NOAA Technical Memorandum NMFS

MAY 1989

ALBACORE MANAGEMENT INFORMATION DOCUMENT

Task Force Members

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Norman W. Bartoo
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NOAA-TM-NMFS-SWFC-126

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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National Marine Fisheries Service
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INTRODUCTION

This report has three principal purposes: to describe the results of the cooperative albacore research and development program which is presently nearing completion; to use the results of the program to describe the present status of the resource and fishery; and to present recommendations for management and future research on the North Pacific albacore resource.

The present National Marine Fisheries Service (NMFS) North Pacific albacore research and development program has been heavily influenced by several historical factors. First, NMFS and other U.S. and foreign agencies had already carried out a large amount of research on North Pacific albacore prior to the program. In addition, many of the research studies completed during the current program were started before this program was initiated. In particular, in 1981 the Southwest Fisheries Center (SWFC) established an Albacore Task Force whose recommendations resulted in a significant reorganization of the albacore research program, placing a major emphasis on the development of a "state of the art" fishery simulation model.

Second, the U.S. Pacific albacore fishery has an unusually large component of industry sponsored research due primarily to the efforts of the Western Fishboat Owner's Association, the American Fishermen's Research Foundation and the foresight and cooperation of many individuals in the albacore fishing industry. This work has involved a wide range of activities including tagging programs, fisheries oceanography research, fishery development, exploratory fishing, and processing technology. This effort has been carried out in close cooperation with the National Marine Fisheries Service's research and development programs.

The final factor is that the albacore fishery has had a tradition of international cooperation for research. The United States and Japan have been the principal nations harvesting the North Pacific albacore resource and they have shared both their research information and fishery data for several decades. Canada, Taiwan, and South Korea also harvest albacore in the North Pacific and these nations have also contributed to cooperative research on the resource.

Planning Process

The current NMFS North Pacific albacore program was designed through an interactive planning process in which an albacore 'constituent' group developed a strategic plan. This plan was then translated into an operational plan by a NMFS technical group. The planning process (Mackett 1983; Mackett, Christakis, and Christakis 1983; Mackett 1985; and

Barrett and Fullerton 1986), the strategic plan (Parrish and Mackett 1984) and the operational plan (Parrish et al. 1985) have all been documented.

The 'constituent' group was composed of external 'stakeholders' who collectively represented a wide range of public interests related to albacore. At the time that the interactive planning process was occurring, the U.S. albacore fishery was undergoing considerable change primarily due to alterations in the economics of the processing segment of the industry and to development of distant water fisheries. These factors are reflected in the strong emphasis placed on the processing, marketing, product development and fishery development components of the strategic plan.

The planning process resulted in a significant increase in the amount of NMFS resources allocated to albacore research and development. Within the Southwest Region (SWR) this effort was primarily concentrated on industry grants for the processing and fishery development elements of the plan. In the Southwest Fisheries Center (SWFC) increased emphasis has been placed on analyses and modeling of the albacore resource, on economic analyses and modeling of the harvesting sector, and on speeding to completion biological work already in progress. As the SWFC's initiative was primarily carried out by reassigning existing staff, the analysis emphasis necessitated a reduction in new field research.

The goals of the NMFS North Pacific Albacore Research and Management Program were established by a group of NMFS Directors. These goals were based on ideas developed at the 'constituent' strategic planning meeting and are as follows:

1. Increase the U.S. harvest of albacore to 35,000 tons annually by 1995.
2. Maintain U.S. fishermen's access to the albacore resource.
3. Achieve a management regime to assure optimum productivity of the resource.
4. Assure economic stability of the U.S. fishery.

Finally, a review of the SWFC's research and development programs was carried out by an External Review Committee chaired by Dr. John Harville in March of 1986. Generally the committee recommended that the SWFC should de-emphasize tuna research and fishery development work. Their recommendations with respect to North Pacific albacore were as follows:

"The Committee believes that SWFC should put its research dollars in areas where there is an existing or potential management payoff, and where possible, should stay away from fisheries development.

With respect to stock assessment and population modeling of North Pacific albacore, the committee recommends that the work be completed on schedule by early 1987. If a need for management is identified at that time, then international agreements to facilitate management should be pursued.

If the stock appears to be currently exploited below its maximum potential, then stock assessment work should be cut back to a simple fishery monitoring mode.

The committee was favorably impressed by the long-standing positive relationship between SWFC and the West Coast albacore fishing industry, and recommends that SWFC continue to provide fishery and environmental advisory services in return for complete and accurate fishery statistics as well as industry support for tagging."

As a result of the recommendations by the External Review Committee, the albacore research and development programs have been considerably reduced. The major emphasis has been directed toward finishing work in progress and no new work has been initiated on North Pacific albacore although there have been some new initiatives for albacore work in the South Pacific.

Report Structure

This report is organized into three sections. The first, and most extensive section presents the results of the cooperative albacore research and development program. It includes descriptions of the North Pacific albacore fisheries and their historical fishery statistics, biological and modeling studies, economic analyses, and recent NMFS albacore fishery development activities. The second section describes the present status of both the resource and fishery based on material presented in the first section. The third section presents the Albacore Task Force's recommendations for future research on the North Pacific albacore resource and it's recommendations for management of the resource.

RESEARCH AND DEVELOPMENT PROGRAM

THE NORTH PACIFIC ALBACORE FISHERIES

Overview

Albacore in the North Pacific have been fished by North American and Asian fishermen since the early 1900s. The North American fishery occurs during the summer and autumn months (Figure 1) when the migrating albacore are closest to the North American coast. Commercial fishermen from the United States, and to a lesser extent Canada, pursue them by means of several surface fishing gears. Trolling vessels are by far the most prevalent along with some baitboats. Incidental catches are made by purse seines and drift gill net vessels. Albacore has also proved to be a popular sport species particularly off the coast of California, south of San Francisco, where they come closest to shore (Holts 1985), and off northern Oregon and southern Washington.

