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MODELING THE IMPACTS OF AREA CLOSURES ON THE HAWAII LONGLINE FISHERY: A SPATIAL-TEMPORAL ECONOMIC MODEL INCORPORATING FISH MOVEMENT

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To my parents,

Kihei and Shizue Nemoto

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ABSTRACT

Area closures have been widely used in the management of migratory fish and conservation of endangered marine species, but very few economic models are available to assess the impacts of a closure because economists have paid little attention to complexities in fishery management, such as spatial heterogeneity in fish stocks and fleet dynamics. This study presents a spatial economic model that features (i) heterogeneously distributed stocks of multiple species, (ii) their movement across areas, (iii) travel costs depending on fishing location, and (iv) optimal allocation of fishing trips to areas and of the primary target in each fishing set. Because catch-per-unit-effort (CPUE) diminishes with effort, trips are alternately allocated to several areas, where the expected crew's wages are equalized. While this optimal allocation of trips derives a demand for labor (DDL), fishermen's tradeoff between offshore days (labor) and onshore days (leisure) yields an upward-sloping labor supply curve, which determines, together with the DDL, the equilibrium level of wage and labor.

Using catch and effort data summarized from the federally mandated commercial logbooks into 5° square monthly strata, auction price data, and survey data for longliner's cost structure, this model is applied to the Hawaii longline fishery to conduct policy simulations. While a near-shore area closure leads to fewer trips of longer duration, a closure of the North Pacific to protect sea turtles significantly reduces swordfish catch and significantly increases the catch of near-shore species, which may endanger the stocks of near-shore species or affect the harvests by other boats. The impacts of prohibiting swordfish sets on the industry could be more severe than the above closure for turtle conservation. A revenue tax is not effective in reducing fishing effort.

A closure increases fish movement (FM) from the closed area to open, neighboring areas, resulting in higher levels of the stocks in those open areas. This FM effect benefits the fishery industry, and could reduce the fishermen's income loss from a closure – estimated by the model without FM – by half, if fish are mobile and the closed area(s) is a "source" in terms of the direction of movement.

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PREFACE

This dissertation is the most updated report of a project of the Pelagic Fisheries Research Program (PFRP), entitled "*A Dynamic Model to Evaluate the Effect of Regulation on the Hawaii Commercial Fisheries*" (Project No. 2118, Principal Investigator (PI): Ujjayant Chakravorty), the Joint Institute for Marine and Atmospheric Research (JIMAR), University of Hawaii (UH). It should be noted that economic and legal atmosphere surrounding the Hawaii longline fishery has dramatically changed since this project started at August 1996.

As mentioned in Chapter 1 and Appendix 1, the rapid growth of the longline fishery was primarily initiated by successful discovery of prime swordfish grounds north of the main Hawaiian islands, by the large vessels that migrated from the East and West Coasts of the US continent in the late 1980s. Meanwhile, bycatch control/protection of endangered species, such as sea turtles, became one of the major concerns of the Hawaii fisheries, followed by the critical litigations and court actions during 1999-2001 (Appendix 1). As a result, swordfish-targeted sets (and all other shallow sets) by the Hawaii-based longline vessels, which used to boost the Hawaii fisheries, have ironically been ruled out after March 30, 2001, because longline sets targeting swordfish are believed to be more dangerous to turtles than those targeting bigeye tuna.

Unfortunately, this dissertation research is not completely elaborated with those latest events, due to time constraints. In particular, empirical studies including regulatory policy simulations were done using the NMFS logbook records and market data from the Hawaii Division of Aquatic Resources (HDAR) during 1995-1997. Thus, the reader should interpret the empirical results with caution, considering those latest changes in the Hawaii longline fishery.

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CHAPTER 1
INTRODUCTION

1.1 Problem of Fishery Resource Management

Fishery resources worldwide have been overused in the context of capitalized economies, primarily due to the absence of clearly defined property rights over fishery resources; i.e., negative externalities are costless to the individual. The "race to fish" in traditional open-access (unrestricted access) fisheries results in rent dissipation and over-exploitation of fish stocks (Gordon, 1954). Restricted access, which is known as limited entry or license limitation, proposed in the 1960s was viewed as the replacement for the missing property rights in open access fisheries. Limited entry was aimed at preventing overcapitalized fleets from expanding further. However, experience with limited entry showed that excessive exploitation of fishery resources often continued or even intensified. This was primarily because limited entry did not limit the catch of fish but controlled only certain inputs, and hence gave fishermen an incentive to increase their harvesting capacities by substituting unrestricted economic inputs for those specified by the license.

Around the late 1970s, another approach to restrict the over-exploitation of fishery resources was advocated. Under this system, the total allowable catch (TAC) in a fishery, which is generally established for biological management objectives[1], could be allocated among harvesters. Property rights in this system are better defined since (i) licenses would not only convey access rights but also an exclusive right to take a specific quantity of fish, and (ii) rights would be private property and transferable between operators (Squires, Kirkley and Tisdell, 1995). This harvest-rights approach, individual transferable quotas (ITQs), has been heralded by many fishery economists as the panacea for the management problems that beset most of the world's fish stocks.

[1] For example, New Zealand law requires that TAC be set to produce the maximum sustainable yield (MSY), modified by factors such as economic and environmental considerations (Squires et al., 1995).

However, in a comprehensive review of the regulatory experience with ITQs, Squires, Kirkley, and Tisdell (1995) suggest that many countries still prefer input controls to ITQs in fisheries with multiple and/or migratory species and bycatch problems as well as in situations where the costs of monitoring, enforcement and resource assessment are significant. Other "second best" management methods, such as area closures and gear restrictions, have been adopted in more extensive and multiple species/fleets fisheries in several countries such as the United Kingdom, Norway and Italy. In particular, area and seasonal closures have recently become more widely used in the management of migratory and/or multiple species. Seasonal closures on the central Queensland prawn grounds have been used as a yield-maximizing technique (Gribble and Dredge, 1994). Area closures are increasingly used for the management of pelagic and bycatch species in Gulf of Mexico , Northwest Atlantic, and North Pacific (Kerstetter, 2000).

A large body of literature (see survey by Townsend, 1990) examines the economic and biological impacts of limited entry policies, while other economists consider ITQs (Squires et al., 1995) and various forms of limited entry programs (e.g., gear restrictions). Most published studies have either focused on a single regulatory instrument, such as a quota on harvest or gear restriction or a combination thereof (Moussali and Hilborn, 1986; Stollery, 1984). Other analyses have attempted to endogenize the length and timing of closures in a programming model of stock recruitment (Watson, Die, and Restrepo, 1993). These models, by and large, implicitly assume away "substitution effects" of area closures, i.e., when a certain fishing ground is closed, fishing effort that used to be allocated in this closed area may be reallocated elsewhere[2].

Several studies suggest that these substitution effects may be quite significant. For example, Cadrin et al. (1995) point out that when stocks are migratory, closure of inshore areas to more efficient vessels "may not confer the expected benefits because fishing effort will be displaced to unprotected areas." Closure of inshore fishing areas led to

[2] The "substitution effect" here means a short-term impact of area closures and hence excludes the "entry-exit" of vessels, such as when a vessel changes its base from Hawaii to California.

increased allocation of effort to onshore fishing grounds in the Gulf of Mexico brown shrimp fishery (Gracia, 1997). In 1999, the Federal district court in Hawaii closed an area of the North Pacific to Hawaii-based longline vessels as the result of a lawsuit filed by environmental groups trying to protect sea turtles (Appendix 1; TenBruggencate, 1999). Uncertainty about the economic impacts of this closure on the fishery, including fishermen's income losses, was one of the major concerns. While the fishing ban would be costly to the industry, the substitution effect -- the relocation of fishing trips by Hawaii-based longliners to unprotected areas -- might considerably mitigate fishermen's income loss.

1.2 Hawaii Longline Fishery

Since the late 1980s, the Hawaii longline fishery has grown rapidly. The revenue from longline vessels accounted for more than 80% of the gross Hawaii domestic commercial pelagic revenue in 1997 (about $61 million), up from less than 30% in 1980 (WPRFMC, 1997). The remaining revenue is from baitboat (pole-and-line skipjack), handline and trolling (Figure 1.1). During the 1990s, the major species targeted by longliners were broadbill swordfish and bigeye tuna (He, Bigelow, and Boggs, 1997), while yellowfin and albacore tunas and blue and striped marlins also represented a significant share of the total revenue from longline vessels (Table 1.1). The revenue from these six species accounted for approximately 90% of the total ex-vessel revenue in 1995-97.

Fishing areas for Hawaii-based longline vessels are located between latitude 5° N to 45° N and longitude 140° W to 170° E. Distribution of fishing effort as well as catch-per-unit-effort (CPUE) varies over space and time, and catch and revenue from a given effort level also depend on location and season (Curran, Boggs, and He, 1996). A longline vessel, on average, spends 9.6 days traveling during a fishing trip. However, the number of traveling days varies depending on the distance from the port to destination, while approximately 10 days each trip are spent for fishing[3] (Hamilton, Curtis, and Travis, 1996). Thus, travel

[3] The number of fishing days per trip also varies across fishing trips, and particularly is correlated with the primary target of a trip. See Chapter 3 for the details.

costs account for a significant portion of the total costs of a longline trip, and depend on fishing locations during a trip.

Area Closure as a Primary Regulatory Tool for the Hawaii Fisheries

In the last decade, several distinct regulatory policies were implemented in the Hawaii longline fishery: (i) a moratorium restricting new entry was imposed during 1991-1992 and later replaced with the limited entry system in 1994, (ii) longline fishing was excluded from the near-shore areas around the main Hawaiian Islands (MHI), (iii) longline vessels were also excluded from a 50-mile zone around the Northwestern Hawaiian Islands (NWHI) to protect endangered Hawaiian monk seals from potential interaction with longline vessels, (iv) the Federal district court in Hawaii closed a vast section of the North Pacific in 1999-2000 for sea turtle conservation and subsequently, this closure has been revised a few times (see Appendix 1 for the details), and (v) the State of Hawaii implemented a landing restriction on shark fins.

The first two regulatory policies were implemented in 1991 for the following reasons: (a) conflict between the growing longline fleet and the mixed local fleet of small commercial, charter, subsistence and recreational trollers and handliners which operate in the near-shore waters of Hawaii; and (b) the potential biological impact of the growing longline fleet on some pelagic species, particularly on North Pacific swordfish (Pooley, 1994). Longline and surface fleets (trollers and handliners) had often fished in the same locations, especially within 20 nautical miles (NMI) of the shore (Skillman, Boggs, and Pooley, 1993). In the late 1980s, many longline vessels migrated to Hawaii from the Gulf of Mexico, the West Coast, and the East Coast (Travis, 1999), resulting in a rapid increase in the number of longline vessels from 50 in 1987 to 141 in 1991. While this fleet migration led to significant increases in longline landings, troll and handline landings of several pelagic species (e.g., yellowfin) substantially declined during the same period. Because these two phenomena happened simultaneously, the small boat fleets, including trollers and handliners, believe that their catches were reduced by longliners. In order to limit gear conflicts including short-run stock and crowding

externalities, the number of the Hawaii-based longline vessels was capped at 163 vessels and longline fishing was excluded within 50-75 NMI from the MHI. A similar 50-mile area closure was imposed around the NWHI. Another reason for the moratorium restricting new entry was to avoid the potential over-exploitation of swordfish, because swordfish landings increased substantially from 50,000 lb. in 1987 to more than 13 million lb. in 1993.[4]

As policies (iii), (iv) and (v) indicate, bycatch control/protection of endangered species, including sea turtles and birds, sharks, and marine mammals (e.g., monk seal), is one of the major concerns of the Hawaii fisheries. Bycatch and finning of sharks has emerged as a major concern, because (a) the number of sharks caught and finned had rapidly increased in the 1990s; (b) sharks are theoretically sensitive to over-fishing due to their slow maturity and long life-span, and (c) sharks may play very important roles in the marine ecosystem (Curran, 2000).

Interaction between longline gear and endangered species was reported in the logbook data (Ito, 1995). The interaction of longline vessels with monk seals is unlikely to be crucial any more since no interaction has been reported since the NWHI area closure was implemented (Ito, 1995). As mentioned earlier, the conservation of sea turtles is very urgent (Appendix 1). Leatherback, green sea, loggerhead, and olive ridley turtles were reported to have been accidentally caught a total of 84 times during 1994, although these interactions are widely believed to be under-reported. Kleiber (1998) estimates that approximately 700 sea turtles were taken and around 100 were killed in 1995. Most of the loggerhead and leatherback turtles were caught in the areas north of 30°N.

In order to protect sea turtles from being hooked or entangled, fishery biologists such as Nitta and Henderson (1993) suggested closing fishing areas north of 30°N. However, this

[4] Note that swordfish landings dropped and became stabilized between 5 and 7 million lb. afterward (WPRFMC, 1997). Reasons for this sharp drop include the out-migration of some longline vessels that were specializing in swordfish fishing (Travis, 1999).

turtle conservation policy would have been costly because the North Pacific includes the most valuable fishing grounds for the Hawaii swordfish industry and the economic loss by the area closure would have been significant. Polovina et al. (1999) observed that loggerhead turtle habitat may be strongly associated with sea surface temperature (SST), and suggested an alternative area closure policy prohibiting longline fishing in water colder than 18 - 18.5°C. The closed area in this regulatory policy would, on average, be smaller than that proposed by Nitta and Henderson (1993), particularly in the third and fourth quarters. Hence its adverse economic impacts on the Hawaii longline fishery could be moderate, compared with the year-round closure of fishing areas north of 30°N. Subsequently, despite many controversies, a fishing ban restricting Hawaii longliners from fishing in a zone north of 28°N latitude and between 150 and 168°W was imposed in December 1999. It was to continue until the National Marine Fisheries Service (NMFS) could complete an environmental impact statement (EIS) on the turtle issue (NMFS, 2001)[5].

Thus, area closure is a relevant regulatory policy option for Hawaii fishery management. Specifically, one of the crucial empirical questions for fishery managers may be "how much potential income loss can longliners sustain in preventing certain sea turtles from accidentally interacting with longline gear?" Also, changes in catch of each species due to the redistribution of fishing effort triggered by area closures may be important. However, no empirical model has yet been developed to quantify the economic impacts of such an area-closure policy on the Hawaii fishery industry. A spatial model is needed to answer such a question.

However, two PFRP[6] projects provide useful information to this study. The project team in Hawaii Pelagic Fishing Vessel Economics (Project 2046, Principal Investigator (PI):

[5] That EIS was completed in March 2001 at which point different time-area-gear restrictions were imposed.
[6] The Pelagic Fisheries Research Program (PFRP) was created to provide scientific information on pelagic fisheries to the Council for use in development of fisheries management policies. The PFRP is funded by the National Oceanic and Atmospheric Administration (NOAA), and located at the Joint Institute for Marine and Atmospheric Research (JIMAR), under the University of Hawaii's School of Ocean and Earth Science and Technology (SOEST).

Sam Pooley)[7] has analyzed (i) the relationship between vessel's profitability (cost-earnings) and vessel type, target and other factors, based on the survey (e.g., Hamilton, Curtis, and Travis, 1996) and (ii) the entry/exit behavior in the Hawaii longline fishery (e.g., the movement of longline vessels between the U.S. mainland and Hawaii).

Another PFRP project, "A Multilevel and Multiobjective Programming Model of Hawaii Commercial Fisheries" (Project 2113, PI: PingSun Leung and Stuart Nakamoto), has developed a model that quantifies the economic impacts of regulatory policies on Hawaii fishery industry (see Pan et al., 1999). In their model, fishing areas for Hawaii fisheries are simply divided into five regions based on the distance from Honolulu. However, the closed areas for protecting endangered species (e.g., sea turtles, seabirds, and sharks) are likely to be vast square or rectangle areas, defined by latitude and longitude. Thus, the definition of fishing areas in Leung et al. (1999) is not suitable to examine the impacts of the above area closure policies on marine species conservation.

1.3 Research Purpose

Economists have given little attention to complexities in fishery management, such as the spatial dimensions of population and its movement, which result in few answers to specific questions often asked by managers (Deacon et al., 1998). Although a few fleet spatial dynamic models are found in the literature, such as Hilborn and Walters (1987), Sampson (1992), Sanchirico and Wilen (1999), none is empirically applied. This may be due to a lack of data or because these economic models are still too simplistic to explain reality. Although models developed by biologists often contain age- or size-structure, gear selectivity as well as spatial dimensions, these models also cannot be used for regulatory policy analysis since they do not include fishermen's behavior.

This suggests the need for an empirical model that incorporates biological information on spatially disaggregated fish stocks and their movement over time into an economic

[7]A study by Curtis (see Curtis and Hicks, 2000), focusing on the spatial allocation of longline effort, is not discussed here since her study was not available in the beginning of this research project.

framework that includes fishermen's behavior and determines the benefits and costs of alternative regulatory policies. The literature suggests that a spatial model may need to include the following features:

(i) *An Appropriate Catch Function for a Spatial Model*

Hilborn and Kennedy's (1992) empirical study of the Tasmanian Rock Lobster Fishery with multi-port and multi-fishing areas supported Gordon's theory that net rate of return would be equalized across fishing locations. They also suggest that the catch rate in each area would decrease with the amount of fishing effort allocated in the area within a given period. This feature of the catch function is essential for a spatial fishery model.

(ii) *Detailed Operating Costs as a Function of Fishing and Traveling time*

Sampson (1992) developed a theoretical model for the short-run selection of fishing location by a profit-maximizing fisherman in an open-access fishery. His model demonstrates that it is crucial to distinguish traveling time from fishing time to account for the heterogeneity of operation costs over space, while the ex-vessel revenue is also heterogeneous over space since catch per unit fishing time depends on abundance at each fishing location. Traveling time is estimated by dividing twice the distance to fishing location from port by the average vessel speed.

(iii) *Non-monetary Costs Associated with Fishermen's Behavior*

Hilborn and Kennedy (1992) suggested non-monetary costs should be accounted for in calculating net returns, and the major non-monetary cost might be the fishermen's desire to be near home. Gautam, Strand and Kirkley (1996) point out that the "labor-leisure" tradeoff would be an important determinant of fishermen's labor supply decision; that is, fishermen would not go fishing if the income from spending another day fishing or staying at sea is not enough to compensate the disutility of reducing limited leisure opportunities. Moreover, due to income effects on the consumption of leisure, the labor supply function may, in the short run, exhibit backward-bending properties.

(iv) *Fish Movement*

Many biologists have explored a range of spatial population models (Sanchirico and Wilen 1999). Hilborn (1990) and Kleiber and Hampton (1994) present fish movement in a matrix form of probabilities, which are relatively simple. Some biologists described the movements with three components -- velocity, direction, and diffusion (Deriso, Punsly, and Bayliff 1991; Sibert, et al. 1999). A significant change in catch in a particular area will have an impact on the next period's initial stock in the area as well as the surrounding areas. For example, if certain areas are closed, fish would be more abundant in these areas due to no fishery catch, resulting in more fish movement from the closed area to the neighboring open areas in the next period. Therefore, fish in the neighboring open areas may be more abundant in the following period, by accounting for fish movement. Thus, a spatial model should incorporate fish movement patterns.

1.4 OBJECTIVES

The primary objective of this study is to develop a bioeconomic model that explicitly incorporates spatially disaggregated fish stocks, fleet spatial dynamics, and fishermen's behaviors, and to apply it to the Hawaii longline fishery to examine the economic and environmental impacts of area closure and tax policies. The specific objectives are to:

(i) Validate the theoretical model by applying it to the Hawaii longline fishery.

(ii) Estimate the impacts of the following regulatory policies on the fisheries industry and marine resource conservation:

- Closure of inshore area to reduce gear conflicts (including stock externalities),
- Closure (including seasonal closure) of northern areas to reduce incidental catch of sea turtles,
- Prohibition of swordfish sets to protect sea turtles, and
- Additional revenue tax on all species to reduce fishing effort.

Economic impacts are measured by changes in spatial allocation of fishing effort including choice of set types (targeting tuna or swordfish), overall industry revenue, tax revenue to the State government, and incomes accruing to boat-owner and crew,

while effects on resource conservation are measured by the reduction in catch of marine species.

(iii) Re-estimate the impacts of the above regulatory policies using a modified simulation model that incorporates fish movement patterns.

1.5 Outline of Dissertation

Chapter 2 describes the theoretical model. The empirical model applied to the Hawaii longline fishery is explained from Chapter 3 through Chapter 5. Chapter 3 describes how to calibrate the theoretical model for the Hawaii longline fishery, including the data for fish prices and operating costs of a longline trip, and the simulation algorithm. Chapter 4 focuses on how to estimate catchability coefficients of major species from catch and effort data. In this study, catchability is differentiated according to primary target of each fishing set. Chapter 5 describes the estimation procedure and results of a labor supply function. In Chapter 6, the empirical model, with fish prices, the estimated stocks by location, and other parameters, replicates longline trips over space and time. The results are compared with actual trip data to validate the model. Then the following four regulatory policies are simulated: (i) reduction of gear conflicts near-shore, (ii) closure of the North Pacific for sea turtle conservation, (iii) prohibiting swordfish sets, and (iv) an additional 10% revenue tax. Note that the empirical model does not incorporate fish movement (FM) yet in this chapter. Chapter 7 describes how to extend the original model to incorporate FM, and presents the estimated FM functions, which are later used to conduct the simulations of area closures and examine the effect of FM. The final chapter, Chapter 8, includes a summary of the models, findings, policy implications, and suggestions for further research. Tables and figures are placed at the end of each corresponding chapter.

Table 1.1 Hawaii longline landings and revenues, 1995-97
(Source: NMFS Honolulu Lab.)

Name	1995			1996			1997		
	Landings (x 1,000 lb.)	Revenue (x $1,000)	Ave. Price ($/lb.)	Landings (x 1,000 lb.)	Revenue (x $1,000)	Ave. Price ($/lb.)	Landings (x 1,000 lb.)	Revenue (x $1,000)	Ave. Price ($/lb.)
Marlin, Blue	1280	1100	0.86	1,000	1,000	1.00	1100	900	0.82
Marlin, Striped	1200	1080	0.90	900	1,100	1.22	800	1000	1.25
Swordfish	6010	13460	2.24	5,500	13,700	2.49	6350	14000	2.20
Sharks	3490	830	0.24	4,300	1,800	0.42	5000	2000	0.40
Mahimahi	570	810	1.42	400	800	2.00	500	600	1.20
Moonfish	630	600	0.95	800	800	1.00	800	900	1.13
Ono (Wahoo)	200	330	1.65	100	300	3.00	250	400	1.60
Other	510	440	0.86	400	500	1.25	500	600	1.20
Subtotal (Non-Tunas)	13,890	18,650	1.34	13,400	20,000	1.49	15,300	20,400	1.33
Albacore	1930	2080	1.08	2,600	3,400	1.31	3600	4500	1.25
Bigeye	4580	15340	3.35	4,000	14,100	3.53	5400	17400	3.22
Yellowfin	2150	6110	2.84	1,400	4,250	3.04	2500	6700	2.68
Bluefin	60	1010	16.83	50	900	18.00	50	800	16.00
Skipjack	50	160	3.20	100	50	0.50	250	200	0.80
Subtotal (tunas)	8,770	24,700	2.82	8,150	22,700	2.79	11,800	29,600	2.51
Total	**22,660**	**43,350**	**1.91**	**21,550**	**42,700**	**1.98**	**27,100**	**50,000**	**1.85**
Subtotal from Major 6 speceis	17,150	39,170	2.28	15,400	37,550	2.44	19,750	44,500	2.25
(% of Total)[a]	*75.7%*	***90.4%***		*71.5%*	***87.9%***		*72.9%*	***89.0%***	

[a] This percentage is used as a correction factor to scale up the ex- vessel revenue (Chapter 4).

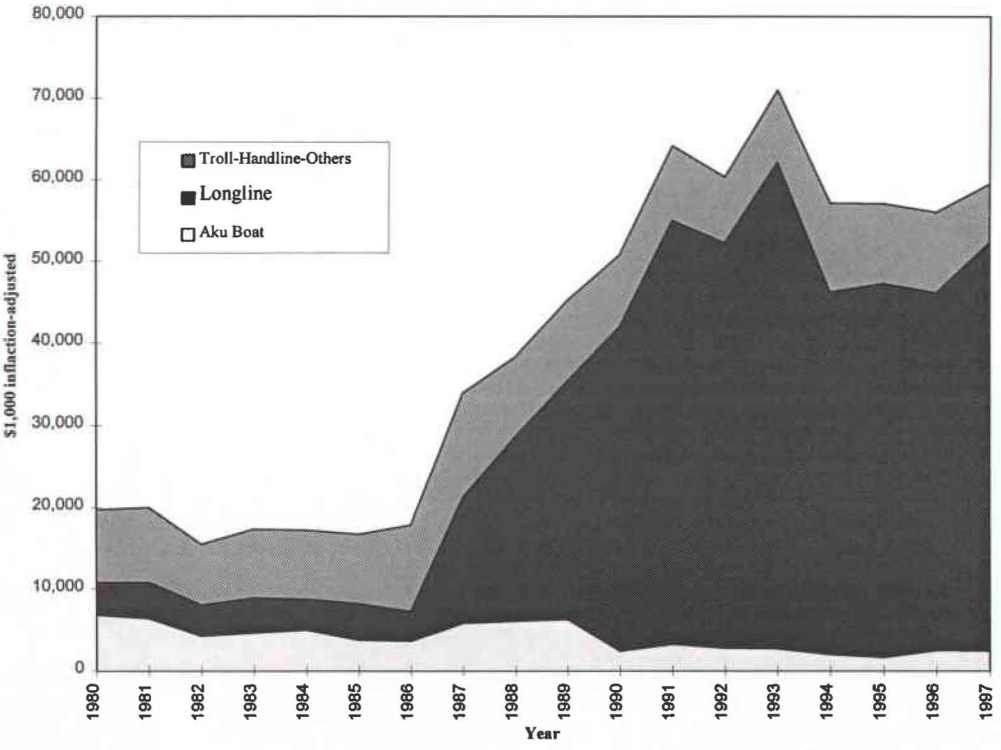

Figure 1.1 Hawaii commercial fishing revenue, adjusted for inflation, 1980-1997
(This figure was created from the data published in WPRFMC (1998)

CHAPTER 2
SPECIFICATION OF A SPATIAL FISHERY MODEL

The proposed model is based on a standard framework for maximizing fleet profit by risk-neutral fishermen in the short run, where the allocation of fishing effort in each period is determined over space based on the comparison of net revenue from each fishing location. The fishery is considered an unconstrained limited-entry fishery, where the total number of vessels is fixed and area closures are used to achieve regulatory objectives such as conservation of marine species including bycatch species.

The model described in this chapter includes the following components:

(1) catch function with
- diminishing CPUE (catch-per-unit-effort),
- multiple species
- multiple set types (i.e., primary targets are differentiated)

(2) trip revenue function (i.e., each vessel is a price-taker)

(3) trip cost structure, including:
- differentiated traveling costs depending on the distance from a single port,
- profit-sharing between boat owners and crew,

(4) an aggregate labor supply (LS) function for the fishery industry, and

(5) fish movement (FM) across fishing areas between two consecutive time periods.

Major assumptions/restrictions imposed on the model here are as follows. First, this model is discrete (not continuous) in terms of space and time. Second, this is a short-run model, where no entry-exit of vessels to the industry is allowed in the time period considered, and fixed costs are not considered in the optimal allocation of fishing trips over space. Furthermore, in the model the industry consists of homogeneous fishing vessels, implying that vessel's features (capital) are the same across vessels and fixed over time. Third, fishermen are assumed to be risk-neutral and have perfect knowledge about stock sizes in each area and fish prices of all species.

Vessel's Owner-Crew Relationship and Crew's Supply Behavior of Labor

One of the unique features in this model is that the labor cost (wage bill) is differentiated from other daily operating costs, which are considered constant. Because of the profit sharing system between the vessel's owner and crew, the crew can be considered as a self-employed worker (see Section 2.4 for details). Since the crew maximize their utilities by trading off between offshore days (labor) and onshore days (leisure), the payment accruing to the crew, in general, needs to be higher to give the crew incentives for working longer. That is, the industry's labor supply (LS) is considered an increasing function of the expected crew's wage. Since fish abundance in each area and fish prices usually fluctuate considerably over months or seasons, the crew's wage also changes greatly, implying that the total amount of labor supplied by the industry could largely depend on this LS function as well as the expected crew's wage.

Derived Demand for Labor (DDL)

Demand for labor is derived (DDL) as a factor demand for a production (or harvest) system, by optimally allocating fishing trips across areas. Each fishing trip with the fixed number of fishing sets is allocated to a single area that yields the maximum crew wage. Various stock sizes across fishing areas and fish price of each species during each period affect the fleet revenue per trip, while distance between the port and each area determines trip length and travel costs. Fishing sets are differentiated according to the primary target (*e.g.*, tuna or swordfish), which affects the catchability of different species as well as fishing costs per set. Thus, the choice of set types within each trip also determines the trip's profitability.

As more trips are allocated into a particular fishing area, the expected revenue and net return per trip from that area diminish due to the stock externality. Hence, the next trip may eventually be allocated to another area because it becomes more profitable than the area in which the previous trips are allocated. Subsequent trips are alternately allocated to a number of areas to maximize the crew wage, resulting in the crew's wages from trips to

each area being equalized across areas.[1] Plotting the optimal points of the computed crew's wage with the total amount of labor yields a downward-sloping DDL curve. This trip allocation process ends when the DDL curve intersects the labor supply curve (i.e., the industry reaches an equilibrium), implying that the crews are unwilling to take any additional fishing trips with the given expected wage.

The model first assumes that the stock sizes of all species in all areas are given. Later the model is extended to incorporate fish movement (FM), where the stocks of each species at the next period are determined by the initial stocks, catch, and movements of each species across areas at the present period.

2.1 Catch Function and Expected Trip Revenue

Consider a fishery in which there are I species of fish (*e.g.*, bigeye and yellowfin tunas and swordfish) denoted by $i = 1,...,I$ and K fishing areas or locations, indexed by $k = 1,...,K$. Stocks of different species are assumed to be known to the fishermen at the beginning of a given time period in each area. These time periods are chosen to be sufficiently short that stock changes in each area within a period due to fish reproduction, natural mortality, and movement across areas can be ignored; *i.e.*, fish stocks within a period are expected to decrease only due to harvesting within that period.

The catch for species i in area k within this time period t is given by:

$$C_{i,k,t} = \left(1 - e^{-Z_{i,k,t}}\right) B_{i,k,t} \qquad (2.1)$$

where subscript t is denoted as period t,

$B_{i,k,t}$ = stock for species i in area k in terms of population,

$Z_{i,k,t}$ = total effort index (nonnegative), and

$(1 - e^{-Z})$ = fishing mortality rate for species i in area k.

[1] Sanchirico and Wilen (1999) call this a rent dissipation process with Richardian notions that resources are exploited across space in a pattern depending upon profitabilities.

As specified in (2.1), the fishing mortality rate, $(1 - e^{-Z})$, is an increasing function of total effort index Z within the limits of 0 and 1, and exhibits diminishing marginal returns (i.e., catch-per-unit-effort, CPUE, decreases with effort), due to the stock externality (see Chapter 5 for the detailed analysis of catch function). Fish stock is also assumed to be "infinitely diffusive" within area k; *i.e.*, the density of fish is linearly related to the residual stock size and is distributed uniformly within each fishing area (Clark 1985).

Assumptions/Restrictions on Vessel's Behavior

Several restrictions are imposed on fishing boats: all boats are identical and once the boat reaches a fishing area k, each boat conducts the same number of fishing sets over an equal number of days during each trip (for instance, spending 10 days for fishing in which 10 fishing sets are conducted). The industry and individual boat maintain the following assumptions: (i) a homogeneous fleet, (ii) each boat uses a single fishing area per trip, (iii) a fixed number of fishing sets per trip, and (iv) spending one day per fishing set are assumed.

Although, in reality, the actual number of fishing sets per trip varies across trips for various reasons, the number of fishing days per trip is assumed to be the same across trips for simplicity. In addition, since all boats and fishing gears are assumed to be homogeneous, the assumption of the same number of fishing days per trip may be reasonable because (i) boats would have the same storage capacity for bait and harvested fish, and (ii) the days spent fishing may be limited since the quality of the freshly harvested fish on board begins to decline rapidly with time.

It is also assumed that each trip involves direct travel to the chosen destination and return to port; *i.e.*, fishing in multiple areas within the same trip is not allowed. Multiple locations would complicate the algorithm for allocating fishing sets over multiple areas and the computation of travel costs, and would necessitate making assumptions about the sequence of fishing locations within the same trip[2]. If the majority of vessels fish in a

[2] Curtis (1999) models vessels' choices of multiple fishing areas within a trip, resulting in a lengthy computer program, although her model does not include stock externalities or labor-leisure tradeoff.

single area and the remaining vessels move to a few neighboring areas, then the restriction of the single fishing area per trip could be reasonable; i.e., resulting aggregate fishing effort in each area would not be altered by this restriction. On the other hand, returning boats could be picking up additional catches (e.g., fresh tuna for sashimi) in the near-shore area during their return to the port (Kelleher 1997), which is not considered in this model. Future extensions of the model might include multiple fishing locations within a single trip as well as endogenous fishing days per trip.

Differentiated Set Types according to the Primary Target

While the fishing fleet is assumed to be homogeneous, each boat is allowed to alter the primary target in each fishing set (i.e., multiple set types). For an example from the longline fishery, a set type may be characterized by the number of hooks, depth of hooks, type of bait, usage of lightsticks, etc., in order to target a specific species. Then the number of days a boat chooses to target (e.g., tuna or swordfish) may vary, while the total number of fishing days per trip (FD) is fixed, such as

$$FD = \sum_{s} FD_{k,s,t}$$

where s represents alternative set types, and $FD_{k,s}$ is the (average) number of days a boat is of type s within a trip in area k. The allocation of set type within a trip is a choice variable (endogenous), while the number of fishing days per trip is fixed.

Also each boat is assumed to expend the same (nominal) fishing effort for each set type but the nominal fishing effort per set is differentiated across set types[3]. For example, longliners use more hooks for a set targeting bigeye tuna than targeting swordfish. Then the total amount of nominal fishing effort in area k by set type s within a period ($E_{k,s}$) is computed as:

[3] One unit of nominal fishing effort is conventionally defined as 1,000 hooks for longline fishery (e.g., WPRFMC, 1998). The empirical model in Chapter 4 follows this convention.

$$E_{k,s,t} \equiv \bar{E}_s \cdot FD_{k,s,t} \cdot N_{k,t} \qquad (2.2)$$

where $\bar{E}_s$ denote a nominal fishing effort by set type s, which is constant, and $N_{k,t}$ denotes the total number of fishing trips to area k per unit time period. Note that ($FD_{k,s,t}$ $N_{k,t}$) represents the total number of fishing sets with type s used in area k.

The effectiveness of the above "nominal" fishing effort ($E_{k,s,t}$) to catch species i may vary across set type s; for an example, a set type primarily targeting swordfish is obviously expected to catch that species more per unit effort than a set targeting bigeye tuna. Then the total effort index $Z_{i,k,t}$ in area k can be aggregated by standardizing effort as follows:

$$Z_{i,k,t} \equiv \sum_s \gamma_{i,s} E_{k,s,t} \qquad (2.3)$$

where $\gamma_{i,s}$ is a constant parameter (hereafter "catchability coefficients") for species i with set type s. A linear function of fishing effort with S fishing set types was used for simplicity. Note that fishing sets are differentiated by primary target, which affect and fishing costs as well as catchability coefficients, as explained later. A slightly more generalized form of catch function has been used by Clark (1985) and Deacon (1989), although they do not consider heterogeneity in the targeting of species.

Ex-vessel fish prices are assumed to be given. Although not attempted here, a demand function for each species can be substituted at the cost of additional model complexity. Implicitly, the model assumes each boat has perfect knowledge of fish stocks over all areas and fish prices. Then the total revenue from fishing in area k is obtained by summing over revenues from each species. The average revenue per trip in area k, $AR_{Trip,k}$, can then be expressed as:

$$AR_{Trip,k,t} = \frac{\sum_i P_{i,t} C_{i,k,t}}{N_{k,t}} = \frac{\sum_i P_{i,t} \left(1 - e^{-Z_{i,k,t}}\right) B_{i,k,t}}{N_{k,t}} \qquad (2.4)$$

where P_i is the price of species i per unit time period. This equation implies that the expected trip revenue will increase with fish price and initial stock of each species, but decrease with the number of trips since CPUE diminishes with effort $Z_{i,k,t}$. Note that AR, rather than marginal revenue (MR), is used here since each fishing area is "open" to all boats, which are assumed to compete with each other (competitive equilibrium) though the total number of vessels in the fishery is restricted. Also, the stock of each species is implicitly assumed to be independent of other species: i.e., two different species are not interacting with each other, such as prey-predator relationship as in Fisher and Mirman (1992).

2.2 Cost Structure Including Profit-sharing

The model incorporates features of the labor-employment relation that affect apportioning of revenue and costs from fishing (Plourde and Smith 1989). For this purpose, the costs of fishing are classified into two categories: fixed and variable (*i.e.*, operating) costs. In the share system that is prevalent in the Hawaii longline fishery (Hamilton, Curtis, and Travis 1996), fixed costs are usually borne by the vessel owner and consist of overhead expenses (*e.g.*, maintenance, mooring, and capital costs including depreciation), which do not depend directly on the fishing trip and are more or less fixed on an annual basis. Therefore, it is assumed that fixed costs do not affect the trip allocation decision in this short-run model.

Taxes (or handling fees) on the harvest are included as a percentage of the total revenue from a trip. Other variable costs are the expenses incurred during the fishing trip (*e.g.*, fuel, bait, and gear). This can be further broken down into costs incurred while traveling to area k and fishing in that location. Travel costs within a fishing area are assumed away because they are likely to be a small fraction of the costs of traveling from port.

Variable costs including taxes are shared equally by the owner and crew. The owner is usually absentee, while all hands on board including the captain are denoted as crew. Then the net revenue from a trip to area k, $NR_{k,t}$, is given by:

$$NR_{k,t} = AR_{Trip,k,t}(1-\tau) - \left(\sum_s a_s \cdot FD_{k,s,t} + b \cdot TD_k \right) \qquad (2.5)$$

where τ denotes the tax rate, and TD_k is the number of days spent traveling from port to destination k and back. While, as mentioned before, the total number of fishing days per trip, FD, is equal across trips, the number of traveling days, TD_k, varies, as estimated by dividing twice the distance to area k from port by average vessel speed.[4] Since set types are differentiated by primary target, daily fishing costs are also differentiated: parameter a_s is the average daily variable costs of fishing with set type s. The daily cost for traveling is assumed to be constant, represented by parameter b.

Computing Crew's Expected Wage and Deriving Demand for Labor

As mentioned before, the vessel's crew and owner are assumed to proportionally share the above net return from a trip to area k. Then the crew's income per trip ($CI_{k,t}$)[5] and the crew's expected wage per day ($w_{k,t}$) are given by:

$$CI_{k,t} = \lambda NR_{k,t} \qquad (2.6)$$

and then

$$w_{k,t} = CI_{k,t} / (FD + TD_k) \qquad (2.7)$$

where λ denotes the relative shares of net revenue accruing to the crew. In terms of computing the wage, $w_{k,t}$, obtained from a trip to a particular area k, TD_k is fixed, and hence the variable costs per trip is constant, while the trip revenue diminishes as $N_{k,t}$ increases. This implies that $w_{k,t}$, also diminishes as $N_{k,t}$ increases. Hence, at area k with given fish stocks and prices for I species, the expected wage $w_{k,t}$ is determined by the number of trips allocated to area k:

$$w_{k,t} = D^{-1}{}_L (N_{k,t}, P_{1,t}, \ldots, P_{i,t}, B_{1,k,t}, \ldots, B_{i,k,t}). \qquad (2.8)$$

[4] Because of the "homogeneous fleet" assumption, vessel's speed are also assumed to equal across vessels.
[5] The income accruing to the owner is $(1 - \lambda) NR_{k,t}$.

The above equation, denoted by D^{-1}_L, is the so-called inverse factor demand function (Varian, 1993, p. 323), which measures what the wage must be for some given quantity of input factor. Here labor is assumed to be the primary input, while the amounts of other inputs (food, fuel, bait, and other operating costs) are proportional to labor (i.e., other inputs are perfect complements, assuming a Leontief-type technology), and capital (vessel itself, equipment, etc.) is fixed in this short-run model.

As more fishing trips are optimally allocated to area k, the crew's expected wage at that area will diminish due to the stock externality. Hence, the next trip may eventually be allocated to another area because it becomes more profitable than the area in which the previous trips are allocated. Subsequent trips are alternately allocated to a number of areas to maximize the crew wage. As a result, the wage from trips to each area must theoretically be equalized across all fishing trips: i.e., $w_t^* = w_{k,t}$ where k is for all areas.

Combining equation (2.8) for all areas and transforming into a matrix and vector form, the trip allocated across areas can be expressed using a function, D_{L2}, as follows:

$$\mathbf{N}_{Trip,t} = D_{L2}\,(w_t^*, \mathbf{P}_t, \mathbf{B}_t) \qquad (2.9a)$$

where

[6]$\mathbf{N}_{trip,t}$ = a vector of the number of trips to area k for k = 1, …, K,

w_t^* = crew's expected wage (which is equalized across areas),

$\mathbf{P}_t$ = a vector of fish prices, and

$\mathbf{B}_t$ = a matrix of initial stocks of I species at K areas.

Since the number of traveling days varies depending on the distance between the fishing area and port, labor is measured by vessel-days, rather than by the number of trips. By aggregating the amount of labor across areas, the industry's aggregate labor, measured by vessel-days, per time period, $L_{D,t}$, is obtained by summing both fishing and traveling days over all trips to all areas:

[6]A **bold** letter indicates a vector or matrix, while a "not bold" *italic* letter indicates scalar.

$$L_{D,t} = \sum_k \left[\left(FD + TD_k \right) N_{k,t} \right] . \qquad (2.10)$$

Therefore, the industry's demand for labor is obtained by transforming equation (2.9a),

$$L_{D,t} = D_{L3} \left(w_t^*, \mathbf{P_t}, \mathbf{B_t} \right) \qquad (2.9b)$$

For a given wage, $w_t^* = \bar{w}$, and a set of fish prices and initial stocks, the optimal allocation of trips over space at period t determines the total amount of labor $L_{D,t}$, such that the industry's total ex-vessel revenue equals the total costs (i.e., TR = TC). In other words, no matter where an additional trip is allocated to maximize the wage, the industry's total costs will exceed the industry's total ex-vessel revenue. Varying the wage $\bar{w}$, the optimal point $(w_t^*, L_{D,t})$ would result in a downward-sloping locus, such as in Figure 2.1, which is referred to as a derived demand for labor (DDL).

2.3 Incorporating Fish Movement into a Derived Demand for Labor (DDL)

In the previous section, the initial stock in each area and period is assumed to be given; i.e., no relationship exists between the fish stocks in two consecutive periods. If fish populations do move or migrate and the movement of pelagic species is "density-dependent" (Sanchirico, 1998), then stock in one area would affect the stock in other areas over time. In particular, if an area were closed, the stock in the closed area would have no depletion by the fishery, and hence more fish might outflow from that protected area to its neighboring areas. As a result, the stocks in those neighboring areas could be more abundant, and therefore, this effect of "fish stock movement" might mitigate the estimated economic losses from the area closure.

The model is extended to incorporate fish movement (denoted as the model "with FM", while the model using given fish stocks $\mathbf{B_t}$ is denoted as the model "w/o FM") in this section. This discrete model implicitly assumes that each period is divided into the following four stages: (i) the beginning of a period where the initial stock in each area is

available for the fishery, (ii) fishing activity, (iii) natural mortality and recruitment, and (iv) movement between areas. Although several models include growth (e.g., Deacon, 1989; Sanchirico and Wilen, 1999), this study does not because the stock is represented by population (number of fish), not weight. The effect of growth on revenue is actually captured by price per piece in equation (2.4). Note that age, size (length/weight), and gender structures are not included in the model, although many biological models do include these features. This omission may have minimal effects if the majority of fish caught are mature (or adult) fish, rather than juvenile; and besides it is often difficult to obtain age, size, or gender information.

A term, "residual stock", of species i in area k at period t (denoted as $B'_{i,k,t}$) is defined as the stock size of species i right after fishing activity (at the end of stage (ii)) at period t. Then it is computed as the initial stock minus the fishery catch. Since fishery catch $C_{i,k,t}$, in turn, is determined by the initial stock $B_{i,k,t}$ and the number of fishing trips $N_{k,t}$ allocated to area k in the present period (see equation (2.1-2.3)), the residual stock can be represented as a simple function of the initial stock and the number of trips in area k:

$$B'_{i,k,t} = B_{i,k,t} - C_{i,k,t} = B_{i,k,t}\, e^{-Z_{i,k,t}} \qquad (2.11)$$

where $Z_{i,k,t} = \sum \gamma_{i,s} \left(\bar{E}_S \cdot FD_{k,s,t} \cdot N_{k,t} \right)$ is the total effort index (see Equation (2.3)). Now let us define the net inflow as a change in the stock size of species i at area k from the present period after fishing to the beginning of the next period: i.e., a change in the number of fish in area k during stages (iii) and (iv). Note that natural mortality and recruitment in stage (iii) are assumed to be negligible in this study. Fish movement in stage (iv) is broken down into two effects: i.e., the net inflow equals (a) "the inflow from other areas to area k", minus (b) "the outflow from area k to other areas".

Sanchirico (1998) used two simple patterns of movement, "density-dependent" and "sink-source". In the latter case, the fish movement (FM) is uni-directional, no matter what kind of circumstances is. Several studies, such as Itano and Holland (2000) and

NMFS-EIS (2001), suggest that pelagic species in the high seas (bigeye and yellowfin tunas) are likely to move around without absolute directions, or move depending on fish densities in the neighboring areas. Thus, the net inflow for species i in area k at the end of period t ($R_{i,k,t}$) is assumed to depend on "density", and be a linear function of the residual stocks in the neighboring areas, as follows:

$$R_{i,k,t} = \beta_{i,0} B'_{i,k,t} + \sum_{\substack{l=1 \\ l \neq k}}^{K} \beta_{i,l \to k} B'_{i,l,t} \qquad (2.12)$$

and hence

$$B_{i,k,(t+1)} = B'_{i,k,t} + R_{i,k,t} \qquad (2.13)$$

where $\beta_{i,0}$ and $\beta_{i,l \to k}$ are movement coefficients of species i from area k itself, and from another area l to area k, respectively. Note that the first term in the right-hand side of equation (2.12) represents "the outflow from area k to other areas", while the second term represents "the inflow from other areas to area k".

Coefficient $\beta_{i,0}$ is expected to be negative since the outflow from area k increase as the residual stock (i.e., the stock after fishing) in area k increases (i.e., becomes more dense). On the other hand, $\beta_{i,l \to k}$ is expected to be positive because the number of fish moving to area k from area l increases as the residual stock in area l increases. Furthermore, the number of fish going out from area k should not beyond the number of fish remaining in area k after fishing. Similarly, the number of fish moving in from area l to area k should not beyond the number of fish remaining in area l. Therefore, it is expected that $-1 \leq \beta_{i,0} \leq 0$ and $0 \leq \beta_{i,l \to k} \leq 1$.

Equations (2.11-13) indicate that the initial stocks in the current period are determined by (a) the initial stocks and (b) the number of trips allocated across areas in the previous period. If the fish movement for all species is defined as a function g, the initial stocks at the current period $\mathbf{B}_t$ can be expressed as follows:

$$\mathbf{B}_t = g(\mathbf{B}_{(t-1)}, \mathbf{N}_{\mathrm{Trip},(t-1)}), \tag{2.14}$$

and hence equation (2.9a) can be rewritten as

$$\mathbf{N}_{\mathrm{Trip},t} = D_{L2}(w_t, \mathbf{P}_t, g(\mathbf{B}_{(t-1)}, \mathbf{N}_{\mathrm{Trip},(t-1)})) \tag{2.9c}$$

implying that the allocation of trips at the current period recursively affects the trip allocation in the following period. If the initial stocks in each area at the first period and fish prices for each species at each period are known, the initial stocks and numbers of trips in each areas at the subsequent time periods can be dynamically computed.

Note that fishermen are implicitly assumed to know the initial stocks and movement patterns (i.e., equation (2.12)) as well as the total number of trips allocated in each area, although the exact fish stocks in all areas in the (near) future are obviously uncertain to fishermen (as well as fishery research). In other words, the deviations between the model predictions and actual outcomes are assumed to be random.

2.4 Labor Supply Function

As mentioned before, the relationship between vessel's owner and crew can be considered as a principal-agent problem: i.e., the vessel's owner (principal) hires the crews (agent), including the captain (sometimes the captain of a vessel himself is its owner). While the owner cannot monitor/enforce the crew's work perfectly, profit from a trip (the ex-vessel revenue minus the operating costs for that trip) largely depends on the quality (e.g., technical skills) of the crew's work. That is, the expected profit is highest if the crews perform their tasks at the "best practice" level. Therefore, the owner needs to provide incentives so that the crews are willing to perform their tasks at the "best practice" level[7].

[7] Although Kreps (1990, p. 580) calls "a high level of effort", this term is not used here because it may be confused with fishing "effort".

Now define that the expected utility of the crew is the "incentive payment" minus "non-monetary cost" for qualitatively hard working (i.e., performing tasks at the "best practice" level). Moreover, this non-monetary cost is assumed to be more expensive for a "better practice". Then the crew is willing to perform their tasks at the "best practice" level if their expected utility is maximized by doing so. To let them do so, an increase in incentive payment accruing to the crew by performing tasks at better practice must be no less than an increase in its "non-monetary cost" (Kreps, 1990, pp. 577-608).

A simple example of the above "incentive payment" is a "profit-sharing" system[8], where the owner and the crew proportionally share the profit earned from a fishing trip. Hence, it is commonly adopted in many fisheries, including the Hawaii-based longline fishery (Hamilton et al., 1996).

Then the fishing industry is ideally suited for modeling the supply behavior of labor. In this profit-sharing system, the crew (in particular, the captain) generally decides if, when, and where to undertake a fishing trip, based on their expected wage, which is estimated from the abundance in each area and prices of each species. Hence, the total amount of labor supplied by the industry, which is computed based on the numbers of trips allocated to each area and the length of a trip to each area (see Equation (2.10)), is a function of the expected crew's wage.

Furthermore, as pointed out by Gautam, Strand, and Kirkley (1996), unlike other professions in which labor and leisure activities coexist almost on a daily basis, commercial fishing in the high seas is demanding work coupled with limited days on shore (i.e., limited leisure opportunities). This makes the disutility of spending additional days for another fishing trip an important determinant of the labor supply decision. That is, in commercial fishing in the high seas, fishermen's tradeoff between onshore days (labor) and offshore days (leisure) determines their labor supply. As a result, unlike other

[8] Weitzman (1984) suggested a shift from a fixed-wage system to a "profit-sharing" system to solve the stagflation from the late 1960s to the early 1980s.

operating costs (which are constant), the crew's expected daily wage needs to be higher for larger mount of labor.

Hilborn and Kennedy (1992) also suggest that a spatial model may need to incorporate a non-monetary cost, which might increase as fishermen work longer or a boat go fishing further away from home. A preliminary study by Chakrovorty and Nemoto (2000) shows that the monthly average crew wage is generally higher (lower) when the larger (smaller) amount of labor is supplied, and vice versa.

Assuming a fixed number of fishing vessels, the aggregate labor supply function can be expressed as:

$$L_{S,t} = S_L(w_t, M_t) \qquad (2.15)$$

where M_t is income from non-fishery activities. Labor supplied by the crew (including the captain) is expected to increase with wage. However, the rate of increase of labor with respect to wage diminishes as wage becomes higher, and furthermore, the labor supply curve may, in the short-run, exhibit backward-bending properties (Varian, 1993; Gautam, Strand, and Kirkley 1996). [9] In general, an increase in non-fishery income M_t will give fishermen disincentives to work. However, it may be ignored if M_t is expected to be small relative to the income from fishery, almost constant over period, and/or it is difficult to obtain data for M_t.

2.5 Equilibrium Allocation of Fishing Trips over Space

As explained in the above, the equilibrium is determined by equating a derived demand for labor (DDL) with the labor supply (LS) function. The fishery is viewed as a production (or harvest) system with a single factor where labor is the primary factor and other factors in operating costs are considered perfect complements to labor (see p. 20), and then the demand for labor is derived. As equation (2.9b) indicates, the DDL curve is

[9] A long-run supply curve could be horizontal with the assumption of free entry (pure open-access), though such a pure open-access fishery rarely exists in these days. This is why Sanchirico and Wilen (1999) might not be applicable since their model can solve only a long-term equilibrium with free entry-exit.

expected to shift over periods in response to changes in fish prices or the distribution of fish stocks. On the other hand, the LS function (2.15), which represents fishermen's tradeoff between onshore days and offshore days, remains constant over time in the short run (assuming the effect of non-fishery income on the LS function is negligible). Finally, the equilibrium levels of wage and the labor (in vessel-days) are obtained by equating the DDL and LS functions: i.e., $L_{D,t} = L_{S,t}$ (see Figure 2.1).

While any change in the fish prices or operating costs will simply shift a DDL curve, the impacts of changes in fish stocks are more complex because of (i) heterogeneity of fish stocks in space, and (ii) interaction between the stocks in the neighboring areas due to fish movement. Furthermore, when the impacts of an area closure policy are analyzed, the stock size in the closed area would be affected in two different ways. First, since the stock in the closed area is not available for fishing (as if the fish stock there becomes zero), the DDL curve will shift down (or to the left). At the same time, the residual stock in the closed area at the end of period would actually be increased due to no fishery catch, resulting in more fish outflow from the closed area to the neighboring open areas, and hence the greater initial stocks in the neighboring areas at the next period, compared with the "no closure" case.

Thus, the mechanism of the impact of an area closure is complex since fish stocks are heterogeneously distributed across areas, and might move from an area to another over time. The model equations by themselves may not be sufficient to explain such a complex mechanism. Therefore, the theoretical model is first illustrated using a simple "two-area-two-period" example in the next chapter, followed by an empirical application to the Hawaii longline fishery.

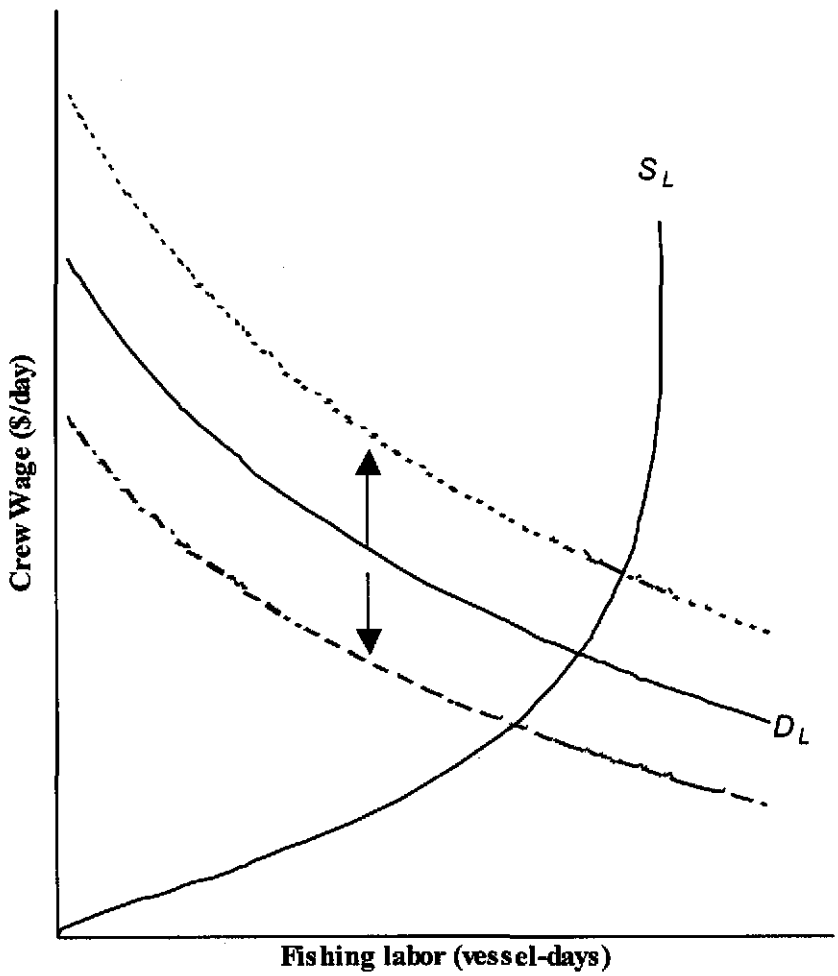

Figure 2.1 Supply of and Derived Demand for Labor

CHAPTER 3
ILLUSTRATION OF THE MODEL USING THE "TWO-AREA-TWO-PERIOD" EXAMPLE

Simulation, econometric and mathematical programming methods are most commonly used for tackling various questions in the fields of applied economic research, including fisheries (Oriade and Dillon, 1997). Econometrics is a classical method that is still widely used in economic research for purposes that include estimating a fishing vessel's production function (see survey by Doll, 1988; see Sharma and Leung, 1999, for an application of the stochastic frontier production approach to the Hawaii longline fishery). This method allows statistical hypothesis tests if the specifications for one or a few model equations and error term(s) are known, or can be justified. If, however, many parameters need to be estimated or several equations are involved, estimation of econometric model becomes more difficult and sometimes impossible, depending on the number of observations available and the complexity of each equation. This suggests that the econometric approach may face difficulties/limitations if the model includes a number of fishing areas and equations as described in Chapter 2.

Mathematical programming (MP) techniques, such as linear programming as well as an advanced method – "multiobjective and multilevel approaches" – are powerful tools for optimization and can potentially be used as a management tool (see survey by Pan, 1998). This method essentially maximizes (or minimizes) a single or a few objective functions under several constraints (including inequalities), and can often reveal a "bottleneck" constraint(s) as well as the optimal value of that objective function. This technique is applied for several fisheries, particularly if the total allowable catch (TAC) or quota of major species is imposed, or could be a reasonable policy option.

However, the above fact also suggests that the MP technique may not be suitable if TAC is not a policy option because bottleneck constraints are based on uncertain stock size (or "total available catch") instead of TAC. In general, the MP technique is vulnerable to data

noise, which is usually severe in fishery data. Although a sensitivity analysis is a common remedy for this kind of problem, the effectiveness diminishes as the number of uncertain parameters increases. Thus, empirical results produced by this technique would not be accurate in such a case. In fact, it is often difficult to monitor and enforce any TAC for pelagic fisheries on the high seas because vessels operating there are from various nations.

In addition, it is not straightforward to apply the MP technique to implement a theoretical model (such as the model described in Chapter 2) if it does not have any explicit objective function to be optimized. Furthermore, the MP technique is like a "black box" where it mechanically produces solutions that might hardly be tractable and provides little intuition if more objective functions and/or constraints equations are involved. Thus, this technique is not very suitable if the focus of research is modeling, rather than obtaining empirical solution(s).

Simulation technique is also widely used in economic research for agriculture (see survey in Oriade and Dillon, 1997), and natural resources and environment (Wilen, 1976; Chakravorty, Roumasset, and Tse, 1997). Simulation is defined here as a technique to implement a theoretical model, using a primitive computer programming language (e.g., Fortran, C++) or a common spreadsheet computer software (e.g., Microsoft Excel). Hence, this technique is more flexible to implement a model (i.e., with much less critical obstacles) than MP or econometrics. In particular, simulation technique is powerful if a model includes many or complex equations, such as non-linear functions and dynamic or stochastic nature. Many fishery researchers use simulation, as Hilborn and Walters (1989) stated that simulation is "a very powerful tool for teaching and training fisheries managers". In a review of simulations used for agricultural research, Oriade and Dillon (1997) regard simulation as "a unique method that can facilitate the resolution of certain complexity or dynamic problems that might otherwise remain intractable."[1]

[1] For examples, an econometric model in Dupont (1993) and the MP model in Pan et al. (1999) incorporate only three and five fishing locations, respectively, while this empirical study includes 60 areas.

However, the critics of simulation conclude that (i) no consensus on the procedure of validation for the simulation program or algorithm, and (ii) "a methodology of convenience", i.e., simulation technique might be used even though other solid methods, such as econometric or MP, can do the same things or better. For example, although objective function(s) or some variables can be optimized in a simulation program if an implementer develops an algorithm, such an optimization can be implemented by the MP technique more simply. In addition, a researcher or his/her assistant must be skillful to use those primitive computer languages or spreadsheet computer software package to use simulation technique. It may be costly to hire a skillful computer programmer or learn such a computer language or software package, while it is becoming less expensive to buy the computer software package specialized for MP.[2]

Thus, although several strengths/weaknesses exist in each of the above three techniques, simulation is likely to be most suitable to implement the model in this study, because the focus of this study is to develop a spatial fishery model, which includes many equations (including nonlinear functions), but has no explicit objective function to be optimized.

3.1 Simplified Model

Due to the complexity of the model, a simple example is helpful to understand the model. Essential policy implications from such a simple example are often the same as those from an empirical application with real data, which is usually more complex. In what follows in this section, the specific settings selected for this simple example are explained.

First, there are only two areas in the simple model, which have differentiated stock sizes and travel costs per trip. Second, two periods are assumed because the fish movement (FM) would affect only the second period or later after certain area(s) are closed; i.e., at

[2] It used to be very expensive to buy a computer software package for MP or econometrics, which also requires more CPU power and disk space. However, such a cost has been greatly reduced lately.

least two periods are needed to examine the effect of FM. Third, only one species is considered here and hence all sets target this species (i.e., primary target cannot be differentiated.) Whether or not a vessel can alter its primary target is not essential to a spatial model, although it is empirically an important issue for some fisheries. It is straightforward to extend this simple example to multiple species, as in equation (2.4).

Assume that two square areas are available for a single-species fishery, as in Figure 3.1, where Area 1 is on the left and Area 2 is on the right, and the two areas are connected. The port is located at the midpoint of the right edge for Area 2, making Area 2 near-shore. A vessel is assumed to take four days to go and return from Area 2, and 12 days to go and return from Area 1 (i.e., $TD_1 = 12$, and $TD_2 = 4$).[3] The respective initial stocks allocated to Area1 and Area 2 are: $B_{1,1} = 3{,}000$ and $B_{2,1} = 2{,}000$ where subscripts, k and t, are for area and time period, respectively. For simplicity, it is assumed that there is no recruitment and no natural mortality, and fish move only at the end of each period. Then the fish stocks will be changed only by fishery activities in each area and movement between the two areas. The FM between the two areas is:

$$R_{2\to1} = -0.4\, B'_{1,t} + 0.6\, B'_{2,t} \qquad (3.1)$$

and

$$R_{1\to2} = -R_{2\to1} \qquad (3.2)$$

where the net inflow from Area 2 to Area 1 ($R_{2\to1}$) depends on "density" of both areas[4]. While some fish may move Area 1 to Area 2, only the net inflow -- "the number moving from Area 2 to Area 1" minus "the number moving from Area 1 to Area 2" -- is of concern here. Equation (3.1) indicates that Area 2 is a "source" since the net inflow is more sensitive to a unit increase in its stock size. Note that the fish stocks in the two areas are in equilibrium at the beginning of Period 1 since the net inflow equals zero, though it is not necessary to be in equilibrium:

[3] See Chapter 2 for the explanations of the notations in this chapter.
[4] Since each area is defined as the exact same shape and size, the stock size itself represents density.

$$R_{2\to 1,0} = -0.4\,(3000) + 0.6\,(2000) = 0.$$

Other parameters used here are listed in Table 3.1. Many of these parameters are similar to those used for the Hawaii longline fishery (see Chapter 4), although they are rounded for computational simplicity. An arbitrary number, 1.429, was applied as a "multiplier" to scale up the ex-vessel revenue to account for the revenue from other minor species.[5]

Labor Supply (LS) Functions

It is assumed that a fixed number of identical vessels follow the labor supply (LS) behavior as described in Chapter 2, and then an arbitrary LS function for this example is specified as follows:

$$\ln VD_t = -7.613 + 4.165(\ln W_t) - 0.3766(\ln W_t)^2 \qquad (3.3)$$

where the wage elasticity for the labor supply decreases as the wage rate increases. If the wage rate is higher than $718 per period, then the LS curve bends backward. See Figure 3.2 for the resulting LS schedule, and refer to Section 4.7 for the detailed discussions about the empirical specification of a LS function[6]. Finally, as explained in Chapter 2, the equilibrium wage and labor (vessel-days) are determined by the derived demand for labor (DDL) and the LS function.

3.2 Area Closure Simulations

Three cases were simulated with this "two-area-two-period" model, Case 0: "no closure", Case 1: "closing Area 2, Area 1 remaining open", and Case 2: "closing Area 1, Area 2

[5] This multiplier was needed to "tune up" the wages from the two areas to be equal to each other. Because the numbers of trips allocated to the two areas are integers, it was difficult to make the two wages almost equal to each other, only by manipulating those two trip numbers, without this "tune-up" multiplier. See also p. 53 regarding this multiplier in the application to the Hawaii longline fishery.

