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ABSTRACT

The Hawaii pelagic surface fisheries and more recently the longline fisheries have grown dramatically. As a result, competition between fisheries on the fishing grounds and in the marketplace has also increased. Physical conflicts between vessels and claims of decreased fishing success by surface (troll and handline) fishermen led to the enactment of Federal regulations limiting the number of domestic longline vessels and the areas in which they can operate. The scientific evidence of biological or economic fishery interaction between longline and small-vessel fishermen is limited but suggests that intense longline fishing near the Hawaiian Islands has the potential to affect catch rates in other Hawaii fisheries. Better data collection and more research are needed to document fishery interaction and to improve fishery management.

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INTRODUCTION

Competition has been apparent between the large-scale commercial fisheries and a variety of small-scale commercial, part-time commercial, recreational, and subsistence fisheries in Hawaii for many years (Pooley 1985). Beginning in 1989, real or perceived interactions among the pelagic fisheries in Hawaii became the focus of fisheries management. Rapid expansion of the longline fishery, a concurrent decline in the landings of small-vessel troll and handline fishermen, and physical interference between longliners and smaller vessels in nearshore areas motivated fishery managers to enact new regulations for domestic longline fishermen.

Although Hawaii's landings of most pelagic fish species are minor compared with stock-wide production, a small number of studies suggest that local fisheries can have substantial impacts on local catch rates. These limited studies formed the only scientific or conceptual basis for the new regulations, and further research is needed (Boggs 1991).

The purpose of this paper is to classify and describe the types of interactions that may occur among Hawaii pelagic fisheries, review the evidence of such interactions, and assess the adequacy of information available for management decision-making. This paper also describes Hawaii's pelagic fisheries; the resources they exploit; the management issues identified by fishermen, scientists, and managers; the regulatory actions taken; and the limited scientific research relevant to the problem. Recommendations are made for improving data collection, conducting additional research, and fine-tuning the management actions taken by fisheries authorities.

BACKGROUND

Concepts and Definitions

Several types of fishery interaction are addressed in this review. **Gear conflict** is a high-profile interaction which occurs when the fishing gear or practices of one fisherman physically interfere with or cause damage to the gear or boat of another fisherman. More subtle **economic fishery interactions** may occur when the sale of fish by one fishery component causes a reciprocal decline in the value of the sales of another component. When large landings of any species occur in a limited market, the prices of that and similar species usually decline in the short term. Interference with access to industry infrastructure, such as crowding of shoreside facilities and

exclusion from well-supplied markets, represent other types of economic fishery interaction. The hardest types of interactions to define and measure are **biological fishery interactions** that occur when the catch of one component of a fishery causes a decline in the abundance of fish available to another (Hampton 1993, Keiber 1993).

Stock-wide biological fishery interaction may occur if the fishing effort by one of several fisheries exploiting a stock is large enough to affect the overall abundance of the exploited stock.[1] The total production of a fish stock, as described by a production model (Schaefer 1954), increases with increasing fishing effort up to a maximum sustainable yield (MSY), but then total production (yield) declines if fishing effort continues to increase (Figure 1A). As total effort increases fish abundance and catch-per-unit effort (CPUE) decrease. When effort is near, or above the level associated with MSY, the stock is referred to as fully utilized, or overutilized, respectively (NOAA 1992). When yield is expressed as revenue and compared with cost (Figure 1A) then the maximum profit that can be sustained is called the maximum economic yield (MEY) and the point at which expanding effort results in zero profit is called the open access equilibrium (OAE, Clarke et al. 1992). The stock-wide consequences of increased fishing effort by each of several fishery components depend on the proportion of the total effort (or catch) attributable to that component. Increased effort by a major fishery component (i.e., one taking a substantial proportion of the MSY) represents a major increase in total effort, which in the case of a fully utilized stock may cause a substantial decrease in fish abundance and stock-wide biological interaction with all other fishery components.

In contrast, Gulland's (1968) introduction of the marginal yield concept showed that if a component of a fishery remains small compared to the total (stock-wide) fishery, increases in fishing effort by that component would be expected to be rewarded with nearly proportional increases in catch even when the stock is fully utilized. Fish abundance and CPUE would decrease only slightly, and the increased take of the expanded component would have a small impact when spread over the remainder of the fishery. Thus, small fisheries may suffer from stock-wide fishery interaction, but are not likely to cause it.

Localized biological fishery interactions may be manifested by changes in local catches and catch rates. Even small, geographically restricted pelagic fisheries like those in Hawaii can cause declining local catch rates without necessarily

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[1]The terms "stock," "stock-wide," and "overall abundance" refer to entire fish populations. For the pelagic species, stocks are generally thought to extend across most or all of the tropical and temperate Pacific (Skillman 1989a, Suzuki 1993a).

contributing to a measurable stock-wide decline. **Catch competition** can occur if one fishery intercepts the fish before they move into range of another, or by virtue of the first fishery's greater fishing power to harvest the resources before the other can do so. In either case, catch competition is the partitioning (via competition) of the available resource among the users. For pelagic fisheries, the available resource is the finite supply of highly mobile fish that pass within range of the local fishery.

Catch competition may also occur through mutual use of the resource even when no one fishery has a competitive advantage. If the fisheries operating in a limited area collectively remove fish more rapidly than the fish are replaced by the influx and growth of fish within the area, local fish abundance and catch rates may decline, affecting all of those fisheries (Boggs 1991, 1993). This localized biological interaction is analogous to stock-wide biological interaction except that the local fisheries affect local abundance, not stock-wide abundance. Suppose the local fisheries have access only to a relatively small portion of a highly mobile, wide-ranging pelagic stock, namely that portion seasonally available on the local fishing grounds. For simplicity, suppose further that the influx of fish into the local area, though seasonal, is the same each year. Then, the annual yield of the limited-range, local fisheries would increase with local effort but approach an asymptote (Figure 1B). This asymptotic yield model (Boggs 1993), previously termed a "threshold" model (Boggs 1991, Sathiendarakumar and Tisdell 1987, Clarke et al. 1992) may usefully describe the dynamics of local fishery yield. As with the production model, by expressing local yield as revenue and using a cost curve, it should be possible to approximate a local economic optimum for fishing effort (Figure 1B). Annual and seasonal changes in the influx of fish complicate this model and greatly influence the dynamics of local fish abundance (Boggs 1993).

These concepts and definitions are used to describe the pelagic fishery interaction issues in Hawaii, following a brief review of the fisheries and the resources they exploit.

The Hawaii Longline Fisheries

Pelagic tuna longline gear, introduced to Hawaii in 1917 by a Japanese immigrant, consists of a main line suspended between surface floats with branch (or hook) lines attached (Kawamoto et al. 1989). Originally, the segmented main line (each segment called a basket) and the float and branch lines were made of fiber rope. An alternative longline technology using monofilament line was first introduced into Hawaii in 1985 and now predominates in the fishery. It consists of a continuous

monofilament main line, with float and branch lines commonly made of smaller gauge monofilament. In the original rope longline method, bamboo flag poles were attached to the floats, resulting in the term, "flagline fishing." In the modern fishery, radio beacons, radar reflectors, and strobe lights are more likely to be used in marking the gear. For targeting tuna, longline gear is most often set at or near sunrise and retrieved in the afternoon and evening. The deepest hooks usually reach 100-300 m depending on the tuna species being targeted. However, in the swordfish *Xiphias gladius* fishery which began in Hawaii in the fall of 1989, the gear is typically set near the surface (depth 30-50 m) at about sunset and retrieved in the morning. Squid is used as bait rather than fish, and chemical light sticks are attached to the branch lines. Some new participants in the fishery experiment with different methods, varying their use of light sticks, set depths, and times of day to target both swordfish and tuna.

After being established in 1917 the longline fishery grew and became second only to the baitboat fishery for skipjack tuna *Katsuwonus pelamis* (Kawamoto et al. 1989). As many as 76 longline sampans comprised the fishery immediately after World War II, but the fleet declined to a low of 16 vessels in the late 1970s. The trend then reversed, and the number of active vessels increased to 30-40 boats by the mid-1980s and to 138 in 1990 (Figure 2). By 1990, the fleet was composed of a few traditional sampans, some vessels from the lobster and bottomfish fisheries as well as other Hawaii fisheries, and a much larger number of modern vessels rigged specifically for monofilament longline fishing. The estimated number of longline trips more than doubled during 1987-90 (Figure 3), and fishing effort increased more than trips increased due to changes in hooks per set[2].

Until the advent of new regulations in the 1990s, important fishing areas for the Hawaii longline fleet included selected areas within and beyond a 37-km[3] (20-nmi) perimeter around the main Hawaiian Islands (Figure 4). With the development of the swordfish fishery and the institution of areas closed to longline fishing near the islands (below), areas in the Northwestern Hawaiian Islands and the high seas have become important (Figure 5).

Prior to 1991, Hawaii longline boats primarily targeted bigeye tuna *Thunnus obesus* and yellowfin tuna *T. albacares*, both termed *ahi* in Hawaiian. During 1987-1990, bigeye tuna averaged

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[2]The average number of sets per trip remained at about eight during 1955-1990, but hooks per set increased from 100-200 in 1955 (Shomura 1959), to about 1,000 in 1990.

[3]The State of Hawaii stratifies catch statistics relative to a boundary 37 km (20 nmi) from shore.