In addition to the North American fishery, North Pacific albacore are harvested by several other, predominantly Japanese, fisheries. These include the Japanese surface, longline, and gill net fisheries as well as similar but smaller fisheries of several other nations. The Japanese surface fishery consists of various sizes of baitboats and has operated off the coast of Japan since the mid 1920s. This fleet, which fishes primarily for skipjack tuna, (*Katsuwonus pelamis*), also fishes for albacore along the Kuroshio and Subarctic Current fronts during the spring months (Figure 1). In recent years, South Korean baitboats have also participated in the albacore harvest. The longline fishery has been in operation in the North Pacific since the early 1950s and is composed primarily of Japanese vessels and, more recently, those from Taiwan and South Korea. This fleet catches albacore in the mid-to-western North Pacific during the winter months (Figure 1) but shifts its emphasis to tropical tunas and billfish during the remainder of the year. The Japanese and Taiwanese gill net fisheries are the most recently developed fisheries for albacore and they are the fisheries for which we have the least information.

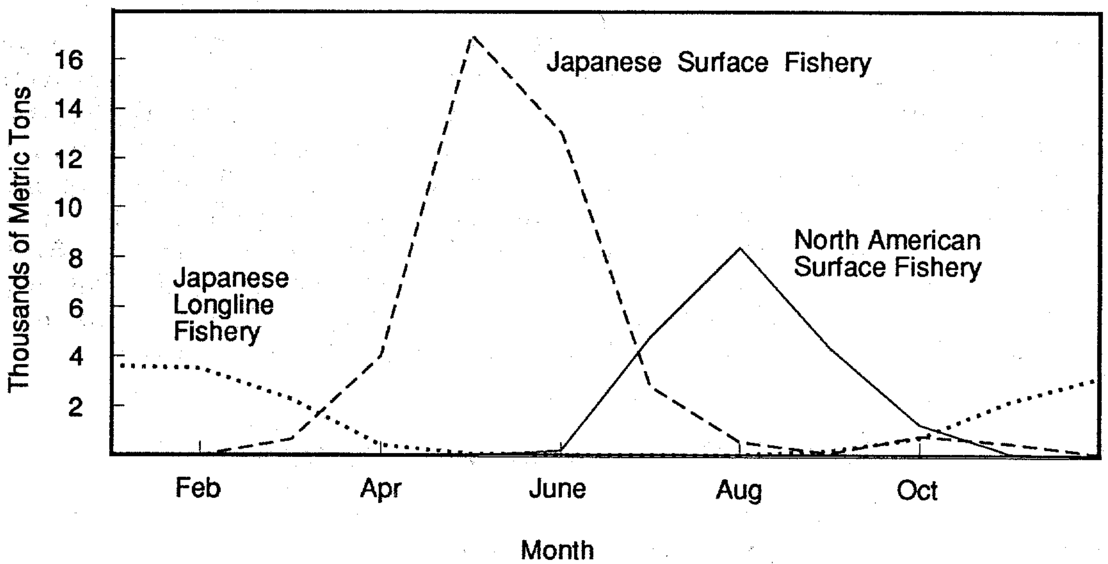

Figure 1. Seasonality of the North Pacific albacore catch by major fishery (1961-82).

In the United States, demand for albacore greatly exceeds domestic supply. Although United States fishermen landed an average of 18,000 tons of North Pacific albacore annually from 1952 through 1985, worth approximately $25 million (at current ex-vessel prices), their landings typically represent only 20% of the total domestic albacore consumption. The remainder is imported from as many as 40 other nations with substantial amounts of these imports believed to have been produced by the other North Pacific fisheries. In 1986 the U.S. imported 101,870 metric tons (MT) of albacore (Herrick et al. 1988) from a world catch of 179,576 MT.

North American Surface Fishery

The North American fishery usually begins operating around July when the migrating albacore approach the west coast of North America. The extent of albacore immigration is variable among years and, therefore, the apparent abundance to North American fishermen varies also. A significant characteristic of the North American fishery is the wide variation in the geographical locations of the most productive fishing grounds. Uniquely, a large proportion of this variability is at the decade rather than the interyear time scale. For example, catches off California dominated the fishery prior to the 1930s and from about 1957 to 1965; catches from Baja California were large from about 1948 to 1956; and those from Oregon and Washington were dominant from during the late 1930s to mid 1940s and from about 1966 to 1975 (Figure 2). It is not known if the low catches which occurred during the late 1920s and early 1930s were related to periods of lesser albacore abundance in the North American fishing grounds. It is possible that during this period albacore had a more northern distribution, such as that which occurred from 1966 to 1975; however, fishing for albacore off Oregon and Washington did not begin until the late 1930s (Clemens and Craig 1965).

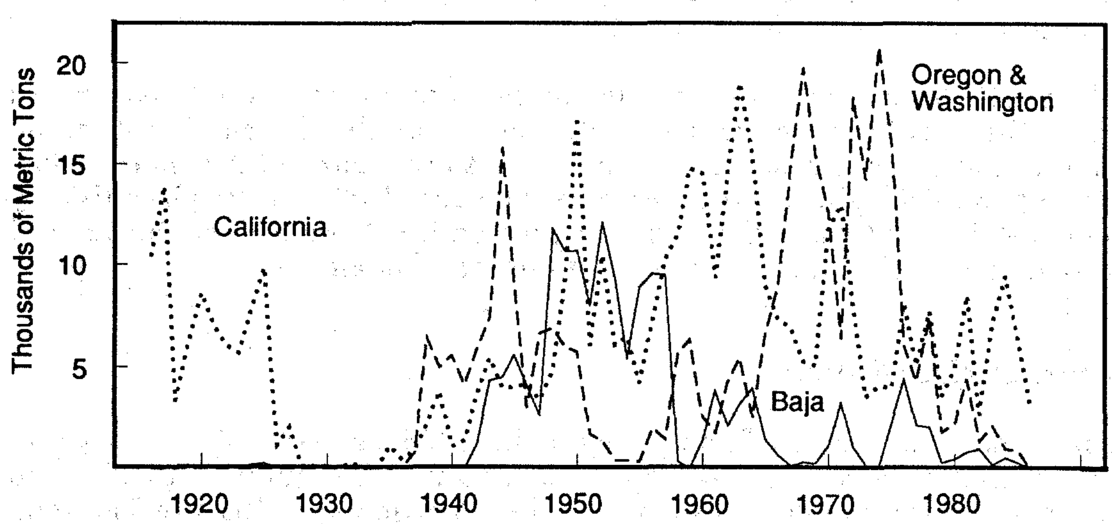

Figure 2. United States albacore catch by area of capture (1916-86).

