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Ocean-Scale Management of Pelagic Fisheries: Economic and Regulatory Issues

Ujjayant Chakravorty & John Sibert

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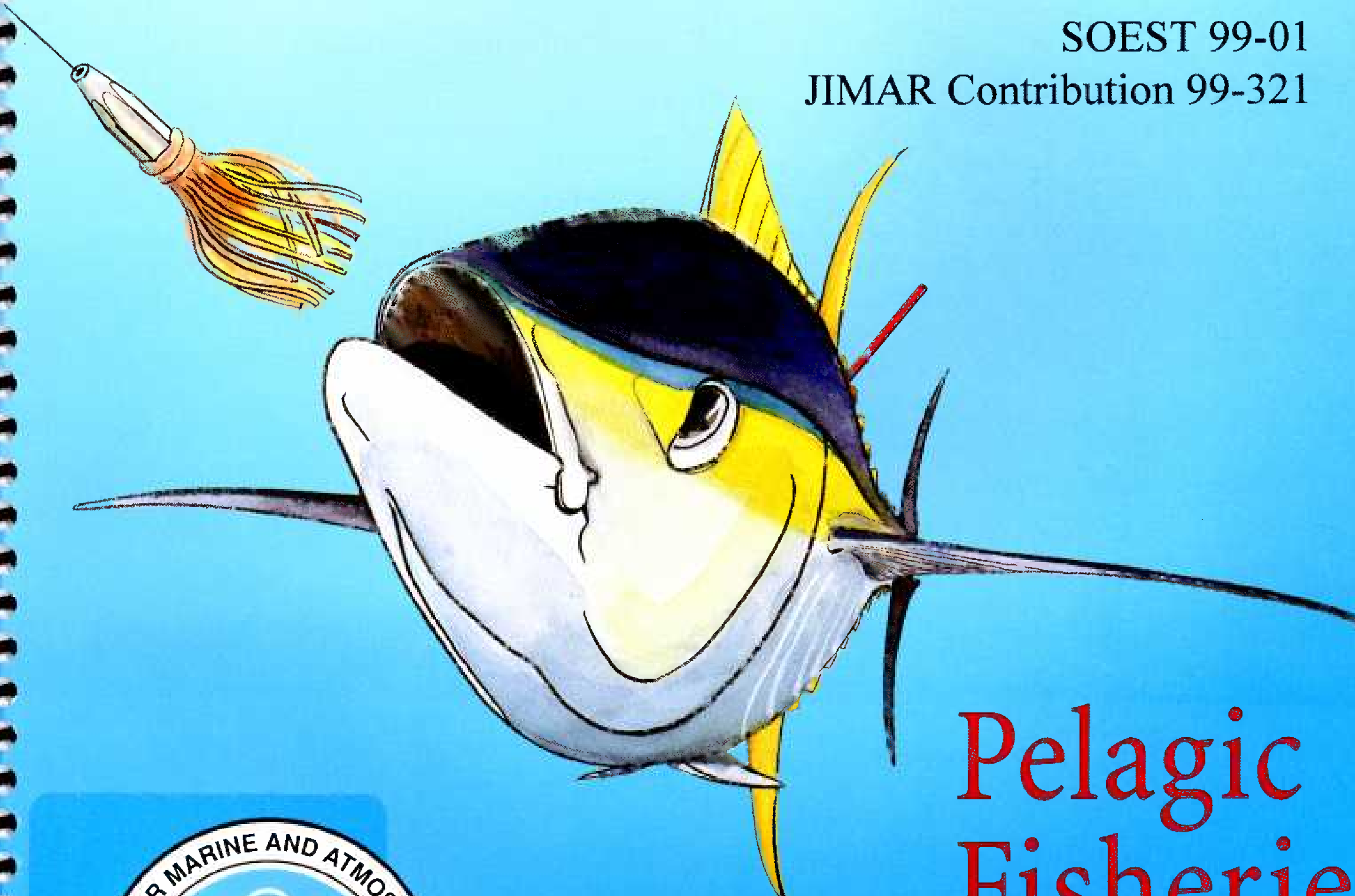

Pelagic Fisheries Research Program

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Ocean-Scale Management of Pelagic Fisheries: Economic and Regulatory Issues

Proceedings of an international workshop organized
by the Pelagic Fisheries Research Program,
Joint Institute for Marine and Atmospheric Research,
University of Hawaii at Manoa, Honolulu, HI
12-13 November 1997

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This project was funded by cooperative agreement #NA67RJ0154 between the Joint Institute for Marine and Atmospheric Research and the National Oceanic and Atmospheric Administration. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its subdivisions.

Introduction to the Volume

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The Pacific Ocean is home to the world's largest pelagic fisheries, providing a majority of the world's canned tuna supplies. The regulation and management of these migratory species is an exceedingly complex task, given the diverse types of gear used, the large number of countries with commercial fishing interest in the region, and the wide spectrum of countries with substantial fishery resources—from the United States on the one hand to tiny Pacific islands such as Tuvalu on the other, with scant management expertise and low bargaining power relative to the bigger fishing interests. These problems, with serious implications for the economic development of the small island nations of the region, have also created a tremendous opportunity for the scientific community to pull together available scientific knowledge to bear upon the critical management and policy issues affecting pelagic fisheries in the Pacific Ocean.

This volume is based upon a two-day workshop organized by the Pelagic Fisheries Research Program at the University of Hawaii, the purpose of which was to bring together fisheries managers and regulatory agencies as well as economists and scientists working on various aspects of fisheries regulation in the Pacific. The papers presented range from examining the legal and regulatory issues to economic modeling of fishing gear interactions and allocation of effort in the Western Pacific and Hawaiian fisheries. The goal of this interaction was twofold: (a) to provide modelers with a perspective on the critical oceanwide management issues relating to the sustainable exploitation and conservation of pelagic fish and (b) to initiate and develop research programs that relate the micro-modeling efforts to the larger oceanwide issues.

In what follows, we synthesize some of the key policy and methodological issues that emerge from the papers contained in this volume.

Legal Aspects of Fisheries Management

Judith Swan's paper deals with the impacts of emerging trends such as "sustainable development" and "globalization" on the fisheries sector, especially in the Western Central Pacific. She observes that globalization, through the introduction of trade, investment, and greater reliance on market forces, is forcing policy makers to take a new look at the existing legal and institutional framework for fisheries management. These trends have come at the same time as governments and international agencies have reduced their support of domestic fishing industries and have forced fishery managers to come up with plans to generate more revenue from their activities. In many countries, domestic artisanal fishing has given rise to harvesting by offshore fleets and has created the need for developing new expertise and knowledge in managing a modern capital-intensive fishing sector.

Swan points out several recent changes that are affecting the fishing industry both internationally as well as at the regional and subregional level. For example, many countries are now seeking profits from their fisheries rather than just resource rents. There is a gradual phase-out of government in the day-to-day management of the fishery that is based on the realization that government involvement has been far from successful. New laws are needed to assist management in access negotiations and these laws need to be flexible in the face of a dynamic and evolving fisheries sector. Management authorities need the legal apparatus to formulate policies such as giving preference to domestic-based vessels and forming long-term agreements with foreign fleets. Increased interna-

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tional trade in fish products has also meant enacting new quality regulation both within the Pacific Island nations and internationally.

On average, countries in the region receive a meager 3.5% of the revenues generated in their fisheries through access fees. Fisheries regulation is needed that can set minimum standards for license fees and make it commensurate with international standards and the economic value of the resource. This would also mean flexibility in the legal and institutional process for potential investors and industry entrants. Enforcement measures also need to be streamlined and coordinated regionally so that they are consistent and penalties imposed match the severity of the offense.

In conclusion, the author suggests that the interdependencies in fisheries management between coastal and distant water fishing states call for a new world body that can effectively monitor and guide the world's fisheries towards the goal of sustainable management. The trend toward globalization dictates that cooperation only at a regional level, as is happening now, may be inadequate and resources, trade, capital and fisheries product flows can be put to maximum use only if they are allocated on a global scale, as has been achieved in sectors such as commodity trading, telecommunications, and international capital markets.

Regulatory and Management Issues

Tony Kingston's presentation focused on the problems of managing tuna resources of the Western and Central Pacific Ocean. He describes the complexity of the problem - a range of primary and secondary fish species, a multiplicity of fishing gears, and the need to monitor and enforce fishing agreements over vast distances often by tiny countries with limited human, technical and managerial resources. There are enormous challenges ahead, and countries need to take joint action not only to better manage migratory resources that move freely between national jurisdictions but also in other areas such as joint marketing of products that can ensure a better price for the tuna. There are also serious problems arising from the fact that most countries are mere passive participants in their fishing zones—limited to collecting access fees and allowing vessels the right to fish in their Exclusive Economic Zones (EEZ).

The paper suggests that there is serious concern that unless effective management measures are put in place, tuna stocks may soon become overfished. This is because world demand for canned tuna, especially in the European and Asian markets, has been steadily increasing at the rate of 5-10 percent per year. Demand for sashimi and for tuna steaks is also growing in the U.S., Korea, and other countries. However, on the supply side, the Atlantic and the Indian Ocean tuna stocks have been fully exploited and it is expected that the increase in global demand will result in more vessels fishing for tuna in the Pacific Ocean.

There is some complacency in the region that stocks of at least three of the four major species—skipjack, yellowfin, and albacore—are doing well and there is no need for immediate measures for their management. According to the author, this tendency towards inaction may be dangerous because there is a lag in collecting and processing scientific information, and it may be too late before the data reveal that there is a problem. Secondly, it is best to implement management schemes before overfishing has occurred, so that stringent cutbacks on effort and catch are unnecessary.

As laid down by the United Nations implementing agreement, the goal of regulation is to ensure long term conservation and sustainable use as well as to assess and mitigate any negative impacts on non-target, associated, and dependent species. However, once the general objective of regulation is agreed upon by the various parties, the next step is to identify which species need to be targeted and what needs to be done to protect them. In some cases, although scientists from different countries agree that there is overfishing, there is little consensus on the stock building scenarios to be followed under different catch levels. The problem of consensus-building multiplies with the addition of new members into the group.

Kingston points out other considerations that have been discussed but are yet to be resolved. For example, countries will need to agree on limit reference points for each species, below which fishing may involve a high risk of depletion. These are biologically determined, as distinct from target reference points, which include economic and social goals. Thus, although it may be easy to define the concept of "optimum utilization" of stocks, getting 25 independent states to agree and abide by any target catch rates may be an arduous task.

Finally the author suggests that a future multilateral arrangement may work if clear catch and effort limitations are agreed to by all the parties. The geographical scope of these arrangements will have to be negotiated, keeping in mind regional as well as national fishing interests. The migratory nature of the resource and wide fluctuations in stock will need to be accounted for. He goes on to describe the evolution of the multilateral negotiations which are expected to be completed by June 2000 by which time a new multinational management program is expected to be in place in the region.

Economic Modeling Approaches

In this section we discuss three approaches toward modeling the economic consequences of alternative regulatory policies. Campbell's paper synthesizes his work on the effect of alternate gear types, namely, longline, pole and line, and purse seine on net economic benefits from the fishery. Although four major tuna species—albacore, bigeye, yellowfin and skipjack—are harvested by the three gear types, the interactions are especially strong for skipjack, which is fished both by purse-seine and pole-and-line fisheries, and yellowfin, targeted by purse seiners and longliners. What is important in computing the effect of these interactions is the price elasticity of demand for tuna. Campbell calculates that a 1 per cent increase (decrease) in the quantity of raw longline-caught tuna in the Pacific Islands Region would result in an approximately 0.4 per cent decrease (increase) in the price of raw tuna. Thus, if the region reduced its purse-seine catch by 1 per cent, the value of raw catch would rise by 0.6 per cent, while increasing its longline catch by 1 per cent would decrease value by 0.4 per cent. This implies that an increase in purse-seine access fees would increase total revenue.

The principle of equality of net marginal benefit across gear types can be used to allocate a certain species across alternative gear. Campbell discusses different policy instruments (differential royalties, rise in access fee) required to reduce purse-seine catches of juvenile yellowfins which could then be caught by longliners after a time lag. He estimates that the benefit/cost ratio of a 1% reduction in purse-seine catches in the Papua New Guinea fishery and a corresponding increase in the longline catch of yellowfin is in the range 10-21. A similar analysis for the Solomon Islands skipjack and yellowfin stocks suggests that the economic value of the fishery would be maximized by increasing the level of purse-seine effort eightfold. Finally, the paper suggests three criteria that management need to take into account in maximizing the economic value from the region's tuna fisheries: (i) the sustainablility of purse-seine catches relative to the size of the fish stock; (ii) the impact of purse-seine catches on the value of the other tuna fisheries in the region; and (iii) the effect of the region's catches on world tuna prices.

Leung et al. develop a two-level programming model of the Hawaiian multifishery that explicitly models fishermen's behavior in an optimization framework. Theirs is a generalization of an earlier LP model developed by the National Marine Fisheries Service. The model includes both commercial and recreational fishing and five major fishing areas around the main Hawaiian Islands. It also takes into account both target species as well as bycatch. Several entry conditions are built in to the model, such as a trip entry condition that says that commercial fishers will at least cover their variable costs for any given trip. Similarly, crew and owner entry conditions introduce a lower bound on their returns per trip. Stock effects are incorporated by postulating a nonlinear negative relationship between CPUE and excess catch, defined as total catch net of current catch.

The model is applied to estimate the impact of area closure, tradeoffs between recreational and commercial fishing and optimal fleet mix under a scenario of increased fish abundance. The impact of area closure to reduce gear conflict was a decline in profits from commercial fishing of approximately $0.44 million. The model was then modified to maximize not only fleet profits but the total number of recreational trips. This would generate tradeoffs between commercial and recreational fishing. A non-inferior set estimation (NISE) procedure was used. The results suggest a very consistent tradeoff of $8–18 reduction in commercial profits for a marginal decrease in recreation trips. At 1993 levels, the cost of an additional recreation trip was approximately $12. Finally, the model is run with an exogenous increase of stock by 150 percent. This resulted in an increase in the number of commercial boats by 7 percent and fleetwide profits by 27 percent. Results suggest that the distribution of profits within the fleet may be non-uniform—medium and large longline vessels increase their operations while charter boats, handliners, and small longliners show a decrease in profits.

Finally, Chakravorty et al. develop an economic model of the Hawaii longline fishery through an optimizing framework that includes both spatial and dynamic elements. The model takes the five-degree square as a spatial unit and uses an estimation procedure to compute the initial stock for the five major species—striped marlin, swordfish, albacore, bigeye, and yellowfin—at the beginning of every time period (month). Based on the variable costs of fishing including traveling from port to any fishing location, longliner vessels are allocated to regions of maximum profit. However, as boats fish in any given region, stocks decline, and that in turn creates a negative impact on the CPUE of subsequent boats. The allocation of vessels in this fashion generates a derived demand function for effort. The corresponding supply function is obtained through an econometric estimation of effort data that incorporates labor-leisure tradeoffs in the allocation decision.

Their baseline model tracks the actual monthly spatial distribution of effort for the year 1995 with a roughly 10 percent aggregate error. Three policy simulations were performed: (i) closure of areas near the main Hawaiian Islands to reduce gear conflict, (ii) closure of areas north of 30°N to reduce turtle catches, and (iii) a demand shock in the form of a 25 percent reduction in ex-vessel prices, that could happen from a severe recession in the Japanese and Hawaiian economies. Results suggest that measures to reduce gear conflict led to a decline in total longline trips, while turtle conservation increased trips since longline vessels were mostly confined to areas closer to port. In the latter case, swordfish catches were reduced by a significant 47 percent, since swordfish are mostly found in the northern latitudes. Interestingly, lower ex-vessel prices of fish did not have a significant effect in reducing the allocation of effort, mainly because of a relatively inelastic labor supply curve. One conclusion is that area closure may be a more effective conservation measure than increased auction fees or other forms of revenue taxation.

Entry-Exit Issues in the Hawaii Longline Industry

Travis provides a fascinating historical account of the reasons behind the various migratory cycles that were observed in the Hawaii longline fishery since the late eighties. He examines entry of vessels from the Gulf of Mexico, the East and West Coasts as well as between Hawaii and Fiji. The impact of these waves of migration, sometimes large, mostly small, consisting of a few vessels, often under common ownership, on the structure of the Hawaiian longline industry is clearly documented. The cultural differences between ethnic (e.g., Vietnamese) groups and local fishermen as well as problems with communication and enforcement of long-standing, often informal, agreements are discussed. His analysis points out the importance of factors that are not traditionally modeled by economic analysts as critical determinants in the targeting of species, choice of trip location, sharing of knowledge related to the distribution of stocks, the structure of costs and finally bottom-line profitability. These insights suggest that a given fishing industry cannot be analyzed in isolation, and the interdependencies between conditions in different fishing grounds such as the Gulf of Mexico, the Atlantic and Hawaii, need to be incorporated in formal models of fisheries regulation.

Sustainable Development in the Pacific Islands

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1. Introduction

"Sustainable development" is a term that is a driving force behind much new law but has escaped legal definition in most treaties and national legislation. It is more than a nineties buzzword, less than a precise measure, and certainly bigger than a breadbox—or even a superseiner.

It was spawned in the eighties, featured at the Earth Summit in the early nineties, and has since come to rest in our communities, governments, international organizations, financial institutions, development assistance policies, hearts, minds and souls. It has become the subject of substantial scrutiny and study. We all want very much to think of the best way to Make It Happen, however we may define "It". Many think of it as using our resources wisely so future generations may benefit.

Sustainable development represents both a global shift in perception and a response to globalisation of the world's economy. We now perceive ourselves as caretakers of our planet's limited resources, rather than conquerors. This is a change in attitude, an eleventh-hour injection of wisdom that future generations will appreciate—largely because it enhances the possibility of the very existence of future generations.

The 1996 Food and Agriculture (FAO) Report on the State of World Fisheries and Aquaculture notes that globalisation of the world's economy is manifested in the fisheries sector through expanding trade, a greater reliance on market forces in policy-making, and a rapid increase in the amount and international mobility of private investment capital. One concrete result is that the growth in the demand for fish products, no matter where it occurs, may affect fish production anywhere in the world through the mechanisms of foreign private investment and/or trade.[1]

This conference offers us an opportunity to take great strides in forwarding the fisheries file of the sustainable development agenda. From a legal point of view, it is fundamental to consider crafting laws and regimes that cater to globalisation, in the contexts of both the caretaker approach and the role of trade, market forces, and private investment.

Conference participants represent governments, industry, research, developmental, private sector and academic endeavours, so the conclusions will have a strong foundation and ensuing action no doubt will be full and productive. This paper, authored by a lawyer, represents none—and all—of these interests.

This paper reflects the latest trend in lawyer-client relationships. While lawyers take instructions from governments in preparing fisheries laws, regulations, treaties or other arrangements, at heart we're all cooperating to work for the resource. As we do this, we have in mind the implications of globalisation and also the interests of traditional and recreational fishers, offshore fishers, foreign fleets, investors, fisheries managers, sashimi lovers, and certainly national and regional policies and economic interests. But our focus is on the fish, and what we really want to see at the end of the day, and at the conclusion of a lifetime, is sustainable development and a plentiful resource.

To that end, this paper will address the following questions.

- What is driving the need for a new look at sustainable development in fisheries and at fisheries law?
- What is the existing legal framework for meeting the need for sustainable development in fisheries in the Western Central Pacific?
- Is law reform needed?

The backdrop to addressing these questions is of course the legal perspective. The author's message will be that as circumstances and needs change, so must the law and legal arrangements. We should keep open minds and a collective will to work for the client—in this case, the highly migratory resources.[2]

2. What is Driving the Need for a New Look at Sustainable Development in Fisheries and at Fisheries Law?

Changes are driving the need for a new look at sustainable development in fisheries. These changes involve increasing scientific knowledge of the resource, the profile of the fishery, technology, economies, subsidies, food security, developmental assistance, private sector investment, trade and market forces. To some extent, international/ regional agreements and national laws are innovative, but for the most part they have been playing catch-up and responding to the results of other changes.[3]

The worldwide profile of fishing has undergone radical changes since negotiations began in 1973 toward the United Nations' Law of the Sea Convention. As the ocean column was carved into 200-mile zones, many governments passed laws to manage the resource over which it claimed sovereign rights. In the western Central Pacific, governments established the South Pacific Forum Fisheries Agency to assist in harmonising management measures and resource programmes at the South Pacific Commission for scientific information and advice.

In other parts of the world, the development of national fishing industries was subsidised, often heavily, by government. This contributed to global overcapacity which in turn contributed to the famous conclusions in the 1994 FAO Report on the State of the World's Fisheries and Aquaculture that 70% of the world's fisheries are fully to heavily exploited, depleted, or slowly recovering from overfishing. That report also concluded that the global value of the fish caught was lower than the expenditure used to catch it—including the massive subsidies.

The 1996 FAO Report on the State of the World's Fisheries concludes that 60% of the world's major fishery resources need urgent management.[4] It presents a number of factors contributing to excessive fishing effort, including the following, which have legal implications:

> insufficient control of fishing fleets by both flag states and port states, leading to considerable unauthorised fishing;
>
> a lack of commitment to international cooperation towards joint management, often coupled with a limited effective authority of regional fisheries bodies.[5]

This situation—certainly affecting profitability—prompted restructuring of national fisheries sectors, downsizing of many distant water fleets, introduction of new management measures such as individual transferable quotas (ITQs), and new initiatives in fisheries enforcement, including increasing use of transponders. Perhaps most importantly it alerted coastal states to the fact that fisheries management inside and outside 200 miles had substantially failed, and new laws would be needed to meet new changes and challenges.

These changes have been taking place in a climate of downsizing developmental assistance envelopes, downsizing government, and a shift in programme priority to improving management and promoting private sector investment to develop the fishing industry.

In the Western Central Pacific, the tuna resource appears to be comparatively healthy.[6] The 1996 FAO report projects that the Pacific Ocean will not be fully fished until 1999.[7] Many innovative regional and subregional management arrangements and agreements have assisted in maintaining the sustainability of the resource.[8]

However, management has been loose and it is unwise to remain complacent in a climate of change. Following are some "awakenings" with legal implications:

First, the global trends described above have had impacts in the region, including downsizing and downsubsidising—even bankruptcy—of fleets.[9] This has a range of possible consequences, such as the terms of renewal or renewal itself of the regional access treaty with the US, license fee levels, and careful choice of fishing grounds by foreign fleets and consequent revenues to host countries.

Second, the modernization of some distant water fleets[10] and increasing interest shown by newer entrants[11] to find productive fishing grounds underline the need for regional and national sustainable development policies and laws to cater to the anticipated situation, mindful of traditional fishing countries.

Third, tuna harvesting is increasingly dominated by distant water countries; twenty years ago a greater relative proportion of tuna production in the region was produced by locally based fishing fleets.[12]

Fourth, the island countries receive around $60 million[13] in annual license fees, a minimal return considering the estimated value of the landed fish to be $1.7 billion. This represents an exceptionally modest return of 3.5%.[14]

Fifth, the general decrease in developmental assistance is accentuated in the Micronesian countries[15] where current compact funding from the US—and consequent support to the fishing industry—is due to expire in another four years.

Sixth, recently adopted policies in Micronesia[16] recognise that far greater revenues are available from the fishery than just the rent; onshore services such as provisioning and servicing vessels can boost revenues considerably.[17]

Seventh, there has been considerable movement internationally to address problems associated with unmanaged fishing and excess fishing effort;[18] this should serve as a bellwether as to the kind of regulation that is needed and should motivate implementation on the regional level.

In short, the days are fading where benefits from the fishery could be realized largely from license fees from offshore fleets and management was commensurately easier. New objectives and goals need to be creatively set to attract and accommodate lucrative, locally based fisheries and as appropriate to progressively develop a domestic fleet when investors are attracted into the sector. Management of the resource needs to acquire a broader breadth in most cases; all aspects of management policy including licensing, investment, science, privatisation (where applicable) and enforcement should be centralised. This has implications in many quarters—for example, developing management talent, attracting capital, restructuring government management authorities, and financing enforcement operations.

The legal implications are far-reaching as new potential benefits and policies are identified. Laws should be made flexible and reasonably user-friendly, balancing sustainability with national development in a new investment climate. This would apply to fisheries and related legislation, including investment, environment, labour, customs, immigration, taxation and banking. The laws should respond to changing circumstances and foreshadow the future at national, subregional and regional levels.

3. The Legal Framework

(a) The Offshore Eighties

In the 1980s national laws in Pacific Island States had developed around three building blocks.

The first was the 1982 United Nations Convention on the Law of the Sea, generated at a time when uniform standards and rules were needed for managing the new 200-mile zones. Focal points in the convention included setting an appropriate level of catch and regulating and enforcing in-zone activities.

Second was the policy at that time favoured development led by the public, not the private sector, and laws were oriented toward an offshore fleet.[19] The region, smarting from an "invasion" by over sixty unlicensed US purse seiners in the early eighties, remedied the situation by concluding the regional Treaty on Fisheries with the United States. It inspired a high regional standard for management of the offshore purse seine fleet,[20] and its provisions were incorporated into most national laws.

The third major source of harmonised law in the region were the minimum terms and conditions of fisheries access, developed by the Nauru Group. Again, the focus was the offshore fleet.

Extensive provisions on the duties of and rights owed enforcement officers and observers were included, and evidentiary provisions were pioneered in regional consultations to close existing loopholes and expedite the prosecution process. Implementing the provisions of the regional treaty with the US and the 1992 Niue Treaty on Cooperation in Fisheries Surveillance and Law Enforcement, many countries authorise non-national enforcement officers and observers to perform duties in their jurisdictions.

The level of fines and penalties was increased to reflect the value of the resource to island countries. While there is growing international agreement that penalties should be high for serious offenses,[21] in some cases offenders have been given onerous fines for relatively minor offenses. While repeated misreporting is considered a serious offense internationally and liable to steep fines, relatively minor errors or omissions should be treated as such. The consequences of imposing steep fines for relatively minor offenses could include withdrawal of the fleet from the host country,[22] or even worse, unlicensed fishing.

This raises the issue of enforcement authority and policies. In some jurisdictions, the fisheries managers do not have lead responsibility for enforcement. This puts the Director of Fisheries in the unenviable position of having to establish good relations with the distant water fleet to attract the fleet and a reasonable fee level, while another arm of government might carry out enforcement activities to raise funds through onerous fines and penalties.

This is not to say that offenses should go unnoticed, just that there should be consistency in setting the enforcement policy and fines or other penalties as provided in the legislation should be commensurate with the offence.

In summary, national laws originally were license (and license fee) oriented, with strong controls over foreign fleets. Sustainability was derived from the conclusions of the OFP at the South Pacific Commission, and development was usually guided by government authorities in a number of ways: under their management authority; through the FFA; developmental assistance programmes; international financial institutions; terms of access treaties. The development did not, for the most part, embrace the industry as a whole with a view to securing higher profits from the foreign fishery operations nor did it encourage private sector investment through simplified procedures or laws.

(b) The New Nineties

New fisheries policies recently adopted in Micronesia[23] have concluded that it is time for change: development priority should be put on profits rather than rents; management authority should be consolidated under one canopy; and governments should stick to the business of management and encourage private sector investment to drive the development of the fishery.

To implement these policies, the Micronesian countries[24] are reviewing and amending national fisheries and related legislation. To attract profits as well as rents, key elements of the new laws include according domestic based vessels advantages over an offshore fleet (such as priority to any allocations and rebates in fees), making viable long-term arrangements possible, and providing for strong but reasonable enforcement. The functions of management authorities are also overhauled to enable a more coherent approach, and related legislation has been reviewed for amendment.[25]

As noted in the introduction, globalisation means that the demand for fish products, no matter where it occurs, may affect fish production anywhere. The demand often depends on the quality of the product, which in turn is regulated by import controls. One important development in this regard is the Hazardous Assessment and Critical Control Point (HACCP) requirements enacted by a major market for this region—the United States. Other markets have similar import requirements. While some countries in the region which are, or may be, engaged in processing may under current law enact regulations to ensure compliance with import requirements, very little has been done on the legal front to ensure that the needed controls are in place.

At the subregional level, the importance of domestic based vessels is reflected in two recent arrangements—the Palau and FSM Arrangements. They are mechanisms patterned somewhat after the regional Treaty with the US and incorporate subregional standards for access. They are designed to manage the purse seine fishery by capping the number of vessels allowed to fish, increase the fishing by domestic based and local fishing vessels, and issuing one license for fishing in the zones of the parties.

Subregional, regional, and international agreements noted above[26] have been implemented by some countries, but for fullest regional effect need consistent implementation throughout the region. This will assist in addressing two of the factors identified by FAO as causes for overexploitation—insufficient control of fishing fleets by both flag states and port states, and lack of international cooperation in management.

A surge of legal activity in the region should also flow from the 1995 UN agreement on straddling fish stocks and highly migratory fish stocks in two streams, as described below. The first is national: early ratification and implementation. The second is international: agreement on and establishment of a management mechanism through the multilateral high level conference (MHLC) process and implementation of the requirements of that mechanism at national levels.

4. The Need for Law Reform

(a) National Laws

The national legal framework for marine resources should effectively implement regional and international agreement, as noted above. This is key to managing the sustainability of a common resource and offers a minimum standard for national laws and management measures.

At the national level, legislation should be reformed to enable new national fisheries policies and priorities to be implemented to meet current and future needs. As noted above, the needs spring from the dramatic global changes in fisheries based on space-age technology, consequent overfishing of the resource, fleet restructuring, policies favouring private sector investment over government ownership, subsidy, market forces, and developmental assistance.

Laws also need to be mindful that governments are downsizing and human and financial resources for managing the fisheries are dwindling. And finally, export markets have introduced standards regarding the quality of the fish product, which will require corresponding regulation by Pacific Island States.

Although policy review should set the priorities for fisheries legislation in each country, following are some areas which are ripe for consideration of law reform as appropriate at the national level.

(i) Government in Fisheries: Management Authority, Management, Development, Participation in Fishing Operations

There is a trend toward gradual phasing out of government in fisheries management and operations in favour of the private sector. Restructuring the management authority either within government or to an autonomous or semi-autonomous body—with political control exercisable principally on the basis of oversight and formal periodic review—could preserve its status in a climate of downsizing. This would be so particularly if it is self-financing[27] as much as possible. Such authorities should have policy, management, scientific, regulatory and developmental functions, and take the lead in fisheries access negotiations and enforcement. This will require law reform in many countries.[28]

Management will need to be able to respond effectively to market trends in terms of access negotiations, terms for domestically based vessels and requirements of export markets. Laws should be framed to ensure maximum economic return on the resource, yet meet each circumstance with some flexibility. Regulations need to be in place to satisfy HACCP and other requirements of export markets.

Government success in fishing operations has been wanting. There is increasing recognition from past mistakes that government should phase out of fishing operations in favour of private sector involvement.[29] Where applicable, this will mean eventual privatisation of government-owned ventures and development through the private sector, in addition to the law reform as described above to facilitate investment.

Management will increasingly need to apply emerging standards consistent with sustainable development. Foremost among these is the precautionary approach, which should be required and defined under national laws and, as applicable, other agreements and arrangements.

Management will need to be outward looking and ensure there is legal basis—and responsibility—for cooperation on subregional, regional and international levels, including implementation of international obligations. The concerns identified by the FAO would be met in this regard, including control of fishing fleets by both flag states and port states, and the need for international cooperation in management.

(ii) Rents and Revenue from the Fishery

As noted above, policies relating to maximising the rent and increasing the revenues from the fishery would need to be accompanied by a spectrum of creative law reform.

There should be a legal basis to bring in a reasonable return for the resource through license fees. The low average 3.5% return should be reviewed in the context of the estimated profits, international standards and the value of the resource to the countries. Mindful that negotiations are market-driven and laws are often difficult to amend, fisheries regulations should set minimum standards for license fees with enough flexibility to respond to market conditions and the type of license granted.[30]

Potential revenue from development of a domestic-based fleet is considerable, as noted above. Policies have been developed to attract domestic based fleets; this is not particularly new. However, new energy may be needed to attract the fleets with appropriate infrastructure and minimal legal/bureaucratic process.

This would require a review of laws relating to domestic-based fleet activities, including taxation,[31] labour,[32] immigration,[33] corporation,[34] banking,[35] and the environment,[36] in addition to investment as described below. A scheme of "one stop shopping" could be devised for potential investors or domestic-based fleets so all permits could be easily obtained through one conduit or, at least, a few key officials. Fisheries laws should be reviewed with a view to implementing regional standards, including the definition of a domestic based vessel and according them special privileges, such as priority in the allocation process.

Investment laws and guidelines should be reviewed and reformed where necessary with a view to allowing maximum flexibility in approving investments. A fisheries investment "welcome mat" should be put out to non-national investors. A laissez-faire philosophy should underlie the law, rather than a series of controls subjecting the investor to a lengthy bureaucratic process where the investment must be justified and evaluated by the government. Laws should be designed to attract capital—national or international—and market forces and project management should determine profitability.

(iii) Fisheries Enforcement

Fisheries management is only as strong as its enforcement component. The legal framework for effective enforcement is complex, with the most important element being determination of enforcement policy and prosecutions consistent with the overall management needs.

As noted above, enforcement authority is often fragmented so that enforcement policy and activities are not set by the same body in government that has management authority. Reform is needed so that the fisheries management authority has the lead in setting enforcement policy or guidelines. This would promote cooperation between the bodies—for example Fisheries and the Attorney General or Sea Patrol—and could leave day-to-day operations to the operations branch. The objective would be to identify and secure enforcement of serious offenses as a priority.