35%, yellowfin tuna 19%, and striped marlin *Tetrapturus audax* 13% of the longline landings by weight (Table 1). Recently, swordfish became the target of a night fishery which by 1991 seasonally included some 98 vessels from the longline fleet. Swordfish alone accounted for 51% of the total longline catch (all methods) in 1991, with bigeye and yellowfin tuna reduced to 18% and 8% of the longline landings, respectively (Table 1). The local abundance of swordfish is greatest in the spring and summer, yellowfin tuna are most abundant in summer, and bigeye tuna are locally abundant in fall, winter, and spring. The seasonality of blue marlin is similar to yellowfin tuna and striped marlin is similar to bigeye tuna. The Hawaii longline fishery operates year-round, shifting target species and methods as appropriate. Incidental landings of the longline fishery from 1987-1991 included albacore *Thunnus alalunga* (6.2%), Indo-Pacific blue marlin *Makaira mazara* (4.7%), black marlin *M. indica*, shortbill spearfish *Tetrapturus angustirostris* (2.3%), wahoo *Acanthocybium solandri* (1.5%), mahimahi *Coryphaena hippurus* (1.8%), opah *Lampris guttatus*, several *manchong* or pomfrets (sickle pomfret *Taractichthys steindachneri*, bigtooth pomfret *Brama orcini*, and *Eumegistus illustris*), *walu* or oilfish *Ruvettus pretiosus*, escolar *Lepidocybium flavobrunneum*, and oceanic sharks (1.4%). Sharks comprise a larger portion of the catch but are seldom landed.

Domestic longline landings reached a historical peak of 2,000 metric tons (t) in 1954 and then declined through 1975 (Boggs and Ito 1993). As the domestic fishery declined, foreign longline harvests within a 200-nmi zone around Hawaii increased, rising to 5,000 t in 1970 (Yong and Wetherall 1980) when total foreign and domestic longline harvest (combined) reached 5,700 t. Foreign longline harvests in Hawaii's waters ceased in 1980 as a result of Federal fishery management actions. Since 1987 Hawaii longline landings have more than quadrupled (Figure 6). In 1988 the longline fishery became Hawaii's largest fishery by both wholesale value ($15.9 million) and weight (3,050 t or 6.7 million lb landed). By 1990 the longline fishery, with a revenue of $30.9 million from landings of 5,800 t (Ito 1992), was larger than all other Hawaii fisheries combined (Pooley 1993) and exceeded the 1970 record harvest of the combined foreign and domestic fisheries in Hawaii's waters. In 1991 longline revenue increased again by 41% and landings increased by 53%. Most longline pelagic landings are purchased by Hawaii wholesalers and brokers, who export some top-grade tuna (primarily bigeye tuna) to Japan and ship some bigeye and yellowfin tuna to the U.S. mainland. Most of the swordfish have been shipped directly to the U.S. mainland.

The Surface Fisheries

The troll and pelagic handline fisheries generally target species found in the warm, mixed surface layer of the ocean (< 100 m) and are thus referred to as surface fisheries. Primary fishing areas are within 37 km (20 nmi) of all main Hawaiian Islands (Figure 4). Anchored buoys called fish aggregating devices (FADs) were widely deployed in these areas in the 1980s for the use of troll and handline fishermen. Recently, a few offshore handline fishing grounds have been developed in association with seamounts and large, anchored weather buoys. The surface fisheries primarily operate in the spring, summer, and fall, and avoid the high winds, rains, and rough seas of winter.

Trolling today in Hawaii runs the gamut from recreational and charter boats equipped with rods and reels to commercial vessels with powered reels. Outriggers are used to fish nine or more lines. Both artificial lures and live bait are used. The monofilament lines are trolled at or near the surface. In addition to normal gamefishing techniques, the "green stick", or "bird" fishing method is commonly employed. Fishing lines are trolled behind a frame of red-painted wood called the "bird" which splashes through the water as it is towed with the "green stick," a very large pole vertically mounted amidships. Various electronic fishing aids including depth sounders are used to troll above selected bottom contours.

A small number of relatively large trollers (up to 14 m or 45 ft long) operating from permanent moorings have fished on a full-time basis. Some of these boats have participated in the albacore troll fisheries in the North and South Pacific. Also, a much larger number of small, trailered boats (8-12 m or 25-38 ft in length) have participated either as a) full-time commercial trollers that move frequently between ports as the fishing season progresses or b) small-scale commercial, part-time commercial, recreational, or subsistence trollers that are more closely linked to individual launching sites. Finally, the troll fishery includes charter boat operators who retain and sell the catches made by their patrons, mostly tourists but local recreational fishermen as well. Some of these boats occasionally hire crew and fish commercially.

The State of Hawaii Division of Aquatic Resources (HDAR) issued 2,409 licenses in 1989 to people who identified troll or handline as their primary gear. The number of recreational and subsistence fishing boats is unknown but a survey reported by Skillman and Louie (1984) suggested the number might be about 3,500 vessels. The HDAR estimates of commercial troll and handline trips were relatively steady around 18,000 trips during 1979-85, substantially increased to a high of about 30,000 in

1987 and then declined to between 25,000-27,000 trips during 1988-91 (Figure 3).

The pelagic handline fishery is quite diverse but until recently was made up of two primary components. The night handline or *ika-shibi* fishery, which grew from an artisanal fishery on Hawaii in the mid-1970s (Ikehara 1981), uses freshly caught squid as bait and fishes the handline subsurface but within the upper mixed layer. The day *palu ahi* fishery, named after the native Hawaiian fishing method, uses a chum bag attached above the hook which is baited with a variety of fish species. Manual and powered reels are both used in the handline fishery. Heavy reliance on one highly seasonal species, yellowfin tuna, contributes to substantial annual variability in the ika shibi and palu ahi fisheries, as variable oceanographic conditions probably affect this species availability and catchability. Catches are more diverse in the recently developed offshore handline fishery, where small bigeye and yellowfin tunas are chummed to the surface and caught with short handlines. With the development of the offshore fishery, bigeye tuna landings have increased and now account for as much as 15% of surface fishery landings (Ito 1992).

Other species harvested by the surface fisheries include skipjack tuna, blue marlin, mahimahi, and wahoo. The troll fishery lands more of the non-tuna species than the handline fishery. Minor species include striped marlin, shortbill spearfish *kawakawa Euthynnus affinis*, and rainbow runner *Elagatis bipinnulatus*. Revenue from the troll and handline fisheries in 1991 was $7.8 million from 2,200 t or 4.9 million lb landed (Table 1; Ito 1992). Most landings of pelagic species by these fisheries have been purchased by Hawaii wholesalers, with only mahimahi being exported in any volume. Tuna caught by the surface fisheries are susceptible to being "burnt" (Watson et al. 1988), a condition that renders the product unsuitable for *sashimi* (fish for raw consumption), thus reducing its price.

The Status of the Resources

Hawaii fisheries generally account for less than 8% of the stock-wide catch of pelagic species (Table 2) and thus are unlikely to cause stock-wide biological fisheries interactions. However, increased fishing effort by large-scale fisheries such as the longline fisheries of Japan, Korea, or Taiwan, or the purse-seine fisheries of the U.S. or Japan will reduce stock abundance[4] creating the potential for stock-wide biological

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[4]According to the production model (Figure 1), any major increase in fishing effort reduces fish abundance and CPUE.

fishery interactions with other, smaller fisheries on the same stocks. The degree of stock-wide biological interaction depends on the status of the individual stocks.

For blue marlin, Suzuki (1989) observed that catches (by all nations) from the presumably single Pacific-wide stock had been sustained over a wide range of standardized fishing effort. Using unpublished catch and effort data as well as utilization and efficiency rates for deep and regular longline, he concluded without fitting an assessment model that fishing was not having a significant impact on the stock. Skillman (1989b) examined trends in estimated blue marlin stock in several index areas, using published catch and effort data, and simulated a range of probable effects of gear changes (current utilization and efficiency rates for deep and regular longline had not been published). A production model fitted to these catch and effort data indicated that the stock was still overutilized but less so than in a 1977 assessment (Shomura 1980). Effective fishing pressure appeared to have declined due to the adoption of "deep" longline gear (Suzuki 1989), while yield had remained fairly steady.

Based on these assessments and the consideration of marginal yield (Gulland 1968), increased Hawaii landings of blue marlin would mostly be fish that would otherwise be caught by the large, non-local fleets. A large increase by the small local fishery would result in only a slight decrease in stock-wide catch rates; the yield of the large-scale, non-local fishery would decline about as much[5] as the small local fisheries yield would increase, but the change would appear small (or unmeasurable) relative to the yield of the large fishery. In contrast, major effort increases by large-scale fisheries would have marked impacts on all fisheries (large or small) on the same stock. Furthermore, localized biological fishery interactions would be intensified when stock-wide exploitation resulted in a decreased local influx of fish (Figure 1B; Boggs 1993) and increased competition for the locally available fraction of the resource. These concepts apply to all pelagic species fished in Hawaii.

For striped marlin in the North Pacific, neither Skillman (1989b) nor Suzuki (1989) were able to fit a production model to the data. With no indication of a leveling off of catch with increased effort, both concluded that the striped marlin stock was underutilized. Thus, it would appear that the stock-wide harvest of this species could be increased. However, catch rates would decline gradually with increased stock-wide fishing effort and the decline in catch rates would affect Hawaii fisheries. Local impacts of Hawaii harvest increases would depend on the

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[5]In theory, slightly more. If the blue marlin stock is over-utilized, an increase in total effort results in a net decline in total yield (Figure 1A).

rate of fish replacement (influx and growth) in the local area and competitive factors. For example, the Hawaii longline fishery exploits this winter-abundant species earlier in the season and farther from the islands than the Hawaii troll fishery, and it could potentially intercept fish that would otherwise be available to the troll fishery.