The local abundance/availability of albacore appears to depend on several factors. First, strong temperature and salinity gradients within transition zone waters, 600 to 1000 miles offshore, appear to enhance albacore congregations in late spring and early summer. Next, as temperatures along the coast warm, the albacore migrate closer to the coast. Once there, albacore congregate near oceanic fronts and offshore of the areas of coastal upwelling. Presumably they are attracted to forage organisms associated with these features. Although local movements at this time are common, albacore will remain in the nearshore region for several months. Generally, albacore first approach the coast off southern California and northern Mexico and gradually, over the course of about a month, begin to appear off the northern coast of United States and Canada. However, the times, places and degrees of local immigrations are highly variable and difficult to predict.

The traditional North American fishery is primarily near shore; from 1961 through 1979 approximately 99% of reported United States catches were made within 200 miles of the North American coast with 84% off the United States coast and 9% to 7% in the jurisdictional waters of Mexico and Canada, respectively. These estimates are based on catches and logbook records of United States fishermen and may not reflect small catches by Canadian nationals. However, in recent years, North American fishermen have been fishing farther offshore, some as far west as the international dateline, in an attempt to locate high catch rate areas and to extend the fishing season.

There have been upwards of 2100 vessels that fish at least part of the season for albacore in the North American fishery. The great majority of these are trolling vessels. However the fleet also has included approximately 30 baitboats and 100-150 combination vessels (i.e. boats that were designed to fish for other species, but are suitable for baitfishing). Trolling vessels range in size from approximately 7.5 m (25 ft) to 24 m (80 ft) and usually carry a crew of two or three.

Although other types of vessels participate in the North American fishery, their catches have generally been small. Catches are made opportunistically by purse seine vessels in some years and experimental longlining and drift gill netting began in the early 1980s. A longline fishery did not develop and the gill net fishery, which has targeted on sharks and swordfish, presently takes only small numbers of albacore.

Japanese Surface Fishery

The Japanese surface fishery began in 1926 as part of an artisanal fishery primarily directed toward skipjack tuna. Although skipjack tuna continue to be the major target species for this fishery, albacore has long been an important alternative species in the spring and early summer. In fact, this fishery has dominated the North Pacific albacore catches for decades. The fishery caught a record 85,336 MT in 1976 following an increase in the number of large (greater than 100 gross tons) baitboats and a concomitant increase in its fishing grounds northward and offshore along the Kuroshio Current Extension. The number of large baitboats began decreasing sharply during the late 1970s, but the fishery nevertheless continues to dominate the fisheries for albacore in the North Pacific with much of the catch intended for Japan's domestic market, and the remainder exported. At its peak, the Japanese surface fishery consisted of several thousand baitboats over a range of sizes from 20 gross tons to over 200 gross tons. However, the number of vessels has decreased in recent years. Each baitboat is crewed by 10 to 30 men. The composition of this fishery is subject to rather abrupt changes as the numbers of vessels in different size classes increase or decrease in response to not only economic conditions, but also government controlled licensing arrangements. The fishing techniques of this fishery are similar to those utilized in the United States baitboat fishery.

Japanese Longline Fishery

The longline fishery was begun by Japanese fishermen in the North Pacific shortly after World War II and has since expanded to nearly all tropical and subtropical ocean areas. In the North Pacific, Japanese vessels continue to account for most of the longline albacore catch; however, South Korean and Taiwanese longliners have participated in this fishery since the early 1960s. The fishery operates in the fall and winter months in the mid to western North Pacific, fishing in the mid-latitudes (primarily between 25° and 35° N) for immature albacore. The rest of the year effort is directed toward mature tropical tunas and billfish closer to the equator. Although they are not the target species, some albacore are caught during this phase of the fishery.

Japanese longline vessels vary greatly in size, but the distant water fleet largely consists of vessels from 200 to 500 gross tons. Each vessel carries a crew of approximately 20 who daily set 2,000 hooks suspended by gangions from mainlines up to 100 km (63 mi.) long. Longline vessels operate in tropical and temperate waters worldwide and will readily relocate or change fishing methods (i.e. depth of set, type of bait) to pursue the most desirable species. Most of the albacore caught in this fishery are exported to the United States.

North Pacific Gill Net Fisheries

The Japanese drift gill net fishery began as an offshoot of the coastal gill net fishery for marlins which has operated since the turn of the century. Albacore catches were recorded for this fishery beginning in 1972. Most of the reported catches from 1972 through 1980 were incidental catches made near the Japanese home islands. In 1981 albacore catches increased substantially due to the expansion of the gill net fishery eastward along the Kuroshio Extension north of the traditional Japanese baitboat fishing grounds and albacore became a target species. The extensive Japanese squid gill net fishery has also expanded rapidly in the North Pacific and albacore are also taken in this fishery. The Taiwanese began developing a gill net fishery for tunas in the North Pacific in 1984 and have expanded this fishery rapidly. The U.S. takes a small number of albacore in a gill net fishery directed at swordfish and sharks.

FISHERY STATISTICS AND MONITORING

Data Sources

Catch and effort data for the three major fisheries are based on landing statistics collected through governmental agencies. Effort data for the North American fishery, originally reported in nominal boatdays, are routinely standardized to account for differences in catch rates among different size vessels. The Japanese surface fishery also reports effort in nominal boatdays but, because this fishery pursues both skipjack tuna and albacore, which are seldom found together, only those days when albacore are caught are considered to be "effective" albacore fishing days. Effort data for this fishery are also somewhat standardized in that they are based primarily on the large offshore vessels that land a predominant share of the total albacore catch. Japanese longline fishermen report effort in nominal number of hooks, but this unit is also converted to "effective hooks" by time/area strata, which represent distinct phases in the longline fishery, and then summed to find the yearly total for the North Pacific.

Once these effort values have been transformed by the appropriate governmental agencies in the United States and Japan, they are used in the estimation of yearly catch-per-unit-of-effort (CPUE) values. These modified catch rates are accepted as being more meaningful than the nominal catch rates for the three major fisheries. It should be noted that effort data among the three major fisheries are not readily comparable due to differences in units and treatments.

The other major monitoring of the albacore fishery involves sampling the lengths of fish caught in the three major fisheries. Very large numbers of length measurements have been taken over the years for the Japanese surface and longline fisheries and for the U.S. surface fishery. The great majority of these samples have reasonable time (monthly) and area (5 by 5 or 5 by 10 degrees latitude/longitude) resolution. Length frequency data have been exchanged between the nations which have significant fisheries for albacore in the North Pacific. Presently, the best available data extend from 1960-82 for the Japanese surface and longline fisheries and from 1961-88 for the U.S. surface fishery.