"Serious offenses" should be identified, implementing international agreement.[37] Fine and penalty levels should be set at a level that reflects the seriousness of the offense. They should not be onerous but should act as a deterrent.

Once a charge has been made for an offense, speedy administrative procedures should be available for those who opt to admit guilt, so they may pay a "parking ticket" type of fine and return to the fishing grounds. Guidelines would be available for the penalty levels, which would reduce the variability seen in out of court settlements.

Finally, enforcement cooperation is being advanced by some countries under the Niue Treaty and a vessel monitoring system is being advanced by FFA member countries. National laws need to ensure that there is adequate provision for cooperation in fisheries surveillance and enforcement, including the use of transponders.

(b) MHLC Process

The MHLC process has already inspired a new wave of legislative reform in the region at both national and regional levels. Nationally, some countries[38] are incorporating the relevant requirements of the UN Agreement[39] in their laws, including adoption of the precautionary approach, licensing their vessels for fishing on the high seas and authorizing high seas boarding/inspection measures.

The reforms should be implemented at an early time by all countries in the region for two reasons: one is the fact that the reforms enhance sustainability and the other is that the FFA member countries will have the higher moral and legal ground in the MHLC process. In addition, it will provide a sound basis for consistent management throughout the region. For the same reasons, the reforms should be coupled with ratification of the UN Agreement by those states that have not yet done so.

The MHLC process is developing a mechanism which adapts, in detail, the requirements of the UN Agreement to the region. This means that there will need to be a second pass at the national legal framework at the completion of the process to ensure that the agreed details fit within the existing laws or can be implemented by regulation. If not, further reform may be needed at that time. In addition, depending on the agreement of MHLC participants, countries may need to take measures to ratify or otherwise formally accept the agreed obligations.

Some fundamental issues that will need to be addressed as the process evolves, and that the law must eventually implement, were identified by the Chairman during the June, 1997, MHLC2 in Majuro. These involve the compatibility[40] of in-zone and high seas management and include basic conservation and management principles, requirements for applying the precautionary approach, obtaining and evaluating scientific advice,[41] the relationship between the regional mechanism and relevant existing bodies, full cooperation by national agencies and industries in implementing recommendations of the mechanism, over-capacity, MCS mechanisms, new entrants, decision-making procedures, institutional arrangements, and dispute settlement.

In formulating this new law, it will be advantageous to take into account the changing seascape in other oceanic regions. For example, a new regional fisheries management organisation is being established in the southeast Atlantic; it is the first such initiative to develop a draft convention to implement the UN Agreement. Existing regional fisheries management organisations have also been seeking to implement the UN Agreement.[42]

5. Conclusions

Changes on a global scale over the past decade ignored sustainability of the resource in favour of development of profits. Achieving "sustainable development" in fisheries has consequently taken on a new approach that is increasingly private-sector driven. A new approach to government management involvement in fisheries operations is also emerging, distancing these activities from direct government control.

The western Central Pacific still supports highly migratory fish stocks in reasonably healthy shape, so the challenge is to adapt the legal framework to the new approach to development and ensure continuing sustainability through strong management authority, and regional and international cooperation.

Subregional, regional, and international arrangements and initiatives are in play that are pioneering a new legal framework—and setting new management standards—bound to play a major role in the future of fisheries in the region. These laws need acceptance and implementation by countries as a priority of national policy. The new generation of laws need to be creative, forward thinking and exemplary for the sustainable development of the resource.

The introduction to this paper described how globalisation of the world's economy is manifested in the fisheries sector. Ambassador Satya N. Nandan, Chairman of MHLC and Secretary General of the International Seabed Authority, emphasised the need for globalisation of fisheries management in a recent statement at the Canadian Summit of the Sea,[43] which appears below. Without such globalisation or powerful regional cooperation, the fisheries sector cannot be reasonably sustained. That is why it is wise for lawyers, governments, industry, and all other stakeholders to pursue the best interests the resource.

> To conclude, let me say that the picture that emerges with respect to fisheries management is that coastal States on their own have not been able to manage the resources in a sustainable manner. Those fishing on the high seas have also failed in their duty to conserve and manage the resources of the high seas. The pressure on fisheries resources is continuing to grow as a result of population growth and in the face of growing demands for food and other uses. As stocks diminish, new commercial species are introduced. There is a limit to such substitution...Statistics show that...there is little scope to increase the total catches from wild fisheries and aquaculture. In retrospect, there ought to have been some form of a body established with effective powers to monitor the state of fisheries around the world

and to deal with those States, whether coastal States or distant water fishing States, which do not adequately address their responsibilities for proper conservation and management...
In the absence of such a global body, the role of regional fisheries conservation and management organizations, of the type envisaged in the Convention and the Agreement, is of critical importance.
Fisheries is part of the global commons. It must be the object of global governance... The sustainable use of fisheries resources, wherever they are found, is a matter of vital concern to all mankind.

Notes:

1. "The State of World Fisheries and Aquaculture, 1996," Food and Agriculture Organization of the United Nations, Introduction.
2. Coastal fisheries resources and reefs are also in need of strong management and sustainable development measures, but this paper will focus on the highly tuna resources common throughout the region.
3. There is further discussion on these points in the text below.
4. Page 47.
5. Page 15. Other factors include a reluctance by many governments to restrict access and take the necessary conservation and management decisions; a lack of financial and technical resources; slow growth in employment and production; management authority that is not being devolved to the lowest practical level.
6. The Oceanic Fisheries Programme at the South Pacific Commission has concluded that the Central and Western Pacific tuna fishery retains considerable capacity to support additional fishing effort in the skipjack and yellowfin fisheries although the capacity of the bigeye fishery to support additional effort is now in question. There are indications that the size and abundance of some stocks in some areas needs further study.
7. This is a general estimate, encompassing the entire Pacific Ocean.
8. These include the Harmonised Minimum Terms and Conditions of Fisheries Access, the Niue Treaty on cooperation in fisheries surveillance and law enforcement, and the Palau and FSM Arrangements for the management of western pacific purse seine fisheries.
9. For example, the Japanese and American fleets, and some government owned fleets in the region.
10. For example, the Russian fleet.
11. For example, the Peoples' Republic of China, France.
12. In Papua New Guinea, Solomon Islands and to a lesser extent, Fiji. Today, a significant locally-based surface fishery for tuna is in the Solomon Islands, with longline fisheries for fresh and chilled tuna slowly expanding throughout Micronesia, Fiji, New Caledonia and Solomon Islands.
13. During 1995.
14. This does not take into account any aid packages offered by fishing countries. It is considered undesirable to link the two since aid can be used as leverage for fishing rights irrespective of fees and enforcement requirements.
15. Federated States of Micronesia and Republic of Marshall Islands.
16. The policy studies were supported by the Asian Development Bank.
17. In 1994, Guam, with virtually no fishery of its own, received revenues of $122 million from purse seiners and $37 million from longliners in the form of onshore expenditure gained from provisioning and servicing vessels. Guam earned nearly three times as much from fleet spending as all the FFA member countries earned from license fees. From ANZDEC Republic of the Marshall Islands National Fisheries Development Plan, February 1997, Asian Development Bank TA No. 2349-RMI.
18. This includes the Rome Consensus on World Fisheries, the Code of Conduct on Responsible Fisheries and the Compliance Agreement, the Kyoto Declaration and more recently the Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks.
19. Approximately 90% of the fish caught in FFA member countries' waters were landed outside the region.
20. Management is carried out by capping the number of vessels allowed to fish in a year. Other features include an observer programme, regional and national reporting requirements and the availability of enforcement proceedings in the US.
21. There is some international agreement on what is a serious offense—e.g. in the UN Agreement.
22. Recent withdrawal of Ting Hong from the Federated States of Micronesia was blamed partly on what they alleged were onerous fines for record keeping.
23. Following studies funded by the Asian Development Bank in the Federated States of Micronesia and Republic of Marshall Islands.
24. This is taking place in the Federated States of Micronesia and Republic of Marshall Islands.
25. In the Federated States of Micronesia, this includes investment laws and the Maritime Code.
26. See especially notes 8 and 18.

27. Self-financing mechanisms would include turning all or part of the fines, penalties, license fees grants, etc over to the management and enforcement authority rather than sending them directly to consolidated revenue. Some formulae for this are being a developed in FSM and Marshall Islands.
28. Governments which have such authorities are the FSM (Micronesian Maritime Authority) and Republic of Marshall Islands (Marshall Islands Marine Resources Authority).
29. This is a conclusion of the ADB studies in Micronesia, and has subsequently been adopted as government policy.
30. they may differ, for example, according to vessel type or whether they are domestic based.
31. Creative approaches can be taken, such as a tax holiday or discount, possibly for a stated period of time in appropriate areas- e.g. fuel, export.
32. e.g., requirements for work permits could be relaxed as appropriate.
33. e.g. entry into the country should be straightforward and visa requirements simplified as appropriate.
34. Legal requirements to establish businesses and corporations should be adaptable to the needs of the fisheries sector.
35. Banking laws should be flexible enough to finance the purchase of vessels and other equipment relevant to the fishing sector—for example, by allowing the bank to have title or other claim to the vessel.
36. Environmental laws should rationally take into account the nature of the risks for these vessels.
37. For example, they are defined in the UN Agreement.
38. Including the Federated States of Micronesia and the Republic of Marshall Islands.
39. And, to a lesser extent, the FAO Compliance Agreement and Code of Conduct.
40. Sustainable management measures will need to be agreed for high seas fishing that are compatible with in-zone measures. This means that while sovereign rights are maintained, an in-zone management standard is indirectly established for the fish stocks. The national legal framework should accommodate the agreed requirements for compatible management measures, ensuring of course that sovereign rights are maintained within 200 miles.
41. Data collection is another central feature of the UN Agreement which, once agreed in the MHLC process, will need to be implemented uniformly in the region both practically and legally. The Agreement obliges States to provide data to regional fisheries bodies in sufficient detail to enable effective stock assessment. The data must be provided in respect of high seas and in-zone fishing. Most important, legal requirements should be regionally agreed and incorporated in national legislation that ensure, as far as possible, timely collection and analysis of the data.
42. For example, the Northwest Atlantic Fisheries Organisation (NAFO).
43. This was held in St. John's Newfoundland, Canada, 1-6 September 1997.

Critical Regulatory and Management Issues in the Pacific Ocean

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The challenges facing those countries working towards the effective management and conservation of the tuna resources of the western and central Pacific are daunting. These resources

- are multispecies in nature (4 principal species, with range of commercially important secondary species);
- represent the largest tuna fisheries in the world, providing 50-60 percent of the world's canned tuna supplies, 30 percent of Japan's sashimi needs, and annual catches of around 1 million metric tons
- support a multigear fishery (3 main gear types)—of course targeting the species at different stages of their life-span;
- are targeted by commercial vessels from a range of nations/entities (4 main countries—Taiwan, Japan, USA and Korea—but with substantial and growing fleets from the Philippines, China, Indonesia, plus some Pacific island countries, and of course the rogue FOCs);
- are of interest to some of the most developed and some of the least developed countries in the world (Japan and US in the first category, Tokelau and Tuvalu in the second—though as from a few months ago telephones have now been introduced in Tokelau);
- in several Pacific island countries, support significant subsistence/artisanal fleets that provide an essential food source for the island peoples; and
- show scant respect for international sovereignty, migrate vast distances through different countries/territories' jurisdictions and the high seas.

Combined, these attributes of the tuna resources lead to a mine field of challenges and issues:

- Classical fisheries interaction problems:
    a) impact of the surface fleet—and especially purse seiners—that is targeting juvenile bigeye and yellowfin on the longline fleet that is targeting these same stocks though at a later stage of their life;
    b) impacts of commercial vessels on the artisanal/subsistence fishermen;
- Interesting marketing issues—could collective action by the countries involved generate sufficient market power to influence tuna prices?
- Fisheries enforcement becomes a challenge given the vast distances involved—FFA countries EEZs alone cover some 20,000 square kilometers of ocean;
- Development issues: The island countries involved in the fishery are, for the most part, passive participants in the fishery, their role at present predominantly limited to collecting access fee payments from allowing vessels the right to fish in their EEZ. The island countries are seeking an increased role in the fishery to generate jobs for their people, to attract increased income into their ports, even in some cases wanting ownership of vessels and other facilities. But many of the efforts by the Pacific island countries to become more active participants in the fishery have not worked, for a variety of reasons. Much work is needed, most, I feel, in-country at the national level. but also regionally, to help countries increase their share of the economic benefits being generated in the fishery.

- Political/legal issues: The many fisheries around the world, even those in a single jurisdiction, that are currently overfished indicate the difficulty that fisheries managers—and politicians—have in conserving marine resources
- Unfortunately, the fact that EEZ boundaries, no matter how heavily the line is drawn on the map, cannot constrain the tunas' movements, such that their management becomes not just a national but an international matter. About 25 independent nations are currently involved in trying to develop a management approach that both conserves the stock and yet is in their respective national interests. Of course, the national goals and objectives of these 25 sovereign states will vary from country to country, and it is inevitable that there will at times be conflict between some of the countries sitting around the management table.
- Again, evidence from the existing fisheries management bodies around the world—such as ICCAT and CCSBT—supports the inherent difficulties that lie ahead.
- These are in addition to the 'mundane, every fishery has them' questions of understanding the biology of the stocks involved, assessing and monitoring their status, establishing appropriate objectives for the fishery, translating these objectives into a management strategy, and then developing appropriate management measures to control catch and/or effort in line with these agreed objectives. And, of course, the perennial problem of obtaining sufficient funds to effectively maintain these management organisations remains.

These factors combine in the western and central Pacific to form what surely is one of the most demanding fisheries management challenges in the world at the present time.

The South Pacific Forum Fisheries Agency

Established by Convention in 1997, the South Pacific Forum Fisheries Agency (FFA) was formed to assist its member countries in effectively managing their fisheries resources. Effective management encompasses both conservation goals and the maximising of economic and social benefits to the member countries.

FFA's membership has since grown to 16 and comprises all the independent sovereign nations of the Pacific, 14 of which are developing island states: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu, and 2 developed states—Australia and New Zealand.

FFA and the South Pacific Commission (SPC) are completely separate entities, though all FFA members are also SPC members, and the two organisations maintain a mutually beneficial and effective dialogue. SPC predominantly looks after fisheries science and is non-political, while FFA is concerned more with developing management arrangements and assisting countries manage the various foreign fleets in the region.

Fisheries Management Issues

The remainder of this paper will provide some initial thoughts regarding the specific fisheries-management issues that Pacific Island countries are currently trying to address. A number of points will be covered:

1. Why do FFA member countries want to regulate the fishery?
2. When do they want such regulations to commence?
3. What do they want these regulations to achieve?
4. What is the preferred scientific arrangement for the region? and
5. How might such regulations actually work?

The paper concludes with an overview of the current status of multilateral discussions.

1. Why should countries want to regulate the fishery?

It is inevitable that unless effective management measures are put in place, the region's tuna fisheries will be overfished. Some people—and some research—would indicate that for bigeye, we are approaching that point right now. While I am not necessarily agreeing with those claims, I am saying that at some point, one or more of the stocks will be overexploited unless effective management arrangements are put in place beforehand.

Why is it inevitable that fishing effort in the region will increase?

Firstly, world demand for fisheries products—and tuna—has been consistently increasing. In the case of canned tuna, while demand in the US is flat, and perhaps even declining, demand in the European Community is increasing somewhere between 5-10 percent/year and the EU is now the largest canned tuna market in the world. Similarly, demand in Southeast Asia and selected South American countries is also growing.

Demand for fresh and frozen seafood is also increasing. Sashimi consumption is growing, not so much in Japan, the main market, but in smaller markets like Korea and the US. Demand for tuna steaks is also increasing. Long-term prospects for tuna demand seem positive.

On the supply side, apart from the western and central Pacific, there is limited scope for growth in the world's other tuna fisheries. The eastern Pacific is considered to have some potential for increased yellowfin catch, though the tuna fisheries of the Atlantic and Indian Oceans are considered to be near or have exceeded full exploitation and thus have limited if any growth prospects.

With demand to continue rising and the Pacific having the greatest potential for sustaining increased catches, more participants to the fishery are expected over the longer term.

These need not be the existing fishing nations. Vessels from the Philippines, for example, are moving eastward: Indonesia and China are believed to have aspirations to increase their distant water fleet.

Without effective management, the fishery will inevitably follow the same path that has happened to fisheries the world over—overexploitation.

It is also worth noting that Pacific Island countries have long recognised that some form of management arrangements was required in the region. For example, the Convention that established the FFA in 1977 makes specific reference to the need to 'develop additional international machinery' to conserve the region's tuna stocks.

2. When should countries implement such regulations?

Present scientific information suggests that skipjack and albacore stocks are capable of sustaining increased catches in the future. Yellowfin stocks also are thought to be in good condition. Status of bigeye is more uncertain—bigeye is the least researched of the four species and there remain many uncertainties regarding its stock structure, biology, and status.

I have heard it said that given the overall healthy shape of the stocks, that management arrangements for the WCP are premature at the present time. 'Little is needed,' these people say, 'until there is scientific evidence to suggest that the stocks are being overexploited. That is the appropriate time to start developing such arrangements.'

This is a very dangerous approach, on two grounds. Firstly, given the lag time associated with obtaining most scientific information, the stock is likely to have been overfished for several years before the analysis indicating that there is problem is completed. This is not a criticism of the scientific process, but simply a comment that the process does require time—in some cases, substantial time. The problem is likely to have existed, and probably worsened, for some time before scientific monitoring is able to detect the problem.

A second reason for acting now, rather than later, is that introducing management measures when there is a problem will inevitably require introducing some reduction in effort/catch. Such cutbacks are never popular and are difficult to implement in what surely would be a fairly politically charged atmosphere. Prolonged delays in agreeing how to implement such cuts will only worsen the situation.

Pacific island countries are committed to developing effective management arrangements for the region's tuna stocks in a timely manner. These same countries were instrumental in convening the first Multilateral High Level Conference on South Pacific Tuna Fisheries (MHLC1), in Honiara in December 1994, which started the process. FFA member countries were again instrumental in convening the second Multilateral High Level Conference on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific (MHLC2) in the Marshall Islands in June of this year.

3. What should these regulations be trying to achieve?

This is where matters start being a little more complex.

The regulations in themselves should promote the objectives of the overall management arrangement. The first issue, then, is to clarify the objectives of the arrangement.

A conservation objective will be central to the aims of any arrangement: it stands to reason that if the arrangement is being established because countries individually cannot conserve the stocks, then the arrangement must seek to achieve such a conservation goal.

In terms of conservation, the text of the United Nations Implementing Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks (UNIA) suggests that a two-tiered approach should be used. UNIA is an international agreement that complements the United Nations Convention on the Law of the Sea. Collectively, these two agreements provide the legal foundation for a management arrangement in the region.

The two-tiered approach suggested by the implementing agreement is

- to ensure the long term conservation and sustainable use of highly migratory fish stocks;

and

- to assess the impacts of fishing on non-target, associated and/or dependent species, and where appropriate, to take action to mitigate negative impacts of fishing on these stocks.

Not all species are to be treated the same: some are to be conserved and managed, others are to be monitored, and action is to be taken, where appropriate. Given that there are around 40 species caught in the tuna fisheries of the region, this differential treatment is also a practical reality, given the limited financial and human management resources available.

Anyway, the point to be made here is that not all species are to be treated the same. This in turn raises the question of which species are to be effectively conserved and managed, and which are 'to be assessed and acted upon, where appropriate.' It is possible that there might even be a third or more tiers—for example, those highly migratory species which are to be conserved and managed, though not just yet, e.g., sharks and possibly billfish.

The question of species was touched upon at the second multilateral conference, and there appeared general agreement that the initial focus should be on bigeye, albacore, skipjack and yellowfin, with a question mark left hanging over billfish.

Having identified the species, the next issue is to determine how the arrangement is to obtain the necessary science on which its management decisions will be based. What mechanism can produce the 'best available science' on these species in question? And the related question—how can the science be made as politically neutral as possible?

Experiences from the Commission for the Conservation for Southern Bluefin Tuna (CCSBT) are a sobering case in point. There are three countries in the commission—Australia, Japan, and New Zealand—and scientists from these three countries meet regularly to discuss and agree on the scientific information to be used in management deliberations.

The good news is that scientists from all three countries have been able to agree that the stock has been severely overfished: the problem is that they are unable to agree on the future stock rebuilding scenarios under various catch levels. A series of difficult scientific meetings and the Commission meetings have been held of late, trying to resolve these differences, though from all accounts little success has been achieved.

That commission concerns only the one species—which has been researched in some detail for an extended period of time—and one fishing gear and has only three members, yet the Scientific Committee still cannot reach consensus. Recalling the multispecies, multigear, multination, and relatively less researched nature of the western Central Pacific stocks, the experiences from CCSBT are sobering news indeed.

4. What is the preferred scientific arrangement for the region?

There has been considerable discussion of the nature of a future scientific advisory body in the region in recent years. At the same time, and no doubt influenced by these discussions, the existing regional scientific bodies have also undergone a transformation.

These discussions started at the MHLC1 in 1994, where it was agreed to convene a subsequent technical-level scientific consultation to further progress in the matter. In addition to considering a range of issues associated with fisheries data, the consultation, which was held at the South Pacific Commission in Noumea in July 1996, was also tasked to consider options under which scientists from all parties involved in the fishery can more fully participate in the stock assessment process and tuna research programmes.

After considerable discussion, the consultation identified a number of important issues:

- That the scientific arrangement should be developed concurrently with a regional fisheries management organisation or arrangement.
- That a scientific secretariat model that involves a significant research, data collection and data management role for the secretariat, along with considerable national scientist involvement, was seen as an appropriate model.

There was, in fact, general agreement that the involvement of scientists from developing states in the scientific structure was seen as highly desirable, in order to build much needed national capacity in stock assessment and fisheries research generally.

These findings were considered, and endorsed, by MHLC2 in Majuro. In addition, MHLC2 generally agreed that

- to the extent possible, existing structures should be utilized; and
- the services of SPC should continue to be utilized and appropriate arrangements might be concluded with SPC, including the possibility of contracting out.

The conference also recognised a need to

- more clearly define the role of the existing bodies and their relationship to the new regional mechanism; and
- address the membership problem, in that a number of Conference participants are not members of SPC and therefore would not be able to participate within the SPC structure in any policy decisions.

10th Meeting of the Standing Committee on Tuna and Billfish (SCTB), Nadi, June 1997

In the week immediately following MHLC2, the Standing Committee on Tuna and Billfish met in Nadi, Fiji. The meeting, attended by a large number of scientists from both coastal and fishing states, decided to change its terms of reference and participation guidelines. Following these changes, the focus of SCTB has shifted from its former goal, that of providing peer review of the scientific work undertaken at SPC, to that of improving the coordination of data collection, research and stock assessment pertaining to the tuna fisheries of the western and central Pacific. Membership of the revised SCTB is open to scientists and others with an interest in the tuna fisheries of the western and central Pacific.

SCTB has also established a Statistics Working Group, and five Species Working Groups, for skipjack, yellowfin, bigeye, albacore, and non-target species, while OFP is to provide administrative and scientific support for SCTB and its various working groups.

There is no explicit link between the MHLC process and SCTB. Whether such a link should be established and whether the revised structure for the SCTB makes it suitable for the role of a future scientific advisory body in the region are issues that need to be considered.

Similarly, more thought is needed to identify alternative structures for a future scientific body and to assess the strengths and weakness of these alternatives, in order to identify that arrangement best suited to produce the best scientific information to those responsible for managing the region's tuna stocks.

Leaving the scientific arrangement aside, the question then becomes that of identifying a preferred level of fishing effort and/or catch.

Precautionary Reference Points

The arrangement will need to include an agreement on an appropriate limit reference point (LRP) for each of the tuna stocks that are to be effectively managed. I suspect that most of you are familiar with the 20% SPR—spawning population rate—that is commonly used in the U.S. Countries involved in a future management arrangement in the WCP will need to go through exactly this same exercise and try to agree on an appropriate point beyond which increased fishing poses an unacceptably high risk of stock depletion (however that is defined).

Countries will need to be made aware of the various approaches that might be used to determine a LRP and to be informed of the implications of these various approaches. In this regard, countries will be relying on the views and advice of their fisheries scientists and the experiences from other MHLC participants. I think that the U.S., with the quality of its fisheries scientists and their experience with the SPR approach, may be able to contribute greatly in this regard.

Once identified and agreed, there is the ongoing problem of monitoring the fishery to assess the current stock status against the chosen limit reference point. Easy to say, perhaps harder to actually do.

Limit Reference Points

There is a second form of reference points, known as target reference points (TRPs), which move beyond the base conservation goal and encompass other possible management objectives, such as economic or social considerations.

In order to consider these TRPs, I need to return back to the matter of objectives and ask that question: Should the arrangement seek any other goals aside from conservation of the stocks?

The UN Implementing Agreement refers to the notion of 'optimum utilisation' of the stocks. Alas—or perhaps fortunately—the agreement does not shed any light on what 'optimum utilisation' actually means.

Arguably, a range of factors—social, economic, and environmental, to name but three—could be included in determining an optimal outcome. However, these factors are very much national-level concerns: what is economically optimal for a fishing state, for example, need not and probably would not generate an optimal return for the coastal state. The point being made here is that it will be very difficult, if not impossible, for 25 sovereign countries to agree on what constitutes the optimal utilisation of the stock.

Consideration might need to be given to defining optimum strictly from a biological perspective, thus limiting discussions at the multilateral level to conservation-focused issues and leaving economic and social factors to each individual state to determine.

The implications of such an approach on a multilaterally agreed target reference point would need to be given some thought. Perhaps they are not needed, or if they are to be developed, perhaps this is best done at the national rather than multilateral level.

5. How might such regulations actually work?

A future multilateral arrangement will need to include agreement on catch limitations (either directly, through quotas, or indirectly, through a limit on fishing effort) if it is to realise its objective of conserving and managing stocks. Having agreed on a common objective, the parties to the multilateral discussions will then need to implement appropriate management strategies if these objectives are to be realised.

A catch or effort limitation that applied only to a relatively small portion of the range of the stock (such as the high seas) would not be sufficient to conserve the species. Similarly, controlled in-zone catches, but poorly regulated high seas fishing, would also jeopardise the long term conservation objective.

Final decisions on the approach to catch and/or effort limitation and where, when, and by whom the fish are caught are likely to be largely determined upon political grounds. The mobility of the resource and large fluctuations in abundance and availability will also have to be taken into account.

A related issue is identifying the geographical area over which these regulations will apply. The arrangement area needs to be broad enough to be able to effectively conserve and manage the stock, yet at the same time needs to recognise countries existing rights to manage their individual EEZs. This in fact is one of the key issues: that of balancing the need for regional conservation and management, yet respecting existing coastal state's rights in their EEZ.

A further issue is to determine how a management arrangement in the western and central Pacific is to relate to existing fisheries management bodies with some interest in the region. Consideration needs to be given to identifying appropriate forms of cooperation between organisations such as the Inter American Tropical Tuna Commission (IATTC), the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), and the interim scientific body established in the northern Pacific.

CURRENT STATUS OF MULTILATERAL DISCUSSIONS

As already noted, the process commenced with the First Multilateral Conference, held in December 1994. From that, three technical consultations were convened, one on science, previously described, in Noumea in July 1996, and two on vessel monitoring systems (VMS), the first in Honolulu in September 1995 and the second in Nadi, Fiji, in November 1996.

These consultations then led into the Second Multilateral Conference, in Majuro in June of this year. The conference was described by the conference chairman, Ambassador Satya N. Nandan (Fiji), as being 'truly a seminal event,' adding that 'history will judge it as one of the most important initiatives that has been taken in this region.'

One of the key outcomes from the conference was the Majuro Declaration, adopted by acclamation by all conference participants. Key aspects of the Majuro Declaration include

- a commitment to establish a mechanism for the conservation and management of highly migratory fish stocks of the region in accordance with the Convention and the Implementing Agreement;
- the decision to cooperate effectively in the conservation and management of highly migratory fish stocks of the region throughout their range;
- acceptance of the use of the precautionary approach;
- a commitment to ensuring that conservation and management measures for highly migratory fish stocks in areas under national jurisdiction and those for the high seas are compatible; and
- the setting of an overall time-frame of three years from June 1997 in which to negotiate and establish the arrangement.

The conference also agreed to establish two intersessional working groups—one on fisheries management, one on monitoring, control and surveillance (MCS)—to meet in December 1997 and March 1998 respectively to discuss these respective issues and to report back to the next session of the conference in mid-1998.

The fisheries management group is to consider many of the issues raised in this paper:

- options for the area and species to be included in the management regime;
- possible fisheries management objectives for fisheries of the highly migratory fish stocks of the western and central Pacific;
- an assessment of the effectiveness and practicalities of different management strategies, including input and output controls (and combinations of both) to meet the objectives for management;
- options for ensuring adequate monitoring, surveillance and compliance to enforce the above management measures (in conjunction with the Technical Consultation on MCS);
- procedures and criteria for evaluating the performance of management measures including the setting of appropriate reference points (including both limit and target reference points);
- procedures to adapt management strategies in reacting to conditions when the reference points are reached or exceeded; and
- issues in relation to methods for the allocation of catch or effort between states and entities.

Similarly, the MCS meeting in March 1998 is to

- examine options for the development and implementation of effective MCS arrangements in the region;
- identify the availability of charts clearly showing by geographical coordinates the maritime boundaries between exclusive economic zones (EEZs) and the high seas and between boundaries of the various EEZs;
- examine mechanisms to ensure proper monitoring and surveillance of fishing vessels within areas under national jurisdiction and on the high seas including, but not limited to
  - vessel marking systems (e.g. the FAO Standard Specifications and Guidelines for Marking and Identification of Fishing Vessels);
  - catch and effort reporting;
  - observer programmes; and
  - surveillance of fishing vessels (vessel monitoring systems (VMS), aerial surveillance, patrol vessels, satellite-based imaging systems, etc.);
- examine the options for a cost-effective standardized VMS system that will enable the monitoring of fishing vessels within the management area;
- examine the options to ensure that participants in the management regime take appropriate responsibility for their fishing vessels operating in the high seas areas;
- consider measures for participants to undertake international cooperation in relation to compliance and enforcement on the high seas.

These working groups have no power and are not decision-making bodies. Instead, they are tasked to identify those areas on which there is general agreement and those areas that require further consideration. Both working groups are to report back to MHLC3 in mid-1998.

The overall timetable is to complete negotiations for the development of a new international fisheries management arrangement for the region by June 2000. That is an ambitious timetable, but given the level of commitment demonstrated by all parties—coastal states and fishing states—it is a timetable that may well be achieved.

How Many Purse Seiners Should Exploit the Western Pacific Tuna Fishery?

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1. The Western Pacific Tuna Fishery

A useful definition of the western Pacific tuna fishery is the area managed by the Forum Fishery Agency (FFA) on behalf of its members and described in Figure 1 as the U.S. Treaty Area. Figure 1 also shows the South Pacific Commission (SPC) Statistical Region which is similar to, but slightly more extensive than, the U.S. Treaty Area.

The western Pacific tuna fishery currently has a gross value of around US$1.6 billion of which purse-seine, longline and pole-and-line fleets account for around 50%, 42%, and 8% respectively. In terms of weight of catch these three gear types account for 79%, 12%, and 8% respectively. The purse-seine fleet expanded rapidly in the period 1980-95, with two important consequences. The total weight of catch from the fishery rose by a factor of 2.4 and the share of purse-seine caught tuna in total catch rose from 13% to 79% (see Table 1). Over the same period the longline catch fell by a third and the pole-and-line catch halved.

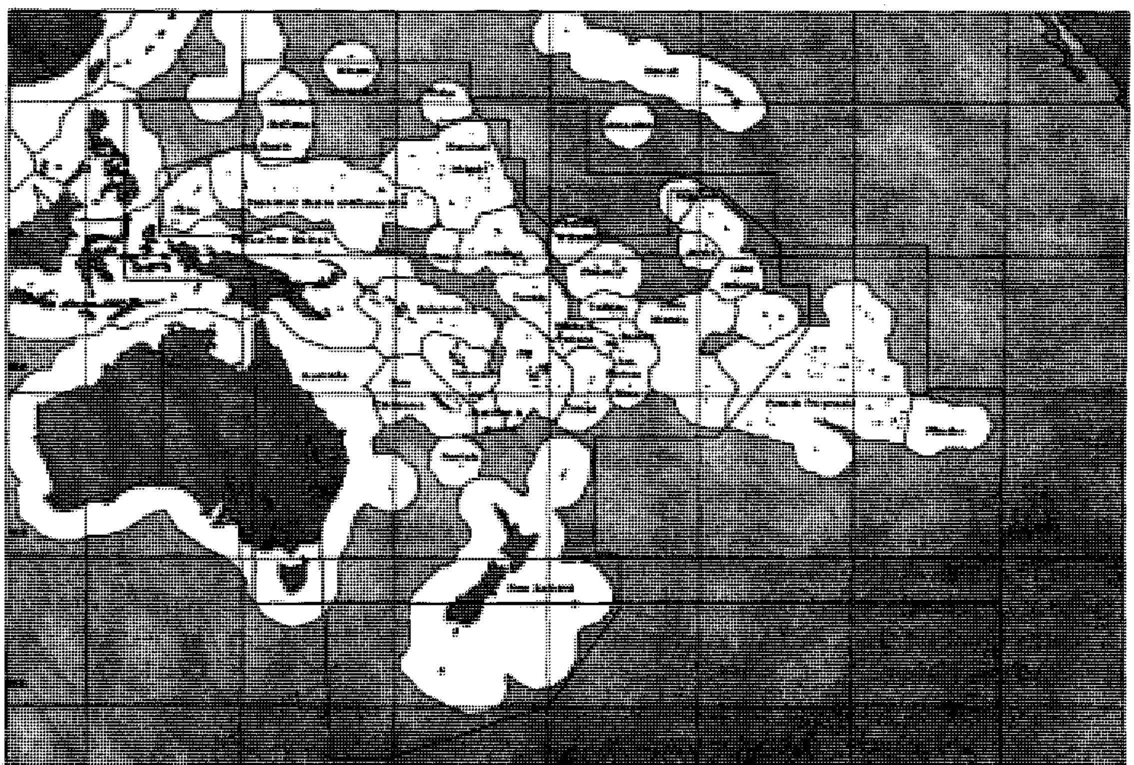

Figure 1. SPC statistical zone.