[6] The exact specification for a labor supply (LS) function for this example may be determined backward. That is, the equilibrium points in each period of each case might be determined first, as the plots for those points are approximately located on an arbitrary upward-sloping curve, which represents a LS behavior. Then the exact LS function, such as equation (3.3), can be obtained later, by a regression using the data for those equilibrium points. See Figure 3.2.

remaining open". In simulating the allocation of fishing trips to the two areas in the "no closure" case, the endogenous variables, the numbers of trips to the two areas at each period ($N_{k,t}$ for $k = 1, 2$ and $t = 1, 2$) are increased one by one, as the average wages from the trips to these two areas must be maintained as approximately equal to each other. As more trips are allocated, the average wage diminishes; i.e. hence, the locus of the points for the wage rate and labor exhibits a downward-sloping curve. Finally, the point closest to the LS curve will be determined as an equilibrium point. If Area 2 is closed (Case 1), it is restricted as $N_{2,1} = N_{2,2} = 0$; Likewise, it is restricted as $N_{1,1} = N_{1,2} = 0$ in Case 2. The results are presented in Table 3.1.

Since fish movement (FM) occurs at the end of each period, the inclusion of FM will affect the initial stocks and the allocation of fishing trips only during Period 2. Then a primary question is: "How does the FM affect the equilibrium wage, labor, and fishermen's income, particularly when one or more areas are closed?" This chapter illustrates this FM effect, using shifts in the DDL curve.

3.2.1 No Closure (Case 0)

The DDL curve for the "no closure" case (Case 0) is represented as D_L^0 in Figure 3.3. Note that although the numbers of trips and fishing and traveling days are nonnegative integers and hence the amount of labor allocated is, strictly speaking, discrete, the labor demand is represented as a smooth downward curve.

Kinked at Point P_0

The first three trips were allocated to Area 1 since vessels can obtain a higher wage than the wage from the first trip to Area 2. The fourth and later trips are alternately allocated between the two areas as vessels switch areas to obtain the next higher wage. Thus, as more trips are allocated, the relative wage decreases much more gradually after the first three trips are allocated. Therefore, the DDL curve (D_L^0) is kinked at point P_0; the curve

becomes flatter when the amount of labor for the first four trips or more is allocated. Similarly, if a third fishing area is added, then the DDL curve will be flatter.

The flatness of the DDL curve indicates that the labor demand is more responsive to the expected wage, and vice versa. A responsive labor demand implies that labor demand is sensitive to any change in operating costs, the net return share rate, fish prices, and stock size, which are constant or exogenous variables influencing the wage rate. On the other hand, if labor demand is less responsive (i.e., the steep DDL curve), then the number of trips allocated in each area, which is an endogenous variable, becomes a more important determinant of the wage rate, implying that stock externality is more significant.

As mentioned above, the wage rate from the first trip to Area 1 is higher than that to Area 2. More effort will then be allocated to Area 1 only until the wage rates from the two areas are equal, implying that the stock externality in Area 1 is greater than in Area 2.

3.2.2 Closure of Area 2, Near-shore and Source (Case 1)

The impacts of area closure on the DDL curve can be separated into the two parts: (i) a tilt-down due to a closure of either area, and (ii) a shift-up (or down in some cases) due to an increase (or decrease) in the net inflow from the closed area to the open area. Note that the latter (the effect of shift-up) occurs only at Period 2. Figures 3.4(a) and (b) depict the impacts of area closures for Case 1, where Area 2 is closed during both periods.

Closure of Area 2 without FM: Case 1(a)

First, the stock sizes in the "no closure" case (Case 0) are assumed to be given (i.e., static). That is, the model does not incorporate FM, where the outcomes in Period 1 have no effect on Period 2. (This is called Case 1(a) hereafter.) As presented in Figure 3.4(a), the DDL curve at Period 2 tilt down from $D_L{}^0$ to $D_L{}^{1a}$. Due to the closure of Area 2, trips are allocated to Area 1 only. As mentioned above, the first three trips, which are allocated to Area 1 in the "no closure" case, remain allocated there, and hence the $D_L{}^{1a}$ overlaps $D_L{}^0$ for the first three trips. Afterward the DDL curve ($D_L{}^{1a}$) slopes downward with no

kinks and steeper than $D_L{}^0$. Because the trips that used to be allocated to Area 2 cannot be allocated anywhere at the same wage level w_0, the original equilibrium point S_0 moves left to Q_{1a} where the difference in the amount of labor between the two points equals that formerly allocated to the closed area. (See Table 3.2 for the wage, labor and fishermen's income level at Q_{1a}.)

Since there is a gap between the demand and supply for labor (i.e., $L_D < L_S$), fishermen are willing to take more fishing trips to reach a new equilibrium point S_{a1}, where (i) both wage and labor levels are lower than the "no closure" case (S_0), and (ii) some of the trips that used to be allocated to Area 2 in the "no closure" case are relocated to Area 1. Hereafter, the latter is called the "area substitution" effect.

Closure of Area 2 with FM: Case 1(b)

Fish movement (FM) is now accounted for at the end of period 1; i.e., the initial stocks at the beginning of period 2 are dynamically estimated. Two determinants for the initial stocks ($B_{1,2}$) in Area 1 at Period 2 are: (i) a decrease in the residual stocks ($B'_{1,1}$) and (ii) an increase in the net inflow from Area 2 to Area 1 ($R_{2\to1}$). The "area substitution" effect will cause more fishing to be allocated to Area 1 at Period 1, resulting in an increase in catch and therefore a decrease in the residual stocks. The residual stocks ($B'_{2,1}$) in the closed area (Area 2) would be higher than the "no closure" case, because no fish are caught in the closed area. Then equation (3.1) implies that the net inflow ($R_{2\to1}$) will be increased due to a decrease in $B'_{1,1}$, and an increase in $B'_{2,1}$.

As shown in equation (2.13), $B_{1,2} = B'_{1,1} + R_{2\to1,1}$, if an increase in the net inflow exceeds an decrease in the residual stocks in Area 1 (due to fishing), then the initial stock ($B_{1,2}$) at period 2 will increase. As in Table 3.1 for Case 1, while the residual stock in Area 1 at the end of period 1 ($B'_{1,1}$) declined (by 389), the net inflow to Area 1 increased from 30 to 666. As a result, the initial stock ($B_{1,2}$) increased by 247 (14%).

This increase due to the "FM effect" is represented by a shift-up of the DDL curve from D_L^{1a} to D_L^{1b} in Figure 3.4(b). Finally, the market at Period 2 will reach a new equilibrium at point S_{1b}. It could be even possible that that the wage rate is higher at S_{1b} and fishermen's income only from Area 1 is also greater than the total income from both areas in the "no closure" case (Table 3.2), although fishermen are always worse off by area closure at period 1. This suggests that fishermen could be better off (i.e., fishermen's income increase and their utility is higher), even though a fishing area is closed, for example, in order to protect marine species.

Closure of Area 2 with Decreased FM: Case 1(b') – a Sensitivity Analysis

A "win-win" situation as in the above may be unusual. In many cases, the equilibrium points for the Cases 0, 1(a), and 1(b) may be as $S_{1a} < S_{1b} < S_0$; i.e., the initial stock(s) in the open area(s), which is dynamically computed, is expected to be greater than the "static" one, but it may not be large enough to increase fishermen's income more than the "no closure" case. Or, fish may be relatively less mobile, making the increase in the net inflow to the open area(s) too small, compared with an increased catch there at Period 1 due to the "substitution" effect, resulting in a decreased initial stock in Period 2 relative to that in the "no closure" case.

To examine such a case, a simple sensitivity analysis was also conducted (which is called Case 1(b') hereafter), where FM equation (3.1) is changed as:

$$R_{2\to 1} = -0.1\, B'_{1,t} + 0.15\, B'_{2,t} \qquad (3.1')$$

implying that fish are less mobile. The results for this case are also listed in Table 3.2, and illustrated in Figure 3.5. In the "no closure" case here with this "less mobile" equation (3.1'), the stock sizes at Period 2 are slightly different from the original "no closure" case: i.e., $B_{1,2}$ was slightly lower and $B_{2,2}$ was slightly higher ($B_{1,2}$ = 1,732 and $B_{2,2}$ = 1,192) since the net inflow was reduced to 7.5 from 30. The kink on the DDL curve

disappears because the wages from the first trip to each area are very close and hence trips were allocated alternately until it reached the equilibrium.

The DDL curve in Case 1(a), Area 2 closed with no FM, is almost the same as D_L^{1a} in Figure 3.4(a). Then, by adding the FM, $B_{2,2}$ will be decreased by 252 (-14%), yielding $B_{1,2}$ = 1,502 (see Table 3.2) since $B'_{1,1}$ declined by 389, and the net inflow to Area 1 was increased only by 137, compared with the "no closure" case. Therefore, the DDL curve shifted down from $D_L^{1a'}$ to $D_L^{1b'}$ as depicted in Figure 3.5. Finally, the market at Period 2 will reach a new equilibrium at point $S_{b1'}$.

3.2.3 Closure of Area 1, Offshore and Sink (Case 2)

Now Case 2, in which Area 1 is closed, is examined. Since Area 1 is offshore, vessels take more days to travel there. Area 1 is a "sink" in terms of movement direction. Figure 3.6 depicts the impacts of this area closure. Similar to Case 1, first the impacts of the closure of Area 1, by assuming the initial stocks are given, are analyzed. This is called Case 2(a) hereafter.

Recall that the first three trips are allocated to Area 1 with no closure. Since only Area 2 is open here, these first trips must also be allocated to Area 2, which yields a lower wage. Hence, the starting point of the DDL in this case (D_L^{2a}) will be lower than D_L^0. Moreover, the DDL curve here becomes steeper without any kinks because trips are allocated to Area 2 only, shifting the DDL curve from D_L^0 to D_L^{2a}. The trips, that used to be allocated to Area 1, cannot be allocated anywhere at the same wage rate w_0. The gap between points S_0 and Q_{2a} exactly equals the amount of labor (= 242) that used to be allocated to the closed area (Area 1).

Then, the market at Period 2 will reach a new equilibrium at point S_{a2}. Although 10 out of the 11 trips are relocated to Area 2, the total amount of labor decreases by 29% (354 → 252) because the closure of Area 1 (offshore) lead to more trips of shorter duration (taking 12 days for traveling to Area 1, while only 4 days for traveling to Area 2). In Case

1(a), only 4 out of 8 trips were relocated to the open area, while the total amount of labor decreases only by 7% (354 → 330) in that case (see Table 3.2).

Closure of Area 1 with FM: Case 2(b)

Next the initial stocks at period 2 are dynamically computed, using the FM equation (3.1). As detailed in Table 3.1, while the residual stock in Area 2 at the end of period 1 ($B'_{2,1}$) declined (by 593), the net inflow to Area 2 increased by 866. The initial stock ($B_{2,2}$) increased by 273, resulting in a shift-up of the DDL curve from D_L^{2a} to D_L^{2b} in Figure 3.6. Interestingly, D_L^0 and D_L^{2b} intersects each other because D_L^{2b} is steeper than D_L^0, indicating that the wage rates from the first few trips are higher in the closure case 2(b) but the wage eventually becomes lower than the "no closure" case. Then, the market at Period 2 will reach a new equilibrium at point S_{2b}. The wage and labor level for each point in Case 2(a) and (b) are also summarized in Table 3.2. While the wage, total catch, labor (vessel-days), and fishermen's income in Period 2 were actually increased by closing Area 2 (Case 1), only 59% of fishermen's income loss, which was generated by closing Area 1 (Case 2(b)) using the "static" stocks is recovered by accounting FM.

3.3 Summary for the Simulation Results and Policy Implications

The allocation of fishing trips over space and time is determined by the supply (LS) of and the derived demand for fishery labor (DDL). The impact of an area closure is analyzed in the three steps. Results using the model without FM indicate that (i) an area closure makes the downward-sloping DDL curve steeper, and labor demand becomes more responsive to wages; and (ii) if the closed area is more profitable than the other (i.e., the first trip was allocated to this area) before the closure, then the DDL curve will also shift downward.

Second, using the model with FM, the expected change in the initial stocks at Period 2 is captured as a shift of the DDL curve as presented in Figures 3.4(b), 3.5, and 3.6. This exercise suggests that the expected negative economic impacts of an area closure on fishermen's income might be overstated unless a gain from an increased net inflow from

the closed area is accounted for. The FM profile determines the degree of overstatement. If fish are not very mobile, the negative impacts of a closure could actually be more severe than those estimated by the model without FM. A shift of the DDL curve, triggered by a closure, will lead to a new equilibrium, where the wage rate is adjusted (usually decreased), and vessels alter fishing areas to the open area to recover their income loss from the closure.

This exercise focuses on analyzing the impacts of area closures because this is more complex than analyzing the impacts of other regulatory policies, such as price policy (taxation). As an extension, some restrictions in this example can be relaxed. For example, the model can include two species and allow vessels to switch the primary target, or a single port can be extended to multiple ports.

The model with FM is theoretically improved from that without FM, but it may not be in an empirical sense since it is not an easy task to estimate FM patterns accurately. In the following chapters, the model is calibrated for the Hawaii longline fishery, where the fishery space is divided into more than 50 areas, and each boat can target either bigeye tuna or swordfish at each set, depending on the abundance of these two species as well as other minor species. First, the empirical model is developed and used to for policy analysis without FM in Chapters 4 and 6, and later is extended to incorporate FM in Chapter 7.

Table 3.1 Simulation Results from "Two-Area-Two-Period" Model

Constant	
Catchability Coeff. (g)	0.003
Unit effort per trip (E-bar)	1.42
Price (P)	300
Costs / *FD*	$800
Costs / *TD*	$300
Multiplier	1.424

* Area 1 is off-shore, and Area 2 is near-shore.

	Area 1 (k = 1)	Area 2 (k = 2)
Fishing Days (FD)	10	10
Travel Days (TD_k)	12	4
Trip length (TL)	22	14
Trip costs	$11,600	$9,200

Net inflow from Area 2 to Area 1: (Area 1 is "sink", and Area 2 is "source".)

R = -0.4 x $B'_{1,t}$ + 0.6 x $B'_{2,t}$

	No Area Closure (Case 0)			Closing Area 2 (Case 1)			Closing Area 1 (Case 2)		
Period 1	Area1	Area2	Total	Area1	Area2	Diff1	Area1	Area2	Diff2
Stock ($B_{k,1}$)	3,000	2,000		3,000	2,000		3,000	2,000	
Trip1 ($N_{k,1}$)	**13**	**12**	25	19	**0**	-6	**0**	28	3
effort (E)	184.6	170.4		269.8	0		0	397.6	
$Z = g\,E_k$	0.5538	0.5112		0.8094	0		0	1.1928	
Fishing Mortality rate	0.425	0.400		0.555	0.000		0.000	0.697	
Catch (C)	1276	800	2,076	1665	0	-412	0	1393	-683
CPUE = C / E	6.91	4.70		6.17	N/A		N/A	3.50	
Total Rev (TR)	$544,947	$341,928	$886,875	$711,078	$0	-$175,797	$0	$595,158	-$291,717
Average Rev (AR)	$41,919	$28,494		$37,425	N/A		N/A	$21,256	
Trip costs (TrC)	$11,600	$9,200		$11,600				$9,200	
Total Costs = TrC_1 x $N_{1,t}$ + TrC_2 x $N_{2,t}$			-$261,200	-$220,400		$40,800		-$257,600	$3,600
Net Return ($/trip) (NR = AR - TC)	$30,319	$19,294		$25,825	N/A		N/A	$12,056	
Wage (= 0.5 NR / TL)	$689	$689		$587	N/A	-$102	N/A	$431	-$259
Vessel-days (VD)	286	168	454	418	0	-36	0	392	-62
Fishermen income	$197,074	$115,764	$312,838	$245,339	$0	-$67,499	$0	$168,779	-$144,058
Residual stock ($B'_{k,1}$)	1724	1200		1335	2000		3000	607	
(Difference in $B'_{k,1}$)				*(-389)*	*(+800)*		*(+1276)*	*(-593)*	
Fish Movement (FM)	-689.7	719.7		-534.2	1200.0		-1200.0	364.0	
Net Inflow (R) =	30.0			665.8		635.8	-836.0		-866.0

Period 2	Area1	Area2	Total	Area1	Area2	Diff1	Area1	Area2	
$B_{k,2}$	1,754	1,170		2,001	1,334		2,164	1,443	
	(Difference in $B_{k,2}$, compared with Case 0)			(+247)	(+165)		(+410)	(+273)	
$N_{k,2}$	**11**	**8**	19	**17**	**0**	-2	**0**	23	4
$E_{k,2}$	156.2	113.6		241.4	0		0	326.6	
Z = g E	0.4686	0.3408		0.7242	0		0	0.9798	
F Mortality rate	0.374	0.289		0.515	0.000		0.000	0.625	
$C_{k,2}$	656	338	994	1031	0	37	0	901	-93
CPUE	4.20	2.97		4.27			N/A	2.76	
TR	$280,361	$144,281	$424,642	$440,501	$0	$15,858	$0	$384,935	-$39,708
AR	$25,487	$18,035		$25,912			N/A	$16,736	
Trip costs	$11,600	$9,200		$11,600				$9,200	
Total Costs			-$201,200	-$197,200		$4,000		-$211,600	-$10,400
Net Return	$13,887	$8,835		$14,312	$0		N/A	$7,536	gap
Wage	$316	$316		$325		$9.69	N/A	$269	-$46.39
VD	242	112	354	374	0	20	0	322	-32
Fishermen income	$76,381	$35,341	$111,721	$121,650	$0	$9,929	$0	$86,667	-$25,054
$B'_{k,2}$	1098	832		970	1334		2164	542	
(Difference in $B'_{k,2}$)				*(-128)*	*(+502)*		*(+1066)*	*(-290)*	
FM	*-439.2*	*499.1*		*-388.0*	*800.5*		*-865.6*	*324.9*	
R =	60			412		352.6	-540.7		-600.5

Period 3	Area1	Area2	Total	Area1	Area2	Diff1	Area1	Area2	
$B_{k,3}$	1,158	772		1,383	922		1,623	1,082	
(Difference in $B_{k,3}$)				(+225)	(+150)		(+466)	(+310)	

Table 3.2 The Effect of Fish Movement on the Closure Results (Period 2)

Point in Figures	Area Subst.*	Net Inflow ($R_{2\to1,2}$)	Stock ($B_{k,2}$)	Wage (w_k)	Trip# ($N_{k,2}$)	Vessel-days ($L_{D,2}$)	Fishermen's Income (FI)	Change in FI	% Change for Recovery
No Closure								D_L^0	
S_0		30	------		19	354	$111,721		
Off-shore (Area1)			1,754	$316	11	242	$76,381		
Near-shore (Area2)			1,170	$316	8	112	$35,341		
Closure, Near-shore, Source **(Area 2)**									
	w/o FM							D_L^{1a}	
Q_{1a}	No	n/a	1,754	$316	11	242	$76,381	-$35,341	
S_{1a}	Yes	----------		$272	15	330	$89,922	-$21,799	
	with FM							D_L^{1b}	
Q_{1b}	No	666	2,001	$397	11	242	$96,112	-$15,610	
S_{1b}	Yes	----------		$325	17	374	$121,650	$9,929	+146%
	with Decreased FM							$D_L^{1b'}$	
$Q_{1b'}$	No	167	1,502	$242	10	220	$53,270	-$58,451	
$S_{1b'}$	Yes	----------		$213	13	286	$61,004	-$50,717	-133%
Closure, Off-shore, Sink **(Area1)**									
	w/o FM							D_L^{2a}	
Q_{2a}	No	n/a	1,170	$316	8	112	$35,341	-$76,381	
S_{2a}	Yes	----------		$202	18	252	$50,966	-$60,755	
	with FM							D_L^{2b}	
Q_{2b}	No	-836	1,443	$466	8	112	$52,190	-$59,531	
S_{2b}	Yes	----------		$269	23	322	$86,667	-$25,054	+ 59%

*"Yes" indicates that "area substitution" effect is included; i.e., at an equilibrium where the derived demand equals the labor supply with the corresponding wage.

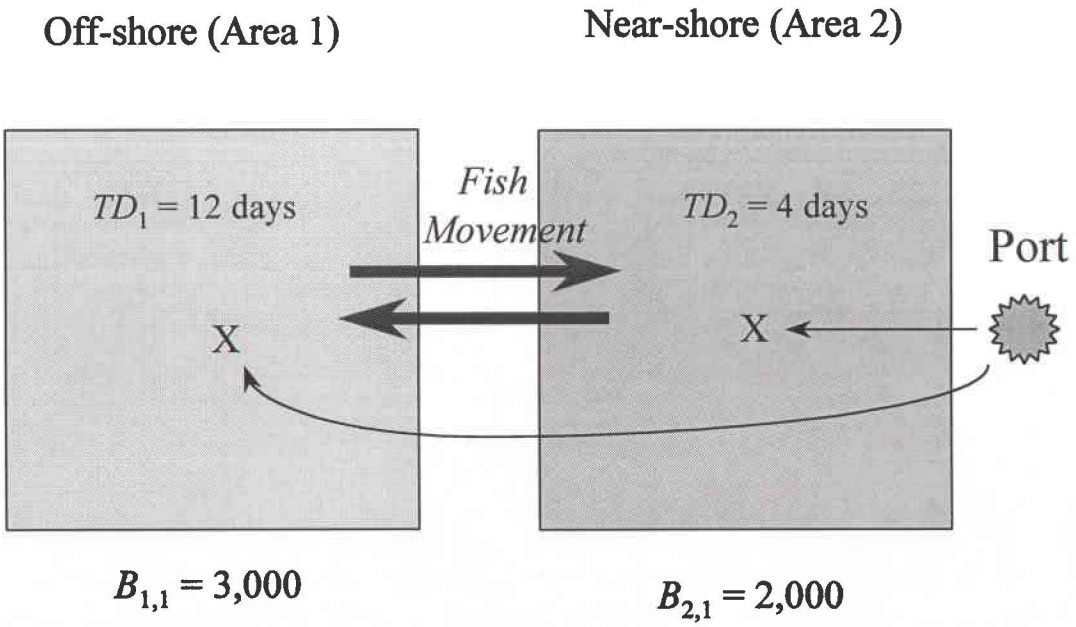

Figure 3.1 **Two-Area-Two-Period Example**

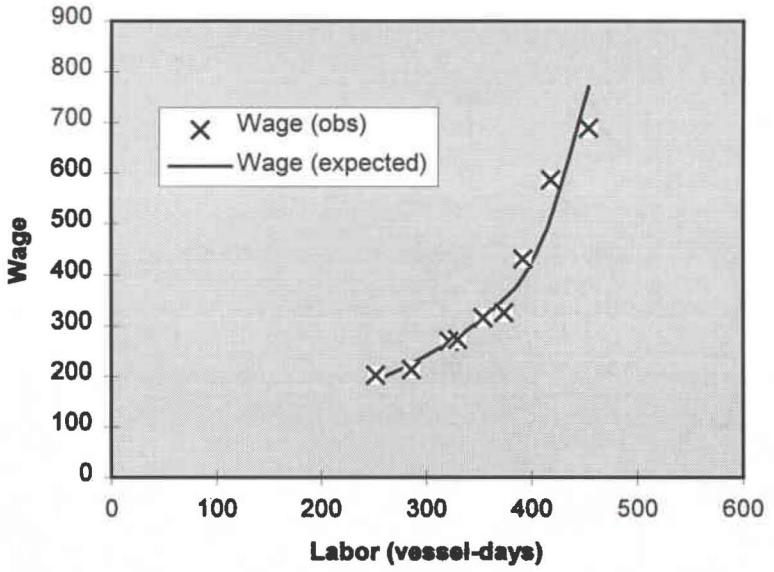

Figure 3.2 Nine equilibrium points in the "Two-Area-Two Period" example, and the labor supply curve predicted by equation (3.3). Nine points are:

- **"No closure" case for Period 1 & 2 (2 points),**
- **"Closure, Area 2" for Period 1, Period 2 w/ FM, and Period 2 w/o FM (3 points),**
- **"Closure, Area 1" for Period 1, Period 2 w/ FM, and Period 2 w/o FM (3 points),**
- **"Closure, Area 2" for Period 2 w/ Decreased FM"**

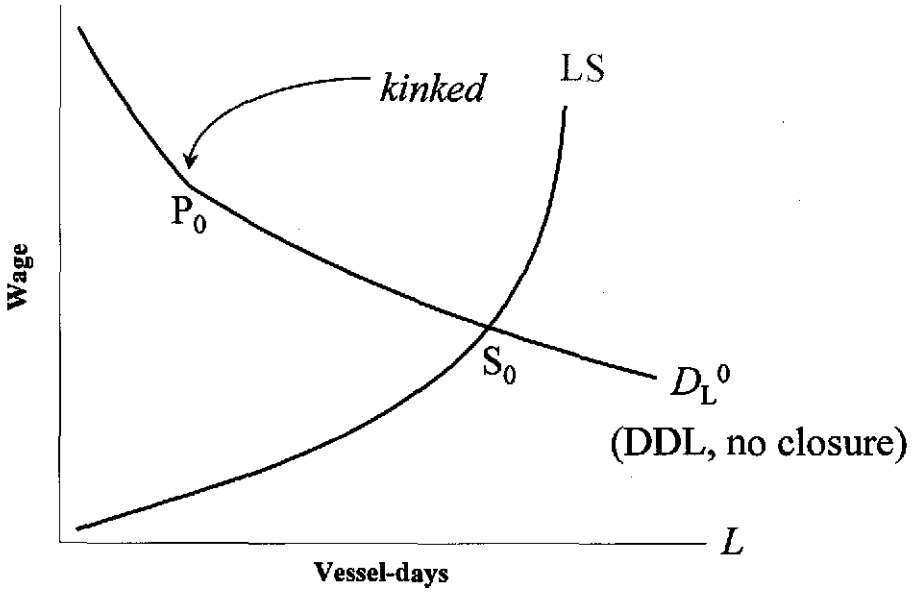

Figure 3.3 DDL and LS Curves: No Closure

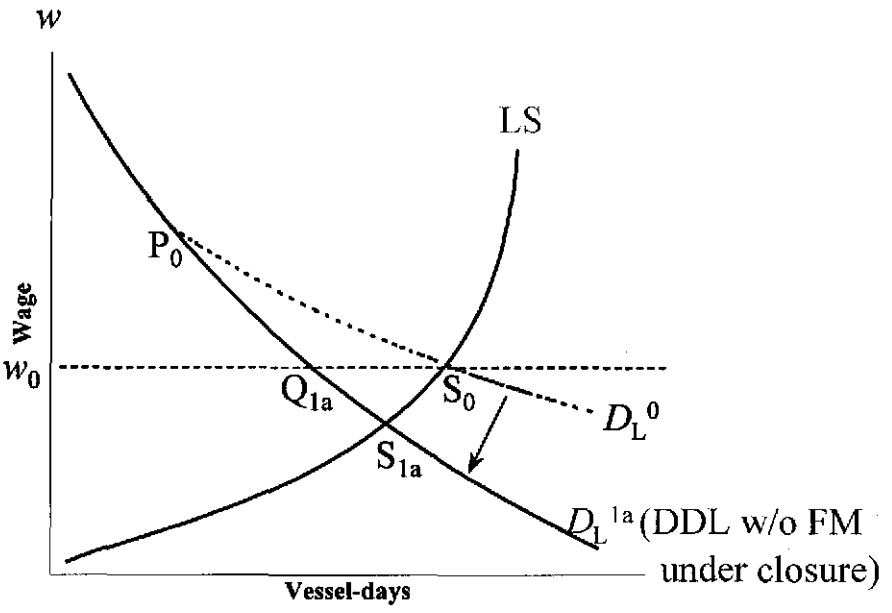

Figure 3.4(a) Closure, Near-shore, w/o FM

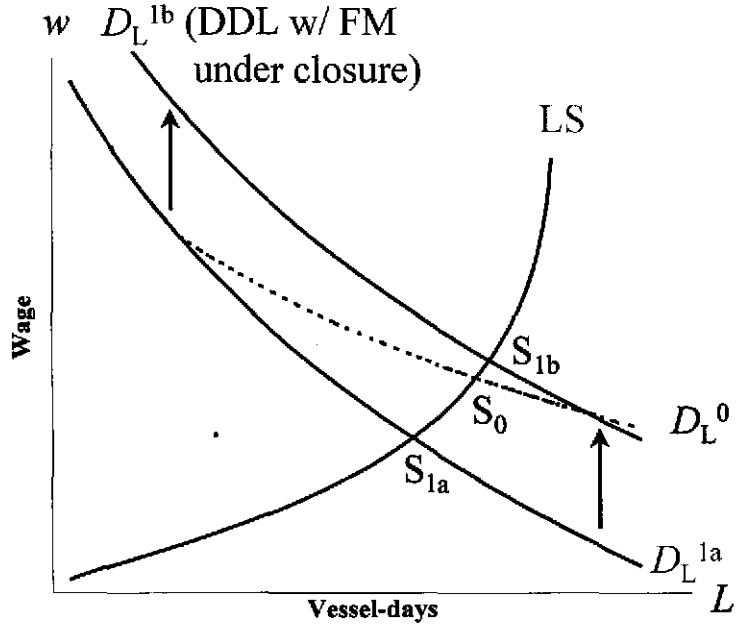

Figure 3.4(b) Closure, Near-shore, with FM

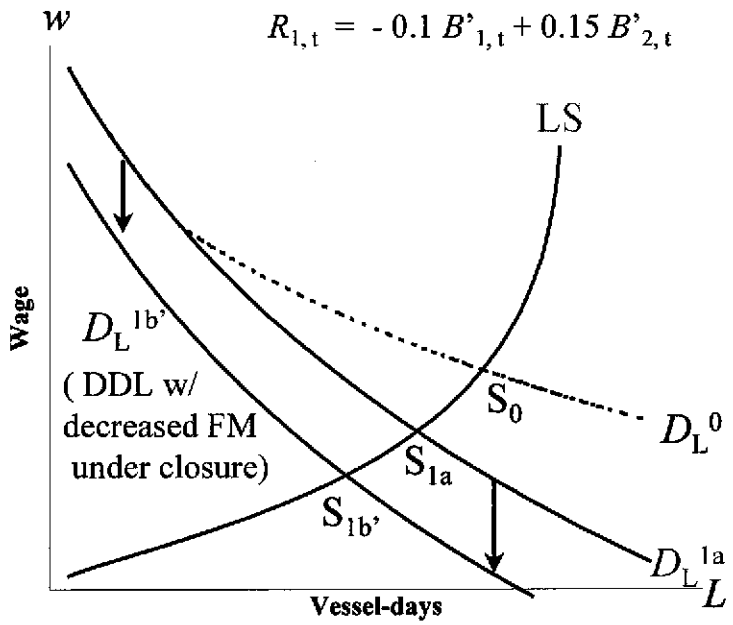

Figure 3.5 Closure, Near-shore, w/ Decreased FM

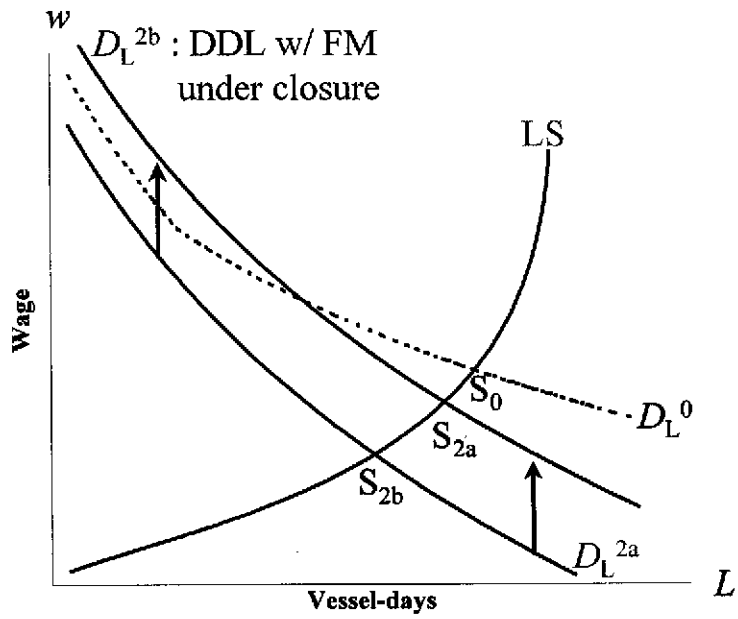

Figure 3.6 Closure, Offshore, with FM

CHAPTER 4
APPLICATION TO THE HAWAII LONGLINE FISHERY

The model developed in Chapter 2 is applied to the Hawaii longline fishery. The procedures to estimate the model parameters for this application are described here. The estimation procedure for catchability coefficients and the results are described in the next chapter. The data used to estimate these parameters include (i) logbook records from the National Marine Fisheries Service (NMFS), (ii) market data from the Hawaii Division of Aquatic Resources (HDAR), and (iii) survey data for Hawaii-based longline vessels by Hamilton, Curtis, and Travis (1996). The empirical model is validated in Chapter 6 by comparing the simulation results with actual data.

4.1 Definition of Fishing Area, Period, and Set Type for the Empirical Model

The present study constructs a spatial grid that divides the fishery into fifty-six 5° squares centered in the Main Hawaiian Islands (MHI) (Figure 4.1) located between latitude 5° N to 45° N and longitude 140° W to 170° E. Each square is defined using its southeast corner as the reference point, e.g., the square between latitudes 15° and 20° N and longitudes 140° and 145° W is labeled as *15N140W* (as per a classification system developed by Curran, Boggs, and He, 1996). One period is defined as a month. This resolution of the logbook data is commonly used for the NMFS data exchange. Campbell and Hand (1999) and many biologists, such as Deriso, Punsly, and Bayliff (1991), used the same framework for space and period.

Fishing Set Type: Targeting Tuna Versus Swordfish

One issue that needs to be considered in empirical work is the targeting strategy of the vessel. For example, a boat may target either bigeye tuna (BE) or swordfish (SW) on all fishing days within a trip, or may switch the primary target from SW to BE in the middle of a trip.[1] Other species, such as yellowfin and albacore tunas and striped and blue marlins, are usually caught as bycatch (He, Bigelow, and Boggs, 1997). Targeting these

[1] The model in Chapter 2 assumes that a boat can target either BE or SW in each fishing set to maximize the crew's wage, though it is rare that a Hawaii longliner switch its target within a trip.

distinct species (SW and BE) imposes distinct fishing and cost characteristics on the boat. For example, swordfish sets are soaked overnight (see figure 4.2) and use more expensive bait (squid) and gear (lightsticks), while tuna sets are soaked in daylight and use cheaper bait, "sanma" (saury, *Cololabis saira*). The catchability coefficients in equation (2.3) would be different for each type of set since swordfish targeting would lead to bigger swordfish catches, and vice versa for BE.

The categorization of fishing sets is done by inspecting logbook data and designating each set as a swordfish or tuna set, depending on whether they satisfy the previously specified qualitative criteria: i.e., fishing time (day or night), bait (sanma or squid), and whether or not to lightsticks were used (Table 4.1). About 11-12 % of the sets did not fall clearly into either category – e.g., a set that soaked in the night, used squid as bait but did not use any lightsticks. These were defined as "mixed sets", and occasionally classified to either tuna or swordfish sets by looking at which of the above criteria they matched more closely (see Table 4.1 for details).

To incorporate the two distinct set types, catch and fishing effort data from the 1995-97 longline logbook, collected by the NMFS (Dollar and Yoshimoto, 1991; Ito and Machado, 2001) are first divided according to set type, next they are aggregated by five-by-five degree squares and by month. Given the two set types, the specification of a total effort index (2.3) can be simplified as:

$$Z_{i,k,t} = \gamma_{i,1} E_{k,1,t} + \gamma_{i,2} E_{k,2,t} \qquad (4.1)$$

where subscripts 1 and 2 denote tuna and swordfish sets, respectively. Following a NMFS convention, one unit of fishing effort is defined as 1,000 hooks. Since the average number of hooks used in a swordfish set (820) was different from a tuna set (1,498), the fishing effort in area k by type 1 and 2 within unit time period in equation (2.2) can be specified as $E_{k,1,t} = 1.498\ FD_{k,1,t} \cdot N_{k,t}$ and $E_{k,2,t} = 0.820\ FD_{k,2,t} \cdot N_{k,t}$. Here $\left(FD_{k,1,t} \cdot N_k\right)$ and $\left(FD_{k,2,t} \cdot N_{k,t}\right)$ represent the total number of tuna and swordfish sets, respectively,

conducted in area k. Moreover, the average number of days spent fishing from 1993 to 1997 ranges from 10.0 to 10.5 sets (WPRFMC 1997), suggesting that on average each longline fishing trip lays approximately 10 sets – one set each fishing day - therefore, $FD_{k,1,t} + FD_{k,2,t} = 10$.

Considerations about the Homogeneity of the Hawaii Longline Fleet

The model described in Chapter 2 assumes a homogeneous fleet, implying that a single labor market (one DDL and one LS function) is considered. If the model were to incorporate (i) the longline fleets from other regions in the US or other nations (e.g., the US West Coast or Alaska, Japan, South Korea, Taiwan) or (ii) other types of gears in Hawaii (pole-and-line, handliners, trollers, recreational boats) in the future research, the model may need to be extended to incorporate multiple fleets that travel from different ports, at the cost of additional model complexity.

When the Hawaii longline fleet is closely examined, the longline vessels are quite diverse in terms of physical characteristics, fishing strategy and management including profit-sharing (Hamilton, Curtis, and Travis, 1996). Many of the Hawaii-based longliners migrated from other regions, and brought socio-economic characteristics associated with their previous ports. For example, several large, steel-hulled vessels with advanced technological equipment came from the US mainland east coast. They had considerable experience at targeting swordfish before coming to Hawaii (Travis, 1999). However, all longliners from the east coast except one left Hawaii in 1994. Because of this, some longliners switched their primary target from swordfish to bigeye tuna, while some others occasionally or permanently start targeting swordfish, switching from tunas or maybe a "mixed" strategy, since their major swordfish competitors had left.

After the above changes, the boundary dividing the longliners into "swordfish boat" or "tuna boat" has become more ambiguous and more longliners were familiar to both strategies. Thus, despite the variation across the Hawaii longline vessels, they are assumed to be homogeneous, and to decide the primary target and fishing location rationally (i.e., to maximize the net return) in this empirical analysis for during 1995-97.

In addition, even though some boats consistently target the same species (at the same areas), they may get out of such a comfortable habit if a strong "shock", such a closure of very profitable fishing areas or a significant price/ tax policy affecting ex-vessel revenue from each species, is imposed. If the Hawaii longliners are divided into different categories and each vessel is assumed to target the same species (e.g., a "swordfish boat" targets swordfish only), the model would not be able to capture such a vessel's behavior of switching its primary target caused by that shock.

4.2 Exogenous Variables and Parameters to Determine a DDL

Estimation of Initial Stocks

Catchability coefficients for each species by set type (*e.g.*, tuna or swordfish set) are estimated from monthly catch and effort data, details for which are given in Chapter 5. The catchability coefficients for the six major species as well as actual data of monthly catch and effort are used to estimate the initial size of the monthly fish stock in each location, by modifying the catch function (2.1) as follows:

$$\hat{B}_{i,k,t} = \frac{C^A_{i,k,t}}{1 - e^{-\sum_s \hat{\gamma}_{i,s} E^A_{k,s,t}}} \tag{4.2}$$

where $\hat{B}_{i,k,t}$ is the estimated initial stock of species i in area k, $C^A_{i,k,t}$ and $E^A_{k,s,t}$ are actual catch and effort data, respectively, and $\hat{\gamma}_{i,s}$ is the catchability coefficient for species i with set type s, estimated in Chapter 5. The estimated initial stock of species i in area k is assumed to be "in place" at the beginning of each month but depletes with harvesting as trips are allocated at each location. A new stock is estimated at the beginning of each month. In one sense, the model simplifies the inflow and outflow of fish movement in each grid, assuming that movement could only occur instantaneously at the point of transition between successive time periods, i.e., at the end of each calendar month. Notice that a calendar month is only an arbitrary device, and the model could be built with weekly price, catch and effort data, if available, although allocation of trips, which usually last longer than a week, may be problematic in that situation.

Prices and Expected Revenue

Monthly fish prices are assumed to be exogenously determined since most of the valuable pelagic species, such as swordfish and much of tunas, are sold in markets in Japan and in the U.S. mainland (WPRFMC, 1995). Prices were computed using revenue data for each species collected by HDAR. Catch data are expressed as numbers of fish caught and fish prices are in dollars per standard-sized fish, as shown in Figure 4.3. Using equation (2.4), the expected revenue in each area was computed from fish prices and stocks. Since the aggregate revenue from the six major species was approximately 90% of the total annual revenue reported during 1995-97, a correction factor for each year (see Table 1.1) was applied to account for other minor species and side catches.

Variable Costs

As mentioned earlier (p. 19), fixed costs of fishing are ignored, and only variable costs and taxes are considered. In Hawaii, longliners are usually obliged to pay two types of costs that depend on the total revenue from a fishing trip: i.e., auction fee and excise tax. Most of the longliners sell their catch to the United Fishing Agency Ltd. (UFA), which charges each vessel 10% of the gross revenue from their catch. The excise tax rate is an additional 0.5% of the gross revenue. Both the auction fee and the excise tax are shared equally between the owner and crew and are a fixed proportion of gross trip revenue (Hamilton, Curtis, and Travis 1996).

Variable costs, including the cost of food, engine oil, fuel, bait, lightsticks, ice, and miscellaneous gear, can be broken down according to their relationship to fishing or traveling activity. Food, engine oil, and fuel are consumed during both, whereas expenses for bait, lightsticks, ice, and miscellaneous fishing gear occur only during fishing. Thus, a fishing day is much costlier than a travel day. Table 4.2 details the breakdown of the variable costs. Note that all costs are in 1997 prices, adjusted by the Honolulu CPI (consumer price index). Based on the survey by Hamilton, Curtis, and Travis (1996), the average daily costs for food and oil are $89.94 and $10.30, respectively. The cost of fuel

is, on average, higher on a travel day ($274.26) than on a fishing day ($239.83). The variable cost per travel day is $374.50 as shown in the table.

The variable cost of fishing depends on a vessel's targeting strategy. It is likely to be higher for targeting swordfish and lower for targeting (bigeye) tuna, due to more expensive bait, lightsticks and miscellaneous gear in the former. Specifically, the average variable cost per fishing day depends on the proportion of swordfish-targeted sets in the 10 sets per fishing trip. As indicated in Table 4.2, the cost of a fishing day is much higher than the cost of a travel day, and swordfish fishing is more than twice as expensive ($1,765.27) as tuna fishing ($854.28). This yields the following formula for variable costs for a trip to area *k*:

$$VC_k = \left(854.28 + 910.99 \times r_{sw,k}\right) \times 10 + 374.50 \times TD_k \qquad (4.3)$$

where $r_{sw,k} = FD_{k,2}/10$ is the share of swordfish sets in the total[2]. See Appendix 2 for the derivation of equation (4.3) from equation (2.5). The above equation implies that the variable costs per trip will increase about $910.99 by substituting a swordfish set for a tuna set.

Net Return and Crew Wage

The net return for a trip to area k and the crew wage can then be expressed as:

$$NR_k = \frac{\sum_i P_i \left(1 - e^{-\left(\gamma_{i,1} E_{k,1} + \gamma_{i,2} E_{k,2}\right)}\right) B_{i,k}}{N_k} \times \delta_{year} \times (1 - 0.105) - VC_k \qquad (4.4)$$

and $$w_k = \frac{0.50\, NR_k}{10 + TD_k} \qquad (4.5)$$

where 0.105 is the total share of revenue paid out as auction fee (10%) and excise tax (0.5%), and the vessel owner and crew each collect 50% of the residual profit (i.e., λ =

[2] Subscript *t* to represent time period is omitted here for simplicity.

0.50) – more than 95% of Hawaii-based longline vessels follow the equal sharing rule (Hamilton, Curtis, and Travis 1996). The correction factors for each year, δ_{year} = 1.1062, 1.1371, and 1.1236 for year 1995, 96, and 97 are applied to account for the revenues from other minor species (see Table 1.1 for the percentage of total by the major 6 species). As explained in Chapter 2, the demand for labor ($L_{D,t}$) in vessel-days is computed as equation (2.10), and then the plots of wage and labor, computed as in the above, yield the derived demand for labor (DDL).

4.3 Estimation of the Labor Supply Function

The labor supply (LS) decision is a classic example in economics where for a given endowment (daily hours and "non-labor" income), an individual consumes two commodities, the composite commodity and leisure, to maximize his/her utility. Theory suggests that an increase in the wage rate tends to increase the quantity of labor supplied since it makes leisure expensive (substitution effect), but at the same time, money income increases due to higher wage rate and increasing hours of work, resulting in an increased demand for leisure (income effect); and eventually, for higher wage rates, an increase in wage may reduce the labor supply (i.e., the LS curve bends backward) as the income effect outweighs the substitution effect.

Evidence of "Backward-bending" Labor Supply (LS) Function

A "backward-bending" labor supply (LS) curve is based on the assumption of "(i) that the individual is free to work just as long as he wishes, and (ii) that the (hourly) wage which he earns is independent of the number of hours he works" (Finegan, 1961). In reality, very few occupations satisfy these assumptions. Hence, such a "backward-bending" LS function is rarely observed in empirical studies.

Several studies (Sloan 1975, Rizzo and Blumenthal 1994, Showalter and Thurston 1997) analyzed the labor supplied by self-employed physicians using cross-sectional data. These results suggested that the wage, in general, affects the labor supply positively, assuming wage elasticity is constant. However, in other empirical studies (see Fleisher and Kniesner 1984, Killingsworth 1983), the wage rate occasionally had no significant or

even a negative effect on the labor supply. Camerer et al. (1997) analyzed the relationship between transitory changes in daily wages for New York cabdrivers and their daily hours supplied, and found that wage elasticity was significantly negative, rather than positive,[3] suggesting that the New York cabdrivers are likely to work until they reach a loose daily income target. A possible explanation for the negative effect of wage rate on labor supply is that their LS curve may start bending backward at a relatively low hourly wage, and the statistical estimation might capture only a part of the LS curve after its bending backward since wage elasticity is assumed to be constant.

One of the statistical limitations in the above studies is that the individual differences are very diverse within a cross-sectional data set and hence many explanatory variables need to be included to capture individual characteristics in estimating LS functions, resulting in a considerable reduction in the degrees of freedom. In addition, wage may not change large enough to capture the entire shape of a "backward-bending" LS curve. Sloan (1975) attempted to find evidence of a backward-bending LS curve for self-employed physicians, by including a squared-term of the logarithm of wage. However, his results were inconclusive since the resulting estimate for that squared-term was not statistically significant. Thus, the statistical evidence for a backward-bending supply is rarely observed in empirical studies.

A few experimental studies were conducted, where irrelevant or uncontrolled events were eliminated so that wage, no-labor income, and all other aspects of workers were strictly controlled. Kagel et al. (1978) conducted a token-economy experiment[4], finding that (i) while increases in real wages were associated with increases or no change in labor supplied by human subjects in the bottom half of the income distribution, (ii) real wages increases were associated with decreases in labor supplied by those in the upper half of the income distribution. Thus, their result indicates that the labor supply curve for the human subjects in this token-economy is likely to bend backward at higher real wage. Battalio, Green and Kagel (1981) also conducted an experiment using non-human

[3] The inter-temporal substitution between days was not significant in their results.
[4] Female psychiatric patients at Central Islip State Hospital in New York were used.

workers (pigeons), and obtained a LS function that bends backward at higher wages; i.e., they got empirical evidence to support economic theory for "backward-bending" LS curve, although non-human subjects were used.

In addition, Rizzo and Blumenthal (1994) pointed out that a spouse's income of a self-employed physician provides disincentive towards working longer, while his/her debt gives incentives towards working longer. Thus, both income earned by a self-employed worker and his/her non-labor income affect his/her labor supply behavior.

A Simple Labor Supply Function for a Fishery Industry

As mentioned in Chapter 2, fishermen can be considered as self-employed workers who choose between "days at sea" and "onshore days" (Gautam et al., 1996). Due to the income effect, the crew would have less incentive towards taking an additional trip[5] as their wage increases. Hence, the wage elasticity of the LS function for the Hawaii-based longline fishery is expected to decrease, and could be negative (i.e., the LS curve bends backward), as the crew's wage increases.

Although the decision by an individual boat is discrete since a boat can take only three or less trips per month, the amount of labor supplied is aggregated across all vessels, and then a continuous function can be used to estimate the industry's labor supply (LS) function. The specification of the LS function in Battalio, Green and Kagel (1981) is simplified as follows:

$$\ln L_{S,t} = b_0 + b_1 (\ln w_t) + b_2 (\ln w_t)^2 + u_t \qquad (4.6)$$

where $L_{S,t}$ is the amount of fishery labor in vessel-days, and w_t is the crew wage. As discussed in Chapter 2, since this is a LS function for the industry as a whole, not for individual vessel or crew, the crew's non-fishery income may have little variation over months even if the data are available, and therefore it is excluded from equation (4.6). Also, note that the fluctuation of crew wage is considered a "transitory change"; i.e., a

[5] Length of each trip is not a choice since the number of fishing sets per trip is assumed to be fixed.

wage rate change is expected to be temporary due to changes in fish prices and abundance, rather than permanent or persistent, while the crew's taste for leisure is assumed to be constant.

Taking the derivative of this equation, the wage elasticity can be expressed as:

$$(\text{Elasticity}) = \frac{\partial L_{S,t}}{\partial w_t} \bullet \frac{w_t}{L_{S,t}} = b_1 + 2b_2 \ln w_t . \qquad (4.7)$$

Parameter b_2 is expected to be negative for a backward-bending LS function. Then this equation implies that the elasticity will decrease from a positive number b_1 as the wage w_t increases, and will be negative (i.e., the LS curve is bending backward) when $w_t \geq e^{-b_1/2b_2}$. The equation also implies that the crew would not go fishing if the expected wage is not high enough. Assuming that the crew would not take a trip if the expected wage is \$1/day, then equation (4.6) indicates that $\ln(L_{S,t}) = b_0 < 0$[6]; thus the intercept, b_0, in (4.6) is expected to be negative.

Data to Estimate the Labor Supply Function

As described in the above, the theoretical model asserts that the derived demand function for labor is expected to shift in response to changes in fish prices and the distribution of fish stocks, while the labor supply function remains constant over time (Figure 2.1). Econometric theory (e.g., Kennedy, 1992) suggests that only the supply function will be econometrically estimated from such a scatter of actual observations. This section first explains how to obtain wage (w_t) and labor ($L_{S,t}$ measured in vessel-days) in each period from actual data.

To estimate the supply function, the monthly total revenue from trips to area k was calculated using actual catch data, by region, from the 1995-97 longline logbook. That is, instead of using equation (4.4), the average net return from trips to area k is obtained as

[6] "No trips" is represented as $0 < L_{S,t} < 1$ because $\ln(L_{S,t})$ cannot be computed if $L_{S,t} = 0$. And $\ln w_t = 0$.

$$NR_k = \frac{\sum_i P_i C_{i,k}^A}{N_k^A} \times \delta_{year} \times (1 - 0.105) - VC_k \qquad (4.8)$$

where N_k^A = (the number of sets actually allocated to area k) / 10 is the "actual" number of trips allocated to area k. This trip number is defined as the "actual" number of trips and is computed in this way because the model assumes that exactly 10 sets are conducted in a single fishing location within a trip.

The variable costs VC_k in the above equation were computed using equation (4.3), but the share of swordfish sets $r_{sw,k}$ was calculated from the actual number of swordfish sets divided by the actual total number of sets. Note that both variables, N_k and $r_{sw,k}$, here to estimate the LS function were obtained from the actual logbook data, while these two variables are determined in the optimization process in the simulation.

Theoretically, the expected wage is equalized across areas. However, the wages w_k for each area, computed using the actual data, may vary across areas, due to fishermen's incorrect expectations regarding prices and stock sizes. Then the expected wage w^* is obtained by computing the weighted average as:

$$w^* = \frac{\sum_k w_k \cdot N_k}{\sum_k N_k}. \qquad (4.9)$$

As mentioned in Chapter 2, this wage ("wage bill") per day at sea is for all crews, including the captain. Finally, the numbers of vessel-days in each area, computed from (2.10), are aggregated by month, and are summarized in Table 4.3. The annual number of trips for 1995-97 ranged approximately from 1,157 to 1,181, while the number of active vessels was 110, 103, and 105 from 1995 to 1997 (WPRFMC, 1998). Monthly ex-vessel revenues shown in the Table 4.3 indicate that the longline industry earned more than $4

million per month during the winter and spring (from December to May), and much less during the other months, particularly from July to October.

Results

A disincentive for fishing, given a crew's labor-leisure tradeoff, comes from the effect of income earned from fishing. It implies that the decision in period t is more likely to be influenced by the income earned in the period (t-1), rather than in the same period. Thus, w_t in equation (4.6) was lagged by one period. Since the Durbin-Watson (D.W.) statistic for the OLS results indicated the presence of autocorrelation, this was corrected, with the resulting LS function as follows:

$$\ln L_{S,t} = -6.0132 + 3.7372(\ln w_{t-1}) - 0.25686(\ln w_{t-1})^2 + u_t . \qquad (4.10)$$

The detailed results by OLS and with the correction of autocorrelation (generalized least square (GLS)) are presented in Table 4.4. The two coefficient parameters, b_1 and b_2, for the GLS results were significant at the 5% level. The estimated labor supply function (4.10) implies that the labor supply increases with wage when wage w^* is less than \$990 / day, but the marginal increase in labor supply in terms of wage diminishing as wage approaches \$990 / day, and furthermore the labor supply starts decreasing (i.e., bending backward) beyond that wage level.[7] The estimated LS function also implies that none of vessels go fishing if the expected wage is less than \$6.31 per day, although this minimum expected wage for the entire crew (average 5.5 members including captain) is likely to be too low[8].

4.4 Implementation

Given exogenous fish prices and stock sizes, in simulating this empirical model, fishing trips - all of which consist of an equal number of fishing, not traveling, days, conducted by homogeneous vessels - are allocated one by one, starting from the area (k) that yields

[7] However, as shown in Figure 4.4, all observed wage data is smaller than the turning point where the LS curve mathematically bends backward (the wages equals \$990 / day). Thus, the negative estimate for a term $(\ln w_t)^2$ is not sufficient evidence to conclude that the LS curve here is "backward-bending".

[8] The corresponding income from that trip is \$120 if it takes a total of 19 days (FD = 10 and TD_k = 9).

the maximum wage (w_k). At the same time, the primary target of each set in each trip is also determined to maximize w_k: i.e., the average number of swordfish sets ($FD_{k,2}$) out of 10 per trip in each area is also a choice variable (endogenous). A boat may conduct more swordfish sets in a fishing area where swordfish are relatively abundant because targeting swordfish might increase the net return from a longline set due to more swordfish catches, even though it increases the cost of the fishing set.

As vessels get assigned to locations generating maximum wage, subsequent harvests in that location decline because of stock externality, and eventually trips are allocated to other competing fishing areas that become more profitable. As a result, trips may be allocated to several areas, alternately.[9] As more trips are allocated over space, the labor demand ($L_{D,t}$) increases, while the expected wage (w^*) decreases. This allocation yields a downward-sloping DDL curve. Meanwhile the labor supply ($L_{S,t}$) will decrease as w^* declines. The labor market for the fishery industry finally reaches an equilibrium where the demand for and supply of labor will equal each other ($L_{D,t} = L_{S,t}$). The above simulation algorithm is implemented by the programming language Turbo C++. See Appendix 6 for the computer program source code.

The next chapter details the procedure of estimating the catchability coefficients and the results. The empirical model developed in this chapter, where the fish stock sizes in each period are given, is used in Chapter 6 for policy analysis. The empirical model is extended to incorporate fish movement (FM) and the effect of FM on the Hawaii longline fishery is analyzed in Chapter 7.

[9] The wages from trips to areas may not be exactly equal across areas, because of the discrete nature of the problem in allocating trips with a fixed number of fishing days. Use equation (4.9) to compute the w_t^*.

Table 4.1 Definition of Fishing Set Types and the Numbers of Sets for Each Set Type Conducted during 1995-1997

Set Type (or strategy)[a]	Hooks/set		Fishing Time[b]	Bait	Use Lightsticks?[c]	1995 # of sets	1995 %	1996 # of sets	1996 %	1997 # of sets	1997 %
Tuna set	1,586		Day	Sanma	No	6,277	53.9%	6,461	55.8%	6,874	58.2%
Mixed-A set[d]	971	(1)	Night	Sanma	No	137	1.2%	59	0.5%	38	0.3%
		(2)	Day	Squid	No	162	1.4%	262	2.3%	306	2.6%
		(3)	Day	Sanma	Yes	25	0.2%	2	0.0%	17	0.1%
					Subtotal	*324*	*2.8%*	*323*	*2.8%*	*361*	*3.1%*
Mixed-B set[d]	846	(1)	Night	Squid	No	970	8.3%	978	8.5%	1,047	8.9%
		(2)	Night	Sanma	Yes	30	0.3%	20	0.2%	13	0.1%
		(3)	Day	Squid	Yes	13	0.1%	27	0.2%	32	0.3%
					Subtotal	*1,013*	*8.7%*	*1,025*	*8.9%*	*1,092*	*9.2%*
Swordfish set	819		Night	Squid	Yes	4,033	34.6%	3,760	32.5%	3,484	29.5%
Total	*1,255*					*11,647*	*100.0%*	*11,569*	*100.0%*	*11,811*	*100.0%*

[a] This categorization is different from the one, T/M/B (tuna/mixed/broadbill), used in the NMFS logbook records.

[b] As a proxy, "fishing during day time" is defined as the begin of hauling time is later than noon and before midnight. Otherwise, sets are defined as "fishing during night time".

[c] "Use Lightsticks" means that number of lightsticks used per set is equal to or greater than 100.

[d] A "mixed" set is one that is not clearly categorized into either swordfish or tuna set, according to the three characteristics of longline sets (i.e., fishing time, bait, lightsticks). A "mixed-B" set is considered a swordfish in the empirical model since it satisfies two out of the three characteristcs of a typical swordfish set. About 96% of the "mixed-B" sets differ from a swordfish set because lightsticks were not used. On the other hands, a "mixed-A" set is considered a tuna set because it satisfies only one of the three characteristics.

Table 4.2 Estimated Average Daily Costs ($/day)

Item	Fishing day		Traveling day
	Tuna set	Swordfish set	
Food	89.94	89.94	89.94
oil	10.30	10.30	10.30
Fuel	239.83	239.83	274.26 [a]
Ice	93.59	42.80	
Bait	298.69	723.17	
Lightsticks	0.00	243.56	
Misc. Gear	121.93	415.67	
Total	854.28	1765.27	374.50

Source: Hamilton, Curtis, and Travis (1996).

[a]In their survey, 37 out of 94 vessels surveyed found no fuel cost differentials between fishing and travel days, 9 reported higher fuel costs for fishing days, and the remaining 48 vessels reported higher fuel costs for travel days. The average fuel cost was $239.83 per fishing day and $274.26 per travel day.

Table 4.3 Data for Estimating the Labor Supply

Month	Number of Fishing Trips[a]	Labor (vessel-days)	Crew Wage ($/day)	Total Ex-vessel Revenue of Longline Industry (million $)	Number of Active Vessels
		Year 1995			
Jan.	99.1	1,687	947	5.14	
Feb.	99.3	1,913	890	5.55	
Mar.	102.5	1,861	916	5.63	
Apr.	104.5	2,003	562	4.49	
May.	120.3	2,052	527	4.51	
Jun.	105.4	1,971	571	4.35	
Jul.	87.6	1,604	343	2.84	
Aug.	61.3	1,289	183	1.63	
Sep.	64.5	1,225	209	1.56	
Oct.	90.3	1,382	421	2.49	
Nov.	111.7	1,878	417	3.38	
Dec.	118.2	2,047	682	4.88	
Subtotal (1995)	1164.7	20,913	556	46.46	110
		Year 1996			
Jan.	125.2	2,364	733	6.06	
Feb.	85.8	1,457	757	3.79	
Mar.	120.1	1,998	778	5.53	
Apr.	120.3	2,008	775	5.48	
May.	126.7	2,272	370	4.09	
Jun.	92.1	1,594	331	2.72	
Jul.	87.8	1,592	228	2.34	
Aug.	60.2	1,170	130	1.32	
Sep.	48.7	788	279	1.16	
Oct.	88.7	1,519	478	2.90	
Nov.	104.1	1,839	685	4.40	
Dec.	97.2	1,696	678	4.07	
Subtotal (1996)	1156.9	20,297	519	43.86	103
		Year 1997			
Jan.	100.0	1,917	737	4.87	
Feb.	115.4	2,050	916	6.10	
Mar.	127.5	2,324	715	5.97	
Apr.	127.7	2,300	637	5.51	
May.	126.7	2,197	721	5.71	
Jun.	102.2	1,775	535	3.89	
Jul.	89.5	1,572	375	2.81	
Aug.	64.2	1,046	302	1.60	
Sep.	49.2	775	332	1.22	
Oct.	72.0	1,060	585	2.27	
Nov.	93.8	1,579	624	3.50	
Dec.	112.9	2,073	798	5.40	
Subtotal (1997)	1181.1	20,668	606	48.85	105
Annual Mean	1,167.6	20,626	560	46.39	

[a]Actual aggregated number of sets divided by 10 fishing days per trip

Table 4.4 Resulting Estimates for the Labor Supply Function

Variable	OLS	AUTO
Intercept	-1.1134	-6.0132
	(4.972) [a]	(4.197) [b]
ln $Wage_{t-1}$	2.1998	3.7372 [**c]
	(1.558) [a]	(1.397) [b]
$(\ln Wage_{t-1})^2$	-0.13663	-0.25686 [**]
	(0.1215) [a]	(0.1041) [b]
RHO		0.5611 [***]
		(0.1399) [b]
R^2 adjusted	0.5895	0.7111
L.L.F.	11.0468	17.0041
Durbin-Watson	0.9419	1.7383

[a]A number inside a pair of parentheses below an estimated coefficient for OLS indicates its standard error.

[b]A number inside a pair of parentheses below an estimated coefficient for AUTO indicates its asymptotic standard error.

[c]Single, double, and triple asterisks indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

The number of observations is 35.

