Economic Analysis of Unregulated and Illegal Fishing in Raja Ampat, Indonesia

by

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Abstract

In an era of declining fish stocks and habitat degradation, ecosystem-based management (EBM) is considered an alternative approach to ensure the sustainability of marine resource use. EBM explicitly acknowledges humans and ecosystems in the management of fisheries. This thesis provides two economic analyses to be incorporated into an EBM plan being developed by the Raja Ampat regency government, in Indonesia. Specifically, these analyses address the issues of unregulated and illegal fisheries in the regency. The coastal environment that supports regency inhabitants is considered the world's most biodiverse marine area, but is threatened due to population and poverty pressures faced by those who depend on its resources. In order to manage fisheries effectively, it is important for the regency to have primary data and catch and profitability estimates for the fisheries currently in operation. Furthermore, the use of destructive fishing gears, such as explosives and cyanide, is threatening both the commercial and the artisanal fishing sectors.

To provide the regency with data regarding an unregulated anchovy fishery operating in Kabui Bay, fisher interviews were carried out. Monte Carlo simulations were run using interview results to provide estimated catch and profitability for 2006. Results suggest that this unregulated fishery removed about 3,500 tonnes of anchovy, worth US $1.6 million, in 2006. The fishery appears to be quite profitable, with anchovy fishers making almost twice as much as the average fisher in Raja Ampat.

The perverse incentives of destructive fishing in the artisanal sector are examined by applying principal-agent theory to analyze how the probability of detecting illegal fishers, and the fine owed by apprehended fishers, can be used to decrease the occurrence of illegal fishing. The elimination of blast fishing could result in a stable snapper stock biomass and an estimated increase in net present value from the fishery of US $3.68 million over the next 45 years. However, the high profitability of the cyanide fishery targeting groupers appears to be a substantial barrier to the elimination of this gear, and to a large increase in economic value of a completely legal fishery.

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Co-Authorship Statement

Several colleagues have contributed to the accepted and prepared manuscripts related to this thesis work. Chapter 3, estimating catch and profitability of the unregulated anchovy fishery, has been accepted for publication in the journal Marine Policy. Both Christovel Rotinsulu, from Conservation International, and U. Rashid Sumaila, my supervisor, are coauthors on the paper. A version of the fourth chapter, modeling destructive fishing practices, will be submitted to the journal Environmental and Resource Economics, with U. Rashid Sumaila, Cameron Ainsworth, the postdoctoral student who developed the Ecopath with Ecosim (EwE) model for Raja Ampat, and Tony J. Pitcher, the EwE principal investigator and one of my committee members, as coauthors.

Chapter 1

Introduction

1.1 Problem Statement

As has been well documented around the world, fisheries and other marine resources are being exploited at an alarming rate using, in many instances, unsustainable means. Collapsed fish stocks, destructive fishing methods, destroyed mangrove forests, depressed economies, and protein shortages in the developing world are too quickly becoming the norm (Eggert 1998). Due to poverty and a high social rate of discount, developing countries can face pressure to over-exploit their fisheries resources in order to meet short-term national demand, and to compete in the global fish market (Pauly 1989). Such unsustainable strategies not only further deplete fish stocks, they can have serious medium to long term social and economic ramifications (Kusuma-Atmadja and Purwaka 1996).

It is clear that traditional methods of marine resource management have focused on only the short term benefits of commodity production (Berman and Sumaila 2006), and therefore have not resulted in sustainable fisheries. Consequently, there is a need for alternative management schemes which incorporate socio-economic, political, and ecological factors into decision making (Gislason et al. 2000). Ecosystem-based management (EBM) is such a scheme, which has the potential to address the varying and complex dynamics of resource management in the developing world[1]. The Raja Ampat regency, in Papua, Indonesia, was chosen as a candidate area for EBM research by the David and Lucille Packard Foundation. The relatively healthy environment and high biodiversity in this area, along with the new governmental structure and plans for future economic development, make it ideal for

[1] Although the focus of this paper is on the developing world, most of what is said here also applies in the developed world.

the types of interdisciplinary and cutting edge techniques involved in EBM. The government of Raja Ampat is seeking management recommendations that will explicitly weigh the tradeoffs between the short term costs of a conservationist fisheries management plan with the long term economic benefits the area hopes to provide for its citizens.

1.2 Research Objectives

This research is part of a larger project, one that brings together Conservation International (CI), The Nature Conservancy (TNC), and World Wildlife Fund (WWF), in association with researchers at the University of British Columbia (UBC), to create a framework for EBM in Raja Ampat. The specific objective of this thesis is to describe and analyze the occurrence of unregulated and illegal fishing in the area, in order to provide input for fisheries management decisions. Both unregulated and illegal fishing can undermine management goals (FAO 2002), and thus analyzing the magnitude of these types of fishing from an economic perspective can assist the regency government in fisheries planning. In this thesis, I answer the following two questions: what is the estimated catch and profitability of the unregulated anchovy fishery in Raja Ampat, and what benefits might the regency government gain in the snapper and grouper fisheries with the elimination of destructive fishing gears.

The analyses here will help contribute to a synthesis EBM project to be completed at the end of 2007. For example, the anchovy catch estimates calculated in this thesis have been used by Divya Varkey, a PhD student at UBC, who is assembling a total area estimate of illegal, unregulated, and unreported fisheries for Raja Ampat. Furthermore, the Ecopath with Ecosim (EwE) model being developed for Raja Ampat can be used to test the 2006 anchovy catch estimate and simulate changes to the ecosystem if this catch is increased or decreased in the future. The destructive fishing analysis can give the government some idea of how perverse this type of illegal fishing is, in terms of its economic incentives, and what might be required, in the form of disincentives, from the government to counteract its profitability.

1.3 Thesis Outline

To contribute to the overall objective of the Raja Ampat EBM project, this thesis is organized into four chapters, with Chapter 2 having been accepted for publication (Bailey *et al.*) and Chapter 3 prepared for submission. The first chapter states the objectives of the research, and outlines the structure of the manuscript. It introduces the reader to the Raja Ampat regency, describing the political structure, economic sectors, and ecological highlights of the area. Some topical issues in fisheries economics that pertain to Raja Ampat are also explored, specifically, ecosystem-based management and the issue of illegal, unreported and unregulated (IUU) fisheries is reviewed. Game theory is then explained, and its current applications to the management of fisheries are discussed.

Chapter 2 provides catch and profitability estimates of the unregulated migrant anchovy fishery in Kabui Bay. Managing fisheries resources requires information on the state of the exploited fish stocks, and the fishing effort exerted. As a new political unit in a country with a poor record of fisheries management, the Raja Ampat regency does not have reliable catch and effort data with which to assess stocks and manage fishery productivity. This chapter illustrates the types of primary data required to construct valuation work, which is crucial in analyzing trade-offs in different management decisions. Here, an economic analysis of the migrant anchovy fishery in Kabui Bay is calculated and described. Data from interviews conducted by Conservation International Indonesia, were used to run Monte Carlo simulations to produce catch, revenue and cost estimates for the fishery. The economic data (revenue and cost) were then used to estimate profitability of the fishery, and the distribution of this profit between and among fishers and boat owners is described.

Similar analyses can help construct a picture of the productivity and economic value of different fisheries. The economics used in the anchovy analysis are very basic, but simple analyses of scant data like these are extremely important in helping the government understand the value of their data-poor fisheries. They also lay the foundation for further data collection and more elaborate analyses in the future. Furthermore, the catch estimates provided by the fisher interviews contribute to the accumulation of ecological data virtually unavailable in Raja Ampat, but crucial for effective EBM.

Chapter 3 focuses on destructive fishing methods being used in Raja Ampat, and how their profitability compares with legal methods. A principal-agent model, essentially a type of game-theoretic application, is developed to study what incentives the Raja Ampat regency government could offer villages in order to discourage fishers from engaging in destructive fishing methods. Both blast fishing (fishing with the use of explosives) and cyanide fishing (stunning fish with poison) occur in Indonesia, and they are considered a major threat to Raja Ampat's marine resources (Halim and Mous 2006).

The principal-agent model is implemented computationally using Powersim (Powersim Software AS 1996). Powersim is a system dynamics simulation software package that allows the user to model various technical situations, and simulate changes to the system over time. Using a graphical modeling language, the user builds a model that represents the elements of a system and how they interact with one another, allowing the user to analyze the behaviour of complex systems over time. The dependencies between the variables are displayed using arrow links, and are defined mathematically with equations (see Appendices A and B for the diagram and equations used in the Powersim model).

Fisheries equations found extensively in the literature are used to build the model. A logistic growth function is used to model the biology of the system. Revenue and cost functions are incorporated. The model predicts how fishing effort is allocated between legal and illegal (destructive) gears in Raja Ampat villages. An objective function is maximized subject to the biological constraints of the model (i.e., $biomass \geq 0$). The profitability of the given fisheries drives the model, and this profitability is influenced by the regency's monitoring and enforcement program. The probability of being caught fishing illegally, and the penalty faced by illegal fishers, may discourage fishers from using destructive gears.

The final chapter serves to synthesize the two component studies contained in this thesis, and summarizes their findings. The outcomes of this thesis were presented at a workshop in Bali in July, with the aim being the integration of economic data and analyses into the Raja Ampat EBM project and plan. Chapter 4 discusses specifically how these thesis results can be used by researchers and government officials in the regency. The strengths and weaknesses of the approaches used here, as well as the scope for future work, are discussed.

1.4 Background and Literature Review

In overcoming rural poverty, especially in alleviating poverty among fishermen, it is necessary to preserve the functions of natural resources which constitute people's livelihoods...

UNDP (1998)

1.4.1 Raja Ampat, Paupa, Indonesia

It has been stated that one of Indonesia's biggest challenges today is trying to reconcile the conflict between increased development and conservation aims in the marine coastal sector (Kusuma-Atmadja and Purwaka 1996; Tomascik et al. 1997). Being a country composed of over 17,000 islands, differing marine resource management needs are felt throughout Indonesia. Historically, the capital city of Jakarta, on the island of Java, has been the center of resource control. But like many other countries, Indonesia has seen destruction of its coral reefs, and the serial depletion of fish stocks, mainly sharks, tuna, and reef-associated fishes (Tomascik et al. 1997). Since 1999, the Indonesian government has been instituting a decentralization plan throughout the country, giving more power to regency level authorities (Usman 2001). One of the main reasons for this shift is to lessen the civil uprisings from some provinces seeking independence (Wahid and Gareth 2003). There is also the assumption that local authorities will have a more accurate idea of the needs of their communities and thus can manage resources more efficiently (Usman 2001; Satria and Matsuda 2004). In fact, Satria and Matsuda (2004) specifically state that centralized fisheries management in Indonesia has lead to resource depletion. Author Tim Severin ventured through Indonesia wanting to retrace Alfred Wallace's steps a century earlier (Severin 1997). On page 15 he writes "To protect over-exploitation of fishing there were government regulations about the method of fishing, the size of the catches and so forth. But a briefcase full of cash was more powerful than any regulation ordained by distant Jakarta." (Severin 1997). Under decentralization, provincial jurisdiction over coastal and ocean resources extends up to 12 miles from the coastline (Satria and Matsuda 2004), inside of which the majority of artisanal fishing occurs.

Raja Ampat, in Papua province, became an autonomous regency in 2003. And although decentralization is probably a preferred management style, the dispersed population and large regency area mean that fisheries management is difficult. The province of Papua is the most easterly of Indonesia's 33 provinces, and shares its island with Papua New Guinea to the east. The island is characterized by a marked dry and wet season. The dry season usually lasts from April to October and is influenced by wind currents brought north from Australia, while the wet season, resulting from mainland Asia and Pacific Ocean currents, falls between November and March. The Raja Ampat regency, located in the far west of the province, includes the four main islands of Waigeo, Batanta, Salawati, and Misool, where the majority of the population resides, and consists of about 600 other islands (Figure 1.1. Note: villages shown as open circles, reefs shown as darker areas, and with $\leq$ 200m isobath indicated by shaded areas). The current population is estimated at 32,000 people (Dohar and Anggraeni 2007).

Before Raja Ampat became autonomous, the marine resources surrounding the islands were under the jurisdiction of the Sorong regency on mainland Papua. The shift of power to new regency officials located in Waisai, the capital of Raja Ampat, on the island of Waigeo, will hopefully lead to increased monitoring of marine resources as well as heightened concern for the needs of the island inhabitants. Raja Ampat officials are seeking to initiate development in the area, with increases in the fisheries sector highlighted as a probable development path (Wanma 2002; The Nature Conservancy 2003). This will mean

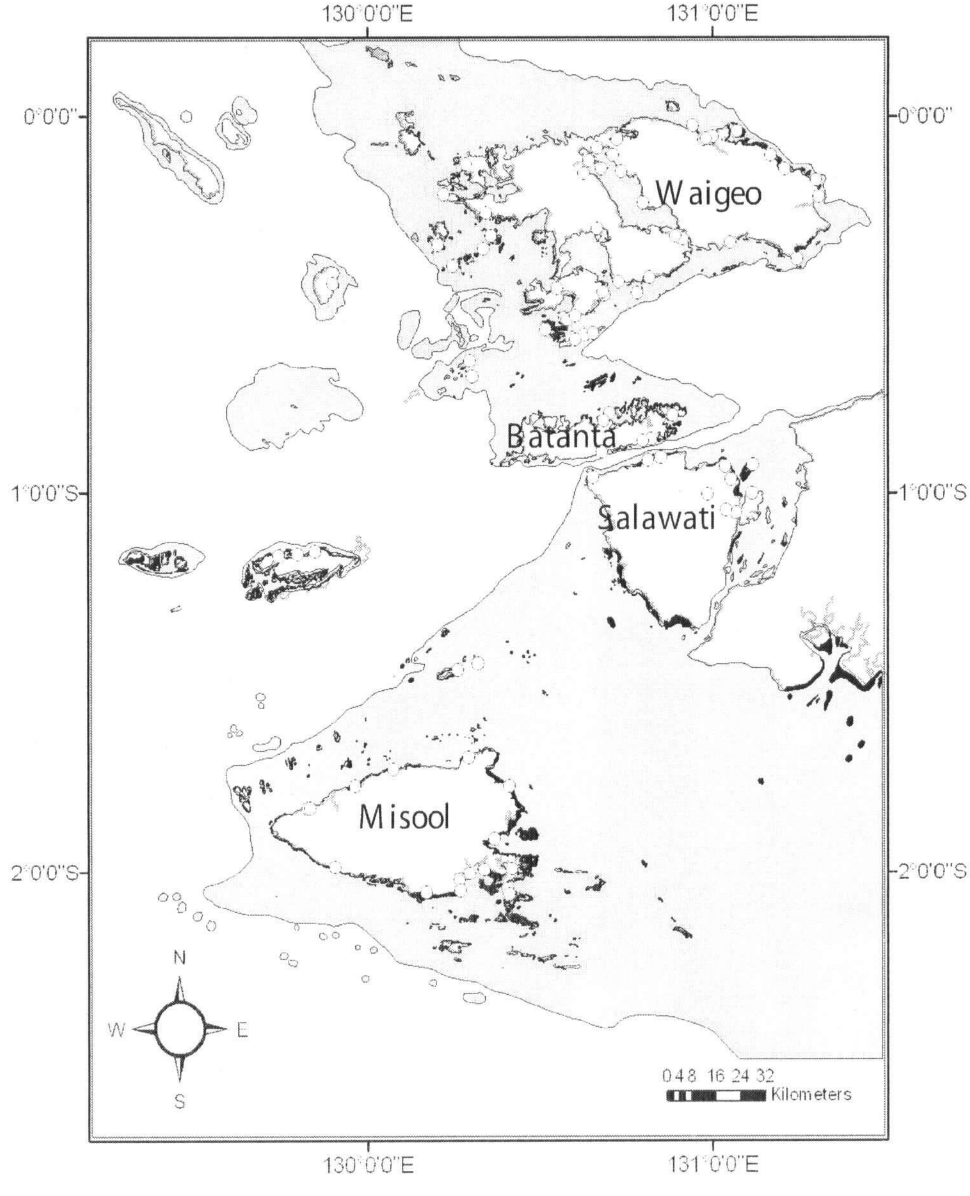

Figure 1.1: Map of Raja Ampat

that members of the newly created Raja Ampat Fisheries Bureau will need to implement increased management, monitoring, and enforcement for fisheries development to proceed sustainably.

The regency government is now responsible for generating its own revenues, and providing social services for its citizens (The Nature Conservancy 2004). Many schools and health clinics in Raja Ampat, however, are either not in use, or functioning with limited supplies and few skilled workers (The Nature Conservancy 2004). Less than one third of households in Raja Ampat have running water (Halim and Mous 2006). The head of the Raja Ampat regency, formally known as the Bupati, is facing the difficult task of increasing the standard of living of Raja Ampat citizens through economic development while conserving the terrestrial and marine biodiversity in the area.

Researchers at CI and the University of Papua (UNIPA) identified nine main economic sectors in Raja Ampat (Dohar and Anggraeni 2007). Table 1.1 lists these sectors, and their estimated 2006 value, in Indonesian Rupiah (IDR) and converted to USD, using an exchange rate of 1 USD = 9000 IRD (Dohar and Anggraeni 2007).

Fisheries are the highest contributing sector, however, pearl farming has been increasing in importance throughout the regency. Future development possibilities for the Raja Ampat regency include more pearl farms, initiation of a grouper mariculture program (to supply grouper for the live fish trade), increases in marine tourism, as well as possible mining. Satria et al. (2006), report that if the institutional structure is adequate, pearl farms can be a successful way of contributing to a community's livelihood. The current situation in Raja Ampat, with Papua's continued fight for independence, and the customary marine tenure rights regime within the regency, could make such institutional agreements difficult. Additionally, it is possible that the majority of highly suitable sites for pearl farming have already been exploited, and thus the scope for increases in this sector may be limited[2].

[2] M. Erdmann, Conservation International, personal communication.

Table 1.1: Economic sectors of Raja Ampat, and their estimated 2006 values

Sector	**Billion IDR**	**Million USD**
Artisanal fisheries	63.1	7.01
Commercial fisheries	20.5	2.28
Reef gleaning	2.2	0.244
Other marine*	0.023	0.0026
Pearl farming	41.0	4.56
Tourism	14.4	1.60
Agriculture	14.8	1.64
Mining**	1.7	0.189
Logging	12.2	1.36
Total	169.9	18.89

*The majority of this sector is composed of seaweed farming.

**This is a potential amount, as nickel mining in the area is still in the exploration phase.

The potential for mining revenues appears to be of interest to the Papuan government. The majority of forest in Raja Ampat is protected, and Indonesian policy states that it should thus be off bounds to mineral extraction. However, due to Papua's regional autonomy, the provincial government has argued that the province should be allowed to grant mining concessions if it so chooses, and test mining is currently underway on the north coast of Waigeo Island[3]. Further development options include the potential of increased revenue from logging and agriculture. Conservation organizations in Raja Ampat (Conservation International, The Nature Conservancy, and World Wildlife Fund) are interested in the creation of quantitative models to link the economic sectors to simulate different development options.

An estimated 1,200 species of fish are present in Raja Ampat (Ainsworth et al. 2007). The main target species in the area include wrasse (family Labridae), grouper (family Serranidae), snapper (family Lutjanidae), fusilier (family Caesionidae), parrotfish (family Scaridae), yellow-fin tuna (*Thunnus albacares*), and surgeonfish (family Acanthuridae), as

[3] M. Erdmann, Conservation International, personal communication.

well as various shellfish and sea cucumbers (family Holothuriidae) (Mckenna et al. 2002; The Nature Conservancy 2003; Ainsworth et al. 2007). Although this area is considered the world's most biodiverse marine habitat, researchers also consider it one of the most threatened, due to population and poverty pressures faced by the communities that depend on its resources (Allen and Werner 2002).