Table 1. Annual Catches by Major Gear Type in the SPC Statistical Area 1980-95.

Year	Longline		Pole and Line		Purse Seine	
	Tonnes	% of Total	Tonnes	% of Total	Tonnes	% of Total
1980	167,145	42	176,684	44	52,446	13
1981	117,173	28	203,634	48	101,255	24
1982	105,941	24	139,197	32	188,065	43
1983	97,178	16	161,250	26	354,862	58
1984	87,494	14	171,026	28	353,127	57
1985	108,114	19	138,013	25	308,297	55
1986	99,225	16	152,005	24	369,282	59
1987	98,024	15	123,599	19	429,964	66
1988	102,308	14	146,321	20	480,840	65
1989	85,841	11	132,523	17	545,614	69
1990	114,164	13	82,451	9	664,391	76
1991	87,531	8	97,833	9	855,074	81
1992	117,181	11	73,045	7	849,800	81
1993	119,951	13	63,872	7	715,052	79
1994	145,647	14	68,394	7	805,326	79
1995	112,147	12	81,379	8	755,337	79

Source: *SPC Statistical Yearbook*, 1995, Table 78.

Currently about 150 distant water fishing nation (DWFN) purse seiners are licensed to operate in the region of the fishery managed by the FFA: the main DWFN countries are the U.S. (46), Taiwan (43), Japan (32), Korea (29). The FFA member countries of Kiribati, Papua New Guinea, Solomon Islands, and Vanuatu also operate a total of around ten domestic tuna purse seiners.

The tuna fishery is an important resource for the developing nations of the Pacific Islands Region (PIR) whose Exclusive Economic Zones (EEZs) or Fishing Zones constitute a substantial proportion of the fishery. The contribution of the fishery to these developing economies depends upon the net value of the fishery; and the developing countries' share of net value in the form of access fees or rents arising from the application of domestic resources to the fishery.

Given the high gross value of the fishery, it is possible that relatively small proportionate changes in resource allocation within the fishery could produce substantial benefits in net value terms. Depending upon the institutional structure, a significant proportion of these benefits could flow through to the developing countries.

The main focus of this paper is the number of purse seiners and the balance between the three gear types which will maximize the net benefits of the fishery. The discussion recognizes that changes in the catch composition of the western Pacific fishery may affect world market prices for tuna because of the substantial contribution of the region to world catches. The paper draws on research results obtained from ACIAR Project 9405 "A Bioeconomic Analysis of the Western Pacific Purse-Seine Tuna Fishery."

Part 2 of the paper discusses the interactions between the various gear types in terms of competition for the available stocks. A brief discussion of the status of bigeye and yellowfin tuna stocks is also included. Part 3 of the paper discusses the response of tuna prices to significant shifts in catch composition. Part 4 discusses the sharing of the yellowfin tuna stocks between the purse-seine and longline fleets. Part 5 discusses the sharing of skipjack stocks between the purse-seine and pole-and-line fleets in the Solomon Islands Fishing Zone. Part 6 discusses a regional bioeconomic model which can eventually be used to calculate a fleet composition which will maximize the net value of the region's tuna fisheries. Finally, Part 7 draws some conclusions and discusses further work that requires to be done.

2. Stock Interactions among Gear Types in the Western Pacific Tuna Fishery

In the western Pacific tuna fishery four major tuna species are harvested by the three major gear types. Table 2 shows average catches of four species by five gear types in the SPC region over the period 1987-91. Currently the driftnet and troll fisheries account for around one percent of catch by weight and can be ignored. It is evident from the averages reported in Table 2 that there may be two significant interactions among the other gear types through competition for the available stocks. The purse-seine and pole-and-line fisheries are both heavily dependent on the skipjack stock, and the purse-seine and longline fisheries both have a significant dependence on the yellowfin stock.

Table 2. Average Catch of Major Tuna Species by Gear Type in the SPC Statistical Area, 1987-91.

Gear Type	Species (mt)			
	Albacore	Bigeye	Skipjack	Yellowfin
Purse seine	-	-	452,675	145,491
Longline	16,932	36,224	-	35,268
Pole and Line	-	-	117,981	3,847
Driftnet	7,278	-	-	-
Troll	5,955	-	-	-

Source: South Pacific Commission (1992). The averages are based on calendar years for purse-seine, longline, and pole-and-line vessels, and fishing seasons for driftnet and trolling vessels. A proportion of the reported yellowfin catch of purse seiners consists of juvenile bigeye.

Since there is currently no concern about overexploitation of the skipjack stock (SPC, 1997), competition between the purse-seine and pole-and-line fleets is of concern only in particular localities, such as the Solomon Islands Fishing Zone, where both fleets exploit the same portion of the stock. This issue is dicussed in Part 5. From Table 2 it can be seen that around 25% of the purse-seine catch consists of yellowfin, mainly juveniles. However it is estimated that 10-15% of the purse-seine catch reported as yellowfin actually consists of juvenile bigeye tuna. There is currently concern about the status of the bigeye stocks with some evidence (SPC, 1997a) suggesting that catch levels are approaching, or possibly exceeding, MSY. There has been a decline in longline yellowfin CPUE, although tagging data provide no evidence that this is due to the increased size of the purse-seine catches. Also purse-seine yellowfin CPUE shows no evidence of persistent decline. However the allocation of limited bigeye, and to a lesser degree yellowfin, stocks between the purse-seine and longline fleets is potentially a significant issue throughout the region.

3. Effects of Significant Shifts in Catch Composition on Prices

The countries involved in the world tuna industry can be divided into four groups: resource owners, harvesters, processors and consumers. In each of these groups there is a significant degree of concentration in the sense that a few countries or groups of countries account for a substantial percentage of the total throughput. Table 3, which is derived from Campbell (1996), reports some significant concentrations based on statistics for recent years. It can be seen that the waters of the western central Pacific provide around 30% of the world tuna catch. Two-thirds of the world catch is harvested by fleets from four catching regions—Japan, EC, Korea and USA. Tuna for canning is harvested by purse-seine and pole-and-line vessels; four areas—USA, Thailand, EC and Japan—process 73% of the catch. Finally, the main consuming regions of canned tuna are USA, EC, and Japan, which together account for 78% of world consumption. These processing and consumption figures refer to canned tuna only. Japan is overwhelmingly the largest processor and consumer of frozen and chilled fresh tuna.

Table 3. Structure of the World Tuna Industry.

(a) Distribution of World Tuna Harvest by Region and Gear Type (1990)

	Western Central[1] Pacific	Other[2] Pacific	Indian[3] Ocean	Atlantic[4] Ocean
% of Total	30	38	16	15
% of Pole and Line	31	-	25	44
% of Purse Seine	35	42	12	11
% of Longline	38	-	31	31
% of Driftnet and Troll	6	-	76	18

1. FAO Areas 71 and parts of 77 and 81, excluding waters of eastern Indonesia and the Philippines.
2. FAO Areas 61-87, excluding those in 1 above.
3. FAO Areas 51-57.
4. FAO Areas 21-47.

Source: *FAO Catch Statistics*

(b) Distribution of World Tuna Catch by Selected Harvesting Countries or Regions (1990)

	Japan	EC	USA	Korea	Others
% of Total	27	18	10	10	35

Source: *ADB/Infofish Global Industry Update: Tuna 1991*

(c) Distribution of World Catch of Canning Tuna by Selected Processing Countries or Regions (1989)

	Japan	EC	USA	Thailand	Others
% of Total	9	16	28	20	27

Source: *ADB/Infofish Global Industry Update: Tuna 1991*

(d) Distribution of World Consumption of Canned Tuna by Selected Countries or Regions (1990)

	Japan	EC	USA	Others
% of Total	9	32	37	22

Source: *FAO Fishery Statistics*

If the PIR decided to reduce the level of purse seining, a convenient policy measure would be to raise the level of access fees. Access fees are set at a notional 5% of the gross value of the catch, although Swan (1997) has calculated that actual royalties in the region currently amount to 3.5% of landed value. What would be the effect of a rise in the notional access fee to, say, 6%? The world tuna industry described above has concentrations of market power in the resource owning, harvesting, processing, and consuming sectors and a great deal of detailed analysis would be required to make an accurate forecast of the effect of an access fee increase on tuna price and quantity supplied by the PIR. However a countervailing power model would suggest that these various forms of market power would tend to offset one another and that the outcome would be similar to that of a set of competitive markets.

The following simple model can be used to work out the elasticity of demand for PIR canning tuna with respect to the ex-vessel price of raw tuna. Let the world demand for processed tuna be $Q = Q_f + Q_o$, where Q is the annual quantity demanded and Q_f and Q_o are the quantities sourced from the PIR and other regions respectively. Let the price of processed tuna be $P = P_r + P_p$, where P is the retail price per unit, P_r is the cost of raw tuna, and P_p is the cost of processing and distribution per unit. Assume that the processing and distribution mark-up does not change when the price of raw tuna changes. The elasticity of world demand for canning tuna at the retail level is

$$e_{dw} = (dQ/dP)(P/Q) = (dQ_f/dP_r + dQ_o/dP_r)(P_r + P_p)/(Q_f + Q_o).$$

Rearranging the above expression yields the following formula for the elasticity of demand for PIR canning tuna with respect to the price of raw tuna:

$$e_{df} = (dQ_f/dP_r)(P_r/Q_f) = e_{dw}(S_r/S_f) - e_{so}[(1/S_f) - 1],$$

where $S_r = P_r/(P_r + P_r)$, the share of raw tuna in the price of tuna at the retail level, $S_f = Q_f/(Q_f + Q_o)$, the share of PIR tuna in the world canning tuna market, and $e_{so} = (dQ_o/dP_r)(P_r/Q_o)$, the elasticity of supply of raw tuna for canning from the rest of the world.

Campbell (1996) cites the following approximate values for the elasticities and cost and market shares contained in the above formula: the elasticity of world demand for canning tuna at the retail level, $e_{dw} = -0.2$; the share of raw tuna in the cost of tuna at the retail level (based on work by King (1986) and others), $S_r = 0.25$; the share of the PIR in the world supply of canning tuna, $S_f = 0.35$; and the elasticity of supply of raw tuna from the rest of the world, $e_{so} = 0.76$ (based on work by Conrad and Adu-Asamoah, 1986). Putting these values into the above formula the value of e_{df} can be calculated as -1.55. This means that a 1% rise in the price of raw tuna from the PIR would result in a 1.55% decline in the quantity demanded. The decline in the quantity demanded from the region would result from a decline in the world quantity of canned tuna demanded at retail level plus an increase in quantity supplied from other regions.

The above information can be used in two ways. Firstly, it can be used to work out the approximate effect of a rise in the access fees required from distant water vessels fishing for canning tuna. A rise in the access fee from a notional 5% to 6% of the value of the catch, a 20% rise, would raise the price of raw tuna by 1%, since the current level of the access fee is 5% of the price of raw tuna. Using the elasticity of demand for the Pacific Islands region's tuna, a 1% rise in the price of raw tuna results in a 1.55% decline in the quantity demanded from the region. In other words, on the basis of these figures, a 20% increase in the royalty will result in a 1.55% decline in quantity demanded. Since the percentage increase in the royalty exceeds the percentage decline in the size of the catch, the model predicts that royalty receipts will rise.

Secondly, if the PIR contemplated a significant change in the balance between purse seining, pole-and-lining and longlining in the region the effect on world prices of raw tuna would need to be taken into account. A 1% increase (decline) in the supply of raw tuna for canning from the region, as a result of increased (reduced) purse-seine and pole-and-line activity, would result in a 0.645% fall (rise) in the world price.

As noted above, Japan is overwhelmingly the largest consuming country of fresh and chilled tuna products. Consumption over the period 1985-91 averaged around 590 thousand tonnes per annum (Owen and Troedson, 1994). Taya (cited in Williams, 1989) has estimated the elasticity of demand in the retail Japanese tuna markets at -1.107. Using this value as the elasticity of world retail demand for longline-caught tuna, and assuming that the share of raw tuna in the retail cost of fresh, chilled and frozen tuna is 0.5, that the elasticity of supply of longline-caught tuna from regions other than the FFA region is the same as that of tuna for canning (0.76), and that the PIR's share in the world tuna longline catch is approximately 0.4, as calculated in Campbell (1996), the model predicts that a 1% rise in the price of raw longline tuna would cause a 2.524% decline in the quantity demanded. Alternatively a 1% increase (decrease) in the quantity of raw longline-caught tuna supplied by the region would result in a 0.396% decrease (increase) in the price of raw tuna.

In summary, these rough calculations suggest that if the western Pacific tuna fishery reduced its purse-seine catch by 1% the unit value of the raw catch would rise by 0.6%; and if it increased its longline catch by 1% the unit value would fall by 0.4%. Consistent with the results presented in Campbell (1996), the calculations also suggest that an increase in the level of the purse-seine access fee would increase the PIR's access fee revenues.

4. Allocation of Yellowfin Tuna Between the Purse-Seine and Longline Fleets

Conceptually the issue of allocating the yellowfin stock between the two gear types is a simple matter: if the objective is maximizing the combined net value of the two fisheries, yellowfin should be allocated between the fleets so as to equalize the net benefit derived from the marginal tonne of fish taken by each gear type (there is also a second-order condition which is likely to be satisfied and which can be ignored in this discussion).

The concept of marginal net benefit can be illustrated by a simple example taken from Campbell (1994) and based on the following stylized facts: juvenile yellowfin weigh 5 kg, are worth $0.74 per kg if caught by the purse-seine fleet; juveniles become adults after 18 months by which time they weigh 26.4 kg and are worth $2.58 per kg if caught by the longline fleet; natural mortality is 6.65% per month; and 25% of the adult yellowfin stock is caught by the longline fishery. Suppose that 100 juvenile yellowfin are released by the purse-seine fleet thereby contributing to the adult stock and the longline catch 18 months later. Assuming no changes in fishing costs or catches of other species the purse-seine fleet loses $370 and the longline fleet gains $550, a real internal rate of return of around 30% per annum. At a 5% real rate of discount, the marginal net benefit of yellowfin to the longline fishery is $511, as compared with $370 in the purse-seine fishery.

Of course fishing effort and costs in the two fisheries may change with marginal changes in catch. However the direction of the effect of these changes on the marginal net benefit calculations is not obvious. For example, suppose the purse-seine fleet maintains its effort level and substitutes skipjack for the 500 kg of yellowfin it gives up. Since the price differential between skipjack and juvenile yellowfin is around $0.04 per kg the marginal cost of the reduction in yellowfin catch is a mere $20.

Medley (1991) has examined the statistical relationship between purse-seine and longline catches using monthly catch data for the period 1978-89 in the sub-region 10°N–20°S, and 125°E–175°E of the SPC data base. In his analysis each 10° square is treated as a separate unit. Longline catch rates are regressed against lagged purse-seine catches, taking account of stock attrition through natural mortality and migration at an assumed combined rate of 13.3% per month. Medley's results suggest that the elasticity of longline yellowfin CPUE with respect to the weight of the purse-seine catch of yellowfin is around 1.68. In other words, a sustained 1% decline in the purse-seine yellowfin harvest is associated with a sustained 1.68% increase in the longline CPUE. Medley's work is open to the criticism that the period of his analysis may have coincided with a cyclical downturn in yellowfin stocks. This, coupled with the substantial increase in purse-seine catch, may be responsible for the statistical association he finds.

A simulation model currently being developed at SPC (Bertignac, Hampton, Campbell and Hand (forthcoming)), and discussed in Part 6 of the paper, can be used to obtain an alternative estimate of the effect of purse seining on longline yellowfin CPUE. Preliminary results from this model suggest that the elasticity of longline CPUE with respect to purse-seine catches may be around 0.2.

A reduction in the purse-seine yellowfin catch would require some reduction in purse-seine effort. However the size of the reduction depends on whether purse seiners can achieve the catch reduction by changing their fishing behaviour so as to more selectively target skipjack. If they can, then a differential royalty or a quota on yellowfin catch could be used (assuming it could be enforced) to achieve the yellowfin catch reduction. Such a measure would make purse seining marginally less profitable and would result in a small decline in effort of the magnitude required to achieve the policy goal. If purse seiners are unable to target species in this way a larger reduction in purse-seine effort would be required.

Campbell and Nicholl (1995) have analysed purse-seine and longline vessel catch performance in Papua New Guinea's (PNG) EEZ in the period 1980-86 to investigate the costs and benefits of a small reduction in purse-seine yellowfin catch in the EEZ. There is some evidence (see Campbell and Nicholl, 1994) that purse seiners can target juvenile yellowfin tuna by choosing fishing techniques, such as making school rather than log sets, which result in a higher proportion of yellowfin in the catch (although, in contrast to this view, SPC (1997a) reports that significant amounts of juvenile bigeye are being caught on log sets). If this is true a policy such as a differential royalty on purse-seine yellowfin catch could be used to provide an incentive to reduce purse-seine yellowfin catch. In these circumstances the monthly cost per vessel of the reduction in yellowfin catch, excluding the cost of the additional royalty (which is not a real cost but simply a transfer from vessel owners to PNG), is estimated to be only $15.91 per large U.S. style purse seiner. Part of the reason for this negligible cost estimate is the small price differential between purse-seine caught yellowfin and skipjack tuna.

Alternatively, if purse seiners are unable to control the species composition of their catch a reduction in purse-seine effort would be required to reduce juvenile yellowfin catch. This could be accomplished by a rise in the level of the access fee. A rise in the access fee would shift some purse-seine effort to less productive fishing grounds outside the EEZ. The monthly cost of this measure, excluding the cost of the higher access fee which, as noted above, is simply a transfer to PNG, is estimated at $34.65 per vessel. Again this is a negligible amount because the portion of effort redirected to fishing grounds outside the EEZ suffers no great loss in productivity.

Based on these estimates, Campbell and Nicholl calculated that the present value of the monthly net cost to the PNG purse-seine fishery, consisting of the equivalent of around 26 large purse seiners, of a 1% reduction in the purse-seine catch of yellowfin in the EEZ was $169 thousand if the decline could be accomplished by targeting, or $368 thousand if a reduction in purse-seine effort was required.

The effect of an increase in longline yellowfin CPUE is to raise the value of catch per unit effort (VCPUE) at each level of effort. An increase in VCPUE will encourage longliners to contribute more effort to the zone, which will result in higher fishing costs. The net effect of a 1% increase in yellowfin CPUE on the monthly profit of each longline vessel operating in PNG's EEZ is calculated to be an increase of $127.39 under the baseline conditions of the first quarter, 1980. Based on a fleet of 53 longliners operating continuously under baseline conditions, the present value to the longline fleet of the 1% increase in yellowfin CPUE is estimated to be $2.1 million. The present value of any other specified percentage change in longline CPUE can be calculated by multiplying the latter value by the size of the percentage change. Thus, using the longline CPUE elasticity estimate of 1.68% derived from Medley's work, the present value of the monthly net benefit, in terms of increased net value of the longline fishery, can be estimated to be $3.6 million. Using the preliminary elasticity estimate of 0.2 derived from the spatially disaggregated model the present value of the monthly net benefit can be calculated to be $0.43 million.

The marginal benefit/cost ratio of an investment in PNG's longline fishery through a marginal reduction in purse-seine yellowfin catches, the ratio of net marginal benefit to net marginal cost, is in the range 10-21, based on Medley's estimate of the change in longline CPUE. Marginal benefit/cost ratios in excess of unity suggest there is scope for some investment in the yellowfin stock, achieved by reducing purse-seine catches, to increase the aggregate net value of PNG's tuna fisheries. Using the preliminary elasticity estimate of 0.2 derived from the spatially disaggregated population model the marginal benefit/cost ratios are much lower, being in the 1.2-2.5 range. These results for PNG's EEZ tend to understate the potential net benefits of this type of investment for the region as a whole as the monthly 13.3% attrition parameter accounts for both natural mortality and outmigration from

PNG's EEZ. On the other hand, they may tend to overstate the potential benefits to the extent that the baseline conditions are more favourable than normal.

Campbell and Nicholl did not apply the benefit/cost model to bigeye stocks because of lack of accurate information about purse-seine bigeye catches and absence of information about their impact on longline bigeye CPUE. A recent sharp increase (SPC (1997a)) in the recorded purse-seine bigeye catch, partly as a result of using deeper purse-seine nets in conjunction with logs or FADs, raises concerns about the impact on the bigeye catch on the longline fishery. Bigeye constituted 31% of the longline catch in 1996, as compared with 41% for yellowfin (SPC (1997b)). However a study of tuna prices by Hand and Forau (1997) has concluded that on average longline caught bigeye fetch a price 40% higher than that of yellowfin. This suggests that the impact of the purse-seine fishery on the bigeye stock is potentially of significance for the economic performance of the longline fishery. The spatially disaggregated model can be used to calculate an elasticity for longline bigeye CPUE in response to changes in purse-seine bigeye catch and the supply and cost structure estimated for the longline fishery could be used to conduct a benefit/cost analysis of the effect of reducing purse-seine bigeye catches.

5. Sharing Skipjack and Yellowfin Stocks Between the Purse-Seine and Pole-and-Line Fleets in the Solomon Islands Fishing Zone

The purse-seine fleet is excluded from waters within the Solomon Islands main group archipelago (MGA) as illustrated in Figure 2. The pole-and-line fleet can fish within or outside the MGA but is excluded from waters within 3 miles of shore which are reserved for artisanal fishers. Both fleets catch skipjack and juvenile yellowfin tuna, and the activities of each fleet can potentially affect the catch of the other. The pole-and-line fleet consists of domestic, joint venture and Japanese vessels. The purse seiners, which are domestic vessels, tend to fish around Fish Aggregating Devices (FADs) which are moored around the boundary of the MGA.

Using tuna tagging data collected by the SPC, Klieber and Hampton (1994) developed a model for estimating the various population parameters for skipjack and yellowfin tuna in the SIFZ, including the effects of

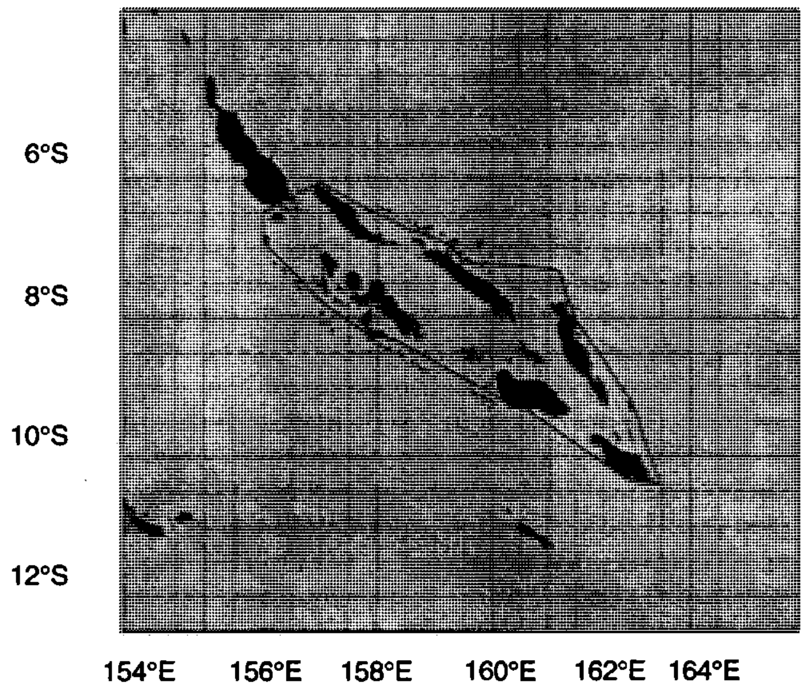

Figure 2. The Solomon Islands main group archipelago (MGA) baseline (heavy line) and the location of FADs (dots). From Hampton et al., 1997.

FADs on tuna movements. The estimation model was then converted to a simulation model which predicts purse-seine and pole-and-line catch as a function of the effort of each fleet and the number of FADs. A study by Hampton, Klieber, Campbell, and Hand (1997) added information on the costs of effort and the prices of purse-seine and pole-and-line caught tuna to the simulation model to generate a bioeconomic model which was used to compare the effects of different levels and composition of effort on profitability.

The model suggests that, assuming tuna prices and unit costs of effort are held constant, the combined value of the SI purse-seine and pole-and-line fisheries would be maximized by increasing the level of purse-seine effort eightfold (see Figure 3). This means increasing the purse-seine fleet from its current level, which is the equivalent of one effective full-time vessel, to eight vessels. As suggested by Figure 3, the results are not sensitive to variations in the level of pole-and-line effort in the range 0-2 times the current level. Expanding purse-seine effort to this extent would raise aggregate annual profit to four times its current level, and, assuming pole-and-line effort was held constant, would reduce pole-and-line profit by around 50%.

The model also suggests that FADs are a very effective investment. FADs have a similar effect to the archipelagic islands in attracting and retaining stocks of fish. The presence of FADs also makes it easier for vessels to locate concentrations of tuna, although the latter effect is not accounted for in the model. When the model is run at the current levels of effort, but without FADs, the annual value of the combined fisheries falls dramatically - by a factor of 10. When the model is run with an additional FAD in each of the twenty half-degree cells comprising the fishing zone the combined profit of the fisheries rises by $1.5 million per annum, which is around 10%. Since an extra 20 FADs would cost around $64,000 per annum to maintain, increasing the number of FADs seems to be a good investment opportunity.

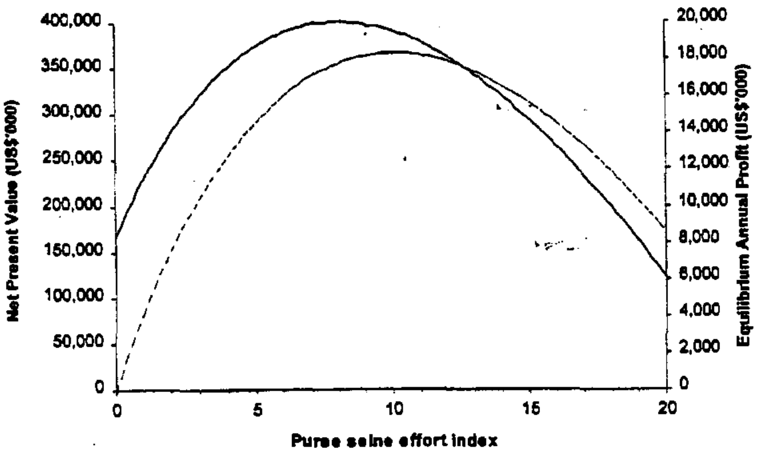

Figure 3. Equilibrium annual profit and net present values in Solomon Islands tuna fishery as functions of purse-seine effort. Solid line is with July 1989-October 1991 average annual pole-and-line effort and the dashed line is with no pole-and-line effort. Source, Hampton et al., 1997.

6. A Multi-Species, Multi-Gear Regional Bioeconomic Model

In Parts 4 and 5 of the paper specific interactions between gear types through availability of stocks were examined. To determine the optimal level of exploitation and the balance among the three major gear types, however, a regional bioeconomic model is required. A complete model would account for the movements of fish in response to environmental variation, the movements of vessels in response to fish movements, fish growth and population age structure, recruitment, gear selectivity, catchability and price and cost structures. Bertignac, Lehodey and Hampton (1997) discuss a regional population simulation model which has some of these characteristics and uses one species (skipjack) and two gear types (purse-seine and pole-and-line) as an example. The model is run with average monthly spatial distributions of effort for the purse-seine and pole-and-line fleets. Since each gear type consists of several fleets, standard fleets were chosen and relative CPUE indices were used. The CPUE was adjusted to reflect the average thermocline depth in each one-degree cell in each month.

The model was used to predict CPUE for each fleet in each cell in each month, given the predicted distribution of the skipjack stock and the observed historical distribution of the two fleets.

The above model is a precursor to the model described in Bertignac, Hampton, Campbell and Hand (forthcoming) which will contain four species - albacore, bigeye, skipjack and yellowfin - and three gear types - longline, pole-and-line and purse-seine. The three gear types are disaggregated into sub-fleets, such as small and large longliners, for example. The population model is age structured, with constant recruitment, and catchability coefficients are subfleet, species, age, area and thermocline depth specific. The model is spatially disaggregated, to the 5 degree square level of resolution, with migration determined by an advection-diffusion model (basically a biased random walk model) modified, for species other than albacore, by systematic environmental effects such as sea surface temperature and tuna forage availability. In this version of the model the historical spatial distribution of effort is maintained, although effort levels can be adjusted on a proportional basis, and average environmental conditions over the period 1988-95 are maintained. A subsequent version of the model will incorporate a fleet dynamics model developed by Campbell and Hand (1997). This will allow the predicted spatial distribution of effort to be calculated at the end of each month on the basis of expected fishing conditions. The model will also incorporate the historical pattern of changes in environmental conditions.

The regional bioeconomic model will be used to assess the effects of changes in fleet size and composition. For example, as discussed in Part 4, preliminary work suggests that the elasticity of longline yellowfin CPUE with respect to purse-seine yellowfin catch may be around 0.2. If after further research using the bioeconomic model it is concluded that the value of the elasticity exceeds 0.17, there may be a case on economic grounds for reducing purse-seine catches because of their effect on the value of the longline fishery.

7. Conclusion

It is well recognized that an unregulated fishing industry tends to be associated with overfishing from an economic, and perhaps a biological, point of view. In the absence of management there are no forces driving the western Pacific tuna purse-seine industry towards an equilibrium which is consistent with maximizing the value of the region's tuna fisheries as a whole. Three considerations which management needs to take into account are the sustainability of purse-seine catches relative to the size of the fish stocks; the impact of the purse-seine fishery on the value of other tuna fisheries in the region; and the effect of the region's catches on world tuna prices. Addressing the first issue, there seems to be no ground for concern about the sustainability of skipjack catches, and while there are emerging concerns about the status of bigeye stocks, the sustainability of the purse-seine fishery does not appear to be an issue at the present time.

Since skipjack is the main target species of purse seiners it might be expected that the most direct impact of the purse-seine fishery on the other gear types would be the impact on the pole-and-line fishery which also exploits the skipjack stocks. However given that the skipjack stocks appear to be relatively lightly exploited from a biological point of view, such an impact, if it exists, is likely to occur at a local level only. A model of the purse-seine and pole-and-line fisheries in the SIFZ, which was developed as a case study, indicated that there was scope for considerable expansion of the purse-seine fishery in that Zone without serious adverse consequences for the pole-and-line fishery.

The issue of whether purse seining has expanded beyond the point at which marginal benefit has fallen to the level of marginal social cost needs further examination. There is some evidence that a reduction in the western Pacific purse-seine yellowfin catch would increase the value of the region's longline fishery by more than the fall in value of the purse-seine fishery, but this issue needs further investigation. In addition, emerging concerns about the status of bigeye stocks need to be addressed in the context of the appropriate balance between purse seining and longlining.

There is some evidence that a reduction in the region's purse-seine catch would increase the price received by vessels for canning tuna, thereby offering the possibility of increasing access fees. It seems that an increase in the level of purse-seine access fees, expressed as a percentage of the price of raw tuna, is very likely to result in an increase

in access fee revenues. A reduction in purse seining would lead to increased longline catches and to a lower ex-vessel price for longline-caught tuna. However the reduction in price would be not be large enough to offset the effect on revenues of the higher catches.

The issue of the appropriate balance among the three gear types poses some important challenges for management. Firstly, more evidence on the effects of marginal changes in fleet sizes on prices, harvests and costs needs to be obtained and assessed. Secondly, if there is a case for change the PINs need to agree on the appropriate management measures. Under the current system of sharing the returns from the region's fisheries among the PINs, any change in fleet composition will involve a change in the distribution of rents as well as a change in their level. This may compound the difficulty of reaching a consensus on policy direction. Thirdly, management needs to be able to enforce whatever measures are decided upon. An implicit assumption in this paper has been that the fishery managers have the means to enforce policy on access and catches and to collect a reasonable share of fishery rents on behalf of the resource owners. A management regime which increases the value of the fisheries also increases the incentive for illegal fishing thereby making enforcement a greater challenge.

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A Bilevel and Bicriterion Programming Model of Hawaii's Multifishery[1]

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Background and Introduction

A linear programming model of Hawaii commercial fisheries was developed by E.R.G. Pacific, Inc. (1986) and was subsequently modified and extended by the National Marine Fisheries Service (Kasaoka, 1989,1990). The initial intent of the model was to analyze the potential impact of limited entry programs on various Hawaii fisheries and on the economic performance of various fishing fleets. The latest version of the model (hereafter referred to as the NMFS LP model) "enables the user to simulate different fishery scenarios that may reflect potential industry trends." For example, a manager might wish to examine the effects that changing fish prices, catch rates, annual yields, or fishing costs might have on fishing strategies and profitability. The model allocated the limited fishing time of each vessel type among fishing areas and target species for each fishing season so as to maximize fleet-wide profits.

