible for the management and development of the fisheries sector, under the overall policy direction from the Minister for Fisheries.

Tuna fisheries are managed under the National Tuna Management Plan (NTMP), which guides PNG policy. The Plan, adopted in 1999, is based on the precautionary approach and recognizes the responsibilities of PNG given the regional management environment (i.e., WCPFC, FFA, and SPC). Even though customary tenure of land is common in PNG, the government has employed a predominantly top-down approach toward fisheries management. The national program is founded on the basic principle that as the national fishing industry grows, the number of purse seine vessels under foreign access will be reduced, a process called domestication.

PNG has taken several regulatory measures to improve management of its tuna stocks. The longline fleet was fully domesticated in 1995, giving the government better management control over that sector. The NTMP has included control measures such as number of licenses; setting of the total allowable catch (TAC); control of fishing effort (i.e., number of boats/day, fishing days); season closures; species length/weight limits; gear type limits; and delineated fishing areas/zones. PNG has also instituted what they call "in-zone measures", essentially spatial controls within their EEZ. These include: closure of the Morgado Square in the Bismark Sea; archipelagic waters closed to non-domestic fleets; territorial waters closed to purse seining (12 miles); all waters south of 5 degrees latitude closed to FADs; inshore waters closed to longlines (6 miles); and currently in process of closing 50 nautical mile corridor along northern border of PNG and Indonesia to all forms of fishing.

In addition to national policies, PNG has also linked their management to several regional arrangements. They are members of the WCPFC, and as such, have taken initiatives encouraged by the Commission to monitor and control FADs. PNG has also adopted the FFA coordinated observer programs, the Niue Treaty, coordinated aerial surveillance, and the Palau Arrangement, which initiated the use of the vessel day scheme. Participation in, and compliance with, regional agreements has greatly facilitated effective tuna management in PNG. Over the past decade, Papua New Guinea has seen improvements in its catch and effort data collection, in part due to the use of the vessel monitoring scheme (VMS), the vessel day scheme (VDS, see below) and pockets of the high seas closed to fishing. PNG's management measures are summarized in Table 5.4

Pacific Marine Industrial Zone

PNG is considering the development of a Pacific Marine Industrial Zone (PMIZ). The Zone would be located on the Vidar Plantation, Madang. It would comprise of 860 hectars across the North Coast Road, and is in close proximity to fishing grounds, thus making it easier for fishing companies to offload their catch at a competitive cost. PNG is also hoping the Zone will increase the level of fishing participation by PNA countries, thus decreasing their reliance on foreign access fees. Furthermore, given the duty-free status of all tuna processed in PNG and exported to the EU, PNA countries would thus have another incentive to process their fish in the Industrial Zone. Currently, the PNG government has allocated about US $7 million to facilitate the project start-up.

That the PMIZ is a good thing for Papua New Guinea is not necessarily agreed upon, however. One newspaper article alleged that some residents of Madang do not support the project (Schenk and Simon, 2009). The article goes on to report that the US $300 million plan to build 10 new processing factories will negatively impact local fishers due to closures in the adjacent waters (Schenk and Simon, 2009).

Vessel Day Scheme

The vessel day scheme (VDS) was adopted by the PNA under the Palau Arrangement for the Management of the Western Pacific Purse Seine Fishery (the Palau Arrangement), to regulate purse seine fishing days in the waters of PNA countries. VDS came into effect in December 2007, and was implemented as a way to provide for effective management in the face of declining fish stocks, and in an attempt to improve economic returns by creating a limit on the number of fishing days. PNG allocates fishing days to all bilateral fishing partners, and monitors these controls using Vessel Monitoring System (VMS) technology.

In this way, the government receives real time data relating to vessel position and utilization of allocated fishing days. Furthermore, vessels can provide their catch declaration electronically.

FADs

PNG also has a very ambitious FAD management plan: of the three countries discussed in this Chapter, they are, in fact, the only one to explicitly include a FAD management plan in their national policy (WCPFC, 2009). The NTMP limits the number of FADs allowed per fisher vessel and includes guidelines on the deployment of FADs. Further to this, they have set an overall limit of 1,000 total allowable FADs in their EEZ (WCPFC, 2009). PNG also requires that the date and position of FAD deployment be recorded, and that an observer must be present at deployment (WCPFC, 2009).

Monitoring, control and surveillance

PNG operates several monitoring, control and surveillance (MCS) initiatives to enforce their regulatory measures. The first is the vessel monitoring system, VMS, which is operated on both a national scale by PNG, and on a regional scale by the FFA. The system monitors the operations of all licensed vessels operating within PNG waters, and as mentioned earlier, the national system helps to implement VDS. An observer program is also in place, and with 127 observers, is the largest in the region. Recent initiatives in the PNA countries have included closures to all tuna fishing in pockets of the high seas from 20^o North and 20^o South of the equator and 100% observer coverage on board purse seines has resulted in lower bigeye catches of up to 20%, as well as a reduction in illegal and unreported catches. Vessels are audited randomly to check with compliance, as are processing facilities. Processing facilities also have to meet certification standards regarding food safety. In 2002, PNG began utilizing four Defence Force patrol boats. These naval crafts participate in ten trips per year, undertaking surveillance along the EEZ border. The management measures and MCS of PNG are linked to regional arrangements under the FFA and the Palau Arrangement.

5.6 Regional options

Tuna fisheries in the Coral Triangle provide food and income security to Indonesia, the Philippines and Papau New Guinea. These fisheries also substantially contribute to the world supply of tuna. As described above, both Indonesia and the Philippines face challenges in managing their transboundary tuna stocks. Table 5.5 presents a summary of

Table 5.4: Summary of Papua New Guinea's tuna fisheries and management.

Fisheries	Purse seine (FADs-free fishery MSC-certified), longline, pole and line
Processing	Important, plans to expand, opportunities for PICs to use facilities, designated Seafood Competent Authority
Challenges	Some juvenile bycatch, subsidies
Management measures	FADs plan, VDS and VMS used, length/weight limits, seasonal closures

the 2009 reported catches for each CT country analyzed here, the types of management systems that are currently in place, and subsidy estimates for the 2003 year. The major management challenges that Indonesia and the Philippines have to overcome are in their data collection and reporting capacity, and their ability to reduce juvenile bycatch of yellowfin and bigeye tuna through FADs management and size/retention controls. The Philippines has two major tuna landing ports, one for purse seine-caught tuna and one for longline- and handline-caught tuna, allowing for better data handling. Both countries, however, could greatly improve their management regimes and their enforcement programs. Papua New Guinea has a unique opportunity to help facilitate better CT tuna management as they are strategically located between Indonesia and the Philippines, and the Pacific Island community.

In paying membership dues to the WCPFC, the Philippines receives more in financial assistance than they put in. Data collection and handling in Indonesia is unacceptable for such a major player in regional tuna fisheries. If financial limitations are deterring the government from improving their collection and analyzing capacity, then Indonesia would do well to join the WCPFC to, at the very least, receive financial help in this context. The joint data collection system between Indonesia and the Philippines is a good start, but the WCPFC needs better access to Indonesian data to improve stock assessments and management recommendations. Given the obvious under-reporting of tuna catches in Indonesia, the government's goal to increase their fisheries sector production by 300% is quite worrisome.

Juvenile bycatch

Both the Philippines and Papua New Guinea have some type of size limit recommendation in their management of tuna. The effectiveness of this in the Philippines has yet to be seen. Weakly enforced mesh limits, if any, and ineffective size controls, result in juvenile yellowfin and bigeye tuna continuingly being captured as bycatch in the Coral Triangle purse seine

Table 5.5: Summary of 2008 catches (SPC, 2009), presence (P) and absence (A) of management measures, EEZ size (*Sea Around Us* Project (seaaroundus.org)) and 2003 subsidies (Sumaila et al., 2010)) in Indonesia, the Philippines and Papua New Guinea.

Summary statistics	Indonesia	Philippines	Papua New Guinea
Regional memberships	None	WCPFC	WCPFC, SPC, FAA
Size of EEZ (million km^2)	3.61	2.27	2.40
Skipjack catch (1,000 t)	211	179	169
Yellowfin catch (1,000 t)	94.1	81.5	45.6
Bigeye catch (1,000 t)	11.6	6.3	6.6
Percentage of total WCPFC catch	13.6	11.4	9.5
Management measures			
Catch limits	A	A	A
Effort limits	A	A	P
FADs plan	A	A	P
Closures	A	A	P
Mesh size limits	A	P	P
Length limits	A	A	P
Harmful subsidies (million USD)	790	610	427
Harmful subsidies (% of Landed value)	40	32	28

fishery. Further to this, Papua New Guinea is the only country to institute both closures and a FADs management plan. On a regional scale, the WCPFC is initiating a FAD management and monitoring plan, recommending the marking and electronic monitoring of FADs, and limits to the number of FADs deployed and set on (WCPFC, 2009). This should probably encourage the Philippines to hasten their pace at instituting such a policy. As a cooperating non-member, it is hard to say if Indonesia, on the other hand, will be so encouraged.

That Indonesia and the Philppines have dragged their feet in implementing a FADs policy is unacceptable both biologically and economically. Juvenile bycatch, highest in archipelagic waters, leads to growth overfishing whereby fish are harvested before they are able to reach a size that results in the maximum yield per recruit. This results in economic waste because the larger fish are more valuable at port. The current recommendations do nothing to counter this, and set up a system that continues to rob tuna-fishing nations of future economic returns from adult harvests, not to mention the ecosystem consequences. The FFA and the SPC include Papua New Guinea, but do not promote observer programs in Indonesia and the Philippines, where juvenile bycatch is high. Being able to monitor and control effort is nearly impossible without some idea of FAD distribution and use. At the very least, VMS should be enabled on board all medium and large tuna vessels. Biological control measures such as gear restrictions, minimum size limits and seasonal/temporal closures should be implemented and enforced to discourage growth overfishing of yellowfin and bigeye stocks. The WCPFC has recommended a 30% decrease in fishing mortality on bigeye tuna (from 2001-2004 levels), and limiting the fishing mortality on yellowfin to its 2001-2004 level (Hampton and Harley, 2009). However, decreases in fishing mortality in archipelagic waters are apparently not required, even though this is where the majority of tuna catches from Indonesia, the Philippines, and to a lesser extent, Papua New Guinea, are concentrated (Hampton and Harley, 2009). Recommended decreases in mortality of bigeye will probably not be met because of this, among other limitations (Hampton and Harley, 2009).

Interestingly, due to the decrease in fuel required for fishing with FADs, purse seining in general was found to have a lower carbon footprint than other forms of tuna fishing (Tyedmers and Parker, 2012), and thus there may be increasing pressure to continue fishing with these aides in an attempt to reduce the carbon footprint of the industry. An interesting idea proposed in the Philippines was to turn FADs into ‘FEDs’ - fish enhancing devices. These would be safe havens for the fish. Although it is unclear how such a plan may alter the natural migratory patterns of the tuna, if drifting FADs were turned into FEDs, they could almost be thought of as mobile marine protected areas.

Economic measures

Papua New Guinea currently subscribes to the vessel day scheme (VDS), as initiated by the PNA. This is a type of effort quota system, that is expected to eliminate some of the competitive nature of shared fisheries. The entire Philippine industry expects that they will soon have to participate in this scheme (Barut and Garvilles, 2005). Philippine distant water fleets operating in the waters of Papua New Guinea are already required to participate. Estimates of fishing effort in both Indonesia and the Philippines are uncertain. Implementing VDS would at least give both countries a better idea of exactly who is operating in their waters, and how many fishing days are being utilized. Limiting effort in order to control catches and capacity would be an obvious next step.

Licensing fees are probably an under-utilized economic tool in the Coral Triangle region. No doubt for the large commercial operations in Indonesia and the Philippines, paying for the privilege of harvesting a public resource should be required. The costs of managing a migratory resource like tuna are large, and those costs need to be shared by parties benefiting from the fishery. Given that purse seine fishers are experiencing increased profits margins in recent years, increased licence fees could be used to improve management in both Indonesia and the Philippines.

All three countries highly subsidize their fisheries, although it is not known at this time, what proportion of those subsidies goes directly to tuna fisheries. Tackling the subsidy problem could be a very good first economic step to promoting more sustainable fisheries (Sumaila et al., 2010). Although the elimination of fuel subsidies is often noted as a conservation initiative (Sumaila et al., 2008), industry in the Philippines acknowledges that the rise in fuel prices increased their dependence on FADs. Removal of fuel subsidies without subsequent economic incentives or enforcement of management regulations may thus be detrimental to stocks. For example, if elimination of fuel subsidies results in higher costs to offshore fishers, then secondary measures need to be in place to ensure that the fleet does not start fishing in inshore waters.

The utility of market-based instruments in promoting conservation is on the rise. The desire of the PNA countries to seek MSC-certification speaks to the industry's growing awareness that retailers and consumers can shift demand. New market-based instruments, such as consumer awareness campaigns and sustainable processor and retailer sourcing, can serve to pull the industry towards more ecologically conscious behaviour. Coupled with a push from top-down improvement in data collection, monitoring, enforcement, and spatial closures, the western Pacific tuna industry could evolve into being a benchmark of sustainability for other tuna RFMOs (Pala, 2011).

Conclusion

In order to adequately manage tuna in the western Pacific, a group of highly migratory species, we first need an understanding of life history parameters, distribution and migratory patterns, and the ecological relationship between tuna and other organisms aggregating around FADs. Research is currently being conducted to meet these needs. That being said, there are some simple first steps that the Philippines and especially Indonesia should be encouraged to take to improve regional tuna management regardless of what is not yet fully understood. Better data collection and management and simple gear and size restrictions would be a good start. Because the decisions in these countries have an impact on the potential for tuna fisheries in other countries, the WCPFC community needs to cooperate in facilitating these improvements by the Coral Triangle region. PNG's involvement in other regional groups, such as the FFA and the SPC may be one reason that they have been more successful in meeting management challenges.

Although closed areas, gear restrictions and effort limits (including VDS) may not be completely adequate to correct the biological and economic problems that mis-managed fisheries can create (Joseph et al., 2010), these measures are simple first steps that Indonesia and the Philippines, who have valuable fisheries, should implement. A third of all tuna caught in the WCPO comes from the Coral Triangle, and thus management actions, or lack thereof, in this region impact the fisheries potential for other nations in the region. If these fisheries are to continue being of economic and social value to communities in the Coral Triangle and elsewhere, all members of the WCPFC should facilitate some kind of benefits sharing system, a 'tuna trust fund' of sorts (Bailey and Sumaila, 2008a), so that all fisheries could share in the possible economic gains from decreasing the bycatch of juvenile fish (see Chapter 6 for a general discussion). This possibility of cooperation has been theorized (Kaitala and Munro, 1993, 1997), quantified (Bertignac et al., 2000; Bailey et al., In press; Campbell et al., 2010), and summarized (Munro, 2008; Bailey et al., 2010) in the literature. Actually implementing such a system on the ground will be vital to encourage Indonesia and the Philippines to contribute to more effective tuna management in region.

Chapter 6

Can cooperative management of tuna fisheries in the western Pacific solve the growth overfishing problem?

6.1 Introduction

The western and central Pacific Ocean (WCPO) is home to many species of commercially targeted fish, the most profitable of which are tuna. About 2.4 million tonnes of tuna were caught in the WCPO in 2007 (Williams and Reid, 2007), accounting for about 54% of the world's tuna supply (Lawson, 2008b). There are four main species found in the WCPO: albacore (*Thunnus alalunga*), skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*Thunnus obesus*). The latter three species, which are mainly found between 10 degrees north and south of the equator, are often found in association with one another, especially around floating objects known as fish aggregating devices (FADs). This association leads to the bycatch of juvenile yellowfin and bigeye tuna in the purse seine fishery primarily targeting skipjack and adult yellowfin. The term bycatch has been defined several different ways (Hall, 1996), but for the purposes of this paper, bycatch is considered to be any species caught, whether retained or not, that is not the main target of the fishery. The catching of juvenile fish of a target species can lead to growth overfishing, and can thus lead to a decline in the resource of interest (Gjertsen et al., 2010). In this context, bycatch of juvenile tuna in the WCPO tuna fisheries has been discussed in recent stock assessments and technical reports (Langley et al., 2007, 2009a; Williams and Reid, 2007; Kumoru et al., 2009; Harley et al., 2010), and the possible decrease in economic rent resulting from this has been analyzed (Campbell, 2000).

Juvenile bycatch of bigeye and yellowfin tuna is generally higher in the western part of the WCPO, such as in the waters around the Philippines, Indonesia and Papua New

Guinea, in an area known as the Coral Triangle[20]. As juvenile tuna grow, they tend to migrate east, resulting in smaller amounts of juvenile bycatch in the waters of the Pacific Island States, and in the high seas (i.e., tuna fisheries in this area catch larger fish). It has been shown through tagging studies that there is a high degree of interaction between tuna fisheries in the western part of the WCPO with fisheries in the more eastern parts of the WCPO (Vera and Hipolito, 2006; Ingles et al., 2008). A recent study initiated in Papua New Guinea suggests that the mean size of bigeye tuna caught in the purse seine fishery has declined in recent years, with the majority of harvested fish being between about 39 and 64 cm in length (Kumoru et al., 2009), even though bigeye mature at about 100 cm in length (Molony, 2008). It is believed that the introduction of drifting FADs in 1996 has increased the amount of bigeye bycatch in the purse seine fishery (Williams and Reid, 2007). Growth overfishing of bigeye, and probably yellowfin, is occurring, and stock depletion of these species has been linked, in part, to juvenile bycatch. Other types of fishing mortality are also thought to contribute to depletion. If left in the ocean, those yellowfin and bigeye who do not die of natural mortality could mature and spawn, supporting productivity of the stocks. Furthermore, the adults could be targeted by longline and handline fishers, whose catch commands a much higher price than that paid for juvenile fish. There is thus a conflict of interest between purse seine fishers in the Coral Triangle and longline and handline fishers targeting adult yellowfin and bigeye. It is important to ask then, could cooperative management of tuna fisheries in this region reduce the economic losses due to growth overfishing?

This question is addressed through the development of a bioeconomic game-theoretic equilibrium model. I examine the potential catches and values of the purse seine, longline and handline fisheries in the WCPO resulting from three alternative management scenarios: (1) the status quo, (2) a regulated FAD plan, and (3) the total elimination of FAD fishing and no juvenile tuna bycatch. All values are calculated at equilibrium, and thus answer the question: what is the best achievable outcome in equilibrium. The status quo assumes that business as usual continues, with purse seine vessels still fishing on FADs with little or no regulation. The regulated FAD plan assumes that national governments institute some sort of management scheme that limits the use of FADs, either seasonally or spatially. Given that sustainability concerns for WCPO tuna stem, in part, from FADs fishing, our third scenario examines the equilibrium solution to the game where there is no fishing on FADs, and thus we assume no juvenile bycatch. We are interested in how the final outcomes could create the necessary incentives to encourage change.

[20] The Coral Triangle encompasses part or all of the waters in Philippines, Indonesia, Malaysia, Papua New Guinea, Solomon Islands and Timor Leste.

Fishing gears and fisheries

Various gears are used to fish tuna in the WCPO. These include several artisanal gears, such as gillnet, hook and line and ring net, as well as commercial gears, including purse seine, longline and handline. There is also a pole and line fishery in the region, but it accounts for only 3%, 6% and 3% of bigeye, skipjack and yellowfin catch, respectively (SPC, 2009). As such, in this paper we are concerned with the three main commercial fisheries. Table 6.1 reviews the stock status and main fisheries for each of the three species of interest in this study.

Purse seine

The purse seine fishery developed rapidly in the 1970s and 1980s. This was due to improved technology, as well as expanded foreign fleets from Korea, Japan and Taiwan. Furthermore, declining market demand for tuna caught in the eastern Pacific Ocean, where dolphin bycatch can be high, along with changing access due to extended jurisdiction, resulted in fleets moving to the western Pacific. Purse seine vessels from both domestic and distant water fleets target both skipjack and adult yellowfin, and they fish with or without FADs. The term FAD is a catch-all word ranging from simple floating objects, such as a log or a coconut, to high-tech devices capable of transmitting sonar information via satellite. Recent research suggests that the fishery is moving in that direction - increasing their capacity through increased technological innovation (Guillotreau et al., 2011). Tuna and other pelagic fish naturally aggregate around floating objects in the open ocean and the use of FADs greatly increases efficiency of purse seine fishing. Smaller pelagic feed fish gather at the FAD (or are released), which attracts skipjack schools, as well as juvenile yellowfin and bigeye. FADs reduce the fuel costs of fishing, which can be as high as 50% of operating costs[21]. In the western parts of the WCPO, most FADs are anchored, that is, they are placed in a fixed area and remain there. It the eastern parts of the WCPO, most FADs are drifting, that is, they are deployed and drift with the ocean's currents. From a management standpoint, it would seem easier to regulate anchored FADs because their position is known. But in reality, anchored FADs are generally associated with higher levels of juvenile bycatch and are thus more of a management concern.

In 2008, there were 1,200 active purse seine vessels in the WCPO tuna fishery (Williams and Terawasi, 2009). About 220 of these were distant water vessels from Japan, Korea, Chinese-Taipei, the US, and from the domestic fisheries of the Pacific Island Countries, while over 1,000 vessels reportedly fished from the Japanese coastal fishery, and from Indonesia and the Philippines (Williams and Terawasi, 2009). In 2008, an overall effort

[21] Dexter Teng, TSP Industries, personal communication.

of about 58,000 fishing days was reported (Williams and Terawasi, 2009), but this is aggregating all days searching and fishing for tuna, regardless of the vessel size or power. The percentage of total logged purse seine sets using FADs has increased in the past few years, from 21% in 2006 and 2007 to 32% in 2008 (WCPFC, 2009). These numbers do not include purse seine sets in Indonesia and the Philippines, which are mostly set on anchored FADs. In the Philippines, it has been suggested that there are over 100 FADs in operation for each catcher vessel,[22] while Papua New Guinea has instituted a limit of 30 FADs per catcher vessel for any fleet operating in its waters (WCPFC, 2009). A study of FAD use by the Korean purse seine fleet reported fork lengths for bigeye and yellowfin tuna of 30-52 cm and 28-132 cm, respectively, for FAD purse seine sets (Moon et al., 2008). Almost all purse seine-caught tuna is destined to be canned, where ex-vessel prices are under $2,000/tonne (Williams and Reid, 2007). The two principal canning destinations for purse seine-caught tuna are Bangkok, Thailand and Papua New Guinea. American Samoa, the Philippines and Indonesia also have sizeable canning industries.

Longline

The longline fleet fishes in deep water, targeting both adult yellowfin and bigeye (Table 6.1). There were reportedly 23 countries longlining for tuna in the WCPO, with a total of 4,869 active vessels engaged in the fishery in 2007 (Lawson, 2008b), however, countries report this differently, so there is uncertainty in this estimate. These vessels represent two categories of the fleet. The first is the large distant water freezer vessels, generally greater than 250 gross registered tonnes (GRT), and taking voyages that can last months. The second category is the smaller, domestically-based vessels, which are most often less than 100 GRT. Longline catch is either destined for the sashimi market, where Japan essentially dominates (Reid et al., 2003), or is destined to become frozen steaks and loins. The longline catch has shifted from a majority yellowfin catch in the 1970s and early 1980s, to a majority bigeye catch in recent years (Williams and Reid, 2007) Longline-caught yellowfin tuna command ex-vessel prices between about $5,000-$7,000 (Williams and Reid, 2007).

Handline

Handlining fleets vary in scale from very small vessels, able to fish only in municipal waters, to large operations that include a mother-boat carrying auxiliary vessels that heads out to fish on anchored FADs in deeper waters. Handliners in Indonesia and the Philippines often fish on FADs owned by purse seine companies. Handliners are allowed to fish on

[22]Benjamin Tobias, Bureau of Fisheries and Aquatic Resources, Philippines, personal communication.

these FADs given that they respect the owners of the FAD, and their gear. Furthermore, allowing handliners to fish on FADs can give purse seine owners a good idea of the possible catch composition of the school aggregating around the device. Handline-caught tuna is destined for the same market as longline tuna, but because its quality is sometimes compromised due to rough handling and lack of ice on board some vessels, it commands a lower ex-vessel price, about \$4,000 -\$6,000/tonne[23]. Reporting of the handline fleet is especially poor, with catches often being lumped under "other".

Table 6.1: Summary of fisheries and markets for WCPO tuna species used in the model.

Species	Stock status	Target fisheries	Total 2009 catch*	Markets
Skipjack	Sustainable	Purse seine, artisanal	1,783,986	Cannery, some domestic
Yellowfin	Fully-exploited	Purse seine, longline, pole and line, artisanal	433,275	Cannery, sashimi, fresh/frozen loin
Bigeye	Overfishing occurring	Longline, pole and line, artisanal	118,023	Sashimi

*Source: SPC (2009).