As indicated above, capture fisheries encompass both commercial and artisanal fleets. Halim and Mous (2006) estimated from household surveys that 70% of fishing boats in Raja Ampat were non-motorized canoes. Several gear types are used for both artisanal and commercial fisheries, including handline, dip net, gill net, lift net, purse seine[4], spear and harpoon, permanent traps, as well as destructive methods such as cyanide and blast fishing. Trawling is illegal in Raja Ampat. Although the original inhabitants of Papua lived in the interior, today all villages in the Raja Ampat regency are coastal. As such, fish provide the main protein source for villagers, although many families keep chicken, cattle, and goats as well. Dohar and Anggraeni (2007), estimate that as much as 70% of the population engages in fishing.

1.4.2 Topical Issues in Fisheries Economics

There are two major issues in fisheries economics that are particularly pertinent to this thesis. These are the growing interest and utilization of ecosystem-based management (EBM) and the issue of illegal, unreported, and unregulated (IUU) fisheries.

Ecosystem-Based Management

Ecosystem-based management (EBM) is a widely used term in the resource management literature, but it is not well defined or understood (Hirshfield 2005; UNEP/GPA 2006). The basic idea of marine EBM, is that management of fisheries resources should take into account all complexities of an ecosystem: including the biology and ecology, as well as the human dynamics such as socio-economic and political factors (U.S. Commission on Ocean

[4] Although the regency government is no longer granting purse seine licences, due to conservation concerns, those vessels given licences before 2006 are still allowed to operate in Raja Ampat.

Policy 2004). One of the more difficult concepts for fisheries managers, is that EBM can involve short term costs in order to attain longer term benefits (Sumaila 2005). From a political point of view, it's often difficult to put in place a management scheme that will result in obvious short-term costs, especially a management scheme that is so poorly defined. However, the very essence of EBM implies that no "fixed" definition could do it justice (Ward et al. 2002). EBM must be able to adapt and evolve as information, ideas, models, and tools are added to the repertoire of available management approaches. In this regard, it can be considered a particularly flexible tool for managers.

The results of this thesis will be shared with stakeholder groups currently developing an EBM plan for the Raja Ampat area. For the purpose of this thesis, EBM is defined as a "regime in which decisions explicitly take into account the effects and values of interactions among living organisms, the physical and biotic environment, and the human actors in an ecosystem" (Ward et al. 2002). Several studies, initiated by the three main conservation organizations involved in Raja Ampat fisheries research, are being undertaken simultaneously, with the goal being the creation of an end synthesis incorporating these diverse studies into an EBM toolkit. This will hopefully improve the implementation of EBM in Indonesia, and possibly throughout the world.

Illegal, Unreported, and Unregulated Fishing

Illegal, unreported, and unregulated fishing (IUU) is gaining attention around the world, with fisheries scientists listing it as a major threat to the sustainability of marine resource use (Pitcher et al. 2002; Sumaila et al. 2006). Illegal fishing is defined as fishing that goes against a regulatory measure, such as the use of illegal gears, or the occurrence of fishing by parties without legal approval to fish in a given area. Unreported fishing is catch not reported to the managing body, and includes underreporting and misreporting. Unregulated fisheries describe fisheries operating where management is not in place (such as in the anchovy fishery analyzed in Chapter 2 of this thesis). IUU fishing can lead to an underestimation of catch and effort for a given fishery (Pitcher et al. 2002), and thus undermines management programs (FAO 2002). In 2001, as an indicator of the magnitude of IUU fishing, the Food and Agriculture Organization (FAO) developed an International Plan of Action to Prevent, Deter and Eliminate IUU Fishing (FAO 2001). A year later, the FAO (2002), reported that illegal fishing was still increasing worldwide.

Sumaila et al. (2006), describe four factors that are important in determining if a fisher can benefit from engaging in IUU fishing, as listed below. These agree with the basic economic assumptions underlying most fisheries economics models. In general, if a fisher can answer yes to any of the following questions, then they will tend to engage in illegal fishing (ceteris paribus)[5]:

1. catch: is it probable that a fisher can obtain a large catch from illegal fishing?
2. catch per unit effort: does one unit of illegal effort remove more fish than one unit of legal effort?
3. price: are prices higher for illegally-caught fish?
4. cost: is the cost of illegal fishing less than that of legal fishing?

Three of these issues are addressed in the principal-agent model developed in Chapter 3 of this thesis. Both blast fishing and fishing with cyanide are considered illegal fishing methods in Raja Ampat. However, the catch per unit of effort associated with blast fishing is generally considered higher than legal capture methods. Furthermore, the costs of fishing are lower. In cyanide fisheries, the price per kilogram of fish is significantly higher for live-caught fish (see Chapter 4 for description of all model assumptions). These factors offer incentives for fishers in Raja Ampat to fish illegally. Chapter 4 develops a model whereby a monitoring and enforcement program implemented by the regency government increases the cost of illegal fishing, thus offering a *dis*incentive to fish illegally.

1.4.3 Game Theory

Game theory is used as a tool for explaining and analyzing "problems of strategic behaviour where one agent's actions depend essentially on what other agents may do" (Eatwell et al.

[5]This list is strictly based on economic principles. Social considerations, which are often crucial in preventing villagers from engaging in illegal acts, are ignored here.

1989). Essentially, it uses mathematics to describe player strategies in sources of conflict. In the early 1900s, game theory was developed to analyze outcomes to society as a whole (Canterbery 2001). Nash (1953), formalized game theory from the perspective of the individual, and this allowed game-theoretic model outcomes where individuals could all win (or lose) (Canterbery 2001). Subsequently, game theory has been used in a number of worldwide applications, including economics, political science, evolutionary biology, military strategies, and computer science (Eatwell et al. 1989).

Game theory is particularly applicable to the study of resource management, such as fisheries and forestry, as many of the world's natural resources are common pool in nature (see for example, Huffman and Just 2000, and Angelsen 2001). Game-theoretic approaches have been widely applied to analyze the exploitation strategies of different fisher groups or fishing nations, with the majority of these models applying cooperative and non-cooperative games (Sumaila 1999). Nash (1953), used the word "cooperative" to define the situation where different user groups (the game's players) are able to discuss and agree upon a joint plan (they can communicate), and that the agreement is "assumed to be enforceable", or binding. It thus follows that non-cooperative games are games in which agreements are non-binding, and where parties cannot collaborate. Game theoretic models assume that players are individually rational (Nash 1953). The first real application of game theory in the fisheries literature was by Munro (1979), who analyzed the issue of trans-boundary stocks in a game-theoretic context. Cooperative and non-cooperative game theory has since been used to analyze shared stocks, such as cod (Sumaila 1997a;b; Kronbak 2004), and herring (Arnason et al. 2000), and has been expanded recently to analyzing fisher behaviour in community-based fisheries (Trisak 2005) and coalitions in three-party models (Kronbak and Lindroos 2007). In these types of models, players sharing the resource are assumed to be fully informed on the structure of the game, and also on the utility function of the other player(s); in other words, the games operate under the assumption of "complete information" (Jensen and Vestergaard 2002).

This assumption of "complete information" is not met in many circumstances, as Nash

(1953) himself admitted. In situations where the parties involved have imperfect information, and thus one player exercises some amount of control over the other player(s), the game becomes one analyzed through the principal-agent model. Principal-agent analysis is used in systems of imperfect information, and also 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). Such situations arise because the principal cannot perform the actions on his/her own, and are often called incentive schemes. In effect, the principal's opportunity cost is higher than his/her expected benefit and so it is to his/her advantage to encourage someone else to do the work. The payoff to the principal depends on the action taken by the agent, and therefore, the principal must provide some incentives for the agent to act on his/her behalf to ensure the job is done to the principal's satisfaction (Gintis 2000).

Principal-agent theory emerged with the division of labour, that is, with the very first of human activity (Laffont and Martimort 2001). When party A delegates a task to party B, a principal-agent model is born. The classic example is the well-analyzed landowner/farmer dynamic. In this example, a landowner (the principal) hires a farmer (the agent) to work his/her land. In the first best solution, the principal would be able to control the agent's actions perfectly, thus reaching its objectives exactly. But with imperfect information, an incentive gap emerges, whereby the principal's inability to perfectly monitor the agent's actions results in a difference between the actual optimization outcome, and that of the first best solution (Clarke and Munro 1987). This is often called the second best solution. Principal-agent theory attempts to determine the optimal incentive scheme; one that minimizes this gap, at a minimal cost to the principal.

To date there are only three published papers, that I am aware of, that use principal-agent analysis to explain the behaviours and decisions made by fisher groups and managing bodies. Clarke and Munro (1987; 1991) have contributed two of these, where they study the relationship between coastal states and distant water fishing nations (DWFN). In their first contribution, the authors use principal-agent theory to determine the optimal catch and effort tax scheme that should be employed by a coastal state in order to optimize the economic arrangement between the state and the DWFN (Clarke and Munro 1987). Their second contribution delves deeper into the issue of discounting, and reanalyzes the coastal state optimization problem by assuming that the principal (coastal state) and agent (DWFN) can have different discount rates (Clarke and Munro 1991). The result of this analysis suggests that it is indeed difficult to reach the first best solution under such circumstances (Clarke and Munro 1991). The third contribution to the field analyzes a tax on EU member state (agent) effort to be enforced by the EU (principal) in an attempt to correct for imperfect information in the system (Jensen and Vestergaard 2002). The authors conclude that a tax system is more desirable than the current TAC system, largely because the TAC plan does not take into account the differences in fishing efficiency and is thus economically inefficient (Jensen and Vestergaard 2002). Furthermore, an EU tax system can solve the issue of asymmetric information (Jensen and Vestergaard 2002).

As only these three papers currently address the principal-agent problem in fisheries, there is a need to further explore if and how principal-agent analysis can be used as a tool for fisheries management. This thesis develops a principal-agent model in Chapter 3, as an addition to the literature in this field.

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Chapter 2

Catch and Income Distribution in the Kabui Bay Anchovy Fishery

...the economically motivated behavior of fishermen must be considered as an integral component of any fishery system.

Clark (2006)

2.1 Introduction

As a country composed of over 17,000 islands, differing marine resource management needs are felt throughout Indonesia. Historically, the capital city of Jakarta, on the island of Java, has been the center of resource control. But like many other countries, Indonesia has seen destruction of its coral reefs, and the serial depletion of fish stocks, mainly sharks, tunas, and reef-associated fishes (Tomascik et al. 1997). In 1999, the Indonesian government instituted a decentralization plan throughout the country, giving more power to regency level authorities (Usman 2001). One of the main reasons for this shift is the assumption that local authorities will have a more accurate idea of the needs of their communities, and thus potentially manage their resources more efficiently (Usman 2001; Satria and Matsuda 2004).

Despite decreasing fish stocks and habitat degradation in other areas of the country, the ecosystem on the western most side of the province of Papua remains relatively healthy.

[5]A version of this chapter has been accepted for publication. Bailey, M., Rotinsulu, C., and Sumaila, U.R. The Migrant Anchovy Fishery in Kabui Bay, Raja Ampat, Indonesia: Catch, Profitability, and Income Distribution. Accepted by Marine Policy September 1, 2007.

A new political unit called the Raja Ampat regency has been created in this area, and recent ecological surveys suggest that the region boasts the highest coral reef biodiversity in the world (Mckenna et al. 2002; The Nature Conservancy 2003). This biodiversity, however, is threatened by increasing fishing activity, both legal and illegal, in Raja Ampat (The Nature Conservancy 2003; 2004). Neighbouring provinces (Komodo, Sulawesi) and countries (Philippines, Palau) can no longer catch sufficient fish from their own depleted waters, and thus fishers from these areas are fishing in the waters of Raja Ampat (Mckenna et al. 2002; The Nature Conservancy 2003; 2004). Not much is known in terms of how much fish is being caught by migrant fishers, or how much revenue these fisheries generate. Such unregulated catches can negatively affect fish stock sizes and undermine management goals (FAO 2002; Pitcher et al. 2002). Thus there is a need to quantify the migrant fishery catch to help ensure that fish stocks in Raja Ampat are being fished sustainably.

This chapter provides a description of the Raja Ampat area, as well as an overview of one of the major migrant-dominated fisheries: the anchovy (*Stolephorus indicus*) lantern fishery. Annual anchovy catch is estimated and economics of the fishery analyzed. Annual gross revenue is calculated and costs are discussed, to produce an estimated annual profit for 2006, from the fishery's point of view (i.e., private costs and benefits). The economic content in this chapter is simple, and thus whatever value it has lies in its contribution in spite of the scant literature and available data pertaining to fisheries in Raja Ampat. The Fisheries Bureau in Sorong, the closest landings port adjacent to Raja Ampat, has no official catch statistics for migrant anchovy fisheries, and thus this paper can hopefully be used by the Raja Ampat regency as they attempt to develop their marine resource management plans in the coming years.

2.2 Area Description

The province of Papua is the most easterly of Indonesia's 33 provinces, and shares its island with the country of Papua New Guinea to the east. Raja Ampat was designated a regency in 2003, and includes the four main islands of Waigeo, Batanta, Salawati, and Misool, where the majority of the population resides, and consists of about 600 other islands (Figure 2.1 shows the Raja Ampat regency area with the island of Waigeo highlighted by a box. Villages are shown by open circles, and reef areas indicated by darker coastline). There are an estimated 32,000 people dispersed throughout the 4 million hectare area that makes up Raja Ampat (Dohar and Anggraeni 2007).

Over 1,200 species of fish are present in Raja Ampat (The Nature Conservancy 2003; Ainsworth et al. 2007), as well as 75% of the world's coral species (Halim and Mous 2006). Fish caught in the area include wrasse, grouper, snapper, parrotfish, tuna, surgeonfish, squid, and small pelagics like sardine and anchovy (Mckenna et al. 2002; The Nature Conservancy 2003; Ainsworth et al. 2007).

In this regency, marine resources are paramount. Throughout the year most regency inhabitants are involved in subsistence fishing, even though they may be employed in other industries as their main economic source (farming, construction, pearl farming, etc.) (The Nature Conservancy 2003; 2004). A recent valuation report estimates that seventy percent of the population engages in fishing (Dohar and Anggraeni 2007). Small-scale sale of fish, often just within a village, occurs throughout the year. When weather permits (during calm seas), the amount of commercial fishing in Raja Ampat increases, and catch is often sold at the Sorong fish market on mainland Papua (The Nature Conservancy 2003; 2004).

The dispersed population and large regency area mean that fisheries management in Raja Ampat waters has historically been limited, or non-existent. But with a new regency government in place, Raja Ampat officials are seeking to increase development in the area, with increases in the fisheries sector highlighted as a probable development path (The Nature Conservancy 2003; Wanma 2002). This will mean that members of the Raja Ampat Fisheries Bureau (DKP) will need to implement effective monitoring, control, and enforcement for development to proceed sustainably. Both native and migrant fishing activity will need to be managed.

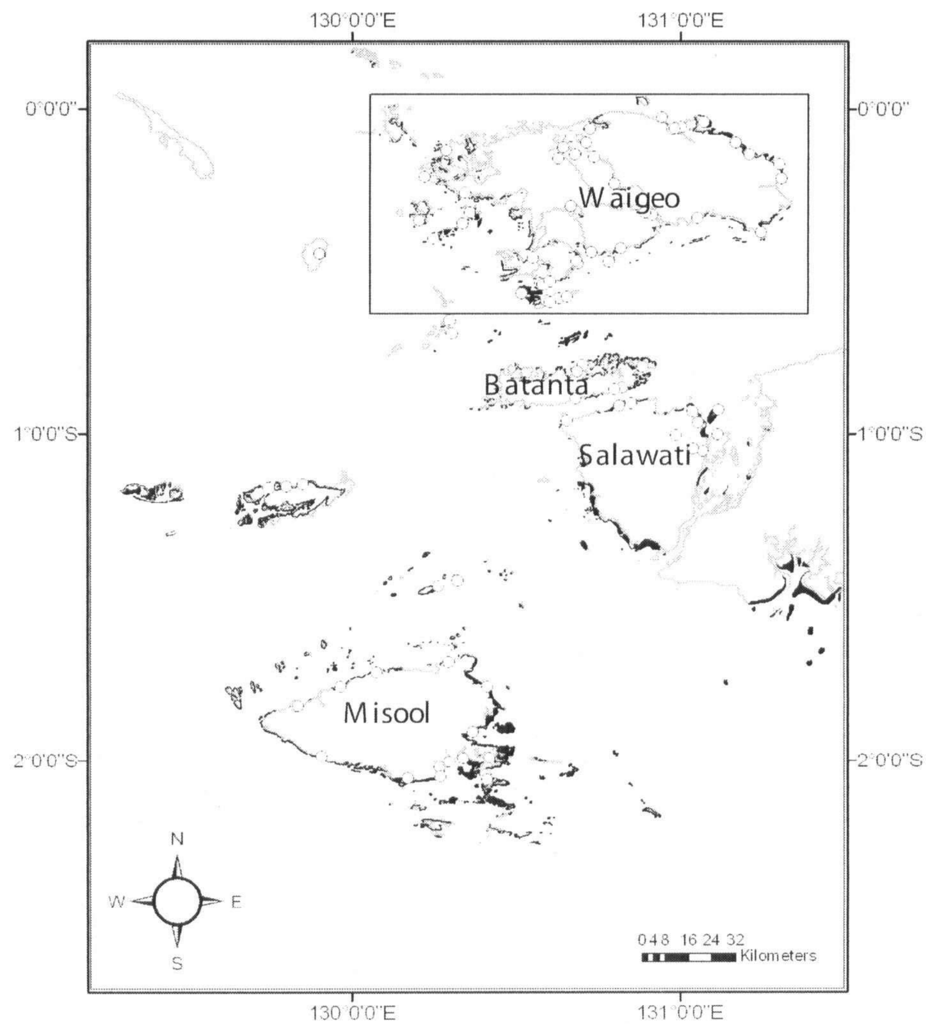

Figure 2.1: Map of Raja Ampat

2.3 The Migrant Anchovy Fishery

Migrant fishers (fishers who travel from one area to another in search of work, engaging in employment away from their permanent residence) can often enter Raja Ampat waters, drop their lines or nets, and fish uninterrupted. This type of migrant fishing activity is rarely regulated. Illegal, unreported, and unregulated (IUU) fisheries in Indonesia, and the world over, make fisheries management difficult (Sumaila et al. 2006). Fisheries stock assessment work depends on accurate records of catch and effort, both of which are underestimated with IUU fishing (Pitcher et al. 2002). For future development of fisheries resources, the DKP will need to invest adequate resources to identify the types of unregulated migrant fishing activity in the area, and to estimate the catch and profitability of such fisheries. Regulating migrant fisheries can increase fisheries revenue to the regency, and can help the DKP monitor destructive fishing practices, a major problem in Indonesia (Pet-Soede and Erdmann 1998).

The anchovy fishery in Kabui Bay is an unregulated migrant fishery. The fishers operate in an area where there are no catch limits set by the DKP, and no requirements for reporting that catch. In 1999, 20 men from the Indonesian province of South East (SE) Sulawesi came to Papua for fishing access in Kabui Bay, on the southwest side of Waigeo Island. At that time, Raja Ampat was under the authority of the Sorong regency, based on mainland Papua. The migrant fishers paid a one-time access fee of 1 million Indonesian Rupiah (IDR) (US $ 111) to the Sorong Fisheries Department, and have been fishing in the bay ever since. The fishers set up a temporary settlement camp, but this has become a second home for the men. Today, about 250 migrant fishers live in Kabui Bay fishing anchovy. Although they no longer pay money to regency level authorities, the anchovy fishers do owe monthly access fees to the villages of Kabui and Wauyai in order to live on the land, and fish in the bay's waters. Figure 2.2 shows Waigeo Island, with the two villages surrounding Kabui Bay to whom money is owed (coloured-in circles).