The NMFS LP model covered the basic commercial fisheries in the major fishing areas in Hawaii. Five principal fleet categories were considered: small trailered/moored boats, medium-sized moored boats, medium-sized multipurpose boats, large multipurpose boats, and large catcher/processor boats. The species that could be targeted are: bottomfish, pelagic management unit species (billfish, mahimahi, ono), lobster, aku (skipjack tuna) and ahi (albacore, yellowfin, and bigeye tuna).[2] The four fishing areas which were delimited roughly along longitudinal lines are: main Hawaiian islands, lower northwestern Hawaiian islands (NWHI), upper NWHI, and a distant-water area. The fishing year was divided into three seasons: holiday (Dec-Jan), summer (May-Aug), and winter (Feb-Apr and Sept-Nov). It was originally envisioned that the model could depict the switching behavior of fishermen among bottomfish, longline, and lobster in the four fishing areas, and exit from the Hawaii fisheries entirely.

However, the results of baseline run of the model did not realistically depict the actual fisheries situation in Hawaii. In particular, this baseline solution shows that aku (skipjack tuna) is never caught in any season from any area.[3] As Kasaoka (1990) puts it "it is important to reiterate that these (the baseline) results are hypothetical." The developer of the original model (E.R.G. Pacific, Inc., 1986) provided the following explanations of the unrealistic solution: (1) Relationships in the model may not be linear; (2) Vessels within each fleet group may not be homogeneous with respect to their costs, catch rates, and fishing capacities; and (3) Incidental catches are not modeled. More importantly, as stated by Kasaoka (1990), "the linear program software employs the simplex methodology which does not allocate fishing effort evenly across the feasible range of time and space, but tends to lump it at the smallest possible number of profitable times and spaces (the corner points or vertices of this range)." In other words, the analytical technique "allocates" the limited resources (time and space) rather than "reproduces" the behavior of the fishermen. Another important problem was that detailed verification of the empirical parameters of the model (e.g., catch rates, prices, costs, etc.) was precluded by budget limitations.

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[1] An earlier version of this paper was presented at the Workshop on Ocean-Scale Management of Pelagic Fisheries: Economic and Regulatory Issues, East-West Center, Honolulu, November 12-13, 1997. Senior authorship is not assigned.

[2] See Table 4 for corresponding common names of species.

[3] Interestingly, this model was developed as the aku boat (pole-and-line) fishery was in rapid decline.

Miklius and Leung (1990), in an evaluation of the NMFS LP model, concluded that the omission of the micro level decision-making by the fishermen contributed to the unrealistic solutions of the NMFS LP model. They made the following observations: As it stands, the NMFS LP model is a sector model with the overall objective of maximizing *fleet-wide* (as opposed to individual fisherman) profits. However, fishery decisions generally involve choices on both the macro and micro levels, and fishery management in the U.S. seldom conforms to the NMFS LP objective (which is simply an idealized economic version of regulatory efficiency). At the macro level, fishery policy makers are trying to develop management policies that allocate the limited natural resource (fish) subject to existing capital configurations. This is done with limited understanding on how fishermen will react to each possible allocation. On the other hand, at the micro level fishermen have their own decision problem: how best to respond to possible policy, given their own objectives and limitations of action. Fishermen differ widely in their resources, wealth endowments, and economic opportunities. From an analytical point of view, this accentuates the problem of predicting fishermen's reactions to fishery management decisions. In other words, the macro level problem is generally normative or prescriptive while the micro level problem is positive or descriptive. The micro level problem is almost always the more difficult from an analytical point of view. It is also most important for the following reason: until fishermen's behavior (responses) are properly modeled, the consequences of policy actions cannot be specified for the policy decision model.

The NMFS LP formulation did not incorporate the micro level decision of the fishermen. This would be appropriate only if the policy makers could directly control the fishermen's production decisions, where the problem collapses to the case of pure centralized planning. Obviously the centralized planning formulation is not very useful in Hawaii. Hence the overall policy problem can better be described as a two-level decision problem. In other words, the fishermen's decision (optimization) model should be nested under the overall policy decision (optimization) model. This type of model is not generally solvable directly, but indirect methods have been developed to provide an approximate solution to the two-level problem (Hazell and Norton, 1986; Benson, 1989; Candler et al., 1981; Gelman and Mandel, 1990).

In addition, the typical fishery policy problem is characterized by more than one objective or goal that the policy makers wish to optimize. Maximizing fleet-wide profits is one of many goals of policy makers. The Magnuson Fishery Conservation and Management Act (MFCMA) of 1976, although not explicitly clear in stating management objectives, does imply there should a multiplicity of management goals. It states "economic efficiency should be regarded as a *subset of a larger framework* for fishery management choices involving other decisions about the *distribution of costs and benefits*, provision of *employment opportunities*, changes in the rate and composition of *regional economic development, environmental effects*, etc. (emphasis added)." It goes on by stating that "both advantages and disadvantages of 'efficiency' will have to be carefully weighted in the context of objectives for the particular fishery involved." Christy (1977), in an attempt to interpret the MFCMA, identifies the following possible management goals: protect employment opportunities for the fisherman, maximize access to low cost materials for fish processors, and promote recreational fishing.

In Hawaii, the Western Pacific Regional Fishery Management Council (WPRFMC, 1991) has identified the following management objectives in their Pelagic Fishery Management Plan: manage species for optimum yield, promote recreational fishing experience, and diminish gear conflicts, among others (Ianelli, 1992).

Drynan and Sandiford (1985) categorize fishery management goals into three major groups: economic efficiency, economic distribution, and biological. It is obvious that in order for any models to be useful for policy analysis, a multiple objective approach has to be undertaken. This conclusion is supported by Sylvia (1992) who argues that multiobjective approaches in fisheries and aquaculture provide a valuable tool for helping decision-makers understand the policy problem and guide the policy debate.

In summary, the typical fishery policy problem is characterized by (1) more than one objective or goal that the decision makers wish to optimize and (2) decision making at fishermen and policy levels, with policy-makers having incomplete control over all variables. Multiobjective programming models have been developed to handle the former feature while multilevel programming techniques are suitable to analyze the latter feature. With this in mind, this paper presents a two-level and two-objective mathematical programming model developed for Hawaii's multifishery.

Overview of Hawaii's Multifishery

Pelagic species dominate Hawaii's commercial fisheries, although bottomfish and lobster have also been important. These fisheries are all multispecies in nature. Both the pelagic fishery and the bottomfish fishery land more than ten species each to Hawaii's market. Landings of important pelagic species in Hawaii include four tuna species (yellowfin, bigeye, albacore, and skipjack), three billfish species (blue marlin, striped marlin, and swordfish) and several miscellaneous pelagic species (mahimahi, wahoo, and moonfish). Small amounts of spearfish and black marlin are also landed by the Hawaii pelagic fishery. Important bottomfish landings include the deep-sea snappers locally known as onaga, ehu, opakapaka, and uku as well as a range of groupers and jacks. Table 1 lists the quantity and value of important pelagic species landed in Hawaii's commercial fisheries in 1993.

Table 1. 1993 Commercial fish landed in Hawaii.

Species	Pounds Landed (1,000 lb)	Revenue ($1,000)
Pelagic[a]	*32,015*	*64,853*
Albacore	1,128	1,345
Bigeye	4,758	16,794
Skipjack	2,473	2,889
Yellowfin	3,892	8,487
Blue Marlin	1,441	1,183
Striped Marlin	1,193	1,231
Swordfish	13,126	26,676
Mahimahi	830	1,504
Ono	473	989
Sharks	1,748	564
Other Pelagic	953	3,191
Bottomfish[b]	*862*	*2,749*
All Others[c]	*1,426*	*2,527*
Total	*34,303*	*70,128*

[a] NMFS estimates updated in April 15, 1997.
[b] NMFS estimates updated in June 3, 1997.
[c] 1993 HDAR catch reports.

In 1993, the pelagic fishery accounted for over 93 percent of the commercial catch for all species that totaled 32 million pounds with an ex-vessel value of $65 million.[4] Bottomfish and others combined consisted of about 7% of the total catch and just over 9% of the total catch value. In comparison, the commercial catch was 9-11 million pounds annually for the early and mid-80s before the entry of modern longliners associated with the development of local and export markets for fresh tuna, and new swordfish fishing methods. While the current catch represents a 250% increase, the corresponding catch value, unadjusted for inflation, has grown from $10-$11 million to the neighborhood of $60 million today. No valid recreational catch information is available (Pooley, 1993).

Pelagic species are targeted by commercial, recreational, and part-time commercial (expense boat) vessels (Hamilton et al., 1996; Hamilton and Huffman, 1997). Large (35-40 feet and longer in length) commercial vessels include pole-and-line boats targeting skipjack tuna and

[4] 1993 was chosen for this analysis because it was the baseline year for the JIMAR longline cost-earnings study (Hamilton et al., 1996)

longliners targeting bigeye tuna and swordfish. The smaller commercial vessels as well as recreational and expense boats include handliners and trollers mostly in the 12-25 ft range, many of which are trailered boats. These typically operate well within 20-30 miles from shore. However, some larger handline and trolling vessels operate further offshore. Charter boats up to about 60 ft in length also operate out of several ports and usually sell their catch. Boggs and Ito (1993) succinctly describe the longline, troll, and handline fleets over the history of their existence as well as trends in fishery landings.

Seventy-three percent of commercial landings in 1993, or 24.98 million pounds, were caught by longline vessels. Although most of this catch is swordfish and bigeye tuna, longliners also capture a significant amount of other pelagic species. Conflicts between longliners and the troll and handline fisheries, impacts on endangered species, and the possibility of localized overfishing were the basis for regulations for the domestic longline fishery in 1990 (Pooley, 1990; Boggs and Ito, 1993) and subsequent regulations for longliners under the Pelagic Fishery Management Plan (WPRFMC, 1994).

Improvements over NMFS LP Model

In order to better reflect the current situation of Hawaii's multifishery, the NMFS LP model has been extended to include nine fleets, ten targeted species or species groups, five fishing areas, and four fishing seasons. They are detailed as follows:

Fleets

The nine fleets include both recreational and commercial fleets, the distinction being the extent to which income is derived from fishing activities. Figure 1 shows the characteristics of the nine fleets. The recreational fleets consist of two groups of small-boat fishers: 'pure' recreational boats (fleet 1) and expense boats (fleet 3). Expense boats are those where the fishers sell part of their catch to cover their operating expenses (but not labor). Unfortunately, it is difficult to distinguish between commercial small-boat fishers and expense boat fishers from the available time-series data. For the purposes of this study, small-boat fishers reporting up to $5,000 in annual gross revenue are classified as expense boat fishers.

The seven commercial fleets are: charter boats (fleet 2), commercial handliners (fleet 4), commercial trollers (fleet 5), aku boats (fleet 9), and 3 multipurpose longline boats of different vessel sizes (fleets 6, 7, and 8). Charter boats provide recreational fishing experiences for patrons at a fee and typically sell their catch and thus are classified as commer-

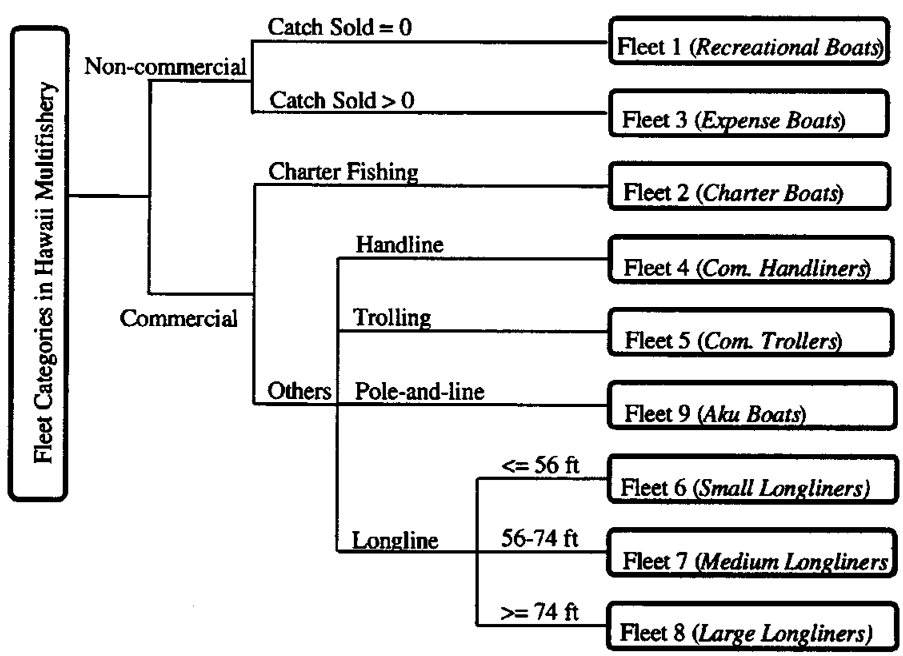


Figure 1. Fleet classification of the Hawaii multifishery.

cial. The commercial handline fleet consists of small vessels which use handline gear and are capable of targeting both pelagic and bottomfish species. The commercial trollers are also small vessels employing trolling gear to target pelagic species. Aku boats use the pole-and-line method and target skipjack tuna (or aku in Hawaiian). The longline multipurpose fleets are classified as small (fleet 6), medium (fleet 7), and large (fleet 8) as in Hamilton et al. (1996). These vessels are multipurpose because they are capable of adding other fishing gears without substantially modifying their vessels. Thus they are capable of switching from one fishery to another in different seasons. As a result, vessels identified as longline can also undertake lobster trapping and bottom handlining in the Northwest Hawaiian Islands (NWHI). Each fleet is assumed to be homogenous with respect to its fishing behavior and fishing technology.

Fishing Areas

To account for the spatial variations of abundance of fish resources in Hawaii, five fishing areas are designated based on the distance offshore in nautical miles (nmi) from the Main Hawaiian Islands (MHI) [Table 2]. Areas 1, 2, and 3 which are within 200 nmi, originate from the MHI, while areas 4 and 5 are beyond 200 nmi originating from the island of Oahu. The reason for choosing the different origins is that small boats fishing within the 200 nmi tend to scatter around all the MHI, while most of the vessels fishing beyond 200 nmi port in the harbors of Oahu.

Table 2. Area designations: distance from origin and origin.

Area Notation (*k*)	Distance from Origin (nmi)	Origin
1	20	Shoreline (Main Hawaiian Islands)
2	21-75	Shoreline (Main Hawaiian Islands)
3	76-200	Shoreline (Main Hawaiian Islands)
4	200-900	Honolulu
5	900-2000	Honolulu

Fishing Seasons

Four seasons are used in the model to account for the seasonal variations of abundance of fish resources in Hawaii. Table 3 shows the delineation of the four seasons along with the major species caught. Pelagic species with landing of over 1 million pounds during a season in 1993 are listed in Table 3. Bottomfish and lobster catches do not vary as much as the pelagic species.

Table 3. Season specifications and the main seasonal catch.

Season Notation (*l*)	Period	Length (days)	Main Species Landed
1	Nov-Jan	90	Bigeye, bottomfish
2	Feb-May	120	Swordfish, bigeye, yellowfin
3	Jun-Aug	90	Swordfish, yellowfin, bigeye, skipjack
4	Sept-Oct	60	Skipjack, mahimahi

Target Species or Species Groups

The current model assumes that each fleet will choose to target a particular species or species group for each fishing trip (in a season and a chosen fishing area) so as to maximize profit for the commercial fleets and to maximize recreational experience (measured by the number of recreational trips) for the recreational fleets. It is also assumed that the target and area do not change during a fishing trip.

Thus the type of fishing trip is synonymous with the type of target in this model. The model includes all the species, both targeted and bycatch, caught and landed in Hawaii. Accounting for bycatch represents a significant improvement over the NMFS LP model since Hawaii's multifishery, especially the pelagic fishery, is technologically interdependent meaning that targeting one species often leads to the harvest of other species whether intentionally or not. In order to keep the model size manageable, only the nine most important pelagic species are individually represented in the model. The rest are classified into five species groups according to their similarities in fishing methods except for shark which is separated out because even as a bycatch it constitutes a large percentage of the longliners' catch.[5]

Altogether there are 14 species or species groups used in the current model as shown in Table 4, nine of which are currently targeted by the fishers in Hawaii. In order to account for fishers targeting more than one species in a fishing trip in the pelagic fishery, a 'mixed target' category is also created. Thus there are ten target species or species groups in the current model.

Table 4. Species or species groups included in the model.

Species Notation (s,j)*	Common Name	Species Family	Scientific Name	Hawaiian or Local Name	Target Species?
1	Yellowfin	Pelagic	*Thunnus albacore*	Ahi	Yes
2	Bigeye	Pelagic	*Thunnus obesus*	Ahi, Ahi po'o nui	Yes
3	Albacore	Pelagic	*Thunnus alalunga*	Ahi tombo	
4	Skipjack	Pelagic	*Katsuwonus pelamis*	Aku	Yes
5	Swordfish	Pelagic	*Xiphias gladius*	A'u ku, Broadbill	Yes
6	Blue Marlin	Pelagic	*Makaira mazara*	A'u	Yes
7	Striped Marlin	Pelagic	*Tetrapturus audax*	Nairagi, A'u	
8	Dolphinfish	Pelagic	*Coryphaena hippurus*	Mahimahi	Yes
9	Wahoo	Pelagic	*Acanthocybium solandri*	Ono	Yes
10	Sharks	Pelagic			
11	Other pelagic	Pelagic			
12	Bottomfish	Bottomfish			Yes
13	Lobster	Lobster			Yes
14	All others				

* Notation s for specific species or species groups and j for target species or species groups.

[5] Until recently, shark had limited or no economic value in Hawaii. However, in the last few years, an export market has been developed for shark fins.

Figure 2 shows the current possible spatial distribution and targeting species or species group for each of the nine fleets. It should be noted that under the longline area closure regulation established by the Council in 1992, longliners (fleets 6, 7, and 8) are prohibited from fishing within 75 nmi (areas 1 and 2).[6]

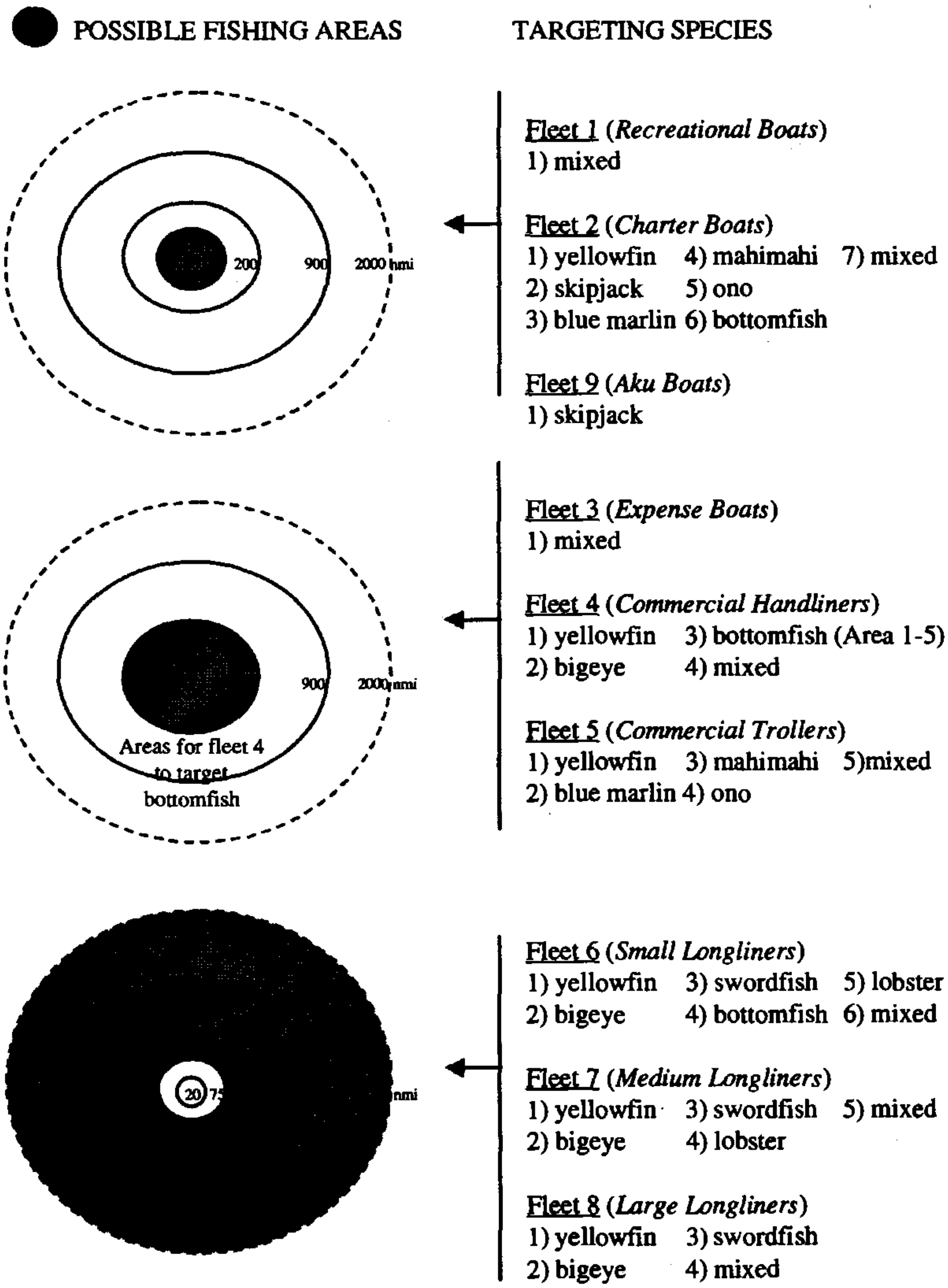


Figure 2. Current possible fishing areas and target species of the fleets.

In addition to the increase in the dimensions of the NMFS LP model and the incorporation of by-catch as described above, the current model also improves upon the previous model in the following aspects:

1. The model allows for the inclusion of other fishery management objectives in addition to maximizing fleet-wide profits. Currently only maximizing recreational experiences measured in terms of number of recreational trips is included in the model. Other management objectives such as minimizing gear conflicts and maintaining the livelihoods of traditional fishing communities are under construction.

2. Several micro-level entry conditions at the fisher's level are incorporated in the current model: a trip entry condition, crew entry condition and owner entry condition. The trip entry condition ensures that commercial fishers will at least cover the variable expenses of the trip, the 'expense' fishers will cover at least 30% of their trip expenses, and the recreational fishers will catch a specified amount of desirable species before a trip will be taken. The crew and owner conditions are specified only for the commercial fleets to ensure that annual crew income is sufficient to attract crew members to engage in the fishery and the owners' return is adequate to cover their investment in the long-run. While there may be other goals that the fishers may want to achieve, in order to keep the model manageable and solvable, we simply assume that commercial fishers aspire to maximizing their profits while recreational fishers want to maximize their recreational fishing experiences.

3. Many studies have suggested that intensive local fishing pressure can reduce CPUE in a local area without affecting availability of the stock as a whole (Curran et al., 1996). Without any empirical estimation of the relationship between CPUE and catch nor an estimate of local stock abundance, we postulate that CPUE will drop if the total catch exceeds the current catch, following a nonlinear relation.

4. The NMFS LP model charges vessel fixed cost by season and thus is unrealistic since the fishers have to bear the annual fixed costs for the active seasons as well as the inactive ones. The current model fixes this defect by charging annual fixed cost as long as the vessel is active in any one season.

The above improvements are detailed further in the presentation of the mathematical model below.

A Two-Level Two-Objective Mathematical Programming Model

The current model retains the general spirit of the NMFS LP model as a fleet dynamics model that assists fishery managers to identify the optimal fleet mix spatially (by area) and temporally (by season) given the estimated amount of fishery resources. The current formulation (Figure 3) allows fishery managers to consider the importance of other management objectives such as recreational fishing in addition to the profit-seeking commercial fishing activities. It also considers the behavior of the fishers as well as the fishery managers. Thus the resulting formulation is a two-level multiobjective programming model. Figure 3 illustrates the structure of the model and related inputs and outputs. The current model

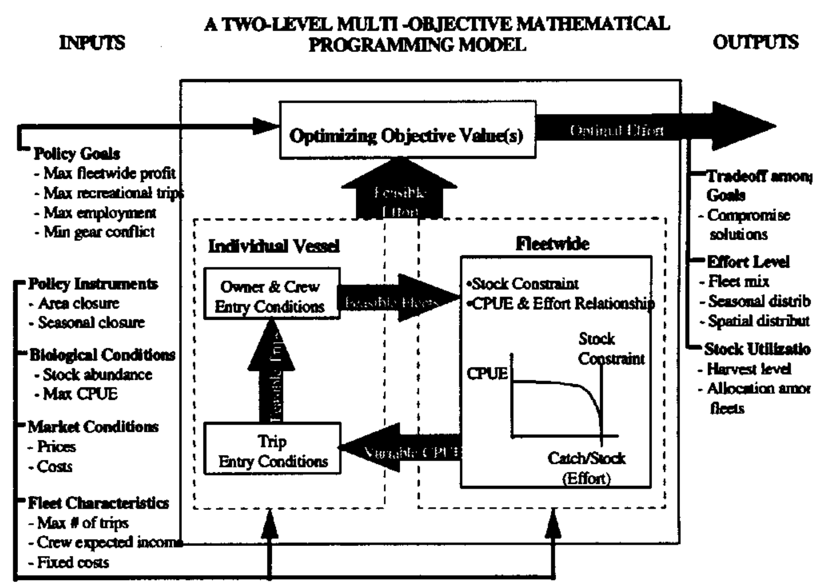


Figure 3. Structure of the two-level multi-objective mathematical programming model.

considers only two objectives although the framework allows for inclusion of other objectives. Ideally, the two-level problem should be solved with the optimization of the fisher's level nested in the optimization of the fishery manager's level. However, given that there is no practical solution algorithm particularly for the nonlinear nature of the current formulation, the optimization at the fisher's level is approximated by a set of entry conditions. The mathematical formulation of the current bilevel bicriterion nonlinear programming model is presented below. Definitions of model variables and parameters appear in Table 5.

Objective functions:

$$\max \sum_i \sum_j \sum_k \sum_l N_{ijkl} E_{ijkl} - \sum_i \sum_j \sum_k \sum_l \omega_i t_{ijkl} E_{ijkl} - \sum_i fc_i V_i \quad \text{for } i = 2, 4 \text{ to } 9$$

[maximize fleet-wide profits] (1a)

$$\max \sum_i \sum_j \sum_k \sum_l E_{ijkl} \quad \text{for } i = 1 \text{ and } 3$$

[maximize recreational trips] (1b)

Subject to:

Stock constraint:

$$\sum_i \sum_j d_{ijkl} R_{ijkls} E_{ijkl} \le s_{kls} \quad \forall\, k,l,s \tag{2}$$

Trips and vessels relations:

Total trips for fleet: $E_{ijkl} - \varepsilon_{ijkl} V_{ijkl} \le 0 \quad \forall\, i,j,k,l$ (3a)

Seasonal fleet size: $V_{il} - \sum_j \sum_k V_{ijkl} = 0 \quad \forall\, i,l$ (3b)

Annual fleet size: $V_i - V_{il} \ge 0 \quad \forall i,l$ (3c)

Trip entry condition:

Recreational fleet: $(A_{kls} - 0.9)\, E_{ijkl} \ge 0$ for $i = 1$ and $\forall\, j,k,l,s$ (4a)

'Expense' fleet:: $\left(\sum_s 0.51 (p_{ils} d_{ijkl} R_{ijkls}) - 0.30\, c_{ijkl} \right) E_{ijkl} \ge 0$ for $i = 3$ and $\forall\, j,k,l$ (4b)

Commercial fleets: $N_{ijkl}\, E_{ijkl} \ge 0$ for $i = 2, 4$ to 9 and $\forall\, j,k,l$ (4c)

Crew entry condition (commercial fleets only):

$$\left(\sum_j \sum_k \sum_l \alpha_i N_{ijkl} E_{ijkl} - \sum_j \sum_k \sum_l \omega_i t_{ijkl} E_{ijkl} \right) V_i \ge 0 \quad \text{for } i = 2, 4 \text{ to } 9 \tag{5}$$

Owner entry condition (commercial fleets only):

$$\left(\sum_j \sum_k \sum_l (1 - \alpha_i) N_{ijkl} E_{ijkl} - fc_i V_i \right) V_i \ge 0 \quad \text{for } i = 2, 4 \text{ to } 9 \tag{6}$$

CPUE and effort relations:

$$A_{kls} = 1 - \left(\frac{Q_{kls}}{s_{kls}}\right)^{10} = 1 - \left(\frac{\sum_i \sum_j d_{ijkl} R_{ijkls} E_{ijkl}}{s_{kls}}\right)^{10} \qquad \forall\ k,l,s \tag{7a}$$

$$R_{ijkls} = A_{kls}\ \overline{R}_{ijkls} \qquad \forall\ i,j,k,l,s \tag{7b}$$

Table 5. List of variables and parameters used in the model

Variable Indices

i = fleets (9)
j = target species (10)
k= area (5)
l = season (4)
s = species (14)

Variables

A_{kls} - catch rate coefficient for species s in area k during season l; $0\ \varepsilon\ A_{kls}\ \varepsilon\ 1$, depending on the ratio of total catch Q_{ksl} to stock s_{kls}.
E_{ijkl} - number of trips taken by fleet i targeting species j in area k during season l.
N_{ijkl} - net revenue after trip variable expenses for trip taken by fleet i targeting species j in area k during season l; $N_{ijkl} = \sum_s \left(p_{ils} d_{ijkl} R_{ijkls}\right) - c_{ijkl}$
Q_{kls} - total catch of species s in area k during season l; $Q_{kls} = \sum_i \sum_j d_{ijkl} R_{ijkls} E_{ijkl}$.
R_{ijkls} - CPUE (variable catch per fishing day) of species s for fleet i targeting species j in area k during season l.
V_{ijkl} - number of vessels in fleet i targeting species j in area k during season l.
V_{il} - size of fleet i operating during season l.

V_i - annual size of fleet i.

Parameters

c_{ijkl} - variable costs for trip taken by fleet i targeting species j in area k during season l.
d_{ijkl} - number of fishing days for trip taken by fleet i targeting species j in area k during season l.
t_{ijkl} - days at sea for trip E_{ijkl}; $t_{ijkl} = d_{ijkl} + d_{ik}'$
fc_i - annual fixed costs per vessel of fleet i.
p_{ils} - price for species s caught by fleet i during season l.
 - the maximum catch per fishing day (CPUE) of species s for fleet i targeting species j in area k during season l.
s_{kls} - total available stock of species s in area k during season l.
α_i - crew share of fleet i; $(1-\alpha_i)$ (owner share of fleet i.
ε_{ijkl} - maximum number of trips that vessels in fleet i can take to target species j in area k during season l.
ω_i - expected crew income per day at sea of fleet i

Equations 1a and 1b represent the objectives of maximizing fleet-wide profits and maximizing recreational experiences, respectively. Each of these two objectives can be optimized separately as in single-objective programming models or alternatively, their tradeoff can be estimated using a bicriterion method or they can be optimized simultaneously using goal programming. Additional objectives can also be incorporated and solved using available multiobjective programming techniques. Fleet-wide profit is defined here as the total annual fleet net revenue after trip variable expenses, crew shares and fixed charges. Crews in Hawaii usually obtain their shares after the fishing trip and they would not get paid if trip revenue does not cover trip expenses (Hamilton et al., 1996). Thus, fleet-wide profit represents precisely the economic rents of the entire fishery if all their inputs are valued at their shadow costs and their outputs are valued at their margins. The current formulation assumes that individual fishers are price-takers and prices of outputs are exogenous. The objective of maximizing recreational experiences is measured in terms of number of recreational trips taken by fleets 1 and 3.

Net trip revenue (N_{ijkl}) is defined as the returns after trip variable expenses and is a function of total catch of a trip, fish price, and trip costs. Total catch of a trip depends on catch per fishing day (R_{ijkls}) and the number of fishing days (d_{ijkl}). Bartram et al. (1996) reported that fresh fish prices in Hawaii are correlated with fish species, fish size, fish harvesting method, and fish quality grade. Since vessels in the same fleet using the same gear tend to catch fish of similar size and quality grade, fish price (p_{ils}) in this model is assumed to vary by fleet, in addition to season which accounts for the seasonal variations in fish supply and demand, and species.

Trip variable cost (c_{ijkl}) is the sum of fishing costs, traveling costs, and turn around (the time to unload catch and get supplies for another fishing trip) costs and is assumed to vary by fleet, target, area, and season. The three components of c_{ijk} can be expressed as follows:

$$c_{ijkl} = c_i^t d_{ik}^t + c_{ij}^f d_{ijkl}^f + c_i^r d_{ij}^r$$

where

c_i^t: costs per traveling day, assumed to vary by fleet (i), includes fuel, oil, and food for crew.

c_{ij}^f: costs per fishing day, assumed to vary by fleet (i) and target (j), includes fuel, oil, food for crew and bait, ice, supplies, expendable gear.