Skipjack

The skipjack stock in the western and central Pacific is found between about 40° N and 40° S of the equator, and exhibits a large and variable degree of migratory movement (Langley and Hampton, 2008). Currently, the stock is estimated at about 5,8 million tonnes, and is thought to be at a sustainable level, that is that current harvests could continue into the future without negative repercussions to the stock (Langley and Hampton, 2008) (Table 6.1).

Skipjack are fished with several gear types, including purse seine, pole-and-line, gillnet, hook and line, and ring net (Hampton, 2002b), however, the majority of skipjack catch is by purse seiners. The biomass trends tend to be driven by recruitment, with more recent years (1985-2001) being characterized by high recruitment, thus allowing for high catches (Langley and Hampton, 2008). However, Hampton (2002b) warns that, should a period of low recruitment occur, skipjack catches would have to decrease substantially. The estimated skipjack spawning area in the WCPO is over 17 nautical miles (Fonteneau, 2003). The 2008 assessment indicates that fishing mortality appears to be the highest in the western regions recently (Langley and Hampton, 2008). Skipjack are primarily sent to canneries (exported to Thailand or America Samoa, or processed directly in Philippines

[23] J. Ingles, World Wide Fund for Nature Philippines, personal communication

or Indonesia), where bycatch of other juvenile tuna species is generally purchased at the same price. In addition to the skipjack canned market, there is a domestic market in countries such as Indonesia and the Philippines for whole fish that are often smoked. In 2008, an estimated 1.579 million tonnes of skipjack were caught by purse seines (SPC, 2009), worth about US $2.491 million (Williams and Terawasi, 2009).

Yellowfin

The WCPO yellowfin tuna stock, estimated at about 2.5 million tonnes, is now believed to be fully exploited (Langley et al., 2009b). This essentially means that they are currently undergoing the maximum amount of exploitation possible, and any increases in exploitation could negatively impact the stock (Langley et al., 2009b) (Table 6.1). Yellowfin in the western and Central Pacific is thought to be a single stock for assessment purposes, but tagging data do suggest a small degree of mixing between the eastern and western stocks (Langley et al., 2009b). Yellowfin is targeted by purse seines and longlines, and in addition to adult fish being caught, there is also a large amount of bycatch of juvenile yellowfin in the skipjack purse seine fishery, where juveniles are found associating with skipjack schools around FADs. Although large yellowfin receive a price premium at the cannery, recent research from Indian Ocean tuna fisheries suggests that this economic incentive does not really influence fisher behaviour to avoid juvenile catch (Guillotreau et al., 2011).

Yellowfin biomass declined in the 1990s, primarily due to lower average recruitment in those years, as well as high fishing mortality (Hampton, 2002c). The estimated juvenile fishing mortality used for assessment purposes increased in the 1990s as a result of both an increase in reported catches from Indonesia and the increased use of FADs (Hampton, 2002c). Hampton (2002c) states that there has been a significant depletion in some areas of the WCPO due to fishing "by the domestic fisheries of the Philippines and Indonesia and the combined purse seine fishery". Yellowfin tend to spawn opportunistically, at water temperatures above 26° C, and mature at about one year of age, or 100 cm in length. However, Langley et al. (2007) report that juvenile yellowfin are encountered in commercial fisheries in the Philippines and Eastern Indonesia when they are only a few months old, or as small as 15 cm (Molony, 2008). Generally, purse seiners catch a wide age range of yellowfin tuna, whereas longliners tend to take mostly adult fish (Langley et al., 2007). The longline yellowfin catch in 2009 was estimated at about 69,000 t, while purse seine catch was about 264,000 t (SPC, 2009). The longline-caught yellowfin fishery was worth about US $486 million in 2008 (Williams and Terawasi, 2009).

Bigeye

Bigeye in the WCPO is thought to be one stock for assessment purposes. The current biomass estimate for bigeye is about 525,000 t (Harley et al., 2010). Tagging studies are still underway, but large scale migrations of over 4,000 nautical miles have been noted, leading stock assessments scientists to report that there is potential for gene flow over a wide area (Harley et al., 2010). Overfishing is occurring on the stock, (Langley et al., 2009a), meaning that more fish are being removed from the stock than the stock is capable of regenerating (Table 6.1). By 1970, bigeye had decreased to about half of its initial biomass (estimated in Harley et al. (2010) as about 1.25 million tonnes before fishing began), and has declined an additional 20% in the last decade (Langley et al., 2009a). A reduction in longline fishing mortality may be necessary to help move the stock to a more sustainable level (Langley et al., 2009a). Adult bigeye are targeted by longliners from both distant water fishing states (DWFS) as well as Pacific Island States (PIS). Of all tropical tunas, bigeye commands the highest price in the sashimi market (Langley et al., 2009a).

There has been a rapid increase in purse seine catches of juvenile bigeye since the early 1990s (Langley et al., 2009a). Furthermore, it has been suggested that purse seine catches are significantly underestimated (Lawson, 2008a) as bigeye is often mistakenly classified as yellowfin in its juvenile years (Lawson, 2007), especially when under 50 cm in length (Molony, 2008). Recently, reported catches have been adjusted to account for this misidentification (Williams and Reid, 2007). However, data were not available for the domestic fleets of Indonesia and the Philippines (Lawson, 2007), and therefore, whatever adjustments have been incorporated disregard the importance of the catches from these two countries. Bigeye purse seine catch is almost exclusively juveniles, and it is thought that this catch has increased in part because of the increased use of FADs (Hampton, 2002a; Langley et al., 2009a). In the Eastern Pacific Ocean, bycatch of juvenile bigeye tuna is thought to be one of the most non-sustainable bycatch forms (Archer, 2005).

The estimated 2009 longline catch of bigeye in the WCPO was about 66,000 t, down from the 2004 high of 91,000 t (SPC, 2009). The 2009 purse seine catch, estimated at 43,000 t, was down from the record high 2008 catch, estimated at 48,000 t (SPC, 2009). In 2007 the landed value of longline-caught bigeye tuna from the statistical area of the Secretariat for the Pacific Community (which does not include catch from Indonesia and Philippines) was approximately US$ 504 million (Williams and Reid, 2007), while the 2008 value was estimated at US $724 million (Williams and Terawasi, 2009).

Management

The tuna fisheries in the WCPO are managed by the Western and Central Pacific Fisheries Commission (WCPFC), which is the regional fisheries management organization (RFMO) in the area. The WCPFC has 23 participating members, including large domestic countries such as the Philippines, Japan, Korea and the U.S. (most of whom also have distant water fleets fishing in the Pacific), PICs such as Kiribati, Vanuatu and Papua New Guinea, and DWFNs, such as the European Union who, through bilateral or multilateral agreements, have access to fish in the exclusive economic zones (EEZ) of countries in the WCPO. The Commission, established under the Convention on the Conservation and Management of the Highly Migratory Fish Stocks of the Western and Central Pacific Ocean in 2000, is currently faced with the challenge of managing declining tuna stocks in the area, namely, yellowfin and bigeye. Reduction in juvenile and adult fishing mortalities on these stocks would likely result in decreased economic benefits to both purse seine and longline fisheries, at least in the short-term, especially those operating in the Coral Triangle countries, where it appears that the smallest bigeye and yellowfin are caught. It is estimated that over 150 million people live in the Coral Triangle, and that about 2.25 million fishers depend on marine resources for their livelihood (The Nature Conservancy, 2004). It is therefore important to create sustainable fisheries management regimes in an effort to provide the population with continued benefits from regional fisheries, which include the valuable tuna fisheries.

The issue of juvenile mortality in the WCPO was explored by Bertignac et al. (2000), who concluded that shifting the fisheries from younger to older fish would improve efficiency. This work, however, notes its limitations in modeling bigeye bycatch in the purse seine fishery due to data deficiencies (Bertignac et al., 2000). Their study estimated that a reduction in effort to about 50% of the 1996 levels would maximize rent generated in the area of the Forum Fisheries Agency (a sub-section of the WCPO). Contrary to this finding, effort has not been reduced over the past decade, but has increased (Williams and Reid, 2007). Of particular interest in the Bertignac et al. (2000) study is the conclusion that a substantial reduction in purse seine effort is required to maximize the combined longline and purse seine profit because of the high level of juvenile bycatch. A more recent bioeconomic modeling paper found similar results: a major reduction in purse seine fishing effort is needed to fully realize economic benefits in the region (Campbell et al., 2010). Here, we tackle the issue specifically from a FADs management perspective through a game-theoretic model, asking whether or not management of FADs fishing, through a decrease in juvenile bycatch, could yield higher joint benefits in the region.

Some preliminaries on 'fisheries game theory'

Game theory is a tool for explaining and analyzing problems of strategic interaction (Eatwell et al., 1989). It is particularly applicable to the study of fisheries management, as many of the world's fisheries are common pool in nature (Sumaila, 1999), thus having more than one interested user. Fisheries also exhibit dynamic externality (Levhari and Mirman, 1980), that is, the underlying stock is affected by all players' decisions, and each player must take into account the other players' actions. Cooperative games occur when players are able to discuss and agree upon a joint plan (they can communicate), and that the agreement is enforceable, or binding (Nash, 1953). It thus follows that non-cooperative games are those in which agreements are non-existent and/or non-binding, and where parties cannot communicate (Nash, 1951). Game theory has been applied to fisheries for over 30 years (Munro, 1979; Bailey et al., 2010).

Much attention has been paid to analyzing the management of transboundary and high seas fisheries through the lens of game theory (Munro, 1990; Kaitala and Munro, 1997; Kaitala and Lindroos, 1998; Bjorndal et al., 2000; Bjorndal and Munro, 2002). Tuna fisheries are a special type of transboundary resource because of their highly migratory nature. Any given tuna stock is generally found in the waters of several countries and in the high seas, often at the same time. This, along with the fact that the number of interested parties exploiting the resource is high, and likely to change (Pintassilgo and Duarte, 2001), exacerbates management challenges and makes the study of tuna fisheries management highly amenable to the theory of games. Of particular relevance to this study, are several game theoretic models developed to explore optimal exploitation of southern (Kennedy, 1987) and North Atlantic bluefin tuna (Brasao et al., 2000; Duarte et al., 2000; Pintassilgo and Duarte, 2001; Pintassilgo, 2003). In these studies, researchers analyzed cooperative and noncooperative management (Kennedy, 1987; Brasao et al., 2000), as well as exploring the possibility of coalition formation in management, through the analysis of the characteristic function approach (Duarte et al., 2000), and the partition function approach (Pintassilgo, 2003; Pintassilgo and Lindroos, 2008), and how these decisions affected optimal exploitation. All studies concluded that the fisheries were currently overcapitalized, and that economic benefits could be increased through cooperation. However, some authors also went on to find that cooperation is not a stable outcome, and that players in the tuna fisheries would have incentives to deviate from cooperation (Pintassilgo and Lindroos, 2008).

In this paper, I formulate a three-player game, partitioned by gear type: purse seine, longline, and handline. Most purse seine owners (the U.S. excluded) are aligned as a solitary unit through their membership in the World Tuna Purse Seine Organization (WTPO).

Here I assume that longline and handline owners are aligned in a similar manner with respective industry organizations. The game is partitioned by gear type because dynamic externality exists at the gear level: in these fisheries all three gear types catch yellowfin and bigeye tuna. Players are assumed to be individually rational, that is, they want to maximize their equilibrium profit, and will choose the strategy that does this. Furthermore, a player will only agree to cooperate if the payoff they receive through cooperation is at least equal to the payoff they would expect from non-cooperation. Players are asymmetric in several ways. The costs of fishing differ, as do the prices the players command for their products. The gears impart different fishing mortalities on the stocks, through differing selectivity.

Side payments

The term side payments has been used in fisheries economics to describe the transfer of benefits from one player to another. They are a type of cooperation facilitator (see Chapter 3), in that they would allow a player who benefits from cooperation to transfer some of their payoff to a player who may bare a cost from cooperation. Side payments help to meet the individual rationality constraint in game theory: that a player will only cooperate if their payoff through cooperation is at least what they would receive by not cooperating. If the cooperative payoff is lower than the non-cooperative payoff, then a side payment can be used to essentially compensate the player who stands to lose. Side payments are explored in the concluding section of this paper.

6.2 Model

A multi-species, multi-gear bioeconomic game-theoretic model is developed here to address this issue of tradeoffs in fishing effort and economic benefits between purse seine, longline and handline fishers. Given WCPFC recommendations for regional nations to adopt a FAD management plan (WCPFC, 2009), we are interested in knowing the optimal fishing effort each player (gear) will choose in order to maximize individual and joint net benefits from the resource under different management options: status quo, reduced FADs and no FADs. We model the status quo as a non-cooperative outcome, whereby each gear chooses their fishing effort based on their expected rent, not taking into account the implications of their actions on the other players. The two management scenarios, reduced and no FADs, are modeled as cooperative games, where the outcomes are calculated through maximization of the joint payoff, that is the sum of payoffs to all three players.

Population dynamics

The population model used here was developed in Botsford and Wickham (1979) and Botsford (1981b,a), and is summarized in Walters and Martell (2004). A yield per recruit model, which considers growth and mortality, is combined with a stock-recruitment model incorporating density dependent population effects.

Recruitment of the three fish stocks is assumed to be of the Beverton and Holt (Beverton and Holt, 1957) form, (Langley et al., 2007, 2009a; Langley and Hampton, 2008). Lengths and weights are assumed to follow von Bertalanffy growth, although it has been suggested that growth of yellowfin and bigeye may divert from this pattern for part of their life histories[24] (Langley et al., 2009b; Harley et al., 2010). Age-specific survivorship is a function of age-specific natural and fishing mortality, where natural mortality decreases with increases in length (see Lorenzen, 1996, for more details). Selectivity-at-age is assumed to be dome-shaped for the purse seine fishery, and asymptotic for the longline and handline fisheries, and is based on the age at which 50% of the population is fully vulnerable to the gear. A logistic function was used for the asymptotic selectivity curves and a three parameter exponential logistic was used for the dome-shaped selectivity. Selectivity curves for the status quo scenario are shown in Figure 6.1. Catchability is gear-specific. The reader is referred to Table 6.2 for a review of the variable definitions used throughout the text.

Growth and mortality

We begin by calculating standard age schedule information (Equations 1-4), such as lengths, l_a, weights, w_a, mortality, m_a and fecundity, f_a, at age, a, for each species, denoted by the i superscript, where i takes values of 1, 2, or 3 for skipjack, yellowfin and bigeye, respectively. Ages go from 0 to the terminal age, A, which is assumed to be 5, 6 and 7 years, for each respective species, i:

$$l_a^i = L_\infty^i(1 - e^{-K^i a^i}) \tag{6.1}$$

$$w_a^i = (a l_a^i)^b \tag{6.2}$$

$$m_a^i = M^i \left(\frac{L_\infty^i}{l_a^i}\right) \tag{6.3}$$

$$f_a^i = w_a^i - w_m^i, \quad f_a^i \geq 0 \tag{6.4}$$

[24] This deviation would not have a significant impact on our model as per P. Kleiber, stock assessment scientist at the National Marine Fisheries Service, HI.

Table 6.2: Variable definitions

g	gear type
i	fish species
l_a	length at age
L_∞	mean asymptotic length
w_a	weight at age
w_m	weight at maturity
v_a	vulnerability at age
lh	length at 50% vulnerability
sd	standard deviation in vulnerability
m_a	mortality at age
z_a	total mortality (natural plus fishing)
f_a	fecundity at age
lx_a	unfished survivorship at age
lz_a	fished survivorship at age
R	recruits
a, b	recruitment parameters
K	von Bertalanffy metabolic coefficient
κ	Goodyear compensation ratio
ϕ_{VB}	per recruit vulnerable biomass
ϕ_B	per recruit biomass
ϕ_e	per recruit egg production (unfished)
ϕ_h	per recruit egg production (fished)
h_{eq}	per recruit yield
q	catchability coefficient
y	total yield
p	ex-vessel price
c	unit cost of effort
TR	total revenue
TC	total cost
F	fishing effort
π	profit

where L_∞^i and W_∞^i are the mean asymptotic lengths and weights, respectively, for each species, i, and k^i is the von Bertalanffy metabolic coefficient. Fecundity is the difference between the weight at age and the weight at maturity, w_{mat}^i, and is assumed to be 0 if $w_a < w_m$.

Survivorship to age in an unfished population, lx_a^i, is the probability of an individual fish surviving to age a given natural mortality at age:

$$\begin{aligned} lx_a^i = lx_{a-1}^i e^{-m_{a-1}^i}, \quad \text{given} \quad lx_0 = 1, \quad 0 < a \leq A \\ lx_A^i = lx_A^i/(1 - e^{-m_a^i}), \quad a = A \end{aligned} \tag{6.5}$$

We next calculate the equilibrium eggs per recruit in the unfished population ϕ_e^i:

$$\phi_e^i = \sum_{a=0}^{A} lx_a^i f_a^i \tag{6.6}$$

Fished population

Selectivity curves are generated for each of the three gears targeting each of the three species. The gear types, g, are purse seine (PS), longline (LL) and handline (HL). Purse seines are assumed to exhibit dome-shaped selectivity, with younger yellowfin and bigeye individuals being more vulnerable to the gear than older individuals. Longlines and handlines are assumed to exert asymptotic selectivity, where fish aren't fully vulnerable to the gear until they are mature. These curves are generated as follows for dome-shaped purse seine selectivity (equation 6.7) and longline and handline logistic selectivity (equation 6.8):

$$v_a^{i,g} = \left[\frac{1}{1 + e^{-sd_1^{-1}(l_a^{i,g} - lh_1^{i,g})}}\right]\left[\frac{1}{1 + e^{sd_2^{-1}(l_a^{i,g} - lh_2^{i,f})}}\right], \qquad \text{g} = 1 \tag{6.7}$$

$$v_a^{i,g} = \left[\frac{1}{1 + e^{-sd_1^{-1}(l_a^{i,g} - \hat{a}^{i,g})}}\right], \qquad \text{g} = 2, 3 \tag{6.8}$$

Here, $lh_1^{i,g}$ and $lh_2^{i,g}$ define the length at which fish are 50% vulnerable to the fishery, and sd_1 is the standard deviation. For the logistic selectivity, the lengths are based on the age at which 50% of the population is fully vulnerable to the gear.

Total mortality at age, z_a^i, in the fished population is then calculated as the sum of natural mortality at age, m_a^i and the sum of the gear-specific mortalities imparted by the three fisheries:

$$z_a^i = m_a^i + \sum_g v_a^{i,g} F^g \tag{6.9}$$

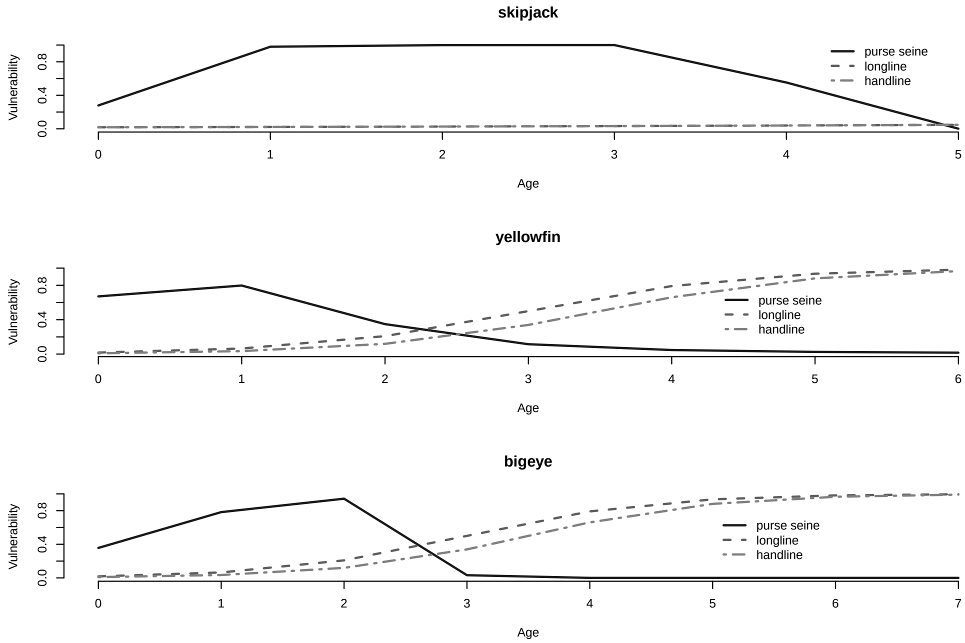

Figure 6.1: Status quo vulnerability to gears at age for three tuna species.

where $F^{i,g}$ is the fishing mortality, which is the product of the gear- and species-specific catchabilities, $q^{i,g}$, and the fishing effort, f^g.

Survivorship to age, lz_a^i, in a fished population is calculated in a similar manner to the unfished survivorship, only that it is a function of the total mortality, not just natural mortality:

$$\begin{aligned} lz_a^i &= lz_{a-1}^i e^{-z_{a-1}^i}, \quad \text{given} \quad lz_0 = 1, \quad 0 < a \leq A \\ lz_A^i &= lz_A^i/(1 - e^{-z_a^i}), \quad \text{given} \quad a = A \end{aligned} \tag{6.10}$$

Equilibrium incidence functions are then calculated for each species in the fished populations, including, eggs per recruit, ϕ_f^i, per recruit gear-specific yield for one unit of fishing effort, $\phi_{VB}^{i,g}$, recruits, R_e^i, spawning biomass, B_e^i, and gear-specific yield, Y_e^i:

$$\phi_f^i = \sum_a^A l z_a^i f_a^i \tag{6.11}$$

$$\phi_{VB}^{i,g} = \sum_a^A \frac{q^{i,g} v_a^{i,g} l z_a^i w_a^i (1 - e^{-z_a^i})}{z_a^i} \tag{6.12}$$

$$R_e^i = R_o^i \frac{\kappa^i - \left(\dfrac{\phi_{oe}^i}{\phi_f^i}\right)}{\kappa^i - 1}, \quad R_e^i \geq 0 \tag{6.13}$$

$$B_e^i = R_e^i l z_a^f \sum_a^A w_a^i \tag{6.14}$$

where κ^i is the Goodyear compensation ratio for a given fish stock[25]. The unfished recruits parameter, R_o^i, is used here as a global scalar. Finally, the equilibrium yield of species i for a specific gear g is given by[26]:

$$Y_e^{i,g} = R_e^i \phi_{VB}^{i,g} F^g \tag{6.15}$$

Economics

Total revenue for a given gear type is calculated as the sum of the product of the equilibrium yield and the ex-vessel price for each species targeted by the gear. Costs are expressed on a per unit effort basis. For the purse seine and handline fleets, one unit of effort is a fishing day. For the longline fleet, one unit of effort is defined as 1 hook. Total cost is therefore the product of the unit cost and the equilibrium effort. Equilibrium resource rent for a given gear type is simply the difference between the total revenue (summed over all three species) and the total cost. We model non-cooperative and cooperative games, where players either seek to maximize their individual or joint rent, respectively.

The per season equilibrium total revenue to gear g is:

$$TR^g = \sum_i Y_e^{i,g} p^{i,g} \tag{6.16}$$

where $p^{i,g}$ is the ex-vessel price of fish species i caught by gear type g, and $Y_e^{i,g}$ is the yield.

[25] The Goodyear compensation ratio is calculated from reported steepness estimates in the stock assessments, using a conversion equation derived in Appendix B of Martell et al. (2008).

[26] Here, our catch equation assumes constant return in catch to changes in fishing mortality.

The total cost of a given fishing gear is the product of the unit cost of fishing, c^g and the fishing effort,f^g:

$$TC^g = c^g f^g \tag{6.17}$$

Total rent to the gear is the difference between the total revenue and cost:

$$\Pi^g = TR^g - TC^g \tag{6.18}$$

We assume that in the non-cooperative game, each player (gear) is trying to maximize this rent without explicitly taking into account implications of their actions on the potential benefits of the other players:

$$\max \Pi^g, \quad \forall g \tag{6.19}$$

From a modeling perspective, we assume that each individual player calculates the optimal effort they should employ to maximize this rent. This is done by calculating the entire space of all possible rent estimates at all possible effort levels. This non-cooperative game is simulated for the status quo scenario, as we assume that little to no cooperation is currently occurring, hence the overfishing of juvenile fish. The competition between 2 players (purse seine and longline) is shown in Figure 6.2. It is clear that major reductions in potential longline profits result at increasing levels of purse seine effort.