For swordfish, Bartoo and Coan (1989) and Skillman (1989b) both pointed out that the dominant Japanese longline fishery had gone through several phases, and there were no published data with which to standardize the effort statistics across all phases. Bartoo and Coan (1989) concluded that the fishery was not having a significant impact on the Pacific-wide stock, or a Northeast Pacific stock, because swordfish catches in late 1970-1980 were at about the same level as in 1950, and catch rates had remained fairly stable since the 1960s. Skillman's (1989b) production model fitted to the catch and nonstandardized effort data indicated that the stock was underutilized. Pacific-wide swordfish landings increased by about 70% from 1980-90 to reach levels much higher than previous MSY estimates. Recent Hawaii longline landings account for about half of this increase and a substantial proportion of the catch in the Northwestern and eastern Pacific (Table 2). If the swordfish stock is now fully utilized, further increases in fishing effort could lead to declines in stock-wide abundance and, especially the abundance of the older, spawning-sized fish. Stock-wide biological fisheries interactions would be likely, but localized biological interactions between Hawaii fisheries would not result since there is effectively only one Hawaii fishery for swordfish (i.e., the longline fishery).

Assessments were not prepared for black marlin, shortbill spearfish, or sailfish for the Second International Billfish Symposium. No attempts to assess the status of mahimahi, wahoo, or central Pacific sharks have been published.

For yellowfin tuna in the central-western Pacific, the mature portion of the resource fished by subsurface longline gear may be fully utilized (Suzuki 1991). While the status of the wider size spectrum of yellowfin tuna vulnerable to harvest by purse seine and other surface gear in the western and central Pacific is not well established, it is possible that increases in the purse seine fleet have caused a decline in longline catch rates (Suzuki 1993b). There is less consensus regarding the status of the stock overall (small and large fish combined). For example, Suzuki (1991) suggests that the stock may be fully utilized while Hampton (1992) suggests that it is lightly harvested. Thus, it is hard to predict the stock-wide impacts of increased fishing effort on yellowfin tuna. Increased landings by the relatively small Hawaii fishery (Table 2) would not have a significant or even measurable impact on the stocks. Local impacts of local fisheries would again depend on the rate of fish replacement in the local area and local catch competition.

Hawaii longliners might conceivably intercept yellowfin outside the range of the troll and handline fisheries. Although the Hawaii surface fisheries exploit more juvenile yellowfin than the Hawaii longline fishery (Ito 1992), the yield of the surface fishery (by weight) is dominated by the same large sizes of yellowfin tuna as those harvested by the longline fishery (Boggs 1993).

For Pacific bigeye tuna, Miyabe (1991) concluded that the resource vulnerable to longline gear was either fully utilized or approaching that state. Thus, increases in the stock-wide harvest would likely have a measurable impact on Hawaii fisheries. Recent catches of North Pacific albacore have been less than the estimated MSY (Suzuki 1991), although increased catches of albacore by driftnets in the 1980s and early 1990s have not been fully documented or incorporated into stock assessments. Driftnet fishing was banned as of January 1, 1993 which should result in a decrease in stock-wide fishing mortality. The harvest of these two species by Hawaii fisheries is minor compared with the stock-wide harvest (Table 2). Relatively little is known regarding local abundance or localized fishery interactions involving either of these species, although both are important to the Hawaii longline and handline fisheries.

The skipjack tuna resource is generally believed to be in good condition although the catch rates in local fisheries fluctuate considerably, apparently due to environmental variation (Boggs and Pooley 1987). The Hawaii skipjack tuna fishery was always small (maximum yield 7,400 t in 1965) compared with Pacific-wide yields of this species (i.e., 870,000 t in 1990), and although the Hawaii skipjack tuna fishery was once Hawaii's largest domestic fishery, it has been in decline since the close of the local cannery in 1984. Analyses have suggested that the decline was not due to local or stock-wide over-utilization, and that the locally available fraction of the stock could support expanded fishing effort (Boggs and Kikkawa 1993).

ISSUES AND ACTIONS

Gear Conflicts

Historically, the Hawaii longline fishery operated on fishing grounds within 37 km (20 nmi) of the shoreline (June 1950, Hida 1966). Some smaller longliners have traditionally set their gear within 9 km or 5 nmi of the shoreline, and in recent years some vessels have set their gear near or attached to FADs in nearshore waters. Most surface fishermen are dependent on fishing grounds within 37 km (20 nmi), and most FADs are anchored

within 6-15 km (3-8 nmi). The overlap in fishing area provided occasions for gear conflicts between longline and surface fishermen. Also, a number of the longliners that entered the fishery in the late 1980s set their gear perpendicular to shore, increasing the potential for conflict with the surface fisheries and established longliners, which tended to operate parallel to shore and along depth contours.

A variety of incidents between the longline and surface fishery participants occurred during 1989-91 before longline area closures were implemented in June 1991 and included the following: 1) tangling of the surface fisheries' fishing gear and boat propellers with longline gear; 2) crowding on popular fishing grounds and around FADs; 3) laying of longline gear between adjacent FADs, tying longline gear off on FADs, and wrapping of drifting longline gear around FADs; 4) larger longline vessels impeding the free movement of smaller boats of the surface fisheries; 5) willful destruction of longline gear; 6) verbal threats; and 7) gunfire (Pooley 1990). The conflicts were initially intensified because of ethnic differences among the fishermen (Pooley 1990).

The dispute became public in 1989, and an informal agreement was reached restricting longliners from fishing within 37 km (20 nmi) of the coasts of the main Hawaiian Islands and 19 km (10 nmi) of fish aggregating devices (FADs). This agreement reduced much of the direct gear conflicts, but lapses in compliance continued as new longliners entered the fishery. Consequently, the problem intensified throughout 1990 and early 1991.

Although opinions regarding the conflict were strong and varied, no research on Hawaii longline and surface fishery gear conflicts had been conducted to support a management solution. Ad hoc summaries of fishery statistics were prepared, and an informal survey of fishing locations was conducted by the Western Pacific Regional Fishery Management Council (WPRFMC). Compilations of annual catches and fishing effort using the HDAR data base showed that many of the key fishing grounds of the longline and surface fleets overlapped, particularly within 37 km of shore (Figure 4). Compilation of the National Marine Fisheries Service (NMFS) Federal longline logbook data collected in late 1990 and early 1991 confirmed this perception. The mail survey conducted in 1991 by the WPRFMC also indicated considerable overlap in fishing areas (K. Simonds, personal communication).[6] Although this survey was not scientifically designed, responses were received from all the segments involved in the controversy. Of the longliners responding ($n = 30$), 25% indicated they never fish beyond 46 km (25 nmi) from shore. Of the troll and handline fishermen responding ($n = 247$, 75%

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[6]K. Simonds, WPRFMC, 1164 Bishop St. Suite 1405, Honolulu, HI 96813.

indicated they never fished beyond 35-65 km (19-35 nmi, depending on the island) from shore.

Public testimony, fishery data, and survey results all indicated that the severity of the gear conflict problem required that something be done to prevent personal injury or loss of life as well as gear loss and damage. Responding primarily to the social aspects of the conflict, the WPRFMC developed and the NMFS implemented an emergency action in June 1991 which established nearshore, fixed-boundary areas closed to longline fishing during the entire year. The boundaries of the closed areas were set at 93-139 km (50-75 nmi) from shore depending on the island. While this action effectively reduced conflicts, consideration of the seasonal dependence of surface and longline fleets on fishing grounds within the nearshore areas led to seasonal reduction in the size of the longline area closures during winter (to 46-93 km, or 25-50 nmi from shore) starting in October 1992.

A regulatory impact review or other review of the socioeconomic impact of the longline area closures was never done. While the conflict involved two general classes of boats, those in the surface fisheries and the longline fisheries, the socioeconomic costs of the area closure are being borne almost entirely by the longline sector. Extremely limited exception criteria were established, and only three small longline vessels qualified. Besides addressing the gear conflict problem, the area closures in effect allocated sole access to nearshore pelagic fishing grounds to troll and handline fishermen, and excluded longline fishermen. The effect of the management action from the perspective of allocation was not thoroughly researched, although the WPRFMC did consider testimony from the longline sector during its deliberations. Even with the reduction in the size of the area closures around Hawaii during the winter, longliners still must travel away from familiar fishing grounds and develop offshore grounds at greater distances, thereby adding to their operational costs and frequently reducing their catch rates. Some sampan longline boats, using 200- to 300-hook gear often with fresh or live bait, have fished near shore since the 1940s. These and some of the recently arrived boats are too small and unseaworthy to operate outside the area closures during rough weather. All but three of these boats have been forced either to enter other fisheries (i.e., the tuna handline fishery) or to cease fishing. In addition, processors, the market, and consumers have been affected to varying degrees by changes in the volume, species composition, size composition, and quality of products landed.