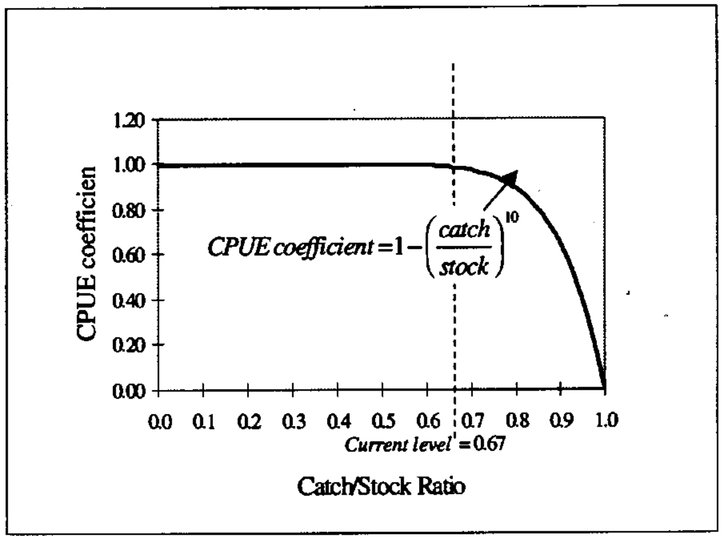
c_i^r: costs per turn around day, assumed to vary by fleet (i), refers mainly to mooring fee.

d_{ik}^t: number of traveling days in a trip, assumed to vary by fleet (i) and area (j) as different fleets may travel at different speeds to different areas.

d_{ik}^r: necessary turn around days between trips, assumed to vary by fleet (i) and target (j), refers to the time spent to unload fish, replenish for the next trip, and rest or break for the fishers. For commercial fishers, d_{ik}^r depends on trip length. The longer the trip length, the longer the time is needed for fishers to unload fish, refill goods and supplies, and rest. For recreational fishers who generally fish on weekends, the necessary turn around days is assumed to be the work week.

d_{ijkl}^f: number of fishing days in a trip, assumed to vary by fleet (i), target (j), area (k), and season (l). Since the number of traveling days is relatively fixed, trip length primarily depends on the number of fishing days. The number of fishing days is generally affected by the shelf life of fish targeted, vessel capacity, and type of fishers. In Hawaii, fishers who target tuna for the 'sashimi' (raw fish) market take fewer fishing days than the fishers who target swordfish, which usually are processed and sold in frozen form. Recreational fishers usually take shorter trips than commercial fishers, as indicated by Hamm and Lum (1992) that small boat fishers who sell at least part of their catch usually had 42% longer trip length than those who did not sell any of their catch.

The first set of constraints (equation 2) ensures that total catch of a particular species in an area during a season does not exceed its 'estimated' available stock. The total catch of a species includes direct catch resulting from trips targeting that species as well as incidental catch from trips targeting other species. Ideally, if maximum sustainable yield (MSY) is available for each species, it can be used as the 'estimated' available stock. Without such an estimate and after consulting with NMFS fishery biologist (Boggs, personal communication, 1997), the current model takes on two formulations: (1) the total exploitable stock for each species is exactly the same as the 1993 catch and the catch rate is assumed constant (referred to as the CCR formulation); and (2) the total exploitable stock for each species is assumed to be 50% more than that of 1993 catch with a declining catch rate beyond the 1993 catch level (referred to as the VCR formulation). The VCR formulation is further detailed below in the discussion of equation set 7. For pelagic species, the assumption of a stock level of 150% of 1993 may be safe and probably quite conservative as the current Hawaii catch of the main pelagic species is a mere 1% of the total catch in the Pacific. However, better estimates may be needed for the bottomfish and lobster fisheries as they are more localized compared to the pelagic fishery and 50% more than the current catch may be beyond their MSY.[6]



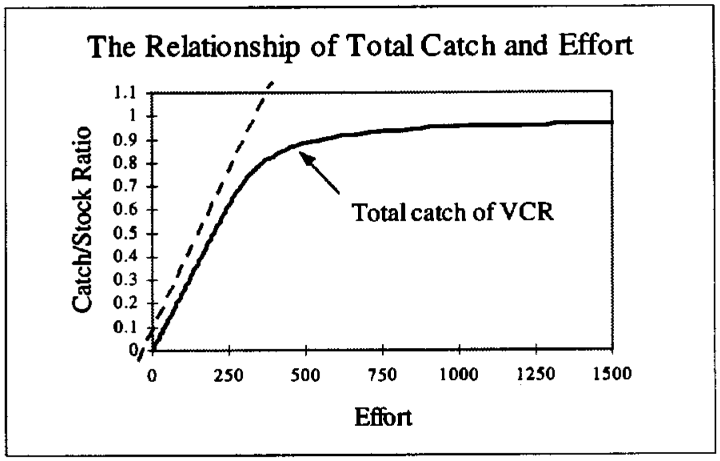


Figure 4. Relationship between CPUE and effort.

The second set of constraints provides the links between the number of trips taken and the number of vessels operating in a season and on an annual basis. Equation 3a states that the total number of trips taken by vessels in fleet i targeting species j in area k during season l (E_{ijkl}) cannot be greater than the maximum number of trips each of those vessels can take (ε_{ijkl}) multiplied by the number of those vessels in operation (V_{ijkl}). The maximum number of trips that can be taken by a vessel in a season depends on the hold capacity of the vessel, shelf-life of the harvested species, distance to fishing ground, and available days at sea. Equation 3b simply serves as an aggregating device to arrive at the seasonal fleet size. Equation 3c states that for each fleet, the annual fleet size is the largest of the seasonal fleet sizes. This allows the model to charge annual fixed costs to vessels as long as they are active in any one season.

[6] At least some bottomfish are often recognized as 'overfished' (e.g., onaga and ehu), and there are restrictions on the lobster fishery. However, the current model formulation focuses primarily on pelagic species and does not distinguish the different species of bottomfish.

The next set of constraints constitutes the trip entry conditions at the micro-level of both the commercial and recreational fishers. Just as a farmer commits resources prior to and during a production cycle, the fisher similarly makes input and production decisions prior to and during a fishing trip. The trip entry conditions represent the short-run conditions that the fishers would need to satisfy before taking a fishing trip. Equation 4a ensures that recreational fishers would catch at least 90% of their current catch for each of the species caught before a trip is deemed satisfying and worth taking. Equation 4b states that 'expense' fishers have to cover 30% of their trip expenses before a trip is taken. It is also assumed that the 'expense' fishers only sell 51% of their catch (Hamilton and Huffman, 1997). Admittedly, both the 90% and 30% rates are arbitrary but we feel they are quite reasonable for the purpose of this modeling exercise. Equation 4c ensures that commercial fishers will at least cover their 'short-rum' trip expenses before a fishing trip will be taken in any area during any season.

Equations 5 and 6 specify respectively, the crew and owner entry conditions for the commercial fleets. These conditions are specified on an annual basis using the division of profits between crew (including captain) and owner based on the average practice in Hawaii for each fleet. Equation 5 states that the annual crew share for each fleet is at least as large as the expected income. For the purpose of this study, expected income is defined as the average crew share obtained in the past. Equation 6 states that owners have to cover their investment (measured as annual fixed costs) and annual operating expenses. The trip entry conditions can be viewed as the fishers' 'short-run' decisions while the crew and owner conditions represent a 'longer-run' view of sustaining the respective fisheries.

The last set of constraints attempts to relate CPUE to 'localized' fishing pressure. Curran et al. (1996) and Boggs (1992) suggest the possibility that local CPUE in highly migratory pelagic species can decline with increasing effort when the catch approaches the rates of fish immigration and recruitment in a limited area. Sathiendrakumer and Tisdell (1987) argue that diminishing returns to effort in similar fisheries are attributed to competition among fleets and vessels and not to long-term population adjustments. However, this should be distinguished from the larger issue of CPUE reduction due to overfishing to the extent that exceeds MSY. The dynamics of such inter-temporal changes in stock abundance is not considered in the current model. Following the spirit of the above authors, we postulate that intensive local fishing pressure can reduce CPUE in an area primarily due to "over-crowding" without affecting availability of the stock as a whole in other areas and future periods. Attempts in estimating the effects on catch rates of expanded fishing effort in Hawaii have not come up with any usable empirical relations (Boggs, 1992, and He and Boggs, 1995). It appears that at the current (1993) level of fishing effort, there is no significant impact on pelagic species CPUE. However, the impact of further expansion in fishing effort remains unknown. Since such estimates are not available, we postulate that CPUE will decline slowly as total catch increases beyond the current (1993) catch level for all species in all areas during all seasons. For convenience and lack of better formulation, we use a standardized relationship between CPUE and total catch as represented by equations 7a and 7b for all species. Figure 4 shows graphically the relationship used in the current model. This nonlinear relationship complicates the model solution process as it leads to a more complex nonlinear programming model, which we refer to as the variable catch rate (VCR) formulation. As mentioned previously, the VCR formulation assumes that the stock level is 50% more than the actual 1993 recorded catch level. The CCR formulation as described above assumes $A_{kls} = 1$, or $R_{ijkls} = \overline{R}_{ijkls}$.

Data

There are five groups of parameters used in the model: CPUE, stock, fish price, trip length, and costs. These parameters are generated primarily from three major data sources: (1) cost-earning studies of longline (Hamilton et al., 1996), and handline and trolling (Hamilton and Huffman, 1997) conducted by the Joint Institute of Marine and Atmospheric Research (JIMAR), (2) 1993 Hawaii Division Aquatic Resources data (HDAR, 1993), and (3) 1993 NMFS longline logbook data (NMFS, 1993). Parameters that cannot be generated from these three sources are estimated based on other previous studies and/or annual reports of NMFS as well as expert opinions of NMFS scientists. Table 6 summarizes the data sources for each group of parameters. Detailed descriptions of the data used in the model and their derivations can be found in Pan et al. (1998).

Table 6. Data sources for the five groups of parameters used in the model.

	DIMENSION	FLEET	SOURCES	NOTE
CPUE	Fleet Target Area Season Species	Longline (fleet 6-8) Others (fleet 1-5,9)	NMFS log book 1993 linked with HDAR HDAR 1993	Define Target: 1. Target defined by trip types, Tuna, Swordfish, Mixed 2. Yellowfin target estimated by HDAR for small & Med. longline Define Target: 1. The the highest proportion species 2. Handline Bigeye Target: no bigeye trips reported in HDAR, need to adjust
STOCK	Area Season Species	Current catch +50%	HDAR 1993 NMFS 1993	1. Find current catch by species and area 2. Adjusted current catch by actual trips taken and CPUE
PRICE	Fleet Season Species	Longline (fleet 6-8) Others (fleet 1-5,9)	NMFS log book 1993 linked with HDAR HDAR 1993	1. Group observations by fleet, species, season 2. Find average price for each group 3. Fill in missing information
TRIP DAYS	Fleet Target Area Season	Longline (fleet 6-8) Others (fleet 1-5,9)	NMFS log book 1993 linked with HDAR Estimated by S. Pooley, M. Hamiltion, & K. Kawamoto.	1. Fleet 1, 2 ,3 ,4 and 5 took one day trip in area 1 and 2 (within 75 nmi) 2. Fleet 3, 4, and 5 took 3-days trip in area 76-200 nmi to target pelagic 3. Commercial Handline fish in the area >200 nmi when they target bottomfish
COSTS 1. FIXED COSTS 2. VARIABLES COSTS (Trip costs)		Longline (fleet 6-8) Others (fleet1-5) Charter Boat By Fleet By Fleet, Target, Area, & Season	Hamilton et al. 1996 Hamilton and Huffman 1997 Estimated by M. Hamilton 1996	1. Fishing cost varied by fleet target 2. Travel cost and turn around varied by fleet 3. Trip costs = Trip fishing days * Fishing cost/day + Trip traveling days*Travel cost/day + Turn-around days*Turn around cost/day

Note: If the data is available, the observations are grouped by the dimensions defined for the parameter and averages are estimated for each group. Otherwise, if data is unavailable, the parameters are estimated based on previous research and reports and expert opinions.

Model Validation

Unlike simulation models where one can calibrate model parameters so as to reproduce as accurately as possible the situations being modeled, mathematical programming models are normative or prescriptive in nature and are not expected to reproduce the actual situation, particularly under the assumption that the actual situation is sub-optimal. However, consistency checks for all the model parameters and constants are necessary especially in our case where data came from three almost independent sources (HDAR, cost-earning surveys, and NMFS logbook) as described above. Model parameters and constants were calibrated such that for each fleet, total catch = CPUE × fleet size × number of trips per vessel. While there is no guarantee that such a process will provide the 'real' parameters and constants for the model, it will provide at least internal consistency among all the parameters and constants.

In addition, two tests were performed to assess the reasonableness of the model. In the first test, economic rents for each commercial fleet were maximized individually using the CCR formulation. One would expect that optimal fleet size would be larger than actual fleet size as there will be no competition for the fish resources. Table 7 compares the results of the optimal fleet size with the actual fleet size and their associated revenues and rents. Except for commercial trollers, the optimal fleet size for all other commercial fleets is larger than or equal to the actual fleet size as expected. It is interesting to note that both charter boats and trollers reported actual negative fleet-wide economic rents. It is conceivable that the optimal number of trollers would then be smaller than the actual as inefficient (unprofitable) trips would not be taken. In fact, a detailed analysis indicated that at the optimal number of 148 trollers, profitable targeted species such as ono and mahimahi were already utilized at their maximum levels. It is then not unreasonable for the optimal number of trollers to be less than the actual. However, the optimal number of charter boats is slightly larger than the actual (113 vs. 99) despite the reported negative rents for the fleet indicating that there were enough fish (particularly yellowfin and blue marlin) to allow sufficient profitable trips to support a larger than actual fleet. It should also be noted that commercial harvest is a byproduct or joint product of primary activity of charter boats. This simple test seems to indicate that the model is behaving in the right manner as expected. This test also establishes the upper bounds of the individual fleet size.

Table 7. Fleet mix, profit and revenues: actual vs. maximum individual fleet profit.

	Actual			Maximum Individual Fleet Profit		
Fleet	Fleet Size (# of vessels)	Profit ($1000)	Revenues ($1000)	Fleet Size (# of vessels)	Profit ($1000)	Revenues ($1000)
Commercial						
Charter Boats	99	(2,203)	9,109	113	1,618	18,457
Commercial Handliners	149	533	11,419	204	4,381	16,123
Commercial Trollers	232	(1,085)	5,970	148	1,953	9,237
Small Longliners	30	180	7,313	30	3,074	14,044
Medium Longliners	48	1,789	20,813	72	5,541	31,613
Large Longliners	44	4,218	27,213	52	9,983	38,151
Aku Boats	8	1,106	2,890	16	1,783	4,593
Total	610	4,538	84,727	635	28,333	132,218

In the second test, economic rents of the entire commercial fleet were maximized allowing for inter-fleet competition, again using the CCR formulation. In this test, we assume (1) the number and distribution of recreational trips are the same as in 1993; and (2) areas 1 and 2 are closed to the longliners as they were in 1993. As expected, the optimal size for each fleet is smaller than that in the first test above. Also, as expected, total catch is less than actual while total economic rents are higher as the model is supposed to provide the optimal allocation of efforts seasonally and spatially. Table 8 compares the optimal fleet size with the actual. For the small boats, which compete for fish in areas 1, 2, and 3, optimal fleet size for the handliners is slightly larger than the actual while optimal fleet size for the charter boats and the trollers is much less than the actual. It seems reasonable, as the profit per vessel is highest for the handliners ($20,000), followed by the trollers ($17,000) and charter boats ($14,000). In addition, both the trollers and charter boats reported negative economic rents in 1993 indicating much inefficiency occurred in these two fleets. The results for the longliners also appear to be plausible.

Table 8. Fleet mix, profit and catch: actual vs. maximum fleet-wide profit.

	Actual		Maximum Fleet-Wide Profit	
Recreational	*(1,000 trips)*		*(1,000 trips)*	
Recreational Boats	34.860		34.860	
Expense Boats	52.360		52.360	
Commercial	*Fleet Size (# of vessels)*	*Profit ($1,000)*	*Fleet Size (# of vessels)*	*Profit ($1,000)*
Charter Boats	99	(2,203)	45	641
Commercial Handliners	149	533	163	3,256
Commercial Trollers	232	(1,085)	64	1,081
Small Longliners	30	180	14	1,273
Medium Longliners	48	1,789	6	856
Large Longliners	44	4,218	52	9,470
Aku Boats	8	1,106	14	1,380
Profits		4,538		17,957
Revenues		84,653		72,020
Catch	*(1,000 lbs.)*		*(1,000 lbs.)*	
Commercial	30.510		26.35	
Recreational	4.597		4.57	
Total	35.107		30.920	

Examples of Model Application

For illustrative purposes, the model has been applied to estimate (1) the impact of the area closure regime (using the CCR formulation); (2) the tradeoff between the recreational and commercial fisheries (using the CCR formulation); and (3) the optimal fleet mix given that fish abundance is assumed to be 150% that of 1993 and catch rates decline after reaching the 1993 level (the VCR formulation).

Economic Impact of Area Closure

The model was applied to examine the economic impact of closing areas 1 and 2 to longliners, which was instituted in 1991 to minimize gear conflicts. In this application, we assumed that areas 1 and 2 were open to the longliners, and recreational activities were the same as it was in 1993. As expected, economic rents will increase as indicated in Table 9. In fact, it is estimated that $0.44 million of economic rents (or profits) of the commercial fisheries were lost due to the area closure. This can be interpreted as the economic cost to the Hawaii commercial fisheries to alleviate gear conflicts. Table 9 also shows that the increase in economic rents is primarily attributed to the increase in profits of the large longliners which can increase their economic efficiency by fishing closer to ports. This increase is partly offset by a decrease in profits of the commercial trollers and the small longliners. The decrease in the profits of the small longliners can be explained by the fact that there were three small longliners which were allowed to fish in areas 1 and 2 under the area closure regime. However, the optimal number of vessels for each fleet is almost identical. Table 10 shows that the distribution of economic rents gained are accrued mainly by the owners of the large longliners at the expense of the small longliners. It should be noted that this analysis is conducted using the 1993 fish abundance situation. The estimated amount of rent dissipation will obviously depend on the size and distribution of fish abundance in a given year.

Table 9. Optimal fleet mix, profit and catch: area closure vs. open access.

Fleet	No. of vessels			Profit ($1,000)			Catch (1,000 lbs.)		
	Close	Open	diff.	Close	Open	diff.	Close	Open	diff.
Recreational									
1. Recreational Boats	2,490	2,490	0			0	1,413	1,413	0
3. Expense Boats	952	952	0			0	3,161	3,161	0
Commercial									
2. Charter Boats	45	45	0	641	642	1	1,320	1,313	-7
4. Commercial Handliners	163	164	1	3,256	3,284	28	5,097	5,140	43
5. Commercial Trollers	64	62	-2	1,081	1,019	-62	1,893	1,827	-66
6. Small Longliners	14	14	0	1,273	966	-307	2,022	1,792	-230
7. Medium Longliners	6	6	0	856	885	29	1,230	1,241	11
8. Large Longliners	52	52	0	9,470	10,220	750	12,025	12,351	326
9. Aku Boats	14	14	0	1,380	1,381	1	2,761	2,759	-2
Total Commercial	358	357	-1	17,957	18,397	440	26,348	26,423	75

Table 10. Fishing rent accrued to owner and crew: open access vs. area closure.

	Area Closure			Open Access			Difference		
Fleet	Owner	Crew	Total	Owner	Crew	Total	Owner	Crew	Total
Charter Boats	-	641	641	-	642	642	-	1	1
Commercial Handliners	543	2,712	3,255	552	2,733	3,285	9	21	30
Commercial Trollers	410	671	1,081	386	633	1,019	(24)	(38)	(62)
Small Longliners	881	392	1,273	651	316	967	(230)	(76)	(306)
Medium Longliners	629	227	856	645	240	885	16	13	29
Large Longliners	7,490	1,980	9,470	8,092	2,128	10,220	602	148	750
Aku Boats	1,287	96	1,383	1,285	96	1,381	(2)	-	(2)
Total	11,240	6,719	17,959	11,611	6,788	18,399	371	69	440

Tradeoff between the Recreational and Commercial Fisheries

Allocation of fish resources between the recreational and commercial fisheries has been a major concern of the fishery management authorities in Hawaii (Pooley 1993). In the preceding validation tests and the area closure application, the model was run using just a single objective of maximizing fleet-wide profits or economic rents. In this application, the model was extended to include an objective to maximizing recreational experience as measured by the total number of recreational trips (see equation 1b) in addition to maximizing fleet-wide profits. The tradeoff between the recreational and commercial fisheries was mapped using a bi-criterion algorithm called the noninferior set estimation (NISE) method. The NISE method developed by Cohon, Church, and Sheer (1979) is the most efficient algorithm in approximating a set of noninferior (Pareto optimal) solutions of a two-objective problem. A feasible solution is considered Pareto optimal if there exists no other feasible solution that will increase fleet-wide profits without reducing the total number of recreational trips. Figure 5 shows the Pareto optimal tradeoff curve using the NISE algorithm. Points A and B in Figure 5 correspond to the points of maximum profits and maximum number of recreational trips, respectively. Obviously, we cannot have both maximum profits and maximum number of recreational trips (the ideal point), and hence there is a tradeoff as the two objectives are clearly in conflict. Figure 5 shows the amount of commercial profits foregone per unit of increase in recreational trip is relatively stable (ranging from \$8 to \$18 per recreational trip) until it reaches point A1 or about 152,300 recreational trips per year. Beyond point A1, the incremental amount of commercial profits foregone becomes extremely large. The 1993 estimated number of recreational trips of 87,220 is somewhere between points A6 and A4 with a tradeoff value of \$12.14 in foregone commercial profits per recreational trip. This provides an alternative to estimate the value of recreational trips from the point of view of foregone commercial profits.

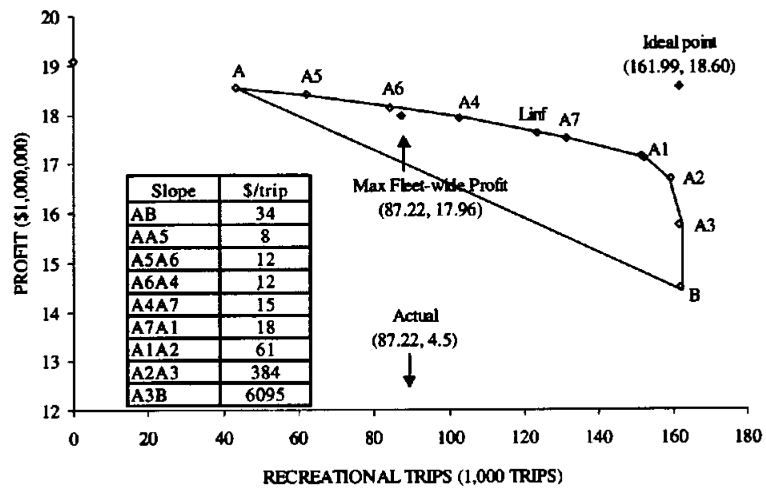


Figure 5. Tradeoff between recreational activities and commercial profit.

Figure 5 also shows point L_{inf} (L_∞), the best-compromise solution that can be thought of as the closest point to the ideal. The ideal point refers to the solution where both objectives achieve their optimum values, i.e., maximum possible commercial profits and recreational trips, which is clearly infeasible when the objectives are in conflict as in our case. Compromise solution can be derived as the nearest solution to the ideal assuming that fishery managers are indeed preferring solutions as close to the ideal as possible. Nearest is represented using some forms of distance measures and in this application the L_∞ metric is used (see Romero and Rehman, 1989). Table 11 compares the maximum profits solution with the recreational activities set at the 1993 level (second validation test) and the best-compromise solution. The best-compromise solution indicates a higher level of recreational activities with a modest decrease in fleet-wide profits (\$17.615 vs. \$17.975 millions). The optimal fleet mix of the longliners for the two solutions are very similar. The decrease in fleet-wide profits comes primarily from the reduction in activities of the commercial trollers and charter boats which compete in areas 1 and 2 with the recreational boats and are generally less efficient compared to commercial handliners.

Table 11. Comparison of fleet mix, profit, and catch: actual vs. best-compromise solution.

Fleet	Fleet size		Profit ($1,000)		Catch (1,000 lbs)	
	L_∞	Actual	L_∞	Actual	L_∞	Actual
Recreational (1,000 trips)						
Recreational Boats	82	35			3,482	1,412
Expense Boats	42	52			2,266	3,185
Commercial (No. of vessels)						
Charter Boats	38	99	542	(2,203)	1,096	1,105
Commercial Handliners	166	149	3,348	533	5,221	4,756
Commercial Trollers	48	232	851	(1,085)	1,412	3,060
Small Longliners	14	30	1,274	180	2,030	3,113
Medium Longliners	6	48	856	1,789	1,230	7,538
Large Longliners	52	44	9,470	4,218	12,025	8,605
Aku Boats	13	8	1,274	1,106	2,502	2,332
Total Recreational	124	87	-	-	5,748	4,597
Total Commercial	337	610	17,615	4,538	25,516	30,509

L_∞ denotes the best-compromise solution.

Optimal Fleet Mix with 150% Stock Level and Variable Catch Rate (VCR Formulation)

In this application, the model was run using the variable catch rate formulation (with equation set 7a and 7b) assuming that the levels of fish stock were 150% that of 1993 and the recreational activities were set at the 1993 level. Table 12 compares the optimal fleet mix between this variable catch rate (VCR) scenario with the constant catch rate (CCR) scenario analyzed earlier (second validation test). It is interesting to note that with a 50% increase in fish stock, the optimal number of commercial boats increases by just 7% and fleet-wide profits by about 27%. However, the increase is not uniform among fleets. In fact, under the VCR scenario, the optimal number of small longliners is only half of that in the CCR scenario (7 vessels vs. 14 vessels). The optimal number of charter boats also shows a slight decrease. The medium longliners shows the largest increase with 11 boats under the VCR scenario as compared with 6 under the CCR scenario. The corresponding change in profits also varies by fleet with the largest increases in the medium and large longliners followed by trollers and aku boats. Charter boats, handliners, and small longliners all show a decrease in profits. Although the catch-effort relationship used is rather arbitrary assuming that catch rate will decrease at a specified rate after the recorded 1993 catch for each species, this application nevertheless shows that expansion of the commercial fisheries in Hawaii assuming a 50% increase in fish abundance will most likely not be uniform among the various fleets. Medium and large longliners show the largest potential for expansion as does commercial trollers.

Table 12. Optimal fleet mix and rent distribution: variable catch rate (VCR) vs. constant catch rate (CCR) formulations.

Fleet	No. of Vessels			Profit ($1,000)		
	VCR 150%	CCR 100%	VCR/ CCR	VCR 150%	CCR 100%	VCR/ CCR
Recreational						
Recreational Boats	2,490	2,490	1.00			
Expense Boats	952	952	1.00			
Commercial						
Charter Boats	43	45	0.96	617	641	0.96
Commercial Handliners	169	163	1.04	2,530	3,256	0.78
Commercial Trollers	77	64	1.20	1,398	1,081	1.29
Small Longliners	7	14	0.50	805	1,273	0.63
Medium Longliners	11	6	1.83	1,386	856	1.62
Large Longliners	60	52	1.15	14,560	9,470	1.54
Aku Boats	15	14	1.07	1,562	1,380	1.13
Total Recreational	3,442	3,442	1.00	-	-	
Total Commercial	382	358	1.07	22,858	17,957	1.27

Concluding Remarks

In order to better reflect the reality of Hawaii's multifishery, the present study modified and extended the structure and scope of the NMFS linear programming model of Hawaii commercial fisheries (E.R.G. Pacific, Inc., 1986). As a result, a bilevel and bicriterion model of Hawaii's multifishery was developed and tested. The bilevel aspect of the model incorporates and analyzes objectives of both policy makers and fishers. The use of a multicriteria framework (the current formulation uses only two criteria) is essential as the complexity of fishery management requires the implementation of more than one general objective. The current model covers nine fleet categories including commercial, semi-commercial, charter, and recreational fleets; five fishing areas; four fishing seasons; and 14 species or species groups, of which ten are the possible targets in Hawaii's multifishery. Fleet size can vary by season, and the annual fixed cost is included as long as the vessel is active in one season of a year. In addition, a nonlinear relationship between CPUE and total fishing effort is incorporated into the model. Fishery bycatch is considered in the model, and the amount and proportion of targeted catch and fish bycatch vary depending on fleet, target, area, season, as well as total fishing effort. Fishers' objectives are incorporated into the model by three entry conditions - trip, crew, and owner - for each fleet. Under various objectives or policy options facing Hawaii's fisheries, the model provides the optimum solutions in terms of fleet mix, harvest level of the different species, fish resource allocation among the different effort groups (fleets), and spatial and seasonal distribution of the efforts. Compared to the NMFS linear programming model, the present model appears to produce more plausible solutions representing Hawaii's multifishery. For illustrative purposes, the model has been applied to estimate (1) the impact of the area closure regime; (2) the tradeoff between the recreational and commercial fisheries; and (3) the optimal fleet mix given that fish abundance is assumed to be 150% that of 1993 and catch rate declines after reaching the 1993 level.

Like any model, the current model is a simplification of reality. Thus, the generated results should be treated as indicative of reality rather than reality itself. The results are only as good as the data and the assumptions we used in constructing the model. In fact, during the course of model development, we found that our understanding of the biology and the economics of Hawaii's multifishery is still limited. Several potential areas for further development of the model are discussed below.

One of the major improvements over the previous model is the recognition of the two-level decision-making structure of the fishery in the current model. However, the current formulation only approximates the fishers' profit-maximizing behavior using a set of entry conditions. This is done primarily to alleviate the solution difficulties with bilevel optimization which have hinder the empirical applications of multi-level programming. How representative is this approximation remains to be seen. Recently, Onal (1996) has suggested exploiting the analytical derivation of the lower-level responses to tackle the bilevel optimization problem. This may provide another alternative to the approximation we employed in the current model.

The current formulation does not model the inter-annual catch and effort. Although the variations of catch per trip by fleet, target, season and area can be captured, universal application of the model to other years may be inappropriate. Therefore, it would be worthwhile to investigate the possibility of explicitly modeling the catch and effort relationship using several years of data.

Similarly, the cost structure of the fleet is based on cost-earnings surveys of a single year. Capturing the cost structure over time may provide more insights on the relationships between costs and fishing activities. The current formulation also assumes that fish prices are constant except for seasonal variations. Further development of the model should investigate the price-quantity relationships of each species to capture the effects of changes in quantity landed on fish prices as well as the mix of different target markets and end products. Information on how the structure of the seafood markets could affect fishing activities can also be very useful in the design of fishery management policies.

The present model is static in nature and model applications are limited to short-run analyses. The model assumes that fish stock is given and there are no relationships between catch and stock among seasons and years as related to fishing mortality. Furthermore the model assumes no catch and stock relationships exist between areas. This can be of concern particularly for pelagic species. However, improvements in this will require considerable amount of inputs from the biologists involving possibly detailed modeling of the population dynamics of each species.

Presently, the model assumes the fishers know with certainty what to target, where to catch fish, trip costs, and the expected CPUE and prices of fish before taking a trip. The certainty assumption eliminates the possibility of equipment breakdowns and formidable weather conditions. However, given the highly uncertain nature of the fishing industry, it may be worthwhile to model some of these parameters as stochastic elements.

The present model assumes that the vessels in each fleet are homogeneous and thus variations of fishing efficiency cannot be captured. While it would be impossible to represent the small boats individually because of their vast number and the lack of detailed information on them, modeling each longline vessel individually may be a possibility worth pursuing. In addition, it may be possible to incorporate some of the results of the on-going vessel efficiency work (Sharma and Leung, 1998) to capture variations within each fleet.

While the next generation of models will improve as our knowledge of the Hawaii multifishery increases, it is important to make the model easily accessible by potential users and to gain more experience on the working of the model. It is in this spirit that the current model has been implemented as a decision support system to facilitate easy experimentation of the model for policy evaluations (El-Gayar and Ji 1998). The decision support system is developed under the Microsoft's Windows environment using Microsoft FoxPro as the database manager, Microsoft Excel as the solution viewer and GAMS as the model solver.

Acknowledgment

The authors are indebted to Dr. Christofer H. Boggs and Ms. Marcia Hamilton for their insightful advice and assistance during the course of this research. This research is supported by Cooperative Agreement Number NA37RJ0199 from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies.

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A Spatial-Dynamic Model for the Allocation of Fishing Effort: Application to the Hawaii Longline Pelagic Fishery

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A model that incorporates spatial distribution of effort and fish stocks is used to evaluate the effects of regulatory policies including area closures and taxation. The model builds in multiple fish species and two fishing methods (tuna- and swordfish-targeted). Given fish prices during each period, a catch function and cost function are estimated, and the fishermen's profit function (i.e., their wage net of opportunity cost) is maximized to replicate the effort allocation for the year 1995. Simulation results indicate that the understanding of fishermen's behavior is likely to be quite significant in predicting the economic impacts of policy instruments. The upward-sloping supply is steep, implying that vessels are likely to be fully allocated during the first quarter when fish stocks are abundant and prices are high.

1. Introduction

A fundamental problem of fishery management is to understand how regulatory policies such as area closure and fishing quota would change the spatial allocation of fishing effort in the complex fishery system that consists of both biological and economic determinants. Attempts to model the allocation of fishing effort are many. Gordon (1953) used a static model to show how fishing location and intensity are determined by the net returns of fishing activities. Fishermen are assumed to possess information on relative catch rates, and as they maximize profits, rates of return are equalized in all fishing locations. Clark (1982, 1985) extended Gordon's static theory to a dynamic framework which included spatial distribution of fish stocks. Although models for single species stock dynamics have developed over time, models that incorporate multiple species/stocks are quite rare (Hilborn and Waters, 1987).