For the cooperative game, we assume that players seek to maximize the overall, or joint profit:

$$\max \Pi = \sum_g \Pi^g \tag{6.20}$$

Here, we assume that each player takes into account the actions of the other players, and chooses the effort they should employ to maximize the overall rent, or the sum of the rents of each individual gear. This cooperative game is simulated for both the FAD management and FAD elimination scenarios. We assume here that full cooperation exists between players in the game through these management plans.

Data and simulations

Biological parameters were taken from recent stock assessment documents of the relevant species (Harley et al., 2010; Langley et al., 2009a; Langley and Hampton, 2008; Langley et al., 2007), as well as from a summary paper by Molony (2008). These values were used for the empirical simulations. As stated in Reid et al. (2003), there is high variability

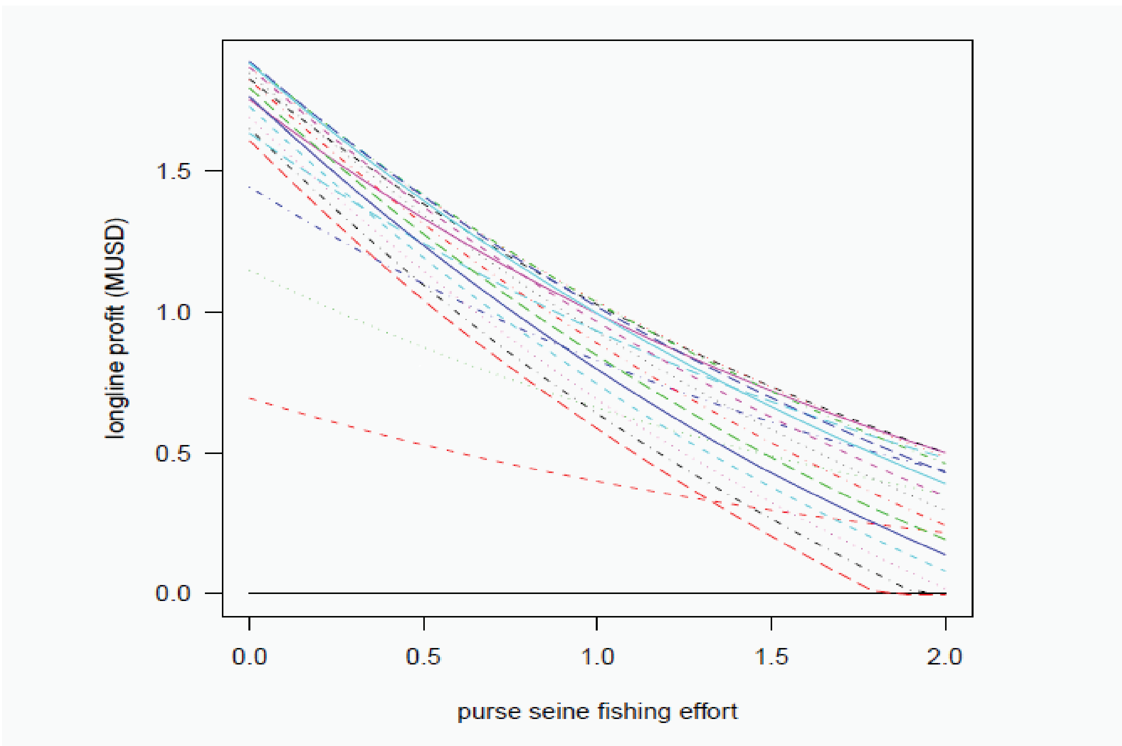

Figure 6.2: Potential profits to the longline fleet at varying levels of relative purse seine effort (x axis). 1.0 refers to the status quo, 0.5 refers to 50% of the status quo effort, and 1.5 refers to 150% of the status quo effort. Varying levels of longline effort are represented by the coloured lines.

in ex-vessel prices for tuna. Estimates for costs of fishing were taken from Reid et al. (2003), where fishing costs are meant to exclude costs representing a division of profit (for example, access fees) and costs incurred in transhipment. These costs are a static estimate, and we have not included any conditional measures (i.e., changes in costs due to stock size) in our model. In our study, costs are averaged over several different fleets (for example, both domestic and foreign purse seine fleets). Due to these data uncertainties, although the direction of simulation outcomes would most likely not change as a result of price fluctuations and disaggregation of costs, the magnitude may differ. A sensitivity analysis is performed to address uncertainties in costs[27]. Parameter values used for each species are shown in Tables 6.3, 6.4 and 6.5.

[27] I performed extra scenario runs assuming fuel costs were 10% and 25% higher than the values used in the main section. See Figure 6.5

Table 6.3: Biological and fishing parameter inputs for skipjack tuna.

Biological		Value	Source
L_∞	Mean asymptotic length (cm)	106	Molony (2008) (average)
L_m	Length at maturity (cm)	43	Langley et al. (2005)
W_m	Weight at maturity (kg)	1.56	Langley et al. (2005)
a	Length-weight relationship	8.6388E-06	Langley and Hampton (2008)
b	Length-weight relationship	3.2174	Langley and Hampton (2008)
K	Growth coefficient	0.3105	Molony (2008) (average)
κ	Recruitment compentation	36	Calculated from Langley and Hampton (2008)
M	Adult mortality (per year)	2	Molony (2008)
Fishing		**Value**	**Source**
q^g (PS, LL, HL)	Catchabilities	3.35e-06, 0, 0	Derived from Williams and Reid (2007); Lawson (2008b)
lh_1 (PS)	Start length of capture (cm)	20	Molony (2008)
lh_2 (PS)	End length of capture (cm)	80	Molony (2008)
sd_1, sd_2	Standard deviation on length of capture	5, 1	
c (PS)	Unit cost of effort (per day) (USD)	22,000	Reid et al. (2003)
p (PS)	Ex-vessel price (USD/t)	1,500	Williams and Reid (2007)

PS = purse seine, LL = longline, HL = handline.

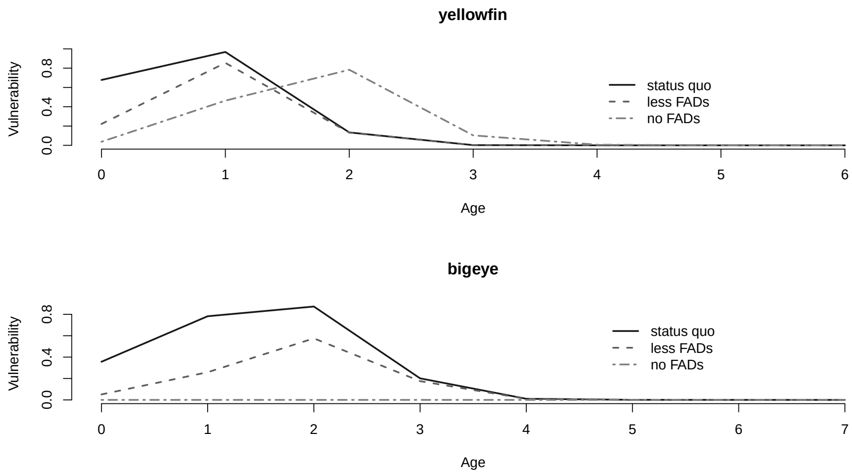

Figure 6.3: Adjusted vulnerability at age to purse seine gear for yellowfin and bigeye tuna.

In running simulations, we assume three possible scenarios. The first scenario is intended to represent the status quo where fishing on FADs is permitted and we model the non-cooperative equilibrium. Here, fishing for juvenile fish is current practice, but adult yellowfin are also harvested. This, in effect, means that purse seine fishers must take into account the fact that their removal of juvenile yellowfin fish does in fact affect their ability to harvest adult yellowfin. In the second scenario we consider the cooperative equilibrium with reduced fishing on FADs, perhaps through spatial or temporal closures. The third scenario also assumes a cooperative game where fishing on FADs is not allowed. To implement scenarios two and three, we modify the vulnerability of yellowfin and bigeye juveniles to the purse seine gear (Figure 6.3). For each scenario, we are interested in the equilibrium catch and rent received by each gear type.

For all simulations, we calculate outcomes for the entire space of possible fishing effort combinations. The non-cooperative simulations are done in two steps. In the first step, each player chooses the effort, given all possible combinations of effort by the three gears, that will maximize its rent from the resource. This level of effort is then fed into the model for each of the three players, and the individual rents are then calculated at this combination of non-cooperative effort choices. In the cooperative game, efforts are chosen based on the single largest joint rent possibility over the entire space.

Data adjustments

To simulate a scenario where there is reduced or no FAD fishing, I change the length at which 50% of the population is vulnerable to the purse seine gear (lh_1^i). By changing

Table 6.4: Biological and fishing parameter inputs for yellowfin tuna.

Biological		Value	Source
L_∞	Mean asymptotic length (cm)	175	Molony (2008)
L_m	Length at maturity (cm)	100	Molony (2008)
W_m	Weight at maturity (kg)	19	Molony (2008)
a	Length-weight relationship	2.512E-05	Langley et al. (2009b)
b	Length-weight relationship	2.9396	Langley et al. (2009b)
K	Growth coefficient	0.392	Molony (2008) (average)
κ	Recruitment compentation	12	Calculated from Langley et al. (2009b)
M	Adult mortality (per year)	1	Molony (2008) (average)
Fishing		**Value**	**Source**
q^g (PS, LL, HL)	Catchabilities	1.34e-06, 1.09e-9, 2.84e-7	Derived from Williams and Reid (2007); Lawson (2008b)
lh_1 (PS)	Start length of capture (cm)	20	Molony (2008)
lh_2 (PS)	End length of capture (cm)	100	Molony (2008)
sd_1, sd_2	Standard deviation on length of capture	15, 15	
$\hat{a}^g$	Age at 50% vulnerability (LL,HL) (years)	2, 3	Molony (2008)
c (PS, LL, HL)	Unit cost of effort (USD)	0, 1, 50	Reid et al. (2003),J. Ingles, pers. com.
p (PS, LL, HL)	Ex-vessel price (USD/t)	1,500, 5,000, 4,000	Williams and Reid (2007)

PS = purse seine, LL = longline, HL = handline.

Table 6.5: Biological and fishing parameter inputs for bigeye tuna.

Biological		Value	Source
L_∞	Mean asymptotic length (cm)	180	Hampton (2002a)
L_m	Length at maturity (cm)	102	Molony (2008)
W_m	Weight at maturity (kg)	23	Molony (2008)
a	Length-weight relationship	1.973E-05	Harley et al. (2010)
b	Length-weight relationship	3.0247	Harley et al. (2010)
K	Growth coefficient	0.188	Harley et al. (2010) (average)
κ	Recruitment compentation	12	Calculated from Harley et al. (2010) (average)
M	Adult mortality (per year)	0.361	Molony (2008) (average)
Fishing		**Value**	**Source**
q^g (PS, LL, HL)	Catchabilities	2.26e-06, 1.36e-8, 1.57e-6	Derived from Williams and Reid (2007); Lawson (2008b)
lh_1 (PS)	Start length of capture (cm)	25	Molony (2008)
lh_2 (PS)	End length of capture (cm)	80	Molony (2008)
sd_1, sd_2	Standard deviation on length of capture	15, 2	
$\hat{a}$	Age at 50% vulnerability (LL,HL) (years)	2, 3	Molony (2008)
c (PS, LL, HL)	Unit cost of effort (USD)	0, 1, 50	Reid et al. (2003), J. Ingles, pers. com.
p (PS,LL,HL)	Ex-vessel price (USD/t)	1,500, 7,000, 6,000	Williams and Reid (2007)

PS = purse seine, LL = longline, HL = handline.

these lengths to larger sizes, I force the model to decrease fishing pressure on juvenile fish, which is what we would probably observe if fishing on FADs was not allowed. In the second scenario, I allow a reduced amount of yellowfin and bigeye bycatch to be taken by the purse seine gear by shifting lh_1^i from 20 and 25 cm, to 50 and 60 cm for yellowfin and bigeye, respectively. In the no FADs scenario, I change the parameters so that adult yellowfin can still be caught by purse seiners, but I do not allow the bigeye population to be vulnerable to purse seining at all. This is done by shifting lh_1^i to 80 cm for yellowfin, and infinity for bigeye. The end length of capture, lh_2^i is also increased to 120 cm for yellowfin, from 100 cm in the status quo simulations. This is done because older, and thus larger, yellowfin are captured when setting on unassociated schools, that is, schools not associated with floating objects. Furthermore, I reduced the catchability of the purse seine gear to all three species by 10% and 30% in the reduced and no-FADs scenarios, respectively. I also assumed that, because the landed yellowfin would now be all adult-sized, the average ex-vessel price was increased by 5% and 10%, respectively, for scenarios two and three.[28]

Responsiveness of tuna prices

Tuna is a global commodity. The quantity of tuna caught in the WCPO can, to a certain degree, affect the global price of tuna (Reid et al., 2003). This is especially true for 'light' cannery-grade tuna, as the WCPO supplies almost a third of the global market. The WCPO also supplies about 11% of the global yellowfin and bigeye supply (Reid et al., 2003). I incorporate this possibility in a second set of cooperative scenarios, using an equation and derived price elasticities published in Reid et al. (2003). The new price of tuna in these modified simulations, pe, is calculated by the following equation (Reid et al., 2003):

$$pe^{i,g} = p^{i,g} - p^{i,g} \left(\frac{ye^{i,g} - q^{i,g}}{q^{i,g}} \right) \frac{1}{\epsilon} \tag{6.21}$$

where $p^{i,g}$ is the gear- and species-specific ex-vessel price, as earlier defined, $ye^{i,g}$ is the yield, as earlier defined, and ϵ is the price elasticity, which takes the values 1.90 and 9.97 for purse seine and longline caught tuna (Reid et al., 2003). As there were no estimates available for the handline fleet, we used the longline value of 9.97, due to the fact that catches from these two gears supply similar markets. The original quantity of species i supplied by gear g, $q^{i,g}$, is taken from the catch quantities estimated in the non-cooperative status quo scenario. In this way, the non-cooperative outcome is a reference or

[28] Reid et al. (2003) explain that there is a size premium paid for larger fish; with fish weighing more than 7.5 kg receiving higher ex-vessel prices.

baseline for the cooperative games assuming non-constant prices. Equation (6.21) assumes a downward sloping demand curve, and results in increased (decreased) ex-vessel prices when the catch from that gear type is decreased (increased). When Equation 6.21 is used, we do not include the 5% and 10% increase in the purse seine-caught yellowfin ex-vessel price as stated above.

6.3 Results

Status quo: Non-cooperative game

The optimum rent for each gear type is reached at effort levels of about 98,000 purse seine fishing days, 591 million longline hooks, and 1.6 million handline days[29] (Table 6.6). At equilibrium, skipjack, yellowfin and bigeye purse seine catches of 2.1 million t, 211,000 t and 44,000 t are possible, respectively. This leads to rent in the purse seine fishery of almost USD $1.4 billion (Table 6.6). Interestingly, in the non-cooperative status quo simulation, longline is not a profitable endeavor, actually yielding negative rents of about US $54 million annually. A constraint on this recalibrates the rent to be 0. The potential negative rent is in spite of yellowfin and bigeye catches of 173,000 t and 38,000 t, respectively. At equilibrium, the total maximum rent attained in the status quo scenario is about US $1.54 billion. For all three species, the ratio of biomass vulnerable to the purse seine gear and spawning biomass is greater than 1, meaning that juvenile fish are being harvested (Figure 6.4).

Reduction in FADs fishing: Cooperative game 1

Our second simulation assumes that the use of FADs is reduced through some sort of management regulation, thereby reducing the vulnerability of juvenile yellowfin and bigeye to the purse seine gear. For this simulation, we assume a cooperative regime, where all players, in this case, cooperatives, unions or organizations based on fishing gear, agree to manage the resource in order to maximize the joint rent, or the sum of all individual rents. As shown in Table 6.6, the maximum rent is achieved with efforts of about 21,000 purse seine days, 830 million longline hooks and over 2 million handling days. This represents quite a large decrease in purse seine effort, resulting in less catch of all three species, and substantially lower overall rent to purse seiners. However, positive rents are possible for each of the gears, namely US $465, $732 and $433 million, respectively, for purse seine, longline and handline. Overall, about US $1.63 billion is attainable at equilibrium, through

[29] The estimated number of handline fishing days for small and large Philippine vessels averaged about one million per year over the years 2005-2009 (J. Ingles, pers. comm.)

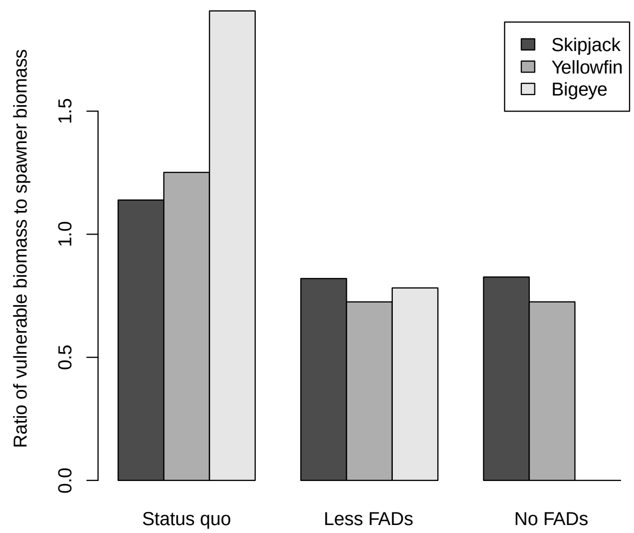

Figure 6.4: Ratio of vulnerable biomass (to the purse seine gear) to spawning biomass. Levels above 1 imply juveniles are vulnerable to the gear.

the reduction of FADs. This is an increase of about US $100 million annually. Results are summarized in Table 6.6. The spawning biomass of all three species is improved in this scenario by 200%, 120% and 274% for skipjack, yellowfin and bigeye, respectively. Due to this, and the reduction in juvenile vulnerability, the ratio of vulnerable biomass to spawning biomass has decreased to below 1 (Figure 6.4).

No FADs fishing: Cooperative game 2

The third scenario assumes that fishing on FADs no longer occurs, and thus, there is no juvenile bycatch of yellowfin or bigeye tuna. This scenario is also run assuming a cooperative agreement is in place, and thus we are trying to maximize the joint rent from all three fisheries. Again, a major reduction in purse seine effort is needed to maximize joint rent in this scenario. Similar to the reduced FADs situation, efforts of about 20,000 purse seine days, 812 million longline hooks, and 2.0 million handline days maximize rent (Table 6.6). Substantial increases in rent to longliners and handliners are possible here, compared to the status quo. This scenario results in the lowest rent to purse seiners, an estimated US $312 million annually, but the highest rents to longliners and handliners, US $839 and $480 million, respectively. The overall rent in this scenario is quite similar to the reduced FADs scenario, an estimated US $1.63 billion. The gain in rent to longliners and handliners in going from a reduced FADs to no FADs fishing policy is canceled out by the decline in the purse seine rent. The gains in spawning biomass are almost the same as in the reduced FADs scenario, with increases of 203%, 121% and 281% for skipjack, yellowfin and bigeye, respectively. Again, we see that the increase in spawner biomass and reduction in juvenile catch, the ratio of vulnerable biomass to spawning biomass has decreased to below 1 for all three species, reaching almost 0 (Figure 6.4).

Cooperative games when price is not constant

In the above cooperative scenarios, we assumed prices remained constant, except in the case of purse seine-caught yellowfin, due to the price premium for large fish. Here, we allow the price to respond to changes in the quantity of fish supplied to the market from the WCPO (i.e., the catch). This results in much higher rent possibilities to the purse seine fleet in both the reduced and no FADs scenarios. The optimal equilibrium effort, estimated at just over 21,000 purse seine fishing days for both scenarios, does not vary greatly from the constant price simulations, yielding catches that are similar to the two cooperative results above. In the reduced FADs cooperative game, 584,665 t of skipjack, 28,438 t of yellowfin and 9,132 t of bigeye are caught, yielding purse seine rents of US $951 million (compared to US $465 in the low FADs non-price responsive model), and an overall equilibrium rent of US $1.885 billion. With the total reduction of FADs, purse seines catch 505,371 t of skipjack and 24,142 t of yellowfin, yielding rents of about US $714 million (compared to US $312 million in the no FADs non-price responsive model). Because of the reduced catchability in the no FADs scenario, the same amount of purse seine effort catches fewer fish, and, even with the increase in price due to the decrease in the quantity supplied, this scenario yields an overall rent of US $1.750 billion. This is less than the reduced FADs scenario incorporating price responsiveness, but it is still higher than both of the cooperative games assuming constant prices.

A sensitivity analysis to cost assumptions was performed. For this, I reran the non-cooperative and cooperative games assuming fuel costs were 10% and 25% higher for all fleets than the estimates used in the main model. Fuel costs represent about half of purse seine and longline costs[30], and we assumed this was true for the handline fleet as well. Results stated above are robust to these changes: the optimal solution is still the less FAD option, although total rent and effort for all fleets is reduced (Figure 6.5).

[30]Dexter Teng, TSP Industries and Mark Filipe, Far East Seafood, Inc., personal communication.

Table 6.6: Scenario results

	Status quo			Low FAD			No FAD		
	PS	LL	HL	PS	LL	HL	PS	LL	HL
Effort*	97,829	591	1.624	20,742	830	2.074	22,062	882	2.206
Skipjack catch (t)	2,138,396	0	0	575,622	0	0	515,674	0	0
Yellowfin catch (t)	210,543	173,184	28,360	28,025	282,972	40,831	14,395	302,626	43,581
Bigeye (t)	44,194	37,571	24,392	9,138	139,498	79,495	0	155,796	87,840
Revenue (m. USD)	3,590	1,129	260	921	2,391	640	797	2,604	701
Cost (m. USD)	2,152	1,183	162	456	1,659	207	485	1,765	221
Rent (m. USD)	1,438	0	98	465	732	433	312	839	480
Total rent (m. USD)	1,536			1,630			1,630		
Increase in skipjack spawning biomass (%)	-			200			203		
Increase in yellowfin spawning biomass (%)	-			120			121		
Increase in bigeye spawning biomass (%)	-			274			281		

*PS=purse seine (effort = num days), LL=longline (effort = num hooks), HL=handline (effort = num days)

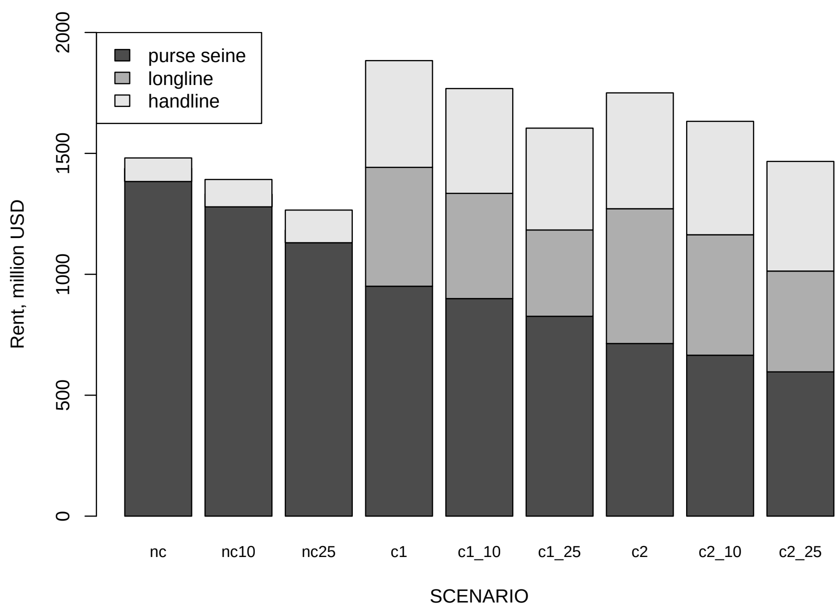

Figure 6.5: Sensitivity analysis: scenario rents when fuel costs are increased by 10% and 25%, compared to the base runs (assuming responsive prices). nc refers to the noncooperative games, while c1 and c2 refer to cooperative games one and two, which assume less FAD and no FAD use, respectively.

6.4 Conclusion

Tuna fisheries in the WCPO have the potential to be profitable, but evidence suggests that at least two of the targeted species, namely, yellowfin and bigeye, may be fully exploited or overfished (Langley et al., 2007, 2009a). The goal of the WCPFC is to try to manage tuna (and other) stocks in the WCPO in a sustainable way, so the Commission is currently facing tough management decisions regarding the potential for tuna fisheries in the area to continue providing benefits to the region. The conflict between purse seine fishers catching juvenile yellowfin and bigeye tuna, and longline fishers targeting adults of these species, is probably only one important challenge to address, but it has been raised numerous times in WCPFC technical reports (Langley et al., 2009a; Williams and Reid, 2007; Itano, 2009; Kumoru et al., 2009). Furthermore, the WCPFC has itself called for a FADs management plan (CCM 2008-01) mandating member countries to establish FAD regulatory measures within their own waters for their purse seine fleets (WCPFC, 2009).