North American Surface Fishery

The North American fishery is dominated by the U.S. fishery and a considerable amount of information is available for this fishery (Laurs et al. 1976; Laurs 1985). The statistics of the various components of the 1961-80 U.S. fishery, the geographical distribution of the catch and summaries from the length frequency monitoring have recently been extensively reviewed by Majors (1987). Catches have been variable throughout the time series with a downward trend since the early 1970s (Table 1, Figure 3).

TABLE 1. NORTH PACIFIC ALBACORE LANDINGS (Metric Tons).

	(---------- Japan			----------)	Taiwan	(---------- U. S.			----------)	Canada	N.Amer Total	Grand Total
	Baitboat	Longline	Gill net	Other	Total		Baitboat	Jigboat	Sport	Total			
1952	41786	26687	-	237	68710	-	-	23843	1373	25216	71	25287	93997
1953	32921	27777	-	132	60830	-	-	15740	171	15911	5	15917	76746
1954	28069	20958	-	38	49065	-	-	12246	147	12393	-	12393	61458
1955	24236	16277	-	136	40649	-	-	13264	577	13841	-	13841	54490
1956	42810	14341	-	57	57208	-	-	18751	482	19233	17	19250	76458
1957	49500	21053	-	151	70704	-	-	21165	304	21469	8	21477	92181
1958	22175	18432	-	124	40731	-	-	14855	48	14903	74	14977	55708
1959	14252	15802	-	67	30121	-	-	20990	-	20990	212	21202	51323
1960	25156	17369	-	76	42601	-	-	20100	557	20657	5	20662	63263
1961	18636	17437	-	268	36341	-	2837	12061	1355	16253	4	16257	52598
1962	8729	15764	-	191	24684	-	1085	19760	1681	22526	1	22526	47211
1963	26420	13464	-	218	40102	-	2432	25147	1161	28740	5	28749	68847
1964	23858	15458	-	319	39635	26	3411	18392	824	22627	3	22630	62291
1965	41491	13701	-	121	55313	16	417	16545	731	17693	15	17708	73037
1966	22830	25050	-	585	48465	16	1600	15342	588	17530	44	17574	66055
1967	30481	28869	-	520	59870	17	4113	17826	707	22646	161	22807	82694
1968	16597	23961	-	1109	41667	15	4906	20444	951	26301	1028	27329	69011
1969	32107	18006	-	1480	51593	21	2996	18839	358	22193	1365	23558	75172
1970	24376	15372	-	956	40704	23	4416	21041	822	26279	354	26633	67360
1971	53198	11035	-	1262	65495	24	2071	20537	1175	23783	1587	25370	90889
1972	60762	12649	1	921	74333	25	3750	23608	637	27995	3558	31553	105911
1973	69811	16059	39	1883	87792	35	2236	15667	84	17987	1270	19257	107084
1974	73576	13053	224	1065	87918	40	4777	20187	94	25058	1207	26265	114223
1975	52157	10060	166	402	62785	28	3243	18975	640	22858	101	22959	85772
1976	85336	15896	1070	1394	103696	37	2700	15932	713	19345	252	19597	123330
1977	31934	15737	688	1039	49398	61	1497	10005	537	12039	53	12092	62051
1978	59877	13061	4029	3209	80176	53	950	16682	810	18442	23	18465	98694
1979	44662	14249	2856	1280	63047	81	303	6801	74	7178	521	7699	70827
1980	46743	14743	2986	1516	65988	-	382	7574	168	8124	212	8336	74324
1981	27426	18020	10348	956	56753	-	748	12694	195	13637	200	13837	70590
1982	29615	16762	12511	1054	59942	-	425	6661	257	7343	140	7483	67389
1983	21098	15103	6884	471	43556	-	607	9512	87	10206	225	10431	53987
1984	26015	15111	10569	3898	55593	-	832	9576	1427	15563	50	15613	71206
1985	20714	14320	13132	1940	50106	-	872	7059	1176	9107	56	9157	59269
1986	16096	12945	9749	2192	40982	-	309	4834	196	5339	30	5369	46351
1987	19091	14642	7617	1394	42744	-	146	2783	7	3003	104	3107	45851
1988	7000	-	5000	-	-	-	627	4198	64	4889	85	4974	-

Figures for 1987-88 are preliminary.
Japanese catches differ from those used previously and were supplied by the Far Seas Fisheries Research Laboratory.
Japanese gill net figures include North and South Pacific catches

U.S. catches from 1961 to 1985 include Hawaii.
U.S. total for 1984 include 3,728 MT caught by purse seine.
U. S. jigboat catches for years 1952-60 include fish caught by baitboat.

The traditional method of standardizing fishing effort and CPUE for the U. S. jig fishery has been to standardize by vessel length. Standardizing the data by time and area strata, which Honma (1974) has shown to be preferable, had not (until very recently) been attempted. As a result of the concern developed by the preliminary version of this report, Kleiber (1989) has reanalyzed the U.S. jigboat catch and effort data. His results (Figure 4) show that standardizing by vessel size has very little effect on estimates of effort and CPUE; however, standardization by time-area strata results in a

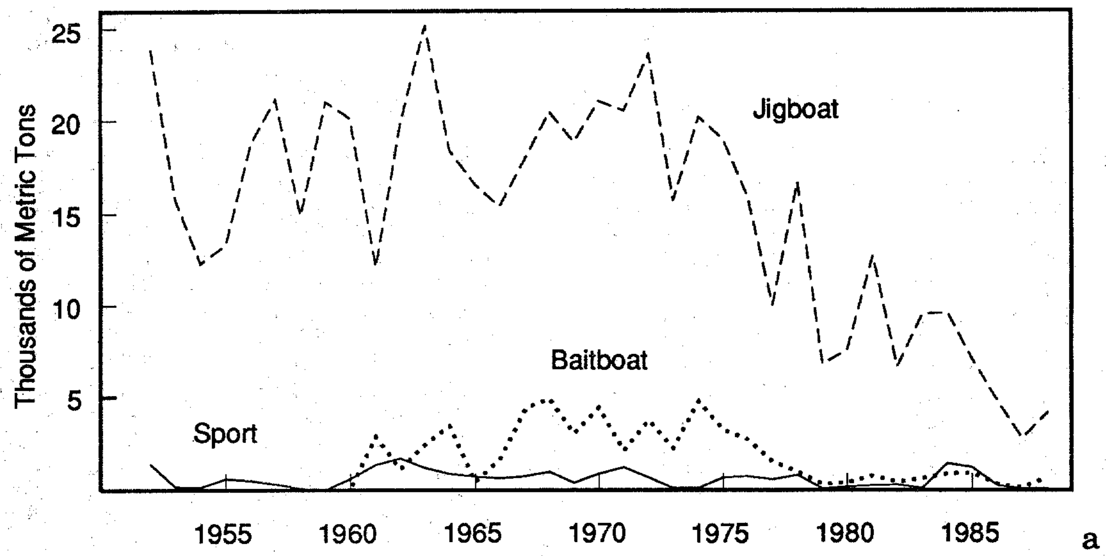

Figure 3. United States albacore catch by gear type.