Furthermore, if the nearshore area closures provide economic benefits to the troll, handline or other small-vessel fishermen, then growth of this sector and development of new fishing strategies by vessels operating in the nearshore waters may be stimulated. With such growth would come increased competition between nearshore fisheries and incentive for the larger trollers

and handliners to expand their range, fishing increasingly beyond
the area closures into longline fishing areas. Gear conflicts
might again occur, stimulating the need for further management
action. In 1991, the offshore tuna handline fishery began
developing on seamounts and around weather buoys some 180-500 km
(100-280 nmi) off the south and west shores of the island of
Hawaii. The seamount area was a popular tuna longline area for a
number of years before the handline fishery expanded its range.
Furthermore, in late 1992, accounts began being received
concerning members of the surface fisheries experimenting with
longline gear less than 1 nmi in length (thus not being defined
as "longline gear" in the Federal regulations) and with vertical
longline gear. Thus, the potential for renewed gear conflict is
rising.

Biological Fishery Interactions

Participants in the surface fisheries have asserted that the
recent increases in Hawaii pelagic landings due to the larger
longline fleet have caused a significant decline in the abundance
of pelagic resources available within the nearshore waters of
Hawaii in which most of them can safely operate. Some fishermen
have claimed that the total domestic harvest, rather than simply
causing a decline in resources available locally, has become
sufficiently large to reduce the stocks over a wider area.
However, the small proportion of the total catch of most stocks
that is harvested by Hawaii's pelagic fisheries (Table 2) is
unlikely to affect the overall abundance of those stocks. Hawaii
fisheries would more likely experience localized biological
fishery interaction (i.e., catch competition).

Most claims that catches and catch rates have fallen to
unacceptably low levels involve yellowfin tuna and blue marlin.
Catches by the newly arrived longliners during 1989-90 contained
high proportions of these relatively shallow dwelling species,
which are also the targets of the surface fisheries. In
contrast, the established longline vessels effectively targeted
deeper-swimming bigeye tuna, which is an insignificant component
of landings of the surface fisheries except for the recently
developed offshore (weather buoy and seamount) handline fishery.

Yellowfin tuna is currently the second most important
species in the tuna-directed component of the longline fishery,
although over the history of the Hawaii longline fishery bigeye
and yellowfin tunas have alternated as the most important
species. Before 1989, longline incidental catches of blue
marlin, mahimahi, and wahoo collectively made up less than 20% of
the total (all fisheries) landings of those species. After
expansion of the longline fisheries during 1989-91 longline
catches accounted for 34-39% of the total (all fisheries)

landings of these three species. Longline catches of yellowfin tuna during 1989-91 and blue marlin during 1990-91 exceeded the landings by the surface fisheries that primarily target them (Table 1). Bigeye tuna landings by the combined surface fisheries recently increased fivefold and accounted for 14-15% of their total landings during 1989-91. Much of this increase is attributable to the specialized offshore, pelagic handline fishery, which lands relatively small bigeye tuna. As mentioned earlier, some fishery interaction concerns are developing because of the latter fishery. Finally, while swordfish is currently the most important species in the longline fishery and striped marlin nearly as important as yellowfin tuna, neither of these species makes up more than 4% of the combined landings of the surface fisheries. Hence, localized biological fishery interaction regarding swordfish and striped marlin is not an issue.

Evidence of localized biological fishery interaction affecting catch rates of yellowfin tuna or blue marlin in the late 1980s or early 1990s was weak (Boggs 1991). Yet, with a tripling of the longline harvest during 1987-90 (Figure 6) with the resulting pelagic harvest exceeding that taken in previous years by both foreign and domestic fleets in Hawaii's waters and with the tuna and billfish fisheries in other management areas declining after rapid expansion (ICCAT 1992) the WPRFMC embarked on a proactive management course. It instituted a 3-year moratorium, implemented by the NMFS in April 1991, on the entry of additional longline vessels into the fishery. The moratorium was intended to stabilize harvest levels and to prevent escalation of biological and economic fishery interactions so that future management options would not be constrained.

Research on Biological Interactions

Does biological fishery interaction occur in Hawaii? Research has sometimes supported an affirmative answer and other times not. While the fishery management plan was being developed for pelagic species in the 1970s, the NMFS and the WPRFMC sponsored several studies to evaluate the purported impacts of foreign longline fishing on the surface fisheries. These studies by Lovejoy (1977a, 1977b, and 1981), Wetherall and Yong (1983), and Skillman and Kamer (1992) as well as later studies by Boggs (1991, 1993) involving domestic longline fishing will be discussed below. Also discussed are examples of fishery interaction off Mexico regarding striped marlin (Squire and Au 1990).

Lovejoy (1977a, 1977b, 1981) used monthly Japanese longline catch per 1,000 hooks (CPUE) data (1962-75) as a measure of resource abundance to model spatial distribution, movement, and changes in abundance of marlin in 27 subareas of the Hawaii EEZ

plus a pooled Pacific area. His analysis incorporated standard fishery equations involving stock abundance, catch, fishing effort, and the catchability coefficient in a compartmental simulation model. Domestic longline and troll fishing effort and the associated catchability coefficients were estimated by calibrating the model to domestic catch and abundance estimates derived from the Japanese data. Fish movement through the EEZ was modeled to match geographic changes in Japanese CPUE in the 27 Hawaii areas, assuming a general north-south movement for blue marlin and a northwest-southeast movement for striped marlin. Recruitment was assumed to be constant and uniformly distributed for blue marlin and constant and seasonal for striped marlin. Under these conditions, the model was run with all fisheries operating. Then, the fishing mortality caused by Japanese and domestic longline fisheries within the EEZ was set to zero, and the simulation model rerun assuming that recruitment, movement, natural mortality, and the fishing effort and catchability coefficients of the remaining gear (domestic longline and troll or only troll gear) remained the same. Increases in the simulated troll catch of blue and striped marlins were small (2% and 7%, respectively) when only the Japanese longline fishing in the EEZ was eliminated but were larger when domestic longline fishing also was eliminated (5% and 21%, respectively). Though smaller than the Japanese fishery in the EEZ at that time, the domestic longline fishery had a greater simulated impact because its fishing grounds overlapped more with the troll fishery.

The Lovejoy simulations showed that, given reasonable assumptions, localized biological fishery interactions were possible. However, the magnitude of the interaction depended on the assumed catchability of fish. When catchability was assumed to be low, only a small fraction of the fish present in the EEZ were caught and thus the effect of removing a fishery was small, and vice versa. For example, when the assumed catchability of fish was doubled and the modeled availability of fish in the Hawaii EEZ was halved (Lovejoy 1981), eliminating foreign longline fishing mortality increased simulated troll catches of blue and striped marlins by 5% and 12%, respectively. Eliminating all longline fishing resulted in 13% and 45% simulated increases in troll catches of blue and striped marlin, respectively. In contrast, when the estimated catchability was halved, eliminating foreign longline resulted in increased troll catches of only 1% and 3% for blue and striped marlins while eliminating all longline mortality resulted in only 3% and 11% increases. Thus, the impact of local fisheries on local fish abundance depends on the true abundance and catchability of fish, which remain unknown.

Using Japanese longline catch and effort statistics for 1962-79 to compute estimates of abundance, Wetherall and Yong (1983) modeled the relationship between blue marlin abundance within the EEZ and factors occurring within and beyond the EEZ. Their regression model using estimated blue marlin abundance at

the beginning of each year in a mid-Pacific area explained 80% of the annual variation in peak third-quarter abundance within a main Hawaiian Island area roughly equivalent to the EEZ. This regression indicated that Hawaii catch rates were highly dependent on factors governing the success of more wide-ranging fisheries. Such factors might include stock-wide abundance or catchability. No other statistically significant predictors of local catch rates were found. However, by including variables for a recruitment trend and foreign fishing effort in local, adjacent, and mid-Pacific areas, they increased the amount of variation explained by the regression from 80% to 95%, suggesting that both wide-scale and local fishing effort influenced local catch rates. With so much of the variation explained by these factors, the impact of local domestic effort is not likely to have been large; however, domestic data were not included in the study.

Skillman and Kamer (1992) extended Wetherall and Yong's (1983) work to other pelagic species but used correlation rather than regression analysis. Also included were data for the domestic Hawaii longline and surface fisheries. Stock abundance indices of blue and striped marlins within the EEZ based on catches by domestic gear were found to be positively correlated with abundance indices for areas outside the EEZ based on Japanese statistics. Thus, stock dynamics occurring within the EEZ as measured by domestic gear mirrored dynamics occurring outside the EEZ, which agrees with Wetherall and Yong's (1983) results for blue marlin.

Skillman and Kamer (1992) also found that domestic catch rates of blue and striped marlins were negatively correlated with Japanese fishing effort in areas outside the EEZ. The significance of the relationship for blue marlin decreased from local to adjacent areas and was not significant in a more distant mid-Pacific area. For striped marlin, the relationship was equally significant in the local and adjacent areas. Thus, for blue marlin, the closer the foreign fishing occurred to the EEZ, the more likely an adverse impact on domestic catch rates within the EEZ. These results agree with Lovejoy (1977a, 1977b, 1981), suggesting that localized biological fishery interaction does occur. Within the domestic fishery, positive correlations of seasonal catch rates indicated that fishery interactions between longline and troll gear for blue marlin, striped marlin, and wahoo would be likely.