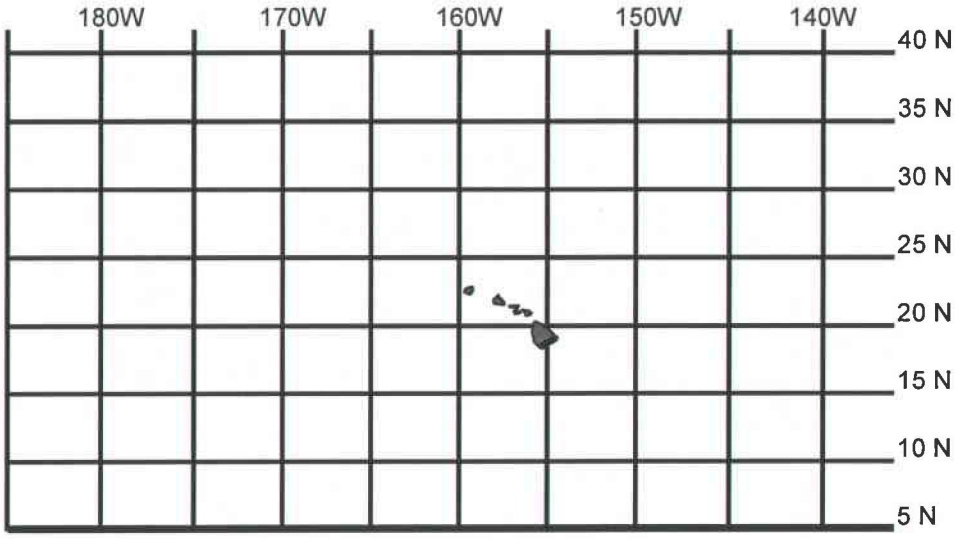

Figure 4.1 Spatial Grid of Five Degree Squares

Surface set during night *Deep set during daytime*

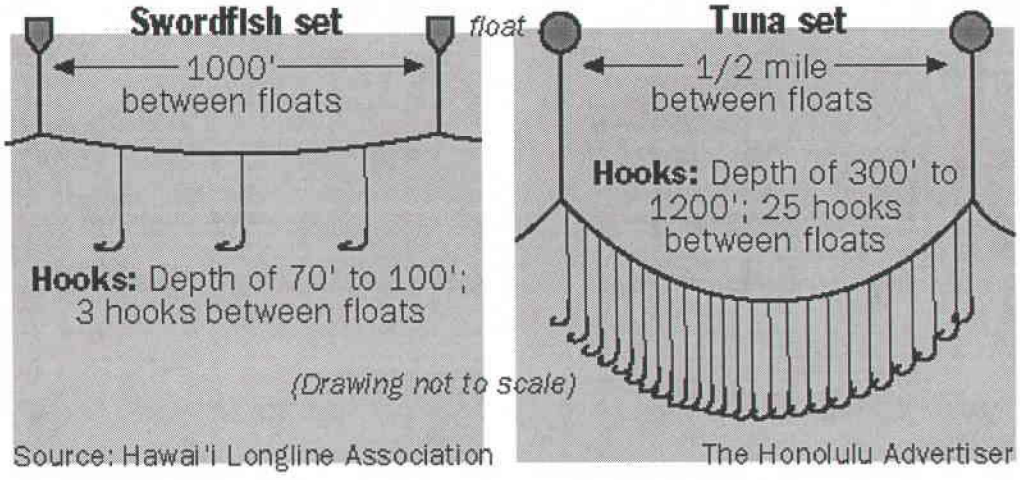

Figure 4.2 Targeting Swordfish vs. Bigeye Tuna

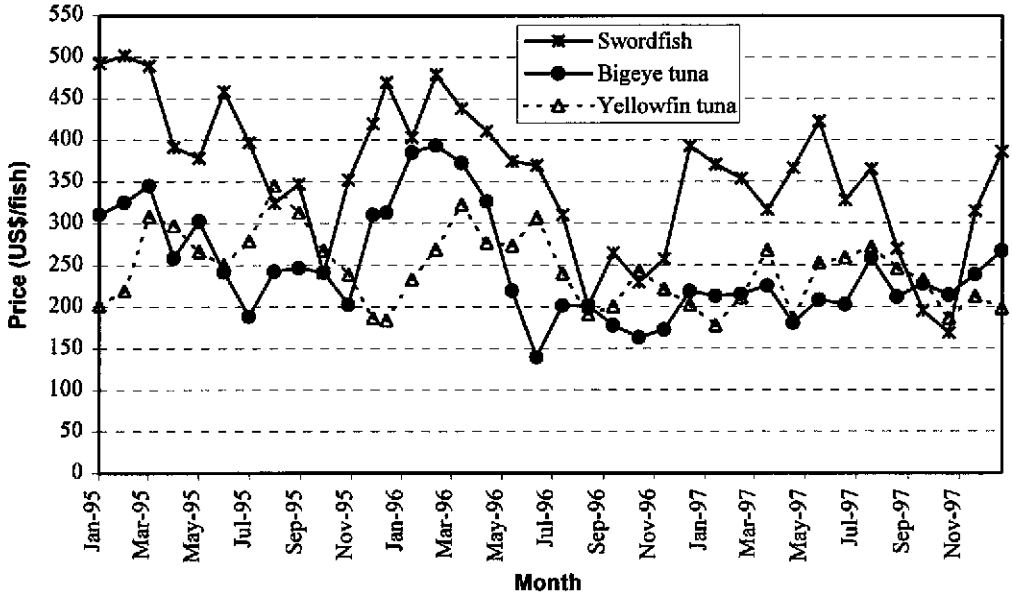

Figure 4.3(a) Average Monthly Price Per Fish of Bigeye and Yellowfin Tunas and Swordfish, Caught by the Hawaii Longliners: 1995-97

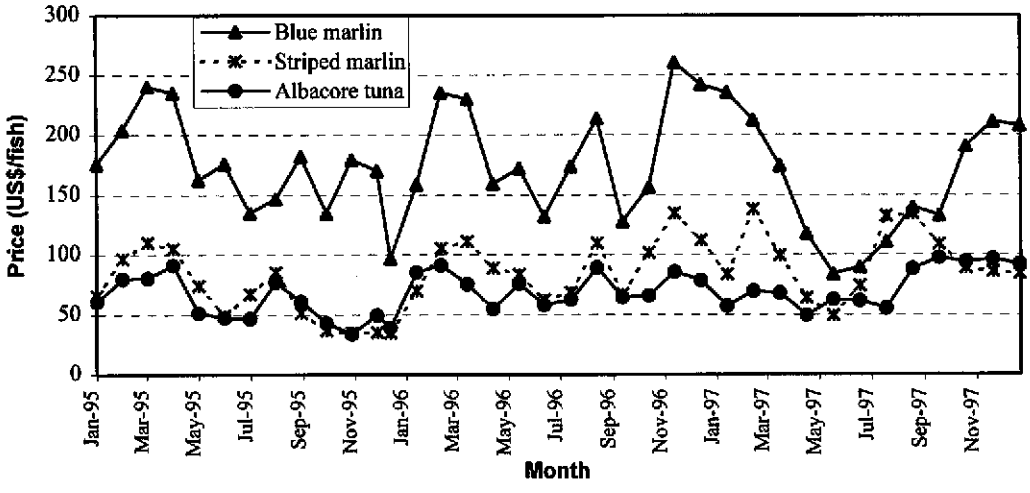

Figure 4.3(b) Average Monthly Price Per Fish of Blue and Striped Marlins and Albacore Tuna, Caught by the Hawaii Longliners: 1995-97

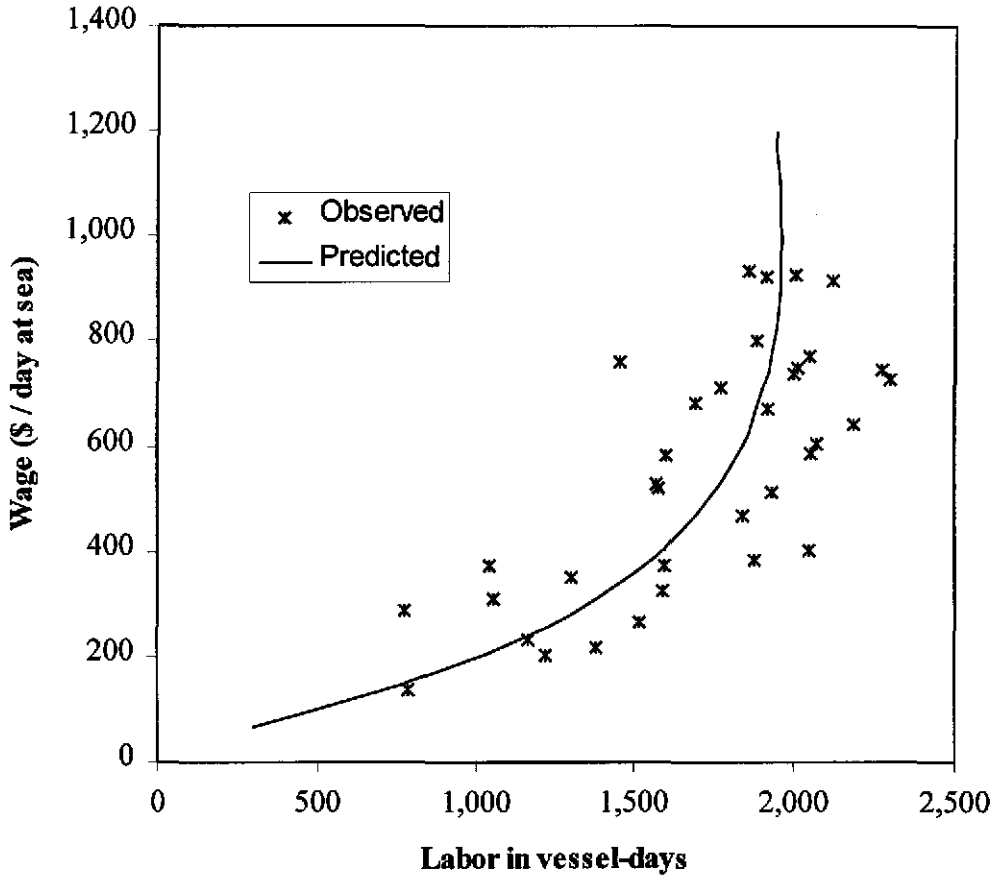

Figure 4.4 Estimation of the Labor Supply Function: Observed and Predicted Data

CHAPTER 5
ESTIMATION OF CATCHABILITY COEFFICIENTS AND FISH STOCKS

As illustrated in Chapter 3, estimates of the catchability coefficients (which are constant over time and space) and stock sizes in each fishing area for each species are needed to run the simulation model. However, information of these parameters for the Hawaii longline fishery is not currently available from other studies. Therefore, this chapter will present a simple method to estimate those parameters.

Catch function (2.1) or similar ones are commonly used by marine biologists (Clark, 1985; Quinn and Deriso, 1999). The total effort index Z in equation (2.1) is often called the "instantaneous total mortality", which can also be divided into two components – natural and fishing mortalities (often denoted as M and F) – though natural mortality is ignored in this study. For simplicity, the fishery is assumed to consist of a homogeneous fleet that uses a single type of strategy (noting that this single set type assumption will be soon relaxed to multiple set types). Moreover, each unit of fishing effort (e.g., 1,000 hooks in the Hawaii longline fishery) is assumed to operate independently and additively. Then fishery mortality is proportional to fishing effort; i.e., $Z = \gamma E$, where the catchability coefficient γ represents the average level of fishing technology – "a vessel's ability to catch fish by one unit of fishing effort in an area with one unit of fish stock" – which is determined by a combination of fishermen's skill and technological aspects of the gear. Because of the assumptions of homogeneous fleet (i.e., all vessels including their crew are identical) and single set type, γ is assumed to be the same across individual vessels, independent of fishing areas, and constant over time in the short run.

In reality, the crew's skills of each vessel (to set fishing gears at the right time and in the right place), and vessel's technical characteristics (e.g., whether or not a vessel is equipped with a line-shooter) may vary across vessels. Moreover, oceanographic and biological conditions may affect the average catchability γ; that is, it might become lower if a boat faces very strong currents (Kleiber, 2001), while it might become higher if fish is overall hungry due to the shortage in natural food (prey) availability (Grubbs and

Holland, 2001). However, such an error from the average catchability γ is assumed to be random in this study.

Now fishing sets are differentiated. The Hawaii longliners earn ex-vessel revenues mainly from six major species using two distinct fishing set types -- tuna and swordfish sets -- and the so-called "mixed" set. Two types of mixed sets (i.e., mixed-A and B in Table 4.1) are also included here in order to standardize effort data more accurately, although the mixed set is not included as a choice for fishing sets when simulating longline trips (Chapters 4, 6, and 7). The following procedure was used to estimate the catchability coefficients for each species with various set types:

(i) Estimate the "catchability ratio" (= $\gamma_{i,s} / \gamma_{i,1}$), where $\gamma_{i,1}$ and $\gamma_{i,s}$ are the catchability coefficients for species i with a tuna set and a set type s, respectively; and standardize effort in terms of tuna sets using the estimates for the "catchability ratio"; and

(ii) Estimate the catchability coefficient for species i ($\gamma_{i,1}$) using the catch and "standardized" effort data, assuming the Hawaii pelagic fishery is in a long-term equilibrium.

Since multiple set types (i.e., tuna, swordfish and mixed sets) are used in many areas around MHI (Main Hawaiian Islands) between 20° - 30° N, fishing effort data need to be standardized before estimating catchability coefficients. As explained below, the "catchability ratio" needs to be estimated in order to standardize effort. This catchability ratio is also crucial when each fishing boat chooses the number of days to target tuna or swordfish within the 10 fishing days as the net return from the trip is maximized in the simulation. On the other hand, the scale of an individual catchability coefficient, gamma ($\gamma_{i,s}$), indicates how quickly fish stock would be depleted by unit effort. The estimation of gamma requires an additional assumption and an iterative procedure with the panel data set, which is relatively costly compared to the estimation of the catchability ratio. As shown in equation (4.2), once the catchability coefficients for each species are estimated, the initial size of the monthly fish stock ($B_{i,k}$) in each location can be computed.

5.1 Analysis of CPUE by Modifying the Catch Function

This section first derives a modified catch function, which is useful to explain the features of the catch function (2.1), particularly the relationship between fish stock ($B_{i,k}$) and the conventional *CPUE* measure. Besides, this theoretical analysis is also used later to estimate the "catchability ratio" of each species. First, rewrite the Total Effort Index $Z_{i,k}$ in equation (2.3) as

$$\begin{aligned} Z_{i,k} \equiv \sum_s \gamma_{i,s} E_{k,s} &= \gamma_{i,1}\left(E_{k,1} + \frac{\gamma_{i,2}}{\gamma_{i,1}} E_{k,2} + \ldots \right) \\ &= \gamma_{i,1} E'_k \end{aligned} \qquad (5.1)$$

where E'_k is fishing effort standardized in terms of a tuna set at area k.[1] Standardization is usually necessary, in particular, to estimate the fish abundance if catch and effort data consist of various gear types (Quinn and Deriso, 1999, pp. 18-25). Although only longline gears are considered in this empirical model, the effectiveness of two distinct fishing set types (i.e., targeting tuna or swordfish) on the catch of each species (in particular, swordfish) is believed to be different, and hence standardization is needed.

Equation (5.1) implies that effort data for various set types can be standardized into a single set type if the "catchability ratio" (= $\gamma_{i,s} / \gamma_{i,1}$) is known. Then the catch function (2.1) can be modified as

$$C_{i,k} = B_{i,k}\left(1 - e^{-Z_{i,k}}\right) = B_{i,k}\,\alpha_{i,k}\,Z_{i,k} \qquad (5.2)^2$$

where

$$\alpha_{i,k} = \begin{cases} \left(\dfrac{1-e^{-Z_{i,k}}}{Z_{i,k}}\right) & \text{if } Z_{i,k} > 0 \\ 1 & \text{if } Z_{i,k} = 0. \end{cases} \qquad (5.3)$$

[1] Subscript t is omitted here for simplifying notation.

[2] Quinn and Deriso (1999) calls ($B_{i,k}\ \alpha_{i,k}$) "the average abundance".

Note that the original catch function (2.1) implies that catch is zero when no effort is applied (i.e., $Z_{i,k} = 0$). Hence, $\alpha_{i,k}$ should be a finite number when $Z_{i,k} = 0$, so that the modified catch function (5.2) yields zero. Now expanding $\left(1-e^{-Z}\right)$ around $Z_{i,k} = 0$ in equation (5.3) as a Taylor series, the following is obtained:

$$1-e^{-Z} = \frac{Z}{1!} - \frac{Z^2}{2!} + \frac{Z^3}{3!} - \frac{Z^4}{4!} + \cdots \quad . \tag{5.4}$$

Note that subscripts, i and k, for Z are omitted here. Dividing (5.4) by Z (> 0), and letting Z approach zero, then we get

$$\lim_{Z \to +0} \frac{1-e^{-Z}}{Z} = \lim_{Z \to +0} \left(1 - \frac{Z}{2!} + \frac{Z^2}{3!} - \frac{Z^3}{4!} + \cdots\right) = 1 \; .$$

This is why it is defined in equation (5.3) that $\alpha_{i,k} = 1$ when $Z_{i,k} = 0$. Then $\alpha_{i,k}$ is positive and monotonically decreasing with $Z_{i,k}$ from a maximum value of 1. Dividing equation (5.2) by the standardized effort (when $E'_k > 0$), it can be rewritten as

$$CPUE'_{i,k} = \frac{C_{i,k}}{E'_k} = B_{i,k}\, \alpha_{i,k}\, \gamma_{i,1} \tag{5.5a}$$

where $CPUE'_{i,k}$ is catch-per-unit-effort for species i in area k in terms of the standardized set. Moreover, equation (5.5a) can be simplified as

$$CPUE'_{i,k} = CPUE^0_{i,k} \cdot \alpha_{i,k} \tag{5.5b}$$

where $CPUE^0_{i,k} = B_{i,k}\, \gamma_{i,1}$ is the maximum $CPUE$ for species i at area k which is a hypothetical $CPUE$ level if effort E_k infinitely approaches 0 (and hence $\alpha_{i,k} \rightarrow 1$),

although, strictly speaking, *CPUE* makes sense only with positive effort. Note that $CPUE^0_{i,k}$ is independent of effort since $\gamma_{i,1}$ is constant and $B_{i,k}$ is also fixed in a given area and period; and *CPUE* in the left-side of equation (5.5b) is always less than $CPUE^0_{i,k}$ and becomes infinitely close to $CPUE^0_{i,k}$ as effort level approaches zero (i.e., $E_k \rightarrow 0$ and hence $\alpha_{i,k} \rightarrow 1$). Equation (5.5b) implies *CPUE* declines with increased effort from the maximum value of $CPUE^0_{i,k}$ due to the stock externality, which is expressed by $(1 - \alpha_{i,k})$.

Campbell and Hand (1999) called the stock externality as the "fish-down" effect, and pointed out that one of the limitations in their model is not incorporating the stock externality. The significance of the stock externality in the Hawaii longline fishery is illustrated as follows: suppose that $\gamma_{i,1} = 0.002$ and $B_{i,k} = 4{,}000$ (hence $CPUE^0_{i,k} = 8$), the corresponding *CPUE* with effort level 10, 300, and 800 would be about 99%, 75%, and 50% of $CPUE^0$, respectively (see Table 5.1 and Figure 5.1). When 10 or less fishing sets are conducted in a given area and period, the stock externality is trivial (about 1% or less) and then CPUE is likely to represent abundance. On the other hand, the maximum level of standardized effort for bigeye tuna (BE) during 1995 - 1997 was 637 (at *20N160W*, November 1997), where $\alpha_{i,k} = 0.565$ and the fishery mortality is 72% of the given stock (4,000). In addition, the first quartile, median, and third quartile of effort level were 31, 73, 158, respectively, and the corresponding values of $\alpha_{i,k}$ were 97%, 93%, and 86%, respectively. This suggests that the model should incorporate the decline in *CPUE* due to the stock externality because it was greater than 5% in more than 50% of strata.

The above illustration also suggests that ordinal *CPUE* should be cautiously used as a measure of fish stocks; i.e., the stock sizes for species *i* in two distinct areas where the *CPUE* values are the same may differ from each other, unless the amounts of allocated effort level in the two areas are the same. The model assumes that the crew on a vessel estimates (or guess) *CPUE* in each area and period, based on the expected stock size ($B_{i,k}$) and stock externality factor ($1 - \alpha_{i,k}$), which is determined by the total effort allocated in this area, including the effort conducted by other vessel.

Note that both $B_{i,k}$ and $CPUE^0_{i,k}$ are indicators of fish stock: $B_{i,k}$ is a capacity or maximum level of fishery catch at area k and period t (though catch would never reach or exceed $B_{i,k}$), while $CPUE^0_{i,k}$ indicates the maximum $CPUE$ which is expected by a fishing set only if no other fishing sets are conducted in a given area and month. Although $B_{i,k}$ is very useful information for stock assessment (i.e., fish population), $B_{i,k}$ depends on the definitions of area and period. For example, suppose that area is defined as 1° square, instead of 5° square, then $B_{i,k}$ would be much smaller, given the same fish abundance. On the other hand, $CPUE^0_{i,k}$ is independent of the definition of area and period, and obviously more relevant information for fishermen since it more directly indicates the expected catch per unit effort and hence the expected revenue with certain operating costs.

5.2 Estimation of "Catchability Ratios"

Now consider a case where two distinct set types, s and q (e.g., tuna and swordfish sets), are used in the same area and same period. Using the modified catch function (5.2), it can be expressed as

$$C_{i,k} = B_{i,k}\alpha_{i,k}\left(\gamma_{i,s}E_{k,s} + \gamma_{i,q}E_{k,q}\right). \qquad (5.6)$$

Catches from set type s ($C_{i,k,s}$) and type q ($C_{i,k,q}$) in area k can be separated from (5.6) as

$$C_{i,k,s} = B_{i,k}\,\alpha_{i,k}\,\gamma_{i,s}\,E_{k,s} \qquad (5.7a)$$

and

$$C_{i,k,q} = B_{i,k}\,\alpha_{i,k}\,\gamma_{i,q}\,E_{k,q} \qquad (5.7b)$$

where $C_{i,k,s} + C_{i,k,q} = C_{i,k}$. Dividing (5.7a) by (5.7b), the following relationship is obtained:

$$\frac{\gamma_{i,q}}{\gamma_{i,s}} = \frac{CPUE_{i,k,q}}{CPUE_{i,k,s}} \qquad (5.8)$$

where $CPUE_{i,k,s} = C_{i,k,s} / E_{i,k,s}$ is *CPUE* for species *i* in area *k* for set type *s*. While both gammas in the left-hand side of equation (5.8) are assumed constant, *CPUE* values with both set types *s* and *q* as well as the *CPUE* ratio in the right-hand side are expected to fluctuate over periods and vary across fishing locations. This equation implies the *CPUE* ratio should be, on average, equal to the catchability ratio regardless of abundance or effort level in each stratum (area *k* at period *t*).

CPUE values in equation (5.8) were computed based on the catch and effort, which were aggregated from set-level data within each stratum. Since the number of fishing sets used in the aggregation process varies across strata, the *CPUE* ratio in each stratum should be weighted by the number of fishing sets. In addition, the data type in the equation (5.8) is a ratio, and therefore the weighted geometric mean was used to estimate catchability ratios ($\gamma_{i,q} / \gamma_{i,s}$). The detailed procedure is described in Appendix 3.

Results and Discussions

As discussed in Chapter 4, the mixed set was originally considered to be an intermediate strategy between tuna- and swordfish-targeting sets, according to certain characteristics (also see Table 4.1), and hence the mixed set was excluded from the choices for longline sets when simulating longline trips in the present study, as in equation (3.1). However, two sub-types of mixed sets (i.e., mixed-A and B) are treated as distinct set types in order to estimate more accurate catchability ratios for each species in this chapter. Three types of catchability ratios -- (i) tuna versus swordfish set, (ii) tuna versus mixed-A, and (iii) mixed-B versus swordfish set -- were estimated for each species. Estimates for catchability ratios for the six species are summarized in Table 5.2.

Tuna vs. swordfish sets

Table 5.2 shows that, for a given stock size and unit effort (1,000 hooks), a swordfish set catches 59 times more swordfish than a tuna set. The table also shows that a swordfish set catches more yellowfin tuna (YF) and blue marlin than a tuna set. However, one should cautiously interpret the catchability ratio of swordfish set to tuna set for BE (= 1.56).

Suppose $CPUE = 1$ for BE with tuna set for given a stock size (i.e., $B_{i,k}$ and $\alpha_{i,k}$ are fixed in equation (5.5a)). A typical tuna set with 1,586 hooks would catch 1.586 BE, while a typical swordfish set with 819 hooks catches about 1.278 BE (= 1.56 * 0.819), implying a tuna set catches slightly more BE than a swordfish set. Besides, a tuna set is much cheaper (Table 4.2). Therefore, fishermen reasonably prefer tuna sets to catch BE.

A null hypothesis that the catchability ratio for striped marlin equals 1 cannot be statistically rejected, implying there is no significant difference in catchability coefficients for striped marlin between tuna and swordfish sets. However, similar to BE's case, since the number of hooks used in a swordfish set is fewer, a tuna set actually catches more striped marlin than a swordfish set. A unit effort of tuna set catches about 7 times more albacore than a unit effort of swordfish set. These results are similar to those of Okamoto (1999) since he found that (a) catches of albacore and striped marlin were higher from tuna sets than from swordfish sets, (b) swordfish catches from swordfish sets were higher than those from tuna sets, and (c) there was no significant difference in catches of BE between the two set types. This earlier study had no results regarding YF or blue marlin.

Okamoto (1999) also pointed out that the average weights of each species caught by the two distinct set types are likely to differ from each other. However, the present study does not incorporate the difference in weight or quality (i.e., marketable price): that is, monthly average price per pound and weight per fish are assumed to be constant, independent of fishing location or set type.

Mixed sets

A mixed-A set is differentiated from the tuna set primarily because it uses squid as bait, and a mixed-B set is differentiated from the swordfish set primarily because it uses no lightsticks. An additional and crucial character of a longline set is the depth of hooks. As summarized in Table 5.2, tuna-set hooks are soaked in deep water, while the hooks in other set types are soaked in relatively shallow water. (Note that the number of hooks per set for a tuna set is much greater than for other set types.) As mentioned before, if a

mixed set is considered to be an intermediate strategy between tuna and swordfish sets according to certain characteristics, the catchability coefficients for mixed sets are expected to be between those for tuna and swordfish sets.

However, Table 5.2 indicates that this hypothesis is likely to be reasonable only for swordfish catch. The types of mixed sets are most likely to catch more blue and striped marlins and YF among the four set types. Besides, a mixed-A set significantly differs from a mixed-B set in terms of BE catch. Most of the mixed-A sets are soaked during the daytime, while most of the mixed-B sets are during the nighttime. A mixed-A set catches BE least among the four set types because BE usually swims in deep water during the daytime and stays in relatively shallow water during the nighttime. Lastly, only a tuna set is likely to be most effective to catch albacore (AC), while catchability for AC with the other three set types are very similar to one another. Since other studies suggest that squid are more prevalent in the diet of fish further from the equator (NMFS, 2001, 3-40), AC should have no problem with squid as bait. Since AC can swim deep, the depth of hooks may be one of the important factors affecting the catchability for AC.

5.3 An Iterative Estimation Procedure for Catchability Coefficients

As mentioned before, all effort data can be treated as a single set type after standardization. Fish stock movement for each species is assumed to be independent. Given the catch function (5.2), a series of harvests in a fishing location over consecutive periods yield the following sequence of catches:

$$\begin{aligned} C_1 &= \gamma\, \alpha_1\, E_1\, B_1 \\ &\vdots \qquad \vdots \\ C_t &= \gamma\, \alpha_t\, E_t\, B_t \\ C_{t+1} &= \gamma\, \alpha_{t+1}\, E_{t+1}\, B_{t+1} = \gamma\, \alpha_{t+1}\, E_{t+1}\left(B_t - C_t + R_t\right) \end{aligned} \tag{5.9}$$

where all subscripts denote the time period only, ignoring species, area, and fishing strategy for simplicity. The net stock inflow during period t, R_t, is defined as the total fish stock inflow minus the stock outflow and natural mortality. It is positive if the inflow is

greater than the outflow, and vice versa. In (5.9), the fish stock changes between periods due to harvest and in and out-migration of fish. Expressing the equations in terms of $CPUE_t / \alpha_t$ and subtracting the equation for t from (t +1), the following is obtained:

$$\frac{CPUE_{t+1}}{\alpha_{t+1}} - \frac{CPUE_t}{\alpha_t} = \gamma\left(-C_t + R_t\right) \tag{5.10}$$

where $CPUE_t = C_t / E_t$ is catch-per-unit-effort at period t. To econometrically estimate γ, the Hawaii pelagic fishery is assumed to be in a long-term equilibrium; i.e., the expected net inflow is equal to the expected catch per period in each area. Equation (5.10) then becomes

$$\frac{CPUE_{t+1}}{\alpha_{t+1}} - \frac{CPUE_t}{\alpha_t} = -\gamma\left(C_t - \overline{C}\right) + \varepsilon_t \tag{5.11}$$

where $\overline{C}$ is the average catch per period, and the random disturbance $\varepsilon_t = \gamma\left(R_t - \overline{C}\right)$ and E(ε_t) = 0. This equation implies that a change in *CPUE* adjusted by α_t (denoted by $\Delta CPUE_{adj}$) between consecutive periods is a negative linear function of catch in the current period. The long-term equilibrium assumption is supported by Boggs and Ito (1993) and other studies of the Hawaii pelagic fishery, who report that species abundance estimated by measures such as average *CPUE* and average weight per fish has not changed to any significant degree (WPRFMC, 1998).

The estimated parameter γ in (5.11) affects the dependent variable since α_t is a function of $Z = \gamma E'$. Therefore, γ was estimated by an iterative procedure as follows; i.e., (i) first estimate or guess the initial value of γ, (ii) compute α_t and $\Delta CPUE_{adj}$ for all observations with this tentative γ, (iii) perform another round of estimation with (5.9) to get the new γ, and (iv) repeat the estimation procedure until the estimate of γ converges.

Empirical Results and Discussions

A panel data set with monthly catch and fishing effort data aggregated by each 5° square was used to estimate γ for each species. Effort data were standardized in terms of a tuna set, using equation (5.1). Fishing areas that reported at least one set every month were used in order to avoid having any missing observations. Based on this criterion, the six areas -- *15N155W*, *15N160W*, *20N155W*, *20N160W*, *25N155W*, and *25N160W* -- were selected. There were 36 months of data for each area.

Monte-Carlo experiments by Baltagi (1992) suggest that if T (# of time periods) is large and N (# of cross-sectional units) is small, the pooling technique described in Kmenta (1986) is better than the error component technique, and vice versa. Since T equals 35 and N is 6 or less in the panel data to estimate γ in (5.11), Kmenta's model is preferred.

Kmenta's model results in efficiency gains if there exist severe (i) cross-sectional heteroscedasticity, (ii) cross-sectional correlation, or (iii) autocorrelation. In general (e.g., see Kmenta, 1986, p. 625; and Greene, 1993, p. 463), cross-sectional independence is a strong assumption and less likely when cross-sectional units are associated with geographical areas, while autocorrelation may not be significant although it appears to rise naturally in time-series data.

The Durbin-Watson statistic for each cross-sectional unit (which is for each species in each area) indicates that autocorrelation was not severe for any ordinary least squares (OLS) result. Therefore, non-autocorrelation is assumed. The Lagrange multiplier (LM) test for cross-sectional heteroscedasticity and the Breusch-Pagan LM test (Greene, 1993) were conducted on the pooled regressions for each species. Both tests indicated significance in terms of all six species. Therefore, heteroscedasticity and cross-sectional correlation were corrected using the Shazam econometric computer software (White, 1993). Results from the final iteration of the estimation procedure are shown in Table 5.3.

All estimated catchability coefficients were significant at the 1% level with expected signs. OLS results are given for the purpose of comparison. Note that raw-moment R^2

was used since the intercept was restricted to zero as indicated in (5.11). Data for one fishing area were excluded for swordfish (SW), albacore (AC), and striped marlin (SM) because results from the pre-estimation of the OLS procedure indicate the model in (5.11) was unlikely to fit the data; the results for AC and SM showed very low R^2 while the catch and standardized effort data and catch in *15N160W* were insufficient.

The Buse-R^2 scores were relatively low, ranging from 0.046 to 0.214 primarily because the random disturbance, ε_t, in (5.11) captured exogenous seasonal (i.e., monthly) fluctuations in the net inflow, and the abundance of pelagic species in Hawaii is likely to be most strongly affected by factors other than local fishing activity (Boggs and Ito, 1993). The Buse-R^2 scores for BE, YF, and blue marlin were relatively higher, possibly due to the greater influence of fishing effort on $\Delta CPUE_{adj}$. The Buse-R^2 scores for swordfish and albacore were lower since they are considered to be highly migratory species (personal communication with Pooley), and their movement over periods might be more influenced by seasonal and other environmental factors, than by local catches.

The finalized catchability coefficients, or gammas, by species and set types are summarized in Table 5.4. The gamma for swordfish on a tuna set was very low, implying that a tuna set catches very few swordfish. The gammas for blue marlin and YF with two mixed sets and swordfish were highest, ranging from 0.0049 to 0.0065). However, the estimated gammas should be cautiously interpreted because the lack of catch data by handliners and trollers might exaggerate the impact of longline catches in (5.11), resulting in the higher gammas. The table shows that the gammas for bigeye (BE), YF and BM with a swordfish set are as high as for swordfish with a swordfish set. However, one should recall that (i) catch data in (2.1) is defined as the number of pieces, not weight, and (ii) the average price per piece for swordfish ($/lb. times average weight) was highest among the six species during the period, and (iii) fishermen's choice for set type is based on profitability, which introduces abundance ($B_{i,k}$) and travel costs to area k into consideration.

Table 5.1 Illustration for the Catch Function:
A Case of a Single Species and Set Type

γ = 0.0020
B = 4000

Effort E	Fishery Mortality $Z = \gamma E$	1 - EXP(-Z)	α	CPUE $= B \alpha \gamma$
0	0	0	1.000	8.00
10	0.02	0.0198	0.990	7.92
50	0.10	0.0952	0.952	7.61
100	0.20	0.1813	0.906	7.25
150	0.30	0.2592	0.864	6.91
200	0.40	0.3297	0.824	6.59
250	0.50	0.3935	0.787	6.30
300	0.60	0.4512	0.752	6.02
350	0.70	0.5034	0.719	5.75
400	0.80	0.5507	0.688	5.51
450	0.90	0.5934	0.659	5.27
500	1.00	0.6321	0.632	5.06
550	1.10	0.6671	0.606	4.85
600	1.20	0.6988	0.582	4.66
650	1.30	0.7275	0.560	4.48
700	1.40	0.7534	0.538	4.31
750	1.50	0.7769	0.518	4.14
800	1.60	0.7981	0.499	3.99
1,000	2.00	0.8647	0.432	3.46
1,250	2.50	0.9179	0.367	2.94
1,600	3.20	0.9592	0.300	2.40
2,000	4.00	0.9817	0.245	1.96
2,500	5.00	0.9933	0.199	1.59

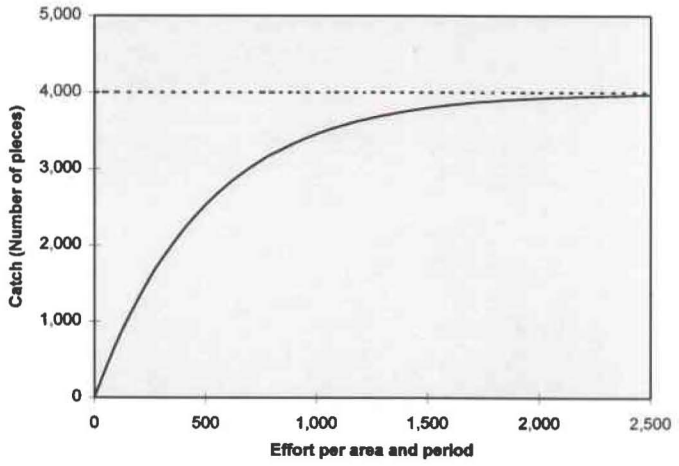

Figure 5.1(a) Cumulative Catch with Effort Level

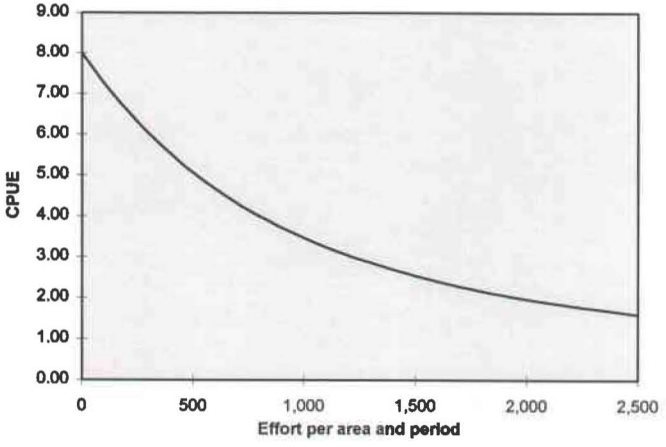

Figure 5.1(b) Change in CPUE with Effort Level:
$\gamma = 0.002$ and $B_{i,k} = 4{,}000$

Table 5.2 Catchability Ratios and Estimated Catchability Coefficients ($\gamma_{i,s}$): Six Major Species in the Hawaii Longline Fishery, 1995-97
(Date source: the NMFS logbook)

	Longline Set Type			
	Tuna	Mixed-A	Mixed-B	Swordfish
Characteristics of sets				
Duration Time	Day	Day	Night	Night
Bait	Sanma	Squid	Squid	Squid
Lightsticks	No	No	No	Yes
(Number of lightsticks / set	0.9	1.7	17.8	234.4)
Depth	Deep	Shallow	Shallow	Shallow
(Number of hooks / set	1,586	971	846	819)
Species	***Catchability Ratio (Base: Tuna Set)***			
Blue marlin	1.00	9.09	6.50	4.73
Striped marlin	1.00	2.28	1.39	0.98
Swordfish	1.00	5.30	40.54	58.90
Albacore	1.00	0.17	0.15	0.14
Bigeye tuna	1.00	0.52	1.42	1.56
Yellowfin tuna	1.00	3.25	5.39	4.58

Table 5.3 Estimated Catchability Coefficients ($\gamma_{i,s}$): Six Species in the Hawaii Longline Fishery

Species	POOL Results			No. of Areas	LM test		OLS Results[b]		
(Logbook code)	Coeff. (γ_i)	Buse-R^2	LLF	(excluded)	Heteroscedasticity	Cross-Sec. Correl.	Coeff. (γ_i)	R^2	D.W. stat
Swordfish	0.00547 ***	0.0464	-418.734	5	12.296 **	39.071 ***	0.00637	0.0594	1.908
(SW)	(0.00188) [a]			(N15W160)	d.f. = 4	d.f. = 10	(0.00192)		
Bigeye	0.00277 ***	0.1645	-428.253	6	16.442 ***	88.631 ***	0.00255	0.1107	1.953
(BE)	(0.00043)				d.f. = 5	d.f. = 15	(0.00050)		
Yellowfin	0.00272 ***	0.1832	-137.961	6	44.041 ***	49.174 ***	0.00301	0.1823	2.095
(YF)	(0.00040)				d.f. = 5	d.f. = 15	(0.00044)		
Albacore	0.00274 ***	0.0621	-538.446	5	181.94 ***	36.792 ***	0.00456	0.0122	2.282
(AC)	(0.00081)			(N20W160)	d.f. = 4	d.f. = 10	(0.00311)		
Blue Marlin	0.00315 ***	0.2140	-48.975	6	80.722 ***	36.025 ***	0.00415	0.1224	2.444
(BM)	(0.00042)				d.f. = 5	d.f. = 15	(0.00077)		
Striped Marlin	0.00200 ***	0.0958	-207.193	5	44.478 ***	35.438 ***	0.00276	0.0720	2.359
(SM)	(0.00046)			(N15W155)	d.f. = 4	d.f. = 10	(0.00075)		

Note: both Buse-R^2 and OLS R^2 are Raw Moment R^2 because of no constant to estimate γ.
Numbers in parentheses below each estimated coefficient indicate its standard error.
Single, double, triple asterisks indicate the statistical significance at the 10%, 5%, and 1%, respectively.

[a] An estimate with a swordfish set

[b] The same value as the pooled estimate was used for the initial value of γ for comparison purposes.

Table 5.4 Estimated Catchability Coefficients: by Species and Set Types, 1995-97 (Date source: the NMFS logbook)

Species Name	Longline Set Type			
	Tuna	Mixed-A	Mixed-B	Swordfish
Blue marlin	**0.00315**	0.02861	0.02047	0.01489
Striped marlin	**0.00200**	0.00455	0.00278	0.00196
Swordfish	0.00009	0.00049	0.00377	**0.00547**
Albacore	**0.00274**	0.00047	0.00040	0.00040
Bigeye tuna	**0.00277**	0.00143	0.00394	0.00431
Yellowfin tuna	**0.00272**	0.00884	0.01467	0.01246

Bold coefficients indicate that they was estimated by the interactive procedure. See equation (5.11) and Table 4.3. Other coefficients are computed by multiplying the corresponding catcahbility ratios in Table 5.2

CHAPTER 6
POLICY SIMULATION WITHOUT FISH MOVEMENT

The National Marine Fisheries Service's (NMFS) final Environmental Impact Statement (EIS) was issued on March 30, 2001, which temporarily ended the litigation, where the Center for Marine Conservation and Turtle Island Restoration Network sued the NMFS, alleging inadequate protection for sea turtles against interactions with the Hawaii longline fishery (see Appendix 1). Next, the Hawaii Longline Association filed on April 10, 2001 for declaratory and injunctive relief from the area closure imposed by the NMFS based on the 2001 Biological Opinion issued by NMFS on March 30, 2001 with the final EIS (Achitoff, 2001; Appendix 1).

Such protracted disputes represent losses to social welfare in the long run, stemming partly from lack of agreement about the impacts of regulatory policies on the fishery industry and the marine ecosystem. Conservationists and environmentalists favor imposing the tightest regulations without discussing the balance between the benefit (or effectiveness, which is usually uncertain) and costs of regulation to protect endangered species under many uncertainties. On the other hand, the industry focuses on appealing the significance of the expected loss in their revenue and profit, which does not account for alternative revenue by substituting fishing locations or switching the primary target species. More accurate estimation of the impacts (including benefits and costs) of each regulatory policy on the industry and marine species could minimize conflicts between conservationist and harvest sectors, and hence help ensure that a fishery regulator adopts the most appropriate policies.

Many empirical studies (see a review by Kerstetter, 2000) used two simple assumptions to evaluate the impacts of area closure: (i) effort is not relocated from in the closed area (while effort allocated in the other area is unchanged), or (ii) the exact same amount of effort in the closed area is relocated to other areas. If an analysis based on these simple assumptions could estimate a rough range of the impacts of closure policies, a contribution could be made. However, such a contribution is small if the estimated range

between the above two extreme cases is wide. As a result, the conflict between conservationist and harvest sectors would not be resolved.

This study has developed a model that explicitly applies economic theory to determine how many fishing trips would be relocated to other areas. Table 3.2 in Chapter 3 shows that the total number of trips could even be increased by an area closure if the closed area is offshore. Furthermore, this model also incorporates the effect of "fish movement" (FM) to more accurately estimate the expected catch and hence revenue in each fishing area. As demonstrated in Chapter 3 with a hypothetical two-area-two-period setting, the effects of "area substitution" and FM are very influential. In Chapters 4-7, this model is applied to the Hawaii longline fishery.

However, as demonstrated in Chapter 3, the significance of FM effect on the closure results is sensitive to the profile of FM, such as fish mobility across areas and whether a closed area is a "source" or "sink". Furthermore, the FM patterns for most pelagic species are still uncertain, and no suitable FM pattern is available for use in this study. If an FM pattern is estimated and included in this spatial model, several limitations and complexities will be introduced into the empirical study. Therefore, this chapter first evaluates the model and analyzes the impacts of some regulatory policies using the model without incorporating FM. Impact assessment of closure polices, using the model with FM, follows in the next chapter.

In this chapter, the model is first validated by replicating fishing trips over space and time. Next, the impacts of the following four policies on marine resource conservation and the fishery industry are examined by simulation: (i) closure of two 5° square areas, including the fishing areas off the main Hawaiian islands (MHI) to avoid gear conflicts, (ii) closure of all fishing areas north of 30°N for sea turtle conservation, (iii) ruling out all swordfish sets to avoid accidental turtle catches, and (iv) an additional 10% revenue tax for revenue generation and creation of a disincentive to fishing effort. Comparison of the impacts across the four policies and policy implications follow.

6.1 Validation of the Baseline Model

Validation is "the process of ascertaining the closeness of the model's ability to reality which is reflected in the model's ability to duplicate the required characteristics of the systems and fulfilling the modeling objectives" (Oriade and Dillon, 1997). Given fish prices and the estimated initial stocks (see Chapter 4), the simulation program (Appendix 6) optimally determines two variables – the number of fishing trips and the ratio of swordfish sets – in each area and month. Therefore, these two decision variables should be examined to measure the forecast accuracy.

Labor (vessel-days, *VD*) and wage are subjectively computed using the above two decision variables as well as constant and exogenous variables (e.g., initial stocks, fish prices, daily operating costs). Therefore, measuring the forecast accuracy using *VD* and wage does not provide additional information about forecast accuracy. However, the comparison of the predicted *VD* and wage with the actual ones is useful to validate the model because these two variables are used to determine a monthly equilibrium in the framework of the industry's demand for and supply of labor. The monthly total catch of each species in the simulation result is also compared with the actual catch since this variable is commonly used as the industry's output[1]. Thus, the model is validated by comparing the numbers of trips, *VD*, wage, the proportion of swordfish sets ($r_{sw,k}$), and the catch of each species as predicted by the simulation to the actual data for those variables. The comparison indicates that (i) the effect of incorporating fishermen's labor-leisure tradeoff is significant, (ii) the predicted number of monthly trips is moderately accurate, and (iii) some notable differences between the actual and simulated results in terms of spatial distribution of trips and choice between two set types (i.e., targeting tuna or swordfish) suggest some limitations in the current model.

Significance of Fishermen's Labor-Leisure Tradeoff

As demonstrated in Chapters 2 and 3, one of the unique features of this model is that an equilibrium wage and effort is determined by a derived demand for labor (DDL) and the labor supply (LS) function. As shown in Figure 2.1, different DDL curves are obtained

[1] The industry's output could be alternatively measured by total landings (i.e., weight) or ex-vessel revenue.

for each month due to the different fish stocks by location as well as fish prices, while there is only a single LS function. Moreover, the DDL curve is relatively flat and downward-sloping due to the stock externality, while the LS curve is rather steep (less responsive to the expected wage).

The number of fishing trips, allocated by the simulation program, is compared with the 'actual' distribution of fishing trips, as well as labor, wage, and the proportion of swordfish sets in Table 6.1. Note that the 'actual' number of trips by area and month are the actual number of fish sets divided by 10 since the model assumes that each longline goes and conducts 10 sets within a single 5° square area in each trip. In other words, this actually compares the simulated number of fishing sets to the observed during each period. The Mean Absolute Percentage Error (MAPE) of the simulated number of trips was 13.9%[2], and the post-sample coefficient of determination (R^2) was 0.525, which indicates that about 53% of the variance of the observed data was explained by the model. Hence, the model forecast was likely to be moderately accurate (see Appendix 4 for the details). Monthly allocation of trips averaged over the three years (1995-97) for both observed and simulated is presented in Figure 6.1.

In order to investigate the importance of the labor-leisure tradeoff in the estimation of the supply function, an alternative model, in which there is no income effect on the consumption of leisure (i.e., days on shore), is also presented in Figure 6.1. Since this alternative model ignores the fishermen's disincentive to supply labor brought on by higher wages (i.e., no labor-leisure tradeoff), the industry's LS is represented by a horizontal line[3], where the crew's wage is fixed to the average, computed from the 1993 wage data (Hamilton, Curtis, and Travis, 1996). As shown in Figure 6.1, the model without the labor-leisure tradeoff is a poor-fit (the MAPE was greater than 70%). For example, the number of trips allocated was extremely overestimated in the first quarter (particular in March) when wage is relatively high (Table 6.1) due to higher fish prices

[2] The MAPE of the ratio of swordfish sets ($r_{sw,k}$) is omitted here because a systematic prediction error is observed (see Figure 6.3), which explains the forecast accuracy in a much better way than MAPE.
[3] A LS curve could also be horizontal for an unregulated open-access fishery in the long run.

and stock abundance, and underestimated from April to November (no trips were allocated during August and September) when wage was relatively low.

On the other hand, the model with the labor-leisure tradeoff performs markedly better in tracking the actual allocation of fishing trips. This comparison suggests that overestimation by the "model without labor-leisure tradeoff" may be due to ignoring fishermen's disincentive to supply labor when crew wages were high, and vice versa. That is, the role of the upward-sloping LS function is crucial to determining the equilibrium wage and labor in the industry.

Deviation of the Simulation Results from Actual Data

Although the number of trips predicted by the model incorporating labor-leisure tradeoff is moderately accurate, Table 6.1 indicates that some gaps between the observed and predicted number of trips still remain. According to the three-year average of monthly trips, the simulated number of trips is somewhat underestimated from March to May, and overestimated from August to September (Figure 6.1). The above pattern of under- or over-estimation may be related to the LS function, presented in Figure 4.4. This figure suggests that all predicted amounts of labor are less than 2,000 vessel-days, while the actual amount of labor during March-May was, on average, slightly greater than 2,000 (Table 6.1).

On the other hand, the model overestimates the number of trips in August and September, especially during 1996 and 1997. The numbers of trips predicted by the model in August and September were lower than other months, primarily due to low fish prices (see Figure 4.3). However, the actual number of trips and the amount of labor (*VD*, vessel-days) were even lower than those predicted for the same months.

This forecast error may have occurred because this period might be an "off-season" for the Hawaii-based longline fishery. Although the model assumes a fix number of vessels (= 110) are ready to go fishing throughout the year, some of them may not actually be able to go fishing during this period, because (i) some boats might have temporarily left

Hawaiian waters to join other fisheries (e.g., American Samoa, California), or (ii) some other boats are sent for maintenance, dry-dock, or mooring[4]. If so, the LS function might need to be re-estimated or adjusted to account for such an "off-season" in the future research in order to improve the forecast accuracy of the model.

The model prediction was not very good during the four subsequent months from December 1995 to Mar 1996. Possible reasons may include that (i) trips and labor are actually over-allocated despite relatively low wages (except for February 1996), (ii) trips are actually over-allocated to near-shore (i.e., the MHI region; see the spatial analysis below) despite relocating some trips to distant-water and switching more sets to targeting swordfish can improve profitability, and (iii) unexpected extremely abundant stocks of albacore in February 1996 (Table 6.3b), which fishermen are unlikely to accounts for but the simulation program accounts for to maximize wage. For further analysis, the spatial distribution of trips and the ratio of swordfish sets are examined below.

Spatial Dimension of Forecast Accuracy
To summarize the spatial distribution of fishing trips, the fishery space is divided into the four regions (Figure 6.2):

(i) "MHI (main Hawaiian islands)" - *15N155W* and *20N155W*,
(ii) "South" – all areas below 20°N latitude excluding the MHI region,
(iii) "Middle" – areas between 20°N and 30°N, excluding the MHI region, and
(iv) "North" – all areas above 30°N latitude.

The numbers of trips per period, for both actual and simulated, are summarized by region in Table 6.2, which is useful to examine the remaining gaps between the observed and predicted number of trips. Conventionally longline trips are categorized into three types, and each type is more strongly associated with certain region. Tuna trips are more common near-shore (e.g., economic exclusive zone, EEZ), swordfish trips are usually conducted in the North Pacific, and so-called "mixed" trips (see Chapter 4 for a detailed

[4] The Hawaii-based longliners are likely to go to dry-dock once every three years (Hamilton et al., 1996).

discussion) are allocated to the rest of region. Since the fishery space is divided into 5° square strata, the "near-shore" is defined by two square areas – *15N155W* and *20N155W* – and the North Pacific is defined as all areas above 30° N. The rest of region is likely to be too wide for this analysis since more than more than 60% of longline sets were allocated there during 1995-97 (see Table 6.2). In addition, longliners may target both swordfish and tunas (bigeye and yellwofin) in the areas relatively north (above 20° N latitude), while longliners seldom catch swordfish south of 20° N latitude. Therefore, the areas below 30° N latitude, excluding the MHI region, are divided into two regions – "South" and "Middle".

As shown in Table 6.2, the goodness of fit in spatial distribution of trips varies over months. The goodness of fit over the four regions is measured by Chi-square (χ^2):

$$\chi^2 = \sum_{R=1}^{4} \frac{\left(f_{o,R} - f_{e,R}\right)^2}{f_{e,R}}$$

where $f_{o,R}$ and $f_{e,R}$ are the observed and expected frequency for region R. The null hypothesis is that the distribution of trips observed in the four regions is as the model predicts, and a smaller χ^2 statistic implies a better fit. Double and single asterisks indicate "very good" and "good" fits, respectively, since the null hypothesis cannot be rejected at the 5% and 1% significant level, respectively. As shown in Table 6.2, the predictions for 10 out of 36 months indicate "very good" fits and the prediction for Nov-95 indicates "good" fit, while the predictions for the rest of months are unlikely to be very good. The above results suggest that the spatial distribution of the simulated trips is quite dispersed from that of the observed trips.

A possible primary reason for deviation is the large variation in CPUE. In this empirical model, the initial stock sizes (and CPUE), which are estimated from the observed catch and effort, may fluctuate daily and vary by detailed location within a single 5° square, and also differ from what fishermen actually expect. As described in the algorithm in

Chapter 2, the choice of fishing areas is sensitive to the estimated initial stock. Second, the assumptions of a homogeneous fleet and no additional costs (either physically or mentally) to switch fishing locations (e.g., go fishing to unfamiliar locations) for a trip and to switch target at each set may result in prediction errors in the spatial distribution of trips. In reality, some vessels may be productive or technically constrained to fish near-shore and targeting tunas, and vice versa. For instance, from January to April 1997, only 6 trips are allocated to the MHI region (*20N155W* and *15N155W*) by the simulation program, although actually 48 trips were occurred there (Table 6.2). This suggests that some longliners may always prefer fishing near-shore, even though other locations might appear to be more profitable.

Relationship between the rates of swordfish sets and trips to the North region

As mentioned before, most fishing sets in the North region are targeting swordfish. However, the opposite is not true: i.e., the region in which longliners target swordfish is not necessary to be the North, but could be "Middle" or "MHI" regions in certain months. Figure 6.3 indicates that very few longliners go to the North region during the second quarter (April-June), while the ratio of swordfish sets is higher than the first quarter. This is because fishermen know swordfish come down to the south and near the MHI region in early summer (Boggs and Ito, 1993). In addition, the gap between "actual" and "predicted" is considerable in the ratio of swordfish sets as shown in Figure 6.3. This suggests that some fishermen consistently target either tuna or swordfish, whereas the model assumes that boats can flexibly switch targets with no additional costs in order to maximize the crew's wage. On the other hand, the difference in the ratio of trips to the North region in Figure 6.3 is much smaller, suggesting that a boat is likely to choose fishing locations rationally as defined in the model, although some small boats might go only to nearshore areas (Pan et al., 1999).

Catches of Major Species

Lastly, the model is validated by comparing the predicted and actual catch of each species. As seen in the species-specific breakdown given in Table 6.3(a) and (b), the simulated aggregate catches of swordfish and yellowfin tuna are greater by about 10%,

while those of other species were underestimated. In particular, blue and striped marlins are underestimated a little more than 15%. These differences may be caused by (i) more swordfish sets and (ii) more trips to the "North" and "Middle" regions, in the simulation results than actually occurred[5].

Possible Causes for Errors: Summary

The spatial distribution of trips – the number of trips allocated to each area – depends on the observed catch and effort data (particularly CPUE; see equation (5.5b)). Large variation in that data may cause errors in replicating the longline trips. Some other factors that may contribute to the differences in results are (i) the assumption of identical vessels in terms of cost structure, speed, and other parameters such as the number of light-sticks used per fishing set, (ii) perfect knowledge about fish prices and stocks in each fishing location, (iii) the assumption of costless switching between tuna and swordfish sets, and (iv) the restriction to one fishing location per trip. In particular, a certain group of vessels may use only one strategy (targeting tuna or swordfish) for a long period of time due to factors such as personal preference and other vessel-related physical constraints.

6.2 Effects of Regulatory Policies on Allocation of Trips over Space and Time

Four policy simulations are explained below. Note that fish movement (FM) is not considered here; i.e., it is assumed that a change in catch at the current period would have no effect on fish stocks at the next period.

(i) Reducing Gear Conflicts: Closure of Areas near the Main Hawaiian Islands (MHI)

Entry restrictions, including area closure, are particularly appropriate in reducing short-run (or crowding) externalities (Townsend 1990). Several gear types often compete for the same species of pelagic fish, and the exclusion of a particular gear type would reduce crowding. In Hawaii, longline and surface fleets (trollers and handliners) have often fished in the same locations, especially within 20 nautical miles of the shore (Skillman, Boggs, and Pooley 1993). Historically, longline vessels have been excluded from fishing in certain regions from time to time. From 1987 to 1992, troll and handline landings of

[5] Some evidences for this interpretation are shown in the simulation results for Policies 1-3 in Table 6.8.

several pelagic species (in particular, yellowfin tuna) had declined substantially, while longline landings had increased (Pooley 1994; WPRFMC, 1998). That incident triggered the conflicts between longliners and small-boat fishermen since small-boat fishermen suspected that longliners intercepted their fish[6]. Thus, a closure of near-shore could (a) reduce physical conflicts between longliners and other small boats, and (b) secure fish stocks for small-boat fishing.

The impact of the year-round closure of the MHI region is examined. Although this region consists of only two areas, *20N155W* (including Oahu and Maui) and *15N155W* (including a major part of the fishing areas close to the Big Island: see Figure 6.2), on average 23.8% of longline trips during 1995-97 were allocated to this region. During October and November 1995, more than 45% of the total trips were centered on the region. Monthly numbers of simulated trips under this regulatory policy are summarized by region in Table 6.4. Since the MHI region is closed, vessels compensate by fishing in distant waters (other 3 regions), which results in an increase in costs and reduced wages (Table 6.8). The aggregate number of trips declines. According to the three-year average, originally 254 trips were annually made into the closed areas, but with the closure policy, only 137 trips (about 54%) were reallocated elsewhere, leading to a net decrease of 117 trips out of the original 1,129 trips - a decline of about 10 %. Figure 6.4 illustrates the "area substitution" effect on the spatial distribution of trips, as a result of area closure: the total number of trips to the three open regions increases but the total for all four regions decreases every month, compared with the baseline case.

(ii) Conserving Sea Turtles: Closure of the North Fishing Areas North of 30 °N

Interaction between longline gear and endangered species, such as sea turtles, has been reported in the logbook data (Ito, 1995). Leatherback, green, loggerhead, and olive ridley turtles were reported to have been accidentally caught a total of 84 times during 1994, although these interactions are widely believed to be underreported. Kleiber (1998) estimates that approximately 700 sea turtles were taken and 100 killed in 1995. Most of

[6]This issue is likely to disappear now since the landings from handline and troll catches in the rest of 1990s have come back from the 1992 level, while longline vessels have been excluded from the near-shore area, and the number of active longline vessels has been stabilized to 125 or less since 1992 (WPRFMC, 1998).

the loggerhead and leatherback turtles were caught north of 30° N. Conservation biologists, such as Nitta and Henderson (1993), suggested the closure of fishing areas north of 30° N to conserve sea turtles, similar to the restrictions imposed in a recent decision by the U.S. District Court in Hawaii (Appendix 1; Masuoka, 2001).

The impacts of such a policy are assessed. Monthly numbers of simulated trips are summarized by region in Table 6.5. Unlike the previous case, this turtle conserving policy confines longline vessels to fishing areas closer to the MHI; i.e., below 30° N. Since more vessels now fish inshore, the number of travel days per trip decreases, which, in turn, gives the crews incentives to take more trips. Thus, the aggregate number of trips shows a small increase. Without the closure of the North region, 159 trips were annually allocated there. Under this closure policy, 206 trips, which is about 30% more than those originally allocated the closed area, were reallocated to the areas below 30° N, leading to a net increase of 47 trips - about 4 % of the aggregate number of trips before the closure.

The ratio of swordfish sets to the total falls from 47% to 37%, and swordfish catches, which mostly occur on the high seas, decline significantly (by 31%) causing crew wages to fall by 3.6% (Table 6.8). Figure 6.5 illustrates the "area substitution" effect of this "offshore closure" policy on the spatial distribution of trips. Unlike the results for Policy 1, the total number of trips to all four regions (not only the total number of the three open region) will increase from the baseline case during most of the months.

(iii) Ruling Out Swordfish Sets

Closely following the recommendation in the final environmental impact statement (EIS) released by NMFS (NMFS, 2001), the regulations for "sea turtle resuscitation" were modified to prohibit longline sets targeting swordfish since longline techniques for swordfish have proven more dangerous to turtles than those used for tuna (Masuoka, 2001). According to the Federal judge's ruling, the minimum depth of longlines is set to 328 feet, while the standard depth of a swordfish set ranges from 70 to 100 feet.

As described in Chapter 4, the depth is not used when all longline sets in the logbook data are divided into swordfish and tuna sets. Thus, "swordfish sets" defined in this study may not be exactly the same as those in the Federal judge's ruling. Also the difficulty and costs for monitoring and enforcement to prohibit swordfish sets may differ from those excluding longline trips from a closed region. Despite the limitations mentioned above, it would be still very useful to simulate the impacts of this policy.

Table 6.6 shows that almost all swordfish sets are substituted by tuna sets since the total number of trips remains about the same as before the policy.[7] Since all sets are targeting tuna, more trips are allocated to near-shore (i.e., shorter trip length), though some trips are still made to the North region (maybe because bigeye tuna is abundant and make that trip profitable: see Figure 6.3). As shown in Table 6.8, ruling out swordfish sets will reduce the ex-vessel revenue most (26%), though it also significantly reduces the variable costs (by 31%), and enables the fleet profit to decline by 22%. Comparison of the two policies for turtle conservation suggests that the recent judge's ruling (Policy 3), based on the NMFS recommendation, may reduce the industry's ex-revenue and fleet profit more significantly than the closure of the North Pacific (Policy 2).

(iv) Imposing an Additional 10% Revenue Tax

An additional revenue tax may serve as both a mechanism to reduce the profitability of fishing and thereby preserve fish stocks and as a mean of generating additional revenues for the state. Thus, the impacts of a 10% revenue tax are examined (Table 6.7). Since the revenue tax is a fixed percentage of total revenue before netting variable costs, this policy results in a disproportionate negative effect on boats specializing in distant-water fishing and targeting swordfish, whose variable costs tend to be higher. As shown in Table 6.7, trips fishing north of 30° N are most significantly affected, down from 159 trips by 24 (15%), much higher than the percentage decrease for all regions (5.5%). The rate of swordfish sets also declines by about 7%.

[7] No entry-exit assumption is imposed in this short-run model. However, in reality, some (or many) of the longliners primarily targeting swordfish have left soon and the number of trips declined after this policy was imposed, though the official data were not available to the author when this analysis was done.

Moreover, because of the backward-bending nature of the labor supply (LS) function, a revenue tax, in general, does not reduce the total number of trips (and hence fishing effort) significantly, or even may increase the number of trips when wages are higher (i.e., the first quarter and April). On the other hand, this policy does result in fewer fishing trips when the slope of the LS curve is positive and flatter; i.e., at low wage levels in the summer and fall (Table 6.7).

6.3 Comparison of the Four Policies

Economic Impacts

The differential impacts of the four policies on various aspects -- such as trip allocation, employment, average trip length, rate of swordfish sets, total ex-vessel revenue, fee and taxes, other variable costs, fleet profits, and wages -- are summarized in Table 6.8. The total industrial revenue from all longline trips will decline under all four policies. Policy 3 (prohibiting swordfish sets) decreases revenue the most (by 26%) among them. Although Policy 4 (imposing 10% revenue tax) reduces the ex-vessel revenue least (only by 5%), it will actually reduce the revenue after fees and taxes by 16%, and hence decrease the fleet profit by 21%, implying the impacts of this revenue-tax policy is likely to be more significant than the two closure policies (1 & 2).

The two closure policies reduce the operating costs by about 5%, but by different reasons. The cost reduction by Policy 1 is brought about by a decrease in trips though vessels conduct more expensive swordfish sets at more distant waters, while the cost reduction by Policy 2 is brought about by switching fishing locations to near-shore and/or to targeting more tuna though the total number of trips actually increases. Policy 3 reduces the operating costs most (31%) since all fishing sets have to target tuna, which is much less expensive than swordfish sets. Therefore, according to the impacts of each policy on the annual fleet profit, the impacts of Policies 3 & 4 are likely to be more severe (decrease fleet profit by more than 20%) than the two closure policies (1 & 2), which reduce fleet profit by less than 10%.

Annual income accruing to vessel owners is simply 50% of the fleet profit divided by the number of active vessels. Thus, boat-owner incomes are most seriously affected by Policies 3 & 4. Sustained low income may cause the net profit to fall below industry long-term average fixed cost, leading to exit from the industry. Some instances of exit from the Hawaii longline fishery to the U.S. Gulf Coast and Fiji have been observed in the late 1990's (Travis 1999).

Comparing two closure policies, Policy 2 decreases crew incomes per trip by 9.5%, while Policy 1 (reducing gear conflict) rather slightly increases crew's income per trip. However, this comparison may be misleading because the average trip length is shorter (boats fish closer to shore) under Policy 2 (closure to conserve sea turtles) than under Policy 1 (gear conflict regulation). Consequently, crew wage (dollars per day at sea) decreases more (7%) by Policy 1 than by Policy 2 (3.6%). Since the annual crew's total income and crew's daily wage under Policy 1 is lower than Policy 2, the economic impact of Policy 1 on the crews is likely to be more severe than Policy 2.

Conservation of Fishery Resources

The effect of alternative policies on conservation of fish stocks is also shown in Table 6.8. Policy 1 (reducing gear conflict) leads to a significant reduction in catch for all species other than swordfish, since they dominate harvests close to port. While the two turtle conservation polices lead to a significant reduction of swordfish catches, they will actually increase catches of bigeye tuna, albacore, and striped marlin. Note that the impact of Policy 3 (prohibiting swordfish sets) would more significantly increase the catch of those three species (particularly albacore), and reduce swordfish catches. Interestingly, Policy 3 reduces the catches of yellowfin tuna and blue marlin, which is opposite to the effect of Policy 2 on these two species. While Policy 4 (a 10 % revenue tax) generates additional tax revenues, it significantly reduces fleet profits. Its impact on fish conservation is minimal (except for swordfish), since there is very little substitution of fishing trips across locations, and the reduction in the number of trips is relatively small (only by 5.5%).

6.4 Policy Implications

This chapter implements a spatial and temporal model of the allocation of fishing trips that explicitly incorporates the spatial distribution of multiple fish stocks, stock externalities from fishing, and heterogeneity in operating costs due to the distance of fishing location from port. The model is used to simulate the monthly allocation of trips in the Hawaii longline fishery during 1995-97. The impact of regulatory decisions, such as inshore (reduction of gear conflict) and offshore (reduction of turtle bycatch) area closures, prohibiting swordfish sets, and taxes on harvest are examined.