Fresh anchovy is fished at dusk by dropping nets attached between two wooden boats

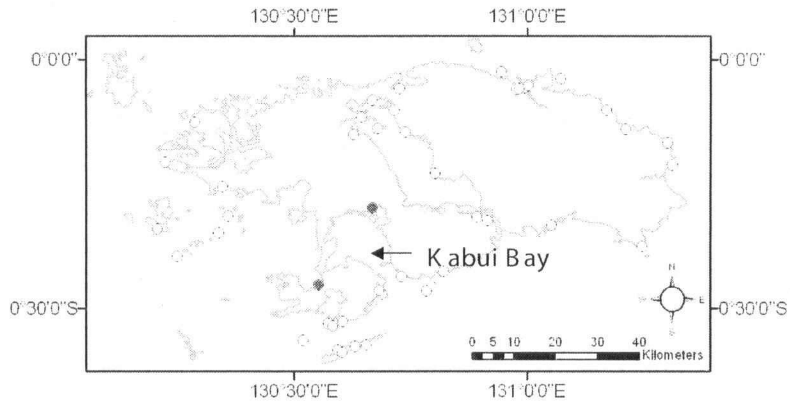

Figure 2.2: Map of Waigeo Island

manned by 5 fishers. The nets are lowered about 13 meters down, and the fishers turn on a kerosene lantern. The light attracts the anchovy, and a few hours later the nets are pulled up with manual winches. Anchovy are then set on dozens of racks for one and a half days to dry out. This fish is called *puri*, or *ikan teri* by Indonesians. Vendors in Sorong do sell bags of dried anchovy at the local market, but the fish caught in Kabui Bay are all transshipped at sea to Java, in western Indonesia.

Fishers remain at the settlement camp for 4 or 5 months, at which time they go back to their homes in Buton, SE Sulawesi. It is in the province of SE Sulawesi that most of the income generated from the fishery will be spent. Other than rice, the men farm or fish everything they consume, including cassava, tomatoes, chili peppers, bananas and coconut. Similar anchovy fisheries are set up elsewhere in Raja Ampat, namely, Aljui Bay and the area north of Misool. However, like Kabui Bay, there are limited catch data from these fisheries. As far as the Kabui Bay anchovy fishers can recall, the DKP has never asked them what, or how much, they are fishing. Furthermore, because the majority of the anchovy catch is never officially landed anywhere in Papua, the province has incomplete catch statistics.

This chapter presents an annual catch estimate, as well as fisher and owner profitability estimates for 2006. A static analysis was chosen to simplify the issue of changes in annual group composition (i.e., number vessels fishing), changes in cost and revenue of fishing, as well as inter-annual catch variations.

2.4 Interviews

Official anchovy fishery data specifically from Raja Ampat are incomplete and unreliable. Therefore, quantitative data were obtained from interviewing the migrant anchovy fishers in Kabui Bay. Interviews, led by C. Rotinsulu from Conservation International Indonesia, took place at the temporary settlement camp in Kabui Bay, Raja Ampat, on April 19, 2006, and November 28, 2006. These times coincide with the dry and wet seasons, respectively. We came with a prepared list of questions, and had anticipated speaking with individuals one at a time. However, our April visit sparked the camp's interest, bringing around 100 men to join the first interview. Ultimately, this led to only one set of questions being asked, with one primary respondent giving answers, and other respondents occasionally pitching in. Our timing was off in November, as most of the people in the camp had traveled back to SE Sulawesi to celebrate Ramadan, and had yet to return to the settlement. Therefore, in November, only two fishers were interviewed. Answers to questions pertaining to prices were given in Indonesian Rupiah (IDR), but are reported in the paper in US dollars by using the rounded current exchange rate of 9,000 IDR to 1 USD. Due to the interview limitations (small sample size) this analysis serves only as a rough snapshot estimating the catch and profitability of the fishery. A more rigorous interview process would serve to better estimate catch, effort, revenue and cost. Hopefully this work will prioritize more elaborate data collection efforts.

2.5 Computations

Catch and revenue distributions were generated using the Monte Carlo simulation method. Answers to most interview questions were given as ranges (for example, the weight of anchovy in the baskets used to collect fish from the nets ranged from 5.5 to 6.5 kg), and all variables were assumed to be distributed uniformly over that range. Ten thousand random draws were sampled from within the variable ranges to produce frequency distributions of all possible catch, revenue, and cost estimates.

2.5.1 Catch

The amount of fish caught annually per boat was estimated from a number of responses from the fishers, and varies with season. The Kabui Bay fishers do not weigh their fish directly, but know that the weight of one basket of fish is about 6 kg. Effort for this fishery is represented by number of days fished per month and per season. Seasonal catch h_s is calculated by the following:

$$h_s = n_s w d_s m_s \tag{2.1}$$

where n_s is the number of baskets caught on a given night in season s (either dry or wet), w is the weight of fish per basket (does not vary with season), d_s is the number of days fished per month in season s, and m_s is the number of months fished in season s.

The total annual catch per boat is thus the sum of these two seasonal estimates:

$$h = h_d + h_w \tag{2.2}$$

where h_d and h_w are the total catches in the dry and wet season, respectively. To estimate catch for the entire fleet, the estimate per boat was multiplied by the number of boats operating in Kabui Bay, which ranged from 50-60.

2.5.2 Revenue

To obtain revenue, the seasonal catch estimates were first divided by two. For the anchovy fishery, it is assumed that the weight of the catch once dried is about one half of the fresh weight harvested [6]. This dried catch is then multiplied by the price for landed, dried fish, in each season. That is, total revenue in 2006 is:

[6] A. Muljadi, The Nature Conservancy, personal communication.

Table 2.1: Catch variable ranges used for Monte Carlo simulations

Variable	Min	Max
Number of baskets caught per night (dry season)	35	45
Number of baskets caught per night (wet season)	45	55
Weight of fish in basket (kg)	5.5	6.5
Number of nights fished per month (dry season)	24	24
Number of nights fished per month (wet season)	21	24
Number of months fished (dry season)	6	6
Number of months fished (wet season)	4	4
Number of boats operating in the fleet	50	60

$$TR = p_d \frac{h_d}{2} + p_w \frac{h_w}{2} \tag{2.3}$$

where p_d and p_w are the prices per kilogram of dried anchovy in the dry and wet season respectively.

The ex-vessel price of anchovy caught and dried during the dry season is fixed at about \$1.30 per kilogram. Fish caught and dried during the wet season, however, fetch a lower and variable price due to unfavorable drying conditions leading to lesser quality fish. The wet season ex-vessel price ranged from \$0.40 to \$0.56 and this range was used in the Monte Carlo simulations.

Table 2.2: Revenue variable ranges used for Monte Carlo simulations

Variable	Min	Max
Exchange rate (IDR per USD)	9,000	9,000
Price per kg of dried anchovy (dry season) (USD)	1.33	1.33
Price per kg of dried anchovy (wet season) (USD)	0.40	0.56

2.5.3 Cost

The total cost TC of the fishery is composed of both fixed, FC, and variable, VC, costs:

$$TC = FC + VC \tag{2.4}$$

The fixed costs in the anchovy fishery include the boat and net setup and the access fees paid by boat owners to the villages. Variable costs include gasoline for the boat engine and kerosene for the lanterns, as well as labour costs. The fishers said that their income, and thus labour costs, depends on the revenue. Each fisher receives $1/16^{th}$ of the total revenue in the form of personal income. The boat owner, on the other hand, takes $3/16^{ths}$ of the total revenue for his personal income. Therefore total labor-associated costs equal $8/16^{ths}$, or one half, of the total revenue.

2.5.4 Profit and gains from the fishery

Profit in this fishery is considered for two cases: boat owner profit and fisher profit. The owner's profit, π_o , is the difference between the total revenue and total cost of the fishery:

$$\pi_o = TR - TC \tag{2.5}$$

The fisher profit, π_f, is the difference between the personal income earned from the anchovy fishery, C_l, and that fisher's opportunity cost, OC , essentially the average annual income the fisher could make in another fishery in Raja Ampat.

$$\pi_f = C_l - OC \tag{2.6}$$

2.6 Results

2.6.1 Catch

Annual per boat catch varied from 49 to 76 tonnes, with a mean of 62 tonnes (Figure 2.3). Annual catch for the entire fleet (50-60 boats) ranged from 2,493 to 4,468 tonnes, with a mean of 3,389 tonnes (Figure 2.4). The 95% confidence intervals are indicated by vertical lines in both figures.

The Kabui Bay anchovy fishery is not the only anchovy fishery currently operating in Raja Ampat. In 2005 an estimated 230 lift net boats were also operating, most catching

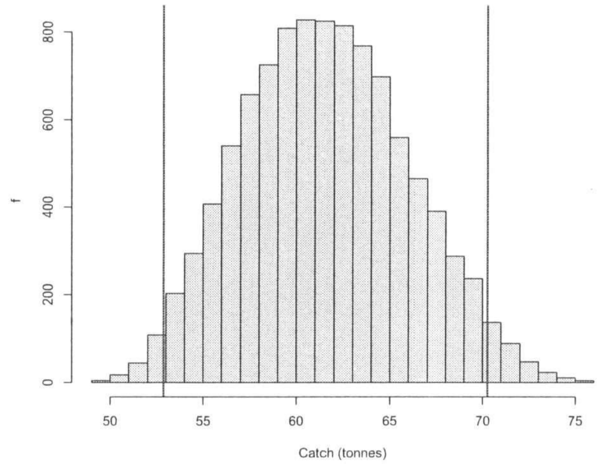

Figure 2.3: Annual catch per boat

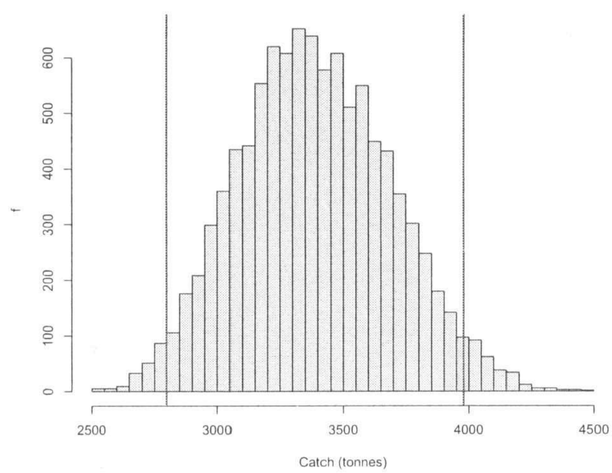

Figure 2.4: Annual fleet catch

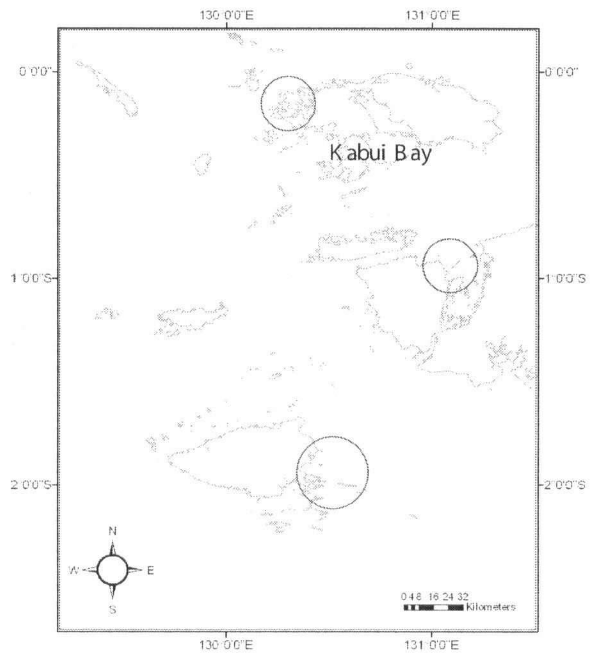

Figure 2.5: Anchovy operations

anchovy, and some targeting squid. Figure 2.5 shows where these anchovy operations are currently fishing. By rerunning the Monte Carlo simulations using a range of 200 to 230 vessels, the total estimated catch for the area is about 13,000 tonnes.

2.6.2 Revenue

Estimated annual revenue per boat ranged from US \$23,280 to \$36,730, with a mean annual revenue of US \$29,380 (Figure 2.6). Annual revenue for the entire fleet ranged from an estimated \$1.16 million to \$2.1 million, with a mean of \$1.62 million (Figure 2.7). The 95% confidence intervals are indicated by vertical lines in both figures.

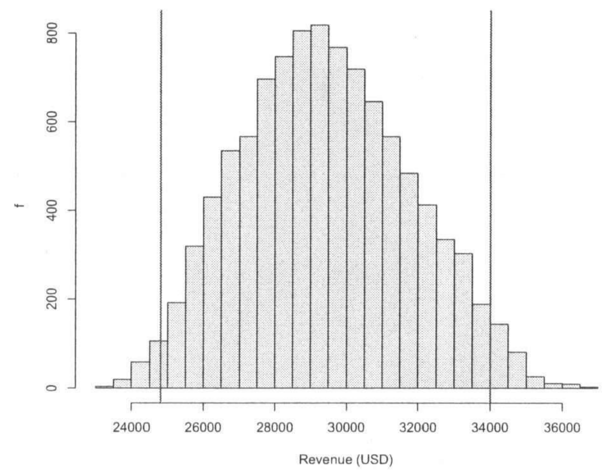

Figure 2.6: Annual revenue per boat

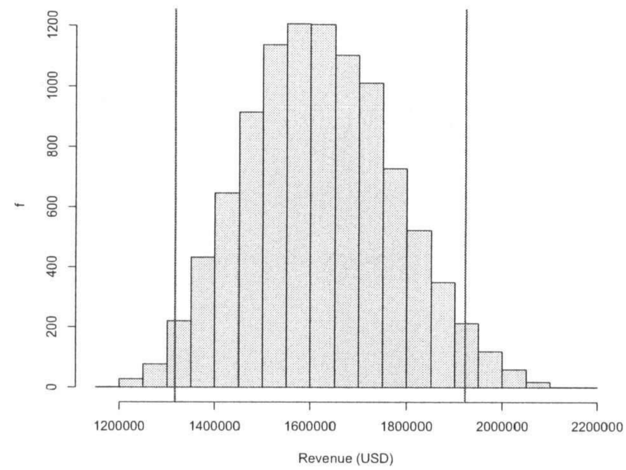

Figure 2.7: Annual fleet revenue

2.6.3 Costs

Discussions with the fishers gave the following cost estimates: annual access fees amount to \$267; annual capital investment equals \$156 (cost of boat and net setup multiplied by 0.2; fishers told us that the setup lasts 5 years, therefore 1/5 of the cost gets allocated to 2006); fuel costs average \$1,455 per year, and kerosene costs average \$468 per year. Thus the boat owner's cost (excluding labor) averages \$2,346 per boat per year. As stated above, the revenue is split in half to pay labor costs. Each fisher receives $1/16^{th}$ of the revenue, which averages about \$1,835 per year. Recall there are 5 fishers per boat, so total labor costs paid out to the fishers average \$9,189 annually. The boat owner takes $3/16^{ths}$ for his personal income, averaging about \$5,513 per year.

2.6.4 Profit and gains from the fishery

The estimated annual owner profit, the difference between the total revenue and total costs, is about \$10,870. This is quite substantial given that the average annual per capita income in the province of Papua was \$938 in 2002 (UNIPA, 2002). Furthermore, fishers told us that owners in fact take half of the revenue (averaging \$14,698 per boat per year) to pay back their "capital investments", even though those costs, as described by the fishers, are substantially lower (recall non-labor costs equal $2,346). Thus it appears that the boat owners are capturing the majority of rent from the fishery.

The estimated annual fisher profit is the difference between the fisher's personal income from the anchovy fishery and his opportunity cost. Unfortunately, direct statistics for average annual fishery income is not available for Raja Ampat. However, a valuation study conducted by Conservation International (CI) reported the average per capita Gross Regional Domestic Product (GRDP) in Raja Ampat in 2004 was $824 (Bappeda, 2004 in Dohar and Anggraeni, 2007). The same CI study estimated the combined net value of artisanal and commercial fisheries in Raja Ampat at about $9.22 million and suggested that about 24,693 people within the regency participate in the fisheries sector (Dohar and Anggraeni, 2006). By dividing the value of the fisheries by the number of fishers, we can roughly estimate that each fisher makes about $1,024 per year. Note, however, that this is an average, and includes artisanal fishers *and* boat owners; groups that probably make very different incomes. If we do assume that the average fisher in Raja Ampat makes about $1,024 per year, and using the estimate from the interviews with the Kabui Bay anchovy fishers yielding a mean annual income of $1,835, it appears that the anchovy fishers are making about 1.8 times as much as other fishers in Raja Ampat.

Table 2.3: Monte Carlo simulation results

Simulation	Min	Max	Mean	SD*
Catch per boat (t)	49	76	72	4.35
Catch per fleet (t)	2,493	4,468	3,389	299
Gross revenue per boat (USD)	23,280	36,730	29,380	2,321
Gross revenue per fleet (M USD)	1.16	2.10	1.62	0.154
Costs per boat (USD)	2,297	2,396	2,346	37
Costs per fleet (USD)	115,000	144,000	129,000	7,100
Fishery profit (USD)	401,000	837,000	596,000	71,100
Boat owner profit per boat (USD)	7,732	14,561	10,868	1,160
Fisher annual profit (USD)	410	1,240	811	146

SD=Standard Deviation

2.7 Conclusion

The inequitable distribution of gains from the anchovy fishery seems quite apparent. Boat owners are capturing the majority of rent from the fishery, making about five times as much as the fishers. One possible consideration is that boat owners owe money to a broker that sets up the boat owners with the vendors who buy the fish[7], and that this cost is unknown to the fishers we interviewed and thus not included in this analysis. The anchovy fishers themselves are also making substantial profits in this fishery, as their annual income is almost twice as much as the average Raja Ampat fisher.

The majority of these profits will be spent in Buton, when the fishers return home. Therefore, there is no possible argument that the large incomes earned by migrant fishers would directly benefit the people of Raja Ampat, through increased personal expenditure.

As current access fees are paid only to villages, and not directly to the regency government, the government is not generating any revenue from the migrant anchovy fishery. Because the regency is a newly created political unit, the initial terms of the original access agreement in 1999 might be subject to change. Regency revenue somehow generated from the profitability of the fishery could help the DKP fund regency-wide fisheries management, such as effort monitoring, stock assessment work, research on illegal and destructive fishing practices, and modeling of economic development options for the area through marine resource use. All of these management programs have the potential of increasing fishers' incomes in the medium and long term.

Specific monitoring of the migrant anchovy fishery is an important consideration not currently part of the Bureau's management plan. The migrant respondents told us that the DKP had never come by their settlement to ask them what they are fishing or how much they are catching. As stated earlier, unreported catches have the potential to severely bias stock assessments and to undermine management objectives (Pitcher et al. 2002;

[7]Lida Pet-Soede, World Wildlife Fund, personal communication.

Clark 2006). The approximate total extraction of 13,000 tonnes of anchovy caught by the estimated 200-300 vessels currently operating in Raja Ampat may in fact be a gross underestimate. The Kabui Bay lift net boats are known to be substantially smaller than the majority of boats targeting anchovy in the area[8]. If this is in fact the case, then it could mean that twice or three times the estimated removals are actually taking place. Because the fishery is so profitable, it is easy to imagine that effort could continue to increase into the future.