Boggs (1991) used graphic techniques to examine monthly HDAR Commercial Catch Report data summaries (January 1987-June 1990) from Hawaii's surface fisheries for evidence of interactions with the rapidly expanding domestic longline fisheries. A substantial decline in the catch rate of yellowfin tuna by the troll fisheries and various segments of the handline fisheries over the last few years in the study was found (Figure 7A). Concurrently, longline catches of yellowfin tuna had increased. However, catch

rates by the surface fisheries had not declined below the level recorded in 1983 when the longline fishery was much smaller than in the study period. In addition, monthly catch rates for yellowfin tuna by the surface fisheries showed much variation unrelated to longline catch. For example, months with low catch rates occurred throughout the range of longline catches both during and out of the usual season of high abundance. Thus, Boggs' (1991) study found only weak evidence of localized biological fishery interaction in recent years. However, the study also emphasized that the quality and coverage of local domestic fishery data may have been inadequate to reveal fishery interactions.

Much of the variation in Hawaii yellowfin tuna catch rates during 1987-90 may simply have reflected variations in stock abundance on a wider scale or variations in catchability or availability of yellowfin to local fisheries. From 1983 to 1988, catch rates for free-swimming schools of yellowfin tuna taken by the Japanese purse seine fishery in the western Pacific (Suzuki 1991) followed a pattern very similar to the catch rate of yellowfin tuna by the troll fishery in Hawaii (Figure 7B). Boggs (1991) found no apparent relationships between the catch rates of the longline and surface fisheries for blue marlin, striped marlin, mahimahi, wahoo, bigeye tuna, and swordfish. Pooley (1991a), using landings data for the same period from the NMFS shoreside market monitoring program, confirmed most of Boggs' conclusions. A more thorough study of the situation was made when data after mid-1990 became available (Boggs 1993). The most dramatic increase in longline effort occurred in the second half of that year, but troll and handline catch rates increased or remained similar compared with the period 1988-89 (Boggs 1993). Consideration of the latter data obliterated the weak evidence of localized interaction seen in the previous study (Boggs 1991).

An unplanned experiment on the effect of longline fishing effort on troll catch rates of marlin occurred in 1977 when the government of Mexico excluded foreign longline fishing from within its 200-mile fishing zone. Troll catch rates of striped marlin in the area west of Mazatlan and around the tip of Baja California doubled over the 1977-80 period after nearly a decade of decline (Squire and Au 1990). Joint-venture longline operations that were allowed to fish in the area during 1979-80 also experienced catch rates double those of 1976. After 1980 when restrictions on foreign longline operations in the area were removed, troll and longline catch rates declined. This series of events suggests longline fishing effort in an area adjacent to the trolling grounds had a much stronger effect on local catch rates than indicated for Hawaii's fisheries (Lovejoy 1977a, 1977b, 1981; Wetherall and Yong 1983; Skillman and Kamer 1992). However, when the catch rates of the joint-venture fishery and the foreign longline fishery off Mexico were analyzed in relation to fishing effort during 1962-84, no clear quantitative relationship was found (Squire and Au 1990), largely because

catch rates in the central area of the fishery declined during 1981-84 despite relatively low levels of effort.

Squire and Au (1990) defined a "core area" as a place where the fish naturally aggregate in much higher concentrations than typical throughout their population range. They hypothesized that a reduction in core area fishing effort would have a disproportionate effect in raising local catch rates. This effect would occur because the local fisheries depend more on the formation and fishing-down of hot spots than on stock production. Consequently, the relationship between fishing effort and catch rates in hot spots could differ from that in a larger area. Data with very fine geographic resolution are needed to demonstrate such a relationship. Surface fishery participants in Hawaii also target well-known spots called *koas,* distinct from the FADs, where yellowfin tuna and blue marlin aggregate. These participants' support of management measures excluding large-scale commercial fisheries from prime nearshore areas is consistent with the hypothesis described by Squire and Au (1990).

In summary, Wetherall and Yong (1983) and Skillman and Kamer (1992), using long time-series of data, found evidence supporting the findings of Lovejoy (1977a, 1977b, 1981). These studies indicated that localized biological fishery interactions can occur in Hawaii fisheries. More recent studies limited to domestic fishery data collected during 1987-90 have not found evidence of such interaction. In addition, Wetherall and Yong (1983), Skillman and Kamer (1992), and Squire and Au (1990) demonstrated that an exogenous change in stock abundance may overwhelm the influence of local fishing effort on local catch rates of highly mobile pelagic fish in a small area. The opportunity to compare pelagic catch rates before and after the abatement of foreign longline fishing in Hawaii's EEZ (1980) was a selling point in the passage of the WPRFMC's pelagic species fishery management plan (FMP) in 1986. Unfortunately, the ability to make such a comparison was hindered when submission of HDAR Commercial Catch Reports by longline vessels declined substantially during 1979-89.

Fishing Depth and Species Selectivity

Pelagic fishes inhabit characteristic depths, making interactions more likely to occur among fisheries deploying gear at similar depths. Changes in the configuration and fishing depth of longline gear have altered the species selectivity and the potential for interactions with surface fisheries like trolling and tuna handlining. One change in gear configuration occurred in the late 1940s when Hawaii's fishermen added a float in the middle of the 4- to 6-hook basket (June 1950). This change resulted in the gear fishing in the upper 120 m rather

than 150 m. Thus, more yellowfin than bigeye tunas were caught and almost half of the catch was billfish. A subsequent account (Otsu 1954) documented a decreased fraction of yellowfin tuna and billfish in the Hawaii longline catch with five to six hooks per basket (no mention was made of a middle float). Hida (1966) reported some boats using five to eight hooks per basket. Increasing the number of hooks per basket results in deeper fishing, since more main line is extended between floats to accommodate the additional hooks.

A deepening of longline gear configuration continued in recent decades. During the mid-1970s, the Japanese longline fishery began doubling up baskets of fishing gear (i.e., 8-12 hooks between floats) to target deep-swimming bigeye tuna, thus reducing the catch rates of yellowfin tuna and billfish (Hanamoto 1976; Suzuki et al. 1977). By the mid-1980s, Hawaii's longline fishery also was using the newer, deep (reaching >300 m) gear with 12 hooks per basket (Kawamoto et al. 1989). In 1987, bigeye tuna constituted 46% of the longline catch but yellowfin tuna only 15% and all billfishes 23% (Table 1). In 1990, with monofilament longline gear predominating, bigeye tuna, yellowfin tuna, and all billfishes comprised 35%, 26%, and 23%, respectively, of the longline landings, exclusive of swordfish (Ito 1992). However, incidental catches of shallow-swimming blue marlin, wahoo, and mahimahi increased from 6% in 1987 to 14% in 1990, exclusive of swordfish landings.

As indicated, the fishing depth of monofilament longline gear can be altered by changing the spacing between the hooks and floats along the continuous main line. However, in experiments where great attention was paid to controlling the distance between hooks and floats, time-depth recorders indicated that the gear was fishing as much as 50% shallower than expected (Boggs 1992). Thus, considering the difficulty of controlling the depth fished with this gear, even experienced fishermen who intend to target deep-swimming bigeye tuna may inadvertently deploy shallow gear when using monofilament main lines.

In experimental longline trials in Hawaii (Boggs 1992), shallow sets with monofilament gear resulted in higher catch rates of billfish and lower catch rates of bigeye tuna (Table 3). In addition, hook timers (Somerton et al. 1990) used to estimate the elapsed time fish were on the longline indicated that less than 12% of bigeye and yellowfin tunas and 21-32% of striped marlin, shortbill spearfish, and mahimahi were caught by longline hooks settling to their full depth or ascending during retrieval (Boggs 1992). Since most marlins were taken on static hooks, removal of the shallow hooks would reduce the incidental catch of marlins. Use of hook timers also indicated that many fish survive for long periods on monofilament longline gear. The recaptures of one striped marlin and three bigeye tuna (Boggs, 1992 and unpublished data), which were tagged and released following capture on monofilament longline, suggest that such

fish can survive if released. These results suggest that regulations that encourage deeper longlining for tunas and discourage retention of some species could be a viable management strategy to mitigate fishery interactions.

Economic Fishery Interactions

With increases in the number of longline vessels and the frequency of large landings, fishermen in the surface fisheries have alleged that the average price received for their landings has declined. Landings of bigeye and yellowfin tunas by longline vessels increased and were perceived to depress the prices of troll- and handline-caught yellowfin tuna. The average inflation-adjusted price for longline-caught yellowfin tuna was $5.93 per kg ($2.69 per lb) during 1987-90, compared to the surface fishery price of $3.44 per kg ($1.56 per lb). However, this price difference is not proof of market displacement.

Surface fishermen, particularly small-boat operators, claim that declining catch rates and heightened market competition have resulted in lower incomes and narrower profit margins. Marketing mechanisms and price structure are said to favor longliners because longline-caught tuna tend to be larger, and dealers (including those who export) believe them to be of better quality on average than tuna caught by the surface fisheries. For example, longline landings are auctioned first with prices declining as buyers fill their needs for prime fish.

Economic competition is not limited to the surface fishery. Ironically, defaults on loans among the newly arrived longline vessels were reportedly high. Competition for access to infrastructure also affects surface and longline fisheries. Docking facilities in Honolulu are in short supply, resulting in longline vessels being tied up several vessels deep at slips designed for only one vessel. This situation is not safe and has resulted in conflicts and delays in off-loading fish as well as loading gear and supplies. In contrast to this relaxation of Hawaii moorage rules to accommodate more longline vessels, owners of new boats in the surface fisheries have reported being placed on a waiting list for slips and not permitted by harbor officials to tie up to boats already assigned slips.