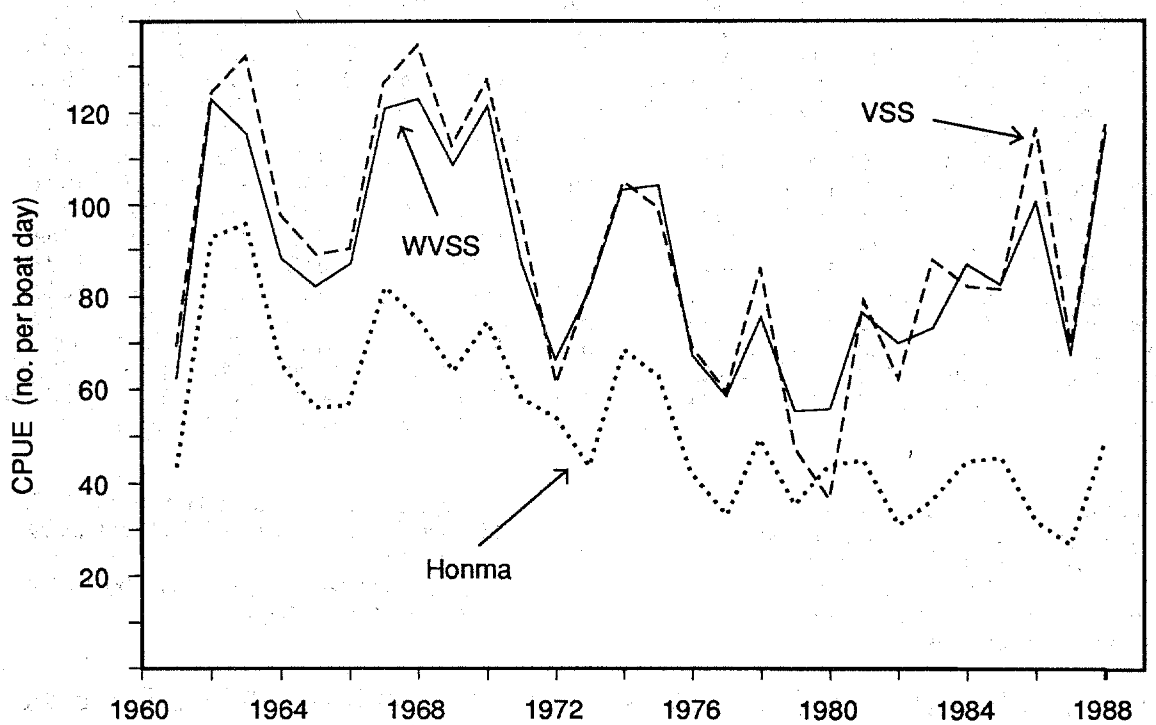

Figure 4. Time series of overall catch per effort with effort calculated: 1) with vessel size standardization and simple sum over strata as routinely reported (VSS); 2) without vessel size standardization and simple sum (WVSS); 3) without vessel standardization but with Honma aggregation (Honma). (From Kleiber 1989).

completely different picture of CPUE. In contrast to earlier studies, Kleiber's analysis shows that CPUE had a marked downward trend from the early 1960s to the present, with no upturn in CPUE in the late 1980s. Catch rates declined from 96 fish per day in 1963 to 27 fish per day in 1987 and have not exceeded 50 fish per day since 1978. The extended period of reduced CPUE preceded the long decline in effort and landings which occurred from the mid 1970s to the present (Figures 3 and 5) and may be the principal reason for the present depressed state of the U.S. albacore fishery.

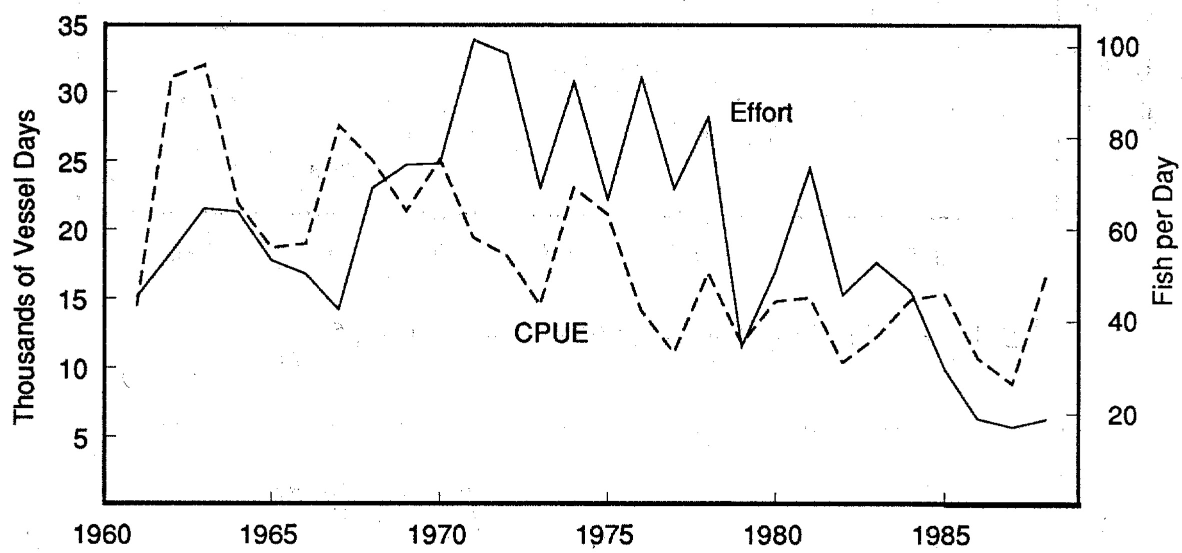

Figure 5. Raw fishing effort and Honma CPUE for the U. S. jigboat fishery.