Assuming constant prices, both reduction and total elimination of FADs yield almost equivalent payoffs. Losses to the purse seine sector are evident when making this type of policy change. When we allow for prices to reflect changes in the quantity of tuna supply, these losses are mitigated to a certain extent. Of all four cooperative scenarios run, the regulation of FADs use with responsive prices yields the highest benefits, an improvement of US $458 million per year. Purse seine effort was estimated at about 58,000 vessel days in 2008 (Williams and Terawasi, 2009). The equilibrium effort of about 20,000 vessel days for purse seiners needed to maximize joint rent, in either the constant or non-constant price scenarios, is therefore quite a reduction. The per day rent, however, increases significantly. In the status quo, the rent generated for each purse seine fishing day is about US $14,700. In the reduced and no FADs scenarios, assuming prices are responsive to the quantities supplied, this per day rent is increased to US $45,300 and US $34,000 per day, respectively. If, from a management perspective, the reduction in purse seine days is unacceptable, the second-best solution may be to allow more effort, but the same amount of catch (if there was a way to actually enforce that), and just allow the profitability of the fishery to be reduced.

I have incorporated changes in size selectivity by the purse seine gear, which would presumably occur if there was a major shift from fishing on FADs to fishing on unassociated schools. Further to this, I have included both a price premium (of 5% and 10%) and the ability of the price to respond to regional supply. Even given these considerations, however, I acknowledge that improvements in the understanding of the complex relationship between the supply of fish produced by a multispecies fishery and the market price, which, although highly influenced by Bangkok, is also dependent on the local supply and processing abilities of the regional canneries and factories, could help improve our estimates of equilibrium rent. Research is currently being conducted to update and improve the estimates of elasticity, which could also be used to improve future analyses in this context.

Side payments are a kind of negotiation facilitator for cooperation, possibly a way to encourage purse seiners to reduce their FAD use (Reid , 2006). Side payments are often envisioned in monetary terms, however, it could be beneficial to think of them in terms of sharing the catches in these fisheries, instead of sharing the rent. For example, purse seine fleets could be given a share of the longline catch, as compensation for not fishing with FADs. If they choose not to enter the longline fishery, their shares could be leased out to other longline fleets, enabling them to derive rent from the fishery. An alternative form of a side payment could be realized through longline fishers leasing catch shares for access to the purse seine fishery, which they would choose to not fish. They would therefore be contributing to offsetting the loss of that fishing ground to purse seiners who are active in the fishery. These types of arrangements could probably be easily achieved for countries that have both purse seine and longline fleets, such as Taiwan. However, as international fisheries quota markets are still in their infancy, trading among countries may prove difficult in the near future (Bailey et al., 2010).

The potential of the longline fishery to bring regional benefits may rest on an effective decrease in juvenile fishing by purse seiners. Both the reduction or removal of fishing on FADs yields benefits to the region. In this study, however, we did not address the costs of management. The overall benefit of total elimination of FADs versus just a reduction may be more or less enticing depending on whether it is more or less costly to impart temporal and spatial closures on FADs versus an all-out ban. Gjertsen et al. (2010) discuss several types of economic incentives for reducing bycatch, including market-based, rights-based, and top-down incentives such as taxes and subsidies. With specific reference to the Eastern Pacific Ocean (EPO), the authors suggest that assigning property rights to set on floating objects, perhaps through a spatial management plan, might help to control the use of FADs (Gjertsen et al., 2010). Another alternative would be to lease or rent out FADs during the fishing season, and require that they be returned upon closures, with fines instituted where this does not happen, as alluded to in Jacquet et al. (2011). In any event, spatial analyses in the future could probably help regulators decide on where and when FADs closures should take place, but it's clear that, in the very least, FADs regulation is necessary.

The WCPFC could probably adopt several management measures that the Inter-American Tropical Tuna Association (IATTC), responsible for management of tuna in the EPO, has considered or implemented. For example, size limits on catch retention might help to decrease the occurrence of juvenile fish, if, for example, a type of quota on by-catch is implemented. Additionally, demand-side measures, such as consumers demanding FAD-free tuna in Britain, may help to force canneries to rethink their purchasing decisions (Pala, 2011). There are several measures currently underway, or in the foreseeable future, that could tackle the sustainability issues associated with growth overfishing and juvenile byctach. Obvious challenges to implementing management measures in WCPO tuna fisheries exist. These challenges, however, are not an excuse to allow the continued growth overfishing of yellowfin and bigeye tuna. The WCPFC should encourage learning by doing, and facilitate the adoption of management measures so this region can continue to provide the world with sustainably-caught tuna well into the future.

Chapter 7

Conclusion: Moving beyond the status quo

Albert Einstein wisely suggested that problems cannot be solved from the same level of consciousness that created them. Globally, tuna fisheries are important for employment and food security, and the tuna stocks themselves provide ecosystem functions throughout the world's oceans. Unfortunately, both fisheries and conservation scientists report that the majority of the world's tuna species are of conservation concern (Miyake et al., 2010; ISSF, 2012; Collette et al., 2011; IUCN, 2011). We are thus faced with a decision: do we continue managing tuna the way we have done in the past, i.e., maintain the status quo, or do we accept that we have not done an adequate management job thus far and alter our methods to head in a new direction?

As societies become more affluent, we know that demand for luxury products, of which tuna can be considered a part, will increase (Delgado et al., 2003). If demand increases and our supplies are not managed sustainably, we are likely to see the end of the global tuna era, which has brought economic, ecological and social benefits to fishers, countries, and consumers throughout the past sixty years. Continuing the status quo of tuna fisheries management, however, will lead to a future of increasingly competitive fisheries, overexploited stocks, a culture of 'haves' and 'have-nots', and biological and economic waste. Furthermore, for the countries that depend on tuna catches for domestic food security, failure to manage tuna stocks sustainably could result in worse circumstances than simply a failing economic sector.

In this thesis, I address deficiencies in the way tuna fisheries are currently managed, and provide ways forward to improve global and regional management. Paths to improvement include better incorporation of economic information in policy-making and stronger national accountability with regards to fishing subsidies (Chapter 2), increases in cooperation (Chapter 3), new allocation approaches (Chapter 4), management capacity building (Chapter 5), and incorporation of policies that take a long-term perspective, such as a FADs management plan (Chapter 6).

While it is true that tuna fisheries are an important revenue source for many fishing nations, to what extent these revenues are realized as resource rent has been largely ignored in economic analyses. There are obvious economic asymmetries associated with fishing for different tuna species using different fishing methods (Chapter 2). Management formulated with these asymmetries in mind may have a greater likelihood of being effectively implemented. Fishers employing longline gear are faced with the lowest rent per tonne of all the major tuna fishing gears, whereas gillnet and purse seine fishers are realizing some of the highest per tonne rents. This is likely due to the fact that fuel is a major contributor to operational costs, and both purse seine and gillnets bring tuna to them (through the use of FADs in the cast of purse seines) and thus decrease their fuel use because of this. Fishing for bluefin (Atlantic, Pacific and southern) still brings in positive private rents, even though two of these stocks are overfished. Skipjack fisheries, considered underexploited today, provide the majority of the global tuna supply, and are profitable to fish before and after subsidies are accounted for.

As economic theory suggests, effort will continue moving into fisheries that are profitable, and thus fishing with purse seines, and for bluefin species and skipjack, may increase in the short term. Depending on the population status of a given species, this increase in effort could be more or less worrisome. A management regime that is proactive and takes into account where resource rent is generated, and where effort is likely to increase or decrease would be a step forward from where we are today, essentially a management system that is always putting policies in place after the fact.

Subsidies have created a gap between social and private rent, creating artificially-higher profits (Chapter 2). In the case of global tuna fisheries, this gap amounts to over US $5.6 billion, money which societies could invest in more sustainable parts of their economy. Civil society needs to have some say in where its economic resources are being allocated, and perhaps the choice of many governments to disinvest in global tuna stocks may be suboptimal for society as a whole.

It has been shown both theoretically and empirically that cooperation in fisheries management can bring benefits above and beyond non-cooperative management (Munro, 1979; Sumaila, 1999; Bailey et al., 2010; Hannesson, 2011). Even with the creation of Regional Fisheries Management Organizations (RFMOs), which are mandated to bring about cooperative management, competitive fishing of tuna and non-tuna stocks has continued largely unabated. Tuna RFMOs are often composed of multiple members, which can make cooperation more difficult, and further to this, face the problem of free riders and new members. The evidence that cooperation will facilitate improvements in sustainability has increased over the past thirty years (Chapter 3) and it is time for these theories to transfer into action.

According to an analysis by Cullis-Suzuki and Pauly (2010), RFMOs are currently not doing enough to enforce their mandates to promote sustainability. One specific way that RFMOs can improve cooperative management is to focus on their allocation programs (Chapter 4), which to this point have by and large failed to prevent the overexploitation of tuna stocks throughout the world (Lodge et al., 2007). Transparent and equitable allocation programs that are accepted by RFMO members could go a long way in promoting sustainability. Most allocation programs have been developed based on catch histories of participating members, and have not taken into account socio-economic factors such as employment, domestic consumption, or management capacity. Global tuna fisheries offer many benefits to nations above and beyond catch quotas.

The Western and Central Pacific Fisheries Commission (WCPFC) has developed a fairly inclusive set of criteria to consider in the future when they implement their allocation program. Although this is beyond what most tuna RFMOs have done, it still does not go far enough to provide any kind of guidance on how these inclusive criteria will be valued or weighted. RFMO members need to have open and honest discussions about what they expect to gain from cooperation, and improved development of allocation criteria and weighting that will help facilitate a program that meets these expectations (Chapter 4). A new approach applied today, and in the future, based on multiple allocation criteria and defined by national *interests* could help us shift the allocation focus from a strictly catch-based perspective to a more benefits-based fisheries management paradigm.

Indonesia, the Philippines and Papua New Guinea are found within the WCPFC convention area, and are part of a sub-region known as the Coral Triangle. About a third of all tuna caught in the western and central Pacific Ocean comes from this sub-region where effective management capacity is limited. Indonesia and the Philippines have poor data collection and management programs, non-existent or ineffective fishing restrictions, lack a plan for how to manage fish aggregating devices (FADs) and have limited membership with regional scientific and management groups. Papua New Guinea, on the other hand, is aligned with several regional initiatives and institutions, and they have been proactive in setting up spatial and temporal management plans, including for FADs. The strategic placement of Papua New Guinea between Indonesia and the Philippines, and the rest of the WCPFC, means that they are well-suited to help facilitate improved management of fisheries in the Coral Triangle region (Chapter 5). Cooperation in management of straddling stocks should extend beyond just sitting in on annual meetings. A future in which tuna fishing nations help raise the standards of fishing sectors and management programs in nations with whom they share a resource would be a bright one indeed.

The challenge of reducing or eliminating FADs in the WCPFC is important because the use of these devices causes bycatch of juvenile yellowfin and bigeye tuna (Langley et al., 2009a). These stocks are considered fully exploited and overexploited, respectively, and thus bycatch of juvenile fish needs to be reduced drastically or eliminated if we are to see long-term sustainability of these stocks. Cooperative management in this region, whereby the joint benefit to the entire region is considered, would increase the spawning biomass of these species, and offer long-term economic benefits to longliners who target adult fish. Further to this, although the amount of purse seine effort would decrease under a cooperative scenario where juvenile bycatch is limited, the potential profitability per purse seine fishing day will increase. The analysis conducted in Chapter 6 is a multi-species 3-player game, that seeks to analyze a highly complex interaction between these different fishing gears. More work is needed here to identify solutions to the conflict of interest. Although my analysis provides evidence that cooperation brings benefits at equilibrium, institutional and governance barriers to cooperation exist and need to be understood. Chapter 6 is an equilibrium approach, meaning that it seeks a long-term solution. If this type of modelling shows us where we would be better off in the future (i.e., through cooperation), then we should focus today on solutions and ways to move us toward this better place.

One thing our generation probably needs to accept (and one thing that we have been unable to even consider), is that short-term losses might be necessary now in order to achieve a better tomorrow. This reality is ubiquitous in the news today, evidenced by the austerity plans put forth by several countries, and by the protests and unrest that such measures create. To counter present-day losses in some tuna-fishing nations, side payments have to be employed more effectively. A non-formal agreement has been crafted between Norway and Russia, with Russia agreeing not to target juvenile herring in its waters in exchange for the right to catch adult herring in Norway's waters (Lodge et al., 2007). Such an agreement could theoretically be struck between a sub-coalition of Indonesia, the Philippines and Papua New Guinea, for example, where purse seiners agree to not fish on FADs, and thus reduce the catch of juvenile yellowfin and bigeye, in exchange for the right to catch adult tuna in the waters of Pacific Island Countries or the high seas.

If open discussions surrounding the present day issues in tuna management are encouraged, hopefully tuna RFMOs can begin the process of solidifying their mandates and promoting more sustainable fisheries. A pointed analysis of tuna subsidies, development of transparent and equitable allocation programs, and improved and facilitated cooperation are all going to be necessary for the realization of long-term benefits derived from global and regional tuna fisheries.

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Appendix A

Rent Analysis

Table A.1: Summary table of rent analysis results

Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Algeria	Atlantic bf	pole/line	-142,531	-147,706	5,175	-1,453
Algeria	Atlantic bf	trap	-421,624	-436,167	14,542	-1,530
Algeria	Atlantic bf	hook/line	-3,449	-3,563	115	-1,587
Algeria	Atlantic bf	purse seine	-281,534	-297,607	16,073	-924
Algeria	Atlantic bf	longline	-717,705	-731,923	14,218	-2,663
Am Samoa*	yellowfin	longline	871,897	386,236	485,661	7,355
Am Samoa	skipjack	hook/line	288,722	140,292	148,430	7,969
Am Samoa	bigeye	longline	250,162	110,818	139,344	7,355
Am Samoa	skipjack	longline	178,939	79,267	99,672	7,355
Am Samoa	albacore	longline	8,220,031	3,641,340	4,578,691	7,355
Am Samoa	bigeye	hook/line	379,356	184,332	195,024	7,969
Am Samoa	skipjack	gillnet	165,260	93,035	72,224	9,374
Am Samoa	skipjack	pole/line	239,850	134,130	105,720	9,295
Am Samoa	skipjack	purse seine	388,605	224,693	163,912	9,713
Am Samoa	albacore	hook/line	3,578,798	1,738,963	1,839,835	7,969
Am Samoa	yellowfin	hook/line	700,538	340,396	360,141	7,969
Am Samoa	albacore	mw trawl	6,301,060	3,776,072	2,524,988	10,224
Am Samoa	albacore	pole/line	5,000,623	2,796,466	2,204,157	9,295
Am Samoa	yellowfin	pole/line	636,881	356,159	280,722	9,295
Am Samoa	bigeye	pole/line	149,533	83,623	65,911	9,295
Am Samoa	albacore	purse seine	1,971,953	1,140,190	831,762	9,713
Am Samoa	yellowfin	purse seine	1,708,835	988,055	720,780	9,713
Am Samoa	yellowfin	gillnet	535,281	301,344	233,937	9,374
Am Samoa	bigeye	purse seine	303,417	175,437	127,980	9,713
Am Samoa	bigeye	gillnet	560	315	245	9,374
Angola	yellowfin	pole/line	-52,570	-59,831	7,260	-1,453
Angola	yellowfin	purse seine	-14,816	-18,033	3,217	-924
Angola	yellowfin	longline	-156,576	-168,374	11,798	-2,663
Angola	bigeye	pole/line	-40,653	-46,267	5,615	-1,453
Angola	bigeye	purse seine	-7,671	-9,336	1,666	-924
Angola	bigeye	longline	-103,131	-110,902	7,771	-2,663
Australia	albacore	hook/line	44,839	6,361	38,478	8,310
Australia	southern bf	longline	33,552,653	-4,668,900	38,221,553	6,260
Australia	yellowfin	longline	12,255,680	-1,705,396	13,961,076	6,260
Australia	skipjack	gillnet	960	372	589	11,637
Australia	bigeye	longline	5,563,754	-774,204	6,337,959	6,260

Table continued on next page

Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Australia	yellowfin	hook/line	41,199	5,845	35,354	8,310
Australia	skipjack	longline	8,873	-1,235	10,107	6,260
Australia	albacore	longline	3,417,754	-475,585	3,893,340	6,260
Australia	bigeye	pole/line	46,965	14,429	32,536	10,294
Australia	southern bf	pole/line	1,816,157	557,978	1,258,178	10,294
Australia	yellowfin	gillnet	10,339	4,003	6,335	11,637
Australia	albacore	pole/line	916,447	281,560	634,886	10,294
Australia	yellowfin	pole/line	416,568	127,982	288,585	10,294
Australia	bigeye	gillnet	1,135	440	696	11,637
Australia	albacore	gillnet	18,233	7,060	11,173	11,637
Australia	skipjack	pole/line	175,942	54,055	121,888	10,294
Barbados	bigeye	purse seine	7,178	4,858	2,319	1,786
Barbados	albacore	longline	14,577	8,469	6,108	1,377
Barbados	albacore	purse seine	3,070	2,078	992	1,786
Barbados	bigeye	longline	29,158	16,940	12,218	1,377
Barbados	bigeye	pole/line	3,199	2,153	1,046	1,765
Barbados	albacore	pole/line	1,219	820	399	1,765
Barbados	skipjack	pole/line	385	259	126	1,765
Barbados	skipjack	purse seine	1,992	1,348	643	1,786
Barbados	yellowfin	purse seine	212,078	143,552	68,525	1,786
Barbados	skipjack	longline	918	534	385	1,377
Barbados	yellowfin	longline	214,101	124,388	89,713	1,377
Barbados	yellowfin	pole/line	31,468	21,177	10,291	1,765
Bermuda*	skipjack	pole/line	38	-49	88	352
Bermuda	albacore	longline	-1,292	-1,946	654	-1,587
Bermuda	bigeye	longline	-1,245	-1,875	630	-1,587
Bermuda	albacore	hook/line	-1	-1	0	-973
Bermuda	Atlantic bf	hook/line	-56	-103	47	-973
Bermuda	skipjack	purse seine	430	-18	448	771
Bermuda	yellowfin	longline	-47,753	-71,927	24,175	-1,587
Bermuda	Atlantic bf	purse seine	69	-3	72	771
Bermuda	Atlantic bf	pole/line	0	0	0	352
Bermuda	bigeye	pole/line	24	-30	54	352
Bermuda	skipjack	longline	-529	-797	268	-1,587
Bermuda	Atlantic bf	longline	-145	-219	74	-1,587
Bermuda	albacore	purse seine	102	-4	106	771
Bermuda	bigeye	purse seine	115	-5	120	771
Bermuda	Atlantic bf	trap	-10	-19	8	-971
Bermuda	yellowfin	pole/line	1,215	-1,557	2,772	352
Bermuda	yellowfin	purse seine	21,165	-908	22,073	771
Bermuda	albacore	pole/line	19	-24	43	352
Brazil	bigeye	longline	663,977	153,650	510,327	598
Brazil	bigeye	pole/line	41,619	22,201	19,418	986
Brazil	yellowfin	longline	14,668,088	8,286,138	6,381,950	3,409
Brazil	skipjack	pole/line	10,721,005	4,274,992	6,446,013	426
Brazil	bigeye	purse seine	26,657	14,485	12,172	1,007
Brazil	skipjack	purse seine	510,939	218,476	292,463	447
Brazil	yellowfin	purse seine	969,271	592,709	376,563	3,818

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Brazil	albacore	pole/line	122,279	70,429	51,849	1,686
Brazil	yellowfin	pole/line	10,499,122	6,397,139	4,101,984	3,797
Brazil	albacore	hook/line	198	-420	618	229
Brazil	skipjack	longline	6,995	-39,405	46,400	39
Brazil	albacore	purse seine	1,733	1,008	726	1,707
Brazil	albacore	longline	754,762	339,224	415,538	1,298
Belize	bigeye	longline	183,491	-31,998	215,488	1,377
Belize	yellowfin	longline	224,825	-39,206	264,031	1,377
Belize	skipjack	longline	163	-28	191	1,377
Belize	albacore	longline	811,368	-141,489	952,857	1,377
Belize	bigeye	gillnet	172	-515	687	405
Belize	yellowfin	gillnet	450	-1,348	1,798	405
Belize	albacore	gillnet	35,675	-106,836	142,511	405
Belize	yellowfin	pole/line	35,819	2,987	32,832	1,765
Belize	bigeye	pole/line	2,398	200	2,198	1,765
Belize	skipjack	pole/line	9,044	754	8,290	1,765
Belize	yellowfin	hook/line	793	-3,033	3,826	335
Belize	albacore	pole/line	72,065	6,010	66,055	1,765
Solomon Is.*	bigeye	longline	11,291	-1,245	12,536	3,893
Solomon Is.	skipjack	longline	7,078,882	-780,850	7,859,732	3,893
Solomon Is.	yellowfin	hook/line	6,983,769	2,128,808	4,854,960	6,218
Solomon Is.	skipjack	hook/line	16,836,843	5,132,245	11,704,598	6,218
Solomon Is.	bigeye	pole/line	10,874	4,944	5,930	7,927
Solomon Is.	bigeye	hook/line	25,238	7,693	17,545	6,218
Solomon Is.	bigeye	gillnet	47	25	22	9,270
Solomon Is.	Pacific bf	hook/line	37,306	11,372	25,934	6,218
Solomon Is.	yellowfin	longline	5,896,612	-650,437	6,547,049	3,893
Solomon Is.	bigeye	purse seine	21,998	10,484	11,514	8,258
Solomon Is.	skipjack	purse seine	24,695,154	11,769,668	12,925,486	8,258
Solomon Is.	skipjack	pole/line	15,288,202	6,951,516	8,336,686	7,927
Solomon Is.	yellowfin	gillnet	6,763,616	3,609,980	3,153,637	9,270
Solomon Is.	yellowfin	purse seine	18,564,381	8,847,752	9,716,629	8,258
Solomon Is.	skipjack	gillnet	12,214,827	6,519,482	5,695,345	9,270
Solomon Is.	yellowfin	pole/line	6,939,883	3,155,552	3,784,332	7,927
Virgin Is.*	yellowfin	pole/line	43	-55	98	352
Virgin Is.	yellowfin	purse seine	627	-27	653	771
Virgin Is.	yellowfin	longline	-1,690	-2,546	856	-1,587
Canada	albacore	purse seine	-6,581	-8,007	1,426	-1,455
Canada	albacore	pole/line	-212	-331	119	-563
Canada	albacore	longline	-9,886,093	-11,079,440	1,193,347	-2,613
Cape Verde	yellowfin	purse seine	-715,721	-1,361,168	645,447	-924
Cape Verde	bigeye	purse seine	-258	-492	233	-924
Cape Verde	bigeye	longline	-997	-1,308	312	-2,663
Cape Verde	skipjack	pole/line	-250,416	-394,043	143,628	-1,453
Cape Verde	yellowfin	longline	-1,817,750	-2,386,575	568,825	-2,663
Cape Verde	skipjack	purse seine	-172,465	-327,997	155,532	-924
Cape Verde	bigeye	pole/line	-503	-791	288	-1,453
Cape Verde	yellowfin	pole/line	-584,186	-919,249	335,064	-1,453