Inshore area closure leads to vessels moving to more distant waters. While vessel-owner incomes decline significantly (9.4%), the effect on crew income per trip is smaller (rather the crew's income per trip increases) since they benefit from taking longer trips. The catch of inshore species is significantly reduced. Offshore area closure policies reduce swordfish catches by about 31%. Average trip lengths decline by 6% since boats fish closer to shore. On the positive side, substitution of boats into inshore areas and an increase in the number of trips allows for a relatively small adverse impact on fleet profits (5.8%). An additional revenue tax on harvest succeeds in skimming profits from the fishery but has little effect on conservation of fish stocks.

These results could be useful in assessing the impacts of regulatory policy on industry groups or on conservation objectives (Wilen 1993). An interesting asymmetry exists between the two area closure policies: reduction of gear conflict (Policy 1) and turtle conservation (Policy 2). In the first, inshore area closures lead to fewer trips of longer duration. The crew continues to receive wages from the increased travel days, but that does not benefit the boat owners. Thus, inshore area closures have a larger impact on incomes accruing to boat owners. On the other hand, distant area closures, such as turtle conservation policies, lead to a larger number of lower-duration trips and has the opposite effect. Fiscal policy instruments, such as revenue tax increases (Policy 4), have a significant effect on both parties because there is limited scope for substitution, while trips yielding marginal returns are no longer profitable.

Unlike a general perception (Masuoka, 2001), the results suggest that a regulatory policy prohibiting swordfish sets (Policy 3) may decrease the industrial revenue and fleet profit more than the closure of the North region if this policy strictly allows all vessels to conduct tuna sets only. However, in reality, some vessels might never target swordfish and hence be unaffected, while some other vessels that always target swordfish would be forced to change their primary target or leave the Hawaii longline fishery after this policy has been imposed. Thus, the impact of this policy on the industry is more heterogeneous and severe than the closure of the North region for turtle conservation.

The other major impact of turtle conservation is the increased harvesting of inshore species, such as yellowfin and bigeye tunas, and striped marlin. Although not considered in the model, this can adversely affect catches by competing fleets, such as handliners and trollers, as well as recreational vessels. On the other hand, inshore area closures increase swordfish catches marginally but have a positive impact on stocks of competing species.

Our results can be used to compute a rough implicit price of saving a loggerhead turtle. For example, Kleiber (1998) estimates that 66 loggerhead turtles were killed through interaction with longline gears in 1995. Using our model results, the rough cost of adopting turtle conserving policies in terms of foregone profits to the longline fleet is approximately $22,000 per turtle by Policy 2 and $84,000 by Policy 3, respectively. These types of implicit valuations can be used by policymakers to analyze tradeoffs and make appropriate policy decisions.

In the empirical model of this chapter, the initial fish stock size is estimated based on current catch and hook data, assuming no inflow or outflow within a period but allowing for stock changes across each period; *i.e.*, between successive months. This empirical model incorporates FM in the next chapter where locational stock movements are a function of stock differentials between adjacent grids.

Table 6.1. Monthly Trips Number, Vessel-days (VD), Wage, and Rate of Swordfish Sets: Actual and Simulated

	Actual				Simulated (W/O FM)			
Month	Trips	VD	Wage	r_{sw}	Trips	VD	Wage	r_{sw}
Jan-95	99.1	1,687	947	34.3%	101	1,848	888	40.4%
Feb-95	99.3	1,913	890	42.8%	97	1,946	909	57.5%
Mar-95	102.3	1,855	916	45.9%	98	1,962	**1090**	50.8%
Apr-95	104.5	2,003	562	52.6%	96	1,946	601	78.4%
May-95	120.3	2,052	527	52.0%	106	1,868	616	76.5%
Jun-95	105.4	1,932	571	53.7%	108	1,851	670	93.7%
Jul-95	87.6	1,604	343	59.6%	98	1,874	330	91.3%
Aug-95	61.3	1,305	183	52.4%	70	1,548	196	54.6%
Sep-95	64.5	1,225	209	43.4%	71	1,204	302	36.2%
Oct-95	90.3	1,382	421	25.5%	86	1,291	487	3.6%
Nov-95	111.7	1,878	417	30.3%	93	1,493	436	16.3%
Dec-95	118.2	2,047	682	32.0%	94 *	1,573	726	14.7%
Jan-96	125.2	2,364	733	44.5%	92 *	1,823	813	69.2%
Feb-96	85.8	1,457	757	31.6%	108 *	1,944	810	11.9%
Mar-96	120.1	1,998	778	46.5%	96 *	1,945	933	83.5%
Apr-96	120.3	2,008	775	42.3%	112	1,971	728	53.6%
May-96	126.7	2,272	370	49.8%	106	1,912	427	67.4%
Jun-96	92.1	1,594	331	46.5%	103	1,675	342	66.5%
Jul-96	87.8	1,592	228	52.3%	81	1,465	232	48.4%
Aug-96	60.2	1,170	130	48.7%	66	1,217	**176**	21.2%
Sep-96	48.7	788	279	25.9%	66 *	979	345	3.5%
Oct-96	88.7	1,519	478	31.3%	73	1,195	633	14.9%
Nov-96	104.1	1,839	685	33.8%	103	1,733	750	27.1%
Dec-96	97.2	1,696	678	33.1%	114	1,890	618	7.0%
Jan-97	100.0	1,917	737	39.9%	91	1,831	803	33.0%
Feb-97	115.4	2,050	916	39.0%	105	1,941	887	50.5%
Mar-97	127.5	2,324	715	44.5%	100 *	1,952	790	73.0%
Apr-97	127.7	2,300	637	46.8%	106	1,933	729	63.3%
May-97	126.4	2,190	721	49.0%	107	1,931	794	94.4%
Jun-97	102.2	1,775	535	54.3%	122	1,939	540	91.3%
Jul-97	89.5	1,572	375	48.4%	85	1,726	386	62.7%
Aug-97	64.2	1,046	302	30.2%	77	1,573	298	41.0%
Sep-97	49.2	775	332	17.7%	78 *	1,241	317	8.8%
Oct-97	72.0	1,060	585	17.5%	81	1,146	596	0.0%
Nov-97	93.8	1,579	624	24.7%	94	1,552	667	0.0%
Dec-97	112.9	2,073	798	27.9%	103	1,800	802	4.9%
Total	3,502.2	61,840			3,387	60,715		
Mean	97.3	1,718	560	41.1%	94	1,687	602	46.7%
				MAPE	*13.9%*			*50.1%*
Annual Subtotal	Trips	VD	Wage	r_{sw}	Trips	VD	Wage	r_{sw}
Yr 1995	1,165	20,884	556	43.7%	1,118	20,404	604	51.2%
Yr 1996	1,157	20,297	519	40.5%	1,120	19,748	567	39.5%
Yr 1997	1,181	20,659	606	36.7%	1,149	20,563	634	43.6%

* An asterisk next to a simulated number of trips indicates that the absolute percentage error is greater than 20%.

Table 6.2 Spatial Distribution of Fishing Trips: Actual and Simulated (without Fish Movement)

	Actual # of trips					Simulated					
Month	MHI	South	Middle	North	All regions	MHI	South	Middle	North	All regions	Chi-square
Jan-95	32.5	26.0	21.4	19.2	99.1	26	25	22	28	101	4.58 **
Feb-95	17.6	28.8	17.7	35.2	99.3	16	19	16	46	97	7.52 **
Mar-95	23.7	27.8	30.7	20.1	102.3	10	42	23	23	98	24.16
Apr-95	18.3	30.8	48.6	6.8	104.5	8	8	67	13	96	72.16
May-95	36.3	22.4	61.3	0.3	120.3	33	4	64	5	106	55.61
Jun-95	22.0	37.5	44.8	1.1	105.4	25	5	74	4	108	236.01
Jul-95	26.0	21.4	33.8	6.4	87.6	22	10	52	14	98	28.93
Aug-95	20.7	8.6	15.7	16.3	61.3	29	1	8	32	70	34.47
Sep-95	12.1	3.7	36.8	11.9	64.5	22	0	43	6	71	15.29
Oct-95	40.8	6.7	32.6	10.2	90.3	44	7	22	13	86	5.21 **
Nov-95	52.8	23.0	14.5	21.4	111.7	51	23	7	12	93	8.11 *
Dec-95	16.1	26.4	53.1	22.6	118.2	6	27	49	12	94	12.96
Jan-96	17.4	22.3	46.8	38.7	125.2	9	12	36	35	92	4.50 **
Feb-96	27.2	25.0	24.4	9.2	85.8	20	17	36	35	108	38.90
Mar-96	29.7	26.7	57.3	6.4	120.1	9	15	47	25	96	42.67
Apr-96	15.4	10.8	92.7	1.4	120.3	3	11	97	1	112	26.99
May-96	24.8	32.3	69.0	0.6	126.7	28	31	46	1	106	5.43 **
Jun-96	22.1	36.3	31.6	2.1	92.1	26	22	52	3	103	21.20
Jul-96	31.9	12.3	29.3	14.3	87.8	44	13	10	14	81	34.09
Aug-96	21.2	13.5	10.9	14.6	60.2	32	24	3	7	66	33.53
Sep-96	19.0	14.9	11.4	3.4	48.7	42	2	22	0	66	78.68
Oct-96	41.3	13.4	14.6	19.4	88.7	40	19	10	4	73	33.29
Nov-96	30.4	24.8	23.2	25.7	104.1	29	40	24	10	103	29.87
Dec-96	14.1	23.4	37.7	22.0	97.2	21	33	52	8	114	42.66
Jan-97	9.7	36.8	26.4	27.1	100.0	0	32	29	30	91	17.46
Feb-97	10.9	37.4	45.6	21.5	115.4	4	38	43	20	105	7.48 **
Mar-97	15.5	37.8	48.2	26.0	127.5	1	21	53	25	100	33.66
Apr-97	12.3	35.4	75.1	4.9	127.7	1	26	73	6	106	19.58
May-97	19.9	47.7	58.3	0.5	126.4	20	28	59	0	107	7.58 **
Jun-97	29.3	26.8	44.6	1.5	102.2	36	1	85	0	122	204.64
Jul-97	30.6	29.2	22.9	6.8	89.5	25	22	33	5	85	6.41 **
Aug-97	25.1	24.6	11.3	3.2	64.2	15	28	11	23	77	31.85
Sep-97	18.5	19.4	9.2	2.1	49.2	21	23	28	6	78	13.53
Oct-97	28.0	6.3	34.5	3.2	72.0	28	6	47	0	81	4.65 **
Nov-97	7.3	13.4	62.5	10.6	93.8	7	12	75	0	94	24.79
Dec-97	13.6	10.1	71.7	17.5	112.9	8	7	76	12	103	5.91 **
Total	834.1	843.7	1370.2	454.2	3502.2	761	654	1494	478	3387	35.40
(%)	23.8%	24.1%	39.1%	13.0%	100.0%	22.5%	19.3%	44.1%	14.1%	100.0%	24.47

Single and double asterisks indicate that the null hypothesis cannot be rejected at the 1% and 5%, respectively.

Table 6.3(a). Catches of Three Billfish Species: Actual vs. Simulated (without fish movement)

	Swordfish			Blue Marlin			Striped Marlin		
Month	Actual[a]	Sim.[a]	%Error[b]	Actual	Sim.	%Error	Actual	Sim.	%Error
Jan-95	2,821	3,344	18.5%	374	354	-5.3%	1,858	1,531	-17.6%
Feb-95	4,299	5,418	26.0%	210	228	8.6%	1,229	771	-37.3%
Mar-95	3,867	4,830	24.9%	371	307	-17.3%	1,335	1,127	-15.6%
Apr-95	5,446	6,715	23.3%	436	200	-54.1%	984	513	-47.9%
May-95	4,500	5,591	24.2%	823	530	-35.6%	2,020	1,587	-21.4%
Jun-95	4,625	6,684	44.5%	846	551	-34.9%	1,209	1,417	17.2%
Jul-95	2,846	4,711	65.5%	678	601	-11.4%	529	690	30.4%
Aug-95	1,320	2,004	51.8%	557	512	-8.1%	249	303	21.7%
Sep-95	771	1,216	57.7%	1,235	970	-21.5%	1,706	1,712	0.4%
Oct-95	774	185	-76.1%	868	584	-32.7%	2,704	2,475	-8.5%
Nov-95	1,742	1,431	-17.9%	875	709	-19.0%	2,903	2,722	-6.2%
Dec-95	2,463	1,486	-39.7%	926	646	-30.2%	4,506	4,153	-7.8%
Jan-96	4,926	5,141	4.4%	651	372	-42.9%	3,163	1,583	-50.0%
Feb-96	1,531	1,210	-21.0%	321	195	-39.3%	1,349	1,152	-14.6%
Mar-96	4,212	6,795	61.3%	347	124	-64.3%	1,259	280	-77.8%
Apr-96	4,970	5,047	1.5%	458	331	-27.7%	1,382	955	-30.9%
May-96	4,413	4,372	-0.9%	691	426	-38.4%	1,672	944	-43.5%
Jun-96	3,328	4,924	48.0%	630	531	-15.7%	1,379	1,333	-3.3%
Jul-96	2,423	2,068	-14.7%	703	587	-16.5%	937	739	-21.1%
Aug-96	858	748	-12.8%	534	523	-2.1%	549	296	-46.1%
Sep-96	199	47	-76.4%	564	394	-30.1%	497	838	68.6%
Oct-96	2,705	733	-72.9%	826	993	20.2%	1,378	1,151	-16.5%
Nov-96	3,929	1,995	-49.2%	547	559	2.2%	959	918	-4.3%
Dec-96	3,004	1,487	-50.5%	247	290	17.4%	887	1,245	40.4%
Jan-97	3,771	3,837	1.8%	220	225	2.3%	1,262	1,133	-10.2%
Feb-97	5,382	5,202	-3.3%	229	168	-26.6%	996	632	-36.5%
Mar-97	7,224	9,020	24.9%	218	121	-44.5%	913	432	-52.7%
Apr-97	6,099	5,788	-5.1%	676	695	2.8%	1,471	1,030	-30.0%
May-97	5,929	7,322	23.5%	943	843	-10.6%	2,481	1,543	-37.8%
Jun-97	4,089	6,690	63.6%	1,267	1,248	-1.5%	1,354	2,013	48.7%
Jul-97	2,189	3,774	72.4%	1,210	902	-25.5%	386	345	-10.6%
Aug-97	300	1,713	471.0%	1,219	1,385	13.6%	159	356	123.9%
Sep-97	76	39	-48.7%	736	943	28.1%	222	455	105.0%
Oct-97	209	10	-95.2%	489	377	-22.9%	539	641	18.9%
Nov-97	1,190	22	-98.2%	462	368	-20.3%	785	901	14.8%
Dec-97	1,876	744	-60.3%	369	293	-20.6%	1,380	1,255	-9.1%
Total	110,306	122,343	10.9%	22,756	19,085	-16.1%	48,591	41,171	-15.3%
Annual Summary									
Yr 1995	35,474	43,615	22.9%	8,199	6,192	-24.5%	21,232	19,001	-10.5%
Yr 1996	36,498	34,567	-5.3%	6,519	5,325	-18.3%	15,411	11,434	-25.8%
Yr 1997	38,334	44,161	15.2%	8,038	7,568	-5.8%	11,948	10,736	-10.1%
Mean	36,769	40,781	10.9%	7,585	6,362	-16.1%	16,197	13,724	-15.3%

[a]Data are in units of standard-size fish.

[b]%Error = [(simulated catch) - (actual catch)] / (actual catch)

Table 6.3(b). Catches of Three Tuna Species: Actual vs. Simulated (without fish movement)

	Bigeye			Yellowfin			Albacore		
Month	Actual[a]	Sim.[a]	%Error	Actual	Sim.	%Error	Actual	Sim.	%Error
Jan-95	7,838	7,284	-7.1%	2,218	2,784	25.5%	1,888	3,990	111.3%
Feb-95	5,971	5,392	-9.7%	2,333	2,345	0.5%	1,753	2,393	36.5%
Mar-95	6,645	7,096	6.8%	2,437	2,409	-1.1%	2,538	3,021	19.0%
Apr-95	4,004	3,101	-22.6%	1,675	1,656	-1.1%	2,230	2,594	16.3%
May-95	4,834	4,587	-5.1%	1,706	1,673	-1.9%	4,213	2,698	-36.0%
Jun-95	3,251	2,907	-10.6%	2,425	2,528	4.2%	6,000	2,008	-66.5%
Jul-95	1,266	1,516	19.7%	3,159	3,231	2.3%	3,696	1,559	-57.8%
Aug-95	1,600	2,893	80.8%	1,144	904	-21.0%	2,012	1,652	-17.9%
Sep-95	2,276	3,017	32.6%	774	684	-11.6%	2,300	2,069	-10.0%
Oct-95	5,533	5,611	1.4%	1,244	922	-25.9%	5,543	9,048	63.2%
Nov-95	6,853	6,613	-3.5%	1,381	1,161	-15.9%	4,572	3,689	-19.3%
Dec-95	8,075	7,071	-12.4%	2,461	2,078	-15.6%	1,776	501	-71.8%
Jan-96	6,533	4,515	-30.9%	3,362	3,381	0.6%	3,100	1,363	-56.0%
Feb-96	4,669	4,483	-4.0%	1,831	1,230	-32.8%	2,550	21,322	736.2%
Mar-96	4,230	2,448	-42.1%	2,242	3,236	44.3%	5,327	3,403	-36.1%
Apr-96	4,602	3,787	-17.7%	718	911	26.9%	8,181	6,794	-17.0%
May-96	3,559	3,275	-8.0%	700	1,213	73.3%	6,593	1,739	-73.6%
Jun-96	1,947	1,438	-26.1%	625	400	-36.0%	5,755	4,901	-14.8%
Jul-96	2,167	2,824	30.3%	1,430	1,438	0.6%	4,985	3,775	-24.3%
Aug-96	2,150	2,735	27.2%	1,133	1,398	23.4%	1,627	1,199	-26.3%
Sep-96	2,708	3,627	33.9%	899	691	-23.1%	1,631	3,463	112.3%
Oct-96	6,542	6,109	-6.6%	1,092	2,120	94.1%	5,239	7,161	36.7%
Nov-96	11,724	12,511	6.7%	1,964	4,116	109.6%	3,017	3,781	25.3%
Dec-96	11,322	13,899	22.8%	1,042	1,361	30.6%	1,608	3,269	103.3%
Jan-97	9,573	8,846	-7.6%	1,711	1,728	1.0%	4,491	4,387	-2.3%
Feb-97	10,348	8,774	-15.2%	3,140	4,737	50.9%	8,723	7,024	-19.5%
Mar-97	6,736	3,900	-42.1%	2,885	2,362	-18.1%	8,547	4,629	-45.8%
Apr-97	4,987	4,020	-19.4%	3,962	4,374	10.4%	10,449	7,436	-28.8%
May-97	5,027	4,504	-10.4%	4,961	7,385	48.9%	10,549	2,591	-75.4%
Jun-97	1,590	1,595	0.3%	2,701	2,836	5.0%	10,256	2,614	-74.5%
Jul-97	1,918	1,932	0.7%	3,301	2,895	-12.3%	5,662	3,847	-32.1%
Aug-97	1,600	2,175	35.9%	2,082	1,469	-29.4%	3,722	2,681	-28.0%
Sep-97	2,731	3,875	41.9%	968	1,151	18.9%	1,145	2,144	87.2%
Oct-97	6,870	7,215	5.0%	753	595	-21.0%	1,591	1,624	2.1%
Nov-97	10,921	11,012	0.8%	976	922	-5.5%	660	3,479	427.1%
Dec-97	15,095	12,325	-18.4%	900	744	-17.3%	639	2,768	333.2%
Total	197,695	188,912	-4.4%	68,335	75,068	9.9%	154,568	142,616	-7.7%
Annual Summary									
Yr 1995	58,146	57,088	-1.8%	22,957	22,375	-2.5%	38,521	35,222	-8.6%
Yr 1996	62,153	61,651	-0.8%	17,038	21,495	26.2%	49,613	62,170	25.3%
Yr 1997	77,396	70,173	-9.3%	28,340	31,198	10.1%	66,434	45,224	-31.9%
Mean	65,898	62,971	-4.4%	22,778	25,023	9.9%	51,523	47,539	-7.7%

[a]Data are in units of standard-size fish.

[b]%Error = [(simulated catch) - (actual catch)] / (actual catch)

Table 6.4 Spatial Distribution of Fishing Trips: Closure of Two Square Areas, *15N155W* and *20N155W*

	Number of Trips Allocated									
Month	MHI	(Δ)[a]	South	(Δ)	Middle	(Δ)	North	(Δ)	All Regions	(Δ)
Jan-95	0	(-26)	31	(6)	31	(9)	32	(4)	94	(-7)
Feb-95	0	(-16)	20	(1)	19	(3)	51	(5)	90	(-7)
Mar-95	0	(-10)	44	(2)	27	(4)	24	(1)	95	(-3)
Apr-95	0	(-8)	9	(1)	68	(1)	15	(2)	92	(-4)
May-95	0	(-33)	8	(4)	78	(14)	6	(1)	92	(-14)
Jun-95	0	(-25)	7	(2)	84	(10)	5	(1)	96	(-12)
Jul-95	0	(-22)	12	(2)	59	(7)	16	(2)	87	(-11)
Aug-95	0	(-29)	5	(4)	14	(6)	37	(5)	56	(-14)
Sep-95	0	(-22)	0	(0)	52	(9)	8	(2)	60	(-11)
Oct-95	0	(-44)	11	(4)	27	(5)	25	(12)	63	(-23)
Nov-95	0	(-51)	35	(12)	14	(7)	23	(11)	72	(-21)
Dec-95	0	(-6)	26	(-1)	49	(0)	11	(-1)	86	(-8)
Jan-96	0	(-9)	13	(1)	37	(1)	38	(3)	88	(-4)
Feb-96	0	(-20)	21	(4)	40	(4)	40	(5)	101	(-7)
Mar-96	0	(-9)	16	(1)	48	(1)	27	(2)	91	(-5)
Apr-96	0	(-3)	11	(0)	98	(1)	1	(0)	110	(-2)
May-96	0	(-28)	38	(7)	53	(7)	2	(1)	93	(-13)
Jun-96	0	(-26)	25	(3)	62	(10)	4	(1)	91	(-12)
Jul-96	0	(-44)	22	(9)	16	(6)	23	(9)	61	(-20)
Aug-96	0	(-32)	33	(9)	3	(0)	11	(4)	47	(-19)
Sep-96	0	(-42)	13	(11)	36	(14)	0	(0)	49	(-17)
Oct-96	0	(-40)	29	(10)	15	(5)	6	(2)	50	(-23)
Nov-96	0	(-29)	45	(5)	33	(9)	13	(3)	91	(-12)
Dec-96	0	(-21)	39	(6)	58	(6)	10	(2)	107	(-7)
Jan-97	0	(0)	32	(0)	29	(0)	29	(-1)	90	(-1)
Feb-97	0	(-4)	38	(0)	44	(1)	22	(2)	104	(-1)
Mar-97	0	(-1)	21	(0)	54	(1)	25	(0)	100	(0)
Apr-97	0	(-1)	26	(0)	74	(1)	6	(0)	106	(0)
May-97	0	(-20)	31	(3)	68	(9)	0	(0)	99	(-8)
Jun-97	0	(-36)	7	(6)	102	(17)	0	(0)	109	(-13)
Jul-97	0	(-25)	24	(2)	39	(6)	8	(3)	71	(-14)
Aug-97	0	(-15)	30	(2)	14	(3)	25	(2)	69	(-8)
Sep-97	0	(-21)	27	(4)	34	(6)	8	(2)	69	(-9)
Oct-97	0	(-28)	10	(4)	60	(13)	0	(0)	70	(-11)
Nov-97	0	(-7)	13	(1)	75	(0)	0	(0)	88	(-6)
Dec-97	0	(-8)	8	(1)	80	(4)	12	(0)	100	(-3)
Total	0	(-761)	780	(126)	1694	(200)	563	(85)	3037	(-350)

Annual Summery

Year	MHI		South		Middle		North		All Regions	
1995	0	(-292)	208	(37)	522	(75)	253	(45)	983	(-135)
1996	0	(-303)	305	(66)	499	(64)	175	(32)	979	(-141)
1997	0	(-166)	267	(23)	673	(61)	135	(8)	1,075	(-74)
Mean	0	(-254)	260	(42)	565	(67)	188	(28)	1,012	(-117)

Table 6.5 Spatial Distribution of Fishing Trips: Closure of the Northern Sea (North of 30 N)

	Number of Trips Allocated											
Month	MHI	(Δ)[a]	South	(Δ)[a]	Middle	(Δ)[a]	North	(Δ)[a]	All Regions	(Δ)
Jan-95	36	(10)	37	(12)	43	(21)	0	(-28)	116	(*15*)
Feb-95	28	(12)	43	(24)	43	(27)	0	(-46)	114	(*17*)
Mar-95	15	(5)	54	(12)	32	(9)	0	(-23)	101	(*3*)
Apr-95	10	(2)	12	(4)	77	(10)	0	(-13)	99	(*3*)
May-95	34	(1)	5	(1)	68	(4)	0	(-5)	107	(*1*)
Jun-95	26	(1)	7	(2)	79	(5)	0	(-4)	112	(*4*)
Jul-95	25	(3)	13	(3)	66	(14)	0	(-14)	104	(*6*)
Aug-95	45	(16)	13	(12)	29	(21)	0	(-32)	87	(*17*)
Sep-95	20	(-2)	0	(0)	40	(-3)	0	(-6)	60	(*-11*)
Oct-95	50	(6)	11	(4)	26	(4)	0	(-13)	87	(*1*)
Nov-95	58	(7)	29	(6)	10	(3)	0	(-12)	97	(*4*)
Dec-95	10	(4)	31	(4)	57	(8)	0	(-12)	98	(*4*)
Jan-96	16	(7)	22	(10)	60	(24)	0	(-35)	98	(*6*)
Feb-96	30	(10)	31	(14)	55	(19)	0	(-35)	116	(*8*)
Mar-96	13	(4)	20	(5)	67	(20)	0	(-25)	100	(*4*)
Apr-96	3	(0)	11	(0)	98	(1)	0	(-1)	112	(*0*)
May-96	29	(1)	32	(1)	46	(0)	0	(-1)	107	(*1*)
Jun-96	26	(0)	22	(0)	57	(5)	0	(-3)	105	(*2*)
Jul-96	57	(13)	21	(8)	16	(6)	0	(-14)	94	(*13*)
Aug-96	34	(2)	28	(4)	3	(0)	0	(-7)	65	(*-1*)
Sep-96	42	(0)	1	(-1)	21	(-1)	0	(0)	64	(*-2*)
Oct-96	42	(2)	23	(4)	11	(1)	0	(-4)	76	(*3*)
Nov-96	33	(4)	44	(4)	28	(4)	0	(-10)	105	(*2*)
Dec-96	23	(2)	38	(5)	58	(6)	0	(-8)	119	(*5*)
Jan-97	5	(5)	53	(21)	41	(12)	0	(-30)	99	(*8*)
Feb-97	7	(3)	43	(5)	59	(16)	0	(-20)	109	(*4*)
Mar-97	4	(3)	29	(8)	72	(19)	0	(-25)	105	(*5*)
Apr-97	1	(0)	29	(3)	77	(4)	0	(-6)	107	(*1*)
May-97	20	(0)	28	(0)	58	(-1)	0	(0)	106	(*-1*)
Jun-97	36	(0)	1	(0)	85	(0)	0	(0)	122	(*0*)
Jul-97	27	(2)	23	(1)	38	(5)	0	(-5)	88	(*3*)
Aug-97	26	(11)	40	(12)	28	(17)	0	(-23)	94	(*17*)
Sep-97	21	(0)	22	(-1)	28	(0)	0	(-6)	71	(*-7*)
Oct-97	28	(0)	5	(-1)	46	(-1)	0	(0)	79	(*-2*)
Nov-97	7	(0)	12	(0)	75	(0)	0	(0)	94	(*0*)
Dec-97	14	(6)	10	(3)	86	(10)	0	(-12)	110	(*7*)
Total	901	(*140*)	843	(*189*)	1,783	(*289*)	0	(*-478*)	3,527	(*140*)

Annual Summery

Year	MHI	South	Middle	North	All Regions
1995	357 (65)	255 (84)	570 (123)	0 (-208)	1,182 (*64*)
1996	348 (45)	293 (54)	520 (85)	0 (-143)	1,161 (*41*)
1997	196 (30)	295 (51)	693 (81)	0 (-127)	1,184 (*35*)
Mean	300 (47)	281 (63)	594 (96)	0 (-159)	1,176 (47)

[a]A number inside each pair of parentheses indicate a change from the base case in the number of trips.

Table 6.6 Spatial Distribution of Fishing Trips: Prohibiting Swordfish Sets

	Number of Trips Allocated									
Month	MHI	(Δ)[a]	South	(Δ)[a]	Middl	(Δ)[a]	North	(Δ)[a]	All Region	(Δ)
Jan-95	37	(11)	37	(12)	42	(20)	0	(-28)	116	(15)
Feb-95	33	(17)	43	(24)	44	(28)	0	(-46)	120	(23)
Mar-95	26	(16)	77	(35)	6	(-17)	0	(-23)	109	(11)
Apr-95	41	(33)	38	(30)	33	(-34)	0	(-13)	112	(16)
May-95	37	(4)	29	(25)	32	(-32)	0	(-5)	98	(-8)
Jun-95	20	(-5)	52	(47)	24	(-50)	0	(-4)	96	(-12)
Jul-95	35	(13)	31	(21)	26	(-26)	0	(-14)	92	(-6)
Aug-95	36	(7)	5	(4)	10	(2)	5	(-27)	56	(-14)
Sep-95	24	(2)	0	(0)	38	(-5)	2	(-4)	64	(-7)
Oct-95	43	(-1)	6	(-1)	21	(-1)	10	(-3)	80	(-6)
Nov-95	62	(11)	32	(9)	12	(5)	0	(-12)	106	(13)
Dec-95	10	(4)	31	(4)	58	(9)	0	(-12)	99	(5)
Jan-96	25	(16)	25	(13)	57	(21)	1	(-34)	108	(16)
Feb-96	20	(0)	17	(0)	34	(-2)	32	(-3)	103	(-5)
Mar-96	24	(15)	31	(16)	42	(-5)	13	(-12)	110	(14)
Apr-96	6	(3)	38	(27)	72	(-25)	0	(-1)	116	(4)
May-96	14	(-14)	63	(32)	6	(-40)	0	(-1)	83	(-23)
Jun-96	4	(-22)	53	(31)	30	(-22)	0	(-3)	87	(-16)
Jul-96	56	(12)	17	(4)	0	(-10)	0	(-14)	73	(-8)
Aug-96	34	(2)	26	(2)	0	(-3)	0	(-7)	60	(-6)
Sep-96	42	(0)	2	(0)	20	(-2)	0	(0)	64	(-2)
Oct-96	44	(4)	22	(3)	11	(1)	0	(-4)	77	(4)
Nov-96	39	(10)	35	(-5)	38	(14)	0	(-10)	112	(9)
Dec-96	23	(2)	37	(4)	57	(5)	0	(-8)	117	(3)
Jan-97	5	(5)	53	(21)	41	(12)	0	(-30)	99	(8)
Feb-97	16	(12)	58	(20)	45	(2)	0	(-20)	119	(14)
Mar-97	18	(17)	56	(35)	37	(-16)	0	(-25)	111	(11)
Apr-97	8	(7)	44	(18)	53	(-20)	0	(-6)	105	(-1)
May-97	3	(-17)	69	(41)	9	(-50)	0	(0)	81	(-26)
Jun-97	31	(-5)	38	(37)	34	(-51)	0	(0)	103	(-19)
Jul-97	44	(19)	41	(19)	1	(-32)	0	(-5)	86	(1)
Aug-97	20	(5)	32	(4)	14	(3)	6	(-17)	72	(-5)
Sep-97	19	(-2)	21	(-2)	24	(-4)	6	(0)	70	(-8)
Oct-97	28	(0)	6	(0)	46	(-1)	0	(0)	80	(-1)
Nov-97	7	(0)	12	(0)	75	(0)	0	(0)	94	(0)
Dec-97	11	(3)	9	(2)	80	(4)	8	(-4)	108	(5)
Total	945	184	1,186	532	1,172	-322	83	-395	3,386	-1

Annual Summery

Year	MHI		South		Mixed		North		All Regions	
1995	404	(112)	381	(210)	346	(-101)	17	(-191)	1,148	(30)
1996	331	(28)	366	(127)	367	(-68)	46	(-97)	1,110	(-10)
1997	210	(44)	439	(195)	459	(-153)	20	(-107)	1,128	(-21)
Mean	315	(184)	395	(532)	391	(-322)	28	(-395)	1,129	(-1)

[a]A number inside each pair of parentheses indicate a change from the base case in the number of trips.

Table 6.7 Spatial Distribution of Fishing Trips: Imposing an Additional 10% Revenue Tax

	Number of Trips Allocated									
Month	MHI	(Δ)[a]	South	(Δ)[a]	Middle	(Δ)[a]	North	(Δ)[a]	All Regions	(Δ)
Jan-95	28	(2)	25	(0)	23	(1)	26	(-2)	102	(1)
Feb-95	17	(1)	19	(0)	17	(1)	44	(-2)	97	(0)
Mar-95	10	(0)	44	(2)	22	(-1)	21	(-2)	97	(-1)
Apr-95	9	(1)	9	(1)	66	(-1)	13	(0)	97	(1)
May-95	33	(0)	5	(1)	60	(-4)	4	(-1)	102	(-4)
Jun-95	24	(-1)	7	(2)	72	(-2)	2	(-2)	105	(-3)
Jul-95	21	(-1)	11	(1)	47	(-5)	13	(-1)	92	(-6)
Aug-95	29	(0)	1	(0)	6	(-2)	27	(-5)	63	(-7)
Sep-95	20	(-2)	0	(0)	37	(-6)	3	(-3)	60	(-11)
Oct-95	43	(-1)	5	(-2)	20	(-2)	8	(-5)	76	(-10)
Nov-95	51	(0)	23	(0)	7	(0)	7	(-5)	88	(-5)
Dec-95	5	(-1)	26	(-1)	48	(-1)	8	(-4)	87	(-7)
Jan-96	10	(1)	12	(0)	35	(-1)	31	(-4)	88	(-4)
Feb-96	20	(0)	16	(-1)	36	(0)	34	(-1)	106	(-2)
Mar-96	10	(1)	15	(0)	45	(-2)	25	(0)	95	(-1)
Apr-96	2	(-1)	12	(1)	96	(-1)	1	(0)	111	(-1)
May-96	28	(0)	33	(2)	41	(-5)	0	(-1)	102	(-4)
Jun-96	24	(-2)	22	(0)	47	(-5)	2	(-1)	95	(-8)
Jul-96	44	(0)	12	(-1)	9	(-1)	9	(-5)	74	(-7)
Aug-96	32	(0)	20	(-4)	1	(-2)	3	(-4)	56	(-10)
Sep-96	38	(-4)	0	(-2)	16	(-6)	0	(0)	54	(-12)
Oct-96	39	(-1)	17	(-2)	8	(-2)	2	(-2)	66	(-7)
Nov-96	28	(-1)	38	(-2)	22	(-2)	8	(-2)	96	(-7)
Dec-96	21	(0)	33	(0)	51	(-1)	6	(-2)	111	(-3)
Jan-97	0	(0)	32	(0)	29	(0)	26	(-4)	87	(-4)
Feb-97	4	(0)	39	(1)	42	(-1)	19	(-1)	104	(-1)
Mar-97	1	(0)	22	(1)	52	(-1)	24	(-1)	99	(-1)
Apr-97	0	(-1)	26	(0)	72	(-1)	6	(0)	104	(-2)
May-97	19	(-1)	27	(-1)	57	(-2)	0	(0)	103	(-4)
Jun-97	34	(-2)	4	(3)	80	(-5)	0	(0)	118	(-4)
Jul-97	24	(-1)	21	(-1)	29	(-4)	4	(-1)	78	(-7)
Aug-97	15	(0)	28	(0)	12	(1)	17	(-6)	72	(-5)
Sep-97	18	(-3)	19	(-4)	22	(-6)	5	(-1)	64	(-14)
Oct-97	25	(-3)	4	(-2)	38	(-9)	0	(0)	67	(-14)
Nov-97	6	(-1)	10	(-2)	72	(-3)	0	(0)	88	(-6)
Dec-97	8	(0)	7	(0)	74	(-2)	9	(-3)	98	(-5)
Total	740	(-21)	644	(-10)	1,411	(-83)	407	(-71)	3,202	(-185)

Annual Summery

Year	MHI		South		Mixed		North		All Regions	
1995	290	(-2)	175	(4)	425	(-22)	176	(-32)	1,066	(-52)
1996	296	(-7)	230	(-9)	407	(-28)	121	(-22)	1,054	(-66)
1997	154	(-12)	239	(-5)	579	(-33)	110	(-17)	1,082	(-67)
Overall	247	(-7)	215	(-3)	470	(-28)	136	(-24)	1,067	(-62)

[a]A number inside each pair of parentheses indicate a change from the base case in the number of trips.

Table 6.8 Comparison of Alternative Regulatory Policies:

	Baseline	Policy 1 Close two MHI areas	Policy 2 Closing the North sea	Policy3 Prohibit swordfish sets	Policy 4 Imposing 10% tax
Trips and Effort					
Number of Trips (A)	1,129	1,012 (-10.3%)	1,176 (4.1%)	1,129 (-0.03%)	1,067 (-5.5%)
Labor in vessel-days (B)	20,238	19,741 (-2.5%)	19,770 (-2.3%)	18,575 (-8.2%)	18,885 (-6.7%)
Trip length (A / B)	17.93	19.50 (8.8%)	16.82 (-6.2%)	16.46 (-8.2%)	17.69 (-1.3%)
Ratio of swordfish sets	46.7%	50.9% (9.1%)	36.7% (-21.3%)	0.0% (-100%)	43.6% (-6.7%)
Revenue, Costs, and Profits					
Industry Revenue (C)	47,774,679	44,199,557 (-7.5%)	45,238,864 (-5.3%)	35,523,061 (-25.6%)	45,421,421 (-4.9%)
Taxes & Fees (D)	5,016,341	4,640,954 (-7.5%)	4,750,081 (-5.3%)	3,729,921 (-25.6%)	9,311,391 (85.6%)
Shared Costs (E)	17,796,404	16,944,237 (-4.8%)	16,976,031 (-4.6%)	12,371,650 (-30.5%)	16,428,392 (-7.7%)
Fleet Profit (F = C - D - E)	24,961,934	22,614,366 (-9.4%)	23,512,753 (-5.8%)	19,421,490 (-22.2%)	19,681,637 (-21.2%)
Income & Wage					
Boat-Owner's Income (F x 0.50 / 110[a])	113,463	102,793 (-9.4%)	106,876 (-5.8%)	88,279 (-22.2%)	89,462 (-21.2%)
Crew's Income per trip (F x 0.50 / A)	11,055	11,169 (1.0%)	10,000 (-9.5%)	8,604 (-22.2%)	9,220 (-16.6%)
Wage ($ / day at sea) (F x 0.50 / B)	617	573 (-7.1%)	595 (-3.6%)	523 (-15.2%)	521 (-15.5%)
Catches					
Swordfish	40,781	41,341 (1.4%)	28,101 (-31.1%)	468 (-98.9%)	36,959 (-9.4%)
Bigeye	62,971	53,620 (-14.8%)	69,280 (10.0%)	75,169 (19.4%)	61,283 (-2.7%)
Yellowfin	25,023	22,104 (-11.7%)	27,688 (10.7%)	21,251 (-15.1%)	23,973 (-4.2%)
Albacore	47,539	45,256 (-4.8%)	50,856 (7.0%)	84,309 (77.3%)	47,903 (0.8%)
Blue Marlin	6,362	4,991 (-21.5%)	6,899 (8.4%)	6,060 (-4.7%)	5,923 (-6.9%)
Striped Marlin	13,724	11,587 (-15.6%)	15,770 (14.9%)	17,411 (26.9%)	13,402 (-2.3%)

[a]Assuming 110 vessels are active during 1995-97.

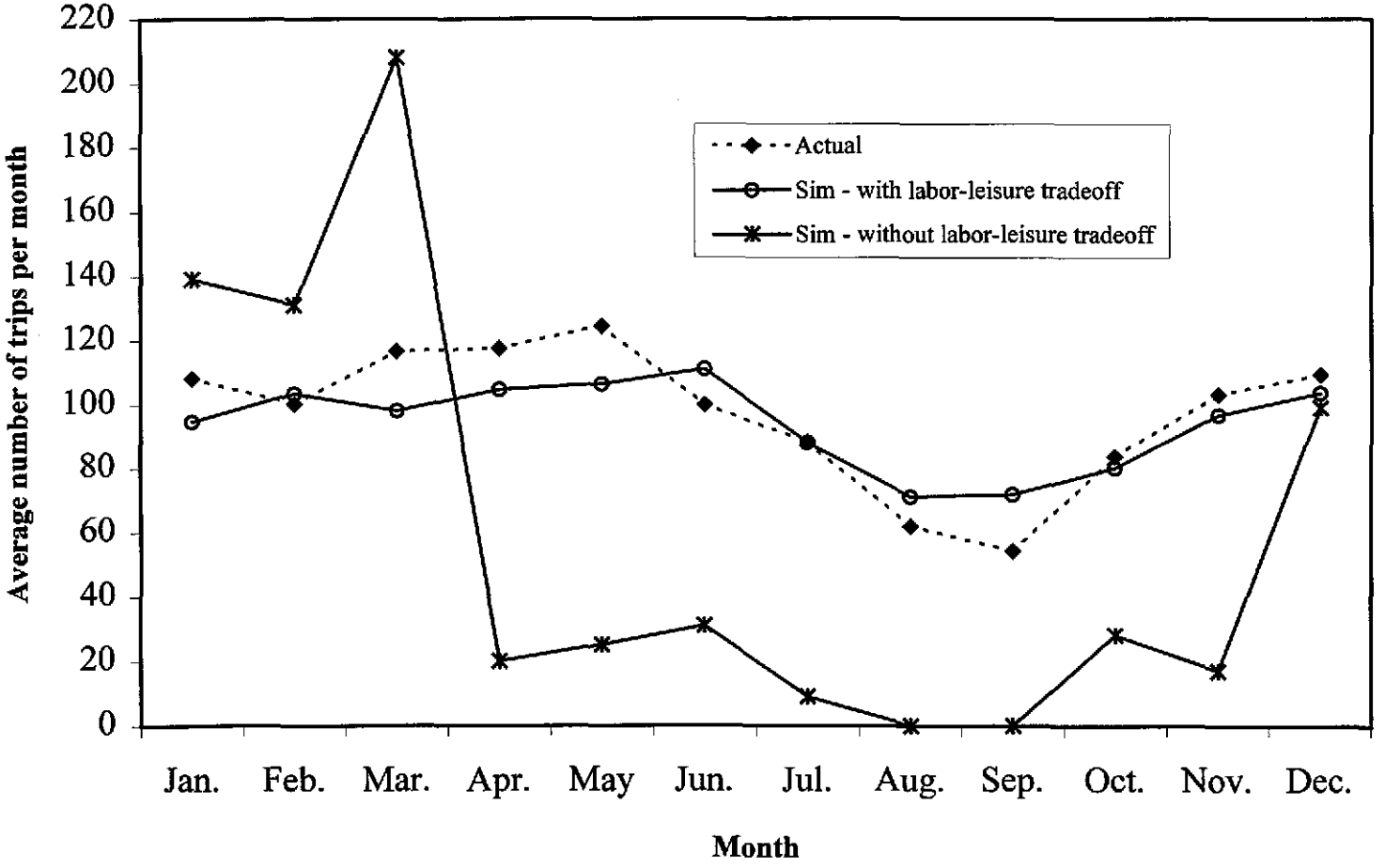

Figure 6.1 Monthly Number of Allocated Fishing Trips: Actual vs. Simulated
(Average of 1995, 1996, and 1997)

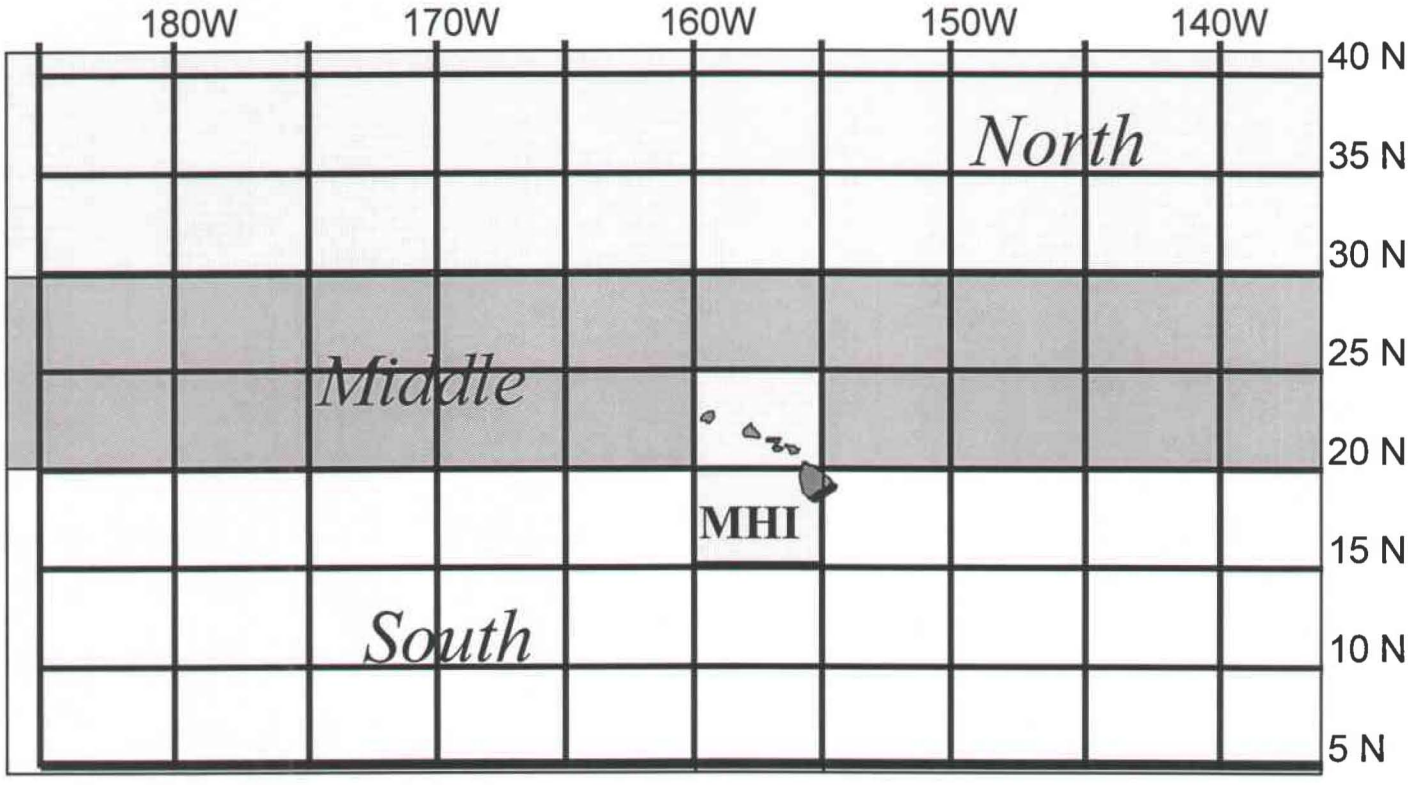

Figure 6.2 Four Regions for the Hawaii-based Longline Fishery

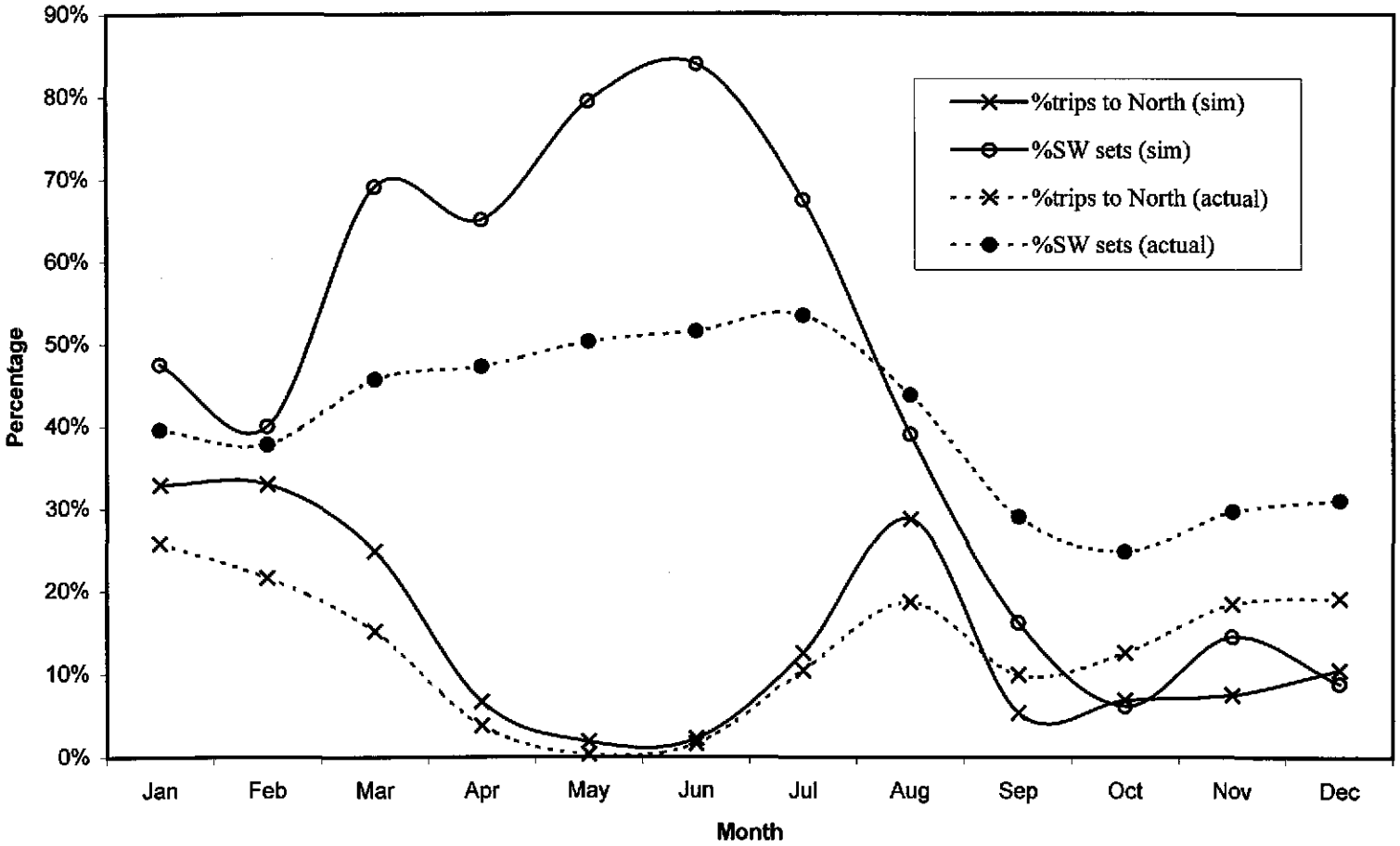

Figure 6.3 Rates of Swordfish Sets and Trips to the North Region: Actual vs. Simulated

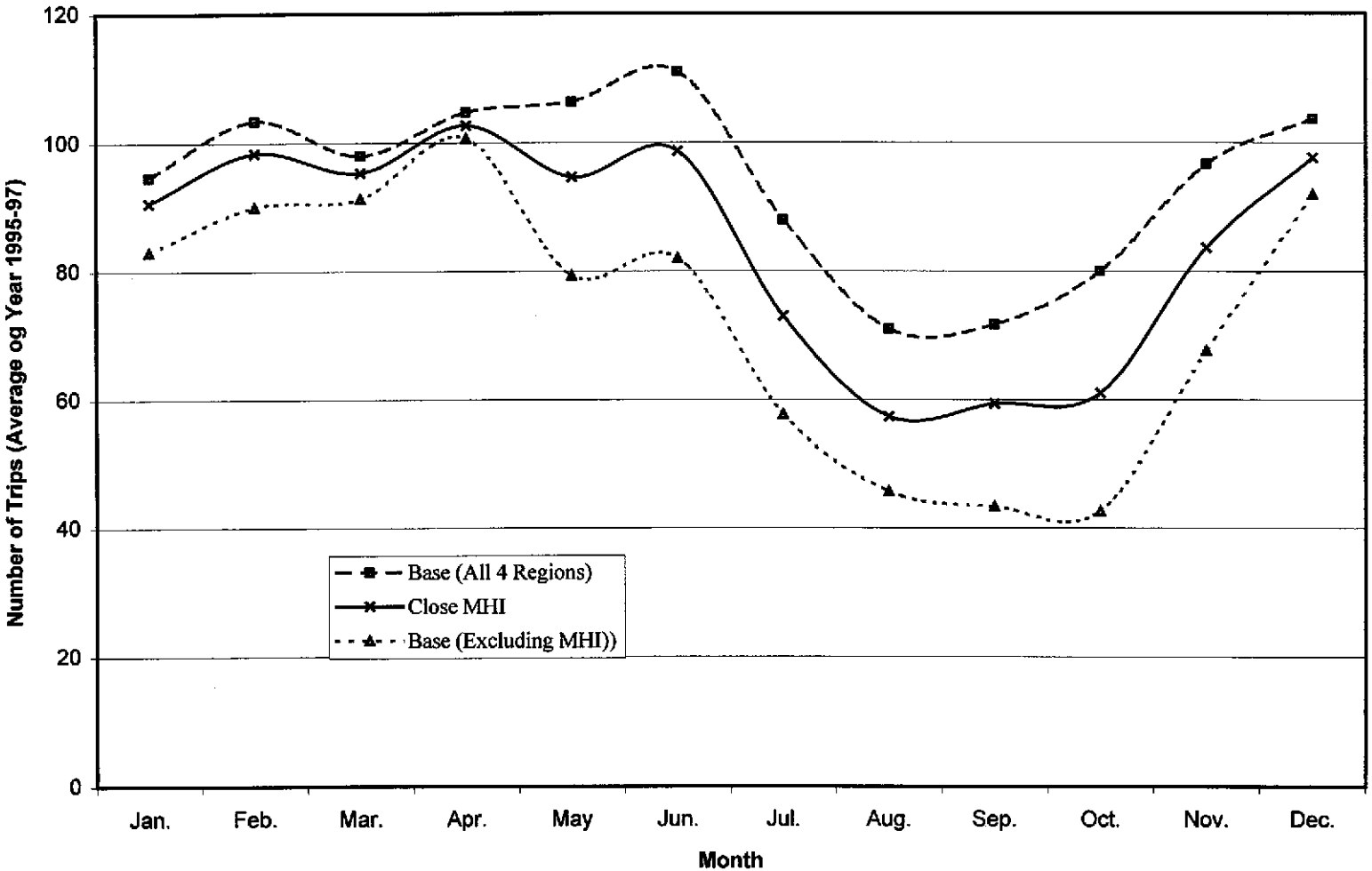

Figure 6.4 Effect of Near-shore Closure on Monthly Trip Allocation

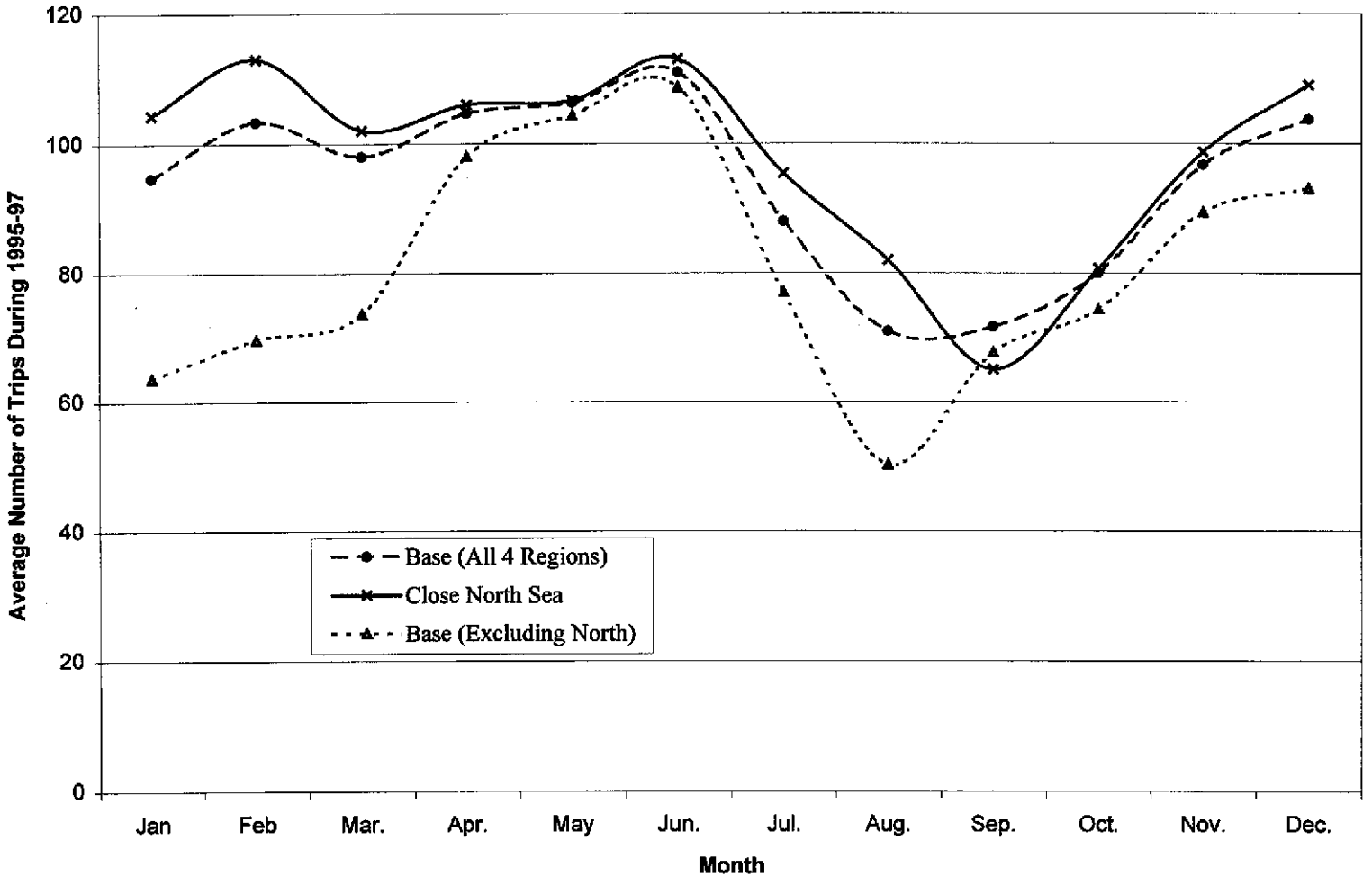

Figure 6.5 Effect of Closure for Sea Turtle Conservation on Trip Allocation

CHAPTER 7
EFFECTS OF FISH MOVEMENT ON CLOSURE POLICY RESULTS

Using the spatial-temporal model, the policy simulations in the previous chapter demonstrate that a large portion of the economic loss caused by an area closure could be offset by the "area substitution" effect, where fishing trips originally allocated to the closed area are relocated to other open areas. This would probably cause an increased fishing pressure in those open areas. As illustrated in Chapter 3 using a "two-area-two-period" model, the effect of fish movement (FM) needs to be included to accurately estimate fishermen's income loss caused by an area closure. If fish are highly mobile and a closed area is a "source", this FM effect could be very significant. The number of fish moving from the closed area to its neighboring open areas increases after implementation of a closure policy, which increases the stocks in those open areas to higher levels than before closure. This FM effect benefits the fishery, and mitigates the negative economic impacts of the area closure. This potential should be investigated further with an empirical application, although information about FM is sparse.

In this chapter, the empirical application to the Hawaii longline fishery, developed in Chapter 4, is extended to incorporate movement of major pelagic species around the main Hawaii islands (MHI). Although the model illustrates more complex, spatial-temporal allocation of fishing effort in the context of area closure, due to necessary simplifying assumptions on the empirical side, its results should be interpreted as indicative, rather than definitive. The significance of the FM effects is evaluated by comparing the results from an area closure policy using the "model with FM", to those using the "model without FM". Discussion and policy implications follow in the concluding section of this chapter.

7.1 Estimation of Fish Movement (FM) Patterns

Movement patterns for pelagic fishes in Hawaiian waters are still under investigation (NMFS, 2001). While research based on a handful of electronic archival tags (e.g.,

Boggs, 2000) indicates patterns of daily vertical movement for bigeye tuna (BE) and yellowfin tuna (YF), the horizontal movement patterns for those species are not certain yet. The number of fish tagged is very small due to the high costs of archival tags, and the duration of monitoring fish movement (FM) is limited due to technical difficulties. Itano and Holland (2000) investigated FM patterns for BE and YF using conventional tagging methods. Despite the larger sample size of 15,397 with about a 10% recapture rate, FM patterns are not conclusive. The majority of recaptured fish are likely to move around the tagged locations, FADs (fish aggregation devices), or MHI areas without solid direction of movement. Thus, no clear movement pattern across 5° square areas has been recognized yet, although it is generally believed to be substantial.

One problem is that most of the tagged BE are juvenile, caught by trollers or handliners, while the longliners target adult BE. Adult BE tunas usually swim in deeper water during the daytime, and may have a different movement pattern from juveniles. Therefore, FM patterns – specifically, the parameters in equation (2.12) – need to be estimated here.

Previous studies use two different approaches to describe FM patterns. While some biologists (e.g., Sibert et al., 1999), described FM with three components -- velocity, direction, and diffusion – others, such as Hilborn (1990) and Kleiber and Hampton (1994) present FM from location i to j as a probability coefficient. In particular, Kleiber and Hampton (1994) used four matrices of "transfer coefficients" to govern movement of skipjack in the north, east, south, and west directions in their discrete spatial grid of half-degree squares. Since their method can be applied straightforwardly to the square grid structure of this study (see equation (2.12))[1], it is used here.

As defined in Chapter 4, an area is defined as a 5° square. Deriso, Punsly, and Bayliff (1991) used discrete stratification of 5° squares to quantify the probabilities of movement

[1] Deriso, Punsly, and Bayliff (1991) developed a method to convert their tag-and-release experiment data, which are summarized into 5° square strata, into the three movement components (velocity, direction, and diffusion). However, it requires additional complex (i.e., costly) computations, while the benefit from estimating the three movement components is not very significant to this study, compared with Figure 7.3.

for YF in the Eastern Pacific Ocean (EPO). They suggest that YF are unlikely to move beyond one 5° square per month. Moreover, there is no clear difference in mobility between YF and BE around the MHI (Itano and Holland, 2000). Therefore, fish are assumed to move only by one-area space per period.

The net inflow to area k in Equation (2.12) is specified as a linear function of the residual stocks in area k itself and the four adjacent areas: the north, east, south and west of that area, as follows:

$$R_{i,k,t} = \beta_{0,k} B'^{0}_{i,k,t} + \beta_{1,k} B'^{N}_{i,k,t} + \beta_{2,k} B'^{E}_{i,k,t} + \beta_{3,k} B'^{S}_{i,k,t} + \beta_{4,k} B'^{W}_{i,k,t} + u_{i,k,t} \quad (7.1)$$

where

$R_{i,k,t}$ = Net inflow for species i in area k at the end of period t,

$B'^{0}_{i,k,t}$ = Residual stock of species i for area k itself at period t,

$B'^{X}_{i,k,t}$ = Residual stock for an adjacent area of area k, where superscript X represents the direction of that adjacent area from area k (Figure 7.1),

$\beta_{0,k} \ldots \beta_{4,k}$ = Parameters, and

$u_{i,k,t}$ = Error term.

To estimate Equation (7.1) econometrically, time-series data without missing observations (or with only a few missing observations) for each area are needed. Such data are hardly available for areas in distant water since fishing trips are not allocated there every month. Due to this limitation, this FM function was estimated only for the four areas around the main Hawaiian islands (MHI), i.e., *15N155W*, *15N160W*, *20N155W*, and *20N160W* (Figure 7.2). Also note that the net inflows from the northeast, northwest, southeast or southwest are not included here because if the four diagonal areas are included, the econometric estimation of Equation (7.1) might suffer from (i) missing observations associated with areas, *10N150W*, *25N150W*, *10N165W*, and *25N165W*, (ii)

the loss in degrees of freedom, and (iii) multicollinearity (see Appendix 5 for details). Thus, a four-grid inflow is deemed appropriate here.