Anchovy have been identified as a key prey item for higher level predators (Skewgar et al. 2007). Within the Raja Ampat ecosystem, tuna, mackerel, billfish, as well as reef-associated and pelagic fishes feed on anchovy (Ainsworth et al. 2007). The groups fishing in Kabui Bay have noticed a decrease in the population of anchovy close to shore, and this could mean reduced prey availability for other fish species. Beginning last year, the fishers expanded their range, and are now traveling twice as far offshore as past fishers did. The fishers told us that they would stop fishing in Kabui Bay if their catches decreased to about half of what they catch now. In light of this, the DKP should monitor and manage this fishery, and other anchovy fisheries in Raja Ampat.

The profitability of the fishery, as reported here, should be incentive enough to manage it sustainably, to ensure the flow of benefits to the area through time. Recent work by Zeller et al. (2006) highlight the need for better catch and revenue statistics in small-scale fisheries in the Pacific as these fishers can contribute substantially to GDP, but are often ignored. Hopefully this study, and the growing attention to the world's small-scale fisheries, will encourage subsequent studies in Raja Ampat.

[8] M. Erdmann, Conservation International, personal communication.

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Chapter 3

Destructive Fishing: An Applied Principal-Agent Analysis

Inadequate incentives mean dissolution ... or failure of cooperation. Hence, in all sorts of organizations the affording of adequate incentives becomes the most definitely emphasized task in their existence.

Barnard (1938)

3.1 Introduction

The Raja Ampat regency in Papua province, Indonesia, is currently trying to develop and implement a sustainable fisheries management system. Raja Ampat boasts the world's highest coral reef biodiversity, with 75% of known hard coral species found in the area (Halim and Mous 2006) and is home to over 1,200 species of fish (Ainsworth et al. 2007). Artisanal fishing in Indonesia is an important economic sector (Dohar and Anggraeni 2007), but the introduction of new gears can throw off the traditional balance artisinal fisheries often encompass (Kusuma-Atmadja and Purwaka 1996). The use of destructive fishing gears, mainly explosives and cyanide, is one of the major threats to sustainable fisheries in the Raja Ampat regency (Halim and Mous 2006). Both practices are considered illegal. This paper develops a model comparing the profitability of illegal (destructive) fishing methods to legal methods. Principal-agent theory is used to simulate how incentives offered by the government could encourage fisher effort away from illegal methods.

[8] A version of this chapter will be submitted for publication. Bailey, M., Sumaila, U.R., Ainsworth, C.H., and Pitcher, T.J. Destructive fishing in Raja Ampat: An applied principal-agent analysis.

3.1.1 IUU fishing

Illegal, unreported, and unregulated fishing (IUU), is gaining attention around the world, with fisheries scientists listing it as a major barrier to the sustainability of marine resource use (Pitcher et al. 2002; Sumaila et al. 2006). Illegal fishing is any type of fishing that violates a regulatory measure. In Indonesia, the use of illegal fishing gears, such as cyanide and explosives, is considered one of the biggest threats to the marine ecosystem (Pet-Soede and Erdmann 1998; Pet-Soede et al. 1999; Halim and Mous 2006). IUU fishing can undermines management programs (FAO 2002) by underestimation of catch and effort (Pitcher et al. 2002). Furthermore, both dynamite and cyanide fishing negatively affect fish habitat, and are thus inherently unsustainable fishing methods (Pauly 1989).

3.1.2 Principal-agent theory

The majority of the world's fisheries are common pool or shared in nature. As such, the use of game theory, essentially the study of strategic interactions between players, has been widely applied to fisheries management models (Munro 1979; Clarke and Munro 1987; Sumaila 1995; 1997; 1999; Trisak 2005; Kronbak and Lindroos 2007). In an era of ecosystem-based management (EBM), the ability to model multiple users of an ecosystem is becoming increasingly important (Sumaila 2005). Differences in resource user uncertainty, rates of discount, and risk aversion can impede sustainable fisheries(Munro 1979; Sumaila 2005), a core EBM goal. Game-theoretic models, because they explicitly model the expected utility functions of the user groups, can help economists elucidate the factors that impede or assist in the collaborative management process, and thus why, perhaps, EBM is such a hard goal to reach.

Principal-agent theory is a special type of game-theoretic approach that models situations where one player in the game (the principal) has effective "ownership" over the resource and those actors exploiting the resource (the agents). In the first best solution, the principal can perfectly control the agents' actions in order to maximize his/her objective function (Clarke and Munro 1987). In terms of fisheries management, for example, the manager would be able to perfectly control the agents' fishing effort. If this first best solution occurs, then the objectives of the principal are fully met, and the benefits realized to the principal are exactly equal to what the principal expects. However, it is unrealistic to assume that perfect control is within the power of the principal and thus that the first best solution would occur. Rather, most situations end up at the second best solution, where due to imperfect control, and imperfect information, the realized benefits to the principal are less than expected.

The difference between the realized benefits in the first and second best solutions is called the incentive gap (Clarke and Munro 1987). Principal-agent theory seeks to decrease this gap through the use of appropriate incentives. The optimal incentive scheme is one that minimizes the incentive gap at a minimal cost to the principal. To my knowledge, only three published articles have applied principal-agent analysis to study fisheries problems. All of these use taxes and subsidies as incentives (Clarke and Munro 1987; 1991; Jensen and Vestergaard 2002). In the current paper, however, the probability of detecting illegal fishers, and the penalty faced by violators, are used as disincentives.

3.1.3 Discounting

In 1973, Colin Clark suggested that disregarding the concept of discounting in fisheries economics "denies the fundamental principles of economics itself" (Clark 1973). The discount rate is a number that allows us to convert values to be received in the future into values today. Theoretically, the discount rate can take both negative and positive values. A negative discount rate implies that we value the future more than the present. If the discount rate is zero, it means we have no time preference. But generally, the discount rate is positive, which implies that we value the present more than we value the future. As the discount rate increases, we value the future less and less.

Generally, we do not value the future as much as we value the present, due to uncertainty and risk (Clark 1990). In the example of resource conservation, we are uncertain about stock sizes, about ex-vessel prices, and about the costs of fishing. We know the present day profitability of fishing, yet we are uncertain of the future and thus we prefer values from fishing today. Furthermore, by foregoing present benefits, we are losing possible interest accumulation on those benefits. Discounting is a complex issue that economists have frequently discussed and debated (Clark 1973; 1990; Nordhaus 1997; Weitzman 2001; Ainsworth and Sumaila 2005; Sumaila and Walters 2005; Berman and Sumaila 2006). One thing seems very clear though: higher rates of discount (social or private) lead to greater resource depletion. To determine the possible differences in management scenarios given such uncertainty in discounting, each of the two models in this chapter (snapper and grouper) is run with various discount rate assumptions.

3.2 Model outline

3.2.1 Artisanal Fisheries

The artisanal fisheries sector in Raja Ampat was valued at $63 billion Indonesian Rupiah (IDR) in 2006, equivalent to about US $7 million (Dohar and Anggraeni 2007). Generally speaking, the artisanal fishery is a mixed-species fishery, with several target species pursued with several gear types. For example, one fisher may fish at any time with a hand line, or spear, and target snapper (Lutjanidae family), grouper (Serranidae family), or trevally (Siganidae family). Legal fishing gears used for artisinal fishing include handline, dip net, gill net, permanent trap, and spear/harpoon. The average artisanal fisher in Raja Ampat fishes about 15 days per month (Dohar and Anggraeni 2007).

Fishing with the use of explosives and cyanide also occurs in Raja Ampat. Pet-Soede and Erdmann (1998), report that the low population densities in eastern Indonesia make monitoring and enforcement difficult. Blast and cyanide fishing are used to catch reef-associated fish, with snapper (dynamite), grouper and Napoleon wrasse (*Cheilinus undulatus*) (cyanide), being the main targets (Pet-Soede et al. 1999). When Halim and Mous (2006) asked households in Raja Ampat if family members engaged in destructive fishing practices, all respondents said no. However, most fishers that I spoke with during my field trips in Raja Ampat, admitted that they usually heard blast fishing every day. The environmental damage that occurs due to blast fishing may result in a loss of 13 % coral cover per year (Saila et al. 1993). Reefs exposed to repeated blasts "are often reduced to little more than shifting rubble fields" (Pet-Soede and Erdmann 1998). Today blast fishing occurs with homemade fertilizer bombs (Pet-Soede et al. 1999), which means the cost of making the bombs is probably much lower than it once was, when fishers used actual dynamite. Blast fishers in large operations can make between US \$50-\$150 per week (Pet-Soede and Erdmann 1998), while the small-scale blast fishers net about US \$14 per week (Pet-Soede et al. 1999).

The current management regime states that fishers have to be caught in the act of cyanide fishing in order to be charged with illegal fishing[9]. The result is that regulators are powerless even if they find a fisher with cyanide and live fish in his boat[10]. The discussion regarding how much reef damage is caused by cyanide fishing varies widely, but quantitative simulations suggest that the worst case scenario could result in a loss of 9.5 % coral cover per year (Saila et al. 1993). Furthermore, the high catch per unit effort of cyanide fishing can quickly lead to overfished populations (Mous et al. 2000). The price for live fish caught using cyanide varies, but Pet-Soede and Erdmann (1998), report that live fish, such as the coral trout (a grouper species, *Plectropomus leopardus*), can fetch up to US \$18.8/kg.

3.2.2 Players

Principal-agent analysis is structured around the players in the game, and their objective functions. Because the regency government is the effective legal "owner" of marine resources in Raja Ampat, it is assigned the role of the principal in this analysis. However, villagers tend to respect the authority of the traditional village Clan over the formal government (Halim and Mous 2006). Based on his journey through the remote islands of Indonesia, Severin (1997), writes "...the authority of these traditional leaders was more respected than the regulations which ultimately come from Jakarta ... exploitation of the

[9] M. Erdmann, Conservation International, personal communciation.

[10] Although women do participate in some fishing activities, such as coastal gleaning, boats are generally owned and operated by men.

land and sea should be done according to custom." (page 67). Customary marine tenure rights are still enforced and respected in Raja Ampat. The traditional Clans represent descendants from the first families in Raja Ampat. These Clans, present in each village, are the informal "owners" of land and marine resources[11]. The model developed herein assumes that the agents in the game are the Clans, who have the ability to control fisher actions. That is, the Clans have two different fishing strategies available to them: legal or illegal (or any combination thereof).

Two principal-agent models are simulated to evaluate the effort and profitability of illegal fishing, and the possible incentives that can be applied by the regency. The first model considers blast fishing targeting snapper species. Using grouper species, the second model analyzes the cyanide fishery, and the implications for effort, profit, and management. Both simulations are based on the same model developed below. The software package Powersim was used to carry out the simulations (Powersim Software AS 1996).

3.3 The Model

3.3.1 Biological model

Population dynamics without fishing

A simple logistic-growth model is used here to describe the biology of the system. This model assumes that change in the population biomass with time is related to the intrinsic rate of growth of the stock, r, the stock's carrying capacity, K, and the current stock size, B_t, as per the following equation:

$$\frac{dB_t}{dt} = rB_t\left(1 - \frac{B_t}{K}\right), \quad B_t \geq 0 \tag{3.1}$$

Equation (3.1) implies that $\frac{dB_t}{dt} > 0$ for $0 < B_t < K$, and thus that the stock can recover from depletion so long as $B_t > 0$.

[11] A. Suebu, The Nature Conservancy, personal communication.

Population dynamics with fishing

The above equation factors in only natural mortality, contained within the intrinsic rate of growth parameter. Catch is obviously an important part of any fished stock's population dynamics. A simple production model of the Cobb-Douglas form, (Cobb and Douglas 1928), is used to simulate catch, h_t:

$$h_t = qE_t^{\alpha}B_t^{\beta}, \quad E_t \geq 0, \quad B_t \geq 0 \tag{3.2}$$

where q is the catchability coefficient, which is assumed constant in this model over time. The catchability coefficient represents the proportion of the total biomass that is removed by one unit of effort in a given period. In this model, effort, E, is measured in number of trips per year, and must be greater than or equal to zero. It is further assumed that $\alpha = \beta = 1$, that is, there are constant returns to catch based on unit increases in effort or biomass. Hyperstability is implied if the parameters α and/or $\beta < 1$ (increases in biomass and/or effort result in less than equal increases in catch), while α and/or $\beta > 1$ implies hyperdepletion (increases in biomass and/or effort result in greater than equal increases in catch) (Walters and Martell 2004). This simplified catch equation, $h_t = qE_tB_t$, is often known as the Schaefer catch equation (Schaefer 1957).

By incorporating the catch equation, (3.2), into (3.1), we get a more complete picture of the population dynamics of the stock:

$$\frac{dB_t}{dt} = rB_t\left(1 - \frac{B_t}{K}\right) - qE_tB_t, \quad B_t \geq 0, \quad E_t \geq 0 \tag{3.3}$$

Fishing strategies

Recall that the village Clan is assumed to be able to allocate fisher effort to one of two types of fishing strategies: using legal or illegal gears (or any combination thereof). Let the type of strategy, s, be the set of these two types of fishing: $s := \{s, -s\}$, where s represents legal fishing and $-s$ represents illegal fishing.

We can rewrite (3.3):

$$\frac{dB_t}{dt} = rB_t\left(1 - \frac{B_t}{K}\right) - q_s E_{s,t} B_t - q_{-s} E_{-s,t} B_t, \quad B_t \geq 0, \quad E_t \geq 0 \tag{3.4}$$

3.3.2 Economic Model

Revenue

Total revenue, TR, is the product of the catch, h_t, and the unit price, P. Unit price is assumed to be constant over time, however, catches with different fishing strategies can command different prices. Similarly, due to differing catchabilities and effort levels with each strategy, h_t is also indexed by s. We can describe the single period total revenue for a given strategy as:

$$TR_{s,t} = P_s h_{s,t}, \quad \forall s, t \tag{3.5}$$

with the total revenue of that strategy through time being:

$$TR_s = \sum_{t=0}^{T} TR_{s,t}, \quad \forall s \tag{3.6}$$

and the total revenue to the Clan over time and over both strategies as:

$$TR = TR_s + TR_{-s} \tag{3.7}$$

Cost

We assume perfectly malleable capital in this model, i.e., the capital investment for the boat is a sunk cost (the fisher has already paid for the vessel, whether he fishes or not), and the same vessel is used for either type of fishing strategy. Fishing effort can therefore be easily allocated to either strategy on a trip by trip basis. Therefore, only variable costs are considered in this model.

The total cost, TC, of fishing is the product of the effort, E, and the unit variable cost of effort, co, and is modeled as an "almost" linear function (Sumaila 1995). The unit cost of effort is assumed constant through time. Let the single period cost of a given catch strategy be:

$$TC_{s,t} = \frac{co_{s,t} E_{s,t}^{1+b}}{1+b}, \quad \forall s, t \tag{3.8}$$

here, as b approaches 0, the cost function is almost linear. This introduces concavity in the profit function, thus ensuring convergence to a solution (Sumaila 1995).

The total cost of fishing using a given strategy over time is:

$$TC_s = \sum_{t=0}^{T} TC_{s,t}, \quad \forall s \tag{3.9}$$

and the total cost of fishing to the Clan over time and over both strategies is computed as:

$$TC = TC_s + TC_{-s} \tag{3.10}$$

One more cost must be factored in, namely, the potential cost when caught engaging in illegal fishing. This cost is assumed to be a function of the monitoring and enforcement plan put in place by the regency government:

$$Pen_t = \rho * Fee * E_{-s,t} \tag{3.11}$$

In effect, it is the product of the probability of being apprehended, ρ, the penalty imposed when apprehended, Fee, and the amount of illegal effort. Therefore, the single period cost of fishing illegally is:

$$TC_{-s,t} = \frac{co_{-s,t} E_{-s,t}^{1+b}}{1+b} + \rho * Fee * E_{-s,t}, \quad \forall t \tag{3.12}$$

With the total cost over time as:

$$TC_{-s} = \sum_{t=0}^{T} TC_{-s,t} \tag{3.13}$$

Net benefit

The single period net benefit to the Clan, π_t, is therefore the sum of the difference between the total revenue and the total cost of each fishing strategy in a given period:

$$\pi_t = (TR_{s,t} - TC_{s,t}) + (TR_{-s,t} - TC_{-s,t}) \tag{3.14}$$

with the discounted total net benefit over time calculated as:

$$\pi = \sum_{t=0}^{T} \delta^t (TR_{s,t} - TC_{s,t}) + \sum_{t=0}^{T} \delta^t (TR_{-s,t} - TC_{-s,t}) \tag{3.15}$$

where δ is the discount factor, and is equal to $(1+r)^{-1}$, where r is the discount rate of the village Clans (in this model we have assumed a discount rate of 7%; see the section on discounting for a discussion on how changes in this assumption can change the model results).

By expanding the revenue and cost functions, we see that the total net benefit to the Clan, over time and considering both catch strategies, is:

$$\pi = \sum_{t=0}^{T} \delta^t \left(h_{s,t} P_s - \frac{co_s E_{s,t}^{1+b}}{1+b} \right) + \sum_{t=0}^{T} \delta^t \left(h_{-s,t} P_{-s} - \frac{co_{-s} E_{-s,t}^{1+b}}{1+b} - \rho Fee E_{-s,t} \right) \tag{3.16}$$

3.3.3 Optimization

The objective of the village Clans is to decide on a sequence of effort through time, using legal and/or illegal methods, to maximize their net benefit, π, or discounted economic rent, through time, subject to the obvious constraints. This model represents a 2-step principal-agent situation. In step 1, the regency government (principal) sets its monitoring and enforcement program, which produces some probability of detecting illegal fishing, and the penalty that will be applied to apprehended illegal fishers. In the second step, the Clan (agent) decides, given the probability of apprehension and the expected penalty, how to allocate effort between legal and illegal fishing for the entire simulation time (50 years). As such, the optimization is treated like a cooperative solution, in that the overall objective is to maximize the combined discounted net benefits of both fishing strategies. The simulation is run over 4000 iterations, and for a 50 year time period. An artifact of models driven by profitability is that the players see the model's end (year 50 in this model) as the end of the world, and as such, will tend to catch as much as they can in the final years of the simulation. In the results section below, simulation outputs are thus discussed up to year 45, with the final 5 years of the simulations disregarded.

Lagrangian function

A Lagrangian function is used in this model to solve for the maximization problem facing the Clan, subject to the constraints of the model. The natural biological constraint, $B_t \geq 0$, must be met, and thus the model applies a penalty (y_t) when $B_t < 0$.

$$L_t(B_t, E_{s,t}, y_t) = \delta^t \pi + y_t \phi^-(B_t, E_{s,t}), \quad \forall s \tag{3.17}$$

where the term ϕ represents the constraint function for which the modified Lagrange multiplier, y_t, is applied only in the case when $\phi < 0$. That is, ϕ is given by $min(0, \phi)$ (Flam 1993). The profit and constraint functions are expanded in the following equation to give the entire Lagrangian:

$$\begin{aligned} L(B_t, E_{s,t}, E_{-s,t}, y_t) = {} & \delta^t \sum_{t=0}^{T} \left(q_s E_{s,t} B_t P_s - \frac{co_s E_{s,t}^{1+b}}{1+b} \right) \\ & + \delta^t \sum_{t=0}^{T} \left(q_{-s} E_{-s,t} B_t P_{-s} - \frac{co_{-s} E_{-s,t}^{1+b}}{1+b} - \rho Fee E_{-s,t} \right) \\ & + y_t \left[r B_t \left(1 - \frac{B_t}{K} \right) - (q_s E_{s,t} B_t) - (q_{-s} E_{-s,t} B_t) \right]^- \end{aligned} \tag{3.18}$$

The model developed for this analysis was originally constructed assuming an equal biological impact from both legal and illegal fishing. The reason that blast and cyanide fishing are illegal, however, is because they are detrimental to fish habitat, and therefore unsustainable. As such, the model was modified to incorporate this disproportionate impact on the reef. In the constraint equation (ϕ), a new term, a, is added[12]:

$$\begin{aligned} L(B_t, E_{s,t}, E_{-s,t}, y_t) = {} & \delta^t \sum_{t=0}^{T} \left(q_s E_{s,t} B_t P_s - \frac{co_s E_{s,t}^{1+b}}{1+b} \right) \\ & + \delta^t \sum_{t=0}^{T} \left(q_{-s} E_{-s,t} B_t P_{-s} - \frac{co_{-s} E_{-s,t}^{1+b}}{1+b} - \rho Fee E_{-s,t} \right) \\ & + y_t \left[r B_t \left(1 - \frac{B_t}{K} \right) - (q_s E_{s,t} B_t) - a(q_{-s} E_{-s,t} B_t) \right]^- \end{aligned} \tag{3.19}$$

By changing a, we can change the relative impact of illegal fishing. When a, the impact of legal and illegal fishing is equal. For $a > 1$, the impact of illegal fishing is greater than that of legal fishing. This is more realistic, as blast and cyanide fishing decrease productivity of the reef habitat (Saila et al. 1993). In the analysis we varied the a term from 1 to 2.5.