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Cape Verde	skipjack	longline	-13,444	-17,652	4,207	-2,663
Sri Lanka	bigeye	gillnet	2,727	1,965	762	3,400
Sri Lanka	yellowfin	hook/line	331,750	174,768	156,982	2,008
Sri Lanka	skipjack	pole/line	36,522,592	20,544,546	15,978,046	2,172
Sri Lanka	skipjack	gillnet	3,146,610	2,267,472	879,139	3,400
Sri Lanka	skipjack	hook/line	2,532	1,334	1,198	2,008
Sri Lanka	yellowfin	gillnet	1,595,416	1,149,669	445,747	3,400
Sri Lanka	yellowfin	longline	27,842,917	11,930,367	15,912,550	1,662
Sri Lanka	bigeye	longline	418,075	179,140	238,935	1,662
Sri Lanka	bigeye	pole/line	5,570	3,133	2,437	2,172
Sri Lanka	yellowfin	pole/line	4,683,845	2,634,738	2,049,107	2,172
Sri Lanka	skipjack	longline	26,417,153	11,319,443	15,097,710	1,662
Chile	bigeye	purse seine	-594	-741	147	-78
Chile	skipjack	longline	-863	-877	13	-582
Chile	skipjack	purse seine	-751	-790	39	-173
Chile	yellowfin	longline	-12,216	-12,304	88	-623
Chile	bigeye	longline	-3,100	-3,223	123	-487
Chile	skipjack	pole/line	-33	-35	2	-194
Chile	yellowfin	pole/line	-114	-117	2	-236
Chile	albacore	longline	-388	-418	30	-388
Chile	yellowfin	purse seine	-7,066	-7,213	148	-215
China Main	bigeye	pole/line	1,722,191	502,646	1,219,545	2,172
China Main	Atlantic bf	pole/line	8,372	2,444	5,929	2,172
China Main	albacore	hook/line	102,733	24,046	78,687	2,008
China Main	yellowfin	hook/line	143,142	33,504	109,637	2,008
China Main	bigeye	purse seine	1,937,604	482,109	1,455,495	2,047
China Main	albacore	gillnet	24,211	12,245	11,967	3,111
China Main	albacore	longline	743,715	-9,000,351	9,744,065	117
China Main	Atlantic bf	trap	10,492	-8,988	19,481	828
China Main	yellowfin	gillnet	60,845	30,772	30,073	3,111
China Main	bigeye	longline	3,297,799	-39,909,593	43,207,392	117
China Main	albacore	purse seine	1,758	438	1,321	2,047
China Main	yellowfin	longline	2,550,863	-30,870,260	33,421,123	117
China Main	yellowfin	purse seine	559,055	139,102	419,953	2,047
China Main	Atlantic bf	purse seine	12,461	3,100	9,360	2,047
China Main	skipjack	longline	5,613,180	-67,930,088	73,543,268	117
China Main	Atlantic bf	longline	163	-1,974	2,137	117
China Main	bigeye	gillnet	110,167	55,716	54,451	3,111
China Main	albacore	pole/line	242,716	70,840	171,876	2,172
China Main	yellowfin	pole/line	1,468,147	428,500	1,039,647	2,172
Taiwan	skipjack	purse seine	11,874	9,621	2,253	2,573
Taiwan	albacore	gillnet	2,852,480	1,898,738	953,742	1,460
Taiwan	Pacific bf	longline	460,606	239,645	220,961	1,018
Taiwan	bigeye	pole/line	9,103,434	7,056,697	2,046,737	2,172
Taiwan	bigeye	gillnet	251,138	167,168	83,969	1,460
Taiwan	bigeye	purse seine	6,109,794	4,950,619	1,159,175	2,573
Taiwan	yellowfin	pole/line	17,551,474	13,605,354	3,946,121	2,172
Taiwan	skipjack	longline	157,797,869	82,099,303	75,698,566	1,018

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Taiwan	skipjack	pole/line	181,894	140,998	40,895	2,172
Taiwan	yellowfin	hook/line	-22,730	-425,567	402,837	-28
Taiwan	southern bf	longline	934,085	485,987	448,098	1,018
Taiwan	albacore	longline	34,989,508	18,204,392	16,785,116	1,018
Taiwan	yellowfin	purse seine	2,800,080	2,268,837	531,243	2,573
Taiwan	Pacific bf	seine	7,082	5,187	1,895	1,825
Taiwan	southern bf	gillnet	32,440	21,594	10,847	1,460
Taiwan	albacore	pole/line	5,068,786	3,929,164	1,139,622	2,172
Taiwan	yellowfin	longline	113,440,811	59,021,149	54,419,662	1,018
Taiwan	Pacific bf	mw trawl	261,574	220,996	40,578	3,147
Taiwan	Pacific bf	hook/line	-20,406	-382,050	361,644	-28
Taiwan	Pacific bf	gillnet	128,104	85,272	42,832	1,460
Taiwan	skipjack	gillnet	22,177,193	14,762,127	7,415,065	1,460
Taiwan	yellowfin	gillnet	794,720	529,001	265,719	1,460
Taiwan	bigeye	longline	68,173,408	35,469,359	32,704,049	1,018
Taiwan	albacore	purse seine	555,954	450,476	105,478	2,573
Taiwan	albacore	hook/line	-19,683	-368,511	348,829	-28
Colombia	bigeye	longline	-346,240	-523,384	177,144	-254
Colombia	bigeye	purse seine	280,095	45,790	234,305	155
Colombia	skipjack	purse seine	1,457,143	238,213	1,218,930	155
Colombia	skipjack	longline	-695,781	-1,051,757	355,976	-254
Colombia	bigeye	pole/line	130	4	126	134
Colombia	skipjack	pole/line	46,267	1,348	44,918	134
Colombia	yellowfin	longline	-2,074,921	-3,136,496	1,061,575	-254
Colombia	yellowfin	purse seine	2,382,234	389,447	1,992,787	155
Colombia	yellowfin	pole/line	29,082	848	28,234	134
Comoros	bigeye	pole/line	-512	-528	16	-1,453
Comoros	yellowfin	longline	-13,753,869	-13,985,738	231,869	-2,663
Comoros	skipjack	pole/line	-4,649,861	-4,793,539	143,678	-1,453
Comoros	yellowfin	gillnet	-19,943	-20,779	837	-1,070
Comoros	yellowfin	hook/line	-124,482	-128,005	3,522	-1,587
Comoros	bigeye	gillnet	-118	-123	5	-1,070
Comoros	yellowfin	pole/line	-928,102	-956,780	28,678	-1,453
Comoros	bigeye	longline	-91,984	-93,535	1,551	-2,663
Mayotte*	bigeye	pole/line	-325	-350	24	-1,405
Mayotte	bigeye	gillnet	-96	-104	8	-1,326
Mayotte	albacore	longline	-34,239	-35,317	1,078	-3,345
Mayotte	yellowfin	longline	-884,178	-912,025	27,847	-3,345
Mayotte	albacore	pole/line	-1,739	-1,869	130	-1,405
Mayotte	skipjack	pole/line	-663,262	-712,986	49,724	-1,405
Mayotte	albacore	gillnet	-2,023	-2,184	161	-1,326
Mayotte	bigeye	longline	-75,916	-78,307	2,391	-3,345
Mayotte	yellowfin	hook/line	-10,966	-11,389	423	-2,731
Mayotte	yellowfin	pole/line	-45,941	-49,386	3,444	-1,405
Mayotte	yellowfin	gillnet	-1,264	-1,365	100	-1,326
Cook Is*	bigeye	gillnet	954	900	55	9,374
Cook Is	yellowfin	hook/line	569,532	531,148	38,384	7,969
Cook Is	yellowfin	purse seine	1,389,270	1,312,449	76,821	9,713

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Cook Is	bigeye	purse seine	517,456	488,843	28,613	9,713
Cook Is	yellowfin	longline	708,845	657,084	51,762	7,355
Cook Is	bigeye	hook/line	646,963	603,361	43,602	7,969
Cook Is	albacore	hook/line	2,901,959	2,706,381	195,578	7,969
Cook Is	skipjack	longline	38,522	35,709	2,813	7,355
Cook Is	albacore	longline	6,665,420	6,178,695	486,725	7,355
Cook Is	albacore	purse seine	1,599,008	1,510,590	88,418	9,713
Cook Is	yellowfin	gillnet	435,179	410,246	24,933	9,374
Cook Is	bigeye	longline	426,633	395,480	31,154	7,355
Cook Is	skipjack	hook/line	62,155	57,966	4,189	7,969
Cook Is	skipjack	pole/line	51,634	48,651	2,984	9,295
Cook Is	skipjack	gillnet	35,577	33,538	2,038	9,374
Cook Is	albacore	mw trawl	5,109,376	4,840,964	268,412	10,224
Cook Is	albacore	pole/line	4,054,883	3,820,577	234,307	9,295
Cook Is	bigeye	pole/line	255,018	240,282	14,736	9,295
Cook Is	skipjack	purse seine	83,658	79,032	4,626	9,713
Cook Is	yellowfin	pole/line	517,779	487,860	29,919	9,295
Croatia	Atlantic bf	pole/line	-73,701	-99,776	26,075	-699
Croatia	Atlantic bf	trap	-523,153	-596,423	73,270	-1,766
Croatia	Atlantic bf	purse seine	323,792	242,810	80,983	989
Croatia	Atlantic bf	longline	-1,059,655	-1,131,292	71,637	-3,659
Croatia	Atlantic bf	hook/line	-1,780	-2,358	578	-762
Cuba	skipjack	pole/line	99,193	82,365	16,828	1,765
Cuba	yellowfin	purse seine	13,800	11,487	2,313	1,786
Cuba	yellowfin	pole/line	2,048	1,700	347	1,765
Cuba	skipjack	longline	236,488	185,084	51,404	1,377
Cuba	yellowfin	longline	13,931	10,903	3,028	1,377
Cuba	skipjack	purse seine	512,827	426,871	85,956	1,786
Cyprus	albacore	pole/line	190,936	-174,361	365,297	1,602
Cyprus	Atlantic bf	longline	-57,375	-186,932	129,557	-1,357
Cyprus	Atlantic bf	purse seine	157,209	10,749	146,460	3,290
Cyprus	albacore	longline	-169,567	-552,464	382,897	-1,357
Cyprus	albacore	hook/line	206,551	-204,797	411,348	1,539
Cyprus	Atlantic bf	hook/line	525	-520	1,045	1,539
Cyprus	Atlantic bf	pole/line	24,649	-22,509	47,158	1,602
Cyprus	albacore	purse seine	153,725	10,511	143,214	3,290
Cyprus	Atlantic bf	trap	23,138	-109,373	132,511	535
Benin	bigeye	longline	-3,986	-4,474	487	-2,663
Benin	bigeye	purse seine	-1,034	-1,398	364	-924
Benin	bigeye	pole/line	-2,012	-2,462	451	-1,453
Dominica	skipjack	pole/line	7,319	-14,082	21,401	1,765
Dominica	yellowfin	longline	86,520	-237,610	324,131	1,377
Dominica	yellowfin	pole/line	12,717	-24,466	37,183	1,765
Dominica	skipjack	purse seine	37,840	-71,472	109,312	1,786
Dominica	skipjack	longline	17,450	-47,922	65,371	1,377
Dominica	yellowfin	purse seine	85,703	-161,876	247,579	1,786
Dominican Rp	yellowfin	purse seine	79,892	43,950	35,942	1,786
Dominican Rp	yellowfin	pole/line	11,854	6,456	5,398	1,765

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Dominican Rp	skipjack	pole/line	13,675	7,448	6,227	1,765
Dominican Rp	skipjack	longline	32,603	13,582	19,022	1,377
Dominican Rp	yellowfin	longline	80,654	33,598	47,056	1,377
Dominican Rp	skipjack	purse seine	70,700	38,893	31,807	1,786
Ecuador	bigeye	pole/line	1,220	367	853	134
Ecuador	skipjack	purse seine	16,617,799	6,605,565	10,012,234	155
Ecuador	yellowfin	pole/line	58,858	17,701	41,157	134
Ecuador	skipjack	pole/line	639,511	192,330	447,182	134
Ecuador	yellowfin	longline	-3,770,951	-5,160,522	1,389,571	-254
Ecuador	bigeye	longline	-2,086,924	-2,855,942	769,018	-254
Ecuador	yellowfin	purse seine	4,386,087	1,743,467	2,642,620	155
Ecuador	bigeye	purse seine	2,589,078	1,029,157	1,559,921	155
Ecuador	skipjack	longline	-7,852,651	-10,746,301	2,893,651	-254
Ecuador	yellowfin	gillnet	-26	-28	2	-1,226
El Salvador	yellowfin	purse seine	11,919,554	10,418,320	1,501,235	1,786
El Salvador	bigeye	purse seine	1,350,395	1,180,316	170,078	1,786
El Salvador	skipjack	purse seine	8,416,745	7,356,680	1,060,066	1,786
Faroe* Is	Atlantic bf	pole/line	-27	-80	54	-83
Faroe Is	Atlantic bf	purse seine	170	85	85	335
Faroe Is	Atlantic bf	longline	-234	-254	19	-2,023
Faroe Is	Atlantic bf	trap	-1,485	-1,661	177	-1,406
Fiji	skipjack	pole/line	130,681	71,303	59,378	7,927
Fiji	bigeye	longline	434,172	32,492	401,681	3,893
Fiji	yellowfin	gillnet	2,072,536	1,267,323	805,212	9,270
Fiji	bigeye	pole/line	418,153	228,155	189,997	7,927
Fiji	bigeye	purse seine	845,909	476,987	368,922	8,258
Fiji	skipjack	longline	60,509	4,528	55,981	3,893
Fiji	albacore	pole/line	12,981,698	7,083,162	5,898,536	7,927
Fiji	albacore	longline	13,244,159	991,139	12,253,020	3,893
Fiji	albacore	mw trawl	19,190,300	12,433,186	6,757,114	10,229
Fiji	yellowfin	longline	1,806,865	135,218	1,671,647	3,893
Fiji	bigeye	gillnet	1,815	1,110	705	9,270
Fiji	albacore	hook/line	10,707,017	5,783,439	4,923,578	7,832
Fiji	skipjack	hook/line	181,290	97,925	83,366	7,832
Fiji	skipjack	gillnet	104,410	63,845	40,565	9,270
Fiji	yellowfin	pole/line	2,126,549	1,160,302	966,247	7,927
Fiji	albacore	purse seine	5,103,759	2,877,883	2,225,876	8,258
Fiji	skipjack	purse seine	211,089	119,028	92,061	8,258
Fiji	yellowfin	purse seine	5,688,577	3,207,647	2,480,930	8,258
Fiji	yellowfin	hook/line	2,695,704	1,456,095	1,239,608	7,832
Fiji	bigeye	hook/line	1,222,551	660,366	562,185	7,832
France	Atlantic bf	hook/line	-34,380	-44,160	9,780	-1,740
France	bigeye	pole/line	-111,160	-866,822	755,662	-119
France	skipjack	longline	-207,131	-394,984	187,853	-1,526
France	bigeye	longline	-22,581,026	-28,515,146	5,934,120	-3,079
France	yellowfin	hook/line	-1,026,209	-1,220,503	194,294	-2,036
France	albacore	gillnet	-10,421	-20,553	10,132	-1,032
France	yellowfin	purse seine	11,898,120	1,081,833	10,816,287	424

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
France	albacore	purse seine	446,443	232,557	213,886	2,094
France	skipjack	purse seine	73,454,314	40,901,520	32,552,794	3,122
France	yellowfin	longline	-165,473,435	-180,571,778	15,098,343	-4,224
France	Atlantic bf	longline	-9,957,218	-11,211,725	1,254,507	-3,928
France	Atlantic bf	purse seine	2,261,171	706,705	1,554,466	720
France	yellowfin	pole/line	-15,143,715	-19,760,526	4,616,811	-1,264
France	skipjack	gillnet	-3	-832	829	-4
France	albacore	pole/line	215,049	-315,964	531,013	406
France	Atlantic bf	pole/line	-1,091,180	-1,648,898	557,718	-968
France	bigeye	purse seine	1,101,467	533,521	567,946	1,569
France	Atlantic bf	trap	-2,793,544	-4,416,061	1,622,517	-852
France	yellowfin	gillnet	-445,375	-508,886	63,511	-2,703
France	skipjack	pole/line	49,273,348	1,732,005	47,541,342	1,434
France	albacore	hook/line	-828,340	-3,105,317	2,276,977	-365
France	albacore	mw trawl	2,832,589	329,698	2,502,891	1,136
France	bigeye	gillnet	-31,761	-48,260	16,499	-1,557
France	albacore	longline	-1,262,371	-1,758,473	496,102	-2,553
French Polynesia*	albacore	longline	18,564,374	8,306,821	10,257,553	7,355
French Polynesia	bigeye	longline	4,457,215	1,994,427	2,462,788	7,355
French Polynesia	yellowfin	longline	10,201,580	4,564,802	5,636,777	7,355
French Polynesia	skipjack	longline	8,259,823	3,695,943	4,563,880	7,355
Gabon	yellowfin	longline	-1,956	-2,048	93	-2,663
Gabon	yellowfin	purse seine	-770	-875	105	-924
Gabon	yellowfin	pole/line	-628	-683	55	-1,453
Ghana	skipjack	longline	-1,649,934	-1,735,222	85,288	-2,663
Ghana	yellowfin	purse seine	-6,734,863	-7,738,149	1,003,286	-924
Ghana	skipjack	purse seine	-21,165,398	-24,318,387	3,152,989	-924
Ghana	bigeye	purse seine	-3,597,077	-4,132,930	535,853	-924
Ghana	bigeye	pole/line	-6,999,551	-7,662,722	663,171	-1,453
Ghana	skipjack	pole/line	-30,731,673	-33,643,340	2,911,667	-1,453
Ghana	yellowfin	longline	-17,104,838	-17,989,023	884,185	-2,663
Ghana	yellowfin	pole/line	-5,497,130	-6,017,954	520,825	-1,453
Ghana	bigeye	longline	-13,869,752	-14,586,708	716,956	-2,663
Kiribati	skipjack	hook/line	8,049,328	3,607,400	4,441,929	6,218
Kiribati	bigeye	hook/line	767,601	344,009	423,592	6,218
Kiribati	bigeye	longline	343,392	40,736	302,656	3,893
Kiribati	bigeye	gillnet	1,435	904	531	9,270
Kiribati	yellowfin	hook/line	2,250,337	1,008,515	1,241,823	6,218
Kiribati	skipjack	longline	3,384,259	401,469	2,982,790	3,893
Kiribati	yellowfin	pole/line	2,236,196	1,268,224	967,973	7,927
Kiribati	skipjack	gillnet	5,839,641	3,678,242	2,161,399	9,270
Kiribati	bigeye	purse seine	669,039	391,066	277,973	8,258
Kiribati	skipjack	pole/line	7,308,955	4,145,160	3,163,795	7,927
Kiribati	yellowfin	gillnet	2,179,399	1,372,748	806,651	9,270
Kiribati	yellowfin	longline	1,900,030	225,397	1,674,633	3,893
Kiribati	skipjack	purse seine	11,806,211	6,900,954	4,905,257	8,258
Kiribati	yellowfin	purse seine	5,981,888	3,496,527	2,485,361	8,258

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Kiribati	bigeye	pole/line	330,722	187,564	143,158	7,927
Greece	albacore	hook/line	242,384	-267,021	509,406	771
Greece	Atlantic bf	trap	-102,408	-306,151	203,743	-695
Greece	Atlantic bf	purse seine	335,570	110,380	225,190	2,060
Greece	albacore	purse seine	275,954	98,600	177,354	2,522
Greece	Atlantic bf	longline	-372,840	-572,042	199,201	-2,588
Greece	albacore	longline	-621,615	-1,095,788	474,173	-2,125
Greece	Atlantic bf	hook/line	359	-1,247	1,607	309
Greece	albacore	pole/line	232,830	-219,547	452,377	834
Greece	Atlantic bf	pole/line	19,514	-52,994	72,508	372
Grenada	bigeye	pole/line	237	-116	353	1,765
Grenada	yellowfin	pole/line	53,130	-25,991	79,120	1,765
Grenada	albacore	hook/line	5	-37	42	335
Grenada	yellowfin	longline	361,478	-328,229	689,708	1,377
Grenada	skipjack	longline	10,102	-9,173	19,276	1,377
Grenada	albacore	longline	32,518	-29,527	62,045	1,377
Grenada	albacore	pole/line	2,720	-1,330	4,050	1,765
Grenada	bigeye	longline	2,160	-1,961	4,121	1,377
Grenada	albacore	purse seine	6,849	-3,228	10,077	1,786
Grenada	bigeye	purse seine	532	-251	782	1,786
Grenada	skipjack	purse seine	21,907	-10,325	32,232	1,786
Grenada	yellowfin	purse seine	358,062	-168,753	526,816	1,786
Grenada	skipjack	pole/line	4,237	-2,073	6,310	1,765
Guam*	skipjack	longline	18,639	8,257	10,382	7,355
Guam	yellowfin	hook/line	17,927	8,711	9,216	7,969
Guam	yellowfin	purse seine	43,730	25,285	18,445	9,713
Guam	yellowfin	pole/line	16,298	9,114	7,184	9,295
Guam	yellowfin	gillnet	13,698	7,712	5,987	9,374
Guam	skipjack	gillnet	17,215	9,691	7,523	9,374
Guam	yellowfin	longline	22,312	9,884	12,428	7,355
Guam	skipjack	pole/line	24,984	13,972	11,013	9,295
Guam	skipjack	hook/line	30,075	14,614	15,461	7,969
Guam	skipjack	purse seine	40,480	23,406	17,074	9,713
Guatemala	yellowfin	longline	1,956,191	1,284,433	671,758	1,377
Guatemala	bigeye	longline	516,962	339,437	177,525	1,377
Guatemala	yellowfin	purse seine	5,525,920	4,062,654	1,463,266	1,786
Guatemala	bigeye	pole/line	612,665	448,457	164,207	1,765
Guatemala	skipjack	purse seine	7,531,211	5,536,944	1,994,267	1,786
Guatemala	yellowfin	pole/line	1,124,457	823,078	301,379	1,765
Guatemala	bigeye	purse seine	501,065	368,383	132,682	1,786
Guatemala	skipjack	pole/line	5,359,644	3,923,143	1,436,501	1,765
Guatemala	skipjack	longline	268,215	176,109	92,105	1,377
Guinea	yellowfin	gillnet	-44	-47	3	-1,070
Guinea	yellowfin	hook/line	-274	-289	14	-1,587
Guinea	yellowfin	pole/line	-2,045	-2,161	117	-1,453
Guinea	yellowfin	longline	-30,305	-31,247	942	-2,663
Honduras	bigeye	purse seine	2,343,858	1,626,272	717,586	1,786
Honduras	yellowfin	purse seine	3,069,674	2,129,875	939,799	1,786

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Honduras	yellowfin	pole/line	44,535	30,734	13,800	1,765
Honduras	skipjack	purse seine	6,633,604	4,602,687	2,030,917	1,786
Honduras	bigeye	pole/line	1,367	943	424	1,765
Honduras	skipjack	longline	1,732,609	1,044,708	687,901	1,377
Honduras	bigeye	longline	1,500,042	904,477	595,565	1,377
Honduras	yellowfin	longline	1,409,408	849,828	559,580	1,377
Honduras	skipjack	pole/line	254,780	175,829	78,951	1,765
India	yellowfin	longline	-25,768,758	-26,816,385	1,047,626	-3,445
India	yellowfin	gillnet	-21,370	-34,227	12,857	-233
India	skipjack	longline	-1,412,848	-1,470,287	57,439	-3,445
India	skipjack	gillnet	-5,559	-8,904	3,345	-233
India	yellowfin	hook/line	-140,977	-154,911	13,934	-1,417
India	skipjack	hook/line	-46	-51	5	-1,417
India	yellowfin	pole/line	-1,305,705	-1,437,170	131,465	-1,391
India	skipjack	pole/line	-2,033,457	-2,238,197	204,739	-1,391
Indonesia	southern bf	gillnet	-296,140	-384,296	88,156	-761
Indonesia	albacore	longline	-8,700,998	-9,206,590	505,593	-3,897
Indonesia	southern bf	seine	-97,422	-136,428	39,006	-566
Indonesia	skipjack	gillnet	-34,718,360	-43,483,011	8,764,651	-806
Indonesia	skipjack	pole/line	-34,409,032	-39,653,726	5,244,694	-1,335
Indonesia	yellowfin	hook/line	-24,628,110	-34,155,735	9,527,626	-585
Indonesia	yellowfin	pole/line	-2,062,088	-2,424,164	362,076	-1,290
Indonesia	albacore	hook/line	-13,397,433	-18,580,362	5,182,929	-585
Indonesia	skipjack	hook/line	-101,999,059	-134,908,359	32,909,300	-631
Indonesia	yellowfin	gillnet	-4,618,210	-5,992,968	1,374,758	-761
Indonesia	southern bf	hook/line	-597,944	-829,265	231,321	-585
Indonesia	bigeye	gillnet	-21,087	-27,365	6,277	-761
Indonesia	yellowfin	longline	-48,388,633	-51,200,372	2,811,739	-3,897
Indonesia	skipjack	longline	-95,388,182	-100,311,512	4,923,331	-3,942
Indonesia	bigeye	hook/line	-17,082,196	-23,690,611	6,608,415	-585
Indonesia	bigeye	longline	-33,879,424	-35,848,070	1,968,646	-3,897
Indonesia	southern bf	mw trawl	-44,246	-76,160	31,914	-314
Indonesia	albacore	gillnet	-255,052	-330,977	75,924	-761
Indonesia	bigeye	pole/line	-114,350	-134,429	20,078	-1,290
Iran	yellowfin	longline	4,476,275	-49,278,667	53,754,942	117
Iran	yellowfin	hook/line	1,163,212	346,594	816,618	2,008
Iran	yellowfin	pole/line	10,243,223	3,594,768	6,648,455	2,172
Iran	yellowfin	gillnet	428,079	234,148	193,931	3,111
Iran	skipjack	pole/line	175,139,908	61,463,795	113,676,113	2,172
Ireland	skipjack	pole/line	18	-2,956	2,973	4
Ireland	albacore	hook/line	-1,385	-16,061	14,675	-59
Ireland	albacore	mw trawl	455,949	293,514	162,435	1,763
Ireland	Atlantic bf	trap	-483	-814	332	-914
Ireland	Atlantic bf	longline	-171	-207	36	-2,956
Ireland	Atlantic bf	purse seine	429	270	159	1,692
Ireland	skipjack	longline	-410	-497	87	-2,956
Ireland	skipjack	purse seine	8,674	5,454	3,220	1,692
Italy	albacore	gillnet	1,854	-1,878	3,732	1,128