Two recent reports reviewed economic interactions at the market level to assist the WPRFMC in its decision-making on the longline moratorium issue rather than as definitive treatments of the subjects. In the first report, Pooley (1991b) examined average monthly prices of yellowfin tuna using market data for 1987-90 collected by the NMFS shoreside market monitoring program, which monitors fishery landings at the major auction and processors in Honolulu. The data were categorized into three

components based on the landings being made by longline vessels, the Oahu surface fisheries, or the surface fisheries on the remaining main Hawaiian Islands. No long-term trend in prices was evident, although prices were not adjusted for inflation. Monthly price variation as measured by the coefficient of variation was 20% for longliners, 18% for the Oahu surface fisheries, and 29% for the surface fisheries on the other main Hawaiian Islands.

The central economic issue has been the relationship at the market level between surface fishery prices and longline landings. The correlations between prices and landings versus time trend and market season are presented in Tables 4 and 5. The strongest determinant of the surface fishery price for yellowfin tuna was market season, but a linear regression of Oahu surface fishery yellowfin tuna price on indexed longline landings (observed values divided by their mean) and season accounted for only 3% of the monthly variation in price (Pooley 1991b). While the regression coefficients for the season variable and the indexed longline landings were statistically insignificant, their signs were as expected (i.e., positive for season, negative for landings).

Pooley (1991b) concluded that the monthly aggregations of prices were probably too gross to reveal short-term price effects (weekly price aggregates would have been preferable) and that failing to adjust prices for inflation (the Honolulu consumer price index rose 30% from January 1987 through December 1990) also may have confounded the analysis. Furthermore, the substantial changes in the Hawaii fresh tuna market also may have disrupted the normal price-quantity relationship. Finally, the volume of exports (primarily bigeye tuna) and imports (primarily yellowfin and skipjack tunas) should have been taken into account, but export and import data for 1990 were not available.

The purpose of the second paper (Pooley 1991c), a regulatory impact review, was to assist in understanding the economic consequences of alternative management actions presented in the WPRFMC's proposed amendment to the pelagic species FMP calling for a moratorium on the entry of additional longline vessels. The study provided a qualitative evaluation of the management alternatives proposed to check increases in fishery interactions; insufficient data existed for a quantitative approach. These alternatives were evaluated in terms of 10 segments of the fishing community, including different boat classes and types of shoreside infrastructure. They were also evaluated in terms of nine types of economic and biological impacts.

Pooley (1991c) found that the greatest projected benefits and costs would be realized by a complete moratorium (i.e., no additional longline vessels entering the Hawaii fishery, even beyond the 200-mile EEZ). The largest cost would be the loss of income incurred by Hawaii's current longline vessels being

excluded from the fishery and by Hawaii's market and shoreside industries. The largest projected benefit from the complete moratorium would derive from potential improvements in logistics for the included longline vessels and for reduced gear conflicts in the absence of inshore areas closed to longline fishing. Improved catch rates for the surface fisheries might provide more substantial benefits, but the statistical evidence for a relationship between surface fishery catch rates and longline landings during 1987-90 was extremely weak. The catch rate effects would occur whether the moratorium was complete or partial (a proposed alternative moratorium allowed additional longline vessels to enter but only fish beyond the 200-nmi EEZ). In the case of a partial moratorium, the costs of the proposed regulation were reduced substantially, with the only apparent cost of the moratorium being increased travel time for longline vessels required to fish outside the EEZ. Nonetheless, the projected benefits for surface fishermen remained essentially the same as for the complete moratorium. This study did not evaluate alternative management actions, presented in a separate WPRFMC proposed amendment, involving area closures to resolve the nearshore gear conflict problem. However, Pooley's (1991c) analysis showed clearly that the greatest expected benefits would be from the longline area closures, rather than any of the moratorium alternatives. While this study identified a number of social concerns regarding fishery interaction, social problems are beyond the scope of this paper. For the small-boat participants, some of these issues were described by Meyer Resources (1987).

RECOMMENDATIONS

Gear Conflicts

Now that gear conflicts have essentially been eliminated and tensions have calmed considerably, we believe that the following issues should be addressed. First, the socioeconomic impact that the area closure and the upgradability and transferability restrictions in the longline moratorium have had on small longline vessels should be documented. Second, data on the socioeconomic benefits to the surface fisheries are needed to evaluate the overall costs and benefits of the area closures. Third, improved data on the area fished by the surface fisheries should be collected so that the efficacy of specific boundaries of the area closures can be monitored. Fourth, these fishing area statistics should be used to monitor for expansion of the surface fisheries that could lead to recurring gear conflict. Economic data may also be needed to evaluate this situation if it occurs.

The existing area closures could be viewed as part of an adaptive management strategy in which an interim regulation is adopted to solve a critical social problem and at the same time provide the circumstance whereby data could be collected to evaluate the efficacy of the regulations and modify them accordingly to arrive at optimum yield. Adaptive management is being promoted today as a realistic and practical strategy of handling uncertainty in fisheries management (Collie and Walters 1991; Hilborn 1992; McAllister and Peterman 1992).

Biological and Economic Fishery Interactions

Collection and analysis of data and consultations among the fishing industry, the WPRFMC, and NMFS during the moratorium were intended to lead to the formulation of a long-term management plan to replace the moratorium.[7] Most of the past research on fishery interactions in the Hawaii fishery pertained to blue and striped marlins. These studies must be updated, and comparable studies should be conducted for bigeye and yellowfin tunas. The research necessary to determine and quantify biological and economic fishery interactions in the Hawaii pelagic fishery was outlined in a 3-year plan prepared by the WPRFMC's Pelagic Plan Monitoring Team (see Boggs 1991) and in a workshop report prepared by NMFS, the WPRFMC, and the Joint Institute for Marine and Atmospheric Research (JIMAR) at the University of Hawaii (Ianelli 1992). The workshop report provided priorities for the JIMAR-funded Pelagic Fishery Research Program. A variety of research projects addressing Hawaii fishery interactions have been proposed by NMFS and funded by the JIMAR program.

The following two fundamental determinations have to be made in evaluating biological interactions. First, the asymptotic effect of local fishing effort on local yield must be shown to occur and then be described quantitatively (Boggs 1993). Second, the effect of fishing effort or catch of each component of the fishery on the catch rate or the catch of the other components in the fishery must be shown and quantified (e.g., Boggs 1991; Skillman and Kamer 1992). Ensuing modeling would also benefit from updated assessments of the status of relevant stocks. Then, these relationships would be used in developing statistical predictive models (e.g., Wetherall and Yong 1983) to evaluate the effects of alternative fleet growth scenarios and management options.

It would also be beneficial to construct simulation models (e.g., Lovejoy 1977a) as early in the process as possible. Doing

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[7]In fact, the replacement of the moratorium will precede the scientific elements of this plan.

so would help identify critical areas requiring further quantification, especially since such models have not been attempted for tunas in Hawaii's fisheries. Such models would help in designing tagging studies, the results of which would lead to more realistic models. In the end, such models could be very instructive in predicting the overall dynamics of the system and its probable reaction to alternative management strategies. However, simulation models may not be as useful in providing specific quantitative management advice as would statistical models, especially without data from an intensive tagging study.

Several lines of research are necessary to show economic fishery interactions in the Hawaii pelagic fishery. First, the effect of the sales of each component of the fishery on the price and income of the other components must be detected and quantified. Second, the dynamic relationship between supply and demand in the Hawaii pelagic seafood market should be modeled. Third, baseline costs and earnings for the major components of the Hawaii pelagic fleets must be measured, with an emphasis on the relationship between operating characteristics and income. Fourth, models of the movement and search pattern of the pelagic fleets (Mangel and Clark 1986; Wilson 1990) are needed to evaluate the impacts of variable economic and biological conditions and to evaluate the impacts of changing regulations. These models will be useful in determining the extent to which fishing effort is driven by catch rates and economic variables. not the reverse as implicit in the production model and asymptotic yield model. Such comprehensive studies would require the design and implementation of data collection programs at significant cost. A more experimental approach might be to use the discrete-choice approach to modeling the behavior of owners and captains of individual fishing vessels in the face of changing conditions (Miklius and Leung 1990).

Most aspects of the research described above have been proposed to the JIMAR Pelagic Fishery Research Program. If the proposed research were completed, and the results showed significant effects of the longline harvest or the total harvest of pelagics on the catch rates and economic yield of the surface fisheries, then rational targets for the appropriate levels of fishing effort to be allowed in Hawaii's longline fisheries could be devised. In addition to determining an optimal level of fishing effort that maximizes net revenue and nonmonetary benefits by the assembled fishery sectors, some political consideration will be needed to allocate total fishing effort among fishery sectors. In addition to limiting fishing effort, the following management actions could also be considered: 1) possession, landing, or sales restrictions for selected species or sizes of these species by the longline fisheries, commercial surface fisheries, all pelagic fisheries, or selected components of these fisheries; 2) reduction of the incidental catch of shallow-swimming pelagic fishes important to troll and handline fishermen by promoting or mandating the elimination of the

shallow hooks closest to longline floats or by setting the length of the float line; and 3) promoting the tag and release of all bycatch species by the longline and surface fisheries or only fish of certain sizes (large or small) or sexes depending on the fishery.

Fishery Data

A variety of fishery data must be available to conduct the research described above. Additional data also will be needed to evaluate the effects of management actions.