3.3.4 Solution algorithm

The solution algorithm used in this analysis is modeled after Flam (1993), and Sumaila (1995), assuming a cooperative outcome. The partial differentials for the effort, biomass and multiplier adjustments are derived in this section in order to identify the rates of change of effort, biomass and the multiplier. For these equations, a switch function is used, and denoted $H(r)$. Let $H(r) = 1$ when $r < 0$, and $H(r) = 0$ otherwise. Thus $H(r)$ attains a value of one when a constraint is violated.

Effort adjustment: How does the Lagrange function change with respect to a change in effort? This is in fact the agent's decision variable of the model. If the marginal profit of type s effort is greater than the marginal profit of type $-s$ effort, then effort will be reallocated from $-s$ effort to s effort.

[12]The version of this chapter to be submitted will further address the issue of a. The baseline simulations will be run with $a = 1$, while the optimal simulations will be run with $a > 1$. This will allow us to use the impacts of destructive fishing as an externality that the Clans do not incorporate in their fishing decisions, but that society as a whole considers.

First, we consider the adjustment of legal effort, s:

$$\frac{\partial L_t}{\partial E_{s,t}} = \delta^t(q_s B_t P_s - co_s E^b_{s,t}) + y_t[H(r)(-q_s B_t)] \tag{3.20}$$

Again, by expanding the $H(r)$ function we get:

$$\begin{aligned} \frac{\partial L_t}{\partial E_{s,t}} &= \delta^t(q_s B_t P_s - co_s E^b_{s,t}) \\ &+ y_t \left[H\left(rB_t \left(1 - \frac{B_t}{K}\right) - q_s E_{s,t} B_t - aq_{-s} E_{s,t} B_t \right)(-q_s B_t) \right] \end{aligned} \tag{3.21}$$

Now the adjustment of illegal effort, $-s$:

$$\frac{\partial L_t}{\partial E_{-s,t}} = \delta^t(q_{-s} B_t P_{-s} - co_{-s} E^b_{-s,t} - \rho Fee) + y_t[H(r)(-aq_{-s} B_t)] \tag{3.22}$$

Again, by expanding the $H(r)$ function we get:

$$\begin{aligned} \frac{\partial L_t}{\partial E_{-s,t}} &= \delta^t(q_{-s} B_t P_{-s} - co_{-s} E^b_{-s,t} - \rho Fee) \\ &+ y_t \left[H\left(rB_t \left(1 - \frac{B_t}{K}\right) - q_s E_{s,t} B_t - aq_{-s} E_{s,t} B_t \right)(-aq_{-s} B_t) \right] \end{aligned} \tag{3.23}$$

Biomass adjustment: How does the Lagrange function change with respect to a change in the biomass? Here we consider the first order partial differential with respect to biomass:

$$\frac{\partial L_t}{\partial B_t} = \delta^t(q_s E_{s,t} P_s + q_{-s} E_{-s,t} P_{-s}) + y_t \left[H(r) \left(-1 + r - \frac{2rB_t}{K} - q_s E_{s,t} - aq_{-s} E_{-s,t} \right) \right] \tag{3.24}$$

By expanding $H(r)$, we get the following equation:

$$\frac{\partial L_t}{\partial B_t} = \delta^t(q_s E_{s,t} P_s + q_{-s} E_{-s,t} P_{-s}) + y_t(H\left(rB_t\left(1-\frac{B_t}{K}\right) - q_s E_{s,t} B_t - aq_{-s} E_{s,t} B_t\right)$$
$$\left(-1 + r - \frac{2rB_t}{K} - q_s E_{s,t} - aq_{-s} E_{-s,t}\right)) \tag{3.25}$$

Multiplier adjustment: How does the Lagrange function change with respect to a change in the multiplier? When the multiplier is higher, then essentially a higher punishment is applied within the Lagrangian function, forcing the system to obey the constraints.

$$\frac{\partial L_t}{\partial y_t} = -H(r)\left(rB_t\left(1-\frac{B_t}{K}\right) - q_s E_{s,t} B_t - aq_{-s} E_{-s,t} B_t\right) \tag{3.26}$$

Again, by expanding the $H(r)$ function we get:

$$\frac{\partial L_t}{\partial y_t} = -H\left(rB_t\left(1-\frac{B_t}{K}\right) - q_s E_{s,t} B_t - aq_{-s} E_{-s,t} B_t\right)$$
$$\left(rB_t\left(1-\frac{B_t}{K}\right) - q_s E_{s,t} B_t - aq_{-s} E_{-s,t} B_t\right) \tag{3.27}$$

3.3.5 Data

The following section outlines the data and assumptions used in the model. A subsection of the results presents a sensitivity analysis exploring how changes in some of the assumptions used affect the results of the model.

Snapper fishery biological data

The initial biomass (at $t = 1$) and carrying capacity (K) for the model were taken from the Raja Ampat Ecopath with Ecosim model (EwE) developed by Ainsworth et al. (2007). This model presented biomass estimates for three age classes of snapper, aggregated across 26 species: adult, sub-adult, and juvenile (see Ainsworth et al. 2007, for an explanation of species used in the EwE model). These estimates were added together to produce a (2006) biomass of 0.153 tonnes/km^2 (Ainsworth et al. 2007). The carrying capacity was estimated from the 1990 biomass estimates in the EwE report (Ainsworth et al. 2007). Although EwE has the ability to estimate an unfished population's biomass, the 1990 estimates are more reliable at this stage in the EwE model[13]. I assumed that the 1990 biomass was about 20% lower than an unfished state, and multiplied the 1990 biomass estimates by 1.2 to estimate the carrying capacity resulting in the use of $K = 16,416$ tonnes. The estimated initial and unfished biomass were then multiplied by the study area, $45,000\text{km}^2$, to give biomass estimates for all of Raja Ampat (Table 3.1).

The intrinsic rate of growth, r, was calculated using the equation:

$$r = \frac{4msy}{K} \tag{3.28}$$

where msy is the maximum sustainable yield (maximum catch) and K is the carrying capacity, as described above (Cadima 2003). The msy was taken from the Raja Ampat EwE model (Ainsworth et al. 2007).

Catchability for snapper was calculated by dividing the average biomass of fish caught per trip by the total estimated biomass in the system. According to Dohar and Anggraeni (2007), the average artisanal fisher catches 5 kg of mixed snapper species per trip. This value was used in the model. Pet-Soede et al. (1999), reported that small-scale blast fishers catch about 8 kg of fish per trip. Our model assumes that fishers are only targeting snapper, and thus uses this value. These catch estimates and the derived catchability coefficients are listed in Table 3.1.

Snapper fishery economic data

Price data used in the snapper model were taken from Dohar and Anggraeni (2007) and Pet-Soede et al. (1999). The average price of legal-caught adult snapper is about US \$1.26/kg (averaged over all legal gears) (Dohar and Anggraeni 2007). Pet-Soede et al. (1999) estimated that for small-scale blast fishing, fishers received on average US \$1/kg

[13] C. Ainsworth, UBC, personal communication.

Table 3.1: Snapper model biological and fishing parameters and sources

Variable	**Symbol**	**Amount**	**Source**
Initial biomass (t)	Bo	6885	Ainsworth et al. (2007)
Carrying capacity (t)	K	16416	estimated from Ainsworth et al. (2007)
Maximum sustainable yield (t)	msy	369	Ainsworth et al. (2007)
Intrinsic rate of growth	r	0.09	derived from Ainsworth et al. (2007)
Catch per trip (kg)	-	s=5, $-s$=8	Dohar and Anggraeni (2007), Pet-Soede et al. (1999)
Catchability	q	s=7.26e^{-7}, $-s$=1.16e^{-6}	derived from Dohar and Anggraeni (2007), Pet-Soede et al. (1999)

Table 3.2: Snapper model economic parameters and sources

Variable	**Symbol**	**Amount**	**Source**
Unit price of fish ($/t)	P	s=1260, $-s$ =1000	Dohar and Anggraeni (2007), Pet-Soede and Erdmann (1998)
Unit cost of effort ($/trip)	co	s=3.25, $-s$=3.00	Pet-Soede and Erdmann (1998), Pet and Pet-Soede (1999)

for their catch (Table 3.2).

Pet-Soede et al. (1999), report that the variable cost of small-scale blast fishing averaged US $3.00 per trip. I have assumed that blast fishing requires less time to fish and thus requires less fuel than trips using legal gear. As such, I have added one extra liter of diesel fuel to the legal cost of fishing (valued at $0.25/L (Pet-Soede and Erdmann 1998)), resulting in a cost per trip of US $3.25 for legal gears[14].

[14]Although the price of fuel has increased in Indonesia due to the reduction of fuel subsidies, such an increase would effect both legal and illegal fishing, and as such, is ignored in this model.

Grouper fishery biological data

A total of 46 grouper species (family Serranidae) were aggregated in the Raja Ampat EwE model (see Ainsworth et al. 2007, for an explanation of species). The same method described in the snapper section was used to estimate initial biomass ($t = 1$) and carrying capacity K. The Ainsworth et al. (2007) model reported an estimated 2006 grouper biomass, aggregated across the three age groups, of 0.257tonnes/km^2. The grouper carrying capacity was estimated by multiplying the 1990 EwE biomass estimate of 0.513tonnes/km^2 by 1.2, assuming that the unfished state is about 20% more than the 1990 biomass. The initial and unfished biomass estimates were then multiplied by the total marine area of Raja Ampat, $45,000$km^2, to determine initial biomass and carrying capacity (Table 3.3).

Again, the intrinsic rate of growth, r, is calculated using Equation (3.28). The msy parameter was taken from the Raja Ampat EwE model (Ainsworth et al. 2007).

The catchability coefficients used in the grouper model were calculated in the same manner as for snapper. Dohar and Anggraeni (2007) reported that the average artisanal fisher catches about 11 kg of mixed grouper per trip. Pet and Pet-Soede (1999), reported that small-scale cyanide operations catch 1kg of fish per trip with medium-scale operations catching up to 20kg. The average weight of one individual grouper varies, but a report conducted for the Madang region in Papua New Guinea found that the average weight of "grouper" caught in that area was about 5 kg, although no gear types are mentioned. (Kinch 2004). Based on this information, we assume in this model that the average catch per trip for small-scale cyanide fisher is equal to 5 kg, which could mean one large individual grouper, or 2-3 smaller fish. These two production values, 11 kg and 5 kg, are divided by the total grouper biomass to give the catchability coefficients used in the model (Table 3.3).

Table 3.3: Grouper model biological and fishing parameters and sources

Variable	Symbol	Amount	Source
Initial biomass (t)	Bo	11,565	Ainsworth et al. (2007)
Carrying capacity (t)	K	27,702	estimated from Ainsworth et al. (2007)
Maximum sustainable yield (t)	msy	1215	Ainsworth et al. (2007)
Intrinsic rate of growth	r	0.18	derived from Ainsworth et al. (2007)
Catch per trip (kg)	-	s=11, $-s$=5	Dohar and Anggraeni (2007), Kinch (2004)
Catchability	q	s=9.51e^{-7}, $-s$=4.32e^{-7}	derived from Dohar and Anggraeni (2007), Pet-Soede et al. (1999)

Grouper fishery economic data

The average price of legal-caught grouper in Raja Ampat was about US $5.60/kg (averaged over all legal gear types), according to Dohar and Anggraeni (2007). Ainsworth et al. (2007), however, used an average price of US $2.64, which included adult and sub-adult grouper. For the model, the average of these two estimates is used, $4.13/kg. A price of US $7.50/kg was used in the EwE model for the average unit price of cyanide-caught grouper (Ainsworth et al. 2007). However, Pet-Soede and Erdmann (1998) suggest that fishers can receive upwards of US $18.80/kg for live coral trout (*Plectropomus leopardus*). I have used the average of these two estimates, US $12.80/kg, in the model (Table 3.4).

The unit cost of US $3.25 per trip for legal fishing estimated in the case of snapper is also used in the grouper model, as the same (legal) gear is used to target both types of fish. Pet and Pet-Soede (1999), report that cyanide is quite cheap, with a small-scale cyanide operation using about 1L of cyanide per trip, at a cost of $1.11. I have therefore taken the Pet-Soede and Erdmann (1998) cost estimate for blast fishing, subtracted the cost of the locally-made bombs ($2.50/trip), and added in the cost of cyanide ($1.11), resulting in a cost estimate of US $1.61 per trip.

Table 3.4: Grouper model economic parameters and sources

Variable	Symbol	Amount (USD)	Source
Unit price of fish ($/t)	P	s=4,130, $-s$=12,800	Dohar and Anggraeni (2007), Ainsworth et al. (2007),Pet-Soede and Erdmann (1998)
Unit cost of effort ($/trip)	co	s=3.25, $-s$=1.61	Pet and Pet-Soede (1999),Pet-Soede and Erdmann (1998)

3.4 Snapper model results

3.4.1 Exploring the value of a

Because we have no information on how illegal fishing may impact the ecosystem, the model was run with four different values for a, the parameter that changes the relative impact of illegal fishing. Figure 3.1 shows these four scenarios. Figures 3.1A and 3.1B illustrate that there is less effort, both legal and illegal, with higher levels for a. Consequently, there is also less catch with higher a values (Figure 3.1C and 3.1D). The biomass estimates over the 45 year period remain fairly similar regardless of the value a takes. (Figure 3.1E). Due to smaller catches with a higher a, the net benefits from fishing also decrease (Figure 3.1F).

Destructive fishing practices, such as cyanide and blast fishing, alter the marine habitat and are therefore unsustainable (Pauly 1989). The effects of destructive fishing could impact reefs at such a state that recovery from cyanide and explosives does not occur for over 2 decades (Saila et al. 1993; Fox and Caldwell 2006). The simulations run for this model suggest that lower catches occur with higher values of a. The impact of explosives and cyanide in Raja Ampat has lead to a decrease in the catches of target and non target species[15]. For this reason, as well as in keeping with ecosystem-based management principles, we took the precautionary approach and assumed that the impact of blast fishing (and cyanide fishing) on the biology of the system is about twice that of legal fishing (i.e. a = 2). This value for a is used in running all subsequent snapper (and

[15] Mark Erdmann, Conservation International, personal communication.

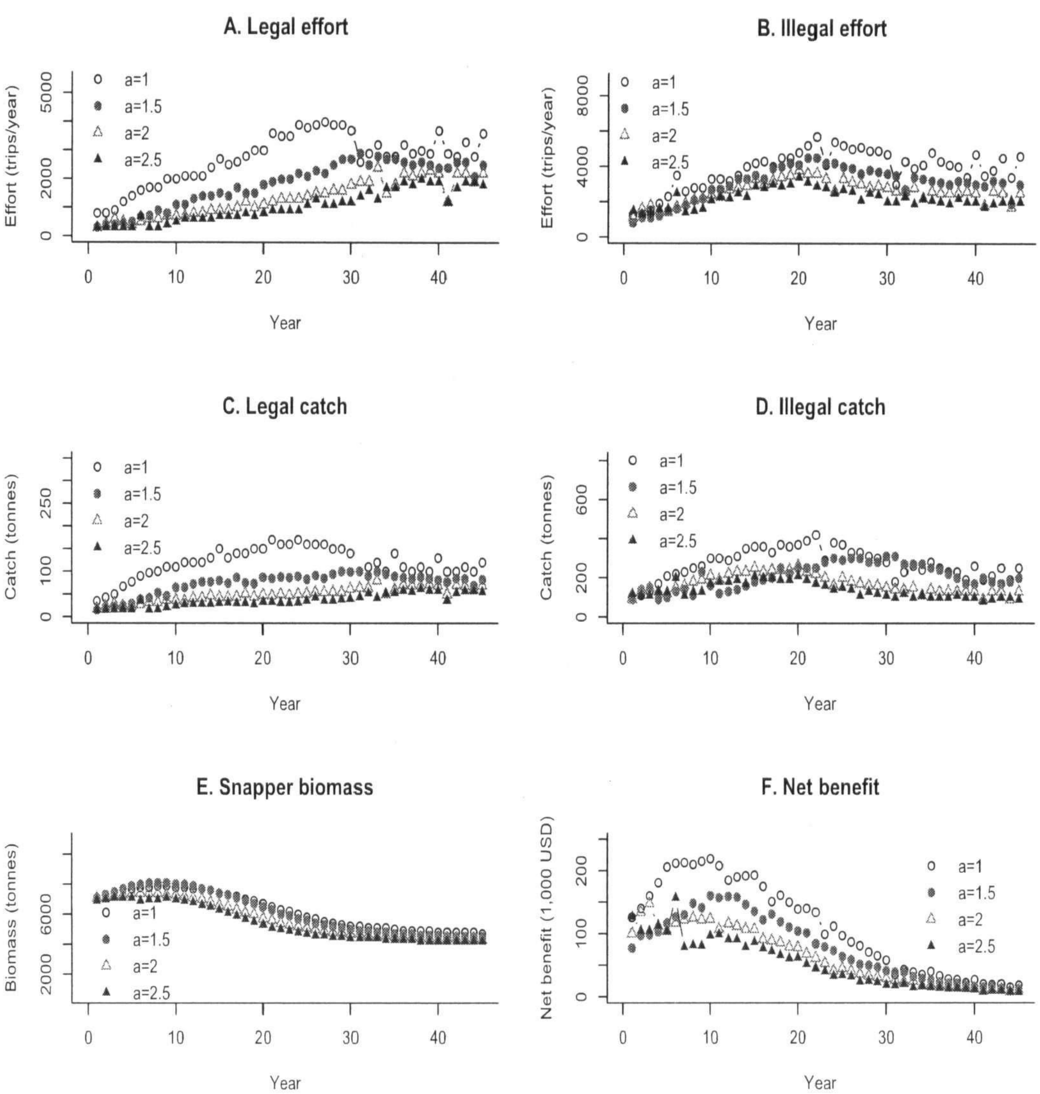

Figure 3.1: Snapper simulations run for varying a

grouper) simulations.

3.4.2 Baseline

There is currently no formal monitoring and enforcement program in Raja Ampat to detect and punish fishers using destructive gears[16]. The first model simulation is thus run with this in mind, such that there are no extra costs associated with illegal fishing (i.e. $\rho * Fee * E_{-s,t} = 0$). This is the baseline, or present-day, scenario, against which the potential monitoring and enforcement program is compared.

With no monitoring and enforcement, the total discounted net present value (discounted net benefits summed over time), or NPV, from legal fishing is US \$0.61 million. The NPV from blast fishing is almost four times this, at US \$2.24 million. The total NPV from both types of fishing is the summation of these two, and is equal to US \$2.85 million (Table 3.5).