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Italy	albacore	pole/line	2,053,337	619,259	1,434,078	3,251
Italy	Atlantic bf	purse seine	7,666,626	4,142,360	3,524,266	4,939
Italy	Atlantic bf	pole/line	1,624,778	490,012	1,134,766	3,251
Italy	yellowfin	pole/line	1,745,064	526,288	1,218,776	3,251
Italy	bigeye	gillnet	1,089	-1,104	2,193	1,128
Italy	albacore	longline	195,425	-1,329,602	1,525,027	291
Italy	albacore	purse seine	1,220,483	659,440	561,043	4,939
Italy	yellowfin	gillnet	17,659	-17,892	35,551	1,128
Italy	albacore	hook/line	2,262,589	651,133	1,611,456	3,188
Italy	yellowfin	hook/line	210,189	60,489	149,700	3,188
Italy	yellowfin	longline	1,262,769	-8,591,433	9,854,202	291
Italy	Atlantic bf	longline	399,497	-2,718,040	3,117,537	291
Italy	Atlantic bf	hook/line	35,305	10,160	25,145	3,188
Italy	skipjack	longline	4,946	-33,649	38,594	291
Italy	skipjack	pole/line	13,151,928	3,966,448	9,185,480	3,251
Italy	Atlantic bf	trap	1,011,288	-2,177,336	3,188,624	720
Italy	bigeye	pole/line	10,044	3,029	7,015	3,251
Italy	bigeye	longline	88,134	-599,629	687,763	291
Cote d'Ivoire*	yellowfin	pole/line	-54,993	-59,234	4,240	-1,453
Cote d'Ivoire	yellowfin	longline	-171,117	-178,316	7,199	-2,663
Cote d'Ivoire	skipjack	purse seine	-596,522	-668,844	72,322	-924
Cote d'Ivoire	yellowfin	purse seine	-67,376	-75,544	8,169	-924
Cote d'Ivoire	skipjack	longline	-46,501	-48,458	1,956	-2,663
Cote d'Ivoire	skipjack	pole/line	-866,136	-932,923	66,787	-1,453
Japan	Atlantic bf	pole/line	9,029,156	5,679,904	3,349,252	21,662
Japan	skipjack	hook/line	551	176	374	3,169
Japan	Atlantic bf	hook/line	536,794	324,271	212,523	20,295
Japan	southern bf	gillnet	9,236,433	5,953,415	3,283,018	22,739
Japan	bigeye	pole/line	51,172,425	29,120,078	22,052,347	6,812
Japan	yellowfin	pole/line	24,834,824	10,906,037	13,928,787	2,742
Japan	Pacific bf	gillnet	10,869,936	6,784,709	4,085,227	8,440
Japan	southern bf	longline	62,380,996	35,835,061	26,545,935	18,993
Japan	skipjack	longline	9,677,299	-2,378,351	12,055,650	1,729
Japan	Atlantic bf	trap	27,518,100	16,635,757	10,882,343	20,319
Japan	yellowfin	hook/line	674,807	-79,530	754,337	1,376
Japan	albacore	gillnet	1,593,085	849,179	743,905	2,215
Japan	albacore	pole/line	1,723,684	325,585	1,398,098	1,275
Japan	yellowfin	longline	-6,201,145	-155,349,819	149,148,674	-64
Japan	skipjack	pole/line	1,624,459,449	853,007,414	771,452,035	4,535
Japan	albacore	longline	-110,455,479	-185,051,639	74,596,160	-1,531
Japan	Atlantic bf	longline	10,805,338	6,200,703	4,604,635	18,856
Japan	bigeye	longline	434,654,185	116,134,530	318,519,655	4,006
Japan	albacore	purse seine	169,945	14,091	155,854	1,128
Japan	southern bf	mw trawl	7,123,261	4,595,358	2,527,903	22,775
Japan	bigeye	purse seine	56,228,992	31,461,932	24,767,060	6,665
Japan	albacore	hook/line	-30,450	-374,814	344,364	-91
Japan	Atlantic bf	purse seine	16,379,809	10,262,317	6,117,493	21,515
Japan	bigeye	gillnet	525,590	326,546	199,044	7,752

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Japan	yellowfin	purse seine	21,680,918	8,830,650	12,850,268	2,595
Japan	skipjack	purse seine	413,215,387	210,391,298	202,824,089	4,388
Japan	Pacific bf	mw trawl	1,519,189	950,661	568,527	8,476
Japan	yellowfin	gillnet	580,244	337,863	242,381	3,682
Japan	southern bf	purse seine	1,164,088	729,550	434,539	21,652
Japan	southern bf	hook/line	52,006,834	31,435,100	20,571,734	20,433
Japan	southern bf	pole/line	864,271	543,831	320,440	21,799
Japan	skipjack	gillnet	697,933	423,375	274,558	5,475
Japan	Pacific bf	longline	3,934,976	1,275,965	2,659,011	4,694
Japan	Pacific bf	hook/line	4,063,559	1,962,205	2,101,354	6,134
Kenya	skipjack	pole/line	-781,798	-911,849	130,051	-1,453
Korea Rep	Atlantic bf	hook/line	2,786	-364	3,150	1,234
Korea Rep	yellowfin	hook/line	-13,579	-66,527	52,948	-212
Korea Rep	yellowfin	longline	-192,997,756	-258,228,919	65,231,164	-2,444
Korea Rep	albacore	purse seine	936	340	596	1,519
Korea Rep	Atlantic bf	pole/line	184,271	42,130	142,141	1,808
Korea Rep	Atlantic bf	trap	-184,215	-583,622	399,407	-643
Korea Rep	albacore	hook/line	4,828	-26,868	31,696	147
Korea Rep	yellowfin	pole/line	322,971	-412,756	735,728	363
Korea Rep	yellowfin	purse seine	176,462	50,845	125,617	1,160
Korea Rep	albacore	pole/line	65,155	-22,167	87,323	722
Korea Rep	bigeye	pole/line	2,203,040	1,040,601	1,162,439	5,093
Korea Rep	southern bf	longline	-32,937	-78,965	46,028	-998
Korea Rep	Atlantic bf	purse seine	824,761	383,311	441,450	2,606
Korea Rep	albacore	gillnet	42,589	8,047	34,542	1,193
Korea Rep	Atlantic bf	longline	-279,444	-669,946	390,503	-998
Korea Rep	albacore	longline	-9,135,415	-13,374,382	4,238,966	-2,085
Korea Rep	bigeye	purse seine	1,972,289	1,072,532	899,757	5,891
Korea Rep	bigeye	longline	85,137,810	-14,918,574	100,056,384	2,287
Korea Rep	yellowfin	gillnet	37,827	341	37,486	833
Korea Rep	bigeye	gillnet	70,128	36,257	33,872	5,564
Korea Rep	skipjack	longline	-815,885,692	-905,507,308	89,621,617	-3,551
Latvia	yellowfin	pole/line	-97,973	-170,788	72,815	-699
Latvia	yellowfin	longline	-870,455	-994,070	123,615	-3,659
Latvia	yellowfin	purse seine	266,977	126,710	140,267	989
Liberia	yellowfin	pole/line	-37,395	-38,798	1,403	-1,453
Liberia	yellowfin	longline	-116,359	-118,740	2,381	-2,663
Liberia	yellowfin	purse seine	-45,815	-48,517	2,702	-924
Liberia	bigeye	longline	-31,891	-32,544	653	-2,663
Liberia	bigeye	pole/line	-16,094	-16,698	604	-1,453
Liberia	bigeye	purse seine	-8,271	-8,759	488	-924
Libya	yellowfin	pole/line	-22,940	-23,860	920	-1,453
Libya	yellowfin	longline	-71,380	-72,943	1,563	-2,663
Libya	yellowfin	purse seine	-28,105	-29,878	1,773	-924
Lithuania	skipjack	longline	-14,055	-14,961	906	-3,659
Lithuania	skipjack	purse seine	140,448	106,949	33,498	989
Lithuania	skipjack	pole/line	-91,685	-122,620	30,934	-699
Malaysia	bigeye	pole/line	-4,494	-5,833	1,338	-682

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Malaysia	yellowfin	longline	-5,320,537	-5,715,389	394,852	-2,736
Malaysia	yellowfin	gillnet	-21,490	-35,689	14,199	-307
Malaysia	bigeye	gillnet	-633	-1,052	418	-307
Malaysia	yellowfin	purse seine	-40,764	-51,030	10,267	-806
Malaysia	yellowfin	hook/line	-32,393	-41,350	8,957	-734
Malaysia	albacore	gillnet	-401	-666	265	-307
Malaysia	bigeye	longline	-1,768,381	-1,899,618	131,237	-2,736
Malaysia	albacore	longline	-23,787	-25,553	1,765	-2,736
Malaysia	yellowfin	pole/line	-181,160	-235,114	53,954	-682
Maldives	yellowfin	longline	17,230,265	8,896,544	8,333,721	960
Maldives	skipjack	pole/line	284,493,835	223,626,776	60,867,059	2,170
Maldives	skipjack	longline	880,512	454,637	425,875	960
Maldives	skipjack	hook/line	148	114	34	2,037
Maldives	yellowfin	pole/line	4,820,468	3,789,135	1,031,332	2,170
Maldives	bigeye	pole/line	22,868	17,976	4,893	2,170
Maldives	bigeye	longline	991,827	512,112	479,714	960
Maldives	bigeye	gillnet	8,410	6,881	1,530	2,553
Maldives	yellowfin	gillnet	181,407	148,413	32,994	2,553
Maldives	yellowfin	hook/line	552,493	426,531	125,962	2,037
Maldives	skipjack	gillnet	136,347	111,548	24,799	2,553
Malta	albacore	longline	-16,131	-28,732	12,601	-3,659
Malta	albacore	hook/line	-3,610	-17,147	13,538	-762
Malta	Atlantic bf	trap	-177,288	-464,219	286,931	-1,766
Malta	albacore	purse seine	1,631	-3,082	4,713	989
Malta	Atlantic bf	longline	-359,099	-639,634	280,534	-3,659
Malta	Atlantic bf	pole/line	-24,976	-127,089	102,113	-699
Malta	Atlantic bf	hook/line	-603	-2,866	2,263	-762
Malta	albacore	pole/line	-2,941	-14,963	12,022	-699
Malta	Atlantic bf	purse seine	109,728	-207,406	317,134	989
Mauritius	yellowfin	gillnet	-539	-590	52	-1,070
Mauritius	yellowfin	longline	-371,587	-385,901	14,314	-2,663
Mauritius	bigeye	longline	-153,482	-159,395	5,912	-2,663
Mauritius	skipjack	pole/line	-22,377	-23,957	1,580	-1,453
Mauritius	yellowfin	hook/line	-3,363	-3,581	217	-1,587
Mauritius	albacore	longline	-101,499	-105,409	3,910	-2,663
Mauritius	albacore	pole/line	-6,694	-7,167	473	-1,453
Mauritius	bigeye	gillnet	-197	-216	19	-1,070
Mauritius	albacore	gillnet	-6,083	-6,666	583	-1,070
Mauritius	bigeye	pole/line	-854	-914	60	-1,453
Mauritius	yellowfin	pole/line	-25,074	-26,845	1,770	-1,453
Mexico	Pacific bf	hook/line	-954,621	-1,021,493	66,872	-2,115
Mexico	bigeye	purse seine	-138,531	-151,338	12,807	-1,603
Mexico	Pacific bf	gillnet	-2,661	-4,149	1,488	-265
Mexico	Atlantic bf	purse seine	-12,686	-13,859	1,173	-1,603
Mexico	Atlantic bf	longline	-22,238	-23,432	1,194	-2,760
Mexico	skipjack	pole/line	-908,404	-1,049,205	140,802	-828
Mexico	albacore	longline	-13,305	-14,019	714	-2,760
Mexico	yellowfin	longline	-15,889,345	-16,742,452	853,107	-2,760

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Mexico	Pacific bf	purse seine	-651,000	-711,183	60,183	-1,603
Mexico	yellowfin	purse seine	-216,555,343	-236,575,359	20,020,016	-1,603
Mexico	albacore	pole/line	-13,976	-16,889	2,914	-711
Mexico	skipjack	purse seine	-22,240,516	-23,900,339	1,659,823	-1,721
Mexico	bigeye	longline	-304,936	-321,308	16,372	-2,760
Mexico	skipjack	longline	-1,210,073	-1,264,070	53,997	-2,878
Mexico	yellowfin	gillnet	-26	-41	15	-265
Mexico	Pacific bf	longline	-268,880	-283,317	14,436	-2,760
Mexico	Atlantic bf	trap	-2,440	-2,577	137	-2,644
Mexico	Atlantic bf	pole/line	0	0	0	-711
Mexico	Pacific bf	pole/line	-22,143	-26,760	4,617	-711
Mexico	bigeye	pole/line	-6,475	-7,825	1,350	-711
Mexico	yellowfin	pole/line	-1,910,151	-2,308,393	398,242	-711
Mexico	Atlantic bf	hook/line	-10,799	-11,556	756	-2,115
Morocco	Atlantic bf	longline	-88,615	-92,944	4,329	-2,663
Morocco	bigeye	purse seine	-134,144	-153,028	18,883	-924
Morocco	yellowfin	purse seine	-70,456	-80,374	9,918	-924
Morocco	yellowfin	longline	-178,940	-187,680	8,741	-2,663
Morocco	bigeye	pole/line	-261,031	-284,401	23,370	-1,453
Morocco	bigeye	longline	-517,239	-542,504	25,265	-2,663
Morocco	skipjack	longline	-70,084	-73,507	3,423	-2,663
Morocco	Atlantic bf	trap	-2,442,258	-2,649,958	207,700	-1,530
Morocco	Atlantic bf	purse seine	-792,445	-903,996	111,551	-924
Morocco	yellowfin	pole/line	-57,507	-62,656	5,149	-1,453
Morocco	Atlantic bf	pole/line	-13,803	-15,039	1,236	-1,453
Morocco	albacore	pole/line	-99,759	-108,690	8,931	-1,453
Morocco	skipjack	purse seine	-897,608	-1,023,963	126,355	-924
Morocco	albacore	hook/line	-59,223	-64,078	4,856	-1,587
Morocco	Atlantic bf	hook/line	-334	-361	27	-1,587
Morocco	skipjack	pole/line	-1,302,573	-1,419,192	116,618	-1,453
Morocco	albacore	purse seine	-295	-337	42	-924
Morocco	albacore	longline	-190,968	-200,296	9,328	-2,663
Oman	yellowfin	gillnet	162,295	86,480	75,815	3,111
Oman	yellowfin	longline	1,697,066	-19,317,758	21,014,825	117
Oman	yellowfin	pole/line	3,883,458	1,284,328	2,599,131	2,172
Oman	yellowfin	hook/line	441,002	121,756	319,247	2,008
Oman	skipjack	pole/line	1,557,656	515,144	1,042,512	2,172
Namibia	yellowfin	purse seine	-16,896	-18,669	1,772	-924
Namibia	albacore	hook/line	-61,368	-104,748	43,380	-137
Namibia	southern bf	pole/line	-611	-652	41	-1,453
Namibia	yellowfin	longline	-192,363	-199,365	7,002	-2,663
Namibia	bigeye	longline	-423,193	-438,598	15,405	-2,663
Namibia	southern bf	longline	-1,543	-1,599	56	-2,663
Namibia	albacore	purse seine	-13,121	-14,498	1,376	-924
Namibia	yellowfin	pole/line	-64,648	-68,962	4,313	-1,453
Namibia	bigeye	purse seine	-30,968	-34,217	3,249	-924
Namibia	albacore	pole/line	-1,611,343	-1,718,851	107,508	-1,453
Namibia	bigeye	pole/line	-166,514	-177,623	11,110	-1,453

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Namibia	albacore	longline	-2,059,890	-2,134,874	74,984	-2,663
Nauru	bigeye	gillnet	13	6	7	9,270
Nauru	skipjack	hook/line	20,336	3,099	17,237	6,218
Nauru	bigeye	hook/line	6,883	1,049	5,834	6,218
Nauru	bigeye	purse seine	5,999	2,171	3,829	8,258
Nauru	yellowfin	purse seine	34,320	12,418	21,902	8,258
Nauru	skipjack	longline	8,550	-3,025	11,575	3,893
Nauru	bigeye	longline	3,079	-1,089	4,169	3,893
Nauru	yellowfin	gillnet	12,504	5,395	7,109	9,270
Nauru	bigeye	pole/line	2,966	994	1,972	7,927
Nauru	yellowfin	hook/line	12,911	1,967	10,944	6,218
Nauru	skipjack	purse seine	29,828	10,792	19,035	8,258
Nauru	skipjack	pole/line	18,466	6,188	12,277	7,927
Nauru	yellowfin	pole/line	12,830	4,300	8,530	7,927
Nauru	yellowfin	longline	10,901	-3,857	14,758	3,893
Nauru	skipjack	gillnet	14,754	6,366	8,388	9,270
Netherlands	skipjack	purse seine	-4,216	-4,356	140	-411
Netherlands	skipjack	longline	-1,403	-1,407	4	-5,059
Netherlands	skipjack	pole/line	-19,878	-20,007	130	-2,099
New Caledonia*	yellowfin	hook/line	617,797	302,744	315,052	7,969
New Caledonia	yellowfin	pole/line	561,659	316,082	245,576	9,295
New Caledonia	albacore	hook/line	1,946,063	953,646	992,417	7,969
New Caledonia	bigeye	longline	147,382	65,948	81,435	7,355
New Caledonia	bigeye	pole/line	88,097	49,578	38,519	9,295
New Caledonia	albacore	pole/line	2,719,217	1,530,283	1,188,934	9,295
New Caledonia	albacore	purse seine	1,072,300	623,643	448,657	9,713
New Caledonia	bigeye	hook/line	223,496	109,522	113,975	7,969
New Caledonia	albacore	longline	4,469,852	2,000,081	2,469,770	7,355
New Caledonia	bigeye	purse seine	178,758	103,964	74,793	9,713
New Caledonia	yellowfin	purse seine	1,507,005	876,464	630,540	9,713
New Caledonia	yellowfin	longline	768,917	344,060	424,857	7,355
New Caledonia	skipjack	longline	311	139	172	7,355
New Caledonia	yellowfin	gillnet	472,059	267,410	204,649	9,374
New Caledonia	bigeye	gillnet	330	187	143	9,374
New Caledonia	albacore	mw trawl	3,426,363	2,064,371	1,361,993	10,224
New Caledonia	skipjack	gillnet	287	163	124	9,374
New Caledonia	skipjack	purse seine	675	392	282	9,713
New Caledonia	skipjack	hook/line	501	246	256	7,969
New Caledonia	skipjack	pole/line	416	234	182	9,295
Vanuatu	yellowfin	longline	3,554,934	720,646	2,834,287	3,893
Vanuatu	bigeye	purse seine	24,597,987	15,353,048	9,244,940	8,258
Vanuatu	albacore	hook/line	838,251	419,805	418,446	6,218
Vanuatu	albacore	purse seine	528,843	330,082	198,761	8,258
Vanuatu	bigeye	longline	3,319,770	672,975	2,646,796	3,893
Vanuatu	bigeye	pole/line	84,385	51,343	33,043	7,927
Vanuatu	albacore	pole/line	2,162,156	1,315,526	846,629	7,927
Vanuatu	yellowfin	purse seine	105,895,138	66,095,371	39,799,767	8,258
Vanuatu	albacore	longline	39,156,884	7,937,773	31,219,110	3,893

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Vanuatu	skipjack	purse seine	555,333,696	346,616,355	208,717,341	8,258
Vanuatu	yellowfin	pole/line	435,117	264,740	170,378	7,927
Vanuatu	skipjack	longline	3,331,983	675,450	2,656,533	3,893
Vanuatu	skipjack	pole/line	778,650	473,756	304,894	7,927
New Zealand	Pacific bf	seine	47,349	44,808	2,541	10,008
New Zealand	southern bf	hook/line	711,890	650,396	61,494	6,218
New Zealand	skipjack	gillnet	24,196,998	22,795,097	1,401,902	9,270
New Zealand	bigeye	longline	543,998	468,946	75,052	3,893
New Zealand	albacore	longline	4,995,017	4,305,883	689,133	3,893
New Zealand	bigeye	pole/line	523,927	488,426	35,500	7,927
New Zealand	bigeye	purse seine	1,059,885	990,954	68,931	8,258
New Zealand	yellowfin	pole/line	2,700,685	2,517,692	182,993	7,927
New Zealand	southern bf	gillnet	684,203	644,563	39,641	9,270
New Zealand	southern bf	mw trawl	348,435	330,140	18,296	10,229
New Zealand	bigeye	gillnet	2,274	2,142	132	9,270
New Zealand	skipjack	pole/line	30,285,212	28,233,148	2,052,064	7,927
New Zealand	southern bf	seine	416,675	394,314	22,361	10,008
New Zealand	yellowfin	hook/line	2,717,763	2,483,000	234,764	6,218
New Zealand	albacore	mw trawl	7,237,595	6,857,562	380,033	10,229
New Zealand	albacore	hook/line	3,205,691	2,928,780	276,911	6,218
New Zealand	Pacific bf	gillnet	77,750	73,246	4,505	9,270
New Zealand	albacore	pole/line	4,896,030	4,564,285	331,745	7,927
New Zealand	Pacific bf	hook/line	80,897	73,909	6,988	6,218
New Zealand	skipjack	longline	14,022,932	12,088,269	1,934,662	3,893
New Zealand	yellowfin	purse seine	7,224,408	6,754,556	469,852	8,258
New Zealand	albacore	purse seine	1,924,876	1,799,688	125,188	8,258
New Zealand	yellowfin	gillnet	2,632,089	2,479,594	152,495	9,270
New Zealand	skipjack	purse seine	48,919,942	45,738,351	3,181,592	8,258
New Zealand	Pacific bf	mw trawl	39,595	37,516	2,079	10,229
New Zealand	skipjack	hook/line	33,353,003	30,471,931	2,881,072	6,218
New Zealand	bigeye	hook/line	1,216,027	1,110,985	105,042	6,218
New Zealand	yellowfin	longline	2,294,692	1,978,107	316,585	3,893
Nicaragua	bigeye	purse seine	27,246	19,926	7,319	1,786
Nicaragua	skipjack	pole/line	41,286	30,060	11,226	1,765
Nicaragua	bigeye	hook/line	1,114	-480	1,594	335
Nicaragua	yellowfin	pole/line	6,201	4,515	1,686	1,765
Nicaragua	skipjack	purse seine	4,356,218	3,185,976	1,170,242	1,786
Nicaragua	bigeye	pole/line	1,995	1,452	542	1,765
Nicaragua	bigeye	longline	18,307	11,930	6,378	1,377
Nicaragua	skipjack	longline	280,761	182,950	97,811	1,377
Nicaragua	yellowfin	longline	236,160	153,887	82,272	1,377
Nicaragua	yellowfin	purse seine	12,746,637	9,322,417	3,424,220	1,786
Niue*	albacore	longline	154,617	143,327	11,291	7,355
Niue	yellowfin	purse seine	114,371	108,047	6,324	9,713
Niue	bigeye	gillnet	43	41	2	9,374
Niue	skipjack	purse seine	10,795	10,198	597	9,713
Niue	skipjack	gillnet	4,591	4,328	263	9,374
Niue	yellowfin	gillnet	35,826	33,773	2,053	9,374