Equation (7.1) does not provide explicit evidence that a particular individual fish moves from one place to another. Rather, it explains how fishermen might infer the stock size in each area, based on their information about FM patterns and prior information about residual stocks in the previous period. In addition, since this estimation procedure requires only logbook data, the movement of various species can be explored at relatively low cost. Then, the resulting movement patterns may be useful to marine biologists as preliminary analysis results.

As defined in equation (2.13), the initial stock at period $(t + 1)$ is computed as follows:

$$B^{0}_{i,k,(t+1)} = B'^{0}_{i,k,t} + R_{i,k,t} \ .$$

The above equation accompanied with Equation (7.1) indicates that a change in catch at one of the adjacent areas (e.g., zero catch due to a closure) would affect the net inflow and hence the next-period initial stocks in the four areas. On the other hand, the stocks in other areas are assumed to be fixed (or static) as in the model without FM; i.e., the initial stock in area k never changes even though the residual stock sizes in area k itself and the adjacent areas at the previous period are, by a regulatory policy, considerably different from the baseline case.

Movement of Bigeye Tuna (BE)

Due to the complexity of analyzing the movement effects of multiple species (if each species has a different movement pattern), this empirical model incorporates the movement of only one species here. BE was chosen because it is the primary target and major income source for longliners operating in the four areas.

Using the above econometric procedure, parameters in equation (7.1) for each of the four areas are estimated as follows (see Appendix 5 for details):

$$R_{15N155W,t} = 0.373\,B'_{15N155W,t} - 0.951\,B'_{20N155W,t} + 0.0632\,B'_{15N150W,t} + 0.743\,B'_{10N155W,t} + 0.202\,B'_{15N160W,t} \quad (7.2a)$$

$$R_{15N160W,t} = -0.156\,B'_{15N160W,t} + 0.276\,B'_{20N160W,t} + 1.005\,B'_{15N155W,t} + 0.111\,B'_{10N160W,t} - 0.288\,B'_{15N165W,t} \quad (7.2b)$$

$$R_{20N155W,t} = -0.416\,B'_{20N155W,t} - 0.507\,B'_{25N155W,t} + 1.212\,B'_{20N150W,t} + 0.313\,B'_{15N155W,t} - 0.191\,B'_{20N160W,t} \quad (7.2c)$$

$$R_{20N160W,t} = -1.284\,B'_{20N160W,t} + 0.899\,B'_{25N160W,t} + 1.552\,B'_{20N150W,t} + 0.257\,B'_{15N160W,t} - 0.539\,B'_{20N165W,t} \quad (7.2d)$$

As discussed with equation (2.12), the estimated parameters for its own areas ($b_{0,k}$ in equation (7.1)) are expected to be negative, while the estimated parameters for adjacent areas ($b_{1,k} \ldots b_{4,k}$) are expected to be positive. In addition, the absolute values of all estimated parameters are expected to be no greater than 1. However, some of the above estimates in equations (7.2a-d) were actually beyond this expected range. Possible reasons for these unexpected estimates may include: (i) the FM functions do not explicitly include some other factors, such as recruitment, natural mortality, and oceanographic variables (e.g., Sea Surface Temperature), and (ii) measurement errors, particularly in estimating the "actual" initial stock $B_{i,k,t}$. See Appendix 5 for the detailed results of econometric estimation.

A significantly positive estimate for an adjacent area suggests significant inflow from that adjacent area to the own areas (e.g., from the south *10N155W* to *15N155W* in Equation (7.2a)). Then movement directions, suggested by the above results, are illustrated by arrows in Figure 7.3. Thick and normal solid arrows indicate that the corresponding estimate is significant at the 1% and 5% level, respectively. Two dotted-line arrows from *15N160W* and *20N160W* to the west are suggested by negative estimates for the residual stocks in the west (-0.288 in equation (7.2b) and -0.539 in equation (7.2d)). A negative estimate for an adjacent area is likely to appear when outflow to that area significantly overweighs the inflow from that area, such as -0.951 in equation (7.2a) and -0.191 in (7.2c).

Overall, BE tunas appear to move from the east to the west around the MHI. Also BE moves from the south to the north between 155° *W* and 160° *W* longitude, while the movement of BE is not clear between 160° *W* and 165° *W* in the north-south direction. Now dividing these four areas into two groups by the 160° W longitude line; the first group includes the two areas around the MHI – *15N155W* and *20N155W* – which is called the "MHI region" in Chapter 6, while the other group include the rest – *15N160W* and *20N160W* -- which is hereafter called the "West HI region"[2]. As shown in Figure 7.3, since BE moves from the east to the west, the MHI region can be considered a "source", while the West HI region is a "sink". These two regions will be used in Section 7.3 to compare the relationship between the FM effects and whether closed areas are "sources" or "sinks".

7.2 Replication of Fishing Trips using the Extended Model with Fish Movement

The model without FM has already been validated in the previous chapter. The extended model with FM also replicates monthly allocation of trips in the Hawaii longline fishery during the years 1995-97. An essential difference between the two simulated results – one by the model without FM and the other by the model with FM – is whether or not monthly initial stocks of BE are computed by the FM functions (7.2a-d).

The estimated stock sizes in the four areas are examined. Figure 7.4 presents two series of stock sizes: one is "static" which was computed through equation (4.2) with catch and effort data in the logbook and the estimated catchability, and the other was "dynamically" computed using the FM functions. The stock size $\mathbf{B}_t$ should ideally be the stock (or CPUE including a decline due to stock externality) that fishermen expected. The estimated "static" stock (denoted as $\hat{\mathbf{B}}_t$) may be very different from the true stock $\mathbf{B}_t$ due to the sampling error ("outliers" problem). On the other hand, while the "dynamically" estimated stock (denoted as $\hat{\hat{\mathbf{B}}}_t$) may suffer from specification error in estimating the FM functions, though it is more resistant to the sampling error. Note that it is assumed that both stock sizes are equal at the first period: $\hat{\mathbf{B}}_1 = \hat{\hat{\mathbf{B}}}_1$.

Overall, there were a couple of spiky peaks in the "static" stocks that were not accurately predicted by the FM functions. For examples, there is a peak in the stock size for *20N160W* from November to December in each of the three years, but the FM functions significantly underestimated those stocks, which resulted in the fewer trips allocated to the "Middle" region during those periods (see Table 7.1). Similarly, the stock sizes for the MHI region at October and November 1996 were significantly underestimated. Hence, only 7 and 12 trips were allocated to the MHI region for those months, respectively, whereas the actual numbers of trips were 40 and 29. Since the FM functions for *15N155W* and *20N155W* tend to overestimate the stocks during May-July every year, fishing trips are over-allocated during the same period. Thus, errors in predicting the stock sizes are likely to be the one of the major causes for simulation errors (i.e., difference between the simulated number of trips and the actual one).

Comparison of the spatial distributions from the model with FM ("W/ FM" model) to those from the "baseline" model without FM ("WOFM" model, which is used in Chapter

[2] *15N160W* and *20N160W* also belong to the "South" and "Middle" regions, respectively (Figure 7.2).

6) also confirms that the spatial distribution of trips is very sensitive to stock size in each area. Even though the initial stocks in all areas of the "North" region were the same in both models, (because the FM functions do not cover any of the areas in the North region), incorporating FM significantly affects even the number of trips allocated to the North region. For example, while only 37 trips were allocated to the North region by the WOFM model from October to December 1995, 59 trips were allocated by the W/FM model.

Aggregate monthly numbers of trips allocated by the W/FM mode were compared to the actual numbers of trips and those allocated by the WOFM model in Figure 7.5. The Mean Absolute Percentage Error (MAPE) of monthly trips allocated by the W/FM model was 18.7%, which is greater than that for the WOFM model (13.9%: see Appendix 4 for the detailed discussion about MAPE). On the other hand, the goodness-of-fit, measured by the Chi-square statistic, for spatial distribution of trips across the four regions is improved by incorporating FM since the median is smaller (21.868 for W/FM vs. 24.475 for WOFM) and the aggregate trips over three years also show better fitness (16.497 for W/FM vs. 65.070 for WOFM). It suggests that the FM functions, which are stochastically estimated, have potentials to solve the vulnerability to data noise in estimating the stock size in each area, although the FM equations need to be improved to cope with many other factors that might affect FM.

7.3 Policy Simulations for Area Closure

The empirical model in this chapter is extended to incorporate fish movement (FM) to analyze the impacts of regulations (in particular, area closure) on the pelagic fishery because fish move across areas, and the number of fish moved across areas may be significantly affected by area closure. The empirical model with FM in this chapter ("W/FM" model) is much more complex than conventional economic models for fishery, and much closer to the real situation in the Hawaii longline fishery than the hypothetical two-area-two-period setting in Chapter 3.

However, the "W/FM" model is still too simple, relative to the actual fishery, which includes uncertain, diversified features of oceanographic phenomena, ecological relationships within and among fish and invertebrate species, and fishermen's behaviors. In particular, movement of pelagic species in the North Pacific is still under investigation. Besides, as discussed in the previous section, the estimation of FM Equations (7.2a-d) faces several limitations, such as (i) FM functions are estimated for four areas in the MHI and West HI regions only, and (ii) the estimated parameters for the FM functions may be accompanied with considerable estimation errors (i.e., large confidential intervals).

Definition of "Recovery Rate"

The predicted impacts, represented in an absolute term (e.g., fleet profit and the number of trips changed by FM effect), tend to be sensitive to errors in fish prices, stocks, and other parameters. On the other hand, since some of those fluctuations and errors could be offset during the computation of a relative measure (e.g., representing an effect by percentage), a relative measure could be relatively less sensitive to errors in the estimated variables or model parameters.[3] Therefore, the FM effect is measured using a relative term, "recovery rate", in this chapter.

As discussed in Chapter 3 ("% Change for Recovery" in Table 3.2), the effect of FM is measured as a difference in the impacts of a closure policy on certain variable (e.g., fleet profit) by two models – one is without FM (WOFM) and the other is with FM (W/ FM). While the initial stocks are given (i.e., static) in the WOFM model, they are dynamically computed by the FM functions in the W/FM model. A recovery rate is computed as

$$\text{Recovery rate} = \frac{Loss_{CP1,WOFM} - Loss_{CP1,W/FM}}{Loss_{CP1,WOFM}}.$$

[3] See Appendix 4 for more details regarding "absolute" and "relative" terms.

Although a term "loss" can be expressed by any variables (e.g., the number of trips), fleet profit should be focused on because the 50% of fleet profit is accruing to fishermen (and the rest is accruing to the owner). The loss in fleet profit by Closure Policy 1 (denoted as $Loss_{CP1, WOFM}$) is computed as the fleet profit without closure minus the fleet profit under Closure Policy 1. Subscript "WOFM" (or" W/FM") indicates a model that is used to estimate fleet profit.[4]

Choice of Policy Simulations

Unlike the policy simulations in Chapter 6, the focus of policy simulations in this chapter is to examine the magnitude of the FM effect, rather than to attempt to conduct realistic policy simulations. Hence, policy simulations again include the movement of BE only to simplify the explanation of the FM effect. The following two closure policies are simulated: first, two "source" areas (*15N155W & 20N155W* in the MHI region: Case 1) are closed; and second two "sink" areas (*15N160W & 20N160W* in the West HI region: Case 2) are closed. Then the comparison of the FM effects in the above two closure cases could evaluate how much the FM effect depends on the FM profile ("source" and "sink" relationship).

The number of trips in each of the four regions is presented in Table 7.2, and the computed stock sizes for the four areas are presented in Figures 7.6 and 7.7. To examine the FM effect, the results from the "WOFM" model are presented in both table and figures for comparison purposes. Note that only results for the first year (i.e., 1995) are presented here because some minor errors in each period could accumulate and become large errors in the later periods, when the simulation model computes stock sizes over periods using the FM functions.

[4] The "WOFM" model in this section consumes the initial stocks that are predicted by the FM functions (7.2a-d) without any policies imposed, instead of using the initial stocks originally estimated by Equation (4.2), which are used in the analyses in Chapter 6. By this replacement, both models – "WOFM" and "W/ FM" – produce the exact same results as presented in Table 7.1 when no policy is imposed.

Case1 Results – Two "Source" Areas are Closed.

The FM effects on the initial stocks of BE in each of the four areas over time are presented in Figure 7.6. As demonstrated in the two-area-two-period model in Chapter 3, it is useful to examine the stock change during the period right after a closure is imposed to avoid the effect of accumulation of errors, which is caused by dynamic computation of stocks over periods. The stocks in the two open areas – *15N160W* and *20N160W* – increased by 7 - 8% in February. Overall, stock size during year 1995 for *20N160W* increased about 50%, while those for *15N160W* increased only by 1% (Figure 7.6). Since BE move from the east to west and from the south to the north (Figure 7.3), it is reasonable that the stock in the north-west area (*20N160W*) would increase if the stocks in the MHI areas are protected. On the other hand, the stock in *20N155W* – one of the two closed areas – almost doubles, while that in *15N155W* – the other closed area – on average declines slightly, although it increases considerably during the first four months (see Figure 7.6). This result is unlikely to be realistic since this area is closed and the BE in the area is protected. Some estimation errors may become significant in the second half of the year. The stocks in *15N155W*, which was unexpectedly low, may also affect the stock in *15N160W* since the FM function (7.2) indicates a significant inflow from *15N155W* to *15N160W*.

Consequently, as shown in Table 7.2, because the stock level in 20N160W (one of the "Middle" region) is much higher when incorporating FM, more trips (+124) are allocated to the "Middle" region, though the numbers of trips allocated to the "South" and "North" regions decline due to the displacement to the "Middle" region. Overall, 55% of the trips lost (79 out of 144) by the closure of the MHI region are recovered by the FM effect.

Case2 Results – Two "Sink" Areas are Closed.

For Case 2, while the stocks in the two closed areas (*15N160W* and *20N160W*) increased substantially (by 200% and 60%, respectively), the stocks in the two open areas increased little or declined. The stock size in *15N155W* increased by 7% in February and by 26% during 1995 overall, while that in *20N155W* slightly decreased in February and declined

by 20% during 1995 overall (Figure 7.7). Thus, the results from this simulation indicate that the overall stock level in the open areas would increase little when the closed areas were "sinks".

As shown in Table 7.2, because the stock level in *20N155W* (in the MHI region) is higher by incorporating FM, more trips (+27) are allocated to the MHI region, though the numbers of trips allocated to the "South", "Middle", and "North" regions slightly declined due to a displacement to *20N155W*. Overall, only 7.5% of the trips lost (8 out of 106) by the closure of the West HI region are recovered by the FM effect.

Comparison of FM Effect between Case 1 and Case 2

Results from the above five simulations – "No Closure", "Closure of the MHI region" without and with FM, and "Closure of the West HI region" without and with FM – are summarized in Table 7.3 (see the catches of BE). In general, the model incorporating FM (W/FM) experiences an increase in the stock level of the open areas, compared with the results by the "WOFM" model, resulting an increase in BE catch. Such an increase in the BE catch is greater when the closed areas are "sources" (Case1) than when the closed areas are "sinks" (Case2). According to the "WOFM" model, 12% of the 1995 feet profit (about $28.4 million) will be lost by closing the MHI region (Case 1), however, 45% of that loss in fleet profit will be offset because of the benefit from the FM effect. On the other hand, such a benefit from the FM effect accounts only for 6% of the loss caused by closing the West HI areas, which are "sinks" (Case 2).

Thus, as demonstrated using the "two-area-two-period" example in Chapter 3, the effect of FM depends primarily on whether the closed area(s) is a "source" or "sink" in terms of the direction of movement. If the closed area(s) is a "source", then the benefit from not harvesting in that closed area would be significant, and vice versa.

Implications for a Closure of the North Pacific to Conserve Sea Turtles

A vast region of the North Pacific was closed during 1999-2001 to protect bycatch species (sea turtles), and hence substantial revenue loss from longliners targeting swordfish was expected. As mentioned before, the fish movement model was not applied to the other areas due to data limitations. Therefore, a closure of the North Pacific to protect sea turtles could not be simulated in this study. Nevertheless, a discussion of the implications of this study for this actual area closure for sea turtle conservation is useful.

Swordfish is believed to be highly mobile, and swordfish stocks usually come down toward the MHI region from the north in the early summer. (See a discussion in the previous chapter and Figure 6.3.) More swordfish might come down to the south if the North Pacific is closed, which might benefit fishermen. However, other studies suggest swordfish movement is more likely to depend on environmental factors, such as SST rather than density of the stocks, compared to BE and YF (NMFS, 2001). The latter suggests that the assumption of the FM function (2.12) – FM depends on the stock density – may not hold.

Preliminary estimates (see Appendix 5) indicate that the movement of swordfish in *20N155W* is also likely to depend on the stock density; i.e., the inflow of swordfish to that area increases as the residual stock in the north area increases, although there is no statistical evidence regarding the other three areas. Since more swordfish might come down to the south if the North Pacific (e.g., above 25° N) is closed, the FM effect may somehow offset the negative economic impact of the northern closure.

Summary and Implications

This chapter estimates a movement pattern of BE using the NMFS logbook data, and examines the fish movement (FM) effect on the fishermen's income loss, caused by area closure. The resulting FM effect depends on the fish movement profile. About half of the loss in fishermen's income could be recovered if two areas in the MHI region – "sources" – are closed, while less than 10% of the loss in fishermen's income is recovered if two

areas in the West HI – "sinks" – are closed. Thus, FM needs to be considered to estimate the impact of area closures on the fishery, although the improvement in estimating the FM functions is crucially needed.

In general, a closed area(s) may be a "source" if the objective of a closure policy is to protect a breeding area where more juvenile fish are growing. If so, the closure of source area(s) may be consistent to the objective of conserving or protecting fishery target species. The findings of this study support such a closure because the negative economic impact of such a closure on the fishery would be much less than the common expectation, which does not consider the benefits from the protecting the fish stock in a closed area (due to the FM effect) in estimating the impact of regulation on the industry.

Table 7.1 Spatial Distribution of Fishing Trips: No Closure Case, Estimated by the Model With Movement of Bigeye Tuna

	Number of Trips Allocated											
Month	MHI	(Δ)[a]	South	(Δ)	Mixed	(Δ)	North	(Δ)	All Regions	(Δ)
Jan-95	26	(0)	25	(0)	22	(0)	28	(0)	101	(0)
Feb-95	13	(-3)	27	(8)	28	(12)	38	(-8)	106	(9)
Mar-95	24	(14)	36	(-6)	33	(10)	17	(-6)	110	(12)
Apr-95	20	(12)	23	(15)	60	(-7)	7	(-6)	110	(14)
May-95	22	(-11)	34	(30)	59	(-5)	2	(-3)	117	(11)
Jun-95	35	(10)	19	(14)	65	(-9)	1	(-3)	120	(12)
Jul-95	49	(27)	33	(23)	29	(-23)	8	(-6)	119	(21)
Aug-95	36	(7)	20	(19)	14	(6)	22	(-10)	92	(22)
Sep-95	24	(2)	0	(0)	55	(12)	6	(0)	85	(14)
Oct-95	19	(-25)	10	(3)	25	(3)	22	(9)	76	(-10)
Nov-95	33	(-18)	36	(13)	0	(-7)	17	(5)	86	(-7)
Dec-95	27	(21)	20	(-7)	17	(-32)	20	(8)	84	(-10)
Jan-96	0	(-9)	13	(1)	32	(-4)	42	(7)	87	(-5)
Feb-96	12	(-8)	37	(20)	39	(3)	24	(-11)	112	(4)
Mar-96	18	(9)	29	(14)	36	(-11)	21	(-4)	104	(8)
Apr-96	37	(34)	35	(24)	48	(-49)	0	(-1)	120	(8)
May-96	62	(34)	34	(3)	28	(-18)	0	(-1)	124	(18)
Jun-96	42	(16)	29	(7)	44	(-8)	1	(-2)	116	(13)
Jul-96	41	(-3)	24	(11)	11	(1)	13	(-1)	89	(8)
Aug-96	23	(-9)	31	(7)	7	(4)	6	(-1)	67	(1)
Sep-96	12	(-30)	15	(13)	33	(11)	0	(0)	60	(-6)
Oct-96	7	(-33)	25	(6)	17	(7)	7	(3)	56	(-17)
Nov-96	12	(-17)	41	(1)	19	(-5)	15	(5)	87	(-16)
Dec-96	23	(2)	25	(-8)	41	(-11)	14	(6)	103	(-11)
Jan-97	9	(9)	33	(1)	18	(-11)	29	(-1)	89	(-2)
Feb-97	0	(-4)	35	(-3)	38	(-5)	27	(7)	100	(-5)
Mar-97	0	(-1)	20	(-1)	57	(4)	24	(-1)	101	(1)
Apr-97	13	(12)	35	(9)	64	(-9)	3	(-3)	115	(9)
May-97	30	(10)	34	(6)	51	(-8)	0	(0)	115	(8)
Jun-97	58	(22)	26	(25)	48	(-37)	0	(0)	132	(10)
Jul-97	34	(9)	35	(13)	30	(-3)	3	(-2)	102	(17)
Aug-97	34	(19)	28	(0)	14	(3)	18	(-5)	94	(17)
Sep-97	34	(13)	7	(-16)	35	(7)	7	(1)	83	(5)
Oct-97	9	(-19)	17	(11)	43	(-4)	0	(0)	69	(-12)
Nov-97	3	(-4)	14	(2)	63	(-12)	0	(0)	80	(-14)
Dec-97	31	(23)	18	(11)	47	(-29)	7	(-5)	103	(0)
Total	872	(111)	923	(269)	1270	(-224)	449	(-29)	3514	(127)

Annual Summery

Year	MHI		South		Mixed		North		All Regions	
1995	328	(36)	283	(112)	407	(-40)	188	(-20)	1,206	(88)
1996	289	(-14)	338	(99)	355	(-80)	143	(0)	1,125	(5)
1997	255	(89)	302	(58)	508	(-104)	118	(-9)	1,183	(34)
Mean	291	(37)	308	(90)	423	(-75)	150	(-10)	1,171	(42)

[a]A number inside each pair of parentheses indicate a difference from the baseline case (without fish movement) in the number of trips.

Table 7.2 Spatial Distribution of Trips: with and Without Bigeye Movement (only 1995)

	No Closure					Closure (w/o FM)					Closure (with FM)				
Month	MHI	South	Mixed	North	Total	MHI	South	Mixed	North	Total	MHI	South	Mixed	North	Total
						Case 1: Two "Source" Areas (15N155W & 20N155W) Are Closed:									
Jan	26	25	22	28	101	0	31	31	32	94	0	0	0	0	0
Feb	13	27	28	38	106	0	29	31	40	100	0	+2	+2	-2	+2
Mar.	24	36	33	17	110	0	41	39	21	101	0	0	-1	0	-1
Apr.	20	23	60	7	110	0	26	69	8	103	0	-2	+4	0	+2
May	22	34	59	2	117	0	37	68	3	108	0	-3	+5	0	+2
Jun.	35	19	65	1	120	0	22	77	4	103	0	-2	+11	-2	+7
Jul.	49	33	29	8	119	0	40	49	12	101	0	-2	+10	-2	+6
Aug.	36	20	14	22	92	0	25	22	29	76	0	+6	+20	-11	+15
Sep.	24	0	55	6	85	0	0	60	9	69	0	+11	+14	-5	+20
Oct.	19	10	25	22	76	0	14	28	25	67	0	+1	+18	-6	+13
Nov.	33	36	0	17	86	0	45	3	24	72	0	-12	+22	-2	+8
Dec.	27	20	17	20	84	0	22	19	27	68	0	-13	+19	-1	+5
Total	328	283	407	188	1,206	0	332	496	234	1,062	0	-14	+124	-31	+79
	Difference from "No Closure" case:					-328	49	89	46	-144				Diff2	-65
														Recovery Rate =	54.9%
						Difference from "No Closure" case:					-328	35	213	15	-65
						Case 2: Two "Sink" Areas (15N160W & 20N160W) Are Closed:									
Jan	26	25	22	28	101	28	15	27	30	100	0	0	0	0	0
Feb	13	27	28	38	106	18	18	11	48	95	+1	0	-1	0	0
Mar.	24	36	33	17	110	30	26	23	23	102	-6	+1	+1	1	-3
Apr.	20	23	60	7	110	26	7	60	10	103	-1	0	0	0	-1
May	22	34	59	2	117	31	4	63	5	103	+9	-1	-5	0	+3
Jun.	35	19	65	1	120	39	0	66	4	109	+5	0	-2	-1	+2
Jul.	49	33	29	8	119	62	0	33	12	107	-6	0	+4	0	-2
Aug.	36	20	14	22	92	45	0	5	29	79	+6	0	-2	-3	+1
Sep.	24	0	55	6	85	25	0	45	6	76	+1	0	0	0	+1
Oct.	19	10	25	22	76	19	10	25	21	75	+16	-2	-2	-6	+6
Nov.	33	36	0	17	86	39	18	1	23	81	+4	-1	0	0	+3
Dec.	27	20	17	20	84	31	0	8	31	70	-2	0	0	0	-2
Total	328	283	407	188	1,206	393	98	367	242	1,100	+27	-3	-7	-9	+8
	Difference from "No Closure" case:					65	-185	-40	54	-106				Diff2	-98
														Recovery Rate =	7.5%
						Difference from "No Closure" case:					92	-188	-47	45	-98

Table 7.3 Comparison of Two Area Closure Policies With and Without Movement of Bigeye Tuna (1995 Only)

	No Closure	Closure 1: Close two MHI areas		Closure 2: Close two West HI areas	
		W/O FM	With FM	W/O FM	With FM
Trips and Effort					
Number of Trips (A)	1,206	1,062 (-11.9%)	1,141 (-5.4%)	1,100 (-8.79%)	1,108 (-8.1%)
Labor in vessel-days (B)	20,833	19,741 (-5.2%)	20,894 (0.3%)	20,366 (-8.2%)	20,515 (-1.5%)
Trip length (A / B)	17.27	18.59 (7.6%)	18.31 (6.0%)	18.51 (7.2%)	18.52 (7.2%)
Ratio of swordfish sets	41.0%	47.2% (15.3%)	41.1% (0.2%)	53.1% (29.6%)	51.7% (26.2%)
			Recovery Rate = 54.9%		***Recovery Rate = 7.5%***
Revenue, Costs, and Profits					
Industry Revenue (C)	51,972,708	47,248,860 (-9.1%)	49,269,649 (-5.2%)	48,039,944 (-7.6%)	48,276,789 (-7.1%)
Taxes & Fees (D)	5,457,134	4,961,130 (-9.1%)	5,173,313 (-5.2%)	5,044,194 (-7.6%)	5,069,063 (-7.1%)
Shared Costs (E)	18,088,338	17,308,436 (-4.3%)	17,566,985 (-2.9%)	18,223,140 (0.7%)	18,216,323 (0.7%)
Fleet Profit (F = C - D - E)	28,427,236	24,979,294 (-12.1%)	26,529,351 (-6.7%)	24,772,610 (-12.9%)	24,991,403 (-12.1%)
			Recovery Rate = 45.0%		***Recovery Rate = 6.0%***
Income & Wage					
Boat-Owner's Income (F x 0.50 / 110[a])	129,215	113,542 (-12.1%)	120,588 (-6.7%)	112,603 (-12.9%)	113,597 (-12.1%)
Crew's Income per trip (F x 0.50 / A)	11,786	11,760 (-0.2%)	11,625 (-1.4%)	11,260 (-4.5%)	11,278 (-4.3%)
Wage ($ / day at sea) (F x 0.50 / B)	682	633 (-7.3%)	635 (-6.9%)	608 (-10.9%)	609 (-10.7%)
Catches					
Swordfish	36,518	40,154 (10.0%)	37,828 (3.6%)	45,342 (24.2%)	44,895 (22.9%)
Bigeye	72,155	58,285 (-19.2%)	68,111 (-5.6%)	54,528 (-24.4%)	57,251 (-20.7%)
Yellowfin	24,309	19,417 (-20.1%)	19,823 (-18.5%)	18,988 (-21.9%)	19,091 (-21.5%)
Albacore	50,657	44,712 (-11.7%)	46,245 (-8.7%)	39,244 (-22.5%)	34,277 (-32.3%)
Blue Marlin	6,743	4,945 (-26.7%)	5,142 (-23.7%)	5,399 (-19.9%)	5,329 (-21.0%)
Striped Marlin	19,680	15,561 (-20.9%)	17,680 (-10.2%)	15,817 (-19.6%)	15,379 (-21.9%)

[a]Assuming 110 vessels are active during 1995.

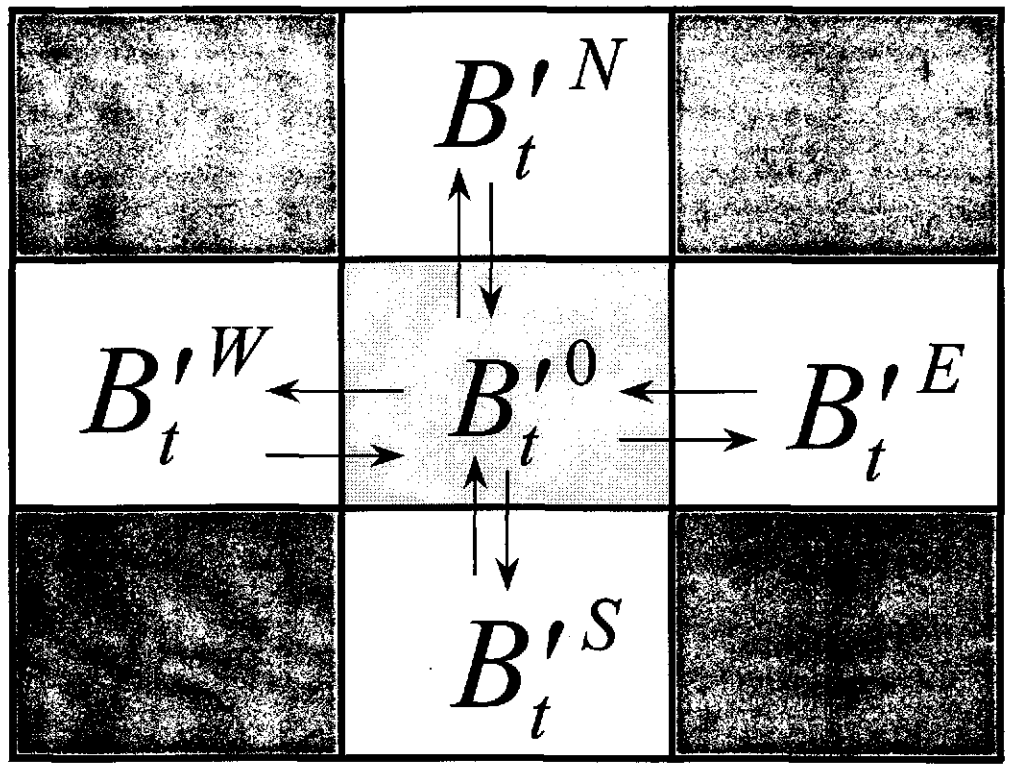

Figure 7.1 Net Inflow from Adjacent Areas

End of Period t ⟶ Begin of Period $(t+1)$

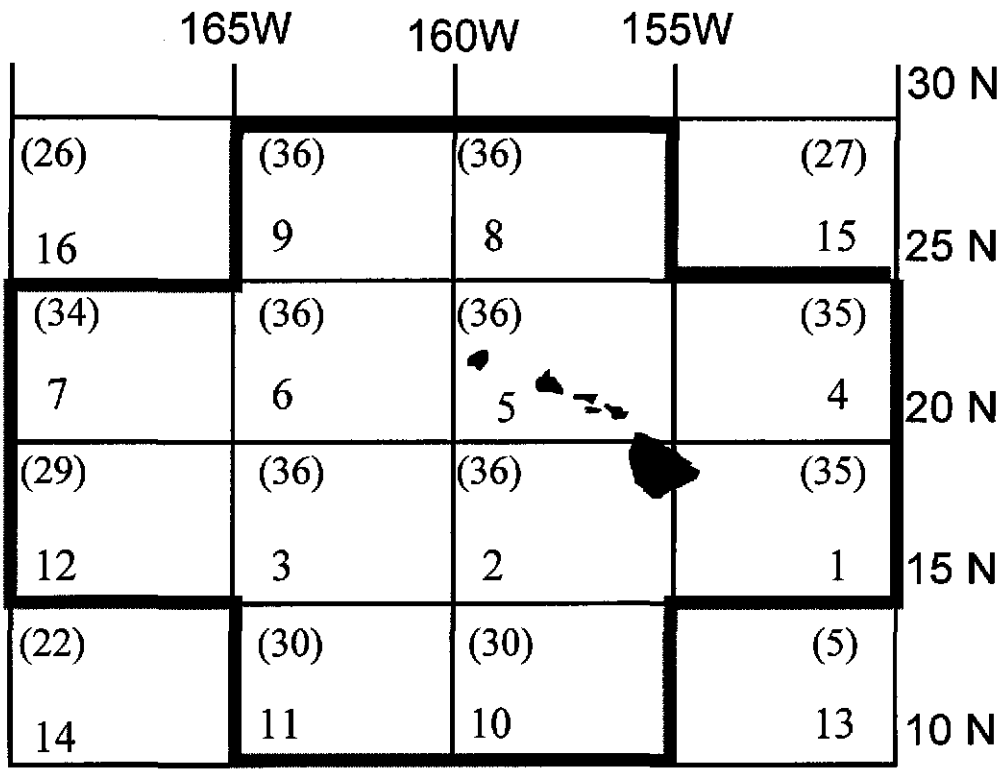

Figure 7.2 Five-degree Square Areas Used to Estimate Fish Movement, with the Corresponding Area code and the Number of Observations, 1995-97

Area Code

1: 15N150W, 2: 15N155W, 3: 15N160W,

4: 20N150W, 5: 20N155W, 6: 20N160W, 7: 20N165W

8: 25N155W, 9: 25N160W,

10: 10N155W, 11: 10N160W, 12: 15N165W

13: 10N150W, 14: 10N165W, 15: 25N150W, 16: 25N165W

Note: Four areas (codes = 13-16) were not used at all. See Appendix 5 for details.

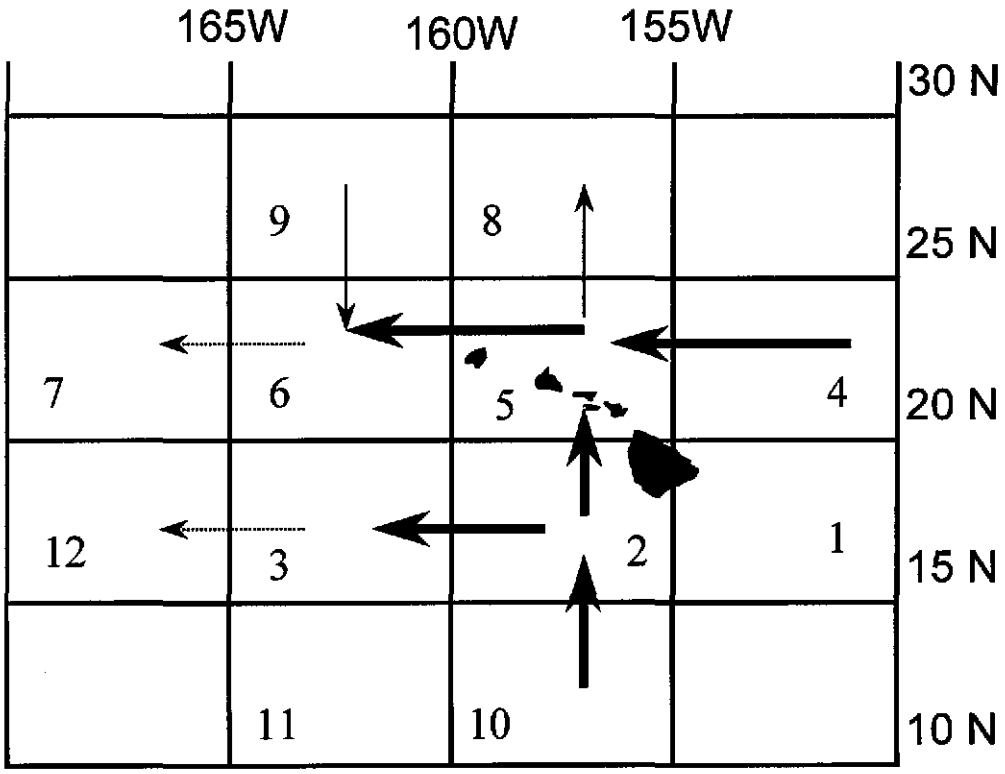

Figure 7.3 Estimated Movement Pattern of Bigeye Tuna

Area Code

1: 15N150W, 2: 15N155W, 3: 15N160W,

4: 20N150W, 5: 20N155W, 6: 20N160W, 7: 20N165W

8: 25N155W, 9: 25N160W,

10: 10N155W, 11: 10N160W, 12: 15N165W

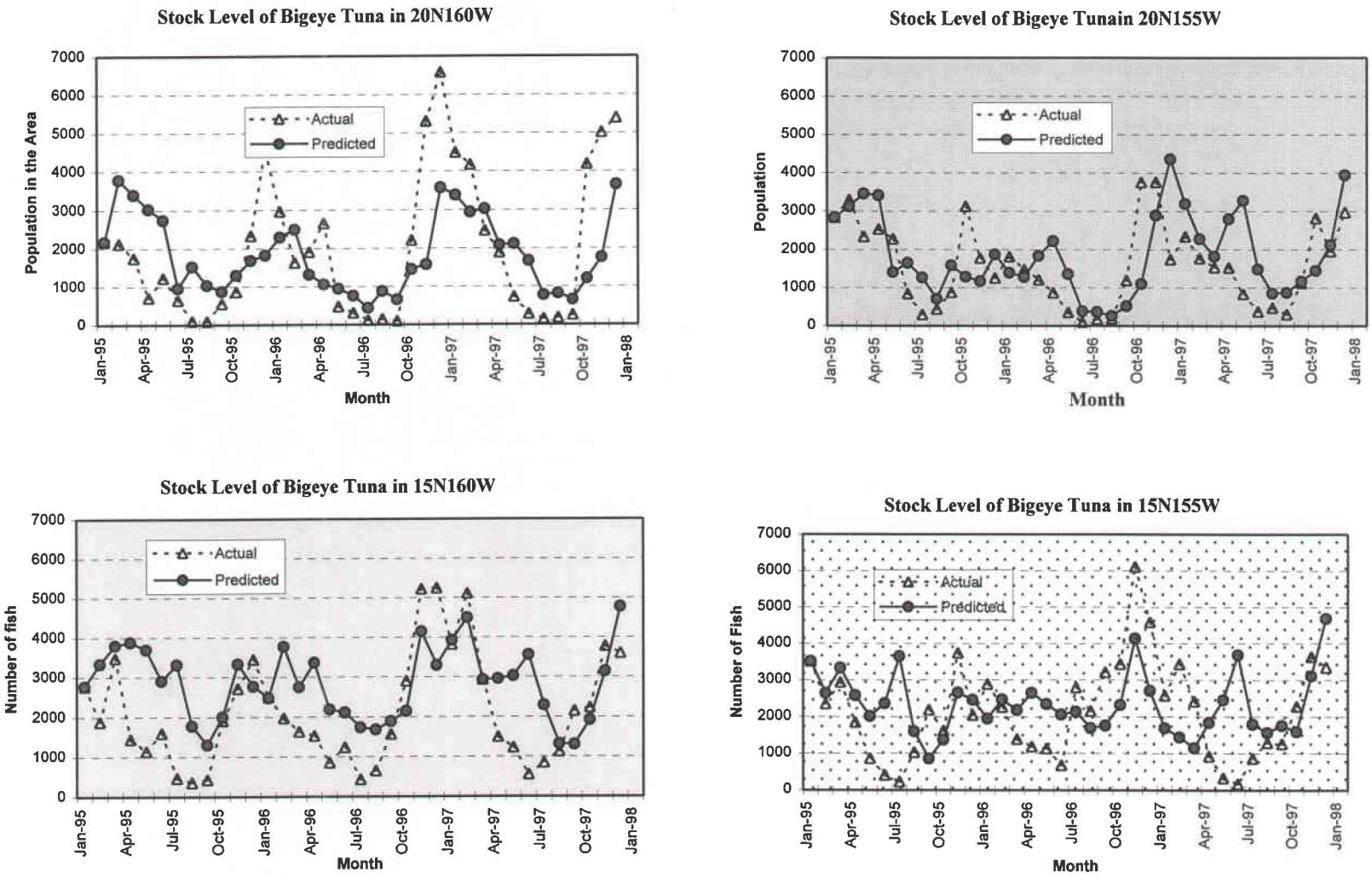

Figure 7.4 Changes in Bigeye Tuna (BE) Stock Level: Actual vs.Predicted by BE Movement Equation

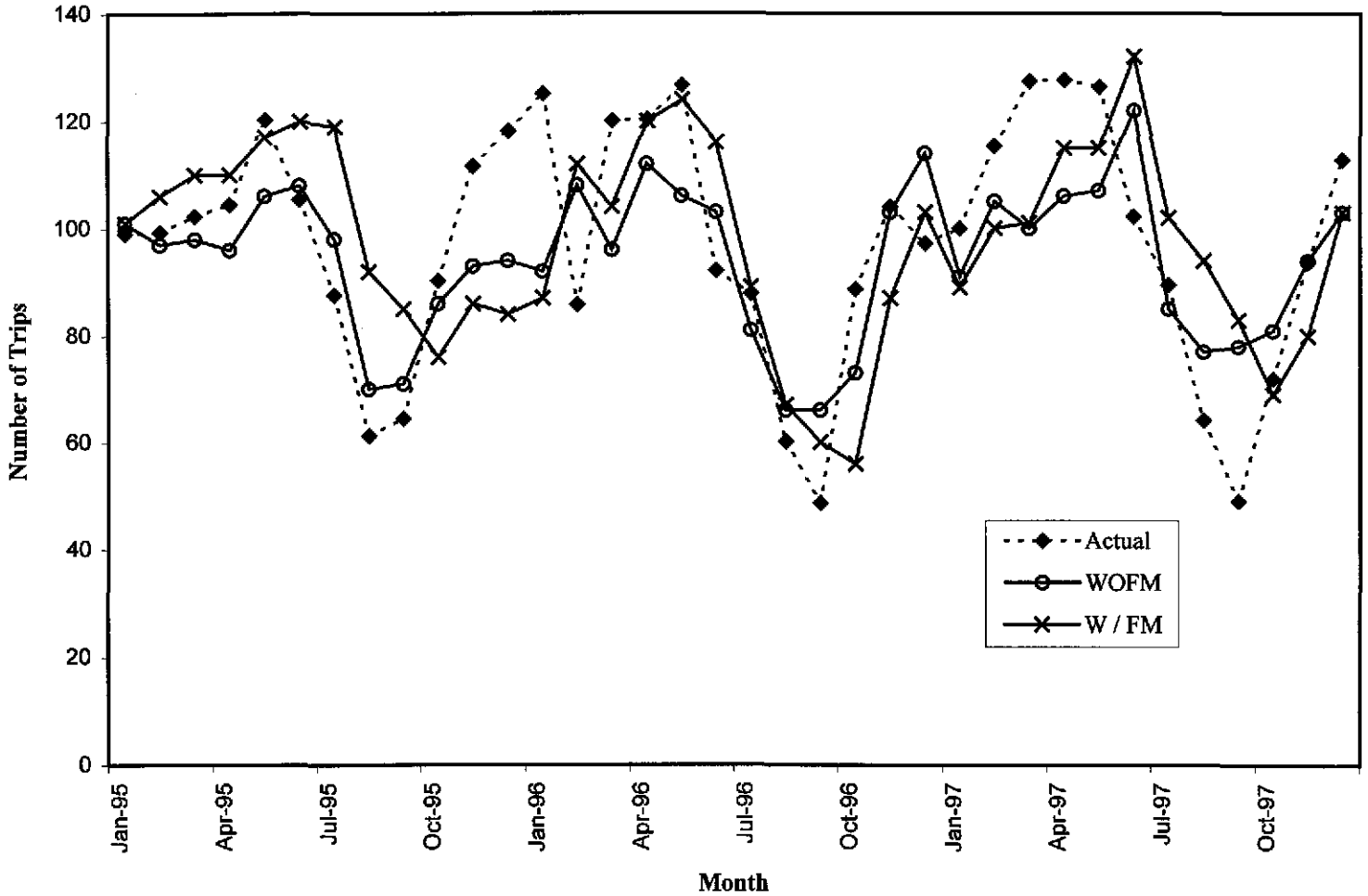

Figure 7.5 Monthly Allocation of Fishing Trips: Actual and Simulated Without and With Fish Movement

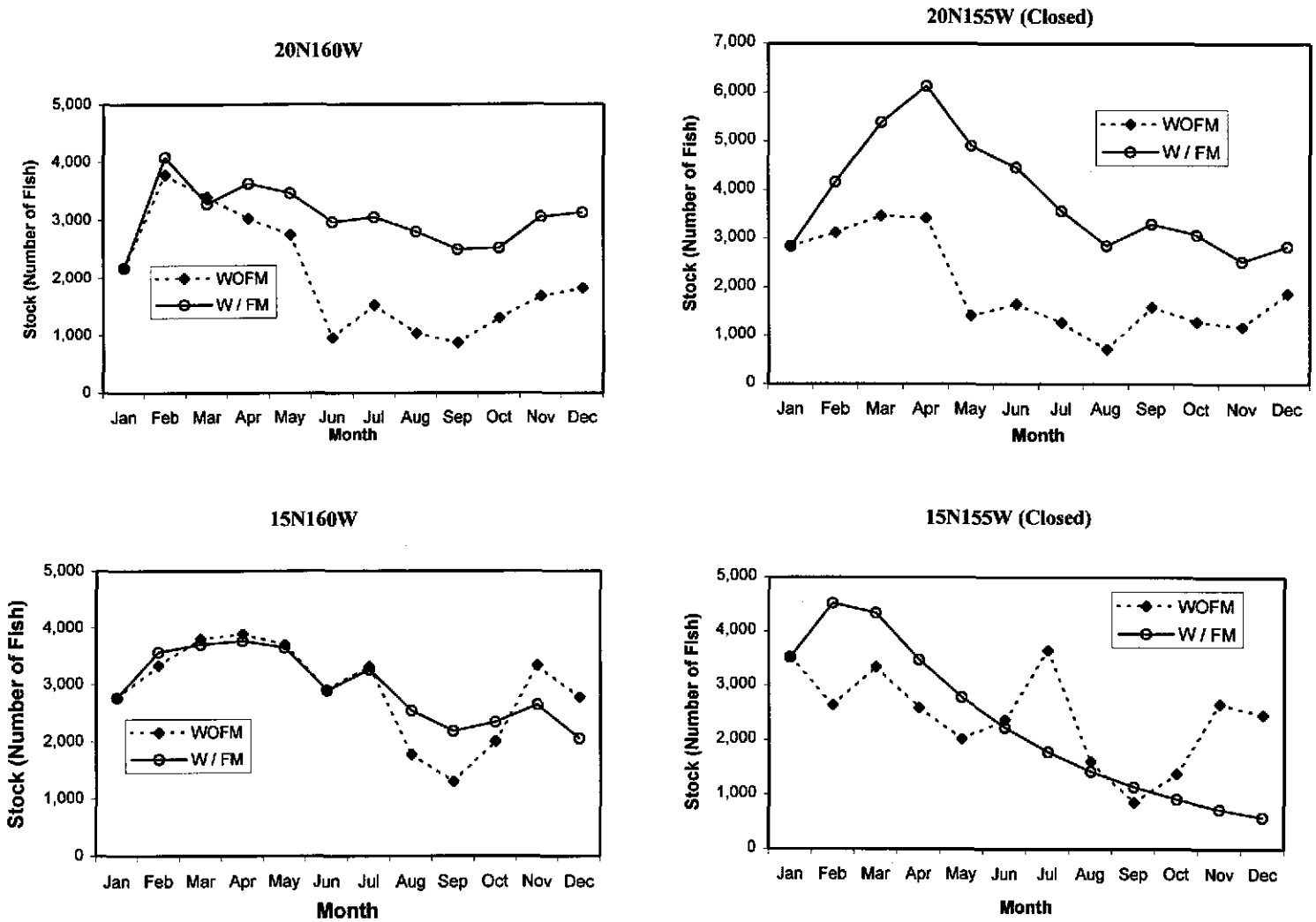

Figure 7.6 Changes in Bigeye Stock Level When the MHI region (*15N155W* and *20N155W*) is Closed: With and Without Movement of Bigeye Tuna

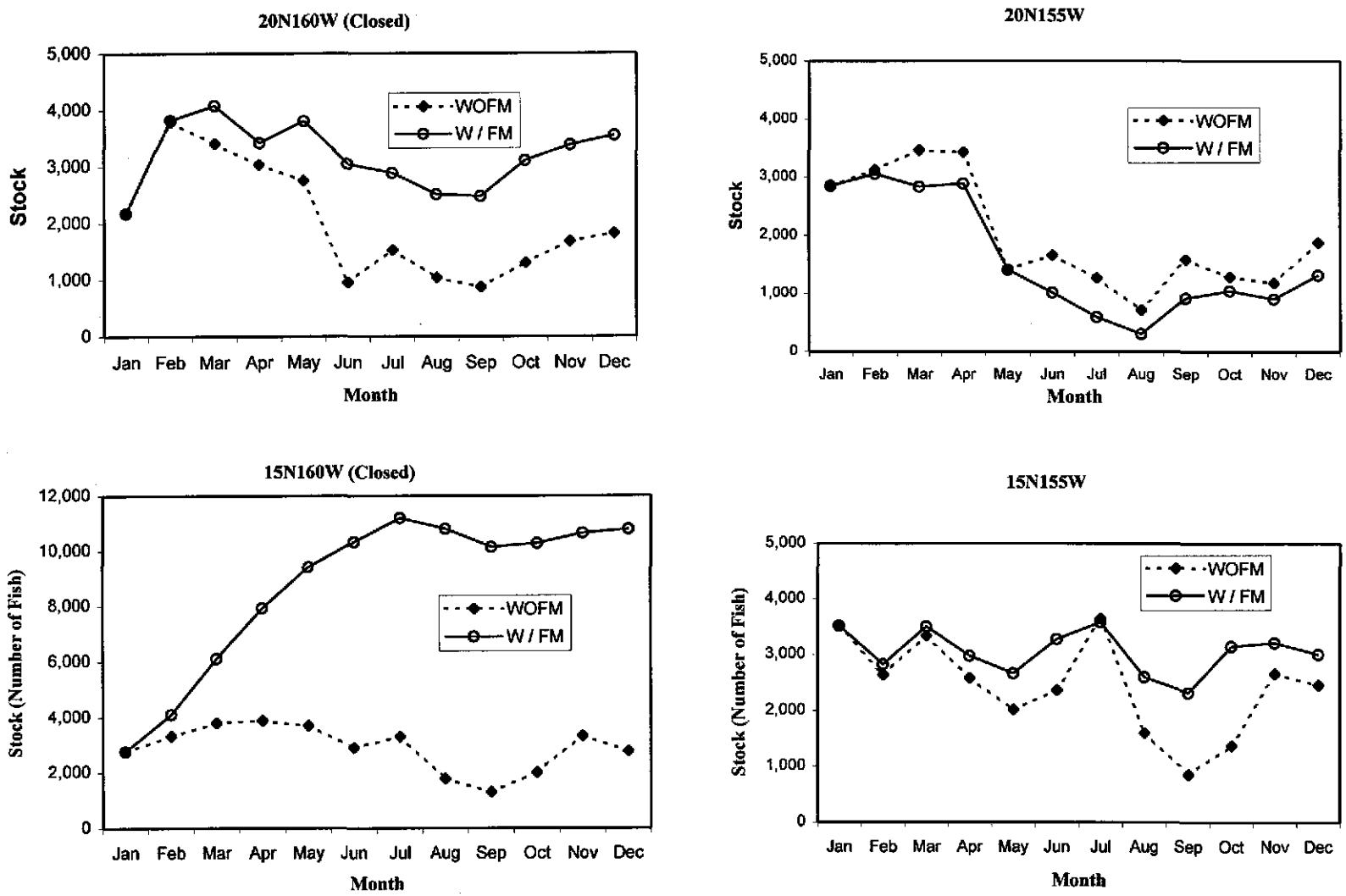

Figure 7.7 Changes in Bigeye Stock Level When the West HI region (*15N160W* and *20N160W*) is Closed: With and Without Movement of Bigeye Tuna

CHAPTER 8
CONCLUSIONS AND POLICY IMPLICATIONS

8.1 Summary and Conclusion

This study has developed a spatial economic fishery model, and applied it to the Hawaii longline fishery. The model includes: (i) heterogeneously distributed stocks of multiple species, (ii) movement of fish stocks, (iii) heterogeneous travel costs that are a function of the distance from port to fishing location, and (iv) optimization to determine both the location of each fishing trip, with space divided into 5° square grid, and the primary target of each fishing set.

The model is unique for two reasons. First, the fishery is modeled from the fishermen's viewpoint. While the crew's labor is regarded as an input in the derived demand for labor (DDL), labor supply (LS) function represents the fishermen's utility-maximizing level of labor supply, based on their tradeoff between offshore days (labor) and onshore days (leisure) per period. Since this is a short-run model and most of the fisheries are regulated to some degree (i.e., at least the number of vessel permits is controlled), the LS curve is not expected to be horizontal (i.e., constant wage), but upward-sloping or possibly backward-bending at higher wages. Moreover, a change in fish prices, fish stocks, or regulations is represented by a shift in the DDL curve, while the LS curve is constant over time, assuming the number of vessels and fishermen's preferences are constant. The optimal allocation of fishing trips over space is determined by setting DDL equal to LS.

The impacts of various regulatory policies on vessel's behavior in terms of choices of fishing location and primary target for each set, the ex-vessel revenue, costs, and fleet profit for the fishing industry, and the stocks of major species are assessed, using this model. The following four policy simulations are conducted (without incorporating fish movement): (i) closure of near-shore areas to reduce gear conflicts, (ii) closure of the northern sea to conserve sea turtles, (iii) prohibiting swordfish sets, and (iv) revenue taxation to reduce fishing effort. While the closure of near-shore areas leads to fewer trips

of longer duration, the northern sea closure to protect sea turtles leads to a larger number of lower-duration trips. While it significantly reduces swordfish catch, the latter policy significantly increases fishing pressure in near-shore areas, and hence potentially has a negative impact on conservation of near-shore species, which might also affect the harvests by other boats.

The economic impact of another sea turtle conservation policy, prohibiting swordfish sets, on the industry could be more severe in terms of the annual fleet profit than a northern sea closure. This finding is contrary to those common beliefs that the prohibition of swordfish sets is less restrictive than a northern sea closure (Masuoka, 2001). Besides, the secondary effect of the former on some species may be greater than the latter since the catches of bigeye tuna, albacore, and striped marlin would increase more by the former policy. A revenue tax policy was not found to be an effective method to reduce fishing sets or catches because the LS function is not very responsive to a wage change, although this tax policy tends to discourage boats from taking distant trips and targeting swordfish.

Second, this economic model is unique because it incorporates fish movement (FM). The initial stocks in the following period are computed from the current-period residual stocks, using the FM functions. Thus, two consecutive periods are dynamically linked through fish stocks. A closure policy may increase the number of fish moved from the closed area to open neighboring areas, and hence make fish more abundant in the open areas. This change in fish stocks is represented by a shift-up of the DDL curve.

Theoretical analysis suggests the above FM effect could be significant. A significant portion of fishermen's income lost by a closure policy, which is estimated by the model without FM ("WOFM" model), could be offset with the FM effect. The FM effect also depends on the FM profile; it would be more significant if (i) the closed area(s) is a "source" in terms of the direction of fish stock movement, and (ii) FM is highly "density-dependent". An area closure may increase the total catch in an extreme situation. Results from the application of the model to the Hawaii longline fishery indicate that about a half

of fishermen income losses are recovered by the FM effect if two "source" areas (i.e., the MHI region) are closed, while less than 10% of fishermen income losses are recovered if two "sink" areas (i.e., the West HI region) are closed.

Thus, the fishermen income losses from a closure policy may be overstated if the following two factors were ignored:

- "Area substitution" effect, where fishing trips originally allocated to the closed area are relocated to other open areas, and
- "Fish movement" effect, where fish movement from the closed area to its neighboring, open areas increases.

Pressure on unprotected marine species outside the closed area also increases by the "area substitution" effect. This additional impact associated with an area closure might alter the marine ecosystem. It is imperative that an economic model for the pelagic fishery includes the above two factors to more accurately estimate the impacts of a regulatory policy. Otherwise, management that ensures marine species being conserved and at the same time prevents the fishery industry from declining cannot optimally be achieved.

8.2 Limitations and Future Research

This study has made a significant contribution to the literature since there are very few spatial models that estimate the impacts of various regulatory policies on the fishery industry and fish stocks. This spatial economic model is much more complex in terms of various aspects than other conventional economic fishery models. However, it could be improved in several different ways to make it more realistic.

Homogeneity vs. Heterogeneity in Vessels

The assumption of a homogeneous fleet is limiting. According to the NMFS logbook data, all fishing trips and sets are conventionally categorized into three types: tuna, mixed, and swordfish. Longline vessels are also often categorized by primary target and size. However, as discussed in Chapter 4, the definition of a "mixed" boat is ambiguous

since some "mixed" boats are likely to target none or species other than bigeye tuna or swordfish, while others switch target species within or between trips (Hamilton, Curtis, and Travis, 1996).

Furthermore, boats also differ from each other in terms of other aspects, such as equipment and ethnicity of their owners and crews, which might be associated with management style and fishing strategy. In a sense, every boat may be unique. Thus, there may be many ways to categorize the Hawaii longliners depending on the research objective(s). If the Hawaii-based longline vessels are divided into two or more mutually exclusive groups, the LS function, as well as other parameters (e.g., catchability coefficients for each species and set type, daily operating costs), may need to be estimated for each.

Multiple Fleets

One of the major criticisms of the current regulations to protect sea turtles from incidental catch by longline sets is that "foreign (non-domestic)" fleets – including US vessels from the US West Coast, Alaska, and American Samoa – continue to fish in Hawaiian waters outside the US EEZ without restrictions or regulations to protect sea turtles. If this continues, protecting sea turtles from their incidental interaction with longline gears may not be effective. Thus, the current model requires an extension to heterogeneous longline fleets that belong to multiple ports in order to incorporate "foreign" fleets. The model can also be extended to account for interactions with other gear types (*e.g.*, handline and troll). For example, a moratorium on distant shore fishing will increase inshore fishing by longline boats and may increase incidences of gear conflict.[1]

Relaxation of Perfect knowledge and Competitive Equilibrium

This study assumes that competitive equilibrium occurs in each area: i.e., given a wage level, trips are allocated to each area until the ex-vessel revenue per trip equals the trip

[1] Pan et al. (1999) incorporate multiple gear types, including three groups of longline vessels, which are divided by vessel's length, although the focus of their model is different from the model in this study.

costs to that area. Strictly speaking, there is a two-stage competition in this model. The first stage is the whole industry level and the second stage is a fishing area level. Since this is a short-run model, no "entry-exit" is assumed at the first stage, and hence the LS curve is not horizontal. On the other hand, "entry-exit" at the second stage is free: i.e., about 110 active boats theoretically have no restrictions to enter a fishing area. Even a boat can fish in the same area twice per period. This indicates that the area-base competition can be considered approximately "perfect", rather than "imperfect" (e.g., monopoly, oligopoly). Thus, the assumption of competitive equilibrium in each area does not conflict with the short-run assumption.

Due to strict regulations to protect sea turtles (see Appendix 1), some longline vessels may leave Hawaii, resulting in a decrease in the number of vessels. This might give incentives to vessel-owners to cooperate each other. Then each vessel might belong to a handful of groups, where the vessels are operated by a single owner or a few cooperative owners. Such a situation of the industry is likely to be under imperfect competition. Thus, the assumption of competitive equilibrium should be relaxed. Moreover, the assumption that fishermen have perfect knowledge about fish stocks including their movement across areas and prices can also be relaxed. Game theory could be applied to model an imperfect competition under incomplete information.

Improved Estimation of Fish Movement (FM)

An improvement is needed in estimating FM. Oceanographic factors (e.g., SST) or parameters that display seasonal variations could be incorporated into the model. Either method requires longer periods of data to increase the degrees of freedom. A more advanced statistical method that is more robust for a small sample size and missing observations may be considered, such as a generalized additive model (e.g., Walsh and Kleiber, 2001). Alternatively, the extended model may be able to directly use outside information about FM in the near future since many research projects related to movement of pelagic species in the Hawaiian water are ongoing. Since many fishery

biologists incorporate age, size, and sex of fish or prey-predator relationship, the spatial model may need to incorporate these biological aspects.

Limitations Stemming from the Definition of Fishing Areas and Set Types

Several limitations are associated with the definition of areas in this study. More precise resolution than a 5° square grid would probably benefit the model to yield more accurate stock sizes or CPUE estimates in each area. However, access to such a data set (e.g., where catch and effort data summarized by 1° square and month) is restricted, and some assumptions used in this study, such as "a single fishing area per trip", may not hold if such a precise data set is used. Although Curtis (1999) models multiple fishing areas per trip, significant complexity is added in the algorithm. Thus, the tradeoff between the current definition of fishing areas and a more precise resolution, such as a 1° square grid, should be considered. In addition, the definition of a 5° square grid is deemed appropriate if the model is extended to incorporate foreign vessels because of the size of the fishery and data availability.

According to the first court ruling, the northern sea areas above 28° N, instead of 30° N, were closed. The current model cannot simulate the same area closures that are imposed on the Hawaii-based longline fishery, although the average impact of two area closures – one is a closure of the areas above 25° N latitude, and the other is to close the areas above 30° N latitude – could be used as an approximation. Closure of near-shore may also depend on the distance from the Hawaii islands (see Pan et al. 1999), implying that the shape of a closed area is likely to be a circle, rather than a square.

One should also note that the definition of set type (see Chapter 4) used in this study is different from the one recorded in the NMFS logbook. The captain (or lead fisherman) ordinarily designate the trip and each set as tuna, swordfish, or mixed. If the captain does not provide this designation, the NMFS Honolulu Laboratory personnel assign a classification on the basis of operational parameters, including previous history of trip types for that particular vessel (Ito and Machado, 2001). He, Bigelow, and Boggs' (1997)

cluster analysis suggest that the longline sets are divided into two (targeting swordfish or tunas) or five groups, supporting a viewpoint that protecting sea turtles from incidental catch by longline sets should focus on the depth of longline sets. The judge's ruling on March 30, 2001 has set the minimum depth of longlines to be 328 feet, while the depth of a standard swordfish set is believed to range from 70 to 100 feet (Masuoka, 2001). The depth is usually determined by the number of hooks between floats, but it can be significantly influenced by currents (Kleiber, 2001). The policy simulation in Chapter 6 for prohibiting all swordfish sets does not account for the difference in definition, cheating, or possible new types of fishing sets where the longline can be set around the minimum depth.

Limitation Stemming from Old Cost Data for the Hawaii-based Longline Vessels

Lastly, while the price and catch data for 1995-97 are available, the cost data for the Hawaii-based longline vessels is for 1993. This asymmetry could introduce errors in results in this study, although it is implausible that the cost structure may have changed significantly in two years. As described in Chapter 1, the Hawaii longline fishery has been dramatically changing in terms of size and regulatory requirements. Updated vessel information is desirable, although it is costly to collect and produce new cost-earnings data. This limitation could be serious if the model is used to simulate recent years such as 2001-2002.

Fishery economists have started to closely examine spatial heterogeneity in terms of fish stocks and operating costs. Fishery models may need to be further extended in both biological and economic aspects to produce useful impact assessments of proposed regulatory policies. Despite the limitations described above, including the fact that the empirical results (in particular, those by the model with FM) are indicative rather than definitive, this study has made a significant contribution in filling a gap between economics and other disciplines in order to improve marine resource management.

APPENDIX 1
LITIGATION AND COURT ACTIONS (IMPLEMENTED BY NMFS EMERGENCY REGULATIONS) DURING 1999-2001: ABBREVIATED SUMMARY
(Source: NMFS Honolulu Laboratory)

2/24/1999 The Center for Marine Conservation and Turtle Island Restoration Network, represented by the Earth Justice Legal Defense Fund, sue NMFS in Federal district court in Hawaii alleging inadequate protection for sea turtles against interactions with the Hawaii longline fishery and inadequate preparation of environmental impact documents. [Court reference: Civ No. 99-00152 DAE]

*12/23/1999[1] Effective this date, the Federal district court in Hawaii closed an area of the North Pacific to Hawaii-based longline vessels (now effectively known as Area A -- see Figure A1.1) [Court order of 11/25/1999]

4/17/2000 NMFS issues its draft Environmental Assessment for the conduct of the pelagic fisheries of the western Pacific region. It was approved (FONSI) on 8/22/2000.

4/27/2000 NMFS issues emergency rule implementing dip net and line clipper requirements.

5/25/2000 Earth Justice Legal Defense Fund, representing the Turtle Island Restoration Network and the Center for Biological Diversity, informed the Department of Commerce of their intention to sue within 60 days concerning the short-tailed albatross and the Hawaii longline fishery.