It is currently more profitable to fish snapper using bombs, rather than legal methods, as indicated by the effort trends (Figure 3.2A). For the most part, over all time periods more effort is allocated to blast fishing than to legal fishing. The higher effort level, along with the assumed higher catchability of blast fishing, leads to a greater catch by blast fishing at all time periods, shown in Figure 3.2B. Although catch initially increases through time (due to increased effort and an initial biomass increase), the future decrease in biomass leads to declining catches near the end of the model. Over the 45 year period, a total of 9,798 tonnes of snapper are caught, with an annual average catch of 218 tonnes. Figure 3.2C shows a decrease in snapper stock biomass over time. The net benefits from blast fishing are greater than those for legal-caught methods for all time periods (Figure 3.2D).

3.4.3 Optimal solution

Assuming that the objective of the government is to totally eliminate blast fishing, the simulations were rerun at increasing probabilities of detection, ρ, and penalty fees, Fee.

[16]Mark Erdmann, Conservation International, personal communication.

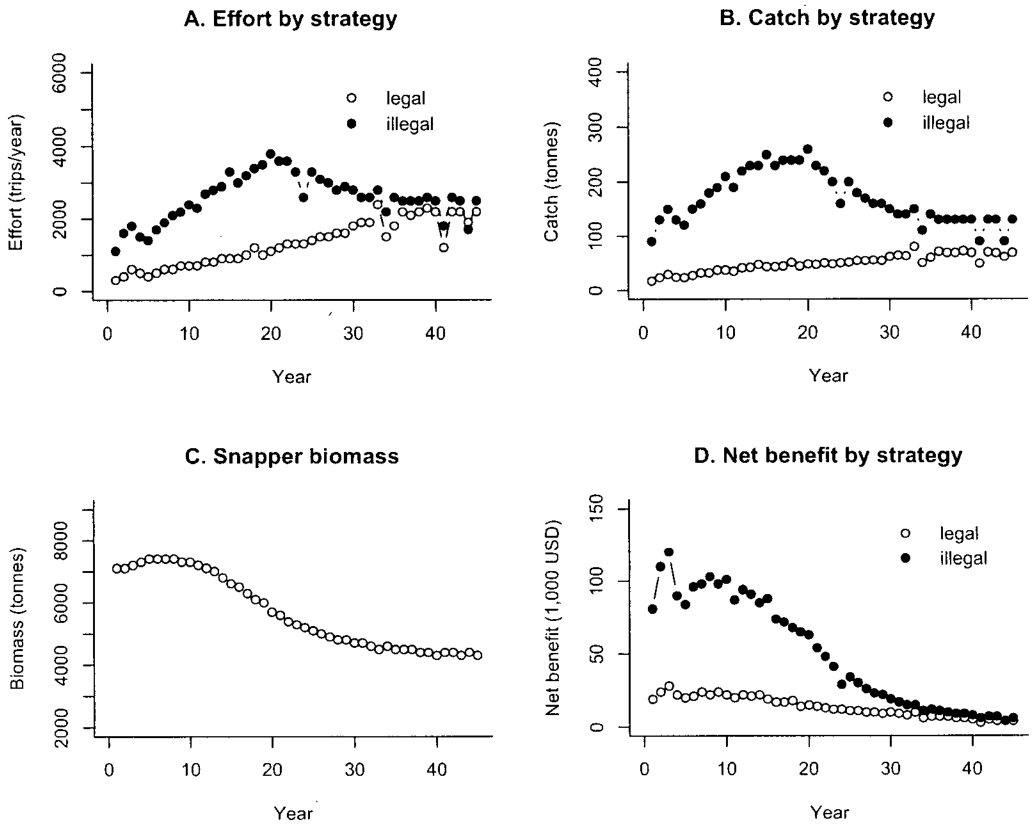

Figure 3.2: Snapper baseline simulations, no monitoring and enforcement

It is important to note that each of these regency decision variables need to take on values that are both positive and realistic. Mathematically, they are multiplied with effort in the cost function, so if either value is zero then the fisher faces no extra cost from illegal fishing. This makes intuitive sense as it does not matter how high the fines of illegal fishing are if the probability of detecting illegal fishing is zero. Similarly, there is no point in putting money into a detection program and then not imposing a penalty once an illegal fisher is apprehended. In terms of realism, with the Papuan per capita Gross Domestic Regional Product (GDRP) at less than US $1000 (Bappeda, 2004 in Dohar and Anggraeni, 2007), one can imagine that fining fishers an exorbitant amount and expecting payment would be an unrealistic situation.

Table 3.5: Snapper baseline and optimal simulation net present value (NPV)

Simulation	Legal NPV	Illegal NPV	Total NPV
Baseline	0.61	2.24	2.85
Optimal	6.53	0	6.53
Difference	5.92	-2.24	3.68

Values are in millions of USD

Several combinations of detection probabilities and fines are possible to reach the desirable solution of no blast fishing. Table 3.6 shows some of these combinations. The Raja Ampat government would have to evaluate the possible combinations to determine which meet their budget and fisheries management plans. As can be obviously noted in Table 3.6, there is a direct tradeoff between investing a lot in detecting power (monitoring)[17], versus investing little but fining apprehended fishers a high, and possibly unrealistic, amount (enforcement).

Table 3.6: Snapper optimal detection probability(ρ) and fine (Fee) combinations

ρ(%)	Fee (USD)
10	2,020
15	1,350
20	1,010
25	810
30	680

In completely eliminating blast fishing, the net present value (NPV) of the artisanal snapper fishery increases from US \$2.85 million to US \$6.53 million over the 45 year period (Table 3.5, Figure 3.3D). Figures 3.3A and 3.3B show that all effort is allocated to, and thus all catch is taken by, legal fishing. Over the 45 year period, a total of 19,090 tonnes of snapper are caught, averaging 424 tonnes/year. Figure 3.3C shows the biomass trajectory through time.

[17] This statement assumes that it would cost the regency government more to increase their probability of detection from 10 % to 15%, to 20%, etc.

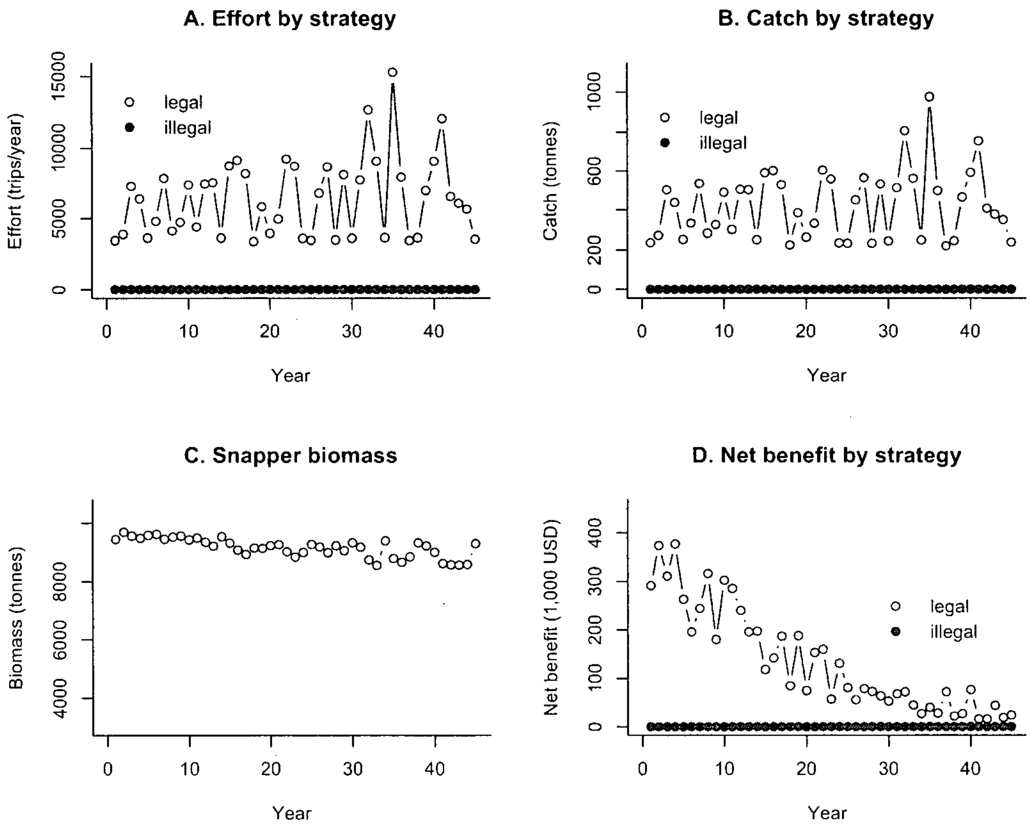

Figure 3.3: Snapper optimal simulations

Figure 3.4 graphically compares the effort, catch, biomass and NPV results of the baseline and the optimal simulations. Catches are higher in the optimal solution. Also of obvious importance is the higher biomass through time associated with the optimal solution. Furthermore, the net benefits are higher with the elimination of blast fishing.

We can measure the incentive gap in the principal-agent framework by comparing the first and second best solutions. Table 3.5 shows the difference between the baseline simulation (second best solution) and the optimal simulation (first best solution). The incentive gap is thus US \$3.68 million. This implies that the Raja Ampat regency is losing an estimated

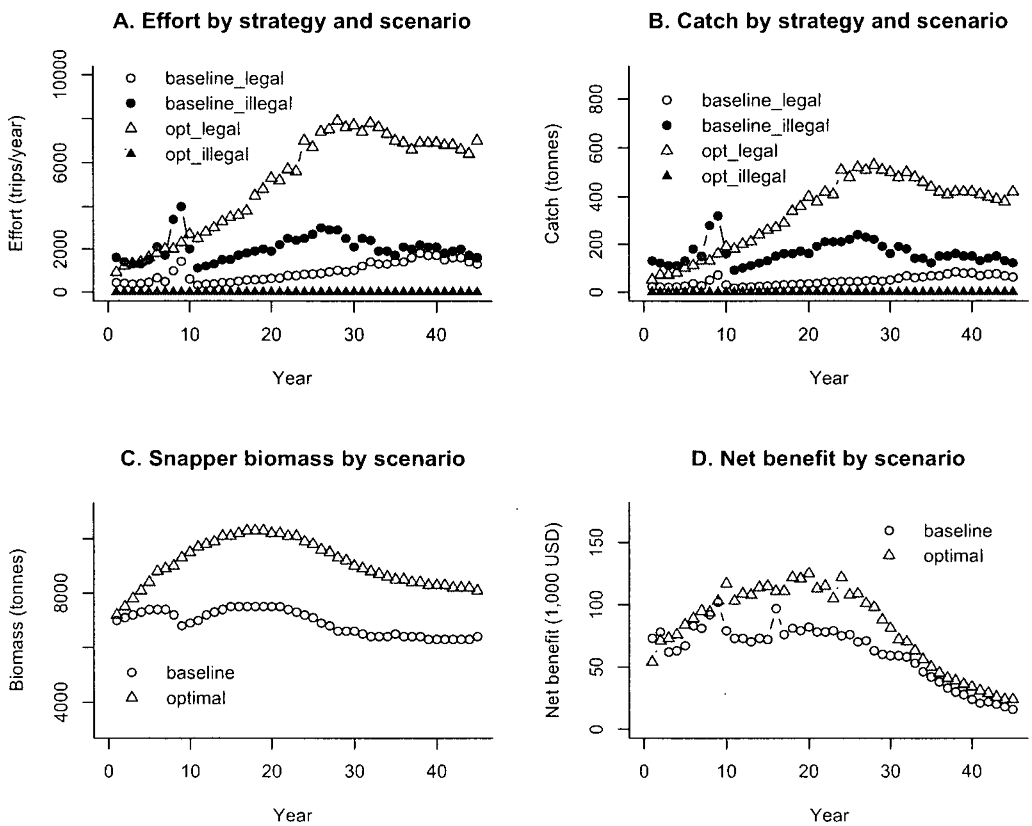

Figure 3.4: Snapper baseline and optimal simulations

US $82,000 per year in potential fisheries revenue by not eliminating blast fishing.

3.4.4 Discounting

Sustainability implies that the present generation's use of a resource does not prevent future generations from enjoying the same resource. It is known that high rates of discount tend to result in societies overexploiting their resources today (Clark 1990). The simulation results presented for the snapper model above were created by assuming a 7% discount rate (a discount factor of 0.935). To examine the effect of the discount rate on baseline catch, biomass and economic value of the fishery, the snapper simulations were re-run with varying discount rates. The catches and NPV, as well as the biomass in year 45, are shown for different discount rates in Table 3.7. In this model, as supported by the literature (Clark 1973; 1990; Sumaila 2004; Berman and Sumaila 2006), higher rates of discount generally lead to a lower stock size in the future, as well as a lower (NPV) of the fishery (Table 3.7). As the discount rate increases, the proportion of illegally caught fish decreases, perhaps because legally caught fish actually command a higher price.

Table 3.7: Snapper baseline simulation run with increasing discount rates, δ

	Discount Rate			
	0*	4	7	10
Legal catch (t)	1,246	1,479	2,228	2,716
Illegal catch (t)	7,148	7,920	7,570	6,882
Total catch (t)	8,394	9,399	9,798	9,598
Illegal catch proportion (%)	85	85	77	72
Legal NPV (M USD)	1.49	0.73	0.61	0.56
Illegal NPV (M USD)	6.88	3.2	2.24	1.74
Total NPV (M USD)	8.37	3.93	2.85	2.30
Biomass (t), year 45	8,300	6,100	4,300	3,600

*This is actually $\lim_{\delta \to 0}$ to allow convergence (Clark 2006).

It is particularly interesting to examine how the optimal Fee varies with the discount rate. Table 3.8 compares the optimal simulations run with a higher discount rate ($\delta = 10\%$), to the original simulations run with $\delta = 7\%$. If we keep the detection probability the same (ρ), a higher Fee is required in each case, given the higher discount rate. This is an important issue for the regency government to consider when instituting an incentive scheme.

3.4.5 Sensitivity analysis

Models are, by definition, simplifications of reality. Many data assumptions had to be made to apply the model developed in section 3.3. These assumptions are explored by rerunning the model while changing one parameter value at a time.

Table 3.8: Snapper optimal combinations with different discount rates (δ)

$\rho(\%)$	*Fee* (USD)	
	$\delta = 7\%$	$\delta = 10\%$
10	2,020	3,370
15	1,350	2,230
20	1,010	1,680
25	810	1,350
30	680	1,150

Carrying capacity

The carrying capacity (K) used to run the model was calculated by multiplying the 1990 snapper biomass by 1.2 (see section 3.3.5). The model was rerun using a lower K estimate, by assuming that the 1990 biomass was the unfished state, and a higher K, assuming that K is actually 1.5 times the 1990 biomass. As would be expected, a larger snapper carrying capacity leads to a greater catch and a higher NPV over time. Obviously, if the model simulations were being used to recommend allowable catches, it would be important to understand and quantify the uncertainty around this parameter, and thus in the catch estimates. The sensitivity of the model to changes in the intrinsic rate of growth (r) is explored in the grouper section. Table 3.9 presents the biomass in year 45, total catches and NPV over the 45 year period at varying K values. The low and high values used in the sensitivity analysis simulation are given on either side of the main value used in the model. The relative profitability of the optimal solution (versus the baseline) ranges from about 2 to 2.7.

Price

The price of legal caught snapper used in this model is US \$1,260/tonne (see section 3.3.5). The bounds for the sensitivity analysis were calculated by multiplying this price by 0.75 to get the low price bound and 1.25 to get a high price bound. The model was then rerun with these bounds (Table 3.10). A similar method was used to calculate the low and high bounds for illegal caught snapper: the base price of US \$1,000/tonne was multiplied by 0.75 and 1.25. Changes in price do not tend to change the biomass at the

Table 3.9: Sensitivity analysis for snapper model: Carrying capacity

Result		**Carrying capacity (t)**		
		low (13,680)	model (16,416)	high(20,520)
Biomass (t) year 45	Baseline	4,320	4,300	4,326
	Optimal	7,298	9,300	10,352
Total catch (t)	Baseline	8,822	9,798	10,934
	Optimal	15,067	19,089	26,167
NPV (M USD)	Baseline	2.51	2.85	3.10
	Optimal	5.06	6.53	8.42
Difference in NPV	(M USD)	2.55	3.68	5.32
Relative profitability		2.02	2.29	2.72

end of the simulation time, nor the total amount of catch over the 45 years, but they do obviously change the value of the catch. As would be expected, the relative profitability of eliminating illegal fishing increases with higher prices for legally-caught fish (Table 3.10). Conversely, when illegally-caught snapper fetches a higher price, the relative profitability of eliminating that fishing strategy decreases. The low and high values used in the sensitivity analysis simulation are given on either side of the main value used in the model.

Table 3.10: Sensitivity analysis for snapper model: Price

Result		**Legal price (USD/t)**		
		low (945)	model (1,260)	high(1,575)
Biomass (t) year 45	Baseline	4,297	4,300	4,440
	Optimal	8,954	9,300	8,948
Total catch (t)	Baseline	9,594	9,798	9,927
	Optimal	18,820	19,089	18,127
NPV (M USD)	Baseline	2.69	2.85	2.97
	Optimal	4.71	6.53	8.03
Difference in NPV	(M USD)	2.02	3.68	5.40
Relative profitability		1.75	2.29	2.86
		Illegal price (USD/t)		
		low (750)	model (1,000)	high(1,250)
Biomass (t) year 45	Baseline	4,400	4,300	4,268
	Optimal	9,300	9,300	9,300
Total catch (t)	Baseline	10,080	9,798	9,775
	Optimal	19,087	19,089	19,087
NPV (M USD)	Baseline	2.33	2.85	3.34
	Optimal	6.53	6.53	6.53
Difference in NPV	(M USD)	4.2	3.68	3.19
Relative profitability		2.80	2.29	1.96

3.5 Grouper model results

3.5.1 Exploring the value of a

In order to model the negative ecological impact destructive fishing has on reef systems, a variable called a was introduced in Equation (3.19). As explained in section 3.41, the simulations were run several times while varying the value of a, essentially the relative ecosystem impact that destructive fishing has compared to non-destructive methods. Figure 3.5 shows the results of these simulations.

In keeping with the precautionary approach to management, a value of 2 was used for a in all subsequent grouper simulations.

3.5.2 Baseline

The baseline scenario is one which assumes the status quo of zero monitoring and enforcement continues in Raja Ampat for the next 45 years. Under this scenario, the fishery yields US \$62.45 million in total net present value (NPV) over the 45 years (Table 3.11). Figures 3.6A and 3.6B show the effort and catch profiles for the baseline solution. Over 45 years a total of 42,380 tonnes of grouper are caught, averaging 941 tonnes annually.

More effort is allocated to, and more catch is taken by, legal methods in all years, although effort converges near year 45. The price of illegally-caught grouper is higher, and the cost lower, and yet fishers are spending more effort fishing with legal gears. The higher catchability of legal methods assumed in this model is what most likely drives the large amount of legal effort. The decrease in legal effort, and increase in illegal effort, at the end of the simulation, is probably driven by "end of the world" scenario, as described earlier. Grouper biomass increases at the start of the simulation, but after reaching its maximum at about year 20, the biomass starts to decrease for the remaining time steps (Figure 3.6C). Figure 3.6D shows the net benefits attained from grouper fishing over 45 years.