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Niue	bigeye	longline	19,392	17,976	1,416	7,355
Niue	skipjack	longline	4,971	4,608	363	7,355
Niue	albacore	hook/line	67,317	62,780	4,537	7,969
Niue	albacore	mw trawl	118,522	112,296	6,226	10,224
Niue	bigeye	purse seine	23,521	22,220	1,301	9,713
Niue	albacore	purse seine	37,092	35,041	2,051	9,713
Niue	skipjack	hook/line	8,020	7,480	541	7,969
Niue	yellowfin	pole/line	42,626	40,163	2,463	9,295
Niue	albacore	pole/line	94,061	88,626	5,435	9,295
Niue	yellowfin	hook/line	46,886	43,726	3,160	7,969
Niue	bigeye	pole/line	11,592	10,922	670	9,295
Niue	bigeye	hook/line	29,407	27,426	1,982	7,969
Niue	yellowfin	longline	58,355	54,094	4,261	7,355
Niue	skipjack	pole/line	6,662	6,278	385	9,295
North Marianus*	yellowfin	hook/line	26,201	12,731	13,470	7,969
North Marianas	yellowfin	pole/line	23,820	13,321	10,499	9,295
North Marianus	skipjack	hook/line	186,466	90,605	95,861	7,969
North Marianas	skipjack	purse seine	250,974	145,114	105,860	9,713
North Marianas	yellowfin	purse seine	63,913	36,955	26,958	9,713
North Marianus	yellowfin	gillnet	20,020	11,271	8,750	9,374
North Marianas	yellowfin	longline	32,610	14,446	18,164	7,355
North Marianus	skipjack	gillnet	106,730	60,085	46,645	9,374
North Marianas	skipjack	longline	115,565	51,193	64,371	7,355
North Marianas	skipjack	pole/line	154,903	86,625	68,278	9,295
Micronesia	skipjack	purse seine	53,141,729	11,792,879	41,348,850	8,258
Micronesia	skipjack	gillnet	26,285,193	8,065,692	18,219,501	9,270
Micronesia	bigeye	purse seine	927,899	205,914	721,986	8,258
Micronesia	bigeye	gillnet	1,991	611	1,380	9,270
Micronesia	albacore	hook/line	239	-8	247	6,218
Micronesia	albacore	pole/line	365	69	296	7,927
Micronesia	yellowfin	hook/line	4,476,885	-149,741	4,626,626	6,218
Micronesia	skipjack	pole/line	32,898,816	6,229,622	26,669,194	7,927
Micronesia	albacore	mw trawl	539	200	339	10,229
Micronesia	skipjack	longline	15,233,110	-9,910,303	25,143,414	3,893
Micronesia	yellowfin	longline	3,779,973	-2,459,162	6,239,135	3,893
Micronesia	albacore	purse seine	143	32	112	8,258
Micronesia	skipjack	hook/line	36,231,362	-1,211,851	37,443,213	6,218
Micronesia	bigeye	hook/line	1,064,598	-35,608	1,100,206	6,218
Micronesia	bigeye	pole/line	458,683	86,855	371,828	7,927
Micronesia	albacore	longline	372	-242	614	3,893
Micronesia	yellowfin	purse seine	11,900,537	2,640,892	9,259,644	8,258
Micronesia	bigeye	longline	476,255	-309,840	786,096	3,893
Micronesia	yellowfin	gillnet	4,335,758	1,330,441	3,005,317	9,270
Micronesia	yellowfin	pole/line	4,448,753	842,403	3,606,351	7,927
Marshall Is	yellowfin	pole/line	8,155,513	3,708,296	4,447,217	7,927
Marshall Is	yellowfin	hook/line	8,207,083	2,501,702	5,705,381	6,218
Marshall Is	skipjack	hook/line	74,407,177	22,680,965	51,726,211	6,218

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Marshall Is	bigeye	longline	996,646	-109,937	1,106,583	3,893
Marshall Is	skipjack	longline	31,283,747	-3,450,814	34,734,561	3,893
Marshall Is	bigeye	hook/line	2,227,854	679,100	1,548,755	6,218
Marshall Is	yellowfin	longline	6,929,497	-764,372	7,693,869	3,893
Marshall Is	bigeye	pole/line	959,873	436,452	523,421	7,927
Marshall Is	skipjack	pole/line	67,563,248	30,720,880	36,842,368	7,927
Marshall Is	skipjack	gillnet	53,981,057	28,811,586	25,169,471	9,270
Marshall Is	skipjack	purse seine	109,135,430	52,013,757	57,121,673	8,258
Marshall Is	yellowfin	gillnet	7,948,368	4,242,323	3,706,045	9,270
Marshall Is	yellowfin	purse seine	21,816,226	10,397,576	11,418,651	8,258
Marshall Is	bigeye	purse seine	1,941,790	925,454	1,016,336	8,258
Marshall Is	bigeye	gillnet	4,166	2,223	1,942	9,270
Palau	yellowfin	purse seine	715	-94	809	8,258
Palau	yellowfin	hook/line	269	-135	404	6,218
Palau	yellowfin	gillnet	261	-2	263	9,270
Palau	yellowfin	pole/line	267	-48	315	7,927
Palau	yellowfin	longline	227	-318	545	3,893
Pakistan	yellowfin	pole/line	1,140,878	495,974	644,905	2,172
Pakistan	yellowfin	hook/line	129,557	50,345	79,213	2,008
Pakistan	yellowfin	longline	498,562	-4,715,705	5,214,268	117
Pakistan	yellowfin	gillnet	47,679	28,867	18,811	3,111
Pakistan	skipjack	pole/line	7,772,076	3,378,752	4,393,325	2,172
Panama	albacore	hook/line	1,196	-341	1,536	335
Panama	bigeye	longline	7,115,945	4,889,174	2,226,770	1,377
Panama	yellowfin	longline	13,242,029	9,098,242	4,143,787	1,377
Panama	yellowfin	purse seine	44,167,459	33,509,789	10,657,670	1,786
Panama	yellowfin	pole/line	3,156,410	2,385,498	770,912	1,765
Panama	albacore	longline	9,432	6,481	2,952	1,377
Panama	albacore	purse seine	54	41	13	1,786
Panama	bigeye	purse seine	9,676,058	7,341,211	2,334,846	1,786
Panama	skipjack	purse seine	49,378,232	37,463,195	11,915,037	1,786
Panama	albacore	pole/line	11,571	8,745	2,826	1,765
Panama	bigeye	pole/line	1,488,980	1,125,316	363,664	1,765
Panama	skipjack	pole/line	11,493,016	8,685,997	2,807,019	1,765
Panama	skipjack	longline	6,987,193	4,800,713	2,186,481	1,377
Papua N Guin	yellowfin	hook/line	54,884,611	16,730,052	38,154,558	6,218
Papua N Guin	albacore	pole/line	3,045,253	1,384,671	1,660,583	7,927
Papua N Guin	skipjack	longline	109,403,338	-12,067,946	121,471,283	3,893
Papua N Guin	skipjack	pole/line	236,277,461	107,434,910	128,842,551	7,927
Papua N Guin	albacore	hook/line	1,993,889	607,782	1,386,107	6,218
Papua N Guin	bigeye	purse seine	7,437,197	3,544,555	3,892,642	8,258
Papua N Guin	albacore	purse seine	1,197,243	570,604	626,639	8,258
Papua N Guin	yellowfin	purse seine	145,895,246	69,533,422	76,361,824	8,258
Papua N Guin	bigeye	hook/line	8,532,845	2,601,001	5,931,844	6,218
Papua N Guin	bigeye	longline	3,817,227	-421,067	4,238,294	3,893
Papua N Guin	albacore	longline	3,106,821	-342,704	3,449,524	3,893
Papua N Guin	skipjack	hook/line	260,211,634	79,318,304	180,893,330	6,218
Papua N Guin	albacore	mw trawl	4,501,668	2,599,376	1,902,293	10,229

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Papua N Guin	yellowfin	longline	46,340,767	-5,111,707	51,452,474	3,893
Papua N Guin	bigeye	pole/line	3,676,384	1,671,645	2,004,739	7,927
Papua N Guin	bigeye	gillnet	15,955	8,516	7,439	9,270
Papua N Guin	yellowfin	gillnet	53,154,458	28,370,401	24,784,056	9,270
Papua N Guin	yellowfin	pole/line	54,539,722	24,799,107	29,740,614	7,927
Papua N Guin	skipjack	purse seine	381,660,894	181,898,921	199,761,972	8,258
Papua N Guin	skipjack	gillnet	188,778,748	100,757,849	88,020,899	9,270
Peru	yellowfin	pole/line	14,777	2,413	12,364	134
Peru	yellowfin	longline	-1,132,935	-1,632,470	499,535	-254
Peru	skipjack	pole/line	596	97	499	134
Peru	skipjack	longline	-9,853	-14,197	4,344	-254
Peru	yellowfin	purse seine	1,164,258	324,918	839,340	155
Peru	skipjack	purse seine	17,642	4,924	12,719	155
Philippines	albacore	longline	-20,926	-26,622	5,696	-2,416
Philippines	skipjack	hook/line	-19,023,580	-42,696,561	23,672,981	-528
Philippines	skipjack	longline	-58,534,856	-74,431,449	15,896,593	-2,418
Philippines	albacore	pole/line	-379	-1,067	689	-362
Philippines	yellowfin	longline	-231,579,141	-293,156,435	61,577,294	-2,436
Philippines	yellowfin	gillnet	5,942	-964	6,906	557
Philippines	albacore	gillnet	746	-103	849	578
Philippines	bigeye	gillnet	2,488	-343	2,832	578
Philippines	bigeye	pole/line	-4,983	-14,039	9,057	-362
Philippines	skipjack	purse seine	-19,438,220	-45,580,483	26,142,264	-488
Philippines	skipjack	gillnet	10,101,163	-1,417,873	11,519,036	576
Philippines	yellowfin	pole/line	-112,668	-303,619	190,951	-382
Philippines	yellowfin	hook/line	-19,495	-42,621	23,126	-546
Philippines	skipjack	pole/line	-9,341,951	-26,203,198	16,861,248	-364
Philippines	bigeye	longline	-56,258,056	-71,571,853	15,313,797	-2,416
Portugal	yellowfin	longline	-24,988	-141,180	116,192	-527
Portugal	albacore	hook/line	-16,110	-41,949	25,839	-743
Portugal	Atlantic bf	pole/line	-10,677	-16,467	5,790	-1,125
Portugal	albacore	longline	-126,148	-176,926	50,779	-2,960
Portugal	Atlantic bf	longline	-35,743	-41,082	5,338	-4,085
Portugal	bigeye	pole/line	1,062,473	-1,286,764	2,349,238	703
Portugal	bigeye	purse seine	711,197	248,837	462,360	2,391
Portugal	yellowfin	hook/line	427	-192	619	1,690
Portugal	skipjack	longline	-86,556	-93,933	7,377	-4,520
Portugal	yellowfin	purse seine	278,178	112,917	165,260	4,121
Portugal	albacore	pole/line	16	-211,484	211,500	0
Portugal	southern bf	longline	-32,677	-37,558	4,881	-4,085
Portugal	skipjack	purse seine	75,869	-152,692	228,560	128
Portugal	Atlantic bf	purse seine	6,026	-503	6,529	563
Portugal	albacore	purse seine	685	202	483	1,688
Portugal	yellowfin	gillnet	19	-128	147	308
Portugal	yellowfin	pole/line	176,965	-1,106	178,071	2,433
Portugal	Atlantic bf	trap	-111,915	-143,064	31,148	-2,192
Portugal	bigeye	longline	-898,890	-1,518,106	619,215	-2,257
Portugal	skipjack	pole/line	-3,946,223	-4,920,557	974,334	-1,560

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Timor Leste*	yellowfin	longline	716	-3,238	3,954	278
Timor Leste	yellowfin	pole/line	734	225	509	2,218
Timor Leste	yellowfin	hook/line	23	-16	39	893
Timor Leste	yellowfin	gillnet	166	55	111	2,298
Puerto Rico	skipjack	pole/line	884	-1,028	1,912	352
Puerto Rico	skipjack	purse seine	9,880	114	9,766	771
Puerto Rico	yellowfin	purse seine	5,953	68	5,884	771
Puerto Rico	skipjack	longline	-12,172	-18,012	5,841	-1,587
Puerto Rico	yellowfin	pole/line	409	-475	884	352
Puerto Rico	yellowfin	longline	-16,055	-23,759	7,704	-1,587
Reunion*	albacore	pole/line	-102,727	-110,429	7,701	-1,405
Reunion	yellowfin	pole/line	-142,236	-152,899	10,663	-1,405
Reunion	bigeye	gillnet	-2,553	-2,756	203	-1,326
Reunion	bigeye	longline	-2,020,026	-2,083,647	63,621	-3,345
Reunion	albacore	longline	-2,022,737	-2,086,443	63,706	-3,345
Reunion	skipjack	pole/line	-113,822	-122,356	8,533	-1,405
Reunion	yellowfin	hook/line	-33,951	-35,261	1,310	-2,731
Reunion	bigeye	pole/line	-8,655	-9,304	649	-1,405
Reunion	yellowfin	gillnet	-3,914	-4,225	311	-1,326
Reunion	yellowfin	longline	-2,737,438	-2,823,654	86,216	-3,345
Reunion	albacore	gillnet	-119,536	-129,035	9,499	-1,326
Russian Fed	bigeye	pole/line	-242	-461	219	-699
Russian Fed	yellowfin	pole/line	-454	-864	410	-699
Russian Fed	yellowfin	purse seine	1,236	446	790	989
Russian Fed	bigeye	longline	-1,369	-1,606	237	-3,659
Russian Fed	yellowfin	longline	-4,030	-4,726	696	-3,659
Russian Fed	bigeye	purse seine	277	100	177	989
St Helena*	albacore	pole/line	-23,268	-25,123	1,855	-1,405
St Helena	skipjack	pole/line	-451,074	-487,041	35,967	-1,405
St Helena	albacore	hook/line	-18,245	-18,994	749	-2,731
St Helena	albacore	longline	-38,629	-39,923	1,294	-3,345
St Helena	yellowfin	pole/line	-118,091	-127,507	9,416	-1,405
St Helena	bigeye	pole/line	-9,441	-10,194	753	-1,405
St Helena	yellowfin	purse seine	-34,084	-37,953	3,869	-987
St Helena	albacore	purse seine	-209	-233	24	-987
St Helena	bigeye	purse seine	-1,939	-2,159	220	-987
St Helena	yellowfin	longline	-456,338	-471,625	15,286	-3,345
St Helena	bigeye	longline	-31,163	-32,206	1,044	-3,345
St Lucia	yellowfin	purse seine	124,922	68,721	56,201	1,786
St Lucia	albacore	pole/line	188	102	85	1,765
St Lucia	albacore	longline	2,243	934	1,308	1,377
St Lucia	bigeye	purse seine	532	292	239	1,786
St Lucia	yellowfin	pole/line	18,536	10,095	8,441	1,765
St Lucia	bigeye	longline	2,160	900	1,260	1,377
St Lucia	yellowfin	longline	126,114	52,536	73,578	1,377
St Lucia	skipjack	purse seine	158,329	87,099	71,230	1,786
St Lucia	bigeye	pole/line	237	129	108	1,765
St Lucia	skipjack	longline	73,013	30,415	42,598	1,377

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
St Lucia	skipjack	pole/line	30,625	16,679	13,945	1,765
St Lucia	albacore	purse seine	472	260	212	1,786
St Vincent	bigeye	longline	56,156	23,393	32,763	1,377
St Vincent	albacore	hook/line	12	-16	28	335
St Vincent	bigeye	purse seine	13,824	7,605	6,219	1,786
St Vincent	albacore	pole/line	5,908	3,218	2,690	1,765
St Vincent	skipjack	pole/line	55,086	30,002	25,084	1,765
St Vincent	bigeye	pole/line	6,162	3,356	2,806	1,765
St Vincent	skipjack	longline	131,331	54,709	76,622	1,377
St Vincent	yellowfin	longline	1,497,973	624,015	873,958	1,377
St Vincent	albacore	purse seine	14,878	8,185	6,694	1,786
St Vincent	albacore	longline	70,643	29,428	41,215	1,377
St Vincent	skipjack	purse seine	284,793	156,668	128,125	1,786
St Vincent	yellowfin	purse seine	1,483,817	816,267	667,550	1,786
St Vincent	yellowfin	pole/line	220,170	119,913	100,257	1,765
Sao Tome Prn	yellowfin	longline	-141,783	-147,747	5,965	-2,663
Sao Tome Prn	skipjack	purse seine	-78,652	-88,188	9,536	-924
Sao Tome Prn	yellowfin	purse seine	-55,825	-62,594	6,768	-924
Sao Tome Prn	bigeye	pole/line	-3,018	-3,250	233	-1,453
Sao Tome Prn	skipjack	longline	-6,131	-6,389	258	-2,663
Sao Tome Prn	skipjack	pole/line	-114,201	-123,007	8,806	-1,453
Sao Tome Prn	yellowfin	pole/line	-45,566	-49,079	3,514	-1,453
Sao Tome Prn	bigeye	longline	-5,980	-6,231	252	-2,663
Sao Tome Prn	bigeye	purse seine	-1,551	-1,739	188	-924
Senegal	bigeye	purse seine	-186,354	-213,038	26,684	-924
Senegal	yellowfin	longline	-1,274,414	-1,337,735	63,321	-2,663
Senegal	skipjack	longline	-180,022	-188,967	8,945	-2,663
Senegal	yellowfin	pole/line	-408,996	-446,243	37,246	-1,453
Senegal	skipjack	pole/line	-3,353,096	-3,658,456	305,360	-1,453
Senegal	bigeye	longline	-718,552	-754,254	35,702	-2,663
Senegal	skipjack	purse seine	-2,309,332	-2,640,000	330,668	-924
Senegal	yellowfin	purse seine	-500,889	-572,611	71,721	-924
Senegal	yellowfin	gillnet	-24	-27	3	-1,003
Senegal	bigeye	pole/line	-362,627	-395,650	33,024	-1,453
Seychelles	albacore	gillnet	-19,260	-25,718	6,458	-1,070
Seychelles	bigeye	gillnet	-34,445	-45,996	11,551	-1,070
Seychelles	albacore	longline	-321,360	-364,671	43,311	-2,663
Seychelles	albacore	pole/line	-21,043	-26,241	5,198	-1,453
Seychelles	yellowfin	hook/line	-926,488	-1,136,076	209,588	-1,587
Seychelles	bigeye	pole/line	-149,561	-186,507	36,945	-1,453
Seychelles	yellowfin	longline	-102,391,884	-116,191,732	13,799,848	-2,663
Seychelles	skipjack	pole/line	-66,917,008	-83,447,158	16,530,150	-1,453
Seychelles	bigeye	longline	-26,877,524	-30,499,938	3,622,414	-2,663
Seychelles	yellowfin	pole/line	-6,909,540	-8,616,366	1,706,827	-1,453
Seychelles	yellowfin	gillnet	-149,183	-199,209	50,026	-1,070
Singapore	skipjack	longline	79	-195	275	117
Singapore	skipjack	gillnet	1,524	1,324	199	3,111
Singapore	skipjack	pole/line	1,557	1,265	291	2,172

Table continued on next page

Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Singapore	skipjack	hook/line	2,021	1,611	409	2,008
Singapore	skipjack	purse seine	2,275	1,823	452	2,047
South Africa	bigeye	gillnet	-253	-274	22	-1,070
South Africa	yellowfin	gillnet	-220	-239	19	-1,070
South Africa	yellowfin	hook/line	-917	-996	79	-1,061
South Africa	yellowfin	longline	-1,798,720	-1,860,584	61,864	-2,663
South Africa	albacore	hook/line	-647,844	-703,764	55,920	-1,061
South Africa	albacore	longline	-2,820,865	-2,917,884	97,019	-2,663
South Africa	bigeye	pole/line	-120,965	-128,590	7,625	-1,453
South Africa	bigeye	purse seine	-22,293	-24,502	2,210	-924
South Africa	albacore	gillnet	-628	-682	54	-1,070
South Africa	skipjack	longline	-253	-262	9	-2,663
South Africa	yellowfin	pole/line	-563,805	-599,347	35,541	-1,453
South Africa	skipjack	purse seine	-149	-163	15	-924
South Africa	yellowfin	purse seine	-144,681	-159,021	14,340	-924
South Africa	bigeye	longline	-501,753	-519,010	17,257	-2,663
South Africa	albacore	purse seine	-17,902	-19,676	1,774	-924
South Africa	albacore	pole/line	-2,199,102	-2,337,731	138,628	-1,453
South Africa	southern bf	longline	-10,653	-11,020	366	-2,663
South Africa	skipjack	pole/line	-2,535	-2,694	160	-1,453
Spain	yellowfin	longline	-311,666,952	-351,580,046	39,913,095	-4,294
Spain	albacore	longline	-1,070,563	-2,258,415	1,187,853	-1,778
Spain	albacore	purse seine	411,800	128,599	283,201	2,869
Spain	skipjack	purse seine	7,790,008	-6,787,961	14,577,969	268
Spain	Atlantic bf	trap	-4,501,736	-6,993,835	2,492,099	-1,705
Spain	Atlantic bf	longline	-2,416,735	-3,050,754	634,019	-3,598
Spain	albacore	pole/line	13,689,124	-9,178,707	22,867,831	1,181
Spain	yellowfin	gillnet	-467,616	-602,222	134,605	-1,910
Spain	albacore	hook/line	115,726	-25,101,944	25,217,670	9
Spain	bigeye	purse seine	4,591,794	-398,271	4,990,064	671
Spain	Atlantic bf	hook/line	-6,291	-9,571	3,280	-1,810
Spain	yellowfin	purse seine	2,725,372	-1,508,489	4,233,861	354
Spain	skipjack	longline	-7,315,492	-8,152,446	836,955	-4,380
Spain	bigeye	longline	-55,722,119	-65,942,520	10,220,401	-3,977
Spain	bigeye	pole/line	-5,089,532	-8,739,943	3,650,411	-1,017
Spain	skipjack	gillnet	-55	-69	14	-1,996
Spain	skipjack	pole/line	-155,052,827	-209,757,888	54,705,061	-1,420
Spain	yellowfin	hook/line	-2,583,455	-3,150,258	566,803	-2,506
Spain	yellowfin	pole/line	-14,731,221	-20,802,898	6,071,677	-1,334
Spain	Atlantic bf	pole/line	-530,839	-1,316,179	785,340	-638
Spain	southern bf	longline	-10,793	-13,624	2,831	-3,598
Spain	Atlantic bf	purse seine	1,615,855	163,567	1,452,288	1,050
Spain	albacore	gillnet	6,482	-14,655	21,137	605
Spain	bigeye	gillnet	-53,249	-77,629	24,380	-1,593
Syria	Atlantic bf	purse seine	64,332	16,007	48,325	2,047
Syria	albacore	longline	8,555	-103,534	112,089	117
Syria	Atlantic bf	hook/line	450	105	345	2,008
Syria	albacore	hook/line	157,216	36,799	120,417	2,008

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Syria	Atlantic bf	pole/line	21,973	6,413	15,560	2,172
Syria	albacore	purse seine	55,811	13,887	41,924	2,047
Syria	Atlantic bf	trap	23,550	-20,173	43,723	828
Syria	albacore	pole/line	151,011	44,075	106,937	2,172
Syria	Atlantic bf	longline	3,263	-39,486	42,748	117
Thailand	albacore	pole/line	-9,989	-12,692	2,703	-860
Thailand	albacore	gillnet	1,357	-2,616	3,973	80
Thailand	bigeye	gillnet	436	-840	1,275	80
Thailand	skipjack	longline	-344	-372	27	-2,914
Thailand	albacore	longline	-333,174	-359,788	26,614	-2,914
Thailand	bigeye	longline	-5,006,886	-5,406,833	399,946	-2,914
Thailand	skipjack	gillnet	1	-1	2	80
Thailand	yellowfin	longline	-5,990,171	-6,468,662	478,490	-2,914
Thailand	yellowfin	pole/line	-218,665	-277,845	59,180	-860
Thailand	skipjack	pole/line	-6,856,457	-8,712,116	1,855,659	-860
Thailand	bigeye	pole/line	-15,072	-19,151	4,079	-860
Thailand	yellowfin	gillnet	590	-1,137	1,727	80
Thailand	yellowfin	hook/line	-31,974	-39,243	7,269	-1,024
Togo	bigeye	pole/line	-8,047	-8,689	642	-1,453
Togo	bigeye	longline	-15,946	-16,640	694	-2,663
Togo	bigeye	purse seine	-4,135	-4,654	519	-924
Tonga	albacore	longline	421,087	-192,927	614,014	3,893
Tonga	skipjack	pole/line	2,841	806	2,034	7,927
Tonga	yellowfin	hook/line	235,626	20,505	215,120	6,218
Tonga	yellowfin	purse seine	626,344	195,806	430,538	8,258
Tonga	albacore	pole/line	412,743	117,159	295,583	7,927
Tonga	yellowfin	pole/line	234,145	66,463	167,681	7,927
Tonga	bigeye	pole/line	123,568	35,075	88,492	7,927
Tonga	yellowfin	gillnet	228,198	88,462	139,736	9,270
Tonga	skipjack	purse seine	4,589	1,435	3,154	8,258
Tonga	albacore	hook/line	270,244	23,518	246,727	6,218
Tonga	albacore	purse seine	162,270	50,728	111,541	8,258
Tonga	bigeye	purse seine	249,973	78,146	171,827	8,258
Tonga	albacore	mw trawl	610,140	271,532	338,607	10,229
Tonga	bigeye	longline	128,302	-58,783	187,085	3,893
Tonga	skipjack	gillnet	2,270	880	1,390	9,270
Tonga	skipjack	hook/line	3,129	272	2,856	6,218
Tonga	bigeye	hook/line	286,799	24,958	261,840	6,218
Tonga	skipjack	longline	1,315	-603	1,918	3,893
Tonga	yellowfin	longline	198,946	-91,150	290,096	3,893
Tonga	bigeye	gillnet	536	208	328	9,270
Trinidad Tob	albacore	hook/line	110	41	69	1,286
Trinidad Tob	yellowfin	pole/line	77,369	42,138	35,231	1,765
Trinidad Tob	albacore	pole/line	14,452	7,871	6,581	1,765
Trinidad Tob	bigeye	longline	149,503	62,279	87,224	1,377
Trinidad Tob	bigeye	purse seine	36,803	20,246	16,557	1,786
Trinidad Tob	bigeye	pole/line	16,404	8,934	7,470	1,765
Trinidad Tob	albacore	longline	172,809	71,988	100,822	1,377