*6/23/2000 (as modified on 6/26/2000) The Federal court revises its 11/25/1999 order and closes a broader area in the North Pacific [revising the boundaries of Areas A] to Hawaii-based longline fishing, sets restrictions on longline fishing in those areas, and requires extensive observer coverage of longline fishing operations. The restrictions are to be kept in place until the completion of an Environmental Impact Statement (EIS) on the operation of the central and western Pacific pelagic fishery. The EIS is to be completed by April 1, 2001.

*7/21/2000 The Federal Court modifies its previous order to specify three operational areas for Hawaii-based longline fishing. No fishing is allowed in Area A; a restricted number of longline sets is allowed in Area B but only with 100% observer coverage; swordfish-style longline fishing in Area C is precluded (only tuna-style fishing is allowed); Areas B and C are closed from March 15, 2001 until May 31, 2001 (or until or if the closure is lifted by the Judge with the completion of the EIS) – see Figure A1.2 for definition of areas. The Order was

[1] The asterisks indicate the most significant regulations likely to cause operational changes.

effective 8/10/2000 and implemented 8/25/2000 by NMFS emergency regulation. That regulation was modified 11/3/2000 and 12/4/2000.

10/6/2000 The University of Hawaii's Joint Institute for Marine and Atmospheric Research (JIMAR) issues a contract to develop the Environmental Impact Statement (EIS) for the central and western Pacific pelagic fishery. Its expected date for public review is within the first two weeks of December 2000.

____ Endangered Species Act (ESA) biological opinion is issued by NMFS on the operation of the California drift net and longline fishery. A parallel biological opinion is being prepared by NMFS for the Hawaii longline fishery.

3/15/2001 Hawaii-based domestic longline fishery closed by Federal court order pending completion of EIS.

3/30/2001 Federal district court accepts NMFS' "preferred alternative" prohibiting shallow-set targeting (swordfish target sets) and closing an area south of Hawaii (15-0 North, 145-180W) for April and May. See Figure A1.3 and Masuoka (2001).

3/31/2001 NMFS issues its final EIS and ESA biological opinion on the Hawaii longline fishery and the fishery reopens under the "preferred alternative".

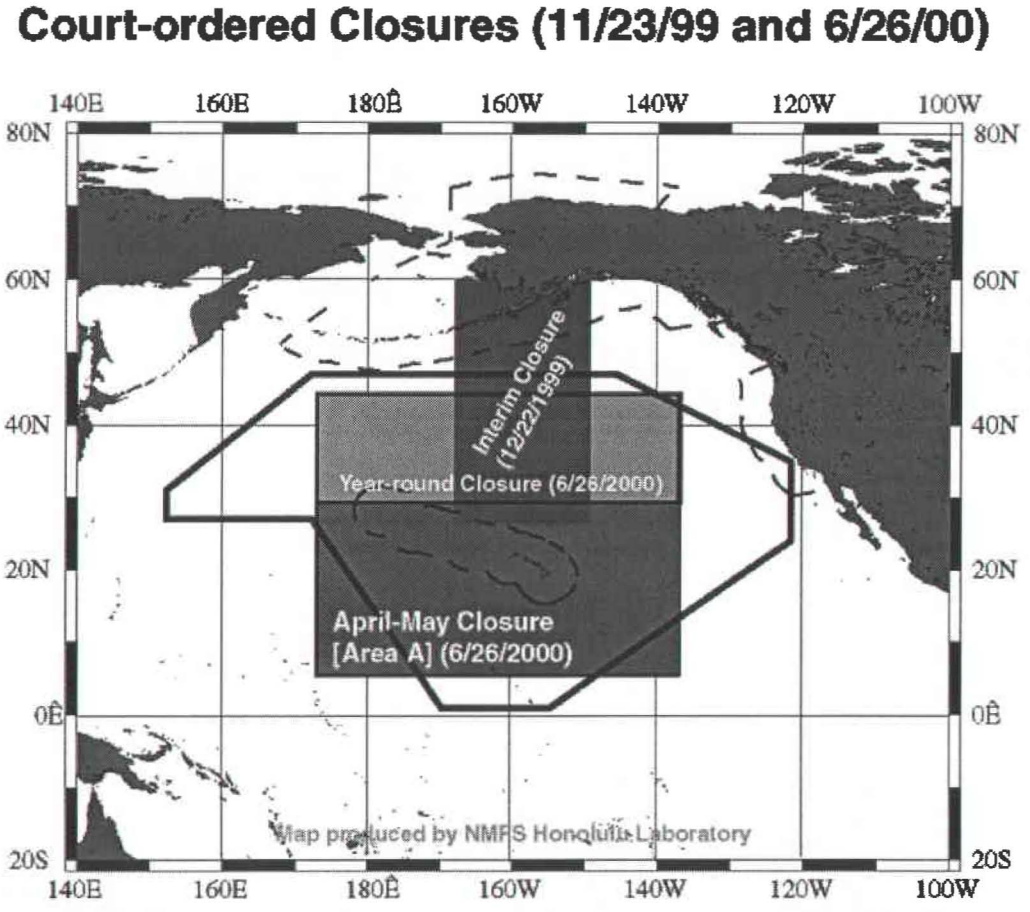

Figure A1.1 History for the Court-ordered Closure (Part 1)
(Source: Honolulu Laboratory, NMFS)

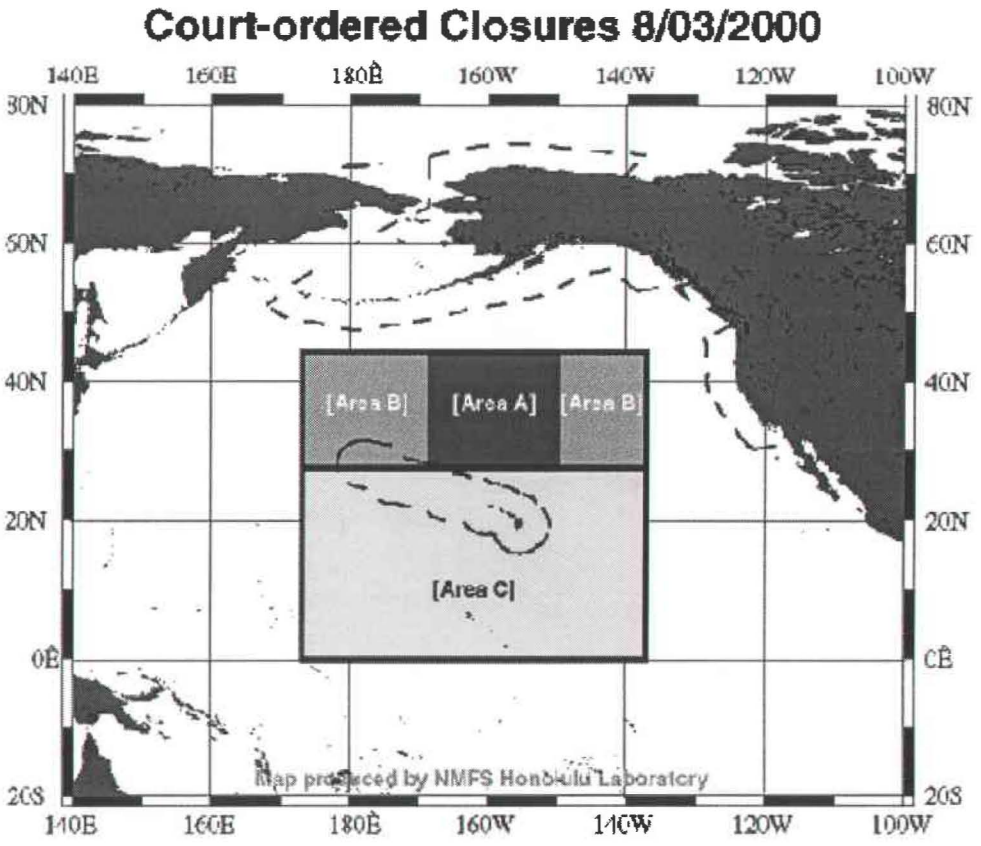

Figure A1.2 History for the Court-ordered Closure (Part 2)
(Source: Honolulu Laboratory, NMFS)

Area A: 44 North - 28 North, 168 West - 150 West
Area B: 44 North - 28 North, 173 East - 168 West and 150 West - 137 West
Area C: 28 North - Equator (0 North), 173 East - 137 West

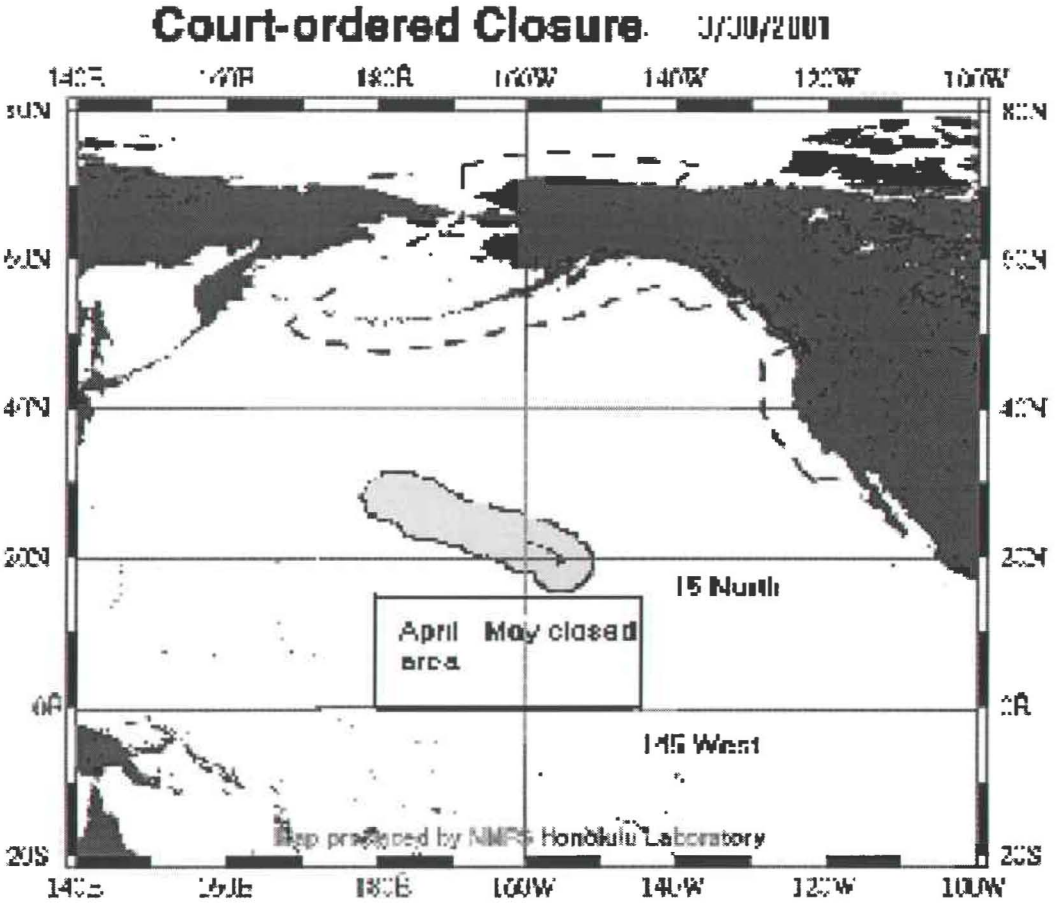

Figure A1.3 History for the Court-ordered Closure (Part 3)
(Source: Honolulu Laboratory, NMFS)

APPENDIX 2

DERIVING VARIABLE COST EQUATION (4.3) FROM EQUATION (2.5)

Since the number of swordfish sets (FD_{k2}) out of 10 sets per trip is a choice variable, the variable costs for a trip to area k (VC_k) in (2.5) can be modified as

$$\begin{aligned} VC_k &= \left[a_1 \cdot (10 - FD_{k2}) + a_2 \cdot FD_{k2}\right] + b \cdot TD_k \\ &= \left[a_1 + (a_2 - a_1) \cdot \frac{FD_{k2}}{10}\right] \times 10 + b \cdot TD_k \end{aligned} \qquad \text{(A2.1)}$$

As indicated in Table 4.2, the daily costs for a swordfish set (a_2 = \$1765.27) are almost double those as for a tuna set (a_1 = \$854.28), due to more expensive bait, lightsticks, and miscellaneous gear in the former. Thus, substituting the estimated values of the parameters (a_1, a_2, and b) into the above equation and expressing the proportion of swordfish sets in the total expended in area k as $r_{sw,k} = FD_{k2}/10$, variable costs can be computed as equation (4.3):

$$VC_k = (854.28 + 910.99 \times r_{sw,k}) \times 10 + 374.50 \times TD_k$$

This implies that substituting a swordfish set for a tuna set would increase the variable costs for a trip by \$910.99, while this substitution increases the catches of certain species (particularly swordfish) and hence might increase the trip revenue. The proportion of swordfish sets in the total, $r_{sw,k}$, in the above formula is also useful to assess the choice of set types in each location as well as overall (see Table 6.8).

APPENDIX 3

ESTIMATING CATCHABILITY RATIOS BASED ON GROUPED DATA

As explained in Chapter 4, catch and effort data from the NMFS logbook were aggregated into 5° square monthly strata. In statistics and econometrics textbooks, this type of aggregated data is often called "grouped data" (Kmenta, 1986, p. 366-373; Greene, 1993, p.277-279). Although set-level detailed data could be available from the original NMFS logbooks with certain restrictions (due to their confidentiality), aggregated data are consistently used throughout this study. This approach eases the burden of computation, and also allows the model to more flexibly incorporate the data for other fisheries, such as the non-domestic US longliners or foreign vessels that operate in the Hawaiian water, because aggregated data is more accessible than the original logbook data.

One of the major empirical issues is data availability to estimate the catchability ratio using equation (5.8). Information from both types of sets within each group is needed to compute the CPUE ratio. However, such grouped data are quite limited. Either tuna or swordfish sets are often dominant in grouped data (particular area and month), while the number of sets with the other type is small (e.g., less than 10; see Table A3.1). For example, only tuna sets are conducted south of 20° N in the winter and spring, while only swordfish sets are conducted north of 25° N in the first quarter. Moreover, even though both types of sets are conducted in the same grouped data, the number of observations in each group, which varies across groups and may be small (Table A3.1), should be taken into account when the average of group-level CPUE ratios in equation (5.8) is computed. That is, each group-level CPUE should be weighted by the number of observations in each group.

This appendix explains the detailed procedure to estimate the catchability ratio, based on this aggregated data set. Specifically this appendix first theoretically explains why the weighted geometric mean of the CPUE ratio should be used; and next describes a few operational concerns and treatments, followed by the results.

A3.1 Weighted Geometric Mean

First, CPUE in each fishing set could be an observation for stock assessment, though such set level data were not used in this study. Suppose a total of N observations can be divided into G groups. Each group corresponds to a 5° square monthly stratum. Let n_1 be the number of observations in the first group, n_2 the number of the second group, and so on. Then the following relationship must hold:

$$\sum_{g=1}^{G} n_g = N \qquad \text{(A3.1)}$$

where the gth group represents a specific area and time period and n_g is the number of observations in the gth group. To simplify the procedure, suppose each observation consists of a pair of sets; one is using set type s (e.g., targeting tuna) and the other is using set type q (e.g., targeting swordfish). This restriction is relaxed later in this appendix. It is also assumed that both sets are conducted in the same location and time, but do not affect each other. Since n_g pairs of sets are conducted in the gth group, denote the jth observation in the gth group by the double subscript jg (following notations in Kmenta (1986)). Then equation (5.8) can be modified as

$$\frac{CPUE_{i,q,jg}}{CPUE_{i,s,jg}} = \left(\frac{\gamma_{i,q}}{\gamma_{i,s}}\right) \cdot Exp\left(\varepsilon_{jg}\right) \qquad \text{(A3.2)}$$

where $CPUE_{i,s,jg}$ is catch-per-unit-effort of species i with set type s, and ε_{jg} is the disturbance for the jth observation in the gth group. Subscripts s and q denote two different set types. Since the data for both sides of equation (5.8) are ratios, the geometric mean is the appropriate measure of central tendency and hence an exponential form of disturbance is used here. Furthermore, it is assumed that $E(\varepsilon_{jg}) = 0$ and $Var(\varepsilon_{jg}) = \sigma^2$, where the variance σ^2 is assumed to be constant. While the catchability ratio ($\gamma_{i,q} / \gamma_{i,s}$) in the right-hand side of the above equation is constant, the $CPUE$ ratio in the left-hand side

varies. Then, by taking the natural logarithms on both sides of the above equation, it can be rewritten as

$$\ln\left(CPUE_{i,q,jg}\right) - \ln\left(CPUE_{i,s,jg}\right) = \ln\left(\gamma_{i,q}/\gamma_{i,s}\right) + \varepsilon_{jg}. \qquad \text{(A3.3a)}$$

To simplify the notation, let θ, X_{jg} and Y_{jg} be denoted as:

$\theta = \ln\left(\gamma_{i,q}/\gamma_{i,s}\right)$ is the logarithm of the catchability ratio and a constant,

$X_{jg} = \ln\left(CPUE_{i,s,jg}\right)$ is the logarithm of *CPUE* for species i with set type s,

$Y_{jg} = \ln\left(CPUE_{i,q,jg}\right)$ is the logarithm of *CPUE* for species i with set type q, and

$Z_{jg} = Y_{jg} - X_{jg}$.

Then equation (A3.3a) can be simplified as

$$Y_{jg} - X_{jg} = \theta + \varepsilon_{jg} \qquad \text{(A3.3b)}$$

and furthermore

$$Z_{jg} = \theta + \varepsilon_{jg}. \qquad \text{(A3.3c)}$$

Summing up for all observations of all groups, equation (A3.3c) is transformed as

$$\sum_{g=1}^{G}\sum_{j=1}^{n_g} Z_{jg} = \theta N + \sum_{g=1}^{G}\sum_{j=1}^{n_g} \varepsilon_{jg}$$

and

$$\theta = \frac{1}{N}\left(\sum_{g=1}^{G}\sum_{j=1}^{n_g} Z_{jg} - \sum_{g=1}^{G}\sum_{j=1}^{n_g} \varepsilon_{jg}\right). \qquad \text{(A3.4a)}$$

Since $E(\varepsilon_{jg}) = 0$, the expected value for the grand mean of disturbance also equals zero: $E\left(\sum_{g=1}^{G}\sum_{j=1}^{n} \varepsilon_{jg} \Big/ N\right) = 0$. Then the estimate of θ is the grand mean of Z_{jg}:

$$\hat{\theta} = \frac{1}{N}\sum_{g=1}^{G}\sum_{j=1}^{n_g} Z_{jg} \,. \qquad \text{(A3.4b)}$$

Now consider the situation where only the mean value of Z for each group is available, instead of being given all observations of Z_{jg}. Then θ can be estimated as follows:

$$\hat{\theta} = \frac{1}{N}\sum_{g=1}^{G}\left[n_g \left(\sum_{j=1}^{n_g} Z_{jg} \Big/ n_g \right) \right] = \frac{1}{N}\sum_{g=1}^{G}\left(n_g \, \bar{Z}_g \right) \qquad \text{(A3.5)}$$

where $\bar{Z}_g = \frac{1}{n_g}\sum_{j=1}^{n_g} Z_{jg}$; that is, the estimate of θ is the weighted average of the group means of Z[1]. Lastly, the catchability ratio is obtained as $(\gamma_{i,q} / \gamma_{i,s}) = \text{Exp}(\theta)$. In other words, the weighted geometric mean -- weighted by n_g -- of group-level CPUE ratios yields the estimate for catchability ratio $(\gamma_{i,q} / \gamma_{i,s})$[2].

A3.2 Operational Details to Process Problematic Data

There are a couple of concerns in the above procedure. The first concern is about computation of the group mean for *CPUE*. As shown in (A3.3c), Z_{jg} is the natural logarithm of a CPUE ratio in the jth observation of the gth group. Hence,

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[1] Alternatively, θ could be estimated by the weighted OLS procedure, which is commonly used to correct heteroscedastic disturbance, using the following transformed equation (Kmenta 1986, p. 367-372):

$$\bar{Y}_g \sqrt{n_g} = \theta \sqrt{n_g} + \beta_X \left(\bar{X}_g \sqrt{n_g} \right) + \bar{\varepsilon}_g \sqrt{n_g}$$

where the transformed disturbance $\left(\bar{\varepsilon}_g \sqrt{n_g} \right)$ is homoscedastic, and $E\left(\bar{\varepsilon}_g \sqrt{n_g} \right) = 0$ and $Var\left(\bar{\varepsilon}_g \sqrt{n_g} \right) = \sigma^2$. As indicated in equation (A3.3b), β_x should be restricted to 1. Although both equation (A3.5) and this weighted OLS procedure yield the same estimates, the former method requires much simpler operations.

[2] See Section A3.3 regarding the estimation of variance of Z.

$$\bar{Z}_g = \frac{1}{n_g}\sum_{j=1}^{n_g} Z_{jg} = \frac{1}{n_g}\sum_{j=1}^{n_g}\left(Y_{jg} - X_{jg}\right) = \bar{Y}_g - \bar{X}_g \qquad \text{(A3.6)}$$

where $\bar{X}_g = \frac{1}{n_g}\sum_{j=1}^{n_g} X_{jg}$ and $\bar{Y}_g = \frac{1}{n_g}\sum_{j=1}^{n_g} Y_{jg}$. The detailed formula for $\bar{X}_g$ is as follows:

$$\bar{X}_g = \frac{1}{n_g}\sum_{j=1}^{n_g} X_{jg} = \frac{1}{n_g}\sum_{j=1}^{n_g} \ln\left(CPUE_{i,s,jg}\right) = \ln\left[\prod_{j=1}^{n_g}\left(CPUE_{i,s,jg}\right)\right]^{1/n_g} \qquad \text{(A3.7)}$$

where C_{jg} and E_{jg} are catch and effort in jth observation (fishing set) of the gth group, and $CPUE_{jg} = C_{jg} / E_{jg}$. Equation (A3.7) expresses the logarithm of the geometric mean of CPUE ratios within the gth group. As mentioned before, the set-level catch and effort data (C_{jg} and E_{jg}) are not used here. Instead, only aggregated catch and effort data for each group are used, implying that formula (A3.7) cannot be computed. Therefore, instead of computing the geometric mean in equation (A3.7), the following formula was used as a proxy:

$$\left[\prod_{j=1}^{n_g}\left(CPUE_{i,s,jg}\right)\right]^{1/n_g} = \left[\prod_{j=1}^{n_g}\left(\frac{C_{i,s,jg}}{E_{s,jg}}\right)\right]^{1/n_g}$$

$$\xrightarrow{approximate} \frac{\sum_{j=1}^{n_g} C_{i,s,jg}}{\sum_{j=1}^{n_g} E_{s,jg}} = \frac{\sum_{j=1}^{n_g}\left(CPUE_{i,s,jg}\cdot E_{s,jg}\right)}{\sum_{j=1}^{n_g} E_{s,jg}} \qquad \text{(A3.8)}$$

where $\sum_{j=1}^{n_g} C_{i,s,jg}$ and $\sum_{j=1}^{n_g} E_{s,jg}$ are the aggregated catch and effort in the gth group, and available to this study. To simplifying notations, subscript i, and s are omitted in the rest of this section. Because $CPUE_{jg} = C_{jg} / E_{jg}$, it can be transformed that $C_{jg} = CPUE_{jg}\, E_{jg}$. Then equation (A3.8) implies that instead of computing the geometric mean of $CPUE$ in the gth group, the arithmetic mean of $CPUE$ weighted by effort E_{jg} is used as a proxy.

Furthermore, the amount of effort (number of hooks) used in the same type of fishing sets in the same area and month is quite similar across fishing sets, comparing with CPUE, which usually vary across fishing sets. If all amounts of effort per set are exactly the same ($E_{jg} = \bar{E}_g$) within the gth group, the right-hand side of equation (A3.8) could be simplified as:

$$\frac{\sum_{j=1}^{n_g}\left(CPUE_{jg} \cdot E_{jg}\right)}{\sum_{j=1}^{n_g} E_{jg}} \cong \frac{\bar{E}_g \sum_{j=1}^{n_g} CPUE_{jg}}{n_g \bar{E}_g} = \frac{\sum_{j=1}^{n_g} CPUE_{jg}}{n_g} \qquad \text{(A3.9)}$$

The right side of this equation is the arithmetic mean of CPUE (no longer weighted by effort E_{jg}) within the gth group, while the left side of equation (A3.8) is the geometric mean of CPUE with the same group data. It is known that the arithmetic mean is equal to or greater than the geometric mean, and is equal if $CPUE$ data are equal for all observations within the gth group (i.e., $CPUE_{jg} = CPUE_{lg}$ for all j and l where $j \neq l$). Thus, the following relationship is obtained:

$$\left[\prod_{j=1}^{n_g} CPUE_{jg}\right]^{1/n_g} \leq \frac{\sum_{j=1}^{n_g} CPUE_{jg}}{n_g} \cong \frac{\sum_{j=1}^{n_g}\left(CPUE_{jg} \cdot E_{jg}\right)}{\sum_{j=1}^{n_g} E_{jg}} = \frac{\sum_{j=1}^{n_g} C_{jg}}{\sum_{j=1}^{n_g} E_{jg}}. \qquad \text{(A3.10)}$$

Since the variation of CPUE within a group (in the same area and month) is expected to be much smaller than the variation among groups, the bias introduced by this approximation is expected to be trivial. The same approximation is applied to calculate $\bar{Y}_g$, and then Z van be computed as (A3.6).

Data Problem: Sample Data for Set Type q are not Paired with Those for Set Type s

The second concern is about sample size within a group, n_g. It is assumed in the previous section that each observation consisted of a pair of *CPUE* data (*i.e.*, $CPUE_{i,s,jg}$ and $CPUE_{i,q,jg}$) for simplicity. In reality, two distinct set types (e.g., tuna and swordfish sets) are independently conducted, and the number of fishing sets with type s ($n_{g,s}$) usually differs from the number of fishing sets with type q ($n_{g,q}$). Here the smaller of $n_{g,s}$ and $n_{g,q}$ was used for n_g in equations (A3.5) and (A3.6).

Eliminating Problematic Group Data: Missing Observations, Zero CPUE, and Outliers

The third concern is about the treatment of problematic group data. Several grouped data were eliminated for the following three reasons. First, if one set type (q or s in equation (A3.2)) never occurred in the gth group (e.g., only tuna sets are conducted and hence no information about swordfish sets is available: i.e., $n_g = 0$), *CPUE* for that set type cannot be computed. Thus, such group data need to be eliminated.

Next, grouped data with "zero CPUE" are also problematic since the logarithm of zero cannot be computed (see equation (A3.3a)).[3] Because most of the grouped data, where the aggregate catch is zero (and hence $CPUE = 0$), appeared in the grouped data with $n_g = 1$, those data are eliminated. Thus, the grouped data with $n_g \leq 1$ were discarded[4], and hence the sample size within each group must be equal to 2 or greater.

Moreover, if some group data with "zero CPUE" might still exist in spite of the above elimination, the following two treatments can be done; (a) to increase the minimum sample size of each group from 2, or (b) to replace the logarithm of "zero CPUE" with the minimum value of the logarithms of the group-level CPUE $\bar{X}_g = \ln\left(\overline{CPUE}_{i,s,g}\right)$[5] with the same set type among all G groups.

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[3] Later the author found this problem can be avoided by using ln (CPUE + 0.1), instead of ln (CPUE).

[4] To maintain the sample unbiased, all group data of which group sample size is zero or 1 should be eliminated, no matter one of the two set types (s or q) has zero CPUE or not.

[5] Group-level CPUE must not be zero. For example, if $\overline{CPUE}_{i,s,1} = 0$ for the first group ($g = 1$) and the minimum of $\overline{CPUE}_{i,s,g} > 0$ for all g is $\min\left(\overline{CPUE}_{i,s,g}\right)$, $\bar{X}_1 \xleftarrow{Set} \ln\left[\min\left(\overline{CPUE}_{i,s,g}\right)\right]$.

There is a tradeoff between the above two treatments. The former way (treatment (a)) loses more grouped data by raising a cut-off line (i.e., the minimum of n_g), while it can avoid manipulating the original data. Treatment (b) manipulates the original data, but it maintains the sample size and qualitatively makes sense since the fact of "no catch" indicates that fish are much less abundant and hence CPUE is very close to zero. Although no definite decision rule is available here, treatment (b) may be preferred to treatment (a) if more than 50% of the groups that would be eliminated by increasing the minimum of n_g by1 would have non-zero CPUE data only. For example, to measure the catchability ratio for striped marlin between tuna and mixed-A sets (see Table A3.1), all 32 groups should be omitted by increasing the minimum group sample size n_g from 2 to 3 (i.e., treatment (a)), if 16 or more groups include "zero CPUE" data for either tuna or mixed-A set. However, after the above elimination, if only 6 or less groups among the 13 groups with $n_g = 3$ include "zero CPUE" data, these 13 groups should be kept and treatment (b) should be applied to those groups with "zero CPUE" data.

Third, the outliers were detected and discarded using a method in Bluman, A.G. (2001). Compute the first and third quartiles (denoting Q_1 and Q_3, respectively) of $\overline{Z}_g$ and then compute the inter-quartiles range (IQR = Q_3 - Q_1). Grouped data would be identified as an outlier if the value of $\overline{Z}_g$ is smaller than Q_1 - 1.5 IQR or greater than Q_3 + 1.5 IQR. This method was used since it does not require the data to be normally distributed.

A3.3 Results

The same data set described in Section 5.2 (in Chapter 5) was used in order to maintain consistency in estimating the catchability coefficients: that is, the data set consists of 36 monthly data entries for the six areas (i.e., a total of 216 grouped data). As described in Chapter 5, all Hawaii longline sets are categorized into four set types, and the three types of comparisons were conducted to measure the catchability ratios (equation (5.8)): i.e.,(i) tuna versus swordfish set, (ii) tuna versus mixed-A, and (iii) mixed-B versus swordfish set -- were estimated for each species. Following the above procedure, the grouped data

with $n_g \leq 1$ were eliminated from the above data set. As shown in Table A3.1, about 50% of the groups were eliminated because the number of observations $n_g \leq 1$. The empirical model focuses only on tuna and swordfish sets since these two set types account for about 90% of the total sets, while the data for mixed-A and mixed-B sets are quite limited (only about 3% and 9%, respectively; see Table 4.1 in Chapter 4). Hence, the data for measuring catchability ratios between the tuna vs. mixed-A sets were only 91 out of 216 group data, which is the least among the three comparisons. On the other hand, 112 groups with $n_g \geq 2$ were available for the comparison between mixed-B and swordfish sets because both types of sets are similar, and then more chance that both types of sets are used in the same area and month, compared with the comparison tuna vs. swordfish sets.

Table A3.2 summarizes the estimated weighted mean and standard deviation of θ, catchability ratio and other information for each species and each comparison in the results. The numbers of outliers and groups with zero CPUE depend on species and type of comparison. Hence, the number of groups available to estimate θ varied, ranging from 21 to 108. For example, 107 and 108 groups were used to estimate θ for swordfish and bigeye, respectively, between mixed-B and swordfish sets since only 3 and 4 outliers were eliminated. Only 21 groups were used to estimate θ for swordfish (SW) between tuna vs. mixed-A sets because a tuna or mix-A set seldom catches SW, resulting in many group data with "zero CPUE", and hence the minimum of n_g is set to 8 to eliminate those "zero CPUE" data.

Estimating Variance of Z and Examining Catchability Ratio

Using a classical formula for ANOVA (analysis of variance), the sum of squares total (SST) of Z_{jg} is can be broken down as follows:

$$\text{SST} = \text{SSA} + \text{SSW} \qquad \text{(A3.11)}$$

where

$$\text{SST} = \sum_{g=1}^{G}\sum_{j=1}^{n_g}\left(Z_{jg}-\theta\right)^2 \text{ is the sum of squares total,}$$

$$\text{SSA} = \sum_{g=1}^{G} n_g\left(\overline{Z}_g-\theta\right)^2 \text{ is the sum of squares among groups, and}$$

$$\text{SSW} = \sum_{g=1}^{G}\sum_{j=1}^{n_g}\left(Z_{jg}-\overline{Z}_g\right)^2 \text{ is the sum of squares within groups.}$$

As mentioned before, only grouped data are used, and hence only SSA can be computed, while SSW cannot be obtained from the group data. Therefore, SSW is estimated from SSA as follows. As derived in equation (5.8) in Chapter 5, the CPUE ratio between two set types s and q for species i is assumed to be constant over space and time, implying that a null hypothesis H_0 below is true:

H_0: $\overline{Z}_1 = \overline{Z}_2 = ... = \overline{Z}_G = \theta$, and

H_1: H_0 is not true.

If H_0 is true, the following test statistic should be about 1 (i.e., F → 1):

$$F = \frac{SSA/(G-1)}{SSW/(N-G)} = \frac{SSA}{SSW} \bullet \frac{N-G}{G-1}. \qquad \text{(A3.12)}$$

Moreover, assuming H_0 cannot be rejected at the 1% significance level, the computed F statistic should be less than the critical value of $F_{0.01,G-1,N-G}$, (denoting F_c) resulting in the following relationship:

$$1 \le F \le F_c,$$

$$1 \le \frac{SSA}{SSW} \bullet \frac{N-G}{G-1} \le F_c,$$

$$SSW \le SSA\left(\frac{N-G}{G-1}\right) \le F_c \bullet SSW,$$

and hence $$SSA\left(\frac{N-G}{G-1}\right)\left(\frac{1}{F_c}\right) \le SSW \le SSA\left(\frac{N-G}{G-1}\right). \quad \text{(A3.13)}$$

Thus, a crude range of SSW could be estimated from SSA, the number of groups (G), and the total number of observations (N). Then the variance of Z_{jg} could be estimated as:

$$\hat{\sigma}^2 = \frac{SST}{N-1} = \frac{SSA+SSW}{N-1}. \quad \text{(A3.14)}$$

Since the purpose of estimating the variance is to show the evidence that the catchability differs depending on set type: i.e., to conduct a hypothesis test (H_0: $\theta = 0$ and H_1: $\theta \neq 0$) with H_0 being rejected. If H_0 is rejected using the upper boundary of a variance, it must also be rejected with the lower boundary of variance. Therefore, a stricter test with the upper boundary of a variance is emphasized. Using the above estimated variance, the standard deviation and the standard error of the sample mean for Z_{jg} ($\hat{\sigma}$ and $\hat{\sigma}/\sqrt{N}$, respectively) are computed, and then a hypothesis test can be conducted. The null hypothesis H_0 implies that there are no differences in the cachability coefficients for species i between two set types, q and s (i.e., $\theta = \ln\left(\gamma_{i,q}/\gamma_{i,s}\right)=0$ and hence $\gamma_{i,q}=\gamma_{i,s}$). If H_0 is rejected, there is enough evidence to support that catchability coefficient for each species depends on set type (e.g., tuna set vs. swordfish set).

Given 18 cases in Table A3.2 indicates that, the number of groups G were relatively large (ranging from 73 to 112) compared to a typical ANOVA's case (except for one case; see Table A3.2), while number of the total observations N ranges 349 to 1,330. The value of F_c ranges from 1.37 to 1.94, while the value of $\frac{N-G}{G-1}$ ranges from 7.92 to 16.40.

Most of the estimates θ for six species and three types of comparisons were significant at the 1% levels, implying that there is enough statistical evidence to conclude that the catchability coefficient for species i with set type s differs from that with set type q, in

spite of large data noise (the standard deviation is larger than the mean). In only three cases – the catchability ratio for striped marline between tuna vs. swordfish sets and the two catchability ratios for albacore and bigeye tunas between mixed-B and swordfish sets – the null hypothesis was not rejected, even if the lower boundary of variance was used at the 5% significance level. It implies that there is statistically no difference in the catchability coefficients for those species between the corresponding two set types. See Chapter 5 for the more detailed interpretations of the estimated catchability coefficients for all six species across the four set types.

This appendix shows statistical evidence to support the common belief that the catchability coefficient for a particular species is different across different set types, although the logbook data contain large noise, which might be created by individual differences in longline vessels and fishermen's skills/strategies, or oceanographic differences in fishing location and time. Since the procedure developed here requires only aggregated data summarized by 5° square area and month, it is more applicable to other fisheries data. Furthermore, the use of aggregate data accompanied with a few approximation and elimination of problematic data can afford the quite large sample to estimate the catchability ratios accurately, in terms of a smaller confidence interval for $\theta = \ln\left(\gamma_{i,q}/\gamma_{i,s}\right)$. This is a significant advantage for the empirical work in this study since the catchability ratios are important parameters used to standardize catchability coefficients and to determine the allocation of fishing set types in each area and period in the simulation.

Table A3.1 Frequency Distribution of Group-level Sample Size (n_g)[a]

Sample size	Tuna vs. Swordfish		Tuna vs. Mixed-A		Mixed-B vs. Swordfish	
(n_g)	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	99	45.8%	90	41.7%	83	38.4%
1	14	52.3%	35	57.9%	21	48.1%
2	13	58.3%	32	72.7%	7	51.4%
3	10	63.0%	13	78.7%	9	55.6%
4 - 5	16	70.4%	14	85.2%	16	63.0%
6 - 10	20	79.6%	17	93.1%	31	77.3%
11 - 15	15	86.6%	7	96.3%	21	87.0%
16 - 20	11	91.7%	2	97.2%	11	92.1%
21 - 30	11	96.8%	4	99.1%	12	97.7%
31 - 50	5	99.1%	2	100.0%	4	99.5%
51 - 70	2	100.0%	0	100.0%	1	100.0%
Total	216 [b]		216		216	
Total with $n_g >= 2$	103	47.7%	91	42.1%	112	51.9%

[a] In comparing two types of fishing sets, s and q, the group-level sample size (ng) is defined as

the smaller of $n_{g,s}$ and $n_{g,q}$

where s and q represent one of the four set types (i.e., tuna, swordfish, mixed-A and mixed-B) and $n_{g,s}$ and $n_{g,q}$ are the number of fishing sets with type s and q, respectively, in the gth group.

[b] The gth group represents area k at period t. The 216 grouped data consist of 36 months entries from the six areas around Main Hawaiian Islands (MHI).

Table A3.2 Summary Table for Estimation θ

Species code	Number of groups (G)	Total number of observation (N)	Estimated θ	$(\gamma_{i,q} / \gamma_{i,s})$ = Exp(θ)	SSA	N - G / G - 1	F-value critical[b]	SSW estimate Low-B	SSW estimate Up-B	St Dev (σ) Low-B	St Dev (σ) Up-B	t-stat	p-value
		Tuna vs. Swordfish											
Blue marlin	74	1,127	1.5542 **[a]	4.73	840	14.42	1.447	8,374	12,117	2.861	3.392	15.38	0.000
Striped marlin	73	1,143	-0.0199	0.98	765	14.86	1.450	7,837	11,362	2.744	3.259	-0.21	**0.837**
Swordfish	79	1,164	4.0758 **	58.90	1,493	13.91	1.432	14,507	20,768	3.709	4.375	31.78	0.000
Albacore	83	1,205	-1.9353 **	0.14	1,182	13.68	1.420	11,390	16,177	3.231	3.797	-17.69	0.000
Bigeye tuna	98	1,240	0.4429 **	1.56	901	11.77	1.386	7,656	10,613	2.628	3.048	5.12	0.000
Yellowfin tuna	94	1,195	1.5221 **	4.58	552	11.84	1.395	4,685	6,536	2.094	2.436	21.60	0.000
		Tuna vs. Mixed-A											
Blue marlin	60	527	2.2071 **	9.09	826	7.92	1.525	4,287	6,537	3.118	3.741	13.54	0.000
Striped marlin	57	524	0.8233 **	2.28	513	8.34	1.538	2,783	4,281	2.511	3.028	6.23	0.000
Swordfish	21	349	1.6668 **	5.30	381	16.40	1.935	3,227	6,243	3.220	4.363	7.14	0.000
Albacore	43	470	-1.7621 **	0.17	573	10.17	1.625	3,586	5,825	2.978	3.694	-10.34	0.000
Bigeye tuna	81	541	-0.6609 **	0.52	328	5.75	1.456	1,297	1,887	1.735	2.026	-7.59	0.000
Yellowfin tuna	91	589	1.1786 **	3.25	822	5.53	1.428	3,186	4,551	2.611	3.023	9.46	0.000
		Mixed-B vs. Swordfish											
Blue marlin	104	1,314	-0.3180 **	0.73	572	11.75	1.374	4,894	6,723	2.040	2.357	-4.89	0.000
Striped marlin	86	1,215	-0.3501 **	0.70	683	13.28	1.413	6,423	9,073	2.419	2.835	-4.30	0.000
Swordfish	108	1,330	0.3735 **	1.45	311	11.42	1.366	2,603	3,557	1.481	1.706	7.98	0.000
Albacore	90	1,259	-0.0218	0.98	488	13.13	1.402	4,569	6,408	2.005	2.341	-0.33	**0.742**
Bigeye tuna	107	1,326	0.0900	1.09	737	11.50	1.368	6,196	8,477	2.287	2.637	1.24	**0.217**
Yellowfin tuna	103	1,311	-0.1633 **	0.85	228	11.84	1.375	1,962	2,699	1.293	1.495	-3.95	0.000

[a]A double asterisk indicates that a null hypothesis

H_0: $\theta = 0$ $(\gamma_{i,q} = \gamma_{i,s})$

is rejected at the 1% significance level.

[b]$F_{0.01,(G-1),(N-G)}$

APPENDIX 4
MAPE AND MODEL FORECAST ACCURACY

The primary objective of MAPE and other measures for forecast accuracy is (i) to measure the extent to which one model is better than other alternative models, or (ii) to rank order alternative models (Makridakis and Wheelwright, 1982, p. 459). However, these measures are useful only when different models attempt to predict the same variable(s) (or index, indicator). MAPE is neither a statistic for any hypothesis test regarding a model's appropriateness nor a useful measure to compare the forecast accuracy by two or more models that predict different types of variables. For example, comparing the MAPE for the monthly number of longline fishing trips is not comparable to that for a quarterly GDP index.

For the purpose of such a general comparison, the post-sample coefficient of determination R^2 is likely to be more appropriate. The post-sample $R^2 = 0.525$ in this study (Chapter 6) suggests that the forecast accuracy of the model without fish movement (w/o FM) is moderately good. The resulting MAPE values, 13.9% by the model w/o FM and 18.7% by the model with FM (Chapter 7), rather suggest that the time-series forecast accuracy is not improved by incorporating FM[1]. Furthermore, empirical models developed in the future that attempt to predict the monthly number of longline fishing trips in Hawaii (including an extension of this study) are expected to compute MAPE to evaluate their improvement in forecast accuracy, although the contribution of each model should not be evaluated solely by forecast accuracy.

A4.1 MAPE and Other Measures for Forecast Accuracy

Although no single criterion can be accepted for judging the appropriateness of a forecasting model in a given situation, the follow measures are commonly used (Makridakis and Wheelwright, 1982; Pindyck and Rubinfeld, 1991):

[1] It should be noted that the model with FM can theoretically predict the impacts of an area closure more accurately and has improved the forecast accuracy in the spatial dimension (Chapter 7).

RMS – Root Mean Square error[2]

RRMS – Relative RMS or RMS percentage error

MAE (or MAD) – Mean Absolute Error (or Deviation)

MAPE – Mean Absolute Percentage Error[3]

Absolute vs. Relative (Percentage) Measure

RMS and MAE have the same units of measurement as the observed series. When forecasting a popular indicator, such as GDP or stock market index, it has no problem to express its forecast accuracy with the same unit as that indicator. On the other hand, the monthly number of fishing trips and units measuring labor or fishing effort (in a more general sense than this study) may vary depending on each study, (i.e., the numbers of hooks, fishing sets, or fishing days or total days in which boats are absent from port). Therefore, a relative measure representing by percentage (i.e., RRMS or MAPE) is likely to be more useful than an absolute measure (i.e., RMS or MAE).

The following two potential problems with a relative measure should be checked. First, it would be problematic in computing a relative measure if the observed number is near zero. However, since the smallest number of trips was 49.2 (Table 6.1), this potential problem associated with a small denominator can be ignored. Second, a relative measure (e.g., MAPE and RRMS) generally suffers from a bias favoring forecasts that are below the observed value, which might need to be considered when interpreting the resulting MAPE (Makridakis and Wheelwright, 1982, p. 459).

RRMS (quadratic) vs. MAPE (linear)

RMS and RRMS penalize large individual errors more heavily. If a researcher attempts to successfully predict extreme periods of actual observations, then RRMS may be preferred (Pindyck and Rubinfeld, 1991, p. 338) to MAPE. However, it is generally not easy for an

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[2] Some econometrics textbooks use Mean Square Error (MSE), instead of RMS.

[3] In addition to the above four measures, Theil's U coefficient is also frequently cited in the literature (e.g., Pindyck and Rubinfeld, 1991). Theil's U coefficient is more complex and may be appropriate to evaluate the forecast accuracy of alternative models that focus on time-series forecast of macroeconomic indicators. However, the four simple measures introduced here seem are preferred to Theil's U coefficient since the focus of the model in this study is spatial dimension of fishing trips.

economic model to forecast some extreme cases in the fishery, which may be caused by some unexpected oceanographic phenomena affecting fish abundance or vessel's catchability (and hence CPUE) significantly. Therefore, it is not preferred to penalize large individual errors heavily. Thus, MAPE is likely to be preferred to RRMS here. Therefore, MAPE is used as a measure for forecast accuracy.

A4.2: MAPE vs. Post-Sample Coefficient of Determination (R^2)

MAPE is commonly used to measure the extent to which one model is better than other alternative models. Using a neural network (NN) approach, Lin et al. (1995) forecast the Hang Seng Index for a further 60 weeks, where the index ranges from 2,500 to 3,600 points. They present that their new approach improves the forecast accuracy from 1.7% to 1.38% in terms of MAPE. Law and Au (1999) also demonstrate that their NN approach for forecasting Japanese demand for travel to Hong Kong is superior to classical forecast models, such as naïve, moving average, exponential smoothing, and a multiple regression. The MAPE by their NN approach was 10.6%, while the MAPE values by other methods were between 18 and 27%.

However, as mentioned before, the above MAPE values are not comparable to the one in this study (MAPE = 13.9%) because the degrees of variation of the original data in each study are very different from each other. For example, using the neural network (NN) approach, Vishwakarma (1995) forecasts the growth rate of index of industrial production over 25 month from March 1995, resulting in 0.89% of MAPE, which one might consider an excellent forecast accuracy. However, the coefficient of variation (CV = the standard error divided by the mean) was also only 1.22%, implying the original time-series data itself have little variation. If the post-sample mean were used as the predicted values for all periods, this simple prediction has already achieve 0.96% of MAPE. This comparison indicates that an improvement in forecast accuracy (from 0.96% to 0.89% in MAPE) by Vishwakarma's (1995) NN model is not very great.

Makridakis and Wheelwright (1982, pp. 461-462) suggest another measure of accuracy, the post-sample coefficient of determination given by:

$$R^2 = 1 - \frac{\sum_{t=1}^{T}(y_t - \hat{y}_t)^2}{\sum_{t=1}^{T}(y_t - \bar{y})^2} \qquad \text{(A4.1)}$$

where y_t and $\hat{y}_t$ are the (actual) observed and predicted data at period t, respectively, while $\bar{y}$ is the mean of the observed data. Note that this measure is different from a popular R^2, which is computed by a regression. This post-sample R^2 indicates how much portion of variation from the mean of the observed data can be explained by the forecast model. In an extreme case, if all predicted values equals the mean ($y_t = \bar{y}$ for all t), then $R^2 = 0$, implying that the prediction is no better than a simple prediction using the post-sample mean $\bar{y}$. In another extreme case (perfect forecast) where each predicted value at period t exactly equals the actual value ($\hat{y}_t = y_t$ for all t), $R^2 = 1$.

Since this post-sample R^2 measure might not be computed by a regression, it cannot be used to conduct a hypothesis test. However, the R^2 computed by a simple regression with "one explanatory variable and intercept" indicates that a model seems to make no sense if $R^2 < 0.20$, according to the F-test (the degrees of freedom for numerator and denominator are 1 and 30, respectively) at the 1% significance level. It suggests that the post-sample R^2 by a model that can be considered "useful" must be at least greater than 0.20. Although no definitive boundaries are available here, the levels of forecast accuracy could be roughly categorized as follows: (i) no better than a simple prediction using the post-sample mean if $R^2 \leq 0.20$, (ii) not very accurate if $0.20 < R^2 < 0.50$, (iii) moderately accurate if $0.50 \leq R^2 < 0.80$, and (iii) excellently accurate if $R^2 \geq 0.80$.

The resulting MAPE, CV and this post-sample R^2 for the present and the above three studies are summarized in Table A4.1. According to the post-sample R^2, Vishwakarma (1995) model result was least accurate, despite the MAPE in his result was the lowest. Law & Au's (1999) results are likely to be excellent since post-sample R^2 is greater than 0.90. In fact, their NN approach results yield much smaller MAPE than other statistical

models to predict the numbers of Japanese tourists to Hong Kong. The forecast results of this fishery model is moderately accurate, not because of the MAPE (=13.9%) but because of the post-sample R^2 (= 0.525).

Table A4.1 Comparison of MAPE, CV, and Post-sample R^2 in Four Different Forecasts

Measure	The Present study Nemoto (2002)	Law & Au (1999)	Vishwakarma (1995)	Lin et al. (1995)
Predicted Variable	# of trips	# of visitors	GDP indicator	Hang Seng Index
Forecasted period	36 months	10 years	25 months	60 weeks
CV	23.3%	68.2%	1.22%	N/A
MAPE	13.9%	10.6%	0.89%	1.38%
Post-sample R^2	0.525	0.945	0.297	N/A

APPENDIX 5

ESTIMATING FISH MOVEMENT: PROCEDURE, RESULT, AND DISCUSSION

This appendix first discusses the rationale of the fish movement (FM) function (7.1) in Chapter 7. Next, it explains the econometrics procedure to estimate the FM functions for the four areas around the main Hawaiian islands (MHI), followed by the evaluation and interpretation of the results and comparison with other studies.

A5.1 Tradeoff between the FM equation (7.1) and a possible extended equation including additional explanatory variables for the four diagonal areas

As discussed with Equation (2.12), theoretically the FM function (7.1) could be extended to include four diagonal areas (and possibly other neighboring areas if fish move beyond a 5° square area) for more accurate accounting of fish moving from the Periphery to the center area (see Figure 7.1). However, the gain from this "extended" FM function is not significant to this study because the direction of FM can be approximated by the simple FM equation (7.1) without these four diagonal areas. For example, if fish move from the southeast to the center area, the estimates for the south and east would be significant.

In fact, Kleiber and Hampton (1994) measured FM in the similar functional form as equation (7.1) excluding diagonal areas. If one needs to more accurately estimate the direction of FM, an alternative approach by Deriso, Punsly, and Bayliff (1991), or Sibert et al (1999) – measuring the velocity, direction, and diffusion of FM – should be adopted, although its computation would be complex (see Chapter 7).

More importantly, the estimation of this "extended" FM function could be very costly. First, the number of coefficients to be estimated would increase from 20 (= 5 parameters x 4 equations) to 36 (= 9 parameters x 4 equations), resulting in the loss in degrees of freedom (d.f.). Since the data set in this study covers only 36 months, the loss in d.f. by 4 in each area is considerable.

Second, the estimation of the FM function would suffer from multicollinearity (MCL) if the 4 diagonal areas are included. As shown in Figure 7.1, the four neighboring areas (N, E, S, and W)[1] are connected to each other only through a corner of each square area. That is, these four areas still maintain a certain distance from each other. If the four diagonal areas (NE, SE, SW, and NW) are included, a total of 8 areas in the FM function would become closer to each other, since some paired of areas would be connected through an edge of each square area (e.g., *N* and *NE*, or *NW* and *W*). Patterns of changes over time in the stock size and fishery catch in such a pair of closest areas could be similar to each other, implying that two or more explanatory variables (residual stocks in those two areas) might be more strongly correlated, resulting in severe MCL.

MCL, where two or more explanatory variables are highly inter-correlated, could lead to the following two problems; (a) coefficients may have very high standard errors (and tend to be insignificant) in spite of the higher R^2 in the regression is quite high, and (b) parameter estimates are often unstable and sometimes result in having the wrong sign or an implausible magnitude (Greene, 1993, p. 267). In general, MCL is considered to be severe if the "condition number" (CN) is greater than 20 (see Greene, 1993, p. 269).

The CNs, computed for the FM functions (both simple and extended) for each of the four areas are presented in Table A5.1 (see also Figure 7.2). Note that only three diagonal areas, instead of four, are included in the extended FM function, because a considerable number of observations are missing from the excluded diagonal areas. See below for the detailed explanation about the missing observation problem. Table A5.1 indicates that (a) the inclusion of the diagonal areas definitely increases the CN, and (b) the CN for the extended FM equation for *15N160W* and *20N160W* would be greater than 20 if one more diagonal area (*10N165W* and *25N165W*, respectively) is included, implying that the estimation of these extended FM equations would suffer from MCL.

[1] N, E, S and W stand for the north, east, north, south, and west

Problem of missing observations

The data for four areas –*10N150W*, *10N165W*, *25N150W*, and *25N165W* – are required for the "extended" FM functions. As indicated in Table A5.1, the number of missing observations out of 36 months was 9 or greater in the above four areas (Figure 7.2), implying that at least one-fourth of all potential observations were missing. In particular, due to very poor data availability in *10N150W*, the estimation of this extended FM function for area *15N155W* is likely to be problematic.

In general, missing observations in a time-series data set could be solved by replacing the missing observations with the estimated ones (e.g., "first-order regression": see Greene 1993, p.273-277). This method may be useful if all potential observations are available to estimate missing observation(s). Obviously, the method is not relevant to estimate the above extended FM function for *15N155W*, due very poor data availability in *10N150W*. Moreover, if missing observations regarding the other three areas are replaced by the "first-order regression" using information associated with other neighboring areas, and these three variables are used to estimate the extended FM function, then the MCL problem theoretically would be worse than a hypothetical situation, where there were no missing observations.

Thus, while the benefit from including the four diagonal areas into FM equation (7.1) is quite modest, the cost of this inclusion is substantial: i.e., the estimation of the extended FM equation is too problematic or almost implausible, due to (i) loss in degrees of freedom, (ii) multicollinearity (MCL), and (iii) missing observation problem. Therefore, the simple FM function (7.1), without the four diagonal areas, is preferred.

A5.2 Seemingly Unrelated Regressions (SUR)

Assuming the abundance and movement of pelagic species have no correlation with each other, the FM equation (7.1) for each species is estimated for the four areas around the Main Hawaiian Islands (MHI): i.e., *15N155W*, *15N160W*, *20N155W*, and *20N160W* (see Chapter 7). Since the geographical settings of the MHI and the Cross Seamount seem to

create the diversity in the fishing grounds, the parameters in equation (7.1) may be different across the four areas. However, since these four areas are geographically connected with each other (Figure 7.3), the FM equations are likely cross-sectionally correlated to each other by their disturbances, suggesting that the *seemingly unrelated regressions* (SUR) model might be appropriate, rather than the ordinary least squares (OLS) procedure.

Dividing both sides of equation (7.1) by $B'^{0}_{i,k,t}$ (assuming > 0), equation (7.1) becomes:

$$\frac{R_{i,k,t}}{B'^{0}_{i,k,t}} = \beta_{0k} + \beta_{1k}\left(\frac{B'^{N}_{i,k,t}}{B'^{0}_{i,k,t}}\right) + \beta_{2k}\left(\frac{B'^{E}_{i,k,t}}{B'^{0}_{i,k,t}}\right) + \beta_{3k}\left(\frac{B'^{S}_{i,k,t}}{B'^{0}_{i,k,t}}\right) + \beta_{4k}\left(\frac{B'^{W}_{i,k,t}}{B'^{0}_{i,k,t}}\right) + \varepsilon_{k,t} \qquad \text{(A5.1)}$$

where k represents one of the four areas and the expected value of the residual $E(\varepsilon_{k,t}) = 0$. Movement patterns (i.e., the movement coefficients) are assumed to be constant even if the allocation of fishing effort has been significantly changed by some regulatory policy.

It is also assumed that $E[\varepsilon_{mt}\ \varepsilon_{ns}] = \sigma_{mn}$ if $t = s$, and 0 otherwise, where m and n represent mth and nth equations (i.e., one of fishing area) and t and s denote periods. Using matrix notation, it is described as:

$$E\left[\varepsilon\varepsilon'\right] = \mathrm{V} = \begin{bmatrix} \sigma_{11}\mathrm{I} & \sigma_{12}\mathrm{I} & \cdots & \sigma_{1M}\mathrm{I} \\ \sigma_{21}\mathrm{I} & \sigma_{22}\mathrm{I} & \cdots & \\ \vdots & & \vdots & \\ \sigma_{M1}\mathrm{I} & & \cdots & \sigma_{MM}\mathrm{I} \end{bmatrix}. \qquad \text{(A5.2)}$$

If the equations (A5.1) for each cross-section are actually unrelated, or $\sigma_{mn} = 0\ \ (m \neq n)$ in the $M \times M$ covariance matrix of disturbances, a generalized least squares (GLS)

estimation has no gain compared with OLS. Breusch and Pagan (1980) suggest the following Lagrange multiplier (LM) statistic:

$$\lambda_{LM} = T \sum_{m=2}^{m} \sum_{n=1}^{m-1} r_{mn}^2 \qquad \text{(A5.3)}$$

where $r_{mn}^2 = s_{mn} / \sqrt{s_{mm} s_{mn}}$ is the estimated correlation of the OLS residuals. Asymptotically, this B-P LM statistic is distributed as chi-square with $M(M\text{-}1)/2$ degrees of freedom (Greene, 1993, p. 492-493). The null hypothesis – the covariance matrix Σ is diagonal (i.e., OLS is valid) – can be rejected if the LM statistic is significant. In such a case, the FM equations for each area are linked only by their disturbances, implying the SUR model is preferred. The elements of the covariance matrix Σ were estimated using the OLS residuals, the feasible GLS procedure was conducted with

$$\mathbf{V} = \Sigma \otimes \mathbf{I} \qquad \text{(A5.4)}$$

where the elements of Σ were consistently estimated as $\hat{\sigma}_{mn} = s_{mn} = \frac{\mathbf{e}_m' \mathbf{e}_n}{T}$.

Data to estimate this system of equations were prepared as follows. First, as described in Chapter 4 (page 49), monthly initial stocks $B_{i,k,t}$ in all areas in Figure 7.3 were computed using equation (4.2) with the estimated catchability coefficient for each species and actual catch and effort data from the logbook. Second, the residual stock in each area can be computed by subtracting the actual catch from the initial stock $\hat{B}_{i,k,t}$, estimated in the above. Then the net inflow for each of the four areas was computed as:

$$R_{i,k,t} = \hat{B}_{i,k,t+1} - \hat{B}'_{i,k,t} = \hat{B}_{i,k,t+1} - \left(\hat{B}_{i,k,t} - C^A_{i,k,t} \right). \qquad \text{(A5.5)}$$

Finally, the data are formulated for each of the four areas, and the parameters for equation (A5.1) were estimated using the GLS procedure with the SHAZAM econometric computer software (White 1993).

A5.3 Results and Discussion

Although the policy simulations in Chapter 7 only incorporate movement of bigeye (BE) tuna, the results for yellowfin (YF) and swordfish (SW) are also presented and discussed in this appendix because:

- More applications contribute toward evaluating this FM estimation procedure,
- These three pelagic species are the most valuable to the Hawaii longline fishery,
- Itano and Holland (2000) investigate the movement of both BE and YF by a tag-and-release experiment, and hence it could evaluate the results in this study, by comparing them with their study results, and
- Swordfish had been the most important species in the North Pacific area, although this sector of fishery was closed by the ruling of a US federal judge (Appendix 1).

Overall

The results of the above estimation procedure for each species are summarized in Tables A5.2, A5.3, and A5.4. According to the resulting B-P LM statistic, the null hypothesis $\sigma_{mn}=0 \ (m \neq n)$ was rejected at the 5% significance level for all three species, implying that the SUR model is preferred to the OLS. The overall goodness-of-fit of the GLS estimation is represented by the raw-moment R^2 as well as the log-likelihood function (LLF). According to the raw-moment R^2, the overall goodness of fit for the SUR model for BE (.7036) is better than for YF (0.5299). The raw-moment R^2 for swordfish was 0.5098, which is the lowest among the three species[2].

[2] However, it is not comparable to the other two species since two areas, *15N155W* and *15N160W*, were excluded from this system of equations due to data limitations (insufficient swordfish catches, causing too little variation in observations) and then much less explanatory variables are used in the GLS estimation.

The OLS results for each species in each area are also presented for purpose of comparison. The resulting adjusted R^2 from the OLS results indicate the goodness-of-fit for each specific area. For example, the value of the adjusted R^2 for BE at *20N160W* is high (0.7336), while that at *15N160W* is low, suggesting that the goodness of fit varied across the four areas; i.e., this FM model, represented by equation (A5.1), is likely to be suitable for the movement of BE at *20N160W*, but not at *15N160W*. The Durbin-Watson (D-W) statistic for the OLS results examines the significance of autocorrelation. None except for YF at *20N155W* indicate the existence of significant autocorrelation. Therefore, autocorrelation was not corrected in the GLS estimation.

Efficiency gain

The major improvement from the GLS is in terms of efficiency gain. The standard errors for most of the coefficients became smaller with GLS estimation, while the absolute value of each coefficient only changed slightly. As a result, more coefficients become statistically significant with the GLS estimation. Since the B-P LM statistic for the YF case is more significant than for the BE case (i.e., the residuals for the four equations are more cross-sectionally correlated), the efficiency gain from the GLS in the YF case is greater, where the estimates were considerably changed by the GLS, resulting in more coefficients becoming significant.

Coefficients – expected and resulting signs and values

As discussed in Chapter 2, the underlying assumption of equation (2.12) suggests that the estimates for residual stock in the own areas $B'^{0}_{i,k,t}$ are expected to be negative, ranging from -1 to zero, while the estimates for the residual stocks in the adjacent areas are expected to be positive, ranging from zero to 1. That is, the estimates for movement coefficients in equation (A5.1) are expected as $-1 \le \beta_{0k} \le 0$ and $0 \le \beta_{mk} \le 1$ where $m = 1$, 2, 3, and 4.

However, these estimates could be out of the expected range for several reasons. First, the impact of significant recruitment and natural mortality[3] may result in unexpected estimates. For example, if the number of fish in the east ($B'^{E}_{i,k,t}$) significantly increases at stage (iii) due to much greater recruitment than natural mortality, the number of fish moving from the east to area k (e.g., from *20N150W* to *20N155W*) could be greater than the residual stock size at stage (ii), resulting in $\beta_{2k} > 1$.

Second, while the empirical FM model, equation (A5.1), includes only 4 adjacent areas, some fish could move from other areas, in particular, the 4 diagonal areas (e.g., south-east), resulting in an estimate greater than 1. If fish inflow from the southeast as well as the east and south does occur, then the estimates for the east and south (β_{2k} and β_{3k}) account for the inflow from the southeast and might be greater than 1.

Third, since the data (i.e., the residual stocks and net inflow) used for estimating equation (A5.1) are also estimated from catch and effort data and the estimated catchability coefficient γ,[4] it might include some measurement errors, which could, in turn, affect the estimation of equation (A5.1). In addition, data noise or specification errors (e.g., nonlinear functional relationship in the FM function) could cause estimates beyond the expected range.

Resulting movement coefficients for BE, YF, and SW are presented in Tables A5.2, A5.3, and A5.4, respectively. As predicted in the above, all estimates for residual stocks in the own areas (β_{0k}) were negative, except for one case; the estimate for the area *15N155W* (B20') for BE (Table A5.2) was unexpectedly positive. Some of the negative estimates for the own area were significant, while the others were not. Besides, all

[3] Biologists often assume that recruitment is constant and independent of stock size, while natural mortality is proportion to stock size. Adam et al. (2002) estimate natural and fishery mortalities, resulting ratio of natural to fishery mortality (M/F) for adult BE and YF were 0.7 and 0.5, respectively (i.e., natural mortality is smaller than fishery mortality).

[4] See equation (4.2) and Chapter 5. IN particular, the initial stock depends on the catchability coefficient, which might seasonally fluctuate due to a change in food (prey) availability.

significant negative estimates for β_{0k} (*20N160W* for BE, and three areas for YF) were out of the expected range (i.e., less than -1) except the one for swordfish. Thus, five out of 10 estimates for β_{0k} were out of the expected range, suggesting that the limitations in estimating the FM function (A5.1), mentioned in the above, might be critical and need to be solved to improve the results.