The general objective of this paper is to present a model that captures both the biological and economic features of a fishery. The model employs profit maximization as the underlying behavioral assumption and allocates fishing effort spatially as well as dynamically through time. It is assumed that fishermen will make trips only when expected total revenue to be earned exceeds expected trip costs. Fish abundance and fish price are important parameters in determining catch and trip length, and thus, revenues and costs. The basic model utilizes multiple fish species and two fishing methods (tuna and swordfish-targeted) although all vessels are assumed to be identical in terms of physical features and in the number and quality of captain and crew. The major components of the model include the catch function, equations related to the costs of fishing, the revenue and profit sharing between the vessel owner and crew members, and the labor supply function.

The paper is organized as follows. Section 2 develops the basic model for the allocation of fishing effort. Section 3 describes the calibration of the model using data from the Hawaii fishery. Section 4 demonstrates the model application with two simulation exercises on regulatory policy changes. Section 5 concludes the paper with a discussion on the limitations of the model and further research.

2. The Model

The model, which is based on a standard neoclassical framework of profit maximization, is driven by the allocation of fishing effort over space based on the comparison of net revenues from

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each fishing location. These revenues in turn are dependent on residual stocks of each species, catchability, and exogenous fish prices. As boats are allocated into regions of maximum profit, residual stocks decline, which in turn create a stock externality by increasing the cost of subsequent effort. Over time, regions being fished exhibit declining profit and are replaced by new fishing areas. Both distance from the harbor and initial estimates of stock in each region play an important role in determining profitability. To capture such a decision process, the model consists of three main components: the catch function, the revenue function, and the cost function described as follows:

Catch Function

Consider a fishery in which there are I species of fish (e.g., bigeye, swordfish, and yellowfin) and K fishing areas or locations, indexed respectively as $i = 1,...,I$ and $k = 1,...,K$. The fish stocks of different species are given at the beginning of a period in each area. The time period is assumed to be short such that in each area stock change due to reproduction or mortality can be ignored, and also there are no outflow and recruitment (i.e., fish migration and exchange of fish stocks between areas are minimal) during the period; thus the fish stocks decrease only because of fishing.[1] The catch function for a unit time period is as follows:

$$C_{i,k} = \left(1 - e^{-\gamma_i E_k}\right) B_{i,k} \tag{1}$$

where $C_{i,k}$ is the catch per time period of species i in area k, γ_i is the catchability coefficient for species i, E_k is the fishing effort in area k, and $B_{i,k}$ is the fish stock for species i in area k. There are several characteristics about the catch function. First, the function utilizes the concept of continuous decreasing stock, and the catchability coefficient, γ_i, is the instantaneous rate of decrease (due to fishing) of the fish stock per unit effort and time period. Thus $\left(1 - e^{-\gamma_i E_k}\right)$ gives the ratio of cumulative catch to fish stock at the end of a period. Second, the rate of decrease of the fish stock is proportional to the amount of effort, and the catch is proportional to the size of the stock. Third, in each fishing area, catching different species of fish depends on a common amount of effort E_k, and thus we assume away the use of different fishing methods for different fish species.

It is possible to take the catch function as a production function giving the total physical product ($TPP_{i,k}$), a concave function of E_k. Further, from the production function, the average physical product ($APP_{i,k}$), which is also the catch per unit effort ($CPUE_{i,k}$), and the marginal physical product ($MPP_{i,k}$) of species i in area k are

$$APP_{i,k} = \frac{C_{i,k}}{E_k} = \frac{B_{i,k}\left(1 - e^{-\gamma_i E_k}\right)}{E_k} > 0 \tag{2}$$

and

$$MPP_{i,k} = \frac{\partial C_{i,k}}{\partial E_k} = \gamma_i e^{-\gamma_i E_k} B_{i,k} > 0. \tag{3}$$

To examine the properties of $APP_{i,k}$ and $MPP_{i,k}$, we take the derivative on (2) and (3) to obtain

[1] If we can take fishing as a daily activity, the assumptions, such as no migration, about the fish stocks will be likely to be true. But in practice, data restrictions very often prohibit us to implement the model with such a short period. In that case the assumptions may only be roughly true.

$$\frac{\partial APP_{i,k}}{\partial E_k} = \frac{B_{i,k}\left(\gamma_i e^{-\gamma_i E_k} E_k + e^{-\gamma_i E_k} - 1\right)}{E_k^2} < 0 \tag{4}$$

and

$$\frac{\partial MPP_{i,k}}{\partial E_k} = -\gamma_i^2 e^{-\gamma_i E_k} B_{i,k} < 0. \tag{5}$$

So within a period both the average physical product (i.e., the catch per unit effort) and the marginal physical product are diminishing as fishing effort increases (see Figure 1).

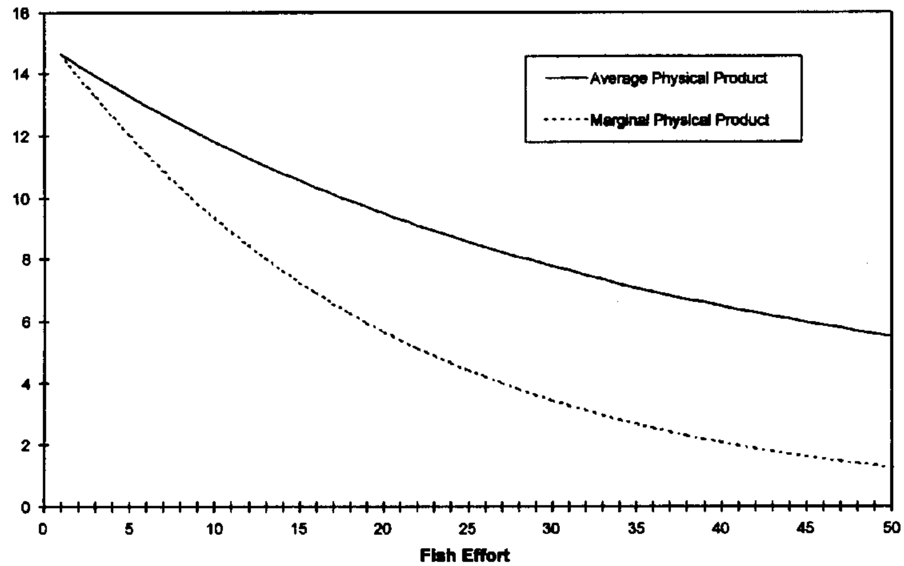

Figure 1. Average and Marginal Physical Product of the Catch Function

Revenue from Fishing

With the catch function, the calculation of revenue is straightforward. Assuming the prices of fish to be given within a period, the total revenue from fishing in area k is obtained by summing over the revenues from the catches of different fish species as follows

$$TR_k = \sum_i P_i C_{i,k} = \sum_i P_i\left(1 - e^{-\gamma_i E_k}\right) B_{i,k}, \tag{6}$$

where TR_k is the total revenue of fishing in area k, and P_i the given price of the fish species i. In equation (6) the total revenue is a function of the fishing effort E_k, but since fishing takes place as a fishing trip, it will be useful to reformulate the equation as revenue per trip. Let $\overline{E}$ denote the fishing effort (e.g., a certain number of sets of hooks) per trip which is taken to be the same and fixed for all trips and N_k the number of fishing trip(s) to area k, we have the fishing effort $E_k \equiv \overline{E} N_k$ .2 The average revenue per trip in area k, $AR_{Trip,k}$, can be expressed as

[2] Given the limitations in storage capacity for bait and fish caught, and the requirement for fish freshness, the number of fishing days and thus the amount of fishing effort in different trips should not diverge widely. Hence, the simplified assumption is adopted that the amount of fishing effort (e.g., the number of sets of hooks) per trip is fixed.

$$AR_{Trip,k} = \frac{\sum_i P_i\left(1 - e^{-\gamma_i \bar{E} N_k}\right) B_{i,k}}{N_k}. \tag{7}$$

It is easy to see in (7) that the average revenue will increase with fish prices and stocks, and decrease with the number of trips.

The Costs of Fishing and the Supply of Labor

In the fishing industry, profit sharing is a commonly employed system in distributing the net return from fishing. In order to take profit sharing into account, we classify the costs of fishing into three categories: the fixed costs, the variable (operational) costs, and the returns to the vessel owner and the crew members. The fixed costs, usually borne by the vessel owner, are the overhead expenses (e.g., maintenance, mooring, and depreciation charges) which do not depend directly on the fishing trip and are more or less fixed annually; whereas the variable costs are the expenses incurred in the fishing trip (e.g., fuel, bait, fishing gear, and auction fee). Since in the short run, fixed costs do not determine the decision of fishing, we write the incomes of the owner and the crew members from a trip with respect to only variable costs as

$$OI_k = (1-\lambda)\left(AR_{Trip,k} - VC_k\right) \tag{8}$$

and

$$CW_k = \lambda\left(AR_{Trip,k} - VC_k\right) \tag{9}$$

where OI_k denotes the average income of the owner from a fishing trip to area k, CW_k denotes the average wage return of the crews, λ denotes the net return share ratio of crews, and VC_k denotes the total variable cost per trip to area k.

The amount of labor that the fishermen are willing to provide for the whole fishery within a time period depends on the wage return to the crews. But since the return to crews, CW_k, is a gross return not standardized with respect to the distance of travel to different fishing locations and the number of fishing days, we cannot use it directly in the labor supply function.[3] Thus we define the expected crew return or wage $EW_k\left(FD_k, TD_k\right)$ for area k to be a function of the number of fishing days FD_k and travel days TD_k and obtain the standardized wage indices for area k and for the whole fishery as

$$WI_k = \frac{CW_k}{EW_k} \tag{10}$$

and

$$WI = \frac{\sum_k WI_k N_k}{\sum_k N_k}, \tag{11}$$

[3] For example, when the fishing location is far away, it takes more days to travel there, and it is very likely that the gross return to crews will be higher than a short trip; but this does not mean that the standardized return is higher for the long trip.

where WI_k is the wage index for area *k*, WI is the wage index for the entire fishery, and N_k is the number of fishing trips to area *k*. Further, we measure the quantity of fishing labor in vessel-day, and the labor/vessel-day supply function, which is a function of the wage index WI, becomes

$$VD(WI) = \sum_k (FD_k + TD_k)N_k. \tag{12}$$

VD denotes the vessel days supplied for the entire fishery. The labor/vessel-day supply is assumed to increase as the wage index increases and possess the standard properties of a labor supply function.

The Fishing Trip Allocation Mechanism

Given the discussion above, we can now look at the way fishing trips are allocated to different areas. The essential idea is that trips are allocated sequentially, and each trip will be allocated to the area that gives the highest standardized wage return to the crews. Suppose now a fishing trip is to be allocated, and the wage indices WI_k for all the *K* areas will be computed first. These indices will then be compared to each other, and one more fishing trip will be assigned to the area, labeled as $\tilde{k}$, with the largest wage index if the following condition is fulfilled:

$$VD_{Sim} \leq VD(WI_{Sim}). \tag{13}$$

In (13), WI_{Sim} is the simulated wage index for the entire fishery, computed with equation (11) including the additional one trip to the area with the largest wage index. VD_{Sim} is the simulated vessel days after adding one more fishing trip. $VD(WI_{Sim})$ is the vessel days read from the supply function given WI_{Sim}. So equation (13) says that the simulated vessel days for the entire fishery have to be less than or equal to the vessel days obtained from the labor/vessel-day supply function evaluated at the simulated wage index WI_{Sim}. The fishing trip allocation process will continue until (13) is violated.

As the model is implemented with a computer algorithm, the details of the fishing trip allocation process are shown as a flow-chart in Figure 2. At the beginning the fishing stocks of each area are given. The allocation of fishing trip goes through the following steps:

1. Compute the expected crew return EW_k for each area.
2. A fishing trip is assigned to each area, and the catches $C_{i,k}$ are estimated using equation (1).
3. Compute the average revenue per trip $AR_{Trip,k}$ for each area with equation (7).
4. Determine the costs of a fishing trip to each area and compute the average crew wage with equation (9).
5. Calculate the wage index WI_k for each area and the simulated wage index WI_{Sim} for the entire fishery using equations (10) and (11).
6. Determine the area $\tilde{k}$ where the wage index $WI_{\tilde{k}}$ is the largest.
7. Determine if the condition stated in equation (13) is satisfied or not. If yes, a fishing trip will be added to the area $\tilde{k}$, the fish stocks of area $\tilde{k}$ will be lowered by the amount of catches, and the process goes on by returning to step 2; otherwise the fishing allocation process will stop.

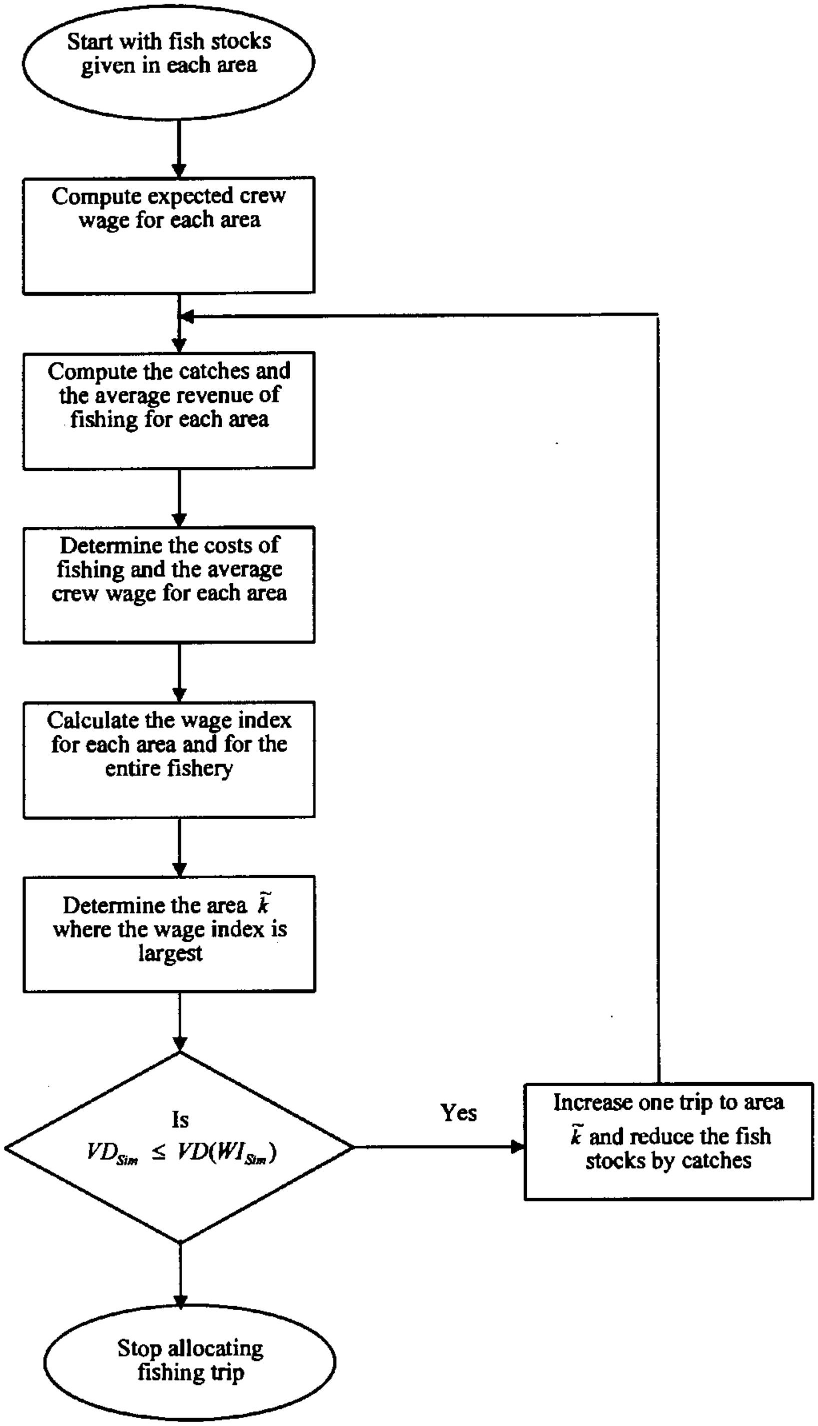

Figure 2. A schematic diagram of the fishing trip allocation algorithm.

3. The Empirical Model: Data and Model Calibration

Before the application of the model to policy analysis can be demonstrated, we need to set up the empirical model and carry out various parameter estimations for model calibration. The data from the Hawaii pelagic fishery will be used for these purposes. For simplicity and due to data limitations, we focus only on the longline fishing.

Hawaii Longline Pelagic

Hawaii fisheries, especially pelagic fishery, have been rapidly growing in the last decade, although the Hawaii pelagic fishery is relatively small in comparison with other Pacific pelagic fisheries (NMFS, 1991). The total commercial value of Hawaii fishery was $58 million in 1994, and about 90% of the sales value was from the sales of pelagic fish (Hawaii Data Book, 1994). Before the 1980s, skipjack tuna -- known locally as aku -- dominated the commercial fishery in Hawaii, and commercially caught skipjack were sold mainly to the local cannery (i.e., the Hawaiian Tuna Packers). However, after the shutdown of the cannery in 1984 (due to high production costs) and subsequent oversupply of pelagic fish, Hawaii had explored new markets for non-aku species including export markets. As results, the non-aku landings in Hawaii increased substantially, and consequently the dominant fishing methods have changed to longline, handline, and troll. As shown in Figure 3, about 70% of the revenue is from longline operation, and 21% is from handline and trolling operation. In addition, a number of longline vessels (so-called "black boats") transferred from the East Coast to Hawaii from the end of 1980s and started developing swordfish market in Hawaii. Thus, the Hawaii pelagic fishery, especially by longline vessels, has rapidly grown in terms of both tunas (except for skipjack) and swordfish from 1988 to 1993 (see Table 1).

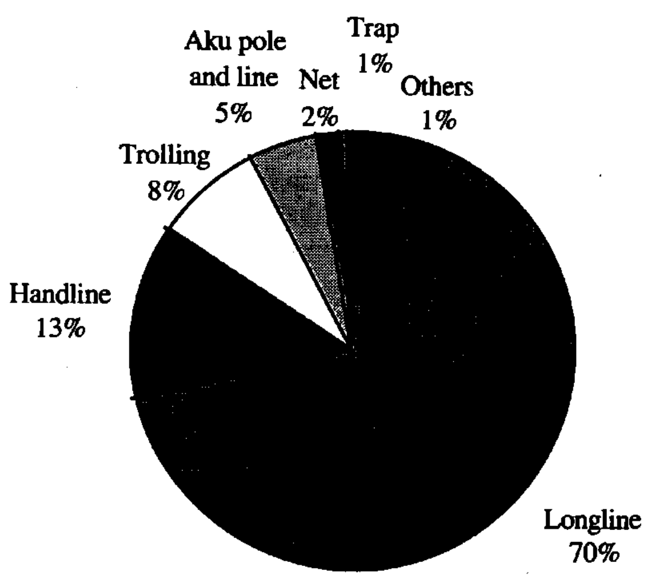

Figure 3. Revenues from Commercial Fishery by Fishing Method, 1994

According to Boggs and Ito (1993), the longline fishery targets mainly broadbill swordfish (*Xiphias gladius*), and bigeye tuna (*Thunnus obesus*). But since yellowfin tuna (*T. albacares*), albacore (*T. alalunga*), and striped marlin (*Tetraphurus audax*) together represent a significant share of the total catches, the empirical model builds in five species of fish, and the five species together account for more than 90% of the longline fishery's total revenue in 1995. To represent the idea of spatial distribution, we divide the fishery, centered around the main Hawaiian Islands, into fifty-six locations or areas. The areas are situated between latitude 5° N to 45° N and longitude 140° W to 170° E. The definition of a fishing area follows Curran, Boggs, and He (1996); that is, each area is a five-degree square using the southeast corner as the reference point. For example, the square with latitude 15° to 20° N and longitude 140° to 145° W is labeled as *15N140W*.

Table 1. Hawaii-based Longline Fleet Ex-vessel Revenue ($1000) of Selected Pelagic Species, 1987-95.

	Billfish			Tunas			Miscellaneous			
Year	Swordfish	Blue Marlin	Striped marlin	Bigeye	Yellowfin	Albacore	Mahimahi	Moonfish	Ono	Sharks
1987	170	140	810	6,510	1,500	520	100	N/A	150	N/A
1988	160	190	1,200	9,160	3,270	910	110	N/A	240	N/A
1989	1,130	640	1,370	10,640	5,070	710	400	N/A	450	N/A
1990	9,710	710	1,530	10,940	5,750	550	590	N/A	200	N/A
1991	21,450	510	1,490	12,760	4,440	910	670	590	230	90
1992	24,130	880	1,280	11,710	2,210	910	830	350	220	190
1993	26,590	640	1,070	16,640	3,810	1,170	440	390	270	490
1994	16,240	1,020	1,220	14,620	2,910	1,360	540	570	240	470
1995	13,870	1,060	1,080	15,750	5,720	2,060	810	700	330	850

Catchability Coefficient and the Initial Fish Stock

The catchability coefficient γ_i is a critical parameter in the model but, unfortunately, to determine the value of it is difficult for two reasons. First, there is no independent information on the fish stock, and therefore it is not possible to estimate the catchability coefficient directly with equation (1).4 Second, the concept that comes from the simple catch function about the fish stock is theoretically inadequate for the situation involving spatial distribution of fishing effort.[5] In spite of the difficulties, we derive the equations to be utilized in an iterative procedure for estimating γ_i (see Appendix A for the details). We use the 1995 longline logbook data, collected by the National Marine Fisheries Service (NMFS), on daily catches and fishing effort to perform the estimations. Data on daily catches and fishing effort are aggregated by area first. Then the changes in catch per unit effort, $\Delta CPUE_{i,k}$, on consecutive days are computed and data of different areas are combined to form a long data series. The regression results are shown in Table 2. With the estimated catchability parameters, the catch functions by area for the five fish species are as follows:

[4] Measuring the fish stock is extremely difficult, and thus often researchers utilize the information on catches to make inferences about the size of the fish stock. If this is the case, we do not have independent information about the fish stock.

[5] In the ordinary catch function, the fish stock is not a totally clear concept, particularly with respect to the distribution of the fish stock. In a spatial model, the fish stock distribution is important because the proximity of the fish school to the fishing vessel is a determining factor on the catch. The probability of a fish school miles away from the vessel being caught is much lower than a fish school close to the vessel. Another thing is that the size of the fish stock depends on the fishing area covered. If one defines a larger fishing ground, the size of the fish stock will be larger, and the corresponding catchability coefficient will be smaller. Theoretically, it is possible to have the concept of "effective" fish stock as a function of the distance from the vessel, but further research in this direction is needed.

Bigeye: $$C_{\text{Bigeye},k} = \left(1-e^{-0.02506E_k}\right)B_{\text{Bigeye},k};\qquad (14)$$

Swordfish: $$C_{\text{Swordfish},k} = \left(1-e^{-0.04228E_k}\right)B_{\text{Swordfish},k};\qquad (15)$$

Yellowfin: $$C_{\text{Yellowfin},k} = \left(1-e^{-0.05285E_k}\right)B_{\text{Yellowfin},k};\qquad (16)$$

Albacore: $$C_{\text{Albacore},k} = \left(1-e^{-0.01472E_k}\right)B_{\text{Albacore},k};\qquad (17)$$

and

Striped Marlin: $$C_{\text{Striped Marlin},k} = \left(1-e^{-0.01658E_k}\right)B_{\text{Striped Marlin},k}.\qquad (18)$$

After obtaining the catch functions, since we have data on the catch and the fishing effort, it is straightforward to obtain the initial fish stocks at the beginning of a time period of each area.[6]

Determining the Costs of Fishing

Based on the 1995 logbook data, a longline vessel on average launches 10.8 fishing trips per year and expends fishing effort measured at 12,040 hooks per trip. Thus in the empirical model, we assume that one unit of fishing effort is 1,200 hooks, and that the fishing vessels are identical in physical characteristics as well as the number of crew members. As a result all fishing trips are taken to be homogeneous in terms of effort, and each trip has fishing effort equal to 10 sets of 1,200 hooks. Further, since fishermen in general put in one unit of fishing effort per day of fishing, the number of fishing days per trip is also 10. Excluding the fishing days from a trip, the remaining will be the number of travel days which depends on the distance between the port and the fishing location. The costs of fishing are, therefore, the costs of launching such a fishing trip.

As mentioned in the previous section, the costs of fishing consist of two main components: the fixed costs and the variable costs. We ignore the fixed costs as explained before. For the variable costs, they can be subdivided into two parts: the auction fee and the excise tax, and the shared costs which include the costs on food, oil, fuel, bait, light-stick, ice, and miscellaneous gear.

The auction fee and the excise tax are proportional to the revenue of a trip. Most of the longliners sell their catches to the United Fishing Agency Ltd. which charges each vessel an auction fee equal to 10% of the total revenue from a fishing trip. According to Hamilton et al. (1996), the excise tax rate is 0.5% of the total revenue.

The different items of shared costs can be analyzed according to their relationship with fishing and traveling. Both the fishing and travel days incur costs on food, oil, and fuel while only fishing incur costs on bait, light-sticks, ice, and miscellaneous fishing gear. Based on the survey of Hamilton et al. (1996), the average daily costs of food and oil are respectively $81.54 and $9.41 per day. The cost of fuel is on the average higher in travel day than in fishing day.[7] Another important factor affecting the shared costs is the fishing method, tuna-targeted versus swordfish-targeted. Targeting swordfish is more expensive compared to targeting tuna because the swordfish set uses light-sticks, and the bait and fishing gear for targeting swordfish are also more costly; in other words, the average cost per fishing

[6] Rearranging equation (1), the equation for fish stock is $B_{i,k} = C_{i,k}/\left(1-e^{-\gamma_i E_k}\right)$. We have all the information for the right hand side, so it is easy to compute the fish stock.

[7] In the survey of Hamilton et al (1996), 37 out of 95 vessels surveyed answered no fuel costs differences between the fishing and travel days, 9 reported higher fuel costs for fishing days, one vessel did not respond, and the remaining 48 vessels reported higher fuel costs for travel days. The average fuel costs for the 94 vessels (excluding the no response case) is $219.11 for fishing days and $250.56 for travel days.

day (out of the 10 fishing days of a trip) depends on the proportion of swordfish-targeted sets in the 10 sets of fishing effort.[8] Table 3 displays in details the various items of the shared costs. In the table, one can see that the cost of fishing day is much higher than the cost of travel day. The cost of targeting swordfish is $1282.77 per fishing day more than targeting tuna. To sum up the ideas, the equation for calculating the shared cost of a fishing trip is as follows:

$$\text{Shared Costs} = (779.84 + 1282.77 \times r_{sw}) \times FD + 341.51 \times TD_k . \qquad (19)$$

FD is the number of fishing days of a specific fishing trip (assumed to be 10), r_{sw} is the share of swordfish-targeted sets, and TD_k is the number of travel days to area *k*.

Table 2. Estimation Results Of Catchability Coefficients

Independent Variable	Parameter Estimate	Standard Error of Parameter	t-Value	p-Value
	A. Bigeye Tuna ($R^2 = 0.0171$)			
Constant	0.35896	0.13600	2.639	0.008
Catch	-0.02506	0.00378	-6.633	0.000
	B. Swordfish ($R^2 = 0.0287$)			
Constant	0.58141	0.19180	3.032	0.002
Catch	-0.04228	0.00625	-6.769	0.000
	C. Yellowfin Tuna ($R^2 = 0.0489$)			
Constant	0.49998	0.07093	7.049	0.000
Catch	-0.05285	0.00489	-10.800	0.000
	D. Albacore ($R^2 = 0.0146$)			
Constant	0.27861	0.10857	2.566	0.010
Catch	-0.01472	0.00288	-5.118	0.000
	E. Striped Marlin ($R^2 = 0.0201$)			
Constant	0.17272	0.04689	3.680	0.000
Catch	-0.01658	0.00255	-6.510	0.000

Table 3. Estimated Average Daily Variable Costs for Hawaii Longline Vessel ($/Day)

	Fishing Day		
Shared Cost Items	Tuna set	Swordfish Set	Travel Day
Food	81.54	81.54	81.54
Oil	9.41	9.41	9.41
Fuel	219.11	219.11	250.56
Ice	85.50	39.10	
Bait	272.88	652.42	
Light-Stick	0.00	529.13	
Misc. Gear	111.40	531.90	
Total	779.84	2062.61	341.51

Source: Hamilton et al. (1996)

[8] Squid, the bait used in swordfish set, is more expensive than sanma, the bait used in tuna set. Also, light-sticks are used in swordfish set but not in tuna set.

Proportion of Swordfish-Targeted Set

It is essential to know the value of r_{sw} before we can use equation (19) to calculate the shared costs. In order to determine the value of r_{sw}, we assume that the share of swordfish-targeted sets out of the total number of sets in a fishing trip is positively correlated to the revenue share of swordfish.9 Since the distribution of swordfish and tuna is strongly related to the geographical location of the fishing area and varies seasonally, we collect the data points by region and by month. The fishery is divided into three regions — 30° N and further north, between 15° N and 30° N, and 15° N and further south — based on the observation that over 95% of the longline vessels that fish at the far north of the Hawaii Islands (30° N and further north) conduct swordfish-targeted sets, and less than 5% of the longline vessels that fish at the far south of the Hawaii Islands (15° N and further south) conduct swordfish-targeted sets. For the revenue share, we calculate the ratio of swordfish revenue to the total revenue from the three principal species (i.e., bigeye, yellowfin, and swordfish). We use the 1995 logbook data to create the data points needed by region and month, and obtain 36 observations. The relationship between the share of swordfish-targeted sets and the revenue share of swordfish is estimated as below:

$$\begin{aligned} r_{sw} &= 1.0 && \text{if } r_R \geq 0.75, \\ r_{sw} &= 1.154(r_R - 0.04)^{0.417} && \text{if } 0.04 < r_R < 0.75, \\ \text{and} \quad r_{sw} &= 0.0 && \text{if } r_R \leq 0.04, \end{aligned} \tag{20}$$

where r_R is the ratio of swordfish revenue to the total revenue from the three principal species.

Fish Price, Net Return, and Return to Crew

For computing the revenue of fishing trips, data containing information on the number of fish caught, pound of fish caught and sold, and the revenue of each species by day from the Hawaii Department of Agriculture and Resources (HDAR) are used. Since catches are in terms of number of fish caught, fish prices are stated in the unit of price per fish. Table 4 shows the weight of fish caught in different months, and Table 5 gives the price per standard fish for different species. Since the weight of fish caught varies across months, one should be careful about the interpretation of these standard fish prices. To gain a better idea about the variation of prices from month to month, we plot the per pound prices of the five main fish species in Figure 4.

9 Ideally, catchability coefficients should be estimated for the two fishing methods, swordfish-targeted and tuna-targeted. If doing so, we will have two sets of catchability coefficients, and the optimal number of swordfish-targeted sets in a trip can be simulated according to which fishing method provides a higher net return. However, data limitations make it difficult to obtain two sets of catchability coefficients.

Table 4. Monthly average weight of fish, 1995 (Pound/Fish)

Month	Bigeye	Swordfish	Yellowfin	Albacore	Striped Marlin
January	77.4	134.7	64.2	40.9	39.0
February	79.9	132.1	62.4	41.8	47.4
March	78.8	133.2	80.4	49.1	60.0
April	66.6	125.0	77.9	52.3	66.1
May	95.6	121.5	102.5	53.2	82.1
June	92.8	121.6	108.3	54.8	74.6
July	81.6	108.2	128.0	52.6	73.0
August	88.5	102.6	116.5	52.1	51.1
September	74.5	124.4	108.0	47.6	59.5
October	82.5	87.6	104.7	49.9	62.6
November	69.8	106.1	96.4	48.2	57.4
December	76.6	123.5	68.0	45.5	54.2

Source: Database of Hawaii Department of Agriculture and Resources.

Table 5. Monthly Average Fish Prices, 1995 ($/Fish)

Month	Bigeye	Swordfish	Yellowfin	Albacore	Striped Marlin
January	294.27	465.92	190.73	57.60	62.40
February	308.22	475.70	207.76	75.69	91.56
March	327.93	464.87	292.69	76.56	104.43
April	246.38	372.53	282.85	86.83	99.81
May	288.56	360.74	254.30	48.98	70.58
June	231.10	437.72	239.28	45.46	46.99
July	180.42	379.71	267.42	44.72	64.28
August	232.70	310.73	330.72	73.91	81.81
September	237.01	333.34	300.24	58.49	49.37
October	231.91	231.16	257.51	41.45	35.65
November	195.44	339.52	230.40	32.76	33.87
December	299.35	405.01	180.20	47.80	34.11

Source: Database of Hawaii Department of Agriculture and Resources.