Catch, Effort, and Location

Longline data are available from the Federal mandatory longline logbook program, established by NMFS on 27 November 1990 and surface fisheries data from the HDAR Commercial Catch Report system. However, the adequacy of these data for assessing gear conflicts and fishery interactions should be examined so that special provisions can be made for the collection of additional data as needed. Two serious problems are already apparent. First, because of the gear conflict issue and the resulting longline area closure, reporting of the location of capture by the longline and surface fisheries may be even more open to question than previously. Potential solutions include logbooks for the surface fisheries and transponders for all full-time commercial vessel operators.[8] Second, historical, time-series indices of local resource abundance were based to a large extent on statistics from longline operations from within what are now closed areas. Future analysis of trends in abundance would benefit from some data being collected on longline fishing within the closed areas. A special, experimental permit might be a solution, with preference given to the small size longline vessels formerly fishing in the area. Carrying of transponders by qualifying boats should be a requirement. Carrying of observers would facilitate collection of biological samples.

Fishing effort statistics are another problem, especially for the surface fisheries which are monitored primarily by HDAR Commercial Catch Reports. Effort is estimated from HDAR data as homogenous trips based on the dates catches were reported (Boggs 1991). Fishing effort in hours, man-hours, or hooks, and details regarding the method, (i.e., green-stick, live bait, *palu ahi*,

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[8]The WPRFMC has already proposed transponders, and recently requested the NMFS to install transponders on Hawaii longline vessels.

ika shibi, etc.) and target species are not reported. A survey
of present and past operational characteristics of major
components of the surface fisheries is needed for meaningful
estimates of fishing effort and catch rates.

Total Landings

Without accurate data on total landings of pelagic fishes,
evaluating the impacts of the longline area closure and
conducting the 3-year moratorium study will be seriously
compromised. Unfortunately, the HDAR dealer and catch reporting
systems continue to have significant coverage problems, and the
NMFS shoreside market monitoring program has limited coverage.
The Federally funded and HDAR-conducted pilot survey of the
small-boat fishery on Oahu was carried out successfully though
with the usual start-up problems in fielding a new survey (Hamm &
Lum 1992). Plans for a statewide survey have been discussed but
not implemented. We recommend establishing a Federal trip sales
and transshipment ticket system for commercial pelagic landings
and implementing a small-boat fishing survey statewide.

Size Composition

Size measurements for the pelagic fishery are incomplete
because data collection has been intermittent, and most of the
data have been collected at the fresh fish auction on Oahu where
longline landings predominate. Other sites must be included to
ensure coverage of troll and handline landings and any
geographical variation in size composition. A regular sampling
schedule must be set.

Market Data

Data on the volume and price of pelagic landings collected
at selected sites on Oahu and Hawaii have been used to make
management decisions for the entire pelagic fishery in Hawaii.
The adequacy of these data will be questioned as the efficacy of
the management actions is evaluated and future management actions
are debated. Thus, we recommend coverage of other island markets
as well as better coverage of some components of the pelagic
fishery to prevent potential biases and to benefit future
analyses. The collection of data on exports to the U.S. mainland
and foreign markets needs to be improved.

Costs and Earnings

Baseline analyses of costs and earnings of components of the Hawaii pelagic fleets are now a decade old. New components like the swordfish fleet have never been analyzed. Thus, we recommend conducting new studies on all major components of the fishery, emphasizing data collection and analyzing the relationship between operating characteristics and income. Such studies will be needed to evaluate the impact of management actions.

CONCLUSION

The current level of understanding of fisheries interaction in Hawaii fisheries is inadequate to make reliable scientific predictions regarding the outcome of alternate management schemes. Even if all of the recommended data collection, analysis, and modeling were conducted the results might be insufficient to convincingly show that biological or economic fishery interactions are occurring, or to predict the best management alternatives.

Due to the uncertainties involved in showing that fishery interactions occur and difficulties in estimating the optimal level of fishing effort, an adaptive management strategy could be embraced. The objective would be to allow controlled increases in fishing effort sizable enough to cause measurable effects involving fishery interaction and dynamics of the locally available stocks. Two possible strategies for effort expansion are 1) incremental increases in the number of permitted longline vessels that could fish both inside and outside the EEZ or 2) expansion of the longline fisheries only beyond the EEZ. The fishery would have to be expanded under an effort control regime that would provide for the downward adjustment of the fishing effort as indicated by triggers built into the adaptive management strategy.

Without a clear scientific understanding of fishery interactions and a framework for optimum effort or catch allocation to guide managers, the longline moratorium may be replaced by a *de facto* continuation of the current situation under a restrictive limited entry regime, or a plan allowing some expansion of longline fishing effort under a more liberal regime. However, without such careful controls on fishing effort, management would be placed in a reactive mode with all of the attendant biological and socioeconomic costs. Therefore, some effective means of controlling longline fishing effort should be maintained until there is a better understanding of local fishery interaction.

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Table 1.--Hawaii pelagic landings (in metric tons) by gear for 1987-90. Estimates are tabulated from the National Marine Fisheries Service shoreside monitoring program (From Ito 1992).

	Pelagic management unit species							Tunas				Other pelagic fishes
Year	Swordfish	Blue Marlin	Striped marlin	Other billfish	Mahi-mahi	Wahoo	Sharks	Bigeye tuna	Yellowfin tuna	Albacore	Skipjack tuna	
					Longline							
1987	50	50	270	50	<20	50	<20	820	270	140	<20	90
1988	50	90	500	90	<20	50	50	1,220	590	320	<20	90
1989	270	360	590	140	90	90	90	1,410	1,000	270	<20	180
1990	1,900	360	500	50	140	50	90	1,360	1,000	180	<20	180
1991	4,490	320	630	180	230	50	90	1,590	730	320	50	230
					Troll and Handline							
1987	<20	360	50	<20	450	140	<20	50	1,220	<20	50	<20
1988	<20	360	90	50	230	90	<20	140	1,040	<20	90	<20
1989	<20	500	90	50	270	90	<20	270	500	<20	90	<20
1990	<20	270	50	<20	500	90	<20	270	500	<20	90	<20
1991	<20	270	90	50	730	140	<20	320	500	<20	140	<20
					Other Gear Types							
1987	<20	<20	<20	<20	<20	50	<20	<20	90	0	1,590	<20
1988	<20	<20	<20	<20	<20	50	<20	<20	140	<20	1,810	<20
1989	0	<20	<20	<20	<20	0	0	0	<20	0	1,320	<20
1990	0	<20	<20	<20	<20	<20	<20	<20	<20	0	450	<20
1991	0	<20	<20	0	<20	<20	<20	<20	50	0	1,000	<20

Table 2.--Stock-wide catch (t) of tuna and billfish species by
areas of interest (areas encompassing putative stocks)
compared with the Hawaii catch (t). Areas as defined
by source. Stock-wide catches are for 1990 except
for source 3 (1986-89 average).

Species	Area stock (?)	Catch (t)	Source[a]	Hawaii[b] (t)	Hawaii (%)[c]
Swordfish	Pacific	29,000	1		14%
	Northwest Pacific	9,200	1		
	Eastern central Pacific	8,900	1	4,490	39%
Blue marlin	Pacific	22,000	1	590	2.7%
Striped marlin	North Pacific	10,000	2	730	7.3%
Yellowfin tuna	Eastern Pacific	290,000	3		
	Central & western Pacific	375,000	4	1,270	0.4%
Bigeye tuna	Pacific	152,000	1	1,900	1.3%
Albacore	North Pacific	59,000	5	320	0.5%

[a]Sources are FAO (1990, and unpublished data, 2-approximation
based on FAO areas 61 and 71 (FAO 1990, FAO unpublished data),
Wild (1993), Suzuki (1993a), NOAA (1991).

[b]Hawaii data for 1991.

[c]Hawaii 1991 catch as a percentage of the total for each area or
stock. Percentage based on the assumption that total catch
stayed relatively stable from 1990-91 except for swordfish. The
large 1990-91 increase in the Hawaii swordfish catch (2,590 t)
was added to the area totals before calculating Hawaii's
pecentage of the swordfish catch.

Table 3.--Predicted catch-per-unit effort (CPUE) for standardized gear types in the Hawaii winter tuna longline fishery based on depth-of-capture experiments during 1989-90 (Boggs 1992).

	CPUE (fish caught per 1,000 hooks)				
Gear depth	Bigeye tuna	Yellowfin tuna	Striped marlin	Shortbill spearfish	Mahimahi
Shallow (40-160 m)	1.0	1.1	9.3	5.3	9.2
Regular (80-200 m)	1.7	0.9	7.1	4.0	3.2
Deep (80-320 m)	6.0	0.8	3.6	2.3	3.2
Proposed (160-320 m)	8.2	0.8	1.5	1.4	2.8

Table 4.--Correlation coefficients of average monthly longline
landings and average troll and handline prices for
yellowfin tuna, 1987-90. "Other islands" includes
Hawaii, Kauai, and Maui counties.

		Landings		
			Troll and handline	
		Longline	Oahu	Other islands
P	Longline	-0.3241*	-0.4117*	-0.3826*
R				
I				
C	Troll and handline			
E	Oahu	-0.2104	0.0387	-0.509
S	Other islands	-0.1702	-0.2190	-0.2727

* P ≤ 0.10

Table 5.--Correlation coefficients of time trend and market
season with average monthly landings and prices in
1987-90 of yellowfin tuna for the longline fishery
and the troll and handline fishery. Time trend rises
sequentially from a value of 1 to 48 from January 1987
through December 1990. Market season equals 1 for the
months from December through March or April, depending
on the date of Easter, and 0 for all other months.
Other islands includes Hawaii, Kauai, and Maui
counties.