As mentioned in the above, the estimates for residual stocks in the four surrounding areas (north, east, south, and west) are expected to range from zero to 1 ($0 \leq \beta_{mk} \leq 1$). And a significantly positive estimate for an adjacent area suggests a significant inflow from that area to area *k*. Besides, if FM is a consistent flow from one direction to another, only one or two estimates should be significantly positive in each FM function. For example, if fish move from the southeast to the northwest, the estimates for residual stocks of the east and south are expected to significantly positive. As shown in the results, two estimates were significant in most of the FM functions, although some of those significantly positive estimates are greater than 1 (i.e., beyond the expected range).

A few estimates were unexpectedly negative, maybe because of the strong movement in the opposite direction (i.e., outflow). Two significantly negative estimates for the north adjacent areas of *15N155W* and *20N155W* (-0.9512 and –0.5074 for *B2N'* and *B5N'*, respectively, in Table A5.2) for BE may reflect a significant movement of BE from the south to the north at these areas (*15N155W* and *20N155W*). Other unexpected negative estimates for adjacent areas were insignificant, which might also reflect an outflow to the corresponding adjacent area (as explained above) or simply indicate no significant inflow. (The estimates of *B5W'* and *B6W'* for BE in Table A5.2 may be the former case, while two estimates of *B5S'* and *B6W'* for SW in Table A5.4 is likely to be the latter case.) The movement directions suggested by the above results are illustrated by arrows in Figures 7.3, A5.1, and A5.2.

Movement Patterns: Bigeye Tuna (BE) vs. Yellowfin Tuna (YF)

As discussed in Chapter 7, BE overall move from the east to the west, and from the south to the north between 155° *W* and 160° *W* longitude. Interestingly, the movement of YF is likely to be opposite. As depicted in Figure A5.1, YF move toward the MHI. That is, there are inflows of YF from the west and from the south in all areas except for *20N155W*, while YF move from the north and from the east to *20N155W*.

There are some notable differences in the econometrics results between YF and BE.

- B-P LM statistic for YF's case is more significant than for BE's case, implying that the efficiency gain from the GLS in the YF's case is greater, while the value (even the sign) of some coefficients changed considerably and more coefficients becomes significant.
- Higher raw-moment R^2 in the GLS results and adjusted R^2s in the OLS results, and stable estimates in the OLS and GLS results for BE indicate that the FM function (A5.1) is likely to more suitable to BE than YF.

Comparison with the Tag-and-release Experiments by Itano and Holland (2000)

Itano and Holland (2000) conducted tag-and-release experiments to elucidate the moving patterns and other characteristics of BE and YF tunas within the Hawaiian exclusive economic zone (EEZ). Movement directions of these two species estimated in their study are compared with the results in the present study, in order to evaluate the consistency between the two studies.

Itano and Holland (2000) found that both tuna species tend to stay around the Cross Seamount or inshore of MHI since most of both species of the recaptured tunas are near the release points. In particular, all recaptured YF made on Cross Seamount were inshore of MHI or around Cross Seamount (except for one, which was recaptured near the coast of northern Mexico after 6 months liberty). The recaptured YF tunas that were released in Midway, NWHI or Buoy 1 (Northwest from Kauai Island) show that YF tend to move down along the Hawaiian Island chain to the MHI and the Cross Seamount. Thus, their

result, suggesting that YF move from the Northwest to the MHI or the Seamount, is likely to be consistent with the movement pattern in Figure A5.1.

Regarding the movement of BE, several of the BE released from Cross Seamount were recaptured by longline vessels to the north, and west of MHI, though a few BE were recaptured to the South East and the rest in the MHI region. On the other hand, the SUR estimation of the FM equation in this study suggests that BE are likely to move from the east to the west and from the south to the north (Figure 7.3). Although some differences exist between the two studies, the BE movement pattern, discovered by Itano and Holland (2000), is likely to be similar to that estimated in this study. As mentioned in Chapter 7, some differences between the two studies may happen because this study focuses on adult BE, usually caught by longliners, while most of the tagged BE in their study were juveniles, caught by trollers or handliners.

Overall, more BE are recovered at a greater distance from the release points, while almost all YF have been recaptured around Cross Seamount or inshore of MHI. At the same time, a few YF engaged in quite long-distance travel (e.g., to the West Coast and Japan EEZ), while none of the recaptured BE engaged in long-distance travel. Then, which is more mobile? Kaneko, Bartram, Miller, and Marks (2000) suggest that YF caught in Hawaii are a mix of resident and migratory fish. If this conjecture is true, YF that engaged in long-distance travel may be "migratory", while the majority of YF are "resident" and less mobile than BE.

Possible Effects of Oceanographic Factors, Such as Cyclonic Eddies, on FM

Although it is believed that many oceanographic factors affect FM, the relationship between oceanographic factors and fish behavior is very complex and the interpretation of their effect on FM is beyond the scope of this study. Therefore, none of oceanographic indicators are included in the FM function (7.1) in this study. It could be extended in the future research to include some oceanographic indicators, such as sea surface temperature

(SST). Recent findings from an oceanographic project[5] are relevant and noteworthy here. Their research shows that cyclonic eddies naturally occur and swirl in the waters west of the Big Island and south of Molokai, bringing nutrient-rich cold water up from the depths and generating a cycle of fertility that brought fish in from miles around (TenBruggencate, 2001). Also, Seki et al. (2001) show evidence that the well-mixed surface layers and strong current flows induced by the cyclonic eddy's presence led to the highest catch rate of blue marlin in the 1995 Hawaii International Billfish Tournament. Furthermore, such a cyclonic eddy that occurs leeward of the Big Island flows westward over time (Polovina and Brainard, 2001). Such a flow of an eddy is very similar to the BE movement, estimated in this study. Although direct evidence is not available yet, the movement of BE could be associated with the movement of the above cyclonic eddies.

Movement of Swordfish

There were too few swordfish catches in two areas, *15N155W* and *15N160W*, for the OLS results for these two areas to be meaningful. Therefore, these two areas were excluded from the SUR model. A significant estimate (0.3844) for the north area in the results for *20N155W* indicates that there was a significant inflow from the north to that area. As mentioned in Chapter 6, it is known that swordfish move close to the MHI during summer (Boggs and Ito, 1993). Figure A5.3 also shows that the stocks of swordfish in *20N155W* significantly increase during summer (see also Figure A7.2(c)). Thus, this simple estimation result for swordfish movement is likely to be consistent with common beliefs. Another significant estimate suggests a movement from the south to area *20N160W*. No other information is available to examine this movement, although this flow suggests that swordfish move back to the northern sea through this area.

[5] "The Role of Oceanography on Bigeye Tuna Aggregation and Vulnerability in the Hawaii Longline Fishery from Satellite, Moored and Shipboard Time Series": Pelagic Fisheries Research Program, JIMAR, Project 656196: PI: R. Brainard, J. Polovina, M. Seki, B. Qiu, and P. Flament.

Table A5.1 Condition Numbers (CNs) and the Number of Missing Observations for Each of the Four Fish Movement (FM) Functions

Area for net inflow (k_0)	Condition Number (CN)[a]		Missing observations[c]		
	Simple FM eq. (N,E,S, & W only)	Extended FM eq. (Including 3 out of 4 diagonal areas[b])	Eliminated area	Direction from the center area	Number of missing obs.
15N155W	6.26	11.88	10N150W	SE	31
15N160W	6.97	18.22	10N165W	SW	14
20N155W	7.40	12.99	25N150W	NE	9
20N160W	10.76	18.05	25N165W	NW	10

[a] This is called "Condition Index" in SHAZAM output.

[b] One area (apearing in "Eliminated Area" tabulation) was eliminated because the data for residual stock for that area was missing many observations.

[c] See Figure 7.2

Table A5.2 Estimates for Movement of Bigeye Tuna: OLS vs. SUR

Area	Variable Residual Stock	OLS results Estimated Coeff.	OLS results Standard Error	GLS (SUR) results Estimated Coeff.	GLS (SUR) results Standard Error
15N155W	B20'	0.4542	(0.4916)	0.3728	(0.4415)
(k = 2)[a]	B2N'	-1.1398	(0.5040) **	-0.9512	(0.4455) ** [b]
	B2E'	-0.0020	(0.6227)	0.0632	(0.5434)
	B2S'	0.7448	(0.1449) ***	0.7434	(0.1277) ***
	B2W'	0.3517	(0.7526)	0.2019	(0.6592)
15N160W	B30'	-0.0220	(0.3864)	-0.1562	(0.3418)
(k = 3)	B3N'	0.1875	(0.2487)	0.2757	(0.2209)
	B3E'	1.0819	(0.4007) **	1.0045	(0.3507) ***
	B3S'	0.0724	(0.1368)	0.1109	(0.1207)
	B3W'	-0.3361	(0.2151)	-0.2875	(0.1884)
20N155W	B50'	-0.7290	(0.4642)	-0.4165	(0.4086)
(k = 5)	B5N'	-0.5279	(0.3260)	-0.5074	(0.2829) *
	B5E'	1.4578	(0.3265) ***	1.2124	(0.2823) ***
	B5S'	0.3244	(0.0984) ***	0.3131	(0.0878) ***
	B5W'	-0.1887	(0.2433)	-0.1909	(0.2125)
20N160W	B60'	-1.3161	(0.6272) **	-1.2843	(0.5790) **
(k = 6)	B6N'	0.8219	(0.4639) *	0.8991	(0.4269) **
	B6E'	1.5622	(0.5472) ***	1.5520	(0.5043) ***
	B6S'	0.3079	(0.5950)	0.2567	(0.5479)
	B6W'	-0.5133	(0.4597)	-0.5392	(0.4234)

Other indicators for each OLS[c]			Other indicators	
Area	R^2-adjust	D-W stat	in GLS results	
15N155W	0.5184	2.4559	LLF	-221.839
15N160W	0.2293	1.4741	Raw-Moment R^2	0.7036 [d]
20N155W	0.4292	2.0556	B-P LM test	22.589 ***
20N160W	0.7336	1.3228	(χ^2 d.f. =	6)

[a]Area codes correspond to those in Figure 7.3.

[b]Single, double, triple asterisks indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

[c]Four OLS estimations were conducted for each of the 4 areas, while a SUR procedure jointly estimated the coefficients for all 4 areas.

[d]Raw-moment R^2 is listed here since the "noconstant" option was used in the GLS procedure, implemented with SHAZAM.

Table A5.3 Estimates for Movement of Yellowfin Tuna: OLS vs. SUR

Area	Variable Residual Stock	OLS results Estimated Coeff.	OLS results Standard Error	GLS (SUR) results Estimated Coeff.	GLS (SUR) results Standard Error
15N155W	B20'	-0.5817	(0.5566)	-1.1042	(0.4141) *** [b]
(k = 2)[a]	B2N'	0.2071	(0.6727)	0.4198	(0.4657)
	B2E'	-0.2773	(0.6598)	0.0332	(0.4400)
	B2S'	0.1268	(0.1914)	0.2418	(0.1384) *
	B2W'	1.4859	(0.6213) **	1.5113	(0.4431) ***
15N160W	B30'	-1.0521	(0.4305) **	-0.3044	(0.5425)
(k = 3)	B3N'	0.3035	(0.3068)	0.2624	(0.2617)
	B3E'	0.6347	(0.3124) *	0.3013	(0.2318)
	B3S'	-0.1246	(0.1144)	0.2848	(0.1440) **
	B3W'	0.5648	(0.2271) **	0.3657	(0.2094) *
20N155W	B50'	-0.9525	(0.3762) **	-1.5419	(0.8125) *
(k = 5)	B5N'	1.0972	(0.2728) ***	1.6878	(0.4000) ***
	B5E'	0.2275	(0.3401)	1.6241	(0.7655) **
	B5S'	-0.0277	(0.0941)	0.1464	(0.2813)
	B5W'	0.0889	(0.0791)	-0.2917	(0.1958)
20N160W	B60'	-0.3644	(0.3431)	-1.2350	(0.3527) ***
(k = 6)	B6N'	0.9859	(0.5322) *	0.0332	(0.4866)
	B6E'	-0.3999	(0.4425)	0.3864	(0.3449)
	B6S'	0.1741	(0.1870)	1.0881	(0.2197) ***
	B6W'	0.1514	(0.1274)	0.5127	(0.1131) ***

Other indicators for each OLS[c]			Other indicators	
Area	R^2-adjust	D-W stat	in GLS results	
15N155W	0.2246	1.6583	LLF	-160.234
15N160W	0.2730	2.1498	Raw-Moment R^2	0.5299 [d]
20N155W	0.5250	1.1669	B-P LM test	34.792 ***
20N160W	0.4324	1.4271	(χ^2 d.f. =	6)

[a]Area codes correspond to those in Figure A5.1.

[b]Single, double, triple asterisks indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

[c]Four OLS estimations were conducted for each of the 4 areas, while a SUR procedure jointly estimated the coefficients for all 4 areas.

[d]Raw-moment R^2 is listed here since the "noconstant" option was used in the GLS procedure, implemented with SHAZAM.

Table A5.4 Estimates for Movement of Swordfish: OLS vs. SUR

Area	Variable Residual Stock	OLS results Estimated Coeff.	OLS results Standard Error	GLS (SUR) results Estimated Coeff.	GLS (SUR) results Standard Error
20N155W	B50'	-0.8234	(0.3192) **	-0.7004	(0.2866) ** [b]
(k = 5)[a]	B5N'	0.4063	(0.1035) ***	0.3844	(0.0927) ***
	B5E'	0.1325	(0.1015)	0.0656	(0.0894)
	B5S'	-0.0092	(0.1535)	-0.0342	(0.1352)
	B5W'	0.2828	(0.2341)	0.3251	(0.2104)
20N160W	B60'	-0.2041	(0.3782)	-0.2283	(0.3442)
(k = 6)	B6N'	0.0284	(0.0613)	0.0343	(0.0553)
	B6E'	0.1926	(0.1706)	0.1899	(0.1541)
	B6S'	0.2498	(0.1097) **	0.2327	(0.0969) **
	B6W'	-0.0714	(0.1804)	-0.0444	(0.1587)

Other indicators for each OLS[c]			Other indicators	
Area	R^2-adjust	D-W stat	in GLS results	
15N155W	N/A	N/A	LLF	-88.5808
15N160W	N/A	N/A	Raw-Moment R^2	0.5098 [d]
20N155W	0.4092	2.2476	B-P LM test	3.968 **
20N160W	0.2804	1.7292	(χ^2 d.f. =	1)

[a]Area codes correspond to those in Figure A5.2.

[b]Single, double, triple asterisks indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

[c]Four OLS estimations were conducted for each of the 4 areas, while a SUR procedure jointly estimated the coefficients for all 4 areas.

[d]Raw-moment R^2 is listed here since the "noconstant" option was used in the GLS procedure, implemented with SHAZAM.

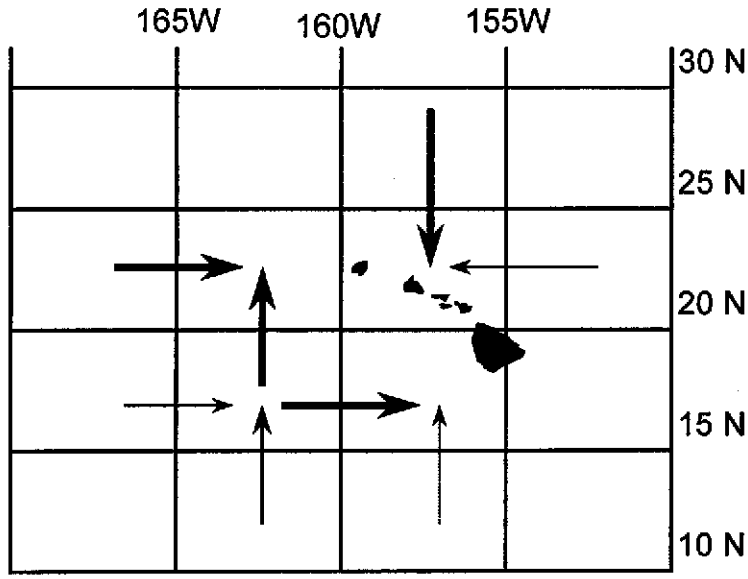

Figure A5.1 Movement Pattern for Yellowfin Tuna

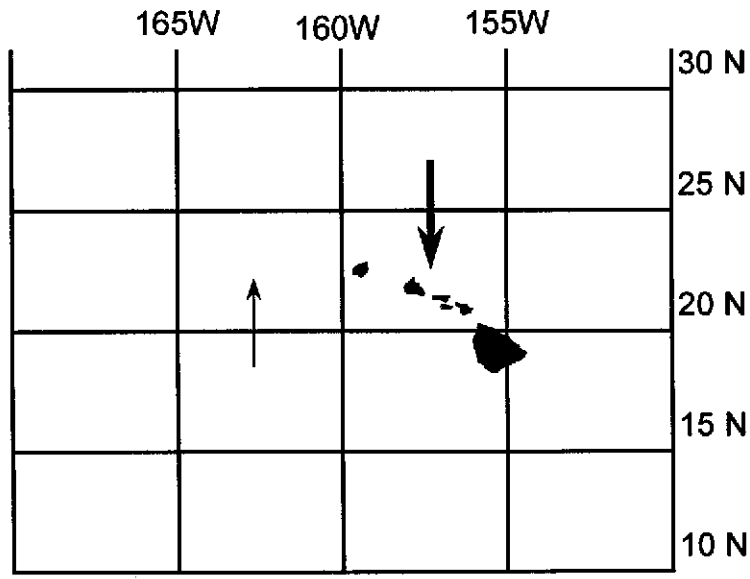

Figure A5.2 Movement Pattern for Swordfish

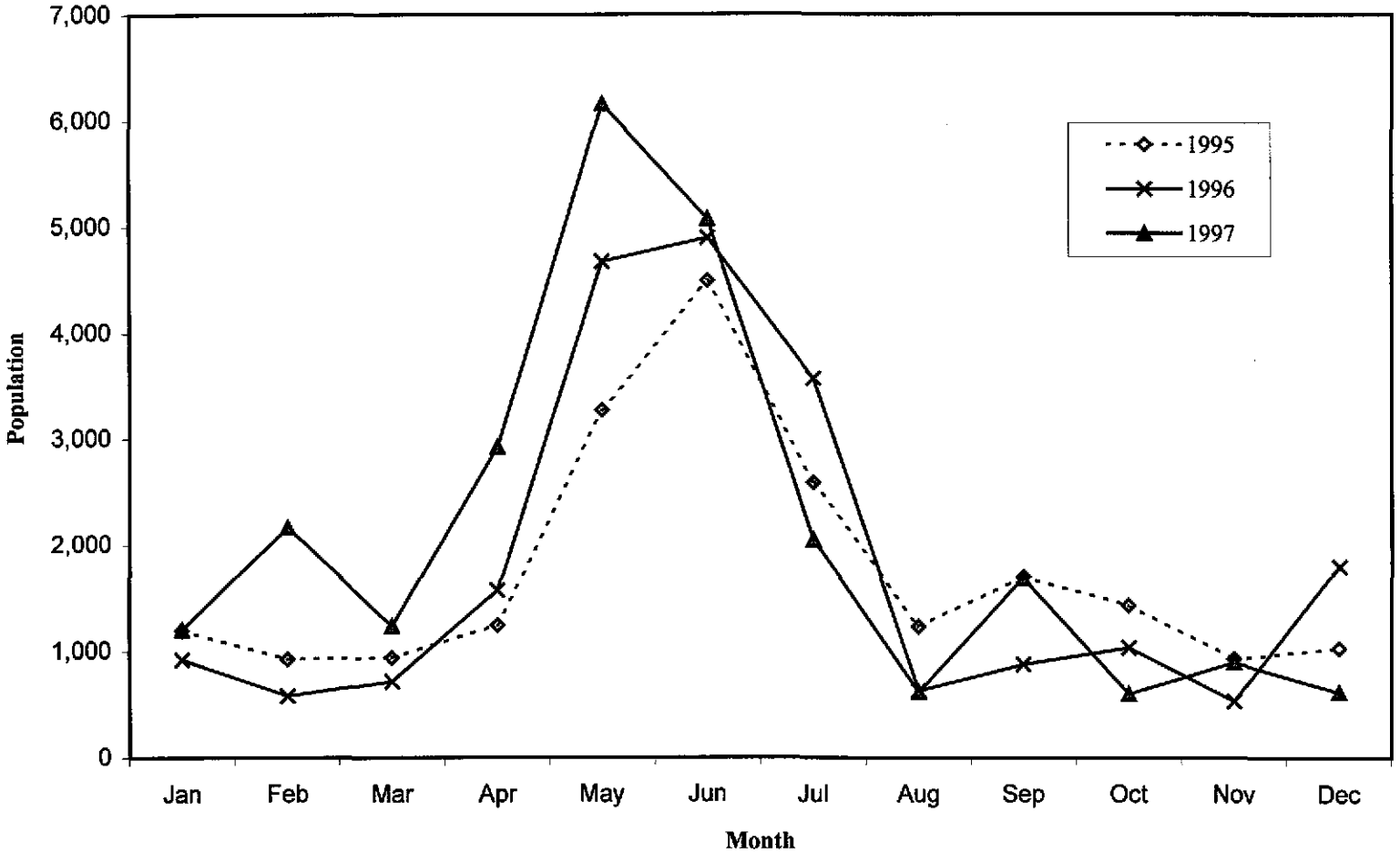

Figure A5.3 Monthly Changes in the Estimated Swordfish Stock in 20N155W

APPENDIX 6

COMPUTER PROGRAM SOURCE CODE (TURBO C++)

```
// Borland C++ - (C) Copyright 1997-99, 2000, and 2001 by Keiichi Nemoto
/*      FSIM12.CPP -- Fishery Simulation Program */
/*                  Change algorithm: Find Area to maximize Wage Index  Include Supply
Function. */

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>

#define MAXSP          6
#define MAXAREA  60
#define Minimum_trips  30

#define MAXMO 36
  /* maximum number of months */

#define minus20percent -0.2000
#define const_3      3.0
#define minus_two_third  -0.6667

#define MAX_vessel   250
/* Just to prevent infinite loop by mis-programming */

#define MAX_NCW        2000
#define setsnum               10
  /* number of sets per trip: fixed */
#define setnum2               10.0
#define unit_effort 1200.00
#define unit_e1        1498.00        /* average hooks per tuna set */
#define unit_e2        820.00         /* average hooks per swordfish set */

#define tuna_costs     854.28
  /* tuna-targeted fishing costs per set, excluding labor. All data are
   based on Hamilton et al (1996).  Thess costs include:
   oil, fuel, food, bait for tuna, and plus (ice + misc)
   for tuna vessels divided by 10.  ice is more costly for tuna, but misc
   gear is much cheaper in tuna sets than SW sets.
        food per day =               $ 81.54
        oil per day =                $  9.41
        fuel per fishing day =       $219.11
        bait per sets =              $272.88
        ice & misc per sets =        $196.90
        ------------------------------------
        Total                        $779.84 --> Changed on Apr 2001
                                     New Costs are in 1997 Price */
#define SW_costs 910.99
  /* Difference in fishing costs per set between SW-targeted and tuna-
  targeted set.  SW would be more expensive due to the use of lightstick
  and more expensive bait (squid), and plus misc gears. SW vessels use less ice.
Originally 1282.77  */

#define V_speed         118.71
 /* This number is estimated by total estimated travel miles, which is
  estimated from the logbook data in 1995, and total travel days which is
  estimated from the data in Hamilton et al (1996).  Original value is 118.71 miles
  per day. */

#define THETA     0.28026
 /* Ratio of the expected wage for a traveling day to that for a fishing day.
        old result:  THETA = 331.43/941.93 = 0.38038
        New result: THETA =  309.35/1103.8 = 0.28026*/

#define unit_TC2  374.50
 /* Travel costs per day.  TC2 includes food, oil, and fuel costs per day.
   TC1 adds labor opportunity cost of labor for all crews (including
   captain 661.51 $/day). Originally $ 341.51 in 1993 price */
```

```
#define adjust_r95     1.10619
#define adjust_r96     1.13714
#define adjust_r97     1.12360
 /* This coefficient is to adjust revenue in 1996 since this simulation
  account only for the revenues from 6 major species. */

#define LSb0   -6.0132
#define LSb1    3.7372
#define LSb2   -0.25686
 /* Parameters for the Labor Supply Function */

 /* Parameters for Bigeye(BE) Movement */
#define mvb0A  0.37281
#define mvb1A  -0.95123
#define mvb2A  0.063198
#define mvb3A   0.74341
#define mvb4A   0.20190
 /* for net inflow for area 15N155W */

#define mvb0B  -0.15618
#define mvb1B   0.27573
#define mvb2B  1.0045
#define mvb3B  0.11093
#define mvb4B  -0.28754
 /* for net inflow for area 15N160W */

#define mvb0C  -0.41647
#define mvb1C  -0.50736
#define mvb2C   1.2124
#define mvb3C   0.31306
#define mvb4C  -0.19089
 /* for net inflow for area 20N155W */

#define mvb0D  -1.2843
#define mvb1D   0.89905
#define mvb2D   1.5520
#define mvb3D   0.25666
#define mvb4D  -0.53921
 /* for net inflow for area 20N160W */


 /* Parameters for Yellowfin (YF) Movement */
#define mvy0A  -1.1042
#define mvy1A  -0.41981
#define mvy2A  0.033211
#define mvy3A   0.24178
#define mvy4A   1.5113
 /* for net inflow (YF) for area 15N155W */

#define mvy0B  -0.30439
#define mvy1B   0.26237
#define mvy2B  0.30134
#define mvy3B  0.28479
#define mvy4B   0.36565
 /* for net inflow (YF)for area 15N160W */

#define mvy0C  -1.5419
#define mvy1C   1.6878
#define mvy2C   1.6241
#define mvy3C   0.14640
#define mvy4C  -0.29170
 /* for net inflow (YF) for area 20N155W */

#define mvy0D  -1.2350
#define mvy1D   0.03322
#define mvy2D   0.38637
#define mvy3D   1.08637
#define mvy4D   0.51272
 /* for net inflow (YF) for area 20N160W */

#define fee_rate       0.1050
 /* Originlly 0.1050.
    Autction fee is 10% of revenue + excise tax is 0.50% */

/* ============================================================  */
```

```
void init_tbl1(void);  /* prototype */
void print_tbl1(int);  /* prototype */
void read_prices(FILE *, int);        /* prototype */

int get_sp_idx(int);  /* prototype */
int get_area_idx(char *);  /* prototype */

/* float calc_initstock(float, int, long); */

void sim_main(int);   /* prototype */
float get_max_WI(void);   /* prototype */
int check_area(int, int);
float calc_WI (int, int);  /* actually calculating Normalized Crew Wage */
float calc_WI2 (int, int);  /* No loop to search optimal tuna vs, SW sets */
long calc_rev2(int, int, int, int);
/* int calc_catch(float, float, int);
long calc_rev(int, int[], int); */

/* float calc_EW(int, float); */
/* long calc_WTGF_wage(int, float, float); */
int exam_WI_supply(int);
float calc_VD(float);          /* calc vessel-days from Normalized Crew Wage */
void calc_next_stock(int);     /* Compute next-period stocks of BE for 4 areas */
void calc_next_YFstock(int);  /* Compute next-period stocks of YF for 4 areas */
void replace_stock_with_estimate (int);
void print_results(int, int);  /* prototype */
void fitness_check(float, int);

struct sp_table               /* struct array for species & gamma */
       {
       int sp_cd;      /* Logbook code: St Marlin, SW, AL, BG, YL */
       float gamma1;  /* gamma for tuna set: from gammas6.prn */
       float gamma2;   /* gamma for swordfish set */
       float price;   /* PRICE data are set from FILE4 */
       };
struct sp_table sp_tbl[MAXSP] = {1, 0.33333, 0.12345, 0.91,
                                 2, 0.55555, 0.11111, 0.01,
                                 6, 0.66666, 0.22222, 0.02,
                                15, 0.77777, 0.33333, 0.03,
                                16, 0.88888, 0.44444, 0.04,
                                17, 0.99999, 0.12345, 0.05};

struct table2  /* Area name & distance (miles) from Honolulu Port */
{
       char    area_nm[8];    /* set from FILE2 */
       int     dist;
       int     set_num1;      /* Actual Set # at area k */
       int     alloc_vessels;   /* Simulated trip # at each period */
       int     SW_set_sum;    /* total SW-targeted sets (simulated) */
       long    revenue_sum;  /* Area sum of Revenue */
       long    cost_sum;  /* Area sum of shared costs excluding tax & fee */
       };
struct table2 area_tbl [MAXAREA];

struct info1          /* Table1 */
{
       /* int   cat1;     CATCH and HOOKS are set from File1
         long hk1;                                          */
       long    stock1; /* Initial stock. */
       int     cat2;   /* total catch from the simulation */
       };
struct info1 fish [MAXAREA] [MAXSP];

/* Global variables, such as index for Tables */
int     Policy_num, MV_flg, k_area, i_sp, SWset_added, catch2[MAXSP];
long    G_ave_rev, G_cost, Next_B[4], Next_BYF[4];
float   tax_rate, wage_adj, adjust_r88,       sum_VD_sv, sum_VD_sv30, MAPE,
       GWI_opt, GWI_prev, GWI_sv2, GWI_sv30, adjust_GWI;
           /* GWI_opt:   Wage_index --> Normalized Crew Wage,
              GWI_prev: NCW (global) at the previous period.
              MAPE: Mean average percentage error */

int main( int argc, char *argv[] )
{
       /*  Input files:
```

```
        *fptr:  "file3.prn": catch & hooks for each Month/Area
        *fptr2: "Areatbl.prn" AREA - distance
        *fptr4: "f_price2.prn" prices of 6 major species
        *fprt5: "gammas6.prn" wage_index and gammmas for 6 major species.
*/
FILE *fptr, *fptr2, *fptr4, *fptr5;
char area[8];
int  mon1, mon2, set_n1, i, n, sim_cnt;  /*  sp_code, */
long hooks, w_stock[MAXSP];
float gamma[MAXSP];
/*
float gamma_adj;  variable to scale down gamma for all species
                  Obtain this from the first line of F_PRICE2 */

/* Command format check */
if (argc != 3)
       { printf("Format: C>FSIM12 filename policy_number");
         exit(1); }
printf("Program name = %s,  filename = %s\n", argv[0], argv[1]);
MV_flg = 0;
Policy_num = atoi( argv[2] );
printf("Policy_num = %d", Policy_num);
/* Policy_num
        00      Basic w/o MV            10  with MV model     20 with YFMV
        01      Closure of MHI                                11 with MV model
        02      Closure of North Sea > 30 N
        03      Revenue tax 10%
        04      Revenue tax only on swordfish
        05      No swordfish sets are allowed
        06      Closure if 15N60W and 20N160W   */

if  (Policy_num > 19)
    {
    MV_flg = 2;
    Policy_num = Policy_num - 20;
    printf("\n --> Model with Movement of BE & YF: Policy_num = %d",
                Policy_num);
    }
else if  (Policy_num > 9)
    {
    MV_flg = 1;
    Policy_num = Policy_num - 10;
    printf("\n --> Model with MV (BE Movement): Policy_num = %d",
                Policy_num);
    };

if  (Policy_num == 3)
        tax_rate = fee_rate + 0.100;       /* 20% tax rate + 0.5% */
else
        tax_rate = fee_rate;
printf("      tax_rate = %.3f\n", tax_rate);

n=0;    /* Read FILE2, and set AREA info into Table2 */
if ( (fptr2 = fopen("AREATBL.PRN", "r")) == NULL)
       { printf("Can't open file AREATBL.PRN.\n"); exit(1); }

while ( fscanf(fptr2, "%s %d", area_tbl[n].area_nm,
       &area_tbl[n].dist) != EOF )
       n++;
fclose(fptr2);
printf("\n number of AREAs = %d     MAXAREA= %d\n", n, MAXAREA);

/*  M A I N    L O O P  */

/* Read Gammas FILE, and set gammas in Table1 */
if ( (fptr5 = fopen("gammas6.PRN", "r")) == NULL)
    { printf("Can't open file gammas6.PRN.\n"); exit(1); };

sim_cnt=0;
/* Read catchability (gammas) for tuna set */
if ( fscanf(fptr5, "%f %f %f %f %f %f %f", &wage_adj,
                       &gamma[0],
                       &gamma[1],
                       &gamma[2],
                       &gamma[3],
```

```
                        &gamma[4],
                        &gamma[5]) == EOF )
        { printf("Can't fscanf gammas6.PRN.\n"); exit(1); };

for (i_sp=0; i_sp < MAXSP; i_sp++)
        sp_tbl[i_sp].gamma1 = gamma[i_sp]*wage_adj;
  /* Increase Gammas, then obtain Marginal Rev instead of Ave Rev */
/* Read catchability (gammas) for swordfish sets */
if ( fscanf(fptr5, "%f %f %f %f %f %f %f", &wage_adj,
                        &gamma[0],
                        &gamma[1],
                        &gamma[2],
                        &gamma[3],
                        &gamma[4],
                        &gamma[5]) == EOF )
        { printf("Can't fscanf gammas6.PRN.\n"); exit(1); };

for (i_sp=0; i_sp < MAXSP; i_sp++)
        sp_tbl[i_sp].gamma2 = gamma[i_sp]*wage_adj;
fclose(fptr5);          /* Close gammas6.prn */

/* ********************************* ************** */
    n=0;
    k_area=0;
    i_sp=0;
    mon1=0;
    MAPE=0.0000;
    GWI_prev = 900.00; /* The average of Dec 1995-97. */
    printf("\nTry out simulation with new gammas ...  ");
    printf("wage_adj = %f\n", wage_adj);

    /* Read FILE4, and set mothly fish prices into Table1 */
    if ( (fptr4 = fopen("F_PRICE2.PRN", "r")) == NULL)
        { printf("Can't open file F_PRICE2.PRN.\n"); exit(1); }

    /* Open main file: FILE1.PRN */
    if ( (fptr = fopen(argv[1], "r")) == NULL)
        { printf("Can't open file %s.\n",argv[1]); exit(1); }

    while ( fscanf(fptr, "%d %s %d %ld %ld %ld %ld %ld %ld",
                &mon2, area, &set_n1, &w_stock[0],
                                        &w_stock[1],
                                        &w_stock[2],
                                        &w_stock[3],
                                        &w_stock[4],
                                        &w_stock[5]) != EOF )

        {
        /* Input data check: month, catch, hooks */
        if (mon2 < 1 || mon2 > MAXMO)
           {
           printf("Month in input File88 was NOT appropriate: %d\n",
                        mon2);
           exit(1);
           };

        /*  Check whether or not the current data is for
            new month */
        if ( mon1 == 0 )
                        /* When current data is the 1st record */
           {
           init_tbl1();                 /* Initialize Table1 */
           mon1 = mon2;         /* set the current month to month2 */
           read_prices(fptr4, mon1);
           }
        else if (mon1 != mon2)
           {
           print_tbl1(mon1); /* print out info. in last month */
           sim_main(mon1);              /* top loop of simulation */
           /* Preparation of simulation with next month data */
           init_tbl1();                 /* Initialize Table1 */
           mon1 = mon2;         /* set the current month to month2 */
           read_prices(fptr4, mon1);
           };
```

```
            k_area = get_area_idx(area);
            if (k_area < 0)
               {
               printf("Area code %s does NOT exist.\n", area);
               exit(1);
               };

            /* set input data into the internal table INFO1 */
            /* fish[k_area][i_sp].cat1=wk_cat;
               fish[k_area][i_sp].hk1=hooks; */
            area_tbl[k_area].set_num1 = set_n1;
            for (i=0; i < MAXSP; i++)
                fish[k_area][i].stock1= w_stock[i];
            n++;            /* Loop counter up */
            }

        /* Final Procedure */
        fclose(fptr);       fclose(fptr4);
        print_tbl1(mon1); /* print out info. in last month */
        sim_main(mon1);      /* Simulation for the last month data */
        sim_cnt++;
        printf("\n  Sim No.= %d  MAPE_total ==> %.4f\n\n", sim_cnt, (MAPE/MAXMO));
    /*****************************************************/
    printf("\n   Thank you for using FSIM12.  Good-by.\n\n");
    return 0;
}

void init_tbl1(void)   /* Initialize Table1 */
{
    int i, k;
    printf("\n\nInitializeing Table1 \n");

    for (k=0; k < MAXAREA; k++)
        {
        area_tbl[k].alloc_vessels=0;
        area_tbl[k].set_num1=0;
        area_tbl[k].revenue_sum=0;
        area_tbl[k].cost_sum=0;
        area_tbl[k].SW_set_sum=0;
        for (i=0; i < MAXSP; i++)
            {
            /* fish[j][k].cat1=0;
              fish[j][k].hk1=0;   */
            fish[k][i].stock1=0;
            fish[k][i].cat2=0;
            }
        }
}

void print_tbl1(int month)     /* Print out info in Table1 */
{
    int j, k, flg;

    printf("\nNo printout info. of fish stock for month=%d\n",
            month);
}

void read_prices(FILE *fptr, int mon1)       /* Read prices for each species */
{
    int    j, mon3;
    float  p[MAXSP];

    if ( fscanf(fptr, "%d %f %f %f %f %f %f", &mon3,
                &p[0], &p[1], &p[2], &p[3], &p[4], &p[5]) == EOF )
            {printf("Price file is EOF\n"); exit(1);}
    else if (mon1 != mon3)
            {
            printf("Month %d in Price file is unmatched.\n", mon3);
            exit(1);
            };

    for (j=0; j < MAXSP; j++)
        sp_tbl[j].price = p[j];

    printf("\nPrice of each species for month=%d.\n", mon3);
```

```
        printf("sp_cd     gamma1      gamma2     price  \n");
        for (j=0; j < MAXSP; j++)
                printf("  %2d     %.6f   %.6f   %.2f\n", sp_tbl[j].sp_cd,
                        sp_tbl[j].gamma1, sp_tbl[j].gamma2, sp_tbl[j].price);
        printf("\n");
}

int get_sp_idx(int sp_code)
{
        int j=0;
        while (sp_tbl[j].sp_cd !=sp_code && j < MAXSP)
                j++;
        if (sp_tbl[j].sp_cd == sp_code)
                return j;
        else
                return (-1);
}

int get_area_idx(char area1[])   /* a function to get idx-area */
{
        int j=0;
        while ( strcmp(area_tbl[j].area_nm, area1) != 0 && j < MAXAREA)
                j++;
        if ( strcmp(area_tbl[j].area_nm, area1) == 0)
                return j;
        else
                return (-1);
}

void sim_main(int month)      /* main function for simulation */
{
        int     v_cnt, trips, exit_flg;
        float   max_WI;

        printf("\n _ _ _ _ Simulation for month=%d _ _ _ _\n\n", month);
        if (month < 1 || month > MAXMO)
           {printf("Month should be between 1 and %d.\n", MAXMO); exit(1);};

        /*
        1. Allocate first vessel to all areas and calculate "wage index"
           (WI) for each area (rather than PROFIT).
           [See GET_MAX_WI for the definition of WI.]
        2. Find one area (k_area) where WI could be maximized.

        3. Compute the global WI (GWI) from WI of all area
           after one additional trip has been allocated to the area.
           Simultaneously, total vessel days (VD) by all vessels
           in the current period is computed.

        4. If VD >= S_func(GWI) (or allocated vessel num > MAX_vessel),
           then - decrease the current stock for each species by catches
                        fish[k_area][i_sp].stock1
                - Print AREA & catch info
                - v_cnt++;
        4. Else
                Stop allocating vessels, and print summarized results.
        */

        if      (month > 24)    /* Year 1997 */
                adjust_r88 = adjust_r97;
        else if (month > 12)    /* Year 1996 */
                adjust_r88 = adjust_r96;
        else
                adjust_r88 = adjust_r95;
        printf("Multiplier (adjust_r88) = %.5f\n", adjust_r88);

        /* Replace the initial stock for the 4 MHI areas with Next_B  if MV_flg == 1.  */
        replace_stock_with_estimate(MV_flg);

        v_cnt=0;
        exit_flg=0;
        sum_VD_sv= 0.0;  sum_VD_sv30 = 0.0;
        GWI_sv2  = 0.0;   GWI_sv30  = 0.00;  adjust_GWI = 0.0;

        while ( (v_cnt < MAX_vessel) && (exit_flg == 0) )
```

```
        {
        /* Find an area where WI is maximized with additional trip. */
        max_WI = get_max_WI();
        /* k_area is also set. */
        printf("(v=%d) Get_MAX_WI: k= %d, Max Area=%s, max_WI=%.2f\n",
                  v_cnt, k_area, area_tbl[k_area].area_nm, max_WI);

        if (max_WI > 0)
            exit_flg = exam_WI_supply(k_area);
        else
            exit_flg=1;
        if (exit_flg == 0)
            {
            area_tbl[k_area].alloc_vessels++;
            trips=area_tbl[k_area].alloc_vessels;
            max_WI = calc_WI(k_area, trips);
            /* Return G_ave_rev & G_cost, SWset_added, too. */
            area_tbl[k_area].revenue_sum = G_ave_rev*trips;
            area_tbl[k_area].cost_sum = G_cost*trips;
            area_tbl[k_area].SW_set_sum+=SWset_added;

            printf(" SWset_added= %d \n", SWset_added);

            /* UPDATE simulated catch of each species */
            for (i_sp=0; i_sp < MAXSP; i_sp++)
                  fish[k_area][i_sp].cat2= catch2[i_sp];
            v_cnt++;
            }
        else
            printf("Wage Index is NOT high enough for vessel#= %d\n",
                    v_cnt);
        };
      /* print summarized results of this month for each area */
      print_results(month, v_cnt);
      /* Set the current global NCW to the previous NCW */
      printf(" GWI_opt= %.2f  GWI_sv2= %.2f  adjust_GWI= %.2f\n\n",
                                  GWI_opt, GWI_sv2, adjust_GWI);
      /* It must be that GWI_opt > 0 && GWI_sv2 >= 0 */
      if  (GWI_opt <= 0.0)
          {
          printf("ERROR: GWI_opt must be positive.\n");
          exit(1);
          };
      /* Set GWI_prev --> determine Max_VD in the next period. */
      if  (GWI_sv2 > 0.00)
           GWI_prev = GWI_sv2;
      else if  ((adjust_GWI/GWI_opt) > 0.20)
             {
             printf("\n Adjust_WI is more than 20 percent of GWI.   ");
             GWI_prev = GWI_opt*(1.000 + minus20percent);
             }
      else if (adjust_GWI > 0.0)
             GWI_prev = GWI_opt - adjust_GWI;  /* Minor adjustment */
      else
             GWI_prev = GWI_opt;
      /*  Calc the initial stocks for the 4 MHI areas */
      calc_next_stock(month);
}

float get_max_WI(void)
{                        /* Find the AREA to maximize WI, and return WI, cat2, k_area */
      int     k, trips, exclusive_flg;
      float   WI, max_WI;
                /* WI: Wage Index */
      /*  At area K,
      1. Compute "Average Revenue (AR)", assuming additional one trip
         is allocated to area K.
      2. Calc Costs of this trip
      2.1  Determine # of SW_sets within 10 sets.
      2.2  Calc Fishing_cost.
      2.3  Calc D_travel (travel days) and Travel_cost.
      2.4  Shared_cost = Fishing_Cost + Travel_Cost
      3. Calc Crews Wage (including captain):
            [AR *( 1 - fee_rate) - shared_cost] * 0.50
      4. Estimate EW (= Expected CW) by fishing & travel days.
```

```
        5. Normalized Crew Wage (WI) = Crew Income/trip
                                       ----------------------------------
                                       FD + (wage-fishg/wage-traveling)*TD
              OLD method: WI = CW / EW
        6. Find area K where WI is maximized.
        */
        max_WI=-9.9999;
        for (k=0; k < MAXAREA; k++)
            {
            /* printf("%s (dist=%d): ", area_tbl[j].area_nm,
                        area_tbl[j].dist); */
            WI=0.00;
            exclusive_flg=check_area(k, Policy_num);

            if (exclusive_flg == 0)
                {
                /* calc TR with additional trip to area K */
                trips=area_tbl[k].alloc_vessels +1;
                WI = calc_WI(k, trips);

                if (WI > max_WI)
                   {
                   max_WI = WI;
                   k_area = k;          /* set the global variable k_area */
                   };
                };
            };
        return max_WI;
}

int check_area(int k1, int p_no)
     /* Check whether fishing area K is closed year round.  If closed, return 1. Otherwise
return 0. */
{
        /* int  k1;  area index for EXCL_AREA_TBL
                        1:      Closure of MHI areas
                        2:      Closure of areas North of 30 N
                        3:      Additional 10% REvenue Tax
                        4:      Tax only on swordfish
                        5:      No swordfish sets are allowed.
                        6:      Closing "n15W160" and "n20w160" */
        int     flag;

        flag = 0;
        if  ((p_no == 1) && (k1 == 9 || k1 == 15))
                                       /* area[15] == "n20w155"
                                          area[9]  == "n15w155" */
              {
              printf("Area Closed ==> %s\n", area_tbl[k1].area_nm);
              flag = 1;
              }
        else if  ((p_no == 6) && (k1 == 10 || k1 == 16))
                                       /* area[16] == "n20w160"
                                          area[10]  == "n15w160" */
              {
              printf("Area Closed ==> %s\n", area_tbl[k1].area_nm);
              flag = 1;
              }
        else if  ((p_no == 2) && (k1 > 28))
                                      /* k1 >= 29  means Areas > 30N */
                 {
                 printf("Area Closed ==> %s\n", area_tbl[k1].area_nm);
                 flag = 1;
                 }
        else
              flag = 0;

        return (flag);
}

float calc_WI (int k, int trips)
{                       /* Calc Normalized Crew Wage at Area K */

        int     j, snum1, snum2, snum1b, snum2b;
              /* snum1: # of tuna sets, snum2: # of swordfish sets */
```

```
long    AR, fishing_cost, travel_cost, shared_cost;
long     crew_income, MAX_income;
float   NCW, D_travel, adj_tripday, tmp1, SWset_rate;
        /* NCW: Normalized Crew Wage */

SWset_added = 0;
/* Compute Travel Costs */
D_travel = area_tbl[k].dist * 2 / V_speed;
travel_cost = unit_TC2*D_travel + 0.50;

snum2 = area_tbl[k].SW_set_sum;    /* Total # of SW sets */
snum1 = trips*setsnum - snum2;     /* Total # of tuna sets */
MAX_income = 0;

for (j=0; j < 11; j++)
    {
    snum1b = snum1 - j;
    snum2b = snum2 + j;

    /* calc TR with additional trip to area K */
    if (trips > 0)
        AR = calc_rev2(k, trips, snum1b, snum2b);
    else
        AR = 0;
    /* printf("calc_WI: AR = %ld, SW_set = %d\n", AR, j); */

    crew_income = 0;
    tmp1 = snum1b + snum2b;

    if (AR > 0 && tmp1 > 0)
        {
        /* Calculate Shared Costs */
        SWset_rate   = snum2b / tmp1;
        fishing_cost = tuna_costs*setsnum
                     + SW_costs*SWset_rate*setsnum + 0.50;
        /*D_travel = area_tbl[k].dist * 2 / V_speed;
          travel_cost = unit_TC2*D_travel + 0.50; */
        shared_cost = fishing_cost + travel_cost;
        /* Compute Crews Wage, assuming the share for
            captain & crews is 50%.  */
        crew_income = (AR*(1.0 - tax_rate) - shared_cost)*0.500;
        if (crew_income > MAX_income)
            (
            MAX_income = crew_income;
            SWset_added = j;
            );
        };
    );

/* Re-calculate AR with SWset_added that maximize crew wage */

if (MAX_income > 0)
    {
    snum1b = snum1 - SWset_added;
    snum2b = snum2 + SWset_added;

    AR = calc_rev2(k, trips, snum1b, snum2b);
    /* catch2[MAXSP] is global variable to return cumulative catch */
    /* Calculate Shared Costs */
    tmp1 = snum1b + snum2b;
    SWset_rate   = snum2b / tmp1;
    fishing_cost = tuna_costs*setsnum
                 + SW_costs*SWset_rate*setsnum + 0.50;
    shared_cost = fishing_cost + travel_cost;
    }
else
    {
    AR = 0;
    shared_cost = 0;
    };

/*WI = MAX_income / calc_EW(setsnum, D_travel); */

adj_tripday = setsnum + D_travel*THETA;
NCW = MAX_income / adj_tripday;
/* emergent printf */
```

```
        /* printf("calc_WI: area=%s, SW_set= %d, trips=%d, Sets num (%d, %d)",
                area_tbl[k].area_nm, SWset_added, trips, snum1b, snum2b);
        printf("  AR= %ld,  WI=%.2f\n", AR, NCW); */

        G_cost = shared_cost;
        G_ave_rev = AR;
        return NCW;
}

long calc_rev2(int k, int trips, int snum1, int snum2)
{       /*
        1. Compute cumulative catches of 6 major species with given
           total trip # (i.e., VNUM).
        2. compute total revenue (TR) from these catches * prices..
        2. return "Average Revenue (AR)" = TR / VNUM.
        3. Returm catch for each speacies, CAT[MAXSP].
        */
        int     i;
                /* snum1: # of tuna sets, snum2: # of swordfish sets */
        long    rev1, rev1tmp, AR;
        float   q1, q2, e1, e2, wk_e;
                /* temp variables to compute the ratio of revenue
                  from swordfish catch */

        /* SWset_rate=0.0; */
        rev1=0;
        /* trips = area_tbl[k].alloc_vessels +1;  See argv for trips */

        for (i=0; i < MAXSP; i++)
            {
            if ( fish[k][i].stock1 > 0 )
                {
                q1 = sp_tbl[i].gamma1;
                q2 = sp_tbl[i].gamma2;
                e1 = snum1*unit_e1/1000.0;
                e2 = snum2*unit_e2/1000.0;
                wk_e = (q1*e1 + q2*e2) * (-1);
                /* Cacth = B0*F() where F() = 1.0 - EXP(-q * effort) */
                catch2[i] = fish[k][i].stock1*(1.0 - exp(wk_e)) + 0.50;

                rev1tmp= sp_tbl[i].price*catch2[i] + 0.50;
                rev1+= rev1tmp;
                /* printf("  cat3[%d]= %d", i, cat3[i]); */
                /* actual_vnum = 1.000 * fish[k][i].hk1 / hks_per_trip;*/
                }
            else
                catch2[i]=0;
            };
        if (trips > 0)
                AR = rev1*adjust_r88 / trips + 0.50;
        else
                AR = 0;
        return  AR;
}

int exam_WI_supply(int k_area)
{       /* Examine if allocated VD (vessel-days) exceed the expected VD based Global WI
(GWI). If given
        GWI level it has already been over allocated, return 1. Otherwide 0. */
        int     j, trips, sum_trips, flg;
        float   WI, sum_WI, GWI, D_travel, slope_b, diff_WI;
                /* WI: Wage Index */
        float   VD2, sum_VD, max_VD, LS_VD, diff_VD3;
                        /* Longline Industrial Total Vessel-Days
                           sum_VD is the one collected,while max_VD is
                           calculated by the labor supply function. */

        printf("exam_WI_supply: k= %d, ", k_area);

        sum_trips=0;  sum_WI=0.00;  sum_VD=0.00;
        /* Compute max_VD using the previos wage */

        for (j=0; j < MAXAREA; j++)
            {
            /* printf("%s (dist=%d): ", area_tbl[j].area_nm,
```

```
                area_tbl[j].dist); */
    /* calc TR with additional trip to area J (MR) */
    if (j == k_area)
        {
        trips=area_tbl[j].alloc_vessels +1;
        WI=calc_WI(j, trips);
        }
    else
        {
        trips=area_tbl[j].alloc_vessels;
        WI=calc_WI2(j, trips);
        };

    /* Summing for computing the weighted NCW */
    sum_WI+=WI*trips;
    sum_trips+=trips;
    /*  SUM vessel-days */
    D_travel = area_tbl[j].dist * 2 / V_speed;
    sum_VD+=(setsnum + D_travel)*trips;
    };

/* After finishing LOOP */
if (sum_trips > 0 && sum_WI > 0)
    {
    GWI = sum_WI/sum_trips;
    /* Compute Labor Supply using function calc_VD */
    LS_VD = calc_VD(GWI);
    max_VD = calc_VD(GWI_prev);
    }
else
    {
    GWI = 0.0;
    max_VD = 0.0;
    };

printf("GWI (%.2f  %.2f) sum_VD= %.1f, max_VD= %.1f\n",
       GWI_prev, GWI, sum_VD, max_VD);

VD2 = (sum_VD_sv + sum_VD) / 2;
if      (VD2 > max_VD)
       flg=1;          /* Stop allocating trips */
else if ((VD2 > LS_VD) && (GWI_sv2 == 0.0))
       {
       flg=0;
       GWI_sv2= GWI;
       printf("\n backup GWI since DDL = LS_VD = %.1f\n", LS_VD);
       }
else
       flg=0;

if  (sum_trips == Minimum_trips)
       {
       sum_VD_sv30 = sum_VD;
       GWI_sv30 = GWI;
       }
else
    if  ((sum_trips > Minimum_trips) && (sum_VD_sv30 == 0))
       {
       printf("\n sum_VD_sv30 inconsistent usuage.\n");
       exit(1);
       };

/* adjust_GWI = 0.0; */
if (flg == 0)
    {
    sum_VD_sv = sum_VD; /* IMPORTANT */

    diff_VD3 = LS_VD - max_VD;
    diff_WI = GWI - GWI_sv30;
    if ((diff_WI < 0) && (diff_VD3 > 0) &&
                        (sum_trips > Minimum_trips))
       {
       slope_b = (sum_VD - sum_VD_sv30) / diff_WI;
       adjust_GWI = (LS_VD - max_VD)*0.9 / (slope_b*(-1));
       printf("   LS_VD= %.1f, slope_b= %.4f, adjust_GWI= %.2f",
                                    LS_VD, slope_b, adjust_GWI);
```

```
                GWI_opt = GWI;
                /*
                if  ((adjust_WI/GWI) > 0.20)
                        {
                        printf("\n Adjust_WI is more than 20 percent of GWI.    ");
                        GWI_opt = GWI*(1.000 + minus20percent);
                        }
                else
                        GWI_opt = GWI - adjust_GWI;  */
                }
            else
                {
                adjust_GWI = 0.00;
                GWI_opt = GWI;
                };
            };

        return flg;
}

float calc_WI2 (int k, int trips)
{                       /* Calc Normalized Crew Wage at Area K */
        int     snum1b, snum2b;
                /* snum1: # of tuna sets, snum2: # of swordfish sets */
        long    AR, fishing_cost, travel_cost, crew_income;
        float   NCW, D_travel, adj_tripday, tmp1, SWset_rate;
                /* NCW: Normalized Crew Wage */

        AR = 0;
        NCW = 0.00;
        /* Compute Travel Costs */
        D_travel = area_tbl[k].dist * 2 / V_speed;
        travel_cost = unit_TC2*D_travel + 0.50;

        snum2b = area_tbl[k].SW_set_sum;    /* Total # of SW sets */
        snum1b = trips*setsnum - snum2b;     /* Total # of tuna sets */

        /* catch2[MAXSP] is global variable to return cumulative catch */
        /* Calculate Shared Costs */
        tmp1 = snum1b + snum2b;
        if  ((tmp1 > 0) && (trips > 0))
                {
                SWset_rate    = snum2b / tmp1;
                /* Calculate AR with SWset_added that maximize crew wage */
                AR = calc_rev2(k, trips, snum1b, snum2b);
                }
        else
                {
                SWset_rate    = 0.00;
                AR = 0;
                };

        if  (AR > 0)
            {
            fishing_cost = tuna_costs*setsnum
                        + SW_costs*SWset_rate*setsnum + 0.50;
            G_cost = fishing_cost + travel_cost;
            crew_income = (AR*(1.0 - tax_rate) - G_cost)*0.500;

            adj_tripday = setsnum + D_travel*THETA;
            NCW = crew_income / adj_tripday;
            /* emergent printf */
            /*printf("calc_WI2: area=%s trips=%d Sets# (%d, %d),",
                        area_tbl[k].area_nm, trips, snum1b, snum2b);
            printf("  AR= %ld  WI=%.2f\n", AR, NCW); */
            };

        /* G_cost = shared_cost; */
        G_ave_rev = AR;
        return NCW;
}

float calc_VD(float NCW)
{       /* Caluculate VD (vessel-days) from Normalized CW (GWI)
        using Labor Supply Function
```

```
                OLD ln(VD) = 2.2918*(lnCW) - 0.17392*(lnCW)^2
                NEW ln(VD) = 2.2777*(lnCW) - 0.17178*(lnCW)^2
                New2 ln(VD) = LSb0 + LSb1*(lnCW) + LSb2*(lnCW)^2  */

        float   wage2, lnCW, lnCW2, lnVD, VD1;

        if  (NCW > MAX_NCW)
                wage2 = MAX_NCW;
        else
                wage2 = NCW;

        lnCW  = log(wage2);
        lnCW2 = lnCW*lnCW;
        lnVD  = LSb0 + LSb1*lnCW + LSb2*lnCW2;
        VD1   = exp(lnVD);
        return VD1;
}

void calc_next_stock(int month)
{     /* Caluculate the initial stocks at the next period. See Chapter 9

                        10: 10N155W (4),  11: 10N160W (5),
        1: 15N150W (8),  2: 15N155W (9),   3: 15N160W (10),  12: 15N165W (11)
        4: 20N150W (14); 5: 20N155W (15),  6: 20N160W (16),  7: 20N165W (17),
                         8: 25N155W (23),  9: 25N160W (24)
        */

        int     i, k;
        long    BR[13];
        float   R15N155, R15N160, R20N155, R20N160, r1;

        printf("calc_next_stock: BE stock at Month = %d\n", month);
        i = 4;
        BR[0] = 0;  /* dummy */

        /* 15N150W */
        k = 8;
        BR[1] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[1] %ld =  %ld  -  %d\n",
                BR[1], fish[k][i].stock1, fish[k][i].cat2);
        /* 15N155W */
        k = 9;
        BR[2] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[2] %ld =  %ld  -  %d\n",
                BR[2], fish[k][i].stock1, fish[k][i].cat2);
        /* 15N160W */
        k = 10;
        BR[3] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[3] %ld =  %ld  -  %d\n",
                BR[3], fish[k][i].stock1, fish[k][i].cat2);
        /* 20N150W */
        k = 14;
        BR[4] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[4] %ld =  %ld  -  %d\n",
                BR[4], fish[k][i].stock1, fish[k][i].cat2);
        /* 20N155W */
        k = 15;
        BR[5] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[5] %ld =  %ld  -  %d\n",
                BR[5], fish[k][i].stock1, fish[k][i].cat2);

        /* 20N160W */
        k = 16;
        BR[6] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[6] %ld =  %ld  -  %d\n",
                BR[6], fish[k][i].stock1, fish[k][i].cat2);
        /* 20N165W */
        k = 17;
        BR[7] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[7] %ld =  %ld  -  %d\n",
                BR[7], fish[k][i].stock1, fish[k][i].cat2);
        /* 25N155W */
        k = 23;
        BR[8] = fish[k][i].stock1 - fish[k][i].cat2;
```

```
printf("residual BR[8] %ld =  %ld  -  %d\n",
       BR[8], fish[k][i].stock1, fish[k][i].cat2);
/* 25N160W */
k = 24;
BR[9] = fish[k][i].stock1 - fish[k][i].cat2;
printf("residual BR[9] %ld =  %ld  -  %d\n",
       BR[9], fish[k][i].stock1, fish[k][i].cat2);
/* 10N155W */
k = 4;
BR[10]= fish[k][i].stock1 - fish[k][i].cat2;
printf("residual BR[10] %ld =  %ld  -  %d\n",
       BR[10], fish[k][i].stock1, fish[k][i].cat2);
/* 10N160W */
k = 5;
BR[11]= fish[k][i].stock1 - fish[k][i].cat2;
printf("residual BR[11] %ld =  %ld  -  %d\n",
       BR[11], fish[k][i].stock1, fish[k][i].cat2);
/* 15N165W */
k = 11;
BR[12]= fish[k][i].stock1 - fish[k][i].cat2;
printf("residual BR[12] %ld =  %ld  -  %d\n",
       BR[12], fish[k][i].stock1, fish[k][i].cat2);

printf("new inflow at the 4 MHI areas: \n");
R15N155 = mvb0A*BR[2] + mvb1A*BR[5] + mvb2A*BR[1]
                      + mvb3A*BR[10] + mvb4A*BR[3];
if  (R15N155 > 2000)
    {
    printf("Warning: R15N155= %.1f: more than 20000.\n",
               R15N155);
    R15N155 = 2000;
    };

r1 = R15N155 / BR[2];
printf("  R15N155= %.1f   BR[2] = %ld  and r1 = %.4f\n",
               R15N155, BR[2], r1);
if (r1 < minus20percent)
       Next_B[0] = BR[2] * (1+ minus20percent) + 0.5;
else
       Next_B[0] = BR[2] + R15N155 + 0.5;

R15N160 = mvb0B*BR[3] + mvb1B*BR[6]  + mvb2B*BR[2]
                                + mvb3B*BR[11] + mvb4B*BR[12];
if  (R15N160 > 2000)
    {
    printf("Warning: R15N160= %.1f: more than 2000.\n",
               R15N160);
    R15N160 = 2000;
    };

r1 = R15N160 / BR[3];
printf("  R15N160= %.1f   BR[3] = %ld and r1 = %.4f\n",
               R15N160, BR[3], r1);
if (r1 < minus20percent)
       Next_B[1] = BR[3] * (1+ minus20percent) + 0.5;
else
       Next_B[1] = BR[3] + R15N160 + 0.5;

R20N155 = mvb0C*BR[5] + mvb1C*BR[8] + mvb2C*BR[4]
                                + mvb3C*BR[2] + mvb4C*BR[6];
if  (R20N155 > 2000)
    {
    printf("Warning: R20N155= %.1f: more than 2000.\n",
               R20N155);
    R20N155 = 2000;
    };

r1 = R20N155 / BR[5];
printf("  R20N155= %.1f   BR[5] = %ld, and r1 = %.4f\n",
               R20N155, BR[5], r1);
if (r1 < minus20percent)
       Next_B[2] = BR[5] * (1+ minus20percent) + 0.5;
else
       Next_B[2] = BR[5] + R20N155 + 0.5;

R20N160 = mvb0D*BR[6] + mvb1D*BR[9] + mvb2D*BR[5]
```

```
                        + mvb3D*BR[3] + mvb4D*BR[7];
        if  (R20N160 > 2000)
            {
            printf("Warning: R20N160= %.1f: more than 2000.\n",
                        R20N160);
            R20N160 = 2000;
            };

        r1 = R20N160 / BR[6];
        printf("  R20N160= %.1f   BR[6] = %ld , and r1 = %.4f\n",
                        R20N160, BR[6], r1);
        if (r1 < minus20percent)
                Next_B[3] = BR[6] * (1+ minus20percent) + 0.5;
        else
                Next_B[3] = BR[6] + R20N160 + 0.5;

        printf("news initial stock at 4 MHI areas = %ld  %ld  %ld  %ld\n",
                        Next_B[0], Next_B[1], Next_B[2], Next_B[3]);

        calc_next_YFstock(month);
}

void calc_next_YFstock(int month)
{       /* Caluculate the initial stocks of YF (Yellowfin) at the next period. */

        int     i, k;
        long    BR[13];
        float   R15N155, R15N160, R20N155, R20N160, r1;

        printf("calc_next_YFstock: Month = %d\n", month);
        i = 5;  /* YF */
        BR[0] = 0;  /* dummy */

        /* 15N150W: compute the residual stock */
        k = 8;
        BR[1] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[1] %ld =  %ld  -  %d\n",
                BR[1], fish[k][i].stock1, fish[k][i].cat2);
        /* 15N155W */
        k = 9;
        BR[2] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[2] %ld =  %ld  -  %d\n",
                BR[2], fish[k][i].stock1, fish[k][i].cat2);
        /* 15N160W */
        k = 10;
        BR[3] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[3] %ld =  %ld  -  %d\n",
                BR[3], fish[k][i].stock1, fish[k][i].cat2);
        /* 20N150W */
        k = 14;
        BR[4] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[4] %ld =  %ld  -  %d\n",
                BR[4], fish[k][i].stock1, fish[k][i].cat2);
        /* 20N155W */
        k = 15;
        BR[5] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[5] %ld =  %ld  -  %d\n",
                BR[5], fish[k][i].stock1, fish[k][i].cat2);

        /* 20N160W */
        k = 16;
        BR[6] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[6] %ld =  %ld  -  %d\n",
                BR[6], fish[k][i].stock1, fish[k][i].cat2);
        /* 20N165W */
        k = 17;
        BR[7] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[7] %ld =  %ld  -  %d\n",
                BR[7], fish[k][i].stock1, fish[k][i].cat2);
        /* 25N155W */
        k = 23;
        BR[8] = fish[k][i].stock1 - fish[k][i].cat2;
        printf("residual BR[8] %ld =  %ld  -  %d\n",
                BR[8], fish[k][i].stock1, fish[k][i].cat2);
        /* 25N160W */
```

```
k = 24;
BR[9] = fish[k][i].stock1 - fish[k][i].cat2;
printf("residual BR[9] %ld =  %ld  -  %d\n",
       BR[9], fish[k][i].stock1, fish[k][i].cat2);
/* 10N155W */
k = 4;
BR[10]= fish[k][i].stock1 - fish[k][i].cat2;
printf("residual BR[10] %ld =  %ld  -  %d\n",
       BR[10], fish[k][i].stock1, fish[k][i].cat2);
/* 10N160W */
k = 5;
BR[11]= fish[k][i].stock1 - fish[k][i].cat2;
printf("residual BR[11] %ld =  %ld  -  %d\n",
       BR[11], fish[k][i].stock1, fish[k][i].cat2);
/* 15N165W */
k = 11;
BR[12]= fish[k][i].stock1 - fish[k][i].cat2;
printf("residual BR[12] %ld =  %ld  -  %d\n",
       BR[12], fish[k][i].stock1, fish[k][i].cat2);

printf("new inflow at the 4 MHI areas: \n");
R15N155 = mvy0A*BR[2] + mvy1A*BR[5] + mvy2A*BR[1]
                      + mvy3A*BR[10] + mvy4A*BR[3];
if  (R15N155 > 2000)
    {
    printf("Warning: R15N155= %.1f: more than 20000.\n",
                R15N155);
    R15N155 = 2000;
    };

r1 = R15N155 / BR[2];
printf("  R15N155= %.1f   BR[2] = %ld  and r1 = %.4f\n",
                R15N155, BR[2], r1);
if (r1 < minus20percent)
       Next_BYF[0] = BR[2] * (1+ minus20percent) + 0.5;
else
       Next_BYF[0] = BR[2] + R15N155 + 0.5;

R15N160 = mvy0B*BR[3] + mvy1B*BR[6]  + mvy2B*BR[2]
                      + mvy3B*BR[11] + mvy4B*BR[12];
if  (R15N160 > 2000)
    {
    printf("Warning: R15N160= %.1f: more than 2000.\n",
                R15N160);
    R15N160 = 2000;
    };

r1 = R15N160 / BR[3];
printf("  R15N160= %.1f   BR[3] = %ld and r1 = %.4f\n",
                R15N160, BR[3], r1);
if (r1 < minus20percent)
       Next_BYF[1] = BR[3] * (1+ minus20percent) + 0.5;
else
       Next_BYF[1] = BR[3] + R15N160 + 0.5;

R20N155 = mvy0C*BR[5] + mvy1C*BR[8] + mvy2C*BR[4]
                      + mvy3C*BR[2] + mvy4C*BR[6];
if  (R20N155 > 2000)
    {
    printf("Warning: R20N155= %.1f: more than 2000.\n",
                R20N155);
    R20N155 = 2000;
    };

r1 = R20N155 / BR[5];
printf("  R20N155= %.1f   BR[5] = %ld, and r1 = %.4f\n",
                R20N155, BR[5], r1);
if (r1 < minus20percent)
       Next_BYF[2] = BR[5] * (1+ minus20percent) + 0.5;
else
       Next_BYF[2] = BR[5] + R20N155 + 0.5;

R20N160 = mvy0D*BR[6] + mvy1D*BR[9] + mvy2D*BR[5]
                      + mvy3D*BR[3] + mvy4D*BR[7];
if  (R20N160 > 2000)
    {
```

```
            printf("Warning: R20N160= %.1f: more than 2000.\n",
                        R20N160);
            R20N160 = 2000;
            };

        r1 = R20N160 / BR[6];
        printf("  R20N160= %.1f   BR[6] = %ld , and r1 = %.4f\n",
                        R20N160, BR[6], r1);
        if (r1 < minus20percent)
                Next_BYF[3] = BR[6] * (1+ minus20percent) + 0.5;
        else
                Next_BYF[3] = BR[6] + R20N160 + 0.5;

        printf("news initial stock at 4 MHI areas = %ld  %ld  %ld  %ld\n",
                        Next_BYF[0], Next_BYF[1], Next_BYF[2], Next_BYF[3]);
}

void replace_stock_with_estimate (int movement_flg)
{
     /* Replace the given initial stocks for bigeye with
       the estimates by fish movement equations Next_B [0-3]. */

        int     i, k;
        long    diff1;

        printf("Replace_Stock_with_Estimae : MV_flg = %d\n\n", movement_flg);

        i = 4; /* bigeye (BE) */
        printf("MHI stock  k_area     in_FILE88c     Next_B     Diff\n");
        k = 9;
        diff1 = Next_B[0] - fish[k][i].stock1;
        printf("MHI stock  k= %d          %ld          %ld        %ld\n",
                        k, fish[k][i].stock1, Next_B[0], diff1);
        k = 10;
        diff1 = Next_B[1] - fish[k][i].stock1;
        printf("MHI stock  k= %d          %ld          %ld        %ld\n",
                        k, fish[k][i].stock1, Next_B[1], diff1);
        k = 15;
        diff1 = Next_B[2] - fish[k][i].stock1;
        printf("MHI stock  k= %d          %ld          %ld        %ld\n",
                        k, fish[k][i].stock1, Next_B[2], diff1);

        k = 16;
        diff1 = Next_B[3] - fish[k][i].stock1;
        printf("MHI stock  k= %d          %ld          %ld        %ld\n",
                        k, fish[k][i].stock1, Next_B[3], diff1);


        if  ((movement_flg > 0) && (Next_B[0] > 0) && (Next_B[1] > 0))
                {
                printf("\n Replace initial stocks with Next_B[0-3].\n\n");
                k = 9;
                fish[k][i].stock1 = Next_B[0];
                k = 10;
                fish[k][i].stock1 = Next_B[1];
                k = 15;
                fish[k][i].stock1 = Next_B[2];
                k = 16;
                fish[k][i].stock1 = Next_B[3];
                }
        else
                printf("\n No Replacement. \n\n");

        if  ((movement_flg == 0) && (Next_BYF[0] > 0) && (Next_BYF[1] > 0))
                {
                printf("\n Replace initial stocks with Next_BYF[0-3].\n\n");
                i = 5; /* Yellowfin tuna (YF) */

                k = 9;
                fish[k][i].stock1 = Next_BYF[0];
                k = 10;
                fish[k][i].stock1 = Next_BYF[1];
                k = 15;
                fish[k][i].stock1 = Next_BYF[2];
                k = 16;
```

```
                fish[k][i].stock1 = Next_BYF[3];
                }
        else
                printf("\n No Replacement for YF. \n\n");

}

void print_results(int month, int v_cnt)
                                /* Print out results of Simulation */
{
        int     i, j, k, v_cnt11, v_cnt2a, c9[MAXSP], freq_e[4], freq_e2;
        int     v1_north, v1_MHI, v1_south, v1_mix,
                v2_north, v2_MHI, v2_south, v2_mix, SWset_total;

        long    sp_sum1[MAXSP], sp_sum2[MAXSP], wk_rev, wk_cost;
        float   actual_V, v_cnt2, actual_Q, sim_Q, D_travel, MAPE1;
        float   Chi_sq, dif1, tmp2, ratio3, wk[4], freq_o[4];

        printf("\nPrint out Sim_Results for month=%d; V_cnt =%d\n\n",
                month, v_cnt);
        /* Note: Since v_cnt counts from zero, it represents # of vessels
          allocated in this month. */

        v_cnt11=0;                      /* Initialize counters */
        SWset_total=0;
        wk_rev=0;
        wk_cost=0;
        v_cnt2a = 0; /* Sum of actual set # */
        v_cnt2=0.0;

        v1_north=0; v1_MHI=0; v1_south=0; v1_mix=0; v2_north=0;
        v2_MHI=0; v2_south=0; v2_mix=0;
        actual_Q=0.0; sim_Q=0.0;

        for (i=0; i < MAXSP; i++)
            {
            sp_sum1[i]=0;
            sp_sum2[i]=0;
            };

        /* Print Image: month, rea, trip# act/sim SWsets, Rev, Cost, catches*/
        for (k=0; k < MAXAREA; k++)
            {
            for (i=0; i < MAXSP; i++)
                {
                /* sp_sum1[i]+= fish[k][i].cat1; */
                sp_sum2[i]+= fish[k][i].cat2;
                c9[i]=fish[k][i].cat2;
                };
                /* Suppose hooks for all species should be the same */
            actual_V = area_tbl[k].set_num1 / setnum2;
            printf("%d AREA[%d]= %s; trip nums= %.1f / %d; SWsets= %d; ",
                        month, k, area_tbl[k].area_nm,
                        actual_V, area_tbl[k].alloc_vessels,
                        area_tbl[k].SW_set_sum);

            printf("%ld; %ld; %d %d %d %d %d %d\n", area_tbl[k].revenue_sum,
                area_tbl[k].cost_sum, c9[0],c9[1],c9[2],c9[3],c9[4],c9[5]);

            fitness_check(actual_V, area_tbl[k].alloc_vessels);

            v_cnt11+=area_tbl[k].alloc_vessels;
            SWset_total+=area_tbl[k].SW_set_sum;
            v_cnt2a+=area_tbl[k].set_num1;
            /* v_cnt2+=actual_V; */
            D_travel = area_tbl[k].dist * 2 / V_speed;
            actual_Q+=actual_V*(setsnum + D_travel);
            sim_Q+=area_tbl[k].alloc_vessels*(setsnum + D_travel);
            wk_rev+=area_tbl[k].revenue_sum;
            wk_cost+=area_tbl[k].cost_sum;
            /* Region-based summary */
            if  (k > 28)
                {
                v1_north+=area_tbl[k].alloc_vessels; /* simulated */
                v2_north+=area_tbl[k].set_num1;      /* actual set */
```

```
        }
    else if  ((k == 9) || (k == 15))
        {
        v1_MHI+=area_tbl[k].alloc_vessels;
        v2_MHI+=area_tbl[k].set_num1;
        }
    else if  (k < 13)
        {
        v1_south+=area_tbl[k].alloc_vessels;
        v2_south+=area_tbl[k].set_num1;
        }
    else
        {
        v1_mix+=area_tbl[k].alloc_vessels;
        v2_mix+=area_tbl[k].set_num1;
        };
    };

if (v_cnt != v_cnt11)
    {
    printf ("v_cnt (%d) not= v_cnt11 (%d)\n", v_cnt, v_cnt11);
    exit(1);};
v_cnt2 = v_cnt2a / setnum2;
printf("\nTotal alloc trips(actual/sim)= %.1f / %d ",
        v_cnt2, v_cnt);

printf("[%.1f / %.1f] w= %.2f; Month = %d\n\n",
        actual_Q, sim_Q, GWI_opt, month);

printf("Catch summary:\nSP_actual/sim= ");
for (i=0; i < MAXSP; i++)
    printf("%ld / %ld; ", sp_sum1[i], sp_sum2[i]);

/* Report Revenue, Costs, and Normalized Crew Wage after re-calculate */
printf("\nSim_Rev/cost= %ld / %ld; NCW = %.2f;  ",
        wk_rev, wk_cost, GWI_opt);

MAPE1 = (v_cnt - v_cnt2) / v_cnt2;
printf("MAPE1= %.4f \n\n", MAPE1);

if (MAPE1 < 0)
    MAPE -= MAPE1;
else
    MAPE += MAPE1;

printf("Regional numbers of trips:  MHI   South  Mix    North\n");
wk[0] = v2_MHI   / setnum2;
wk[1] = v2_south / setnum2;
wk[2] = v2_mix   / setnum2;
wk[3] = v2_north / setnum2;

printf("Region-Sum  %d       Actual:     %.1f  %.1f %.1f %.1f\n",
        month, wk[0], wk[1], wk[2], wk[3]);
printf("Region-Sum  %d       Simulated:  %d     %d    %d    %d\n\n",
        month, v1_MHI, v1_south, v1_mix, v1_north);
freq_e[0] = v1_MHI;
freq_e[1] = v1_south;
freq_e[2] = v1_mix;
freq_e[3] = v1_north;

/* Compute Chi-square goodness-of-fit */
Chi_sq = 0.0;
ratio3 = v_cnt / v_cnt2; /* simulated trips / actual trips */
for (j=0; j < 4; j++)
    {
    freq_o[j] = wk[j]*ratio3;
    if  (freq_e[j] < 5)
        {
        printf(" WARNING: Region%d: Sim Trip-No. is less than 5.\n", j);
        freq_e2 = 5;
        }
    else
        freq_e2 = freq_e[j];
    dif1 = freq_o[j] - freq_e[j];
    tmp2 = dif1*dif1 / freq_e2;
    Chi_sq += tmp2;
```

```
            };

        printf("  Month= %d  SWset_total= %d  Chi-square= %.3f\n\n",
                        month, SWset_total, Chi_sq);
}

void fitness_check(float act_V, int sim_V)
{       /* Check and print WARNING message if sim_V differ from
           act_V significantly.

           act_V = actual trip# = set number / 10:
           sim_V = trips # allocated by this simulation
         */
         float   tmp1;

         if  (act_V < 1.1)
             if  (sim_V > const_3)
                 printf("WARNING1: Over-allocated at the above area.\n");
             else
                 tmp1 = act_V;
         else  /* We know act_V > 1.0 */
             {
             tmp1 = (sim_V - act_V) / act_V;
             if      (tmp1 > (const_3 - 1.0))
                 printf("WARNING2: Over-allocated at the above area.\n");
             else if ((act_V > const_3) && (tmp1 < minus_two_third))
                 /* if  [act_V - sim_V) / act_V > 0.6667] */
                 printf("WARNING3: Under-allocated at the above area.\n");
             };
}
```