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Trinidad Tob	yellowfin	purse seine	521,424	286,842	234,582	1,786
Trinidad Tob	yellowfin	longline	526,399	219,284	307,115	1,377
Trinidad Tob	albacore	purse seine	36,396	20,022	16,374	1,786
Tunisia	Atlantic bf	longline	-2,454,550	-2,613,300	158,751	-2,663
Tunisia	Atlantic bf	trap	-1,441,955	-1,604,325	162,370	-1,530
Tunisia	Atlantic bf	pole/line	-487,456	-545,240	57,784	-1,453
Tunisia	Atlantic bf	purse seine	-962,846	-1,142,308	179,462	-924
Tunisia	Atlantic bf	hook/line	-11,795	-13,075	1,280	-1,587
Turkey	albacore	longline	-18,573	-22,380	3,808	-2,106
Turkey	Atlantic bf	hook/line	-489	-1,467	978	-216
Turkey	albacore	purse seine	-582	-2,007	1,424	-177
Turkey	Atlantic bf	longline	-591,526	-712,793	121,267	-2,106
Turkey	Atlantic bf	purse seine	-56,071	-193,159	137,088	-177
Turkey	albacore	pole/line	-439	-4,071	3,633	-52
Turkey	Atlantic bf	trap	-400,827	-524,859	124,032	-1,395
Turkey	Atlantic bf	pole/line	-5,334	-49,474	44,141	-52
Turkey	albacore	hook/line	-2,047	-6,137	4,090	-216
Tuvalu*	skipjack	hook/line	2,406,014	2,406,014	0	7,969
Tuvalu	yellowfin	purse seine	3,363,850	3,363,850	0	9,713
Tuvalu	yellowfin	gillnet	1,053,702	1,053,702	0	9,374
Tuvalu	skipjack	purse seine	3,238,376	3,238,376	0	9,713
Tuvalu	skipjack	gillnet	1,377,165	1,377,165	0	9,374
Tuvalu	skipjack	longline	1,491,155	1,491,155	0	7,355
Tuvalu	yellowfin	longline	1,716,333	1,716,333	0	7,355
Tuvalu	skipjack	pole/line	1,998,749	1,998,749	0	9,295
Tuvalu	yellowfin	hook/line	1,379,011	1,379,011	0	7,969
Tuvalu	yellowfin	pole/line	1,253,703	1,253,703	0	9,295
UK	albacore	longline	-135	-140	5	-4,832
UK	albacore	mw trawl	-110	-276	166	-113
Tanzania	yellowfin	longline	-1,541,446	-1,620,449	79,004	-2,663
Tanzania	yellowfin	hook/line	-13,951	-15,151	1,200	-1,587
Tanzania	yellowfin	gillnet	-2,235	-2,520	285	-1,070
Tanzania	yellowfin	pole/line	-104,016	-113,787	9,771	-1,453
USA	bigeye	gillnet	16,483	9,342	7,141	7,097
USA	skipjack	gillnet	3,847	1,396	2,451	1,620
USA	Pacific bf	gillnet	189,154	99,892	89,262	4,323
USA	bigeye	longline	7,524,426	2,497,287	5,027,138	4,602
USA	Atlantic bf	pole/line	20	12	8	12,516
USA	albacore	pole/line	815,825	-317,781	1,133,606	584
USA	albacore	purse seine	-40,519	-147,392	106,873	-308
USA	bigeye	pole/line	1,143,552	614,923	528,629	6,651
USA	yellowfin	gillnet	859	448	410	4,079
USA	albacore	mw trawl	14,275	7,702	6,573	1,763
USA	albacore	longline	-11,496,496	-17,868,467	6,371,971	-1,465
USA	Pacific bf	longline	67,606	-7,836	75,441	1,828
USA	skipjack	longline	-288,773	-629,102	340,329	-875
USA	albacore	hook/line	-970	-1,930	960	-820
USA	Pacific bf	hook/line	200,388	35,062	165,326	2,473

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
USA	Atlantic bf	purse seine	539,440	295,241	244,199	11,624
USA	yellowfin	purse seine	32,168,111	9,294,099	22,874,013	2,741
USA	skipjack	purse seine	11,031,485	-29,385,437	40,416,922	282
USA	skipjack	pole/line	4,310,042	521,397	3,788,645	1,174
USA	yellowfin	longline	2,099,004	-483,945	2,582,949	1,584
USA	yellowfin	pole/line	2,120,081	982,737	1,137,344	3,633
USA	Atlantic bf	hook/line	332,610	175,096	157,514	11,112
USA	bigeye	purse seine	58,477,642	27,257,642	31,219,999	5,759
USA	Atlantic bf	trap	57,287	28,804	28,483	10,583
USA	Atlantic bf	longline	494,516	245,907	248,610	10,467
USA	Pacific bf	purse seine	135,042	42,755	92,287	2,985
Uruguay	Atlantic bf	purse seine	12	9	3	155
Uruguay	albacore	longline	-8,118	-9,284	1,166	-254
Uruguay	Atlantic bf	pole/line	3	2	1	134
Uruguay	bigeye	longline	-15,729	-17,988	2,259	-254
Uruguay	Atlantic bf	longline	-15	-17	2	-254
Uruguay	Atlantic bf	hook/line	-50	-51	1	-1,296
Uruguay	yellowfin	longline	-164,645	-188,291	23,645	-254
Uruguay	Atlantic bf	trap	-20	-22	2	-363
Venezuela	skipjack	purse seine	2,113,427	907,288	1,206,139	155
Venezuela	skipjack	pole/line	136,819	46,197	90,622	134
Venezuela	bigeye	purse seine	17,974	7,716	10,258	155
Venezuela	albacore	purse seine	5,381	2,310	3,071	155
Venezuela	albacore	longline	-54,171	-73,079	18,908	-254
Venezuela	yellowfin	pole/line	264,020	89,146	174,874	134
Venezuela	bigeye	longline	-78,247	-105,559	27,312	-254
Venezuela	albacore	pole/line	1,863	629	1,234	134
Venezuela	albacore	hook/line	-189	-202	13	-1,296
Venezuela	yellowfin	gillnet	-7	-8	1	-1,226
Venezuela	yellowfin	purse seine	6,015,594	2,582,477	3,433,117	155
Venezuela	yellowfin	longline	-2,046,778	-2,761,197	714,419	-254
Venezuela	bigeye	pole/line	2,886	974	1,911	134
Venezuela	skipjack	longline	-532,366	-718,187	185,820	-254
Samoa	bigeye	longline	65,690	20,554	45,137	3,893
Samoa	albacore	pole/line	1,842,028	1,220,417	621,610	7,927
Samoa	yellowfin	hook/line	214,107	121,996	92,111	6,218
Samoa	skipjack	pole/line	21,307	14,116	7,190	7,927
Samoa	albacore	hook/line	1,206,073	687,208	518,865	6,218
Samoa	yellowfin	purse seine	569,144	384,794	184,350	8,258
Samoa	yellowfin	pole/line	212,762	140,963	71,799	7,927
Samoa	albacore	purse seine	724,194	489,622	234,571	8,258
Samoa	skipjack	purse seine	34,417	23,269	11,148	8,258
Samoa	skipjack	longline	9,866	3,087	6,779	3,893
Samoa	bigeye	gillnet	275	195	79	9,270
Samoa	albacore	longline	1,879,269	587,999	1,291,270	3,893
Samoa	bigeye	purse seine	127,986	86,531	41,456	8,258
Samoa	albacore	mw trawl	2,722,991	2,010,901	712,090	10,229
Samoa	bigeye	pole/line	63,267	41,917	21,350	7,927

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Country	Species	Gear	Private Rent (USD)	Social Rent (USD)	Opportunity Cost (USD)	Unit Rent (USD/t)
Samoa	yellowfin	longline	180,777	56,563	124,214	3,893
Samoa	skipjack	hook/line	23,465	13,370	10,095	6,218
Samoa	bigeye	hook/line	146,841	83,669	63,173	6,218
Samoa	skipjack	gillnet	17,023	12,111	4,912	9,270
Samoa	yellowfin	gillnet	207,358	147,525	59,833	9,270
Yemen	skipjack	pole/line	20,249,577	10,942,381	9,307,196	2,172
Yemen	yellowfin	gillnet	345,361	234,567	110,794	3,111
Yemen	yellowfin	longline	3,611,318	-27,099,131	30,710,448	117
Yemen	yellowfin	pole/line	8,263,908	4,465,616	3,798,293	2,172
Yemen	yellowfin	hook/line	938,443	471,905	466,538	2,008
Montenegro*	Atlantic bf	longline	-4,017	-5,272	1,255	-2,023
Montenegro	Atlantic bf	hook/line	-23	-33	10	-1,409
Montenegro	Atlantic bf	pole/line	-60	-517	457	-83
Montenegro	Atlantic bf	trap	-2,856	-4,140	1,284	-1,406
Montenegro	Atlantic bf	purse seine	752	-667	1,419	335
High seas*	albacore	purse seine	-16	-55	39	-179
High seas	yellowfin	hook/line	-541,563	-662,593	121,030	-1,923
High seas	albacore	hook/line	-5,507	-6,738	1,231	-1,923
High seas	skipjack	longline	-480,493	-561,885	81,392	-2,537
High seas	bigeye	purse seine	-68,744	-233,427	164,683	-179
High seas	albacore	longline	-1,830,414	-2,140,474	310,060	-2,537
High seas	southern bf	seine	-14	-50	36	-170
High seas	yellowfin	purse seine	-528,969	-1,796,176	1,267,207	-179
High seas	southern bf	hook/line	-1,726	-2,112	386	-1,923
High seas	yellowfin	gillnet	-44,251	-80,960	36,709	-518
High seas	skipjack	gillnet	-4	-7	3	-518
High seas	bigeye	gillnet	-10,197	-18,656	8,459	-518
High seas	skipjack	pole/line	-16,465,509	-28,306,576	11,841,067	-598
High seas	southern bf	mw trawl	38	-11	49	331
High seas	southern bf	gillnet	-81	-147	67	-518
High seas	yellowfin	pole/line	-2,242,462	-3,855,115	1,612,653	-598
High seas	albacore	gillnet	-55,519	-101,575	46,056	-518
High seas	skipjack	purse seine	-924,372	-3,138,811	2,214,440	-179
High seas	yellowfin	longline	-53,090,316	-62,083,454	8,993,138	-2,537
High seas	bigeye	pole/line	-321,033	-551,902	230,869	-598
High seas	bigeye	longline	-16,962,130	-19,835,399	2,873,269	-2,537
High seas	albacore	pole/line	-33,767	-58,051	24,284	-598

* Denotes that weighted means were used in cost calculations for these countries

Appendix B

Allocation by non-tuna RFMOs

In Chapter 4, I discussed how the tuna Regional Fisheries Management Organizations (RFMOs) have decided upon their current allocation programs, or how they will develop their programs in the future. In this Appendix, I discuss the allocation programs present in non-tuna RFMOs in order to provide a broader picture of the current allocation landscape. The programs present in these RFMOs are reviewed in Table 4.1.

B.1 Pacific Salmon

Pacific salmon are a transboundary resource, shared by the United States and Canada. In 1985, the Pacific Salmon Treaty (PST) was signed by both parties, after 25 years of negotiations. Prior to the Treaty, both countries engaged in "fish wars", intentionally over-harvesting in their own waters in order to deny harvesting opportunities to the other country (Jensen, 1986). The Treaty replaced earlier agreements, such as the 1937 Fraser Salmon Convention, which established the International Pacific Salmon Fisheries Commission (IPSFC) charged with sharing Fraser River sockeye 50/50 between Canada and the U.S.. The 1985 Treaty sets out the long-term management goals of both countries. The Pacific Salmon Commission is the regulatory body put in place to implement the Treaty. There are five species of Pacific salmon managed jointly under the treaty: sockeye (*Oncorhynchus nerka*), chinook (*O. tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), and pink (*O. gorbuscha*). Pacific salmon return to spawn in the streams they were born in, meaning salmon that originate in Canada will eventually return to Canadian waters. The Treaty acknowledges this, recognizing "that States in whose waters salmon stocks originate have primary interest in and responsibility for such stocks" (Emery, 1997).

Annex IV, Chapters 1 to 7 of the Treaty contain agreed management, conservation and allocation measures for each species and interception fishery. These chapters are renegotiated separately every 4 to 12 years. Article III 1(b) requires each country to manage its fisheries and enhancement programs so as to ensure that each country receives "benefits equivalent to the production of salmon originating in its waters", the so-called equity principle. This provision has never been fully implemented because the Parties cannot agree on what constitutes an "equitable balance" (Shepard and Argue, 2005).

The Commission has long dealt with the issue of "interceptions": those fish originating in one country but being caught by the other. In 1996, for example, Canada estimated that the accumulated interceptions of both countries favoured the U.S. by about 35 million fish, resulting in a loss of about $500 million (CAD) to Canada (Emery, 1997). Notably, Pacific salmon cannot be fished in the high seas, as per the North Pacific Anadromous Fish Convention (Cohen Commission, 2010a).

Bilateral interception limits are negotiated periodically between Canada and the U.S.. However, Canada actually has to negotiate with several states (Oregon, Washington and Alaska), the U.S. government, and the Pacific Northwest Tribes, instead of just one federal group. That negotiations must take place between more than two interested parties increases the challenge of reaching cooperation. In spite of this negotiating complexity, however, in 1999, after 7 years of difficult negotiations, agreement was finally reached amongst the five U.S. jurisdictions and Canada on renewed fishing arrangements for Annex IV.

For Fraser River sockeye, an annual international TAC is calculated as follows Cohen Commission (2010b):

$$TAC = return - sockeye \quad harvested \quad (test) - escapement \quad target - MA - AFE \tag{B.1}$$

Here, MA is the management adjustment for each Fraser River sockeye stock, and AFE is the Aboriginal Fisheries Exemption. The U.S. TAC is then a fixed percentage of the international TAC, currently 16.5% Cohen Commission (2010b). It is unclear how this fixed percentage was formulated.

B.2 Pacific hake

North Pacific hake (*Merluccius productus*), also known as Pacific whiting, are found from northern Vancouver Island south to the northern part of the Gulf of California, and are thus shared between Canada and the U.S.. Hake are considered the most populous groundfish species in the California current system. The catch is primarily processed into H&G blocks, fillets or surimi. Prior to 2002, the U.S. was claiming an 80% share of the hake fishery, while Canada was claiming 30%, leading to non-cooperation and overfishing (United States Senate, 2004). This was perhaps due to differences in stock assessments performed by scientists within each country. Thus, in 2003, both countries signed the U.S.-Canada Pacific Hake/Whiting Agreement. While the Agreement was ratified in 2003, it was not formally implemented until 2012 (Fisheries and Oceans Canada, 2011). However, from

2003 through 2011, both Canada and the United States operated under the spirit of the Agreement, and complied with the Agreement's national allocations[31]. The document states:

"The Agreement establishes, for the first time, agreed percentage shares of the transboundary stock of Pacific hake, also known as Pacific whiting. It also creates a process through which U.S. and Canadian scientists and fisheries managers will recommend the total catch of Pacific hake each year, to be divided by a set percentage formula. (United States Senate, 2004)"

A TAC is decided upon jointly, with input from scientific advisory panels from both Canada and the U.S., as well as through consultation with the Hake/Whiting Industry Advisory Panel. Allocations of 26.12% and 73.88% of the coastwide TAC (Total Allowable Catch) go to Canada and the U.S., respectively (United States Senate, 2004). This fixed allotment, determined through bilateral negotiation, is in effect for nine years, and will remain fixed unless both Parties agree to change it.

B.3 Pacific halibut

Pacific halibut (*Hippoglossus stenolepis*) are found along the continental shelf in the North Pacific as well as the Bering Sea, and have been commercially harvested by Canada and the United States since the late 1880s. Since 1923, the Pacific halibut fishery has been managed by a joint Canada-U.S. convention. This convention resulted in one of the earliest international groups developed to facilitate conservation-based cooperative management between different countries sharing access to a commercially valuable fish stock. It was initially called the International Fisheries Commission, but today is known as the International Pacific Halibut Commission (IPHC).

Prior to 2006, halibut was managed under the assumption that there were several separate stocks along the Pacific coast with negligible migrations between regulatory areas. Due to an easterly migration of halibut that was originally not accounted for, a disproportionate share of catches were being taken from the eastern areas, notably the waters of Canada and Washington State (Hare, 2010). Modified stock assessment modelling has led scientists to reformulate this assumption, and now the population is managed based on a single coast-wide stock, although this has not been formally accepted by Canada. Through annual stock assessments, IPHC estimates the coast-wide exploitable biomass. Exploitable biomass by regulatory area (8 areas in total) is then calculated based on survey

[31] Bruce Turris, Pacific Fisheries Management Inc., personal communication.

data, and a fixed exploitation rate is applied to that biomass to obtain an allowable yield (constant exploitation yield (CEY)) for each regulatory area (Hare, 2010). Presently, an exploitation rate of about 20% of the exploitable biomass is the management target for each area (Hare, 2010). Allocation is currently done by regulatory area, but the result of this process is a proportion of the stock that Canada is allocated to remove, and proportion of the stock that the U.S. is allocated to remove, essentially a bilateral agreement.

Given that Canada and the U.S share several commercially-exploited fish stocks, it is conceivable that bargaining for multi-species instead of single-species allocations could facilitate improved cooperative outcomes for both countries. In this case, by giving up some allocated hake, for example, Canada could then ask for more sockeye salmon or halibut in return. The apparent process of several different Canadian and U.S. interests all acting in their own best interest is probably counterproductive to each country obtaining the best outcome.

B.4 Northwest Atlantic: NAFO

The International Commission for the Northwest Atlantic Fisheries (ICNAF), now the Northwest Atlantic Fisheries Organization (NAFO), initiated allocation schemes in the early 1970s (ICNAF, 1972). At that time, the primary stocks of management interest for the Commission were of haddock, cod, pollock, halibut, herring and lobster. Between 1969 and 1972, the ICNAF adopted national TACs for individual stocks based on historical catches (Anderson, 1998; Gezelius, 2008). They used an 80% allocation rule, where national TACs were developed based on long-term (40% in proportion to average catches over a 10 year period[32]) and short term (40% in proportion to average catches over a 3 year period) removal histories ICNAF (1972). Further to this, 10% of the TAC was allocated to Coastal States, with the remaining 10% put aside for special needs (ICNAF, 1972). This was referred to as the 40-40-10-10 formula. This special needs category is too often an overlooked option: why not allocate an amount to the precautionary approach? Upon compliance by all cooperating members, and assuming a healthy stock, the extra share could be further allocated to fishers near the end of the season, or at the beginning of the next season. By 1977, ICNAF had developed nationally-allocated TACs for some 70 different regional stocks (Anderson, 1998). The Commission recognized the need for flexibility in allocation schemes, especially because overfishing was already occurring on some stocks, and TACs needed to be adjusted downward in subsequent years. ICNAF

[32] It is unclear why 10 years was thought to be long-term. If this was based on biological considerations of the target stocks, then we have the case where biological reference points are used, with disregard to economic criteria. When dealing with climate science and issues of resilience over time, RFMOs will certainly be forced to expand their considerations of ‘long-term’.

was formally dissolved in 1979, with NAFO being inaugurated that same year (Anderson, 1998).

After Canada and the U.S. declared sovereignty over their 200 nautical mile EEZs, many foreign fleets turned their attention to heavy fishing just outside of the EEZ limits, on the so called “nose and tail” of the Grand Banks. Although NAFO continued to recommend annual allocation TACs, these were often exceeded by several European countries (Anderson, 1998) and the area has been plagued by overfishing for decades (Lane, 2008). NAFO was also challenged by non-member fishing fleets, for example those from Panama, Chili and Mexico (Anderson, 1998) who fished the resource without being party to the group, essentially free-riders. Today, the NAFO allocation system is based on fixed shares, as a proportion of the TAC (Cox, 2009). A working group formed to analyze current and possible future allocation programs for NAFO has had difficulty agreeing on a comprehensive set of allocation criteria (MRAG, 2006).

NAFO has set out guidelines with how to deal with the the new member problem. They simply state that their stocks are fully allocated, and new members should join NAFO with the understanding that their fishing opportunities will be limited, for example to fisheries that are as of yet unallocated (Lodge et al., 2007). The setting of NAFO allocations, however, has often been met with resistance. In the 1980s and 1990s, for example, and average of 10 objections by member states were launched per year which often resulted in unilateral quota allocations being set by the objecting parties (DFO, 2004).

B.5 Northeast Atlantic: NEAFC

The need for national TACs and allocations was also recognized early by the Northeast Atlantic Fisheries C ommission (NEAFC). NEAFC was established in 1959, and is mainly concerned with herring, mackerel, blue whiting and pelagic redfish (Bjorndal, 2009). Despite recognition in the early 1960s that TACs could serve conservation purposes, the Commission was unable to nudge its members into cooperating in an allocation scheme prior to the collapse of the Norwegian Spring Spawning Herring stocks in the late 1960s. This led some of its members, specifically the former USSR, Iceland and Norway, to initiate their own allocation program. In 1974, NEAFC was able to institute TACs for North Sea herring along with other stocks on an ad-hoc basis (Gezelius, 2008; NEAFC, 1974). Like ICNAF, NEAFC used historical catches as the main criteria for their allocation recommendations, along with special considerations for coastal states and new members (Gezelius, 2008).

NEAFC originally ceased overseeing TAC allocation when countries adopted the 200 nautical mile EEZ, leaving individual nations responsible for conservation through smaller bilateral and multilateral agreements (Gezelius, 2008). Today, they recommend a variety of conservation measures, including the setting of TACs and allocations to member nations (called contracting parties, CPs), which include the European Union, Denmark, Iceland, Norway and the Russian Federation (Bjorndal, 2009). For herring, allocation to CPs is based on the "zonal attachment principle": the stock size in a given zone multiplied by the duration of the stay determines the allowable biomass removals for that zone (Bjorndal, 2009). Changes in abundance distribution of herring caused a breakdown in cooperation between CPs in 2003, with Norway demanding a higher allocation (Bjorndal, 2009).

NEAFC has also encountered trouble facilitating cooperation between CPs targeting blue whiting. In the 1990s, although fishing nations agreed that a cooperative sharing scheme was necessary to prevent overexploitation of blue whiting, CPs could not agree on how to share the TAC, and often set their own quotas, greatly exceeding the recommended TAC (Bjorndal, 2009). In the 2000s, CPs presented alternative ways of allocating the TAC based on the zonal attachment principle described above, on catches from a given zone, or a combination of these two, along with an economic dependency argument in some cases. In 2005, an allocation scheme was agreed upon, which was facilitated by fishermen's organizations (Bjorndal, 2009). Currently, NEAFC operates their allocation program based on fixed proportions of the TAC (Cox, 2009).

A promising sign of improved fisheries management in the North Atlantic is communication between NEAFC and NAFO. The two RFMOs have reportedly initiated the development of a pan-North Atlantic list of vessels engaged in illegal, unregulated and unreported (IUU) fishing (Bjorndal, 2009). IUU vessels flagged on the waters of one RFMO would be reported to the other group.