Japanese Surface Fishery

Annual albacore catch, effort and CPUE levels for the Japanese surface fishery in the North Pacific are available; however, minor catches by Korean baitboats in recent years are not included in these data. Catch levels in this fishery did not exhibit a distinct trend until the early 1970s when Japan greatly increased the number of large baitboats and both expanded its fishing grounds offshore to beyond the international dateline and extended its fishing season into the summer by following the emigrating albacore east along the Kuroshio Extension Front (Table 1, Figure 6). Catches rose dramatically to a maximum in 1976, when 85,336 MT were caught, but quickly decreased afterwards. This decrease was due to a decline in the number of vessels in all size classes, but notably the large, offshore vessels. Recent effort levels are near those of the 1960s, but only about one third of the levels which occurred during the late 1970s (Figure 7). Preliminary catch data for 1988 show that the surface fishery has declined to the lowest level in the entire 1952-88 period (Table 1).

Catch-per-unit-of-effort values for the Japanese surface fishery for years 1961 through 1986 (Figure 7), expressed as metric tons per vessel day, indicate variable, but generally high values in the 1960s and early 1970s with decreased values since 1977. During the period of high CPUE, 1961-76,

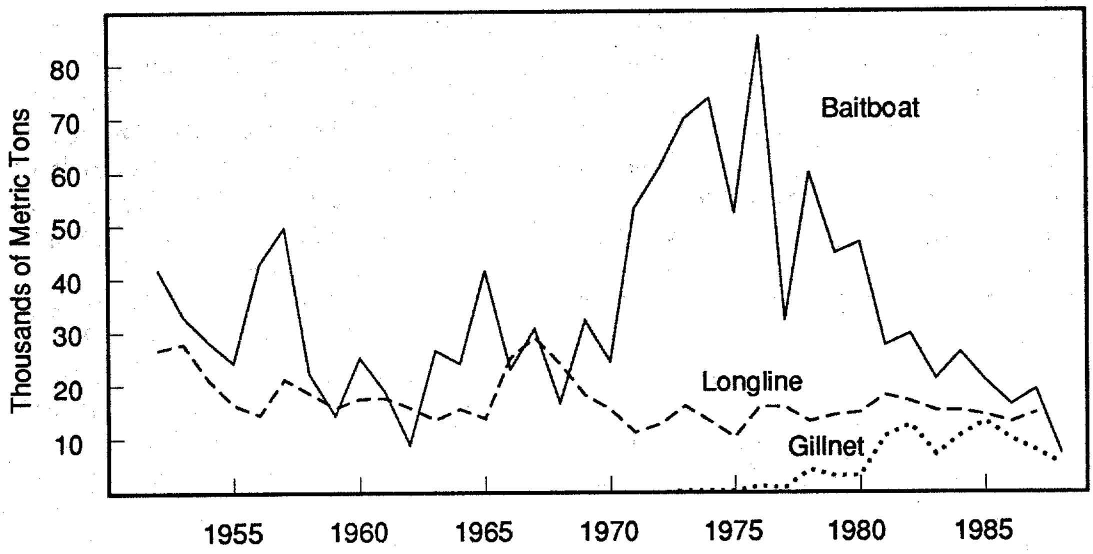

Figure 6. Japanese albacore catch by gear type.

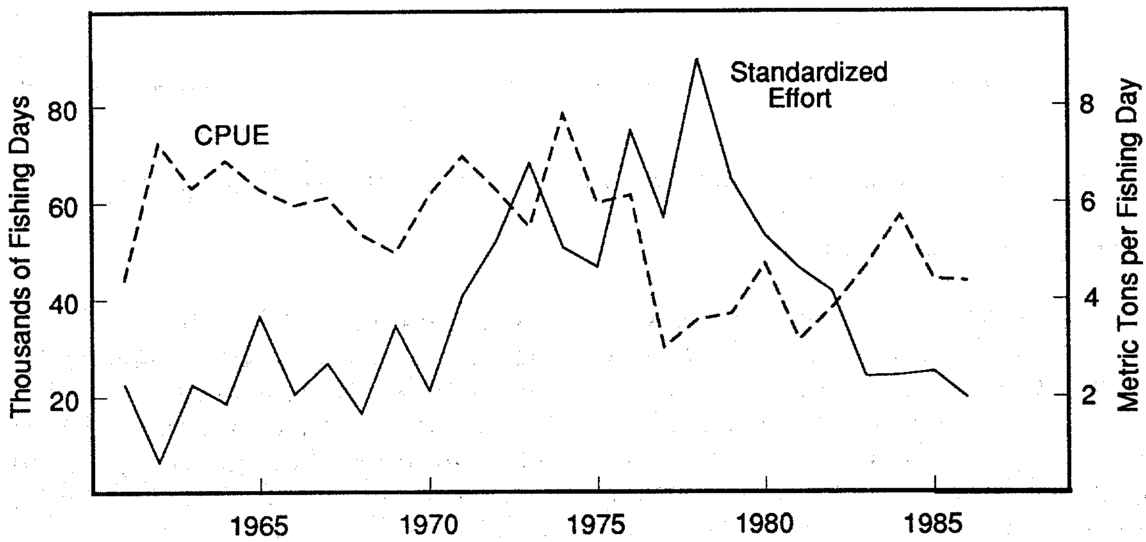

Figure 7. Fishing effort and CPUE for the Japanese surface fishery. Data from Shiohama (1989).

there was an average of 6.13 metric tons per fishing day, but this fell to an average of 3.94 during the 1977-86 period. The decrease in CPUE could be interpreted as an indication that the high catch levels in the years preceding this period may have been near the maximum sustainable yield. In addition, CPUE in the Japanese surface fishery is positively correlated with that in the North American jigboat fishery for the period of 1961-86 (r = 0.679; significant at the 0.01 level).

Japanese Longline Fishery

Annual catches are available for the Japanese fishery and some of the years for the Taiwanese fishery, but not for those by the Korean fishery, which takes minor amounts. Catches have been reasonably stable with peaks in the early 1950s and mid 1960s (Table 1, Figure 6). The return to lower levels during the late 1960s was probably a reflection of Japan's increased interest at that time in tropical tunas. Effective effort, which is adjusted to account for areas fished, reflects this decrease in albacore catches (Figure 8). The longline CPUE pattern is similar to that for catches; peaks occur in the early 1950s and mid 1960s when CPUE approached 6 fish per 1000 hooks, whereas they average about 3 fish per 1000 hooks for the rest of the time series (Figure 8). The longline CPUE does not show a decline associated with those in the surface fisheries and it is not correlated with CPUE in either surface fishery; however, the last year for which data are available (1986) has the lowest CPUE on record.