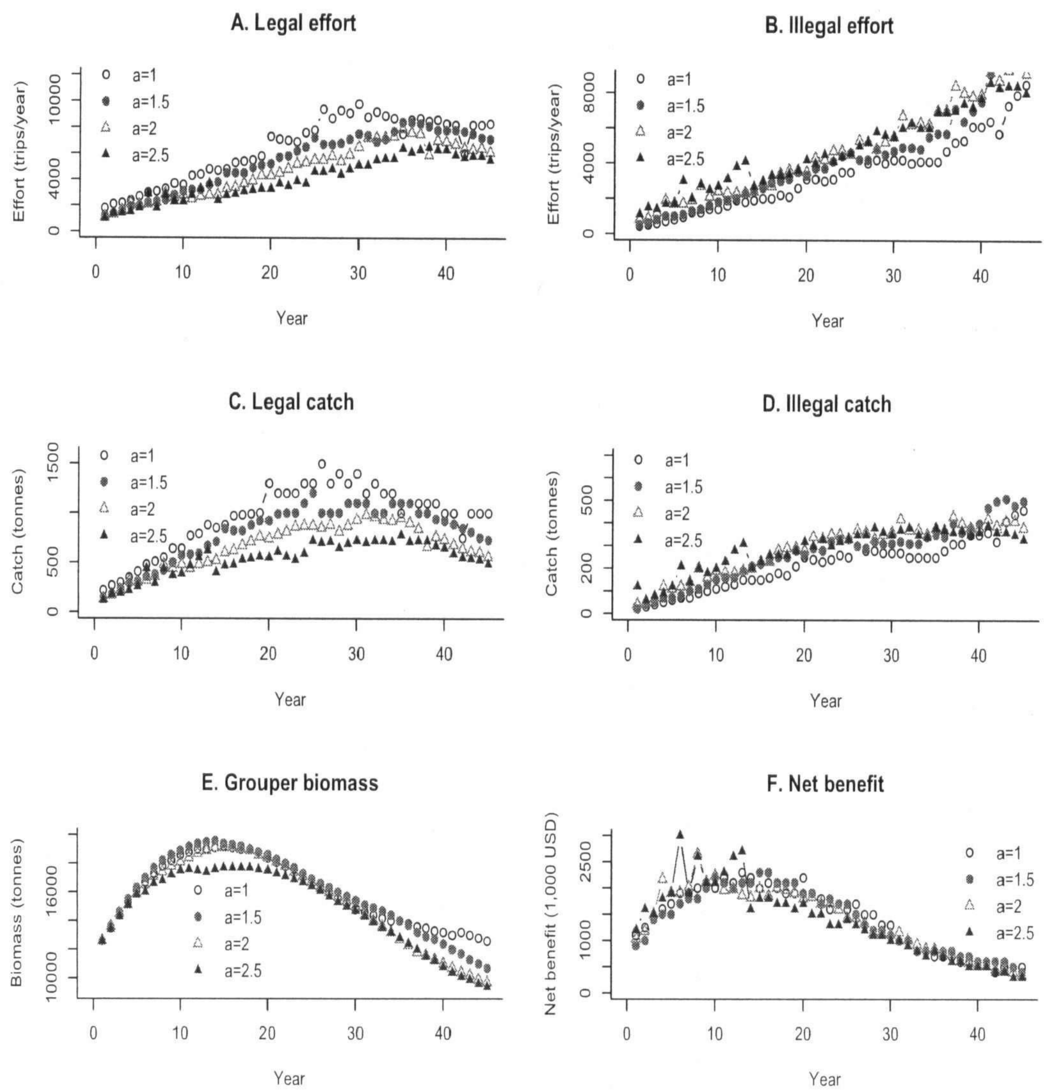

Figure 3.5: Grouper simulations run for varying a

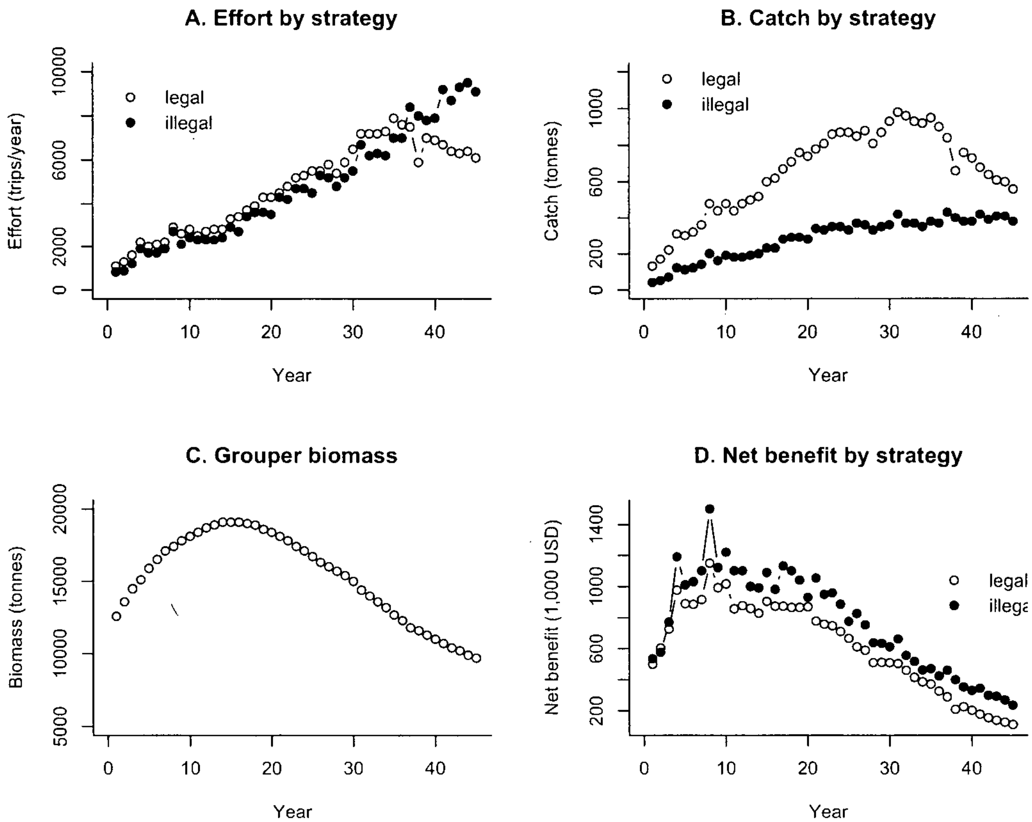

Figure 3.6: Grouper baseline simulations, no monitoring and enforcement

3.5.3 Optimal solution

The optimal solution assumes that the government is trying to completely eliminate cyanide fishing. With the elimination of the cyanide fishery for grouper, the total NPV over the 45 years is US \$52.87 million (Table 3.11). With the total elimination of the illegal fishery, the value of the grouper fishery is worth almost US \$10 million less over the 45 years.

The optimal solution assumes that the price of legal caught fish does not change with the elimination of the illegal fishery. If we assume that in the optimal scenario fishers receive 50% more for their catch, resulting in a price of US \$6195/tonne, then the total NPV of a

Table 3.11: Grouper baseline and optimal simulation net present value (NPV)

Simulation	**Legal NPV**	**Illegal NPV**	**Total NPV**
Baseline	27.80	34.65	62.45
Optimal	52.87	0	52.87
Difference	25.07	-34.65	-9.58

Values are in millions of USD

totally legal fishery would be US $65.38 million. This is only marginally higher than the baseline scenario. This increase of US $2.93 million, if averaged over the 45 year period, could mean a difference of an estimated US $65,000 annually.

To attain the optimal solution, there are several combinations of detection probability (ρ) and fine amount (Fee) the government can offer as incentives. Table 3.12 presents these possibilities. Essentially, the government can have a high detection probability (by investing in monitoring) but fine fishers a relatively small amount, or they can have a low detection probability but fine apprehended fishers a relatively large amount (enforcement).

Table 3.12: Grouper optimal detection probability(ρ) and fine (Fee) combinations

ρ(%)	Fee (USD)
10	10,100
15	6,750
20	5,050
25	4,040
30	3,370

Figure 3.7 compares the baseline and optimal solution. 3.7A and 3.7B show the optimal effort and catch profiles. Over the 45 years, the total grouper catch is 42,380 tonnes in the baseline scenario and 55,578 tonnes in the optimal solution. There does not appear to be a marked improvement in grouper biomass in the optimal solution (Figure 3.7 C).

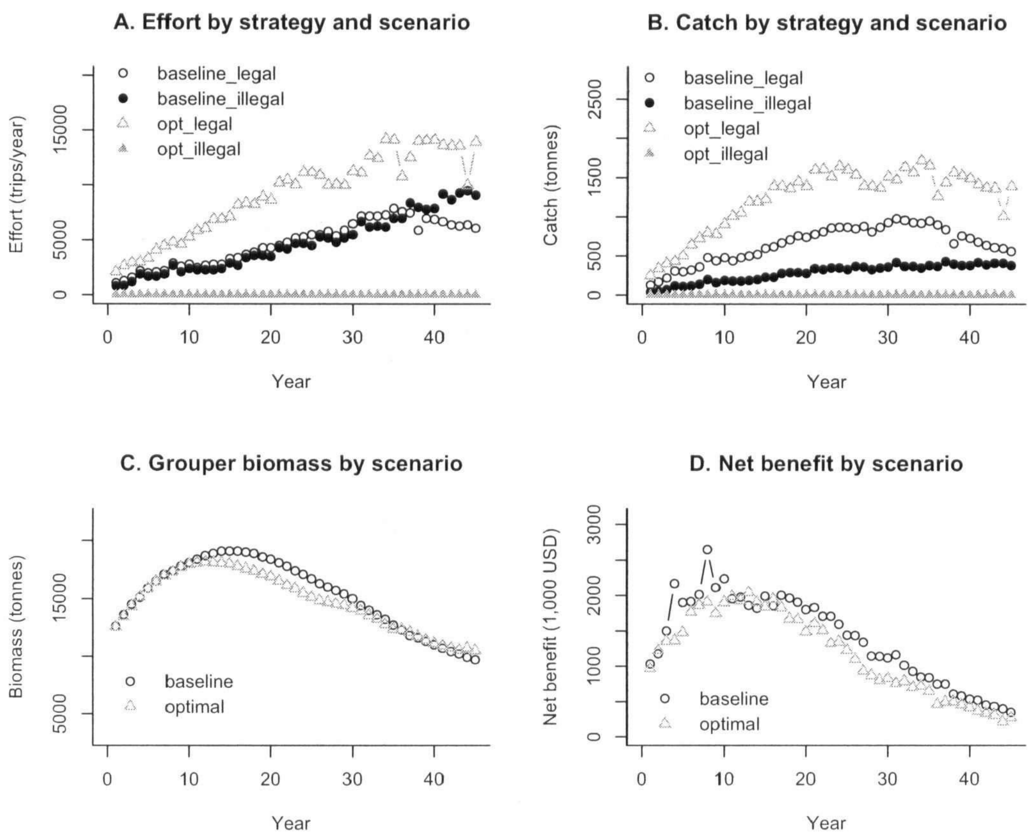

Figure 3.7: Grouper baseline and optimal simulations

3.5.4 Discounting

As explained in the discounting section of the snapper model results, the value of the discount rate (used to express benefits to be received in the future into benefits today) can greatly effect how resources are utilized. Table 3.13 shows the catch, NPV and biomass in year 45 for increasing discount rates in the baseline scenario. A higher discount rate appears to lead to a lower biomass (Table 3.13). Generally, a higher discount rate leads to a larger grouper catch, but this is only true up to a discount rate of 7%. It may be that with a higher discount rate, more catch is taken at the beginning of the simulation, leading to a lower biomass and less future catches. As expected, higher discount rates result in lower NPV of the fishery.

Table 3.13: Grouper baseline simulation run with increasing discount rates, δ

	Discount Rate			
	0*	4	7	10
Legal catch (t)	19,493	20,973	29,500	22,785
Illegal catch (t)	9,418	10,612	12,800	13,194
Total catch (t)	28,911	31,545	42,380	35,979
Illegal catch proportion (%)	33	34	30	37
Legal NPV (M USD)	79.92	35.95	27.8	17.87
Illegal NPV (M USD)	120.0	54.43	34.65	29.36
Total NPV (M USD)	199.9	89.38	62.45	47.23
Biomass (t), year 45	19,000	17,100	9,700	8,054

*This is actually $\lim_{\delta \to 0}$ to allow convergence (Clark 2006).

3.5.5 Sensitivity analysis

Intrinsic rate of growth

The intrinsic rate of growth, r, is a biological parameter defining how quickly a population reproduces (considering natural mortality). The value for r in this model was calculated using Equation (3.28). Table 3.14 shows the results of the sensitivity analysis with the low and high values used in the simulation given on either side of the main value used in the model. We expect the influence of changes in r to be similar to what we would find in changes to the value of the carrying capacity, K. A higher r value implies a more productive population, thus providing for larger catches and value through the 45 years (Table 3.14). It is very interesting to note, however, that a more productive stock appears to result in larger losses in NPV associated with the elimination of cyanide fishing (Table 3.14).

Table 3.14: Sensitivity analysis for grouper model: Intrinsic rate of growth

Result		**Intrinsic rate of growth**		
		low (0.09)	model (0.18)	high(0.36)
Biomass (t), year 45	Baseline	10,200	9,700	14,783
	Optimal	8,728	10,500	14,874
Total catch (t)	Baseline	22,860	42,380	78,000
	Optimal	30,265	55,578	94,198
NPV (M USD)	Baseline	32.86	62.45	115.4
	Optimal	24.97	52.87	89.66
Difference in NPV	(M USD)	-7.89	-9.58	-25.74
Relative profitability		0.76	0.85	0.78

3.6 Discussion

The perverse incentives to fish using explosives and cyanide are apparent in this analysis. In both scenarios effort is allocated to these fishing methods due to their apparent profitability, although in the snapper fishery, more effort is allocated to illegal methods, while in the grouper fishery, more effort is allocated to legal gears. Even with changes in parameter values, as explored in the sensitivity analysis, the baseline simulations suggest that the use of these destructive fishing gears is common in Raja Ampat.

3.6.1 Blast fishing for snapper

In this analysis, the artisanal snapper fishery is estimated to be worth between US $2.85 and $6.53 million over the next 45 years. The elimination of explosives on the reef could result in a higher stock biomass, and fairly consistent catches through time. It appears that the optimal solution is perhaps a desirable one for the regency government. The costs associated with the monitoring and enforcement program are obviously an important consideration for the government. Of course any amounts collected from apprehended fishers could potentially be used to help fund the program.

The recent rise in tourism[18] and pearl farming[19] in Raja Ampat has resulted in a perceived decrease in the number of blasts occurring in the area. The presence of dive operations out on the water, as well as armed guards present at the farms, could potentially act as pseudo enforcers, perhaps decreasing the government's management costs.

Several possible combinations of detection probabilities and fisher fines were presented. Although it is not the author's intention to suggest which combination is best, it is important to note that the potential for bribes in developing countries is often large (Owino 1999; Thyl De Lopez 2003). As such, it might be in the government's best interest to invest heavily in monitoring. If government staff are well paid to begin with, then perhaps the

[18] Eddie Frommenwiler, owner and operator of the Pindito liveaboard boat, personal communication.
[19] Mark Erdmann, Conservation International, personal communication.

incentive for accepting bribes will not threaten the integrity of a management program.

3.6.2 Cyanide fishing for grouper

Grouper populations have decreased in Indonesia (Halim 2003). Researchers in Raja Ampat have suggested that the amount of cyanide fishing has also been decreasing in the area[20]. Evidence suggests that the price of live-caught grouper is still high, although less than before the Asian financial crisis of 1997 (McGilvray and Chan 2002), and the costs of cyanide have not increased in the area. Furthermore, the current inability of managers to charge cyanide fishers with a crime would imply that fishers are not fishing less due to the risk of being apprehended or fined. Therefore, less effort using cyanide may be a result of smaller grouper stock sizes, and therefore a decreased catchability associated for cyanide fishers. Cyanide fishing tends to target grouper spawning aggregation sites (SPAGS), thus possibly leading to recruitment overfishing (Cesar et al. 2000). The Raja Ampat ecosystem-based management (EBM) project has a component study researching grouper SPAGS and preliminary reports suggest that they have been all but eliminated in Raja Ampat[21].

Elimination of the cyanide fishery in Raja Ampat does not seem to yield significant benefits, either biologically, as grouper biomass still declines through time, or economically, as the NPV is actually lower in the optimal solution. However, if a price function could be added into the model to allow price to change with the elimination of the illegal fishery, then perhaps there may in fact be an economic incentive to eliminate cyanide fishing. This implies that perhaps the high prices given to fishers who can provide live reef fish are an overwhelming incentive. The government may be better off supporting alternative capture methods for the live reef fish trade. For example, grouper mariculture has been shown to be a potentially viable option in Indonesia (Halim 2003). During my field visits to several fishing villages in Raja Ampat, I did see several grouper pens in operation. These pens are used to hold any live fish that are caught with nets or traps until a vendor comes to

[20]Mark Erdmann, Conservation International, personal communication.
[21]Christovel Rotinsulu, Conservation International, personal communication.

purchase them from the village.

3.6.3 Conclusion

The use of destructive fishing gears threatens fisheries, marine biodiversity and ecosystem services worldwide (Pauly 1989; Pet-Soede and Erdmann 1998; Cesar et al. 2000; Halim and Mous 2006). In Raja Ampat, with artisanal fisheries currently valued at US $7 million (Dohar and Anggraeni 2007), it seems evident that ensuring sustainable fishery yields through time should be a priority for the government, not to mention conserving ecosystem services through time. And although sustainable fisheries management requires several components, the elimination of illegal fishing is certainly an important one (FAO 2001). The current analysis suggests that if the present-day situation continues, with no monitoring and enforcement by the government, the use of explosives and cyanide in Raja Ampat may lead to a decline in snapper and grouper populations and catches over time. As the government wishes to use the fisheries sector to increase the standard of living for regency citizens (Wanma 2002), sustainability of the artisanal sector is vital.

Munro (1992), explained, in general economic terms, that the present day investment in a stock of capital will benefit a society by increasing the society's productive capacity in the future. By increasing snapper and grouper stocks today, in part by eliminating destructive fishing methods as shown in the snapper analysis, the Raja Ampat regency could be ensuring a flow of benefits to the community through time. Furthermore, other commercially targeted fish, such as trevally and fusiliers, as well as the prized Napoleon wrasse, would most likely benefit from reduced destructive fishing methods.

What is also important to consider, as was highlighted in the section regarding the relative impact of destructive fishing, (the value of a), is that destructive fishing not only jeopardizes fish stocks, but the very ecosystems that commercial species depend on (Pauly 1989; Cesar et al. 2000). The fact that economic valuation analyses generally ignore amenity values, such as ecosystem services, can often lead managers to disregard the potential benefits from ecosystem restoration (Berman and Sumaila 2006). If a valuation study could be done to model the potential ecosystem benefits of eliminating cyanide fishing, then that may offer an economic incentive that does not seem apparent in this model, which only examined the change in value of the grouper fishery itself.

Ecosystem-based management (EBM) explicitly recognizes the impacts that fishing has on the ecosystem (Ward et al. 2002). This analysis has attempted to incorporate this component of EBM, by assuming that the impact of destructive fishing is greater than that of legal fishing methods. The traditional village Clans in Raja Ampat, who regency citizens identified as being responsible for marine management (Halim and Mous 2006), need to be included in fisheries sector planning and educated on the destructive nature of, and lost revenue due to, the frequent use of destructive methods.

An ecosystem model has been developed for Raja Ampat (Ainsworth et al. 2007). The effort profiles simulated in this analysis can be fed into this model in order to predict what types of ecosystem effects could be expected in Raja Ampat based on the use of destructive gears to catch snapper and grouper. In this way, a single-species model may lead to ecosystem-wide predictions, which would be a great contribution to the field of fisheries economics.