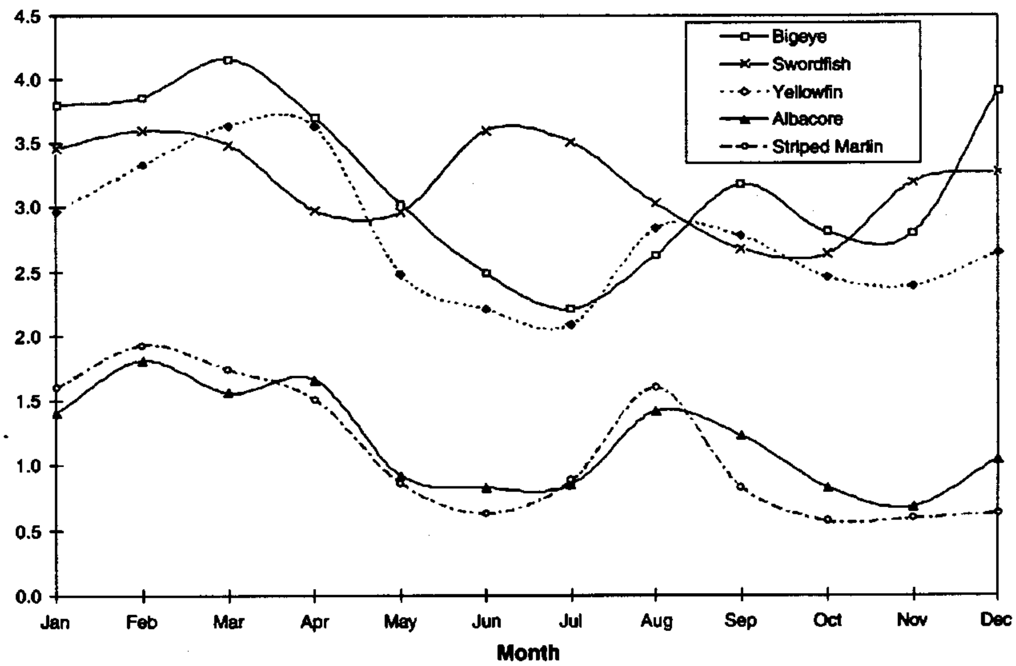

Figure 4. Monthly Average Fish Prices (US$/Pound)

Given fish prices (see Table 5) and using Equation (5) and the estimated catch equations (14) to (18), it is straightforward to calculate the average revenue $AR_{Trip,k}$ of a fishing trip. Note that the total revenue from the five principal species was multiplied by 1.0774 to scale up the revenue since the revenue from the five species does not include all of the income — such as those from other fish species and side catches. The total variable cost, the net return of a trip to area k, and the return to crew members can then be expressed as

$$VC_k = AR_{Trip,k} \times 0.105 + \text{Shared Cost}, \quad (21)$$

$$\text{Net Return} = AR_{Trip,k} - VC_k, \quad (22)$$

$$CW_k = 0.5 \times \text{Net Return}. \quad (23)$$

In Equations (21) and (23), 0.105 is the rate of excise tax plus the rate charged as auction fee (both as a percentage of the revenue), and 0.5 is the share of net return for crew members.

Estimating the Expected Crew Return and the Labor Supply

Using data from Hamilton et al. (1996), we estimate the expected crew return of area k as an equation depending on the number of fishing days and travel days

$$EW_k = 917.17 \times FD + 348.87 \times TD_k. \quad (24)$$

For the labor/vessel day supply estimation, data extracted from the 1995 longline logbook are aggregated into monthly data, and wage indices of different areas are weighted with the number of fishing trips in each area to produce 12 observations as shown in Table 6. The regression result is given in Table 7, and the vessel day supply obtained is

$$VD(WI) = 1980.06 - 119.30 \times WI^{-1}. \quad (25)$$

The vessel day supply is an upward sloping curve as can be seen in Figure 5.

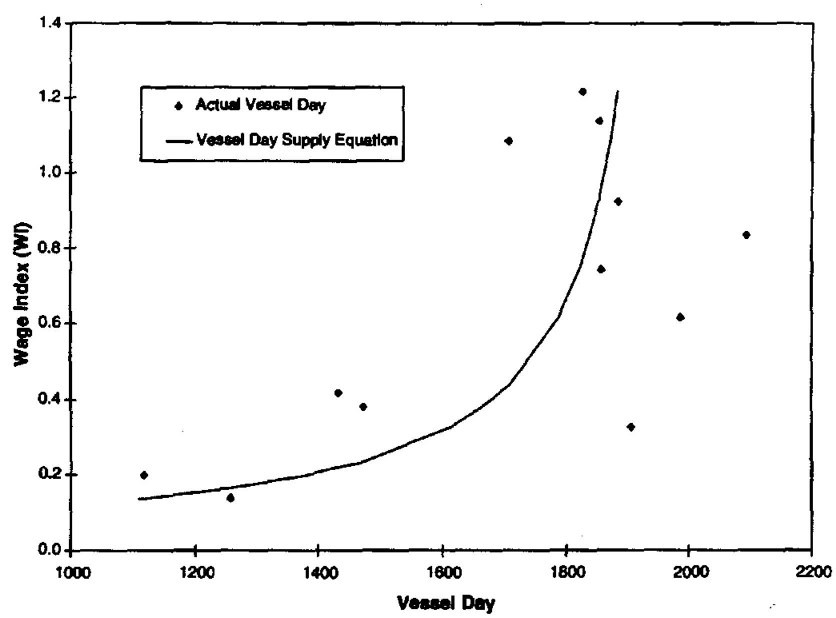

Figure 5. Monthly Labor/Vessel Day Supply

Table 6. Data for Estimating the Vessel Day Supply

Month	Fishing Effort in Vessel Day (VD)	Wage Index (WI)	1/Wage Index	Number of Fishing Trips
January	1706.1	1.085	0.9217	104.1
February	1851.6	1.138	0.8787	101.2
March	1826.0	1.217	0.8217	103.9
April	1883.8	0.923	1.0834	100.6
May	1984.4	0.616	1.6234	117.2
June	1855.0	0.742	1.3477	101.0
July	1431.6	0.416	2.4038	81.0
August	1116.9	0.198	5.0505	57.3
September	1257.0	0.137	7.2993	62.7
October	1472.7	0.381	2.6247	100.1
November	1904.8	0.326	3.0675	120.0
December	2092.6	0.833	1.2005	128.6

Source: Computed from the 1995 logbook data of National Marine Fisheries Service.

Table 7. Estimation Results of the Monthly Vessel Day Supply

Independent Variable	Parameter Estimate	Standard Error of Parameter	t-Value	p-Value
Constant	1980.06	94.01	21.06	0.000
$1/WI$	-119.30	31.03	-3.84	0.003

4. Policy Simulation

An algorithm is written in the program language Turbo C++ that examines fishery policy impacts on allocated trips and fishing efforts, catches of the principal species, and vessel profits, by time and space. The algorithm uses the estimated parameters, including catchability coefficients of the five principal species, which were described in the previous section. The initial stocks of each area in each month were calculated from the catch and hook data, which were summarized by area and month and inputted into the program. The average monthly fish prices for the principal five species were also provided as input data. Two cases of area closure were considered: (i) the closure of two five-degree squares, that include the main Hawaiian islands, and (ii) closure of all fishing areas north of 30 N for sea turtle conservation. Finally we consider a third case (iii) where we assume an exogenous price shock (e.g., triggered by the ongoing Asian economic crisis) that reduces ex-vessel fish prices by 25 percent.

The Baseline model (Base)

First, the model without any area closures or any changes in the ex-vessel fish prices is simulated to (i) examine the accuracy of the model in terms of replicating the behavior of the Hawaii longline vessels and to (ii) evaluate the impacts of fishery policies applied to the Hawaii longline fishery.

The estimated number of trips allocated in each month for the "actual" and baseline cases are compared in Figure 6. The number of "actual" trips was calculated from the actual number of hooks divided by the average hooks used in a trip (i.e., 1200 hooks x 10 sets) as described earlier. In other words, the total number of hooks applied in all fishing areas in each month is essentially compared.

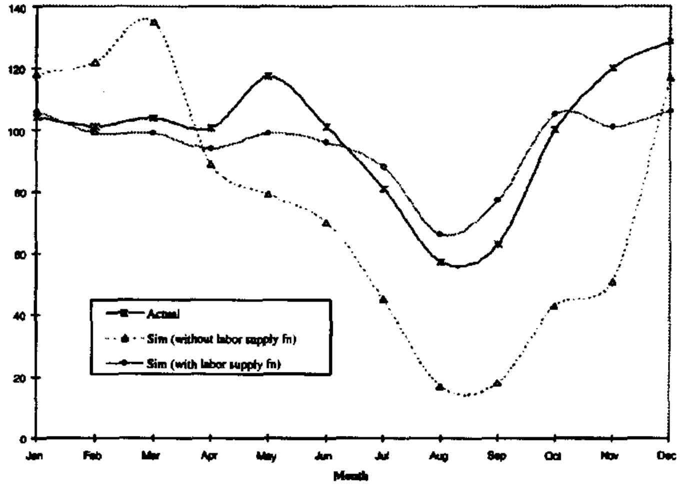

Figure 6. Number of allocated fishing trips for the Hawaii longline fishery, 1995: Actual and simulated (with and without labor supply function).

In order to demonstrate the importance of the labor supply function, simulation results without the labor supply function are presented in Figure 6. The model without labor supply implies that the labor supply curve is horizontal; i.e., a vessel goes fishing to area k simply as long as the condition, $WI_k \geq 1.0$ holds, independent of the total effort (vessel-days) allocated in a month. In other words, equation (13) is ignored.

As shown in Figure 6, the model without the labor supply function demonstrated poor fitness. The mean absolute percentage error (MAPE) over 12 months in 1995 was 37.5%, while that for the baseline model (with the labor supply function) was 10.1%. The number of trips allocated was overestimated in the first quarter and underestimated from May to November, especially in the months of August and September. This pattern of changes in the number of trips was quite similar to the change in the total revenue from the Hawaii longline vessels (Figure 7). The comparison indicates that incorporating the labor supply function, i.e., crew's disincentive in the supply of fishing effort brought about by their higher wages from a fishing trip, is important.

There are some gaps between the actual data and the baseline results. As shown in Figure 6, significant gaps exist in the months of May, November, and December. Further analysis may require a deeper understanding of other factors that affect effort supply decisions. Possible improvements in the model may include the use of price expectations. Although the current estimation of the labor supply function uses the average price data for1995, fishermen may estimate expected prices of the major species based on past price data and other factors.

Another aspect which the baseline model did not explain well was the swordfish catch and spatial distribution of trips. Table 8 summarizes the actual and simulated catches of the five principal species over the 12 months in 1995. It shows that the annual aggregate swordfish catch was nearly 23% higher in the baseline simulation, compared with the actual amount of swordfish catch. The annual totals of striped marlin, albacore, and yellowfin catches were under-estimated but the difference in these catches between actual and simulated were less than 8%, while the simulated annual bigeye catch was almost equal to the actual data.

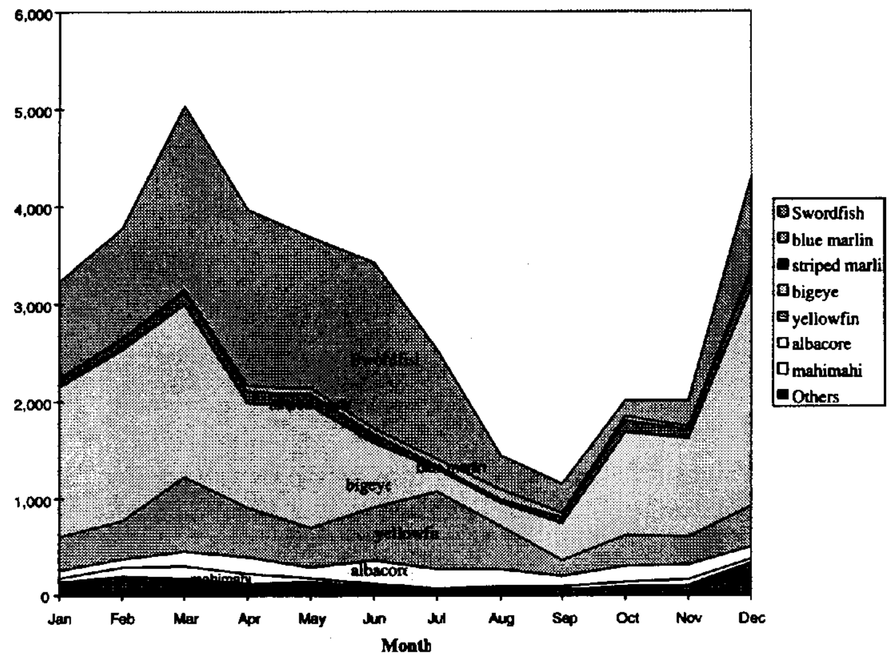

Figure 7. Monthly Revenue from Hawaii Longline Fishery, 1995. (Source: HDAR data)

Table 8. Catch of Five Principal Species in the Hawaii Longline Fishery: Actual vs. Simulated (Base)

Month	Striped Marlin			Swordfish			Albacore			Bigeye			Yellowfin		
	Actual[a]	Simed[b]	%Δ[c]	Actual	Simed	%Δ	Actual	Simed	%Δ	Actual	Simed	%Δ	Actual	Simed	%Δ
Jan	1,858	1,670	-10.1%	2821	3366	19.3%	1888	2625	39.0%	7838	8040	2.6%	2218	2156	-2.8%
Feb	1,229	1,091	-11.2%	4299	5270	22.6%	1753	2301	31.3%	5971	5797	-2.9%	2333	2154	-7.7%
Mar	1,332	1,134	-14.9%	3855	5267	36.6%	2536	2619	3.3%	6593	6512	-1.2%	2432	2276	-6.4%
Apr	1,147	940	-18.0%	5644	6539	15.9%	2538	2335	-8.0%	4744	4473	-5.7%	1817	1733	-4.6%
May	2,020	1,730	-14.4%	4500	5438	20.8%	4213	2943	-30.1%	4834	5136	6.2%	1706	1578	-7.5%
Jun	1,209	1,322	9.3%	4625	5370	16.1%	6010	4934	-17.9%	3251	2651	-18.5%	2426	2335	-3.8%
Jul	529	604	14.2%	2846	3594	26.3%	3696	3209	-13.2%	1266	1370	8.2%	3159	3181	0.7%
Aug	249	227	-8.8%	1320	1734	31.4%	2012	1362	-32.3%	1600	2032	27.0%	1144	1109	-3.1%
Sep	1,706	1,685	-1.2%	772	883	14.4%	2300	2408	4.7%	2276	3189	40.1%	774	801	3.5%
Oct	2,704	2,516	-7.0%	774	829	7.1%	5543	5879	6.1%	5533	5608	1.4%	1244	1201	-3.5%
Nov	2,903	2,564	-11.7%	1742	2291	31.5%	4572	4154	-9.1%	6853	6477	-5.5%	1381	1301	-5.8%
Dec	4,506	4,119	-8.6%	2463	3310	34.4%	1776	1272	-28.4%	8075	7533	-6.7%	2461	2322	-5.6%
Total	21,392	19,602	-8.4%	35,661	43,891	23.1%	38,837	36,041	-7.2%	58,834	58,818	-0.0%	23,095	22,147	-4.1%

[a]Actual number of fish pieces caught
[b]Simulated number of fish pieces caught
[c]Percentage of the ratio, [(simulated catch) - (actual catch)] / (actual catch)

Table 9 indicates that the allocation of longline trips is likely to be biased; i.e., under-allocated for the fishing activities in the south and near the Hawaii principal islands while over-allocated for the fishing activities in the north-west of Hawaii (e.g., latitudes between 25N-30N). Since swordfish is abundant in the North-West sea which is quite distant from Hawaii, the differences between actual and simulated spatial allocation might be related to the high proportion of swordfish in total catch. Some possible explanations may be as follows:

Table 9. Allocated trips by area and by month: base case, 1995.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Sim. Subtotal*	*Actual*	%Δ[a]
n05w155	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	-100%
n05w160	0	2	0	0	0	0	0	0	0	0	0	0	2	15.9	-87%
n10w150	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	-100%
n10w155	1	0	0	0	0	0	0	0	0	0	0	0	1	14.1	-93%
n10w160	0	0	4	3	0	0	0	0	0	0	0	0	7	26.9	-74%
n10w165	0	0	2	6	0	0	0	0	0	0	0	0	8	15.5	-48%
n15w145	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	-100%
n15w150	12	14	0	0	0	0	0	0	0	5	12	0	43	75.3	-43%
n15w155	20	10	8	14	0	1	18	26	17	3	32	3	152	171.3	-11%
n15w160	13	6	15	7	4	17	17	3	0	1	11	24	118	174.5	-32%
n15w165	0	0	4	0	0	0	0	0	0	0	0	0	4	7.9	-49%
n15w170	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	-100%
n20w145	0	0	0	0	0	0	0	0	0	1	0	0	1	2.0	-49%
n20w150	5	7	4	0	7	1	0	7	19	27	2	0	79	113.2	-30%
n20w155	12	10	9	2	28	19	8	2	7	48	19	4	168	165.2	*2%*
n20w160	2	7	4	0	3	5	8	3	2	3	6	47	90	107.5	-16%
n20w165	1	1	0	0	5	0	0	0	4	0	0	1	12	20.2	-41%
n20w170	0	0	0	0	0	0	0	0	0	0	0	0	0	1.2	-100%
n20w175	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	-100%
n25w140	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	-100%
n25w145	0	0	5	6	4	0	0	0	0	0	0	0	15	9.3	*61%*
n25w150	5	0	4	16	3	7	3	0	1	0	0	0	39	20.0	*95%*
n25w155	1	0	0	9	5	12	7	0	7	0	0	2	43	32.0	*34%*
n25w160	10	2	5	4	7	12	0	0	6	2	0	4	52	38.0	*37%*
n25w165	0	2	5	7	12	4	3	0	0	0	0	0	33	22.5	*47%*
n25w170	0	0	6	7	7	3	5	3	1	0	0	0	32	17.8	*79%*
n25w175	0	0	0	0	2	10	6	0	0	0	0	0	18	11.9	*52%*
n25e175	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0	-100%
n30w140	1	4	0	2	0	0	0	0	0	0	4	0	11	4.5	*145%*
n30w145	18	13	8	6	0	0	0	0	0	0	0	0	45	31.8	*41%*
n30w150	5	13	10	2	0	0	0	0	0	0	0	1	31	19.0	*63%*
n30w155	0	4	6	2	0	0	0	0	0	0	0	0	12	3.5	*242%*
n30w160	0	1	0	1	0	0	1	0	4	8	1	3	19	10.0	*90%*
n30w165	0	3	0	0	10	0	1	3	2	3	0	5	27	3.6	*648%*
n30w170	0	0	0	0	2	0	8	7	4	0	0	0	21	4.8	*335%*
n30w175	0	0	0	0	0	3	3	8	0	0	0	0	14	4.9	*185%*
n30e175	0	0	0	0	0	2	0	0	0	0	0	0	2	0.2	*757%*
n35w140	0	0	0	0	0	0	0	0	0	0	2	2	4	3.2	*24%*
n35w145	0	0	0	0	0	0	0	0	0	0	2	3	5	5.3	*-6%*
n35w150	0	0	0	0	0	0	0	0	0	0	0	2	2	1.8	*13%*
n35w155	0	0	0	0	0	0	0	0	2	4	1	0	7	3.3	*111%*
n35w160	0	0	0	0	0	0	0	0	0	0	6	0	6	5.5	*10%*
n35w165	0	0	0	0	0	0	0	0	0	0	3	1	4	2.0	*99%*
n35w170	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	-100%
n35w175	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	-100%
n35e175	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0%
n40w140	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	-100%
n40w145	0	0	0	0	0	0	0	0	0	0	0	4	4	0.8	429%
n40w150	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	-100%
n40w155	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0%
n40w160	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	-100%
n40w165	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	-100%
n40w170	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	-100%
n40w175	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	-100%
n40e175	0	0	0	0	0	0	0	1	0	0	0	0	1	1.8	-44%
n40e170	0	0	0	0	0	0	0	3	1	0	0	0	4	3.5	*15%*
Sim. total	106	99	99	94	99	96	88	66	77	105	101	106	1136	1177.8	*-3.5%*
Actual	104	101	104	101	117	101	81	57	63	100	120	129	1178		
%Δ[a]	1.8%	-2.2%	-4.7%	-6.6%	-15.5%	-5.0%	8.6%	15.4%	22.8%	4.9%	-15.8%	-17.6%	-3.5%	*MAPE =*	*10.1%*

[a] Percentage of the ratio, [(simulated catch) - (actual catch)] / (actual catch)

(1) Assumption of homogeneous vessel type, i.e., the operating costs of some small tuna vessels was much cheaper and hence they can go fishing near and/or south of Hawaii, while such vessels may be limited in their capacity to go distant-water fishing or targeting swordfish.

(2) Only one set of the catchability coefficients are available but ideally two sets are necessary (one for swordfish-targeted sets and another for tuna). If the true catchability for swordfish under the tuna-targeted set is very low, we may significantly overestimate swordfish catch from tuna-targeting sets using the average catchability coefficients for swordfish, and hence lead to an upward bias in overall quantities of swordfish catch.

(3) Fishermen are risk averse rather than risk-neutral, and therefore they hesitate doing distant-water fishing and/or targeting swordfish, which requires more expensive input (i.e., high-risk and high-return).

Closure of Areas near the Hawaii Principal Islands

One of the most popular regulatory instruments is the closure of fishing areas to conserve fish stock size and to avoid gear conflict. In particular, significant quantities of yellowfin are caught by handliners and trollers, and they claim that the longline operations seriously deplete the yellowfin stocks near the Hawaiian islands. Already, longliner vessels are prohibited from fishing within the 200 mile EEZ. Therefore, the closure of two areas, *20N155W* (including Oahu and Maui) and *15N155W* (including most of the Big Island), are examined.

The impacts of this area closure policy on fishing trip allocation is summarized in Table 10. The trips allocated into the two areas which were closed in this simulation (i.e., *20N155W* and *15N155W*) in the baseline case are separately counted from the trips allocated in the other areas. Because of area closure, trips allocated to the closed areas must be reallocated into the other areas. However, the areas where trips are reallocated are more distant and less profitable in terms of wage index (WI). Therefore, in this case, the number of trips reallocated into the other areas was less than the number of trips which were allocated into the closed areas in the baseline case. Consequently, the total number of trips allocated was always reduced by the area closure policy.

Table 10. Trip allocation with and without area closure in Hawaii longline fishery, 1995: The closure of two five-degree squares, *20N155W* and *15N155W*.

	Base Case			Area Closure		
	Closed	Other	All	Other areas[a]		Change in
Month	areas (A)	areas (B)	areas (A + B)	Trips (C)	Change (C - B)	All areas (C - A - B)
Jan	32	74	106	94	+20	-12
Feb	20	79	99	91	+12	-8
Mar	17	82	99	93	+11	-6
Apr	16	78	94	88	+10	-6
May	28	71	99	85	+14	-14
Jun	20	76	96	85	+9	-11
Jul	26	62	88	72	+10	-16
Aug	28	38	66	44	+6	-22
Sep	24	53	77	59	+6	-18
Oct	51	54	105	71	+17	-34
Nov	51	50	101	74	+24	-27
Dec	7	99	106	104	+5	-2
Mean	320	816	1136	960	+144	-176

[a] The number of trips allocated to "closed areas" is zero.

The number of trips was greatly reduced in October (34 trips) since the largest number of trips were allocated into the closed areas in October. The same number of trips were allocated into the closed areas in November, but more trips were reallocated into other areas than in October. On the other hand, only 7 trips are allocated in the closed areas and five of the seven could be reallocated into other areas, and hence the total number of trips allocated was reduced only by two trips. Overall, 320 of 1136 trips in 1995 were allocated into the closed areas in the baseline case, and 144 trips could be reallocated into other areas if the two areas were closed. Hence, a total of 176 trips was reduced by the area closure policy.

Closure of the North Fishing Areas where the latitude is equal or greater than 30° N

There is a strong concern with the conservation of sea turtles, and one option to implement this policy is the closure of fishing areas north of 30° N. Simulation results for this policy are summarized in Table 11. This closure would confine longline vessels within the fishing areas closer to Hawaii, and hence the number of trips will increase. As shown in Table 11, the number of reallocated trips are greater than the number of trips originally allocated into the closed areas. Since most of the catches in the closed areas were swordfish, the area closure substantially reduced swordfish catches (47% reduction, see Table 12).

Table 11. Trip Allocation with and without area cosure in Hawaii longline fishery, 1995: The closure of all five-degree squares north of 30° N.

	Base Case			Area Closure		
	Closed	Other	All	Other areas[a]		Change in
	areas	areas	areas	Trips	Change	All areas
Month	(A)	(B)	(A + B)	(C)	(C - B)	(C - A - B)
Jan	24	82	106	116	+34	+10
Feb	38	61	99	111	+50	+12
Mar	24	75	99	104	+29	+5
Apr	13	81	94	97	+16	+3
May	12	87	99	101	+14	+2
Jun	5	91	96	99	+8	+3
Jul	13	75	88	87	+12	-1
Aug	22	44	66	54	+10	-12
Sep	13	64	77	72	+8	-5
Oct	15	90	105	104	+14	-1
Nov	19	82	101	108	+26	+7
Dec	21	85	106	121	+36	+15
Total	219	917	1136	1174	+257	+38

[a] The number of trips allocated to "closed areas" is zero.

25% lower ex-vessel prices

Ex-vessel price will decrease due to a decrease in demand and/or an increase in tax and fee rates. In this policy simulation, monthly ex-vessel fish prices of the five principal species were reduced by 25%. Results of the simulations are also summarized in Table 12. Average WI, per trip profit and revenue are significantly lower while the catches are reduced by a smaller amount. This is because of the steep labor supply curve, i.e., a reduced income would increase the incentive to allocate more fishing effort. This implies that increasing tax on fishing revenues (auction fees) which are proportional to revenue, will not be very effective in terms of conservation of fish stocks. In other words, area closure is a more effective conservation policy than revenue taxation.

Results on employment (vessel-days), annual total revenue, total shared costs, profit and WI (wage index) are summarized in Table 12. The number of trips are greatly reduced by the area closure of *20N155W* and *15N155W* because the reallocated trips would be further from Hawaii and hence more costly. On the other hand, the closure of the north sea for sea turtle conservation will increase the number of trips because the policy effectively shrinks the feasible fishing area. Employment of fishermen (vessel-days) was most affected by the 25% reduction in ex-vessel prices although the percentage of reduction was much smaller than in revenue, profit, and WI. The shared costs are basically proportional to effort (vessel-days) but the shared costs in the case of the turtle conservation was slightly lower, compared to the other cases because the expensive swordfish sets are reduced significantly. The index "annual average profit per vessel" yields insight into the possibility of some of the vessels exiting the industry due to low annual revenue from longline operations, that may be lower than their fixed costs or annual crew wages. Lastly, the comparison of WI and "profit/trip" indicates that the former is likely to be a better indicator of crew wage level because the latter would likely be higher as the average length of trip becomes longer.

Table 12. Summary and comparison of alternative policies for Hawaii longline fishery, 1995: (i) reducing gear conflict, (ii) sea turtle conservation, and (iii) demand shock.

	Base	Case1 [a]	Case 2 [b]	Case 3 [c]
Trips	1,136	960	1,174	1,030
(Number)		(-15.5%)	(+3.3 %)	(-9.3 %)
Employment	20,663	19,428	19,038	18,340
(Vessel-days)		(-6.0 %)	(-7.9 %)	(-11.2 %)
Revenue	45,095	38,085	35,557	32,359
($1000)		(-15.5 %)	(-21.2 %)	(-28.2%)
Shared Cost	19,246	17,755	17,090	17,077
($1000)		(-7.8 %)	(-11.2 %)	(-11.3 %)
Profit	21,114	20,331	14,734	11,885
($1000)		(-22.6 %)	(-30.2 %)	(-43.7 %)
Profit/vessel[d]	191.9	184.8	133.9	108.0
($1000)		(-22.6 %)	(-30.2 %)	(-43.7 %)
Profit/trip	18.6	21.2	12.5	11.5
($1000)		(-8.5 %)	(-32.5 %)	(-37.9 %)
Average WI	0.737	0.609	0.511	0.443
(Index)		(-17.4 %)	(-30.6 %)	(-39.9 %)
Catch (Number of pieces)				
Striped Marlin	19,602	14,813	20,428	18,868
		(-24.4 %)	(+4.2 %)	(-3.7 %)
Swordfish	43,891	42,629	23,296	40,841
		(-2.9 %)	(-46.9 %)	(-6.9 %)
Albacore	36,041	29,417	34,400	33,682
		(-18.4 %)	(-4.6 %)	(-6.5 %)
Bigeye	58,818	43,659	57,079	57,036
		(-25.8 %)	(-3.0 %)	(-3.0 %)
Yellowfin	22,147	15,683	22,176	21,830
		(-29.2 %)	(+0.1 %)	(-1.4 %)

[a] Case1: Reducing Gear Conflict, where two five-degree squares, 20N155W and 15N155W, are closed.
[b] Case2: Sea Turtle Conservation, where all five-degree squares north of 30° N, are closed.
[c] Case3: Demand Shock, where fish prices are reduced by 25%.
[d] 50% of the fleet profit divided by the number of active longline vessels (110) in 1995.

5. Conclusion and Further Research

This paper develops a spatial and dynamic model of the allocation of fishing effort that explicitly incorporates the spatial distribution of multiple fish stocks, the stock externality from fishing and the relationship between crew wages and fishing effort that is neutral to the duration of the trip and is estimated from primary data. The model is used to simulate the allocation of effort in the Hawaiian longline fishery. The empirical results suggest that area closure is a more effective conservation policy than revenue taxation. For example, the area closure for turtle conservation reduces aggregate quantity of swordfish catch by 47% while the 25% reduction in ex-vessel prices reduces only by 7%, and the area closure of *20N155W* and *15N155W* reduces aggregate quantities of bigeye and yellowfin catch by more than 25% while the 25% reduction in ex-vessel prices reduces only by 3% or less.

The model developed in this paper can be improved in several different ways:

- Initial fish stock size was estimated based on the current catch and hook data, assuming no inflow and outflow. Fish migration is not included in the model but discrete migration (i.e., month-to-month) was included. Possible extensions include incorporating a probability matrix of directional fish movements that may exhibit monthly or seasonal variation.

- We have a heterogeneous cost function (swordfish vs. tuna) but no difference in the set of catchability coefficients for the principal species.

- The supply function uses only 12 (monthly) data points. It is desirable to have at least 3 years data (i.e., 36 months). Estimation of the labor supply function needs to be improved by adding more observations and possibly additional factors affecting fishing effort supply (e.g., time lag, income outside of longline fishery).

- The model does not account for interactions with other gear types (e.g., handline, troll).

- Strong assumptions, such as homogeneous vessels or a constant 10 sets per trip and 1200 hooks per set, could be relaxed for more accurate analysis.

- Locational imperfect competition such as monopoly or duopoly can be incorporated because (i) each vessel often has several familiar fishing spots during particular seasons, information on which is often private and not shared publicly, and (ii) a group of vessels cooperating in searching for fertile fishing locations. In an imperfect competition model, the equilibrium level of allocated effort at each area may be lower than in the perfect competition case. It will be useful to apply Nash bargaining theory or other cooperative and noncooperative game theoretic approaches.

Lastly, the price and catch data used was for the most recent year (1995) available while the cost data used was for 1993. This asymmetry could introduce error in simulation since the Hawaiian fishing industry has undergone significant changes during this two-year period. New data from recent NMFS surveys could be used to further improve the predictive power of the model.

Acknowledgments. We owe a major debt to Sam Pooley for numerous suggestions and insights, as well as Chris Boggs, Marcia Hamilton and Mike Travis of the National Marine Fisheries Service for valuable insights and access to NMFS data.

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Appendix

A Simple Model for Estimating the Catchability Coefficient

In order to implement the fishery model as described in the paper, it is necessary to determine the catchability coefficient (γ_i) of fish species. So in this appendix, we develop the equations for estimating the catchability coefficients. Suppose there is only one species of fish, one area, and one boat type. Start with a widely used but very simple catch function $C = \gamma EB$ from which we form the following series of catches with T periods indexed as $t = 1,...,T$:

$$\begin{aligned}
C_1 &= \gamma E_1 B_1 \\
C_2 &= \gamma E_2 \left(B_1 - C_1 + F_1\right) \\
C_3 &= \gamma E_3 \left(B_1 - C_1 - C_2 + F_1 + F_2\right) \\
&\vdots \qquad\qquad \vdots \\
C_T &= \gamma E_T \left(B_1 - \sum_{t=1}^{T-1} C_t + \sum_{t=1}^{T-1} F_t\right),
\end{aligned} \tag{A1}$$

where C_t is the catch of period t, E_t is fishing effort of period t, γ is the catchability coefficient, B_1 is the initial fish stock of the first period, and F_t is the net fish stock inflow of period t. The net fish stock inflow is defined as the fish stock inflow minus the fish stock outflow, and it is positive if the inflow is greater than the outflow and vice versa. In (A1), the fish stock affected by the catch and the fish inflow and outflow changes from period to period. Dividing both sides of (A1) by effort and substituting the previous period terms into the next period, we get

$$\begin{aligned}
CPUE_2 - CPUE_1 &= -\gamma C_1 + \gamma F_1 \\
CPUE_3 - CPUE_2 &= -\gamma C_2 + \gamma F_2 \\
&\vdots \\
CPUE_T - CPUE_{T-1} &= -\gamma C_{T-1} + \gamma F_{T-1}.
\end{aligned} \tag{A2}$$

$CPUE_t = C_t / E_t$ is the catch per unit effort, and (A2) can be reformulated into change in catch per unit effort ($\Delta CPUE_t$) as a function of catch and net fish stock inflow in the previous period:

$$\Delta CPUE_t = -\gamma C_{t-1} + \gamma F_{t-1}. \tag{A3}$$

Using the principle of conservation which says that the expected fish stock inflow is equal to the expected fish stock outflow plus the expected catch, ignoring the natural and reproduction and mortality, we have the expected value of the net fish stock inflow F_t (fish stock inflow minus outflow) equal to the expected value of catch. Thus (A3) can be rewritten as

$$\Delta CPUE_t = \gamma \overline{C} - \gamma C_{t-1} + \varepsilon_{t-1} \tag{A4}$$

where $\overline{C}$ is the expected catch, and $\varepsilon_t = \gamma F_t - \gamma\overline{C}$ has an expected value of zero. If we assume F_t as a random variable conforming to some standard properties, ε_t can be taken as an error term, and (A4) becomes an estimable equation.