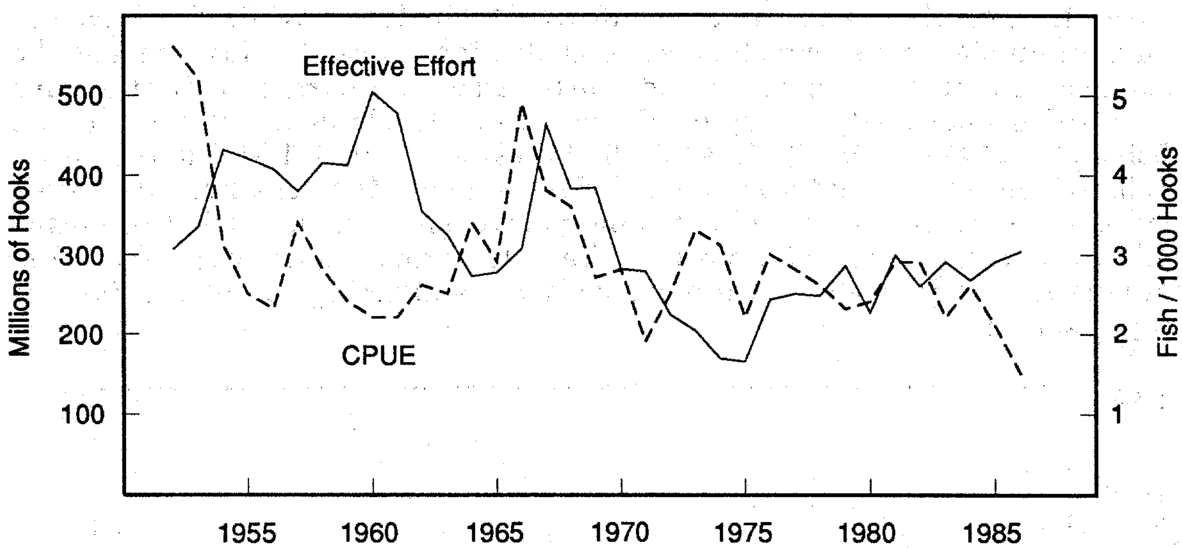

Figure 8. Effective fishing effort and CPUE for the Japanese longline fishery. Data from Shiohama (1989).

North Pacific Gill Net Fisheries

The Japanese gill net fishery is a relatively new fishery and little information is available concerning it. The Japanese catch of albacore in the Pacific increased sharply in 1981 and catches have averaged over 10,000 MT per year since then (Table 1, Figure 6). Neither the proportions of the catches that came from the North Pacific nor the proportions taken by the squid gill net fishery is known. The length frequencies of albacore taken by the Japanese gill net fishery targeting albacore and that targeting squid are also not available. According to Liu and Hsu (1989), Taiwan has gradually increased gill netting effort for tunas in the North Pacific since 1984; catches reached 11,000 MT in 1988, the only year for which data are available. Albacore comprised about 41% of this 1988 catch and skipjack were about 50%. Taiwan's 1988 catch was taken by 168 vessels (about 14,600 fishing days); their catch, in numbers, was dominated by two year olds with sizeable numbers of three year olds and five year olds, but few four year olds.

North Pacific Trends

Annual albacore catches for the four major fisheries suggest that most of the variability in the total catch is due to variability in the Japanese surface fishery (Figure 9). Available annual landings (since 1952) by country and gear type, indicate that the North Pacific albacore fishery has averaged 73,871 MT per year with a maximum of 123,330 MT in 1976 (Table 1). The Japanese surface fishery averaged 35,467 MT per year or 48% of the 1952-86 catch while the North American surface fishery averaged 18,407 MT (25%) and the Japanese longline fishery averaged 16,988 MT or 23%. Japanese gill net catches were first recorded in 1972 and they have averaged 5,017 MT since then, reaching a maximum of 13,132 MT in 1985. While the Japanese longline catches have remained remarkably stable, over the last decade the catches in both the Japanese and North American surface fisheries have declined dramatically. In spite of the recent development of the gill net fishery, catches in 1987 declined to the lowest level (45,851 MT) of the entire 1952-87 period. In addition, partial data suggest that catches were even lower in 1988. The impact of the rapidly developing gill net fisheries on the albacore resource is not known. These fisheries apparently take large numbers of very small albacore, which may be affecting the productivity of the resource.

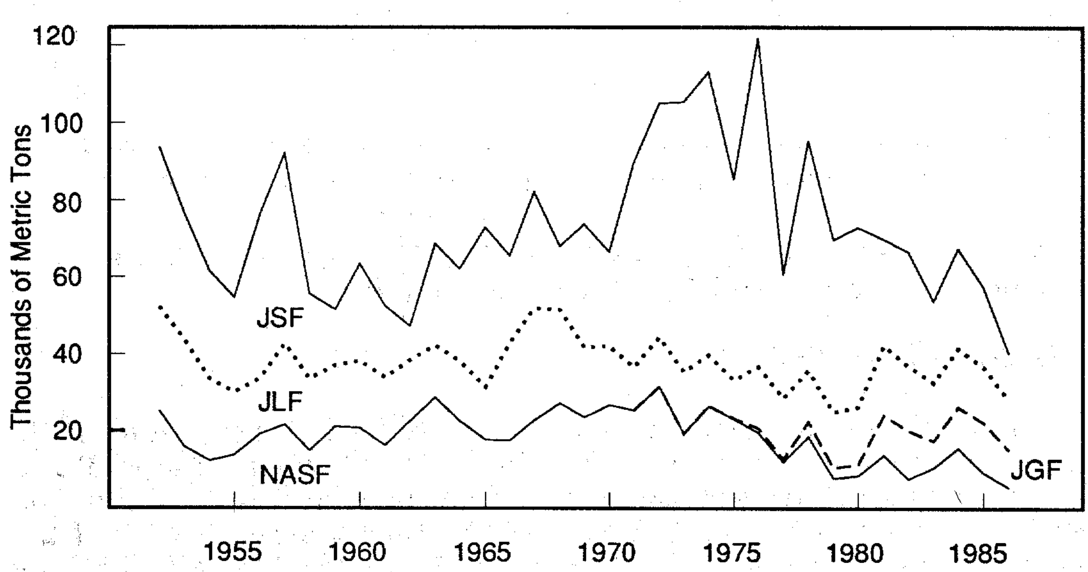

Figure 9. Accumulative North Pacific albacore catch by major fishery: (NASF = North American surface fishery, JSF = Japanese surface fishery, JLF = Japanese longline fishery, JGF = Japanese gill net fishery).