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Chapter 4

Conclusion

4.1 Discussion

The current opinion of fisheries scientists worldwide is that many of the ocean's fish populations are declining. There are several reasons for this accepted decline, but it has been raised that the occurrence of illegal, unreported, and unregulated (IUU) fishing is one major threat to the sustainability of marine resources (Pitcher et al. 2002; Sumaila et al. 2006). IUU fishing threatens not only fish stocks, but also whole ecosystems (FAO 2002). Ecosystem-based management (EBM) is a new paradigm that seeks to manage fisheries within the context of the ecosystem (Ward et al. 2002). The Raja Ampat regency, in eastern Indonesia, is attempting to incorporate EBM into their fisheries development plans in order to help conserve the marine biodiversity that has been highlighted by conservation organizations in the last few years (Mckenna et al. 2002; The Nature Conservancy 2003).

The artisanal and commercial fisheries sectors in Raja Ampat represent 50% of the total regency value (Dohar and Anggraeni 2007). The objectives of this thesis were to provide some primary data for the Raja Ampat government, in the form of catch and profitability estimates for an unregulated fishery, and to compare the profitability of legal and illegal fishing methods in the regency. The two main analyses contained in this thesis present a static estimation of the unregulated Kabui Bay anchovy fishery, based on fisher interview questions (Chapter 3), and a dynamic optimization problem associated with the illegal use of destructive gears (Chapter 4).

The Kabui Bay anchovy analysis is simple, but the underestimation, and apparent lack of concern, for unregulated small-scale fisheries is a problem that needs addressing in coastal communities (Zeller et al. 2006). The addition of primary data to the Raja Ampat regency government can assist in the types of decision making that fisheries officials are currently facing. Furthermore, the output of the static model can be fed into dynamic ecosystem models, such as the Ecopath with Ecosim model being developed by researchers at UBC (Ainsworth et al. 2007). Anchovy are key prey items for larger fish and their importance in marine food webs has been highlighted recently (Skewgar et al. 2007). Understanding how increases in anchovy catch, which could be a potential fisheries development plan given the profitability as analyzed in Chapter 3, may impact the Raja Ampat ecosystem could assist in management use planning.

In principal-agent models, the payoff to the principal depends on agents' actions (Gintis 2000). While many principal-agent models have been developed for the theory of the firm, few fisheries models have been published, even though this underlying dependency remains true. In a fisheries context, fish stocks are natural capital endowed to society by nature (Munro 1992). As such, the payoff to society, through the exploitation of fish stocks, depends on the actions of fishers. The destructive fishing model developed in Chapter 4 contributes to the field of fisheries game theory in general, but specifically to the application of principal-agent theory. It is the first applied principal-agent model, that I am aware of, that uses government incentives to shift fisher effort away from destructive gears.

The research developed for this thesis is part of a large EBM study. Data collection and model development by other teams associated with the project have provided valuable data to the analyses presented. The results discussed herein have been shared with researchers working in Raja Ampat, and will be made available to regency officials. It is my hope, and I believe the hope of all those involved in the Raja Ampat EBM study, that the analyses we have conducted and the conclusions we have reached, can assist with EBM development and implementation not only in Raja Ampat, but in other areas of the world.

4.2 Strengths, Weaknesses and Future Work

In 1954, H. Scott Gordon wrote "The present state of knowledge is that a great deal is known about the biology of the various commercial species but little about the economic characteristics of the fishing industry." (Gordon 1954). Although considerable work has been done within the fisheries economics discipline, as researchers, we are constantly reminded that we actually know very little about both the biology and the economics of fisheries. It is this realization that had led to the use of the precautionary approach in fisheries management, which EBM embraces.

The principal-agent model developed in Chapter 4 attempts to incorporate ecosystem consideration, by adding in a term that increases the relative impact of destructive fishing on ecosystems. Furthermore, many of the input parameters that were used in the analysis were taken, estimated, or derived from, an ecosystem-based model of Raja Ampat (Ainsworth et al. 2007). However, a multi-species principal-agent model would better elucidate any predator/prey effects due to the use of destructive gears such as explosives and cyanide. For example, how could large predatory fish, such as sharks, be affected by a decrease in snapper populations through time? It would also be beneficial to model the ecosystem value through time, rather than just the value attained through fish exploitation (Berman and Sumaila 2006). This would be a considerable undertaking given the data requirements for such a model, but it could offer insights into the larger-scale effects of certain fisheries management plans.

The model I have presented uses profitability as its driver. A principal-agent analysis using only profitability may fail to elucidate other important factors, such as loyalty, pride, as well as social pressures (Sappington 1991). In Raja Ampat, where customary marine tenure is important, there is substantial social pressure to conform. Some villages that have existed in Raja Ampat for a few hundred years may have very strong tenure laws dictating fisher behaviour, while other villages with a large proportion of migrant fishers, may be less inclined to accord by such customary law. These differences were not accounted for in Chapter 4, but are most certainly important in how fishers make decisions.

Uncertainty, not only in fisheries, but in whole ecosystems, is an important consideration that is only now beginning to materialize in fisheries research (Clark 2006). The main issue is that fisheries science cannot presently offer predictions with guaranteed accuracy (Schrank and Pontecorvo 2007). Future models could try to incorporate uncertainty into the system, perhaps by applying a Bayesian approach. Bayes' theorem evaluates the probability of a hypothesis given data, and explicitly accepting uncertainty (Hilborn and Mangel 1997). Bayesian methods are increasing in their importance to decision analysis in fisheries ecology, (see for example, McCarthy 2007, and Clark 2006) and fisheries economists have used a Bayesian approach to study an individual's fishing choice (Salas et al. 2004).

Both developed and developing countries are realizing that ecosystem considerations are important in maintaining sustainable fish stocks through time, and that economic incentives are paramount in designing management plans. This masters thesis contributes to a field that is increasing in importance given the current state of the world's fish stocks, and, as a fisheries economist, I plan to continue making contributions during this era.

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Appendices

Appendix A. Powersim diagram

The software package Powersim (1996), was used to carry out the computations for this thesis. It is similar to other graphical modeling software packages, such as Vensim and STELLA, but offers more memory space and the ability to input and carry out vector mathematics. Powersim uses a graphical interface, where all variables and rates of change are shown with various symbols and arrows. The following appendix uses the model developed for the destructive fishing analysis in Chapter 4, herein called RajaSIM, to illustrate the Powersim modeling environment.

Figure A is the total RajaSIM model. Behind the symbols are a series of equations linking the variables together, and indexing appropriate variables by time or by fishing strategy. Such vectors are represented with a double outline of the symbol (see for example q in box A of Figure A). Table A identifies the symbols used to develop RajaSIM, and illustrated in Figure A.

Table A. RajaSIM symbols, descriptions and examples

Symbol	Meaning	RajaSIM example
Square	Level: something that accumulates	Biomass
Circle with arrow	Flow with rate: influences levels	Rate of change of biomass
Circle	Auxiliary: depends on other variables	Harvest (depends on effort, catchability and biomass)
Diamond	Constant: does not depend on other variables	Catchability
Arrow	Links variables to one another	Links catchability to harvest

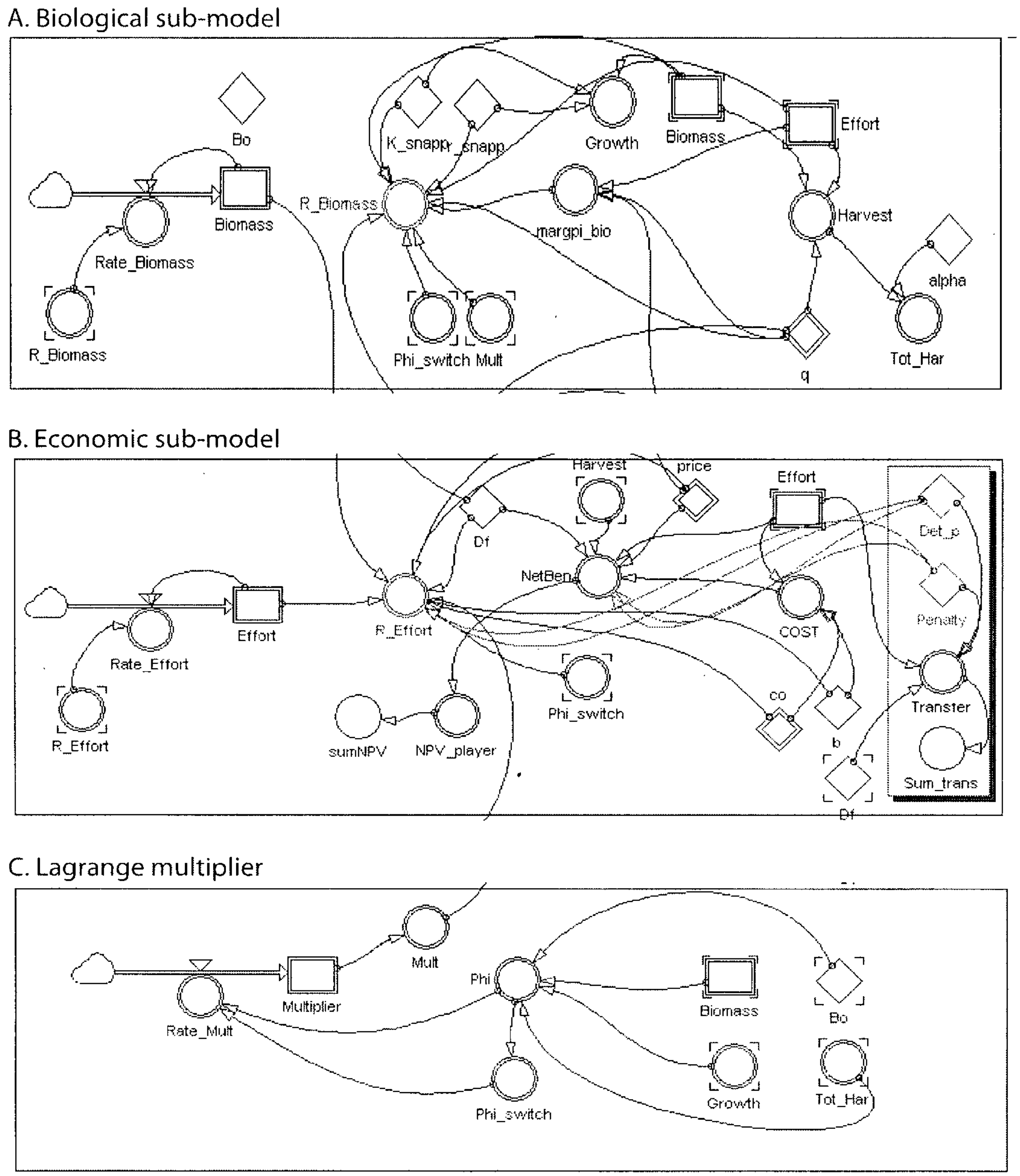

Figure A: Powersim diagram for RajaSIM

In RajaSIM, the stock biomass is called a level, and is represented as a square in the diagram (Figure 6.1A). Levels represent an accumulation of items, and can be thought of as an inventory or a stock. Levels are influenced by rates of change. In RajaSIM, this rate is illustrated by a net flow in of biomass ($Rate_Biomass$), with an open circle and large arrow flowing into the level. The change in the biomass through time is influenced by the growth rate and carrying capacity, as well as the harvest, as explained in the equations in Chapter 4. The biomass is a vector, indexed by time.

Figure 6.1B illustrates the effort portion of the model. Effort is also modeled as a level, indicated by the square symbol in the diagram. The stock of effort changes based on the comparative marginal profitability of the fishing strategies. Thus we can see in Figure 6.1B the fishing costs and prices feeding into the rate of change of effort symbol. Effort is a matrix, indexed by strategy and by time.

The third part of the diagram, Figure 6.1C, shows the Lagrangian multiplier portion of the model. The multiplier is also a stock, and is influenced by the biomass and change in biomass. The multiplier is a vector, indexed by time.

Appendix B. Powersim equations

The following appendix lists the variables and equations developed in RajaSIM, the Powersim (1996) software model used to compute the solutions simulated in Chapter 4 of this thesis. These equations are essentially the same as the equations listed in Chapter 4, only here they are laid out in Powersim form. Note in the following equations that many of the variables are indexed by player, which describes the fishing strategy as outlined in Chapter 4. When a variable is indexed by "1", it is referring to legal fishing, whereas an index of "2" refers to illegal (either blast or cyanide) fishing. The following is a table of the short forms used in the Powersim language:

Table B. Powersim codes and descriptions

Code	**Description**
dim	identifies if variable is a scalar, vector, or matrix, and how it is indexed (for example t=year)
init	the initial/starting value
flow	the rates of change of stocks
doc	written documentation/description of equation or variable
aux	identifies this variable as an auxiliary (depends on other variables in the system)
const	identifies this variable as a constant (does not depend on other variables in the system)

The first argument in each of the equations uses one of the above short forms. The second argument states which variable it is referring to, and what, in RajaSIM, that variable is equal to. For example, the constant (*const*) cathcability (q) variable is indexed by fishing strategy, (p=player), and is set equal to the catchability estimates explained in Chapter 4:

dim q = (p=player)
const q = [0.00000726, 0.00001162]
doc q = Catchability by legal and illegal fishers.

The following equations are taken from the RajaSIM model, and refer to the variables and linkages shown graphically in Appendix A.

dim Biomass = (t=year)
init Biomass = 6885
flow Biomass = +dt*Rate Biomass
doc Biomass = Initial biomass for each time step in each simulation. Has been set to the 2006 biomass for the area.

dim Effort = (p=player, t=year)
init Effort = 0
flow Effort = +dt*Rate Effort
doc Effort = Initial effort for each time step in each simulation. Has been set to 0.

dim Multiplier = (t=year)
init Multiplier = 0
flow Multiplier = +dt*Rate Mult
doc Multiplier = Initial multiplier for each time step in each simulation. Has been set to 0.

dim Rate Biomass = (t=year)
aux Rate Biomass = IF(Biomass(t)+R Biomass(t)¡0,0,R Biomass(t))
doc Rate Biomass = If the biomass plus the change in biomass is negative, then this rate is zero. Otherwise, it is the change.

dim Rate Effort = (p=player, t=year)
aux Rate Effort = IF(Effort(p,t)+R Effort(p,t)¡0,0,R Effort(p,t))
doc Rate Effort = If the effort plus the change in effort is negative, then this rate is zero. Otherwise it is this change.

dim Rate Mult = (t=year)
aux Rate Mult = -Phi switch(t)*Phi(t)
doc Rate Mult = The multiplier changes based on the magnitude of the biomass constraint violation.

dim COST = (p=player, t=year)
aux COST = (co(p)*Effort(p,t))exp(1+b)/(1+b)
doc COST = The unit cost equation is modeled as an ”almost” linear equation.

dim Growth = (t=year)

aux Growth = r snapp*Biomass(t)*(1-Biomass(t)/K snapp)

doc Growth = Logistic growth equation (rBt(1-Bt/K)).

dim Harvest = (p=player, t=year)

aux Harvest = q(p)*Biomass(t)*Effort(p,t)

doc Harvest = Cobb-Douglas/Schaefer catch equation (h=qEx).

dim margpi bio = (t=year)

aux margpi bio = q(1)*Effort(1,t)*price(1)+q(2)*Effort(2,t)*price(2)

doc margpi bio = This is the first partial differential of the Schaefer catch equation with respect to biomass.

dim Mult = (t=year)

aux Mult = Multiplier(t+1)—t¡LAST(t);Multiplier(LAST(t))

doc Mult = Sets the multiplier in the next time step.

dim NetBen = (p=player, t=year)

aux NetBen = Df(exp)INDEX(t)*(Harvest(p,t)*price(p)-COST(p,t))—p=1; Df(exp)INDEX(t)*(Harvest(p,t)*price(p)-COST(p,t)-Det p*Penalty*Effort)—p=2

doc NetBen = Discounted net benefits to each player over time.

dim NPV player = (p=player)

aux NPV player = SUM(t=1..LAST(year); NetBen(p,t))

doc NPV player = Total (summed over time) net benefits of each player.

dim Phi = (t=year)

aux Phi = Biomass(t-1)+Growth(t)-Biomass(t)-Tot Har(t)—t¡1;Bo+Growth(1)-Biomass(1)-Tot Har(1)

doc Phi = Biomass constraint.

dim Phi switch = (t=year)

aux Phi switch = IF(Phi(t) $< 0, 1, 0$)

doc Phi switch = If the Phi constraint is violated, then this switch function takes on a value of 1, thus penalizing fishers by way of the Lagrange multiplier. If the constraint is not violated, this takes on a value of 0, and the multiplier is dropped.

dim	R Biomass = (t=year)
aux	R Biomass = Df(exp)INDEX(t)∗margpi bio(t)+Mult(t)*Phi switch(t)∗(−1+ r snapp-(2*r snapp*Biomass(t)/K snapp)-q(1)*Effort(1,t)-alpha*q(2)*Effort(2,t))
doc	R Biomass = Rate of change of biomass: This is the partial differential of the Lagrangian with respect to biomass.
dim	R Effort = (p=player, t=year)
aux	R Effort = Df(exp)INDEX(t)*q(p)*Biomass(t)*price(p)-co(p)*Effort(p,t)(exp)b+ Mult(t)*Phi switch(t)*(-q(p)*Biomass(t))—p=1; Df(exp)INDEX(t)*q(p) ∗ Biomass(t)*price(p)-co(p)*Effort(p,t)(exp)b-Penalty*Det p + Mult(t) ∗ Phi switch(t)*-alpha*q(p)*Biomass(t)
doc	R Effort = Rate of change of effort. This is the partial differential of the Lagrangian with respect to effort.
aux	Sum trans = SUM(t=1..LAST(year);Transfer)
doc	Sum trans = Sum of all transfer payments made (from illegal fishers to regency government).
aux	sumNPV = SUM(p=1..LAST(player); NPV player(p))
doc	sumNPV = Total discounted net benefits summed over both players.
dim	Tot Har = (t=year)
aux	Tot Har = Harvest(1,t)+alpha*Harvest(2,t)
doc	Tot Har = Total catch in each year.
dim	Transfer = (t=year)
aux	Transfer = Df(exp)INDEX(t)*(SUM(t=1..LAST(year);Effort(2,t)*Det p*Penalty))
doc	Transfer = Total transfer payments made in each year (from illegal fishers to regency government).
const	alpha = 1
doc	alpha = The relative magnitude of the effect of legal and illegal fishing. When *alpha* = 1, the effect is equal. *Alpha* > 1 implies that illegal fishing has a higher impact/effect on the biology of the system than does legal fishing.
const	b = 0.01
doc	b = This is the exponent in the cost equation that allows solution convergence.

const	Bo = 6885
doc	Bo = Initial biomass (2006).
dim	co = (p=player)
const	co = [3.25,3.00]
doc	co = Unit cost of legal and illegal fishing.
const	Det p = 0.25
doc	Det p = DECISION VARIABLE: probability of detecting illegal fishing.
const	Df = 0.935
doc	Df = Discount factor (1/(1+r) where r is the discount rate).
const	K snapp = 16416
doc	K snapp = Carrying capacity.
const	Penalty = 811
doc	Penalty = DECISION VARIABLE: the penalty fee imposed on apprehended illegal fishers.
dim	price = (p=player)
const	price = [1230,1000]
doc	price = Price (per tonne) of fish caught by legal and illegal means.
dim	q = (p=player)
const	q = [0.00000726, 0.00001162]
doc	q = Catchability by legal and illegal fishers.
const	r snapp = 0.09
doc	r snapp = Intrinsic rate of growth.

Appendix C. UBC ethics approval

Certificate of Completion

This is to certify that

Megan Bailey

has completed the Interagency Advisory Panel on Research Ethics'
Introductory Tutorial for the
Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS)

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