Catchability Coefficient for the Instantaneous Catch Model

There are two problems with using (A4) to estimate the catchability coefficients. First, one prominent defect of the simple catch function is that if the fishing effort is high (i.e., whenever $\gamma E > 1$), the catch can be larger than the whole fish stock. Second, to avoid the problem of the first point, the paper uses a instantaneous catch function instead of the simple catch function. So (A4) is not totally consistent with what have been done in the paper. In view of these problems, we will derive the relationship between the simple catch model and the instantaneous catch model and devise an iterative procedure to correct the catchability coefficient estimated with (A4).

Maintaining the one species, one area, one boat type assumption, the instantaneous catch function takes the following form:

$$C = \left(1-e^{-\gamma E}\right)B. \tag{A5}$$

In order to transform (A5) into the form of the simple catch function, we expand $\left(1-e^{-\gamma E}\right)$ into a taylor series as follows

$$1-e^{-\gamma E} = \gamma E\left[1-\frac{\gamma E}{2!}+\frac{(\gamma E)^2}{3!}-\frac{(\gamma E)^3}{4!}+\cdots\right]. \tag{A6}$$

Define α as

$$\alpha = 1-\frac{\gamma E}{2!}+\frac{(\gamma E)^2}{3!}-\frac{(\gamma E)^3}{4!}+\cdots, \tag{A7}$$

and we can rewrite (A5), with $\tilde{E} \equiv \alpha E$, to get

$$C = \gamma\tilde{E}B. \tag{A8}$$

In (A8), $\tilde{E}$ can be taken to be the "effective fishing effort" obtained by modifying the "raw" fishing effort with α. With all the results above, we can estimate the catchability coefficient for the instantaneous catch function by first getting a preliminary catchability coefficient with equation (A4). Then substitute the value of the preliminary catchability coefficient into (A7) to get α and compute the revised fishing effort $\tilde{E}$. Rerun the estimation based on (A8) and obtain a new estimated catchability coefficient. The new coefficient is used to get a new set of revised fishing effort, and another round of estimation can be performed. The procedure goes on until the catchability coefficient converges.

Entry and Exit in Hawaii's Longline Fishery, 1988-1996: A Preliminary View of Explanatory Factors

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1. Hawaii's Pelagic Longline Industry Before 1988

Historically, the pelagic longline industry has been a relatively small but constant component of Hawaii's commercial fisheries. In 1983, fleet size was approximately 30 vessels and had been as small as 14 vessels during the late 1970s. Most vessels were wooden in their construction and relatively small in comparison to their foreign counterparts. In the late 70s and early 80s, state and federal government officials as well as industry participants maintained that the Hawaii longline industry was underdeveloped with respect to the number of vessels, the size of vessels, and the level of technology employed by the participating vessels. Government and industry representatives further believed that a larger, modernized U.S. longline fleet in the Pacific could significantly increase fish production and income derived therefrom, thus serving as a boon to the U.S. and Hawaii economies. This assessment was primarily based on the performance of foreign longline fleets (particularly the Japanese) in waters that had become U.S. Exclusive Economic Zones (EEZs) after the Magnuson Act of 1976.

By 1988, longline fleet size had increased to 55-60 vessels. Conversions of local lobster and bottomfish vessels were the source of growth during the early and mid-1980s. Many of these converted vessels were slightly larger (i.e., medium sized vessels) than their predecessors and made of fiberglass or steel construction. At this time, the fleet's primary target species was bigeye tuna. However, tunas had not yet become a management unit species under the Magnuson Act. As a result, and also because of the fleet's historically small size, federal officials had not yet established a system to monitor longline activity. In addition to the lack of management or regulation, other circumstances that promoted the conversion of local vessels and subsequent growth of the longline fleet included a longer tuna season, improved fish handling methods, favorable exchange rates, and an increased demand for fresh and/or raw fish (sashimi) by U.S. mainland and Japanese consumers. All of these factors enhanced the longline industry's profitability. As economic theory would predict, in the absence of significant barriers to entry, higher profits attracted human and physical capital to the industry.

2. Migrations from the Gulf of Mexico to Hawaii

Initially, the capital which had been attracted to the industry's increased profitability was local in nature. However, these profits were eventually noticed by fishermen from other areas in the U.S. In the latter part of 1988, two vessels migrated from the Gulf of Mexico to Hawaii: *Captain Glynn* and *International*. The vessel owners' task was to determine if their particular method of longlining could be successfully employed in Hawaii. As per their scouting role, this information was to be shared with their fellow Vietnamese fishermen back in the gulf.

Of the fishermen who eventually came to Hawaii from the Gulf States (between 55 and 60 vessels migrated from late 1988 through mid 1991), most had previously participated in the gulf's shrimp industry. These people of Vietnamese descent had arrived in the gulf area during the mid 1970s after the Vietnam War. They primarily settled into the coastal areas of Texas and Louisiana, probably because many had come from coastal fishing communities in Vietnam. However, owing to reduced stocks, increased fleet size, more regulation, and greater import competition, the shrimp industry fell on hard economic times in the mid-1980s. Prices and catch rates declined while costs increased. In addition, the fishermen maintain that shrimping is very hard work, particularly when compared to longlining. With the advice and training of officials from the National Marine Fisheries Service (NMFS), many

Vietnamese shrimpers converted to pelagic longlining. Those fishermen who were initially trained passed along this knowledge to other Vietnamese fishermen, both while in the gulf and after their migration to Hawaii.

According to the fishermen, vessel purchases had initially cost between $250,000 and $400,000 per vessel, depending on factors such as vessel size, age, and equipment on the vessel. These vessels were steel-hulled and tended to be larger than the Hawaii vessels (medium or large in size), but also relatively low tech with regard to their navigation and fish-finding equipment. The average cost of converting from shrimp trawling to pelagic longlining was approximately $75,000 per vessel. Several families pooled their financial resources to pay for these vessels and their conversion.

Given the relatively shallow and calm waters of the gulf, these fishermen were taught the shallow or surface method of pelagic longlining which could be used to target yellowfin and bluefin tuna at night, unlike Hawaii's longline fishermen who used a deep setting method to target bigeye tuna in the daytime. These Vietnamese fishermen were already accustomed to fishing at night as that was the tradition in their homeland. In the Gulf of Mexico and in Vietnam, fishing was also conducted relatively close to shore for safety and cost minimization reasons. As with bigeye tuna, yellowfin and bluefin tunas were not yet managed species under the Magnuson Act.

The migration to Hawaii was motivated by several factors. First, ever since their arrival on the U.S. mainland, the Vietnamese had experienced integration problems with the local mainland cultures. The Vietnamese fishermen were resented because they were good fishermen with a strong work ethic. However, many mainland locals also maintained that the Vietnamese were unwilling to conform to local customs as well as government rules and regulations. Language and cultural differences confounded communication between the two groups. Given the significant Asian influence in Hawaii, many of the Vietnamese thought their assimilation into Hawaii's social/cultural fabric would be much easier than it had been on the mainland.

In addition, although comparatively fewer vessels were in the gulf's longline fleet compared to the shrimp fleet, the fishermen thought too many vessels were in the gulf's longline fleet as well. Given the fleet's size and a relatively small body of water, particularly when compared to the Pacific ocean, they did not believe there was enough physical space or fish for all the vessels to operate successfully. Increased management of pelagic species in the gulf and Atlantic also hastened their departure. In addition, the scouting reports had indicated that fish prices and catch rates were better in Hawaii than in the gulf. Hawaii's subtropical climate and associated lifestyle were also preferable from the Vietnamese perspective. In general, people will move to where they can be relatively comfortable both economically and socially (i.e., they vote with their feet).

After the two scouting vessels, another group of approximately 14 vessels came to Hawaii in the early part of 1989. Other migrations of similarly sized groups occurred over the next two years. These fishermen tended to migrate in groups or mini-communities in order to reduce and spread the risk or costs of migrating over a long distance in unknown and relatively harsh oceanic conditions. Groups were generally organized on the basis of where they originally came from in Vietnam (i.e. the south, central/inland, or north). Though all share the same written language, each has its own distinct dialect, which explains why these groups continued working together after the migration as well. The first group reported that their migration costs averaged about $35,000 whereas later arriving groups estimated such costs at only $20-25,000 per vessel. It is interesting that those who migrated first estimated their costs to be higher than those who came later. This is possibly a result of two factors: (1) the first group had a greater perception of risk (i.e., those who came later had more information and felt less uncertain about their decision to relocate), and (2) the first group bore a greater proportion of the setup costs (e.g., establishing input and output market channels). Relocating entire families and communities is much more costly in an economic sense compared to relocating operators and crews only. However, the social costs of not relocating the fishermen's families (i.e., not maintaining the family unit) must be weighed against the economic costs of relocation. Unfortunately, quantification of the social costs can be quite difficult if not impossible, thus making the comparison with economic costs equally difficult from the decision maker's and a scientific perspective. Nonetheless, the taken path at least reveals the actors' perceptions of these relative costs.

Unfortunately for these fishermen and their families, they lacked crucial information about the area to which they were relocating. First, the scouts did not gather sufficient information on the cost of living in Hawaii, particularly for entire families, mainly because they lived on their boats at the onset. Much to their dismay, these people discovered that the cost of living in Hawaii far exceeded that of living in the Gulf States. In addition, operation and maintenance costs (e.g., fuel, bait, mechanical repairs, drydock, etc.) were also much higher in Hawaii than in the Gulf States. Possibly most important, the Vietnamese fishermen were ignorant of an informal agreement which existed between the "local" longliners and non-longline fishermen. Per this agreement, longline fishermen would fish at least 20 miles from shore in order to avoid interactions with other fishermen. According to the Vietnamese fishermen, state and federal officials had only made them aware of the requirement to fish beyond state waters, which is only three miles from shore. Moreover, though this is a disputed fact, many Vietnamese allege that they were explicitly invited to move to Hawaii by certain government agencies (namely, the State of Hawaii's Department of Business and Economic Development), just as they had been directed by NMFS to shift from shrimping to pelagic longlining.

When the Vietnamese implemented their particular style of longline fishing in the waters immediately around Hawaii, significant conflicts were created with non-longline fishermen. These conflicts ranged from verbal altercations to destruction of gear and, allegedly, the use of firearms at sea. These conflicts would eventually lead to various regulatory changes and, as a result, the cessation of migrations from the gulf. Many of the Vietnamese fishermen stated that they would not have undertaken the move to Hawaii and the associated costs had they known of the informal agreement. Once aware, they were reluctant to adhere to the agreement because it (1) forced them to fish farther out into unknown waters, (2) increased operational costs,(3) kept them from productive yellowfin tuna fishing grounds, and (4) was not government sanctioned. Moreover, they had played no part in establishing an agreement to which they were presumably obligated. In their view, the agreement should have been revisited with their community having a voice in the decision making process. Otherwise, they would not truly be a part of the local community. Although a few vessels returned to the gulf as a result of these events, most stayed because of the costs of migrating back, the investment they had made in the original migration, and the lack of other known and viable options.

3. Migrations from the West Coast to Hawaii

In addition to the migration from the gulf, approximately 20 vessels migrated to Hawaii from the west coast of the U.S. mainland—California, Oregon, Washington, and Alaska. This particular migration began in early 1989 and continued through mid 1991. All of these vessels had converted from nonpelagic longline gears. These vessels were constructed of fiberglass or steel and ranged in size from small to large. Though some vessels did migrate together in small groups because of common ownership, it could not be characterized as a community movement. This migration was much more individualistic in nature. Thus, not surprisingly, the factors behind the migration of these vessels were somewhat different than for the gulf vessels.

Conversion costs were generally the same as for the gulf vessels. However, given the relatively short distance involved, the costs of migration were considerably less, generally no more than $5000 per vessel. Since these fishermen had already been operating in the Pacific, the waters were not foreign to them, which eased the transition. As with the converted local and Vietnamese vessels, the smaller vessels' owners were attracted to the increased profits associated with harvesting bigeye and yellowfin tuna.

However, the owners of the larger vessels had different motivations. In 1988, the owner-operator of the *Magic Dragon* began experimental trips to target swordfish. Swordfish had never been targeted in the Pacific by U.S. longliners and only rarely only by foreign longliners. This particular fisherman had been fishing in Hawaii's lobster, bottomfish, and longline industries for several years and was looking for new options and sources of profit. To that endeavor, he went to the east coast of the U.S. mainland to enlist the assistance of traditional swordfish fishermen in the Atlantic. After learning their particular method of fishing, he applied it in the Pacific. The events which later transpired speak to his success. Upon his discovery, the owners of these larger vessels came to exploit the relatively untapped swordfish resource, which would eventually turn into the largest component of Hawaii's commercial fisheries in terms of landings and value. Although prime swordfish grounds were found much farther from the islands compared to the tuna grounds (as far as 1000 miles), these vessel owners had the ability to be successful because of their larger vessels (which could handle the harsher weather and seas and travel relatively long distances), their knowledge of the waters and environmental conditions, and their use of higher tech navigation and fish finding equipment.

4. Migrations from the East Coast to Hawaii

The success of the *Magic Dragon* and the larger west coast vessels attracted the attention of another group of fishermen, namely the traditional swordfish fishermen on the mainland's east coast. Some of these were the same fishermen who had taught the *Magic Dragon*'s owner how to target swordfish. These fishermen were considerably experienced at targeting swordfish in distant waters, and sufficiently equipped to do so with their large, steel-hulled vessels and advanced technological equipment. At least initially, these vessel owners were more hesitant to shift their operations form the Atlantic to the Pacific. In this instance, the "community" to be relocated was of a corporate nature and the corporate owners were reluctant to move their vessels such a long distance into unknown waters.

The vessels which were sent to Hawaii from the east coast (most came from New Jersey and Florida) were generally members of corporate fleets composed of 2-7 vessels per corporate owner. Given the associated risks and costs, these corporate owners sent scouting vessels to check out the fishing conditions around Hawaii just as the Vietnamese did. The first of these vessels did not arrive until early 1990. The scouting captains' reports of high catch rates and relatively large swordfish motivated the owners to send all or most of their remaining fleets in late 1990 and throughout 1991.

For many of these vessels, the captains and crew were also sent to Hawaii. However, in few instances did these fishermen also relocate their families. These fishermen either did not have families to relocate, did not want to bear the higher costs of raising a family in Hawaii, or did not see the move to Hawaii as being of a long-term nature. The willingness of some to temporarily separate themselves from their families (or to relocate at all) was generally based on the hope of large, short-term gains. Some corporate owners kept their bases of operations on the east coast, choosing instead to allow their captains to make all the operational decisions and/or fly managers out to Hawaii for periodic reviews. The other, more hands-on owners stayed with their vessels for all or most of the year and instead chose to travel back and forth between Hawaii and their homes on the east coast.

The corporate owners estimated the cost of relocating each vessel to be approximately $40,000 per vessel, which included canal fees as well as fuel, food, and labor costs. The latter were not an expense indicated by the Vietnamese fishermen, undoubtedly because the crew were family. However, the corporate owners indicated that this $40,000 figure did not represent the full cost of relocating their vessels. For example, additional costs were incurred due to establishing new market channels for inputs and outputs. There were also attorney costs associated with fighting the legal battle over whether the late arriving vessels would be allowed into the fishery. Their willingness to fight this legal battle was mainly based on their desire to secure future rights to fish in this fishery. That is, they wanted to maintain as many options for their vessels as possible. Finally, given the length of the trip, considerable costs were incurred due to lost fishing time. Thus, the total estimated relocation cost was approximately $100,000 per vessel.

Other factors behind their migration were related to conditions in the Atlantic. Specifically, the Atlantic swordfish fishery is a well-established fishery with a relatively large number of vessels from several countries. Given that the Atlantic is a smaller body of water than the Pacific, competition over productive fishing grounds between U.S. and Spanish longliners in particular was considerable. Moreover, given the relatively high level of fishing, Atlantic stocks and average fish sizes had begun to noticeably decrease. According to the fishermen, increased competition from Chilean product also caused reduced prices.

Declining stocks in the Atlantic had also attracted the attention of domestic and international management (i.e., NMFS, the councils, and the International Commission for the Conservation of Atlantic Tunas (ICCAT)). One important result was the implementation of annual quotas (TACs) in 1990. The threat of future reductions in the U.S. TAC was perceived as very real. In addition, considerable controversy existed over who had the authority to regulate pelagic species in the Atlantic. Management authority was generally vested in the regional councils. However, by their nature, pelagic species migrate and do not recognize man-made jurisdictional boundaries in their migratory behavior. Apparently, the five regional councils could not agree on how to manage swordfish and other pelagic species. Thus, uncertainty regarding future management was an additional motivating factor.

5. The "New" Hawaii Longline Fishery: 1991-1993

In effect, the influx of vessels into the Hawaii longline industry was akin to the California gold rush of 1849. However, the fleet's size was capped at 163 vessels for all intents and purposes with the moratorium of 1991, which was eventually replaced by a permanent limited entry system in 1994. Another significant management measure imposed in the summer of 1991 was the area closures around the main Hawaiian Islands (MHI). Depending on the island and shore, the closed area for longlining ranged from 50 to 75 miles from shore. Both management measures represented attempts by WESPAC to reduce the conflict between the longliners and non-longliners.

The main fishermen to be affected by the closures were those who targeted yellowfin and bigeye tuna relatively close to shore. Since longline fishermen had to fish beyond the closure, their fuel costs per trip increased. Since fuel costs are in effect sunk once the fisherman has decided to travel out a particular distance, an incentive was created to increase the amounts of other inputs as well, such as ice and bait. That is, if a fisherman has already incurred sunk fuel expenses, it is in his best interest to stay out longer (i.e., set his line more times). Fewer but longer trips becomes the preferable strategy. But, the higher costs per trip increased the financial risk associated with a "bad" trip (i.e., a trip that generates little or no revenue) thereby creating a disincentive to fish.

Not only did the closures increase costs per trip, they also prevented longline fishermen from accessing productive fishing grounds. So, although the rule might have been legitimized as a means to weed out "inefficient" fishermen, that argument loses weight when it is realized that the rule also reduced the longliners' ability to generate revenue. For the local fishermen who targeted bigeye tuna, this effect was mitigated to some extent by a seasonal adjustment to the closed areas. Implemented in late 1992, this adjustment to a 25-50 mile closure was politically feasible only because it occurs during the winter months when non-longline activity is minimal and very close to shore.

However, this change did little to help the Vietnamese fishermen who had adopted a "catch whatever you can" strategy but relied heavily on the revenue generated from yellowfin tuna catches, particularly in the warmer weather months. In effect, this strategy's expected profitability had been permanently reduced, thus providing a strong incentive to change their operations. In addition, the swordfish component of the fishery was booming at this time. Catch rates and prices were relatively high and steady. In fact, profitability had become so great as to even attract the attention of local longliners who had targeted bigeye tuna for years. Although the experiment was short-lived for many (i.e., a few trips at most), some did switch to targeting swordfish for at least part of the year.

In general, the ability to switch targets depends on the operator and his crew as well as the vessel and its accompanying equipment. Successful targeting depends on many factors such as line depth, time of day, type of bait, water temperature, and fishing location by time of year. Some knowledge can be discerned via word of mouth, which is common for fishermen. For example, squid is typically the bait of choice when targeting swordfish even though it is much more expensive per piece compared to the various mackerels used by fishermen who target tunas. Lightsticks are also used, presumably because they attract the squid upon which swordfish prey.

On the other hand, some knowledge is not casually shared across different groups of fishermen. Productive fishing locations is an example of such. Thus, one can only gain such knowledge via trial and error or "spying" techniques. The first can be very costly from a financial perspective while the latter is considered thievery by other fishermen and thus highly resented. But once acquired, information on location can be quickly shared within groups. In addition, information on productive fishing locations is often of only short-term benefit. Pelagic species migrate and do not always follow the same patterns over time. Moreover, fish are generally not attracted to a particular location (i.e., they don't recognize man-made latitudes and longitudes) but rather to certain characteristics of a location. A fisherman must gather information on what those characteristics are and be able to discern which locations have such characteristics. Experience and the proper equipment are necessary to make such determinations. Finally, even with all of the foregoing, a fisherman must also have a vessel that can safely navigate to and from the fishing grounds. For the Hawaii fleet, primary swordfish grounds are typically hundreds of miles from port, thus necessitating a fairly large vessel with a large fuel capacity. Though potentially more lucrative, targeting swordfish is much more costly and thus involves a greater financial as well as a greater safety risk.

As time passed and more fishermen participated in the swordfish component of the fishery, those who had the ability began to fish even farther out in order to locate virgin patches of fish and thereby maintain the average fish size to which they had become accustomed. There was also a desire to separate themselves from other groups of fishermen with whom they did not want to fish. The ability to separate had been somewhat restricted by the closure of productive fishing grounds in the northwest Hawaiian Islands (NWHI) in early 1991. Those who could or did not create separation experienced decreasing effective catch rates in popular fishing areas. All were facing higher input prices (particularly for bait) and increasing maintenance/repair expenses. Even though 1993 was the largest year on record for swordfish landings in Hawaii, for various reasons, profits became squeezed as the fleet moved into 1994.

6. East Coast Corporate Owners Depart and Divest

One of the main corporate owners from the east coast decided to leave the Hawaii fishery in mid-1994. The factors noted previously played an important role in the decision, though others were also involved. Specifically, the owner found himself in conflict with the culture in Hawaii (i.e., how people relate, how and at what speed things are done, etc.). Hawaii's lifestyle is not at all similar to that on the east coast. Events involving the Atlantic swordfish fishery provided an additional lure. Specifically, regulatory changes were in motion that would (1) impose limited entry on the fishery and (2) base eligibility on recent and/or historical participation in the fishery. Thus, once more, a migration was motivated by the desire to maintain future fishing rights. Lastly, productive fishing grounds had also been discovered in the South Atlantic. The cost of approximately $25,000 per vessel was apparently minimal when compared to the expected gains of going back to the east coast.

The other main corporate owner divested itself of all but one of its vessels in 1995 and 1996 by selling them to various hired captains. Swordfish catch rates had declined precipitously as 1994 progressed. Although they improved slightly in 1995, many trips were busts and catch rates were still considerably lower than what they had been in the early 90s. For this reasons and those previously mentioned, 1994 and 1995 were financially disastrous years. The corporate owner also pointed to the lack of a qualified labor pool (i.e., experienced longline captains and crew) and the inability of absentee owners to adequately monitor vessel operations over long distances. On the other hand, the owner noted that, in a time of limited entry and ITQ management systems, a corporate resource base was necessary to legally and economically survive under such management systems. A single owner-operator would be at a significant disadvantage. Given these circumstances, the corporate owner decided to shift out of the commercial and into the recreational fishing sector.

The "east coast" fishermen who remained in Hawaii after the first owner's departure noted that it became more difficult to locate and stay on the swordfish. With the problems encountered in 1994 and 1995, all changed their targeting strategies to fully or partially include bigeye tuna and/or became part of another migratory pattern that emerged in 1995.

7. Migrations Between Hawaii and California

In late 1993, longline vessels from the Gulf of Mexico began arriving in California. By the end of 1994, approximately 30 vessels were operating out of California for at least part of the year, most in Ventura and the rest in San Pedro. Only three of these vessels had historically operated out of California. The owners of these gulf vessels saw California as a location from which to access the same fishing grounds as the Hawaii-based vessels or as a stopping point on their way to entering the Hawaii fishery. Initially, they could not enter the Hawaii fishery with their own vessels because, at the time, limited entry permits could only be transferred along with the permit holder's vessel. When the rules regarding transferability became less restrictive in the latter part of 1994, vessel owners who desired to enter the Hawaii fishery could purchase a permit without an attached vessel. Vessel owners opting for this path reported spending between $35,000 and $60,000 per vessel to move their vessels from the gulf to Hawaii via California.

The gulf vessels were joined in 1995 and 1996 by some of the original east coast vessels and some of the Vietnamese owned vessels from Hawaii. With respect to the latter group, only the owners of the larger vessels were part of this group as smaller vessels were unable to regularly make such migrations. The cost of a one-way migration ranged from $5000 to $15,000 depending on whether the crew was paid for the trip and whether it originated in Hawaii or California. Most of the fishermen fished on their way to and from California in order to minimize the loss of fishing time.

California was an option for these various fishermen because (1) it did not fall within the jurisdiction of WESPAC, (2) the Pacific council had no management plan for pelagic or longline fisheries, and (3) the State of California had only minimal rules in place. With respect to the latter, longliners were only prohibited from fishing within the 200-mile EEZ and landing marlin. The growth of the longline fleet would eventually lead to the implementation of a logbook system in 1996.

Given that California had always been an option, the question is why did the Hawaii-based fishermen choose it in 1995-96? The low catch rates in 1994-95 for the areas north and northwest of the MHI led many fishermen to conclude that the stock of swordfish had migrated eastward (i.e., toward California) for at least part of the year. Eventually, they determined that the fish were closer to California than to Hawaii from September through January. The fishermen found relatively large swordfish close to California in 1994 and 1995, and, as a bonus, relatively large bigeye and bluefin tuna too. Prices were also good (average of $4/lb) regardless of whether they sold through the auction in Ventura or through individual dealers at the docks. According to the fishermen, the auction prices were better than what they were receiving through the Honolulu auction. Furthermore, they received their money much faster from the California dealers compared to the non-auction dealers in Honolulu.

Other advantages to fishing out of California became obvious. Operating costs were generally lower. Most inputs were at least slightly cheaper. Loading times to get supplies on the vessels were less. Trips were generally shorter in length and duration, thus lowering per trip costs and the associated risk of taking a trip. Shipping expenses were zero. Docking fees were considerably lower while facilities were considerably better. Repair and maintenance costs were lower and of better quality. For example, drydock costs were generally half of what they would have been in Hawaii.

However, the California "solution" turned out not to be long-term in nature for most vessel owners. Problems either surfaced or became more noticeable in 1996, which reversed the positive trend of the previous two years. In general, the main problem was the inability to establish a stable longline industry in California. The seasonality of swordfish led to inconsistency in the supply of fish. When combined with threats to other fishermen by established fish dealers, this led to the demise of the Ventura auction in 1996. Input supply became problematic as local suppliers did not sell longline gear. Bait and ice were also of low quality.

From a political perspective, the longline fleet was very unpopular with the local recreational fishermen and harpooners who targeted swordfish. The sources of conflict were bycatch with the first group and perceived competition with the latter. There were also communication problems between the fishermen and the California Department of Fish and Game regarding use and submission of logbooks. Fishermen also ended up paying license fees to land their fish in the order of $400 per vessel plus $150 per crew member. Additional fees were charged to move the fish across the docks.

The situation with respect to catch rates and prices also changed in 1996. Although swordfish were abundant, they were much smaller in size. The same applied to bigeye and bluefin tuna, which lacked the fat content of the previous two years. Prices decreased to $2.75/lb. on average a result of the smaller fish size, the lack of selling options (no auction and only 2 buyers at the docks), and increased competition from Mexican product. As a result of these factors, fleet size decreased to 16 vessels by the end of 1996 and was expected to be the same or less in 1997. Those who left returned to whence they came. Some of these vessels did so under different ownership (i.e., they were bought or repossessed).

8. Migrations Between Hawaii and Fiji

Lastly, the problems with the swordfish component of the Hawaii fishery generated another migration of vessels in late 1994 and early 1995. These vessels were owned by Vietnamese fishermen who targeted swordfish on a full or part-time basis. The uncertainty over whether the Hawaii fishery would recover led them to consider other alternatives. Their eventual decision was to move their operations to Fiji. This group was composed of all vessel sizes, with the larger vessels providing assistance to the vessels with smaller fuel capacities. The migration was organized by the company supplying these vessels. This company had extended considerable credit to these vessels' owners, which placed its own financial situation in jeopardy given the losses of 1994.

The company negotiated entry into the Fijian fishery with the individual considered to be the "Godfather" of the local fishing industry. The company and associated fishermen were shown videos of large fish and catches that could be expected if they were to shift their operations to Fiji. Scouting reports also indicated a relatively low cost of living and low labor costs. The costs of moving were relatively low, ranging from $4000 to $6000 per vessel depending on vessel size. The entry fee was set at 5% of each vessel's appraised value. Allegedly, the vessels were intentionally undervalued to ease entry into the fishery. The license to fish was to be good for five years. Although Fiji appeared to be a good alternative, other Vietnamese fishermen decided not to go because they did not trust the Fijian government. They also knew that, once there, the U.S. government could not provide any assistance. Their fears came to be justified.

Initially, all the vessels lost money as they adjusted to the new fishing conditions in Fiji. The seasonality and migratory patterns of the fish were unknown. The lack of a larger and/or established fleet made it more difficult to generate such information. When the fishermen heard that catch rates and prices were rebounding in the spring of 1995, several of the owner operators decided to return to Hawaii after only 6 or less months.

But, the fishermen who remained eventually determined that the swordfish moved out of Fijian waters during the first 6 months of the year, thus making them inaccessible. Therefore, during that time, they targeted yellowfin tuna. As the fishermen learned the patterns in seasonal abundance and location, catch rates improved throughout the rest of 1995 and into 1996. Unlike in Hawaii, the longliners only had to fish beyond 12 miles. Thus, they also learned to revert back to taking shorter trips with lower amounts of inputs, particularly bait. However, even with the shorter trips, it was difficult to maintain the quality of the yellowfin tuna given the warm water temperatures. Thus, even with relatively high catch rates, trips targeting yellowfin tended to lose money because of the lower prices given to lower quality tuna.

On the cost side, lightsticks and bait were shipped in from the supply company's operation in Hawaii. Conversely, ice and fuel were purchased locally and tended to be more expensive than in Hawaii. Docking costs and repair/maintenance costs were lower than in Hawaii, though the quality of the work suffered from a lack of technically qualified local labor.

The crew and pay structure changed considerably when the vessels went to Fiji. In general, they did not bring their Vietnamese crews with them. Only the captains went with the vessels. Local crew was hired at very cheap rates. The typical cost was $150 per crew member per trip. Even though 7-8 crew had to be hired per trip because of their lack of experience (compared to the normal 5-6 used in Hawaii), labor costs were still considerably less. In addition, the split between the vessel owner and the captain/crew was changed from the standard 50/50 system used in Hawaii to a 60/40 split. Initially, one might think this would improve the owner's financial situation. But actually, the opposite was the case. The owners continually lost money while the hired captains made money, the reasons for which lay in the distribution and magnitude of various costs. The only cost borne by the hired captains was the relatively cheap cost of the labor. Conversely, the owners bore the initial migration and entry costs. Thereafter, they had to pay for repair and maintenance costs, unloading fees, trucking fees, packing fees, shipping fees, consignment fees, and auction fees. Basically, the owners had to pay a fee to every middleman who was involved with getting the fish to market and sold. Ironically, most of the fish were sold through the same market channels as when the vessels operated in Hawaii. Although the gross price per pound of fish was therefore about the same as in Hawaii ($3.00-$3.25 per lb.), the net price per pound was much because of these various fees ($1.50-$1.75 per lb.).

In an attempt to avoid many of these fees, the supplying company applied and was initially approved for a license to directly sell their fish to U.S. and Japanese buyers. Exporting was necessary because of the lack of a significant local market for the pelagic fish. But, after establishing the appropriate market channels, the company was then told the license would not be given. The company and fishermen claim that this outcome was the result of corrupt relations between Fijian government officials and the industry's godfather, who was allegedly involved in every part of the Fijian fishing industry.

For a while, the relatively high catch rates (average of 30,000 pounds of fish per trip) kept the vessels financially afloat. But, when catch rates turned bad in the latter part of 1996 (average of 15,000 pounds per trip), all the vessels went into debt that they could not retire. Of the original 13 vessels that went to Fiji, four were sold to help pay off debts or confiscated. The other nine vessels returned to Hawaii in late 1996 and early 1997. Of those who returned, only four remained with their premigration owners. The other owners were forced to sell their vessels at a loss, mostly to Korean fishermen looking to cheaply expand their operations. As for the supply company that organized the migration, it lost considerable money as a result and is now completely out of the fishing industry.

When the Hawaii longline industry was at its peak in 1993, this company supplied approximately 40% of the fleet.

9. Concluding Thoughts

Based on the events described in this preliminary assessment of vessel entry and exit to and from Hawaii's pelagic longline fishery, expected welfare clearly motivates the decision to leave one fishery in favor of another. Welfare expectations are the result of many factors that can vary across different individuals and groups. For a time, most vessel owners will look for less extreme ways to adjust to welfare reductions, such as a change in targeting strategy. Relocating is a reaction to very high welfare expectations in another fishery and/or very low profit expectations in the current fishery. And although these expectations are affected by conditions in output and input markets, two main factors appear to ultimately lead to a relocation decision: availability of fish and government management/regulation (or lack thereof). Whether these factors *should* dominate fishermen's decisions to relocate is a separate and somewhat moot issue. Still, the first factor's importance makes sense because fishermen cannot generate revenue unless they can catch fish. The latter's significance has been seen through its ability to alter the potential revenues of various fishing strategies, the costs associated with those strategies, and even the availability of particular strategies. Therefore, the impact of changes in management regimes on fishermen's decisions certainly deserves further research.

Workshop on Ocean-Scale Management of Pelagic Fisheries: Economic and Regulatory Issues

November 12-13, 1997
University of Hawaii at Manoa

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