Size Composition of Catches

Yearly mean weights for the period 1955 through 1986 for the United States fishery and through 1982 for both Japanese fisheries reflect the size composition of the three fisheries. The average mean weight of albacore caught in the North American fishery for all years combined was 7 kg (15.4 lb) while those of the Japanese surface and longline fisheries were 9.8 kg (21.6 lb) and 16.8 kg (36.9 lb), respectively. Although the mean weights for all fisheries show variability, there does not appear to be a long term trend in any of these. This variability is due to differences in the abundance of year classes that support each fishery. An increase in the mean weights for the Japanese surface fishery in the mid-1970s was due to offshore expansion of the fishery resulting in an increased catch of older fish.

Age Composition

Due to the difficulty in aging albacore with traditional methods, the age structure of the catch, by area, has never been available. However, the length frequencies of the major fisheries have been monitored for many years and a number of factors suggested that statistical methods would be adequate to translate the length measurements into time series of age composition. First, very large numbers of albacore have been measured each year in the Japanese surface and longline fisheries and in the North American surface fishery. Second, the length frequency distributions of most of the fisheries have distinct modes. These modes are the result of the albacore's very fast growth rate, the seasonal nature of the catch in each fishery, and the fact that the great majority of the catch is taken from the immature age groups where growth in length is at a maximum. Third, the length frequency and catch data are available on appropriate time and space scales.

It was therefore decided that a major data processing effort be carried out to produce time series of the age structure of the catch by each major fishery. As the albacore model was at this time in the early development stage, it was decided that the data would be made available for each of the geographical areas which were being used for the development of the albacore model (Figure 10). This effort required matching the length measurements and catch by 5 degree areas (or groups of areas where the data were sparse) and then calculating the number of albacore caught in each area by month for each one centimeter length interval. The methods used in this procedure are described by Perrin and Weber (1987, 1988). The resulting data were then run through a computer program (NORMSEP, Tomlinson 1971) to sort the length frequencies into age frequencies. The data from individual areas were then combined to come up with the calculated age structure for the total catch by each fishery gear type for each month for each model area. Summaries of this information are presented in the next section; time series analyses of the data are in progress.

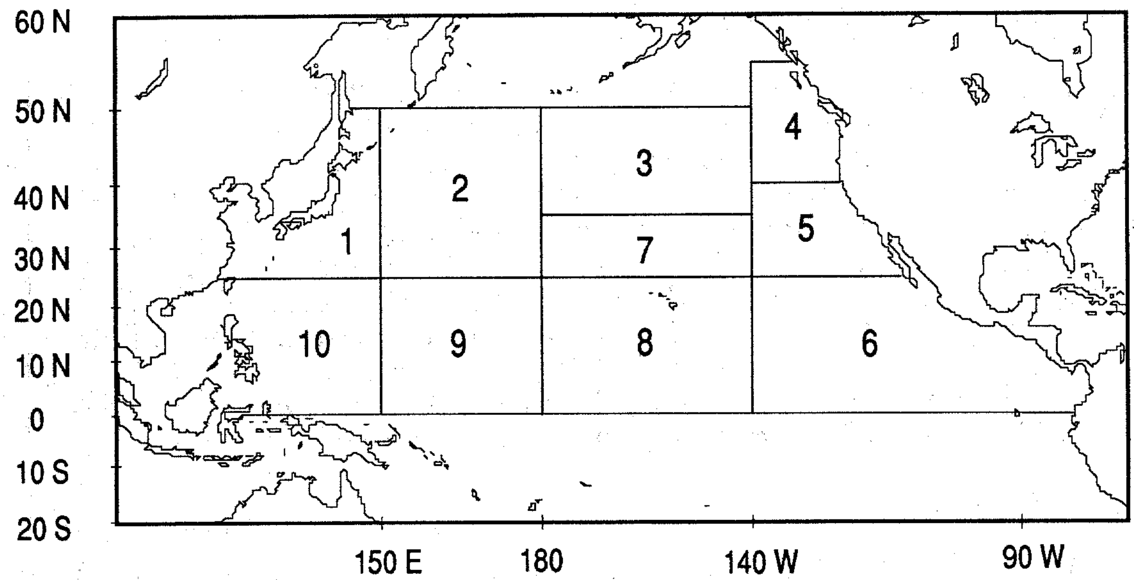

Figure 10. Map of areas used for the albacore model and age structure analyses: Kuroshio region (area 1), Kuroshio Extension region (area 2), California Current region (areas 4 and 5) and longline fishing regions (areas 7-10).

BIOLOGICAL STUDIES

Distribution and Age Structure

Within the North Pacific, albacore occur from the equator to the subarctic convergence (i.e. 0^o N to about 45^o N); however, they are not common in the eastern tropical Pacific or within about 10 degrees of the equator. Their principal habitat occurs in the convergent regions of the North Pacific Gyre. The adult habitat is primarily associated with the tropical convergence whereas the habitat of the immature fish is associated with the subarctic convergence. Thus the size and age structure in the catches are extremely area specific (Figure 11). The North Pacific spawning grounds are concentrated in the tropical western Pacific and albacore larvae occur from near the Phillipines to the vicinity of Hawaii. Spawning occurs all year; however, the area in which the larvae are distributed moves north and south seasonally. According to Nishikawa et al. (1985) albacore larvae are most abundant between 10-20^o N in the winter and between 15-29^o N in the summer.

The youngest fish are primarily located in the western Pacific; almost 100 % of the catch of 1-year-olds and over 90 % of the catch of the 2-year-olds are caught in the Kuroshio or Kuroshio Extension regions (Figure 12). By age three the center of abundance has moved to the east and more than two thirds of the catch of 3-year-olds is taken in the California Current region. At age four albacore are common in the catch from the Kuroshio Current