APPENDIX 7

SUMMARY OF THE NMFS LOGBOOK DATA, 1995-97

(The number of Fishing Trips and Sets, Catch, CPUE and Estimated Stocks)

Tables and figures in this appendix present statistical summaries that may be useful to understand spatial heterogeneity of fish abundance and fishing effort. The catch and effort data summarized from the NMFS logbook records into 5° square monthly strata consist of 842 records. Each record contains the numbers of sets, hooks, and catch of each species for a specific area and month. This data set covers sixty 5° square areas over 36 months. However, if no fishing sets are deployed in a certain area during a certain month, a record for that area and month is excluded from the data set, and is considered as no observations.

Tables A7.1, A7.2, and A7.3 (a) & (b) present the number of sets and catches, effort and CPUE, and estimated initial stocks during 1995-97, summarized by area. Since the initial stocks are not normally distributed, so-called "five number summary (minimum, first quarter, median, third quarter, and maximum)" is presented for each area in Table A7.3 (a) & (b). In addition, "the number of available observations" which is computed as 36 months minus the number of "no observations" for each area, is listed for each area in these two tables.

Tables A7.4 and A7.5 present the same information as Table A7.1 and A7.2, but summarize by year and the four regions – North, Middle, MHI, and South. Monthly changes in fishing sets and catches are presented by polygon, where the number for each month represents the average of 1995, 1996, and 1997. Figure A7.1 presents the monthly change in the number of fishing sets. Figure A7.2 (a)-(f) present monthly CPUE change for each of the six species.

Table A7.1 Effort and Catches of Each Species by Area

	Total		Tuna Set		Swordfish set		Catch					
AREA	No. of sets	Effort	No. of sets	Effort	No. of sets	Effort	BM	SM	SW	AC	BE	YF
N00W160	7	12,630	7	12,630	0	0	8	2	0	3	164	188
N05W155	14	23,278	14	23,278	0	0	4	6	1	0	38	66
N05W160	334	572,390	334	572,390	0	0	217	125	45	23	2,450	3,973
N10W150	6	9,850	6	9,850	0	0	0	72	3	0	10	2
N10W155	346	544,805	346	544,805	0	0	261	271	43	245	2,144	570
N10W160	661	1,073,910	661	1,073,910	0	0	496	790	77	1,806	5,157	1,471
N10W165	452	772,041	452	772,041	0	0	391	602	40	2,582	4,874	1,718
N10W170	3	4,500	3	4,500	0	0	6	5	0	8	19	16
N15W145	3	5,200	3	5,200	0	0	1	1	5	0	12	2
N15W150	1,046	1,513,224	1,045	1,512,552	1	672	263	1,835	124	1,602	7,626	1,607
N15W155	3,983	5,179,820	3,087	4,452,148	896	727,672	3,778	5,201	871	8,683	25,876	11,424
N15W160	5,025	8,023,366	4,752	7,793,695	273	229,671	3,508	8,444	603	41,268	36,214	13,298
N15W165	532	908,948	531	908,148	1	800	379	940	66	10,928	3,549	1,293
N15W170	11	17,000	11	17,000	0	0	9	20	1	140	53	16
N20W145	24	32,596	22	30,660	2	1,936	5	62	49	331	35	14
N20W150	1,980	2,848,242	1,703	2,614,331	277	233,911	931	3,584	2,074	11,982	10,022	1,863
N20W155	4,358	5,137,982	2,352	3,406,886	2,006	1,731,096	3,953	7,629	8,849	21,742	20,436	6,894
N20W160	3,781	5,913,002	3,417	5,607,826	364	305,176	2,659	8,532	1,626	17,514	38,046	7,626
N20W165	1,341	2,191,176	1,279	2,139,302	62	51,874	903	3,502	442	14,604	15,006	2,385
N20W170	57	56,822	16	26,070	41	30,752	36	91	279	419	44	48
N20W175	5	4,070	0	0	5	4,070	5	14	28	1	15	14
N25W135	2	2,000	0	0	2	2,000	0	1	4	38	28	3
N25W140	7	6,850	1	1,000	6	5,850	0	2	52	2	26	13
N25W145	183	168,246	17	26,584	166	141,662	32	60	1,492	400	435	269
N25W150	832	740,137	70	121,590	762	618,547	245	572	7,841	1,668	1,886	1,514
N25W155	1,903	1,625,662	207	264,230	1,696	1,361,432	1,792	2,170	11,419	5,363	5,752	4,178
N25W160	1,775	1,541,192	206	259,299	1,569	1,281,893	1,850	1,794	9,795	3,317	5,976	3,699
N25W165	857	725,727	49	70,490	808	655,237	212	653	8,004	576	1,713	1,102
N25W170	598	494,148	12	19,910	586	474,238	88	246	5,701	484	1,305	729
N25W175	327	258,574	0	0	327	258,574	55	208	3,214	46	404	244
N25E175	32	24,170	0	0	32	24,170	2	5	228	3	34	18
N30W125	41	33,315	4	3,700	37	29,615	0	3	496	11	214	0
N30W130	15	9,985	0	0	15	9,985	0	0	144	0	49	0
N30W135	15	11,931	0	0	15	11,931	0	0	133	4	15	0
N30W140	320	241,340	0	0	320	241,340	8	21	3,585	537	438	17
N30W145	787	625,818	0	0	787	625,818	31	74	8,939	1,363	1,520	226
N30W150	655	506,407	1	600	654	505,807	36	119	7,755	1,955	1,413	513
N30W155	296	241,790	1	1,600	295	240,190	32	34	3,197	850	649	365
N30W160	807	613,658	10	8,780	797	604,878	304	453	7,152	1,701	2,244	566
N30W165	167	126,509	0	0	167	126,509	19	45	1,706	212	449	131
N30W170	205	160,503	0	0	205	160,503	104	165	1,729	26	636	71
N30W175	173	142,420	0	0	173	142,420	97	50	1,697	22	405	93
N30E175	32	26,165	0	0	32	26,165	0	15	298	1	27	4
N35W140	173	137,126	0	0	173	137,126	0	8	2,279	278	72	9
N35W145	161	123,547	0	0	161	123,547	6	28	1,609	320	43	25
N35W150	37	28,519	0	0	37	28,519	3	21	392	108	10	5
N35W155	94	67,809	1	160	93	67,649	0	22	772	418	29	7
N35W160	258	191,965	0	0	258	191,965	8	17	3,069	898	71	38
N35W165	75	52,189	0	0	75	52,189	11	26	586	49	33	5
N35W170	40	30,790	0	0	40	30,790	3	32	325	14	8	0
N35W175	28	21,750	0	0	28	21,750	1	3	168	3	8	1
N35E175	7	5,110	0	0	7	5,110	0	0	46	2	3	1
N40W140	2	1,440	0	0	2	1,440	0	0	1	0	1	0
N40W145	13	9,075	0	0	13	9,075	0	0	153	5	0	0
N40W155	7	3,800	0	0	7	3,800	0	0	45	0	0	0
N40W160	7	5,070	0	0	7	5,070	3	0	64	2	3	0
N40W165	15	10,215	0	0	15	10,215	0	0	60	2	0	0
N40W170	5	3,950	0	0	5	3,950	0	0	21	3	6	1
N40W175	21	13,950	0	0	21	13,950	1	2	168	0	0	0
N40E175	29	21,380	0	0	29	21,380	0	8	191	2	0	0
N40E170	57	41,750	0	0	57	41,750	0	6	550	4	0	0
Total	35,027	43,940,834	20,620	32,305,165	14,407	11,635,669	22,756	48,591	110,306	154,568	197,695	68,335

1 unit errot = 1,000 hooks

Table A7.2 Number of Fishing Sets, and CPUE for Each Species, by Area

	Number of Fishing Sets			CPUE[a]					
AREA	Total	Tuna sets	Swordfish set	BM	SM	SW	AC	BE	YF
N00W160	7	7	0	0.633	0.158	0.000	0.238	12.985	14.885
N05W155	14	14	0	0.172	0.258	0.043	0.000	1.632	2.835
N05W160	334	334	0	0.379	0.218	0.079	0.040	4.280	6.941
N10W150	6	6	0	0.000	7.310	0.305	0.000	1.015	0.203
N10W155	346	346	0	0.479	0.497	0.079	0.450	3.935	1.046
N10W160	661	661	0	0.462	0.736	0.072	1.682	4.802	1.370
N10W165	452	452	0	0.506	0.780	0.052	3.344	6.313	2.225
N10W170	3	3	0	1.333	1.111	0.000	1.778	4.222	3.556
N15W145	3	3	0	0.192	0.192	0.962	0.000	2.308	0.385
N15W150	1046	1,045	1	0.174	1.213	0.082	1.059	5.040	1.062
N15W155	3983	3,087	896	0.729	1.004	0.168	1.676	4.996	2.205
N15W160	5025	4,752	273	0.437	1.052	0.075	5.143	4.514	1.657
N15W165	532	531	1	0.417	1.034	0.073	12.023	3.905	1.423
N15W170	11	11	0	0.529	1.176	0.059	8.235	3.118	0.941
N20W145	24	22	2	0.153	1.902	1.503	10.155	1.074	0.430
N20W150	1980	1,703	277	0.327	1.258	0.728	4.207	3.519	0.654
N20W155	4358	2,352	2,006	0.769	1.485	1.722	4.232	3.977	1.342
N20W160	3781	3,417	364	0.450	1.443	0.275	2.962	6.434	1.290
N20W165	1341	1,279	62	0.412	1.598	0.202	6.665	6.848	1.088
N20W170	57	16	41	0.634	1.601	4.910	7.374	0.774	0.845
N20W175	5	0	5	1.229	3.440	6.880	0.246	3.686	3.440
N25W135	2	0	2	0.000	0.500	2.000	19.000	14.000	1.500
N25W140	7	1	6	0.000	0.292	7.591	0.292	3.796	1.898
N25W145	183	17	166	0.190	0.357	8.868	2.377	2.585	1.599
N25W150	832	70	762	0.331	0.773	10.594	2.254	2.548	2.046
N25W155	1903	207	1,696	1.102	1.335	7.024	3.299	3.538	2.570
N25W160	1775	206	1,569	1.200	1.164	6.355	2.152	3.878	2.400
N25W165	857	49	808	0.292	0.900	11.029	0.794	2.360	1.518
N25W170	598	12	586	0.178	0.498	11.537	0.979	2.641	1.475
N25W175	327	0	327	0.213	0.804	12.430	0.178	1.562	0.944
N25E175	32	0	32	0.083	0.207	9.433	0.124	1.407	0.745
N30W125	41	4	37	0.000	0.090	14.888	0.330	6.424	0.000
N30W130	15	0	15	0.000	0.000	14.422	0.000	4.907	0.000
N30W135	15	0	15	0.000	0.000	11.147	0.335	1.257	0.000
N30W140	320	0	320	0.033	0.087	14.855	2.225	1.815	0.070
N30W145	787	0	787	0.050	0.118	14.284	2.178	2.429	0.361
N30W150	655	1	654	0.071	0.235	15.314	3.861	2.790	1.013
N30W155	296	1	295	0.132	0.141	13.222	3.515	2.684	1.510
N30W160	807	10	797	0.495	0.738	11.655	2.772	3.657	0.922
N30W165	167	0	167	0.150	0.356	13.485	1.676	3.549	1.035
N30W170	205	0	205	0.648	1.028	10.772	0.162	3.963	0.442
N30W175	173	0	173	0.681	0.351	11.915	0.154	2.844	0.653
N30E175	32	0	32	0.000	0.573	11.389	0.038	1.032	0.153
N35W140	173	0	173	0.000	0.058	16.620	2.027	0.525	0.066
N35W145	161	0	161	0.049	0.227	13.023	2.590	0.348	0.202
N35W150	37	0	37	0.105	0.736	13.745	3.787	0.351	0.175
N35W155	94	1	93	0.000	0.324	11.385	6.164	0.428	0.103
N35W160	258	0	258	0.042	0.089	15.987	4.678	0.370	0.198
N35W165	75	0	75	0.211	0.498	11.228	0.939	0.632	0.096
N35W170	40	0	40	0.097	1.039	10.555	0.455	0.260	0.000
N35W175	28	0	28	0.046	0.138	7.724	0.138	0.368	0.046
N35E175	7	0	7	0.000	0.000	9.002	0.391	0.587	0.196
N40W140	2	0	2	0.000	0.000	0.694	0.000	0.694	0.000
N40W145	13	0	13	0.000	0.000	16.860	0.551	0.000	0.000
N40W155	7	0	7	0.000	0.000	11.842	0.000	0.000	0.000
N40W160	7	0	7	0.592	0.000	12.623	0.394	0.592	0.000
N40W165	15	0	15	0.000	0.000	5.874	0.196	0.000	0.000
N40W170	5	0	5	0.000	0.000	5.316	0.759	1.519	0.253
N40W175	21	0	21	0.072	0.143	12.043	0.000	0.000	0.000
N40E175	29	0	29	0.000	0.374	8.934	0.094	0.000	0.000
N40E170	57	0	57	0.000	0.144	13.174	0.096	0.000	0.000
Total/Mean	35,027	20,620	14,407	0.518	1.106	2.510	3.518	4.499	1.555

[a] Nominal CPUE, where effort with swordfish sets or mixed sets were not standardized by catchability ratio.

Table A7.3(a) Estimated Initial Stocks by Area: Minimum, Median, Maximum and the First and Third Quartiles - Three Billfishes

	Number	Blue Marlin (BM)					Striped Marlin (SM)					Swordfish (SW)				
AREA	of Obs.	Min	Q1	Median	Q3	Max	Min	Q1	Media	Q3	Max	Min	Q1	Media	Q3	Max
N00W160	1	N/A	N/A	**205**	N/A	N/A	N/A	N/A	**80**	N/A	N/A	N/A	N/A	**0**	N/A	N/A
N05W155	8	0	0	**0**	58	199	0	0	**35**	429	558	0	0	**0**	0	280
N05W160	18	0	0	**53**	189	251	0	46	**73**	263	669	0	0	**45**	176	388
N10W150	5	0	0	**0**	0	0	279	542	**815**	1,187	1,359	0	0	**0**	238	339
N10W155	30	0	36	**90**	162	476	0	101	**205**	375	1,505	0	0	**100**	233	1,355
N10W160	30	0	88	**135**	186	438	0	102	**282**	474	1,079	0	0	**84**	172	740
N10W165	22	0	88	**139**	195	271	0	102	**369**	609	1,181	0	0	**18**	125	968
N10W170	1	N/A	N/A	**427**	N/A	N/A	N/A	N/A	**559**	N/A	N/A	N/A	N/A	**0**	N/A	N/A
N15W145	1	N/A	N/A	**62**	N/A	N/A	N/A	N/A	**97**	N/A	N/A	N/A	N/A	**625**	N/A	N/A
N15W150	35	0	8	**42**	79	370	0	181	**286**	644	1,483	0	0	**0**	176	1,078
N15W155	36	28	69	**141**	227	621	44	232	**498**	740	1,771	20	56	**111**	260	732
N15W160	36	55	130	**160**	201	434	59	283	**520**	866	2,435	0	41	**76**	172	474
N15W165	29	0	62	**165**	210	431	0	270	**520**	942	2,822	0	0	**42**	209	925
N15W170	4	102	103	**177**	254	265	79	80	**688**	2,017	4,179	0	0	**0**	81	323
N20W145	9	0	0	**0**	0	1,193	0	0	**0**	523	1,473	0	0	**0**	0	2,050
N20W150	35	0	28	**61**	93	370	51	278	**550**	790	1,548	0	95	**203**	632	3,192
N20W155	36	6	64	**141**	219	541	74	363	**675**	951	1,908	71	236	**434**	901	2,880
N20W160	36	0	108	**147**	203	805	0	391	**644**	848	3,004	0	62	**118**	392	2,243
N20W165	34	0	73	**134**	175	653	0	374	**731**	1,027	3,932	0	0	**41**	184	1,615
N20W170	8	0	0	**0**	95	136	0	365	**634**	1,164	2,454	0	757	**1,127**	1,575	2,046
N20W175	3	0	N/A	**0**	N/A	212	0	N/A	**2,239**	N/A	2,954	0	N/A	**917**	N/A	2,293
N25W135	1	N/A	N/A	**0**	N/A	N/A	N/A	N/A	**256**	N/A	N/A	N/A	N/A	**367**	N/A	N/A
N25W140	3	0	N/A	**0**	N/A	0	0	N/A	**0**	N/A	1,111	0	N/A	**205**	N/A	3,080
N25W145	17	0	0	**0**	50	148	0	0	**127**	256	833	0	340	**1,037**	2,009	3,038
N25W150	27	0	10	**24**	52	501	0	69	**286**	524	2,290	0	403	**1,674**	2,392	3,430
N25W155	36	0	34	**91**	166	2,248	0	174	**407**	916	3,894	0	422	**891**	2,010	3,533
N25W160	36	0	21	**60**	121	1,181	27	195	**483**	797	1,587	0	598	**1,019**	1,998	3,318
N25W165	26	0	0	**8**	27	224	0	38	**406**	679	3,079	0	953	**1,805**	2,645	3,783
N25W170	22	0	0	**10**	26	104	0	0	**105**	365	850	602	1,164	**1,918**	2,754	3,865
N25W175	13	0	0	**3**	6	64	0	123	**239**	377	602	722	1,525	**1,870**	2,516	3,543
N25E175	7	0	0	**0**	0	38	0	0	**0**	211	974	698	1,004	**1,718**	1,881	2,225
N30W125	4	0	0	**0**	0	0	0	0	**0**	30	120	0	1,993	**2,945**	3,260	3,344
N30W130	2	0	N/A	**N/A**	N/A	0	0	N/A	**N/A**	N/A	0	2,171	N/A	**N/A**	N/A	4,822
N30W135	5	0	0	**0**	0	0	0	0	**0**	0	0	488	1,173	**1,483**	2,447	3,399
N30W140	15	0	0	**0**	0	112	0	0	**0**	21	137	305	1,390	**2,136**	2,914	4,844
N30W145	19	0	0	**0**	0	23	0	0	**0**	44	165	305	1,518	**2,630**	3,223	3,872
N30W150	16	0	0	**3**	9	15	0	66	**106**	143	314	305	1,996	**2,785**	3,039	3,938
N30W155	19	0	0	**3**	11	493	0	0	**40**	87	166	0	838	**1,831**	2,530	3,747
N30W160	25	0	0	**5**	39	356	0	34	**124**	460	3,674	160	762	**1,780**	2,483	5,422
N30W165	23	0	0	**0**	22	91	0	0	**121**	276	1,461	351	939	**1,853**	2,870	4,390
N30W170	12	0	2	**35**	98	178	0	0	**31**	496	908	1,064	1,498	**1,859**	2,166	2,617
N30W175	11	0	7	**15**	32	166	0	0	**0**	263	477	1,017	1,850	**2,259**	2,430	3,059
N30E175	7	0	0	**0**	0	0	0	0	**0**	286	623	827	1,751	**1,903**	2,119	2,975
N35W140	10	0	0	**0**	0	0	0	0	**0**	20	107	686	1,445	**2,851**	3,322	5,016
N35W145	9	0	0	**0**	5	31	0	0	**49**	117	264	0	1,875	**2,104**	2,284	3,367
N35W150	3	0	N/A	**0**	N/A	13	214	N/A	**434**	N/A	460	1,047	N/A	**2,676**	N/A	3,564
N35W155	6	0	0	**0**	0	0	0	0	**52**	386	502	1,424	1,693	**1,935**	2,326	3,186
N35W160	10	0	0	**0**	2	94	0	0	**0**	45	170	523	1,230	**2,363**	3,584	5,135
N35W165	10	0	0	**0**	0	83	0	0	**16**	294	751	1,184	1,655	**2,179**	2,786	3,034
N35W170	6	0	0	**2**	17	32	0	0	**0**	635	1,077	764	1,130	**1,174**	1,740	2,343
N35W175	3	0	N/A	**0**	N/A	5	0	N/A	**0**	N/A	107	1,304	N/A	**1,689**	N/A	2,564
N35E175	1	N/A	N/A	**0**	N/A	N/A	N/A	N/A	**0**	N/A	N/A	N/A	N/A	**1,667**	N/A	N/A
N40W140	1	N/A	N/A	**0**	N/A	N/A	N/A	N/A	**0**	N/A	N/A	N/A	N/A	**127**	N/A	N/A
N40W145	2	0	N/A	**N/A**	N/A	0	0	N/A	**N/A**	N/A	0	269	N/A	**N/A**	N/A	3,644
N40W155	2	0	N/A	**N/A**	N/A	0	0	N/A	**N/A**	N/A	0	1,220	N/A	**N/A**	N/A	2,361
N40W160	3	0	N/A	**0**	N/A	139	0	N/A	**0**	N/A	0	1,372	N/A	**2,538**	N/A	2,797
N40W165	3	0	N/A	**0**	N/A	0	0	N/A	**0**	N/A	0	756	N/A	**1,017**	N/A	1,199
N40W170	2	0	N/A	**N/A**	N/A	0	0	N/A	**N/A**	N/A	0	1,112	N/A	**N/A**	N/A	1,303
N40W175	4	0	0	**0**	3	11	0	0	**0**	90	360	1,119	1,200	**1,646**	2,266	2,869
N40E175	2	0	N/A	**N/A**	N/A	0	0	N/A	**N/A**	N/A	242	1,540	N/A	**N/A**	N/A	1,912
N40E170	2	0	N/A	**N/A**	N/A	0	0	N/A	**N/A**	N/A	187	2,470	N/A	**N/A**	N/A	2,914
Total	842			Overall Max		2,248			Overall Max		4,179			Overall Max		5,422

Table A7.3(b) Estimated Initial Stocks by Area: Minimum, Median, Maximum and the First and Third Quartiles - Three Tunas

	Number	Albacore (AC)					Bigeye Tuna (BE)					Yellowfin Tuna (YF)				
AREA	of Obs.	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max
N00W160	1	N/A	N/A	88	N/A	N/A	N/A	N/A	***3345***	N/A	N/A	N/A	N/A	***3897***	N/A	N/A
N05W155	8	0	0	**0**	0	0	0	127	**495**	980	1,611	0	0	**750**	1,112	1,945
N05W160	18	0	0	**0**	21	57	0	347	**1,264**	1,815	2,732	0	684	**1,351**	2,498	3,920
N10W150	5	0	0	**0**	0	0	196	201	**302**	836	882	0	0	**0**	100	307
N10W155	30	0	0	**45**	228	604	242	763	**1,269**	1,523	2,668	30	160	**287**	576	1,036
N10W160	30	0	252	**358**	553	2,460	646	1,159	**1,502**	1,854	4,174	109	225	**495**	783	2,017
N10W165	22	0	400	**840**	1,893	4,527	232	1,033	**1,894**	2,636	4,466	0	261	**481**	1,003	1,869
N10W170	1	N/A	N/A	**652**	N/A	N/A	N/A	N/A	1,537	N/A	N/A	N/A	N/A	1,315	N/A	N/A
N15W145	1	N/A	N/A	**0**	N/A	N/A	N/A	N/A	841	N/A	N/A	N/A	N/A	142	N/A	N/A
N15W150	35	0	128	**323**	974	2,592	84	590	**976**	2,182	3,521	0	94	**193**	352	1,267
N15W155	36	0	256	**554**	1,437	2,726	173	1,111	**2,175**	3,006	6,115	96	353	**548**	876	1,436
N15W160	36	14	348	**1,354**	3,622	8,813	351	1,136	**1,755**	2,907	5,251	69	360	**594**	930	1,745
N15W165	29	0	845	**3,186**	5,293	7,655	263	589	**830**	2,299	4,361	62	230	**400**	852	1,843
N15W170	4	2,126	2,299	**2,852**	3,533	4,087	0	703	**1,042**	1,188	1,311	0	0	**238**	531	695
N20W145	9	0	223	**407**	457	5,211	0	0	**287**	477	1,212	0	0	**128**	230	460
N20W150	35	42	740	**1,836**	2,667	4,741	94	636	**1,239**	1,973	3,005	0	67	**128**	252	698
N20W155	36	191	1,427	**2,545**	3,689	5,678	93	747	**1,505**	2,344	3,759	39	174	**312**	471	717
N20W160	36	0	486	**1,562**	2,820	5,134	88	298	**1,685**	2,732	6,584	76	267	**483**	723	1,498
N20W165	34	0	1,269	**2,708**	4,504	6,537	125	518	**1,459**	2,305	6,917	0	181	**482**	735	1,899
N20W170	8	0	0	**532**	3,626	6,866	99	108	**209**	297	2,622	0	0	**21**	235	447
N20W175	3	0	N/A	**0**	N/A	**2,903**	0	N/A	1,337	N/A	1,457	93	N/A	**101**	N/A	557
N25W135	1	N/A	N/A	**2,742**	N/A	N/A	N/A	N/A	**3,266**	N/A	N/A	N/A	N/A	**122**	N/A	N/A
N25W140	3	0	N/A	**365**	N/A	2,972	0	N/A	**845**	N/A	2,897	132	N/A	**285**	N/A	736
N25W145	17	0	346	**2,105**	3,608	5,935	0	293	**506**	885	1,665	0	39	**103**	185	390
N25W150	27	0	1,487	**2,625**	4,254	10,952	0	449	**698**	1,033	2,516	0	80	**146**	261	477
N25W155	36	0	1,660	**3,156**	3,938	11,604	116	469	**763**	1,496	4,358	52	144	**250**	325	985
N25W160	36	0	1,414	**1,979**	3,681	7,296	62	536	**905**	1,325	3,281	45	110	**212**	381	735
N25W165	26	0	25	**736**	1,787	6,929	195	515	**758**	855	1,528	0	41	**100**	239	871
N25W170	22	0	128	**787**	2,937	8,577	90	353	**745**	1,154	1,835	0	17	**68**	245	495
N25W175	13	0	0	**0**	105	2,246	0	144	**265**	393	1,268	0	0	**46**	65	305
N25E175	7	0	0	**0**	0	731	0	278	**443**	755	997	0	0	**0**	16	756
N30W125	4	0	0	**174**	522	1,042	0	868	**1,270**	1,532	1,984	0	0	**0**	0	0
N30W130	2	0	N/A	N/A	N/A	0	289	N/A	N/A	N/A	1,453	0	N/A	N/A	N/A	0
N30W135	5	0	0	**0**	0	13,471	0	67	**209**	310	1,863	0	0	**0**	0	0
N30W140	15	0	0	**125**	3,774	11,151	0	121	**450**	898	1,212	0	0	**0**	7	274
N30W145	19	0	0	**1,680**	4,543	11,225	217	419	**570**	1,004	1,250	0	11	**15**	41	198
N30W150	16	0	1,068	**4,381**	6,778	13,815	0	137	**669**	821	1,218	0	25	**108**	162	311
N30W155	19	0	0	**2,941**	5,004	10,125	73	309	**546**	943	2,227	0	0	**105**	155	253
N30W160	25	0	453	**975**	6,453	12,490	78	466	**651**	1,265	2,898	0	9	**70**	211	273
N30W165	23	0	0	**0**	2,540	9,608	0	219	**558**	1,134	2,420	0	0	**32**	117	414
N30W170	12	0	0	**329**	618	8,981	117	444	**718**	974	2,143	0	0	**16**	38	125
N30W175	11	0	0	**0**	368	1,521	123	181	**395**	498	1,902	0	12	**48**	97	154
N30E175	7	0	0	**0**	0	2,210	0	88	**260**	491	700	0	0	**0**	26	101
N35W140	10	0	0	**1,421**	4,116	21,564	0	0	**24**	126	1,692	0	0	**1**	11	91
N35W145	9	0	0	**3,435**	14,046	20,157	0	0	**40**	107	726	0	0	**7**	16	194
N35W150	3	0	N/A	**6,063**	N/A	9,132		N/A	**94**	N/A	140	0	N/A	**0**	N/A	25
N35W155	6	0	196	**3,998**	7,464	19,949	0	10	**59**	103	194	0	0	**0**	5	27
N35W160	10	0	1,695	**3,546**	6,454	14,604	0	0	**32**	77	215	0	0	**0**	11	70
N35W165	10	0	570	**1,479**	3,572	7,359	0	0	**80**	95	385	0	0	**0**	0	67
N35W170	6	0	0	**268**	1,062	4,722	0	0	**33**	94	109	0	0	**0**	0	0
N35W175	3	0	N/A	**0**	N/A	521	0	N/A	**82**	N/A	119	0	N/A	**0**	N/A	13
N35E175	1	N/A	N/A	**989**	N/A	N/A	N/A	N/A	**138**	N/A	N/A	N/A	N/A	**16**	N/A	N/A
N40W140	1	N/A	N/A	**0**	N/A	N/A	N/A	N/A	**162**	N/A	N/A	N/A	N/A	**0**	N/A	N/A
N40W145	2	0	N/A	N/A	N/A	2,237	0	N/A	**N/A**	N/A	0	0	N/A	**N/A**	N/A	0
N40W155	2	0	N/A	N/A	N/A	0	0	N/A	**N/A**	N/A	0	0	N/A	**N/A**	N/A	0
N40W160	3	0	N/A	**0**	N/A	**3,437**	0	N/A	**0**	N/A	**537**	0	N/A	**0**	N/A	0
N40W165	3	0	N/A	**0**	N/A	648	0	N/A	**0**	N/A	0	0	N/A	**0**	N/A	0
N40W170	2	1,018	N/A	N/A	N/A	**3,331**	0	N/A	N/A	N/A	974	0	N/A	N/A	N/A	**50**
N40W175	4	0	0	**0**	0	0	0	0	**0**	0	0	0	0	**0**	0	0
N40E175	2	**147**	N/A	N/A	N/A	**602**	0	N/A	N/A	N/A	0	0	N/A	N/A	N/A	0
N40E170	2	0	N/A	**N/A**	N/A	628	0	N/A	N/A	N/A	0	0	N/A	N/A	N/A	0
Total	842				Overall Max	21,564				Overall Max	6,917				Overall Max	3,920

Table A7.4 Effort and Catches of Each Species by Region

		Total		Tuna set		Swordfish set		Catches					
Region		# of stes	Effort	# of stes	Effort	# of stes	Effort	BM	SM	SW	AC	BE	YF
North	1995	1,715	1,340,209	4	3,180	1,711	1,337,029	335	517	15,879	3,022	3,314	761
	1996	1,578	1,220,697	10	10,000	1,568	1,210,697	190	470	17,402	3,948	2,068	585
	1997	1,249	948,370	3	1,660	1,246	946,710	142	165	14,049	1,820	2,964	732
	Total	4,542	3,509,276	17	14,840	4,525	3,494,436	667	1,152	47,330	8,790	8,346	2,078
Monthly Ave.		126	97,480	0.47	412	126	97,068	19	32	1,315	244	232	58
(St Dev)		104	81,587	0.97	919	104	81,647	26	43	1,305	347	213	74
Min		3	2,535	0	0	3	2,535	0	0	10	0	4	0
Max		387	317,507	4	3,400	387	317,507	117	203	4,318	1,713	672	301
Middle	1995	4,112	4,756,948	1,963	2,951,783	2,149	1,805,165	3,289	9,118	15,767	12,826	18,875	8,451
	1996	4,489	5,450,668	2,371	3,723,687	2,118	1,726,981	2,276	6,637	15,697	22,115	22,777	4,927
	1997	5,103	6,424,998	2,665	4,505,822	2,438	1,919,176	3,250	5,741	20,784	21,807	39,075	10,341
	Total	13,704	16,632,614	6,999	11,181,292	6,705	5,451,322	8,815	21,496	52,248	56,748	80,727	23,719
Monthly Ave.		381	462,017	194	310,591	186	151,426	245	597	1,451	1,576	2,242	659
(St Dev)		209	267,300	139	237,100	161	130,741	188	546	1,690	1,433	2,457	517
Min		92	112,850	23	37,000	18	16,610	22	46	12	234	125	70
Max		927	1,146,623	620	1,064,682	533	413,322	954	2,666	5,378	6,832	11,986	2,203
MHI	1995	3,189	4,019,151	2,077	3,022,622	1,112	996,529	2,827	6,352	3,484	10,596	17,840	7,304
	1996	2,945	3,586,430	1,925	2,744,064	1,020	842,366	2,538	4,328	3,054	11,271	18,877	5,200
	1997	2,207	2,712,221	1,437	2,092,348	770	619,873	2,366	2,150	3,182	8,558	9,595	5,814
	Total	8,341	10,317,802	5,439	7,859,034	2,902	2,458,768	7,731	12,830	9,720	30,425	46,312	18,318
Monthly Ave.		232	286,606	151	218,307	81	68,299	215	356	270	845	1,286	509
(St Dev)		99	140,688	90	140,329	57	48,807	173	340	402	803	1,069	359
Min		73	101,780	60	83,720	13	10,700	12	43	19	41	191	54
Max		528	725,720	431	637,115	219	198,448	646	1,630	1,335	3,346	4,207	1,418
South	1995	2,631	3,971,861	2,557	3,908,507	74	63,354	1,748	5,245	344	12,077	18,117	6,441
	1996	2,553	4,066,918	2,474	4,001,301	79	65,617	1,513	3,958	345	12,250	18,423	6,322
	1997	3,245	5,425,363	3,123	5,323,191	122	102,172	2,273	3,890	318	34,138	25,717	11,441
	Total	8,429	13,464,142	8,154	13,232,999	275	231,143	5,534	13,093	1,007	58,465	62,257	24,204
Monthly Ave.		234	374,004	227	367,583	8	6,421	154	364	28	1,624	1,729	672
(St Dev)		107	179,095	109	180,852	16	13,317	107	316	25	1,869	1,241	572
Min		37	55,820	36	54,920	0	0	19	6	1	26	74	23
Max		480	832,251	480	832,251	82	67,702	473	1,329	111	7,332	5,039	2,492

Table A7.5 Fishing Effort and CPUE for Each Species by Region

Year	Total		CPUE					
	# of stes	Effort	BM	SM	SW	AC	BE	YF
			North					
1995	1,715	1,340,209	0.250	0.386	11.848	2.255	2.473	0.568
1996	1,578	1,220,697	0.156	0.385	14.256	3.234	1.694	0.479
1997	1,249	948,370	0.150	0.174	14.814	1.919	3.125	0.772
Mean	1,514	1,169,759	0.190	0.328	13.487	2.505	2.378	0.592
			Middle					
1995	4,112	4,756,948	0.691	1.917	3.315	2.696	3.968	1.777
1996	4,489	5,450,668	0.418	1.218	2.880	4.057	4.179	0.904
1997	5,103	6,424,998	0.506	0.894	3.235	3.394	6.082	1.609
Mean	4,568	5,544,205	0.530	1.292	3.141	3.412	4.854	1.426
			MHI					
1995	3,189	4,019,151	0.703	1.580	0.867	2.636	4.439	1.817
1996	2,945	3,586,430	0.708	1.207	0.852	3.143	5.263	1.450
1997	2,207	2,712,221	0.872	0.793	1.173	3.155	3.538	2.144
Mean	2,780	3,439,267	0.749	1.243	0.942	2.949	4.489	1.775
			South					
1995	2,631	3,971,861	0.440	1.321	0.087	3.041	4.561	1.622
1996	2,553	4,066,918	0.372	0.973	0.085	3.012	4.530	1.554
1997	3,245	5,425,363	0.419	0.717	0.059	6.292	4.740	2.109
Mean	2,810	4,488,047	0.411	0.972	0.075	4.342	4.624	1.798
			All Areas					
1995	11,647	14,088,169	0.582	1.507	2.518	2.734	4.127	1.630
1996	11,565	14,324,713	0.455	1.075	2.548	3.461	4.338	1.189
1997	11,804	15,510,952	0.518	0.770	2.471	4.276	4.987	1.826
Mean	11,672	14,641,278	0.518	1.106	2.511	3.516	4.500	1.555

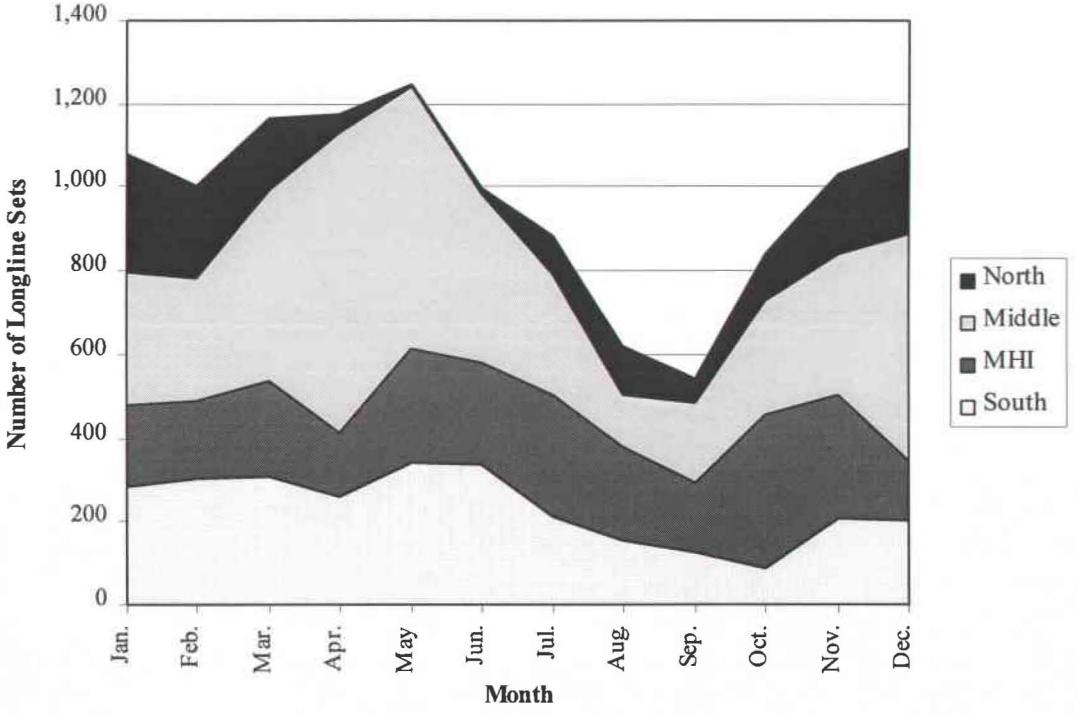

Figure A7.1 Monthly Change in the Number of Hawaii Longline Sets by Region: the Average of 1995, 1996, and 1997

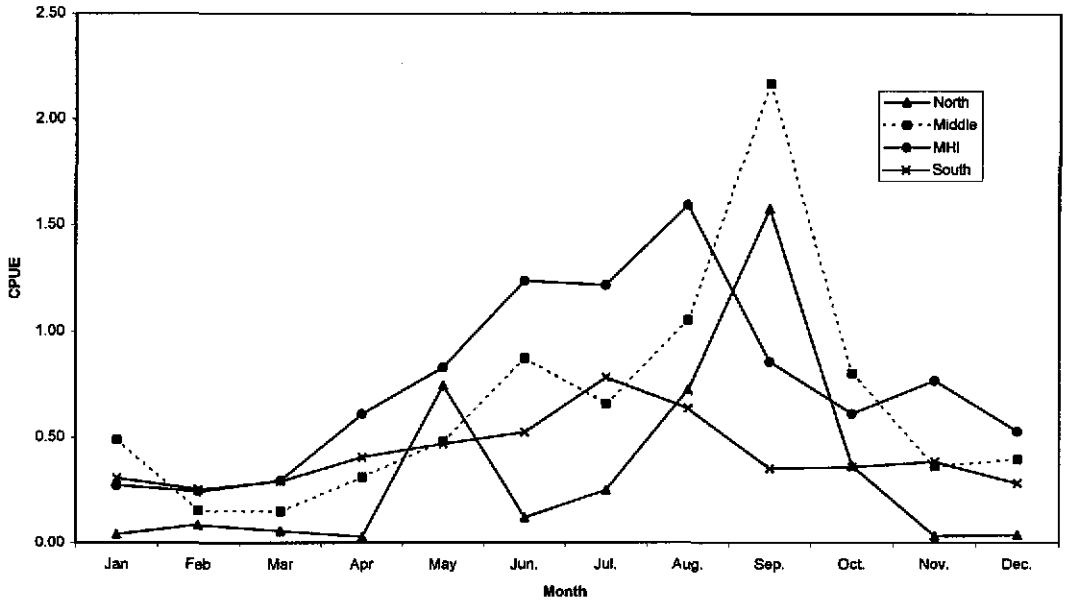

Figure A7.2(a) Monthly CPUE Change by Region – Blue Marlin

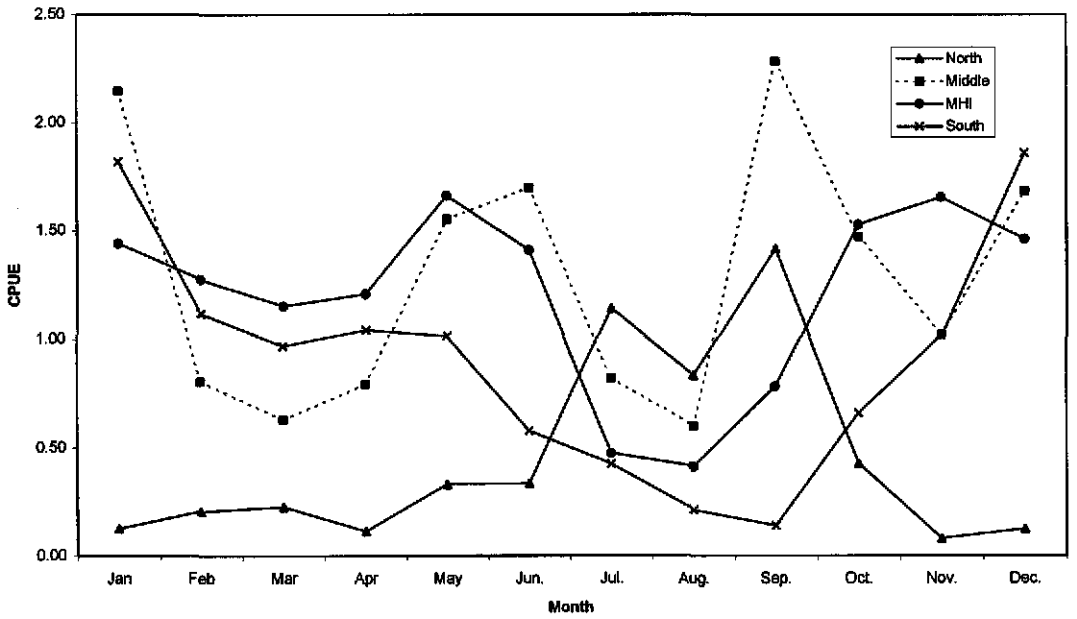

Figure A7.2(b) Monthly CPUE Change by Region – Striped Marlin

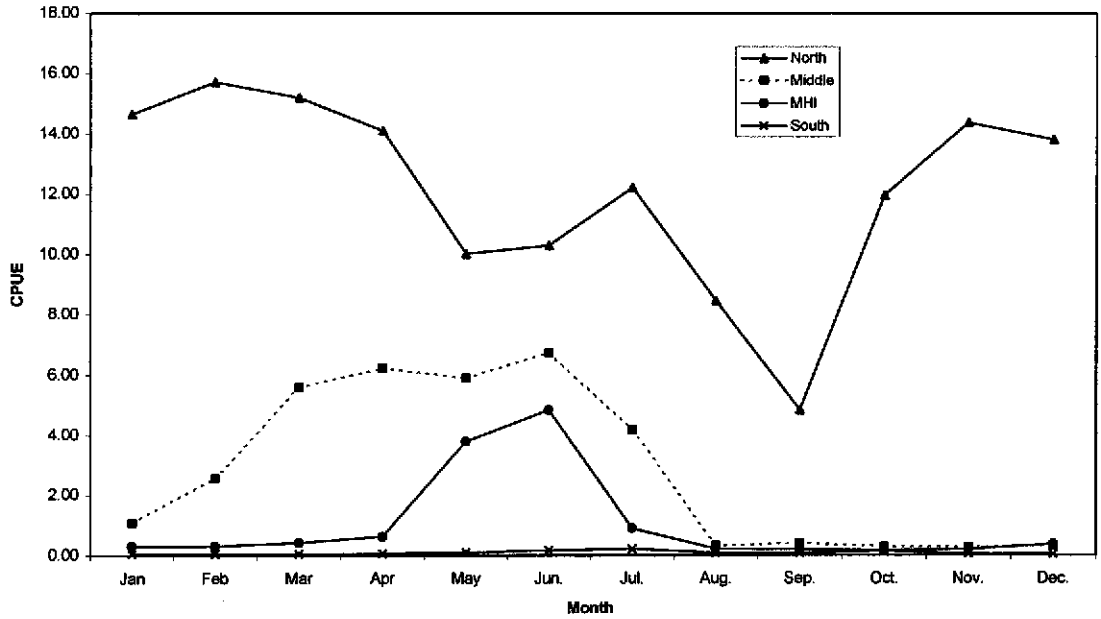

Figure A7.2(c) Monthly CPUE Change by Region – Swordfish

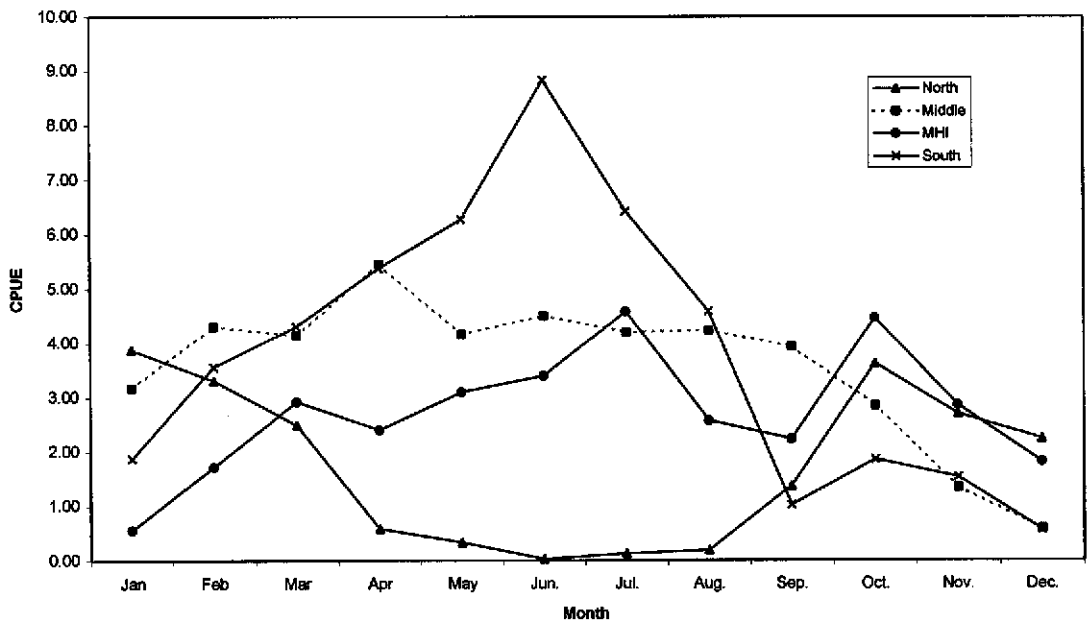

Figure A7.2(d) Monthly CPUE Change by Region – Albacore

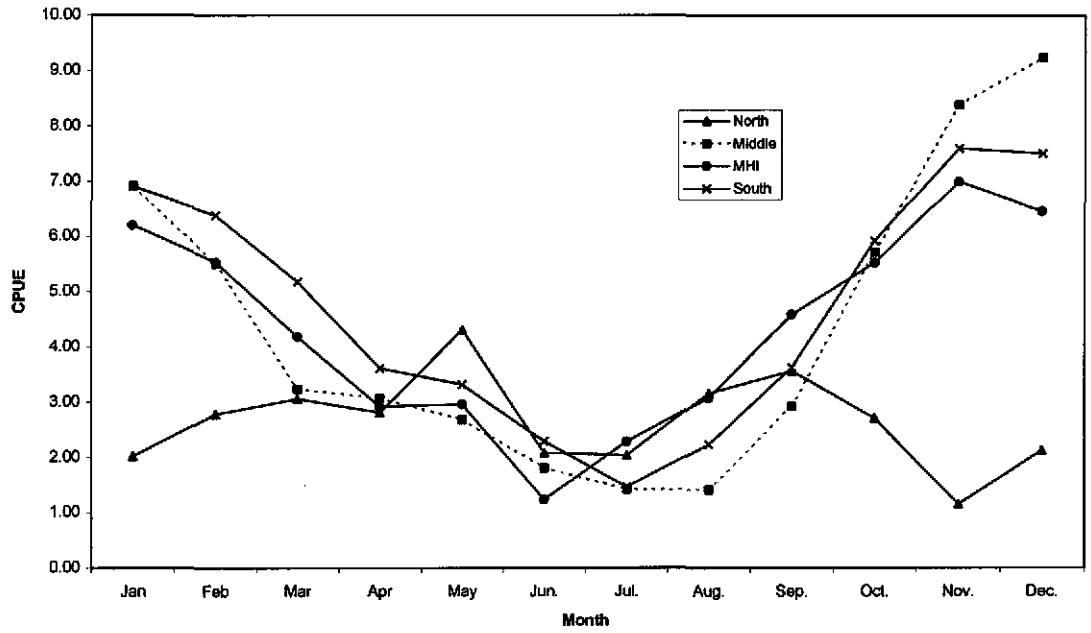

Figure A7.2(e) Monthly CPUE Change by Region – Bigeye Tuna

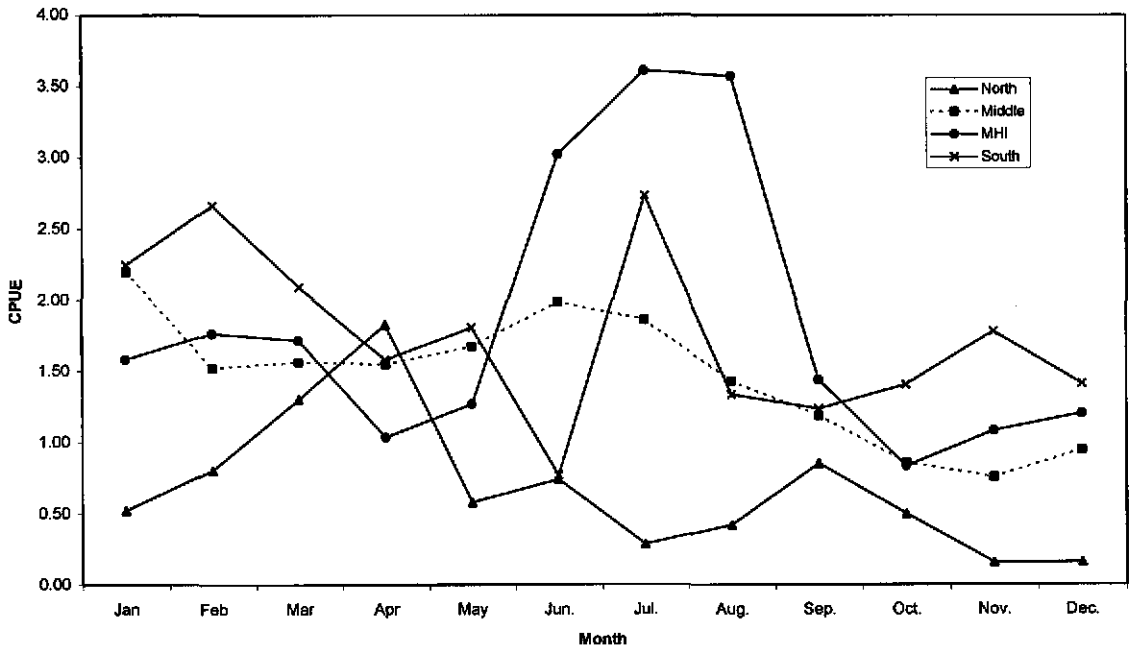

Figure A7.2(f) Monthly CPUE Change by Region – Yellowfin Tuna

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