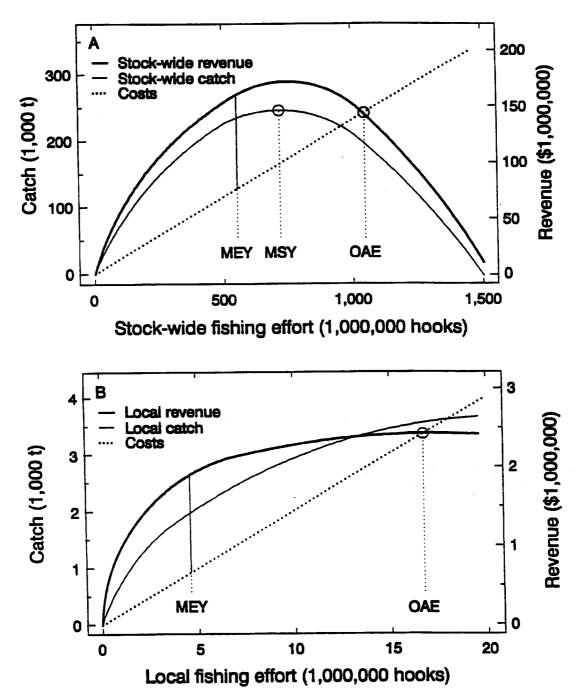|		Time trend	Market season
P R I C E S	Longline	0.0570	0.5799*
	Troll and handline		
	Oahu	0.0799	0.1995
	Other islands	-0.0336	0.3899*
L A N D I N G S	Longline	0.4660*	-0.1346
	Troll and handline		
	Oahu	-0.3907*	-0.2775*
	Other islands	-0.3486*	-0.3988*

*P ≤ 0.10

Figure 1. Simplified general models for the dynamics of (A) stock-wide yield for all fisheries on a pelagic fish species (production model) and (B) fishery yield from the locally available portion of a stock (asymptotic yield model). Yield is expressed in relation to fishing effort on an annual basis as catch (thousand t) and as revenue (millions of dollars). Maximum sustainable yield (MSY) is defined only in the stock-wide model (A). Open access equilibrium (OAE) is the sub-optimal condition where profits approach zero and Maximum Economic Yield (MEY) is the optimal condition where the greatest net profit is achieved.

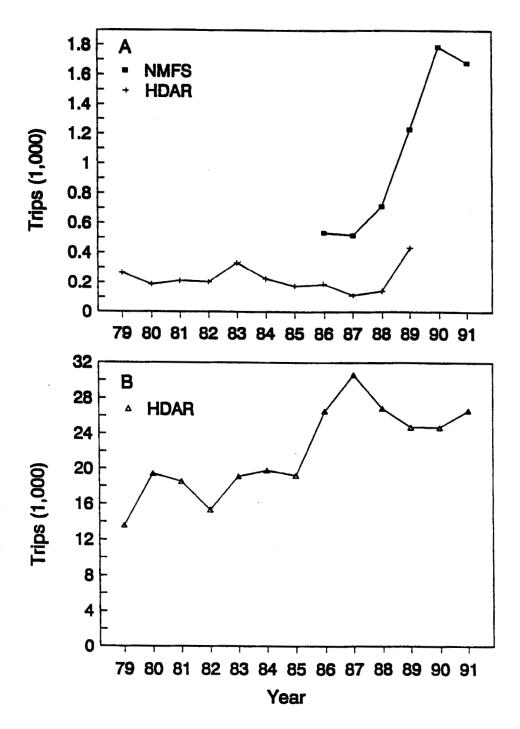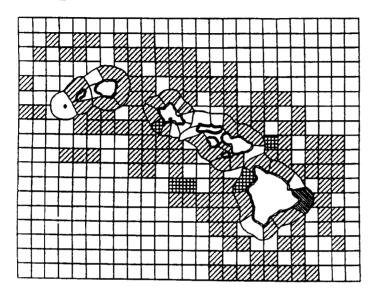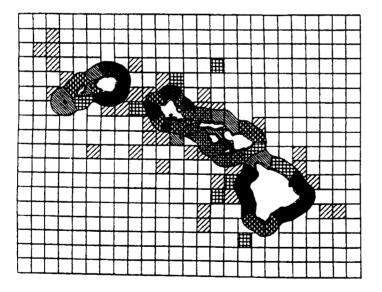Figure 2. Number of longline vessels operating in Hawaii, 1948-1991.

Figure 3. Estimated pelagic fishing trips taken by (A)
longliners and (B) trollers and handliners combined.
Based on the National Marine Fisheries Service
shoreside monitoring program and Hawaii Division of
Aquatic Resources Catch Report system.

Longline

No. of trips

◪ 1−10
⊞ 11−50
▨ 51−100
▩ 101−500
■ 501−1,000
■ >1,000

Troll and handline

Figure 4.   Area fished by the Hawaii longline fisheries and the
troll and handline fisheries.   Chart courtesy of the
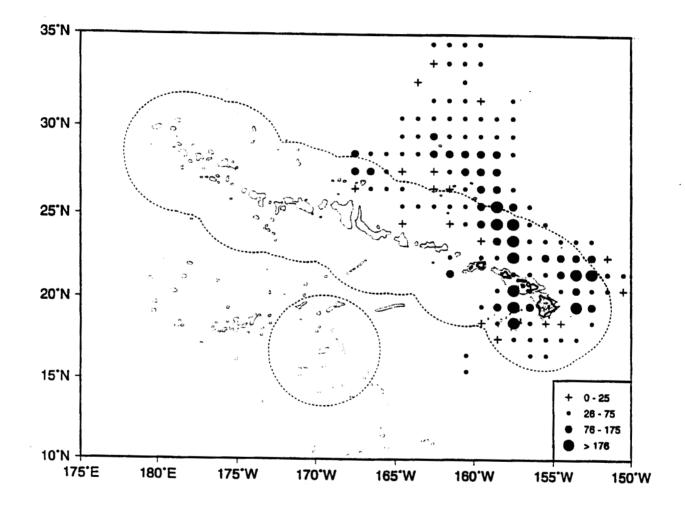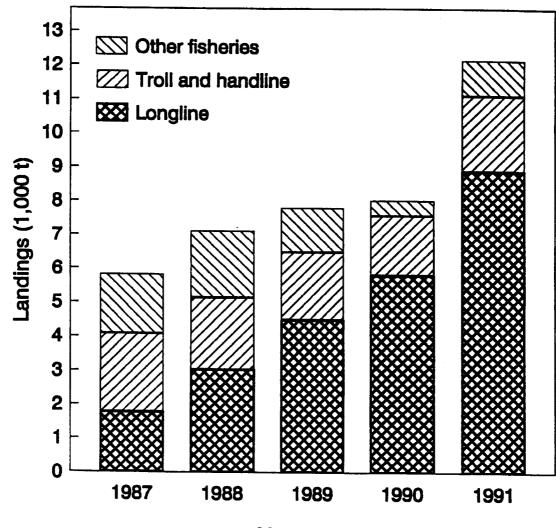Hawaii Division of Aquatic Resources.

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Figure 5.   Offshore longline fishing grounds during 1991 shown by
            number od sets.   Areas fished by few vessels are not
            included (confidential data).

Figure 6. Estimated total annual pelagic landings in Hawaii from NMFS shoreside monitoring program.
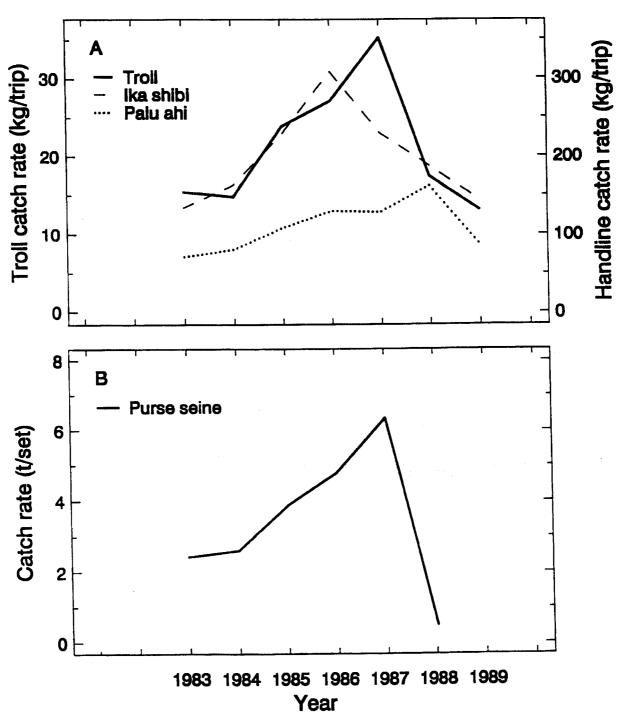
Figure 7. Annual catch rate of yellowfin tuna (A) per trip, by
gear type, in Hawaii during 1983-89, and (B) per set
by Japanese purse seiners in the western Pacific.
Hawaii data from HDAR Boggs (1991) and Japan data from
Suzuki (1991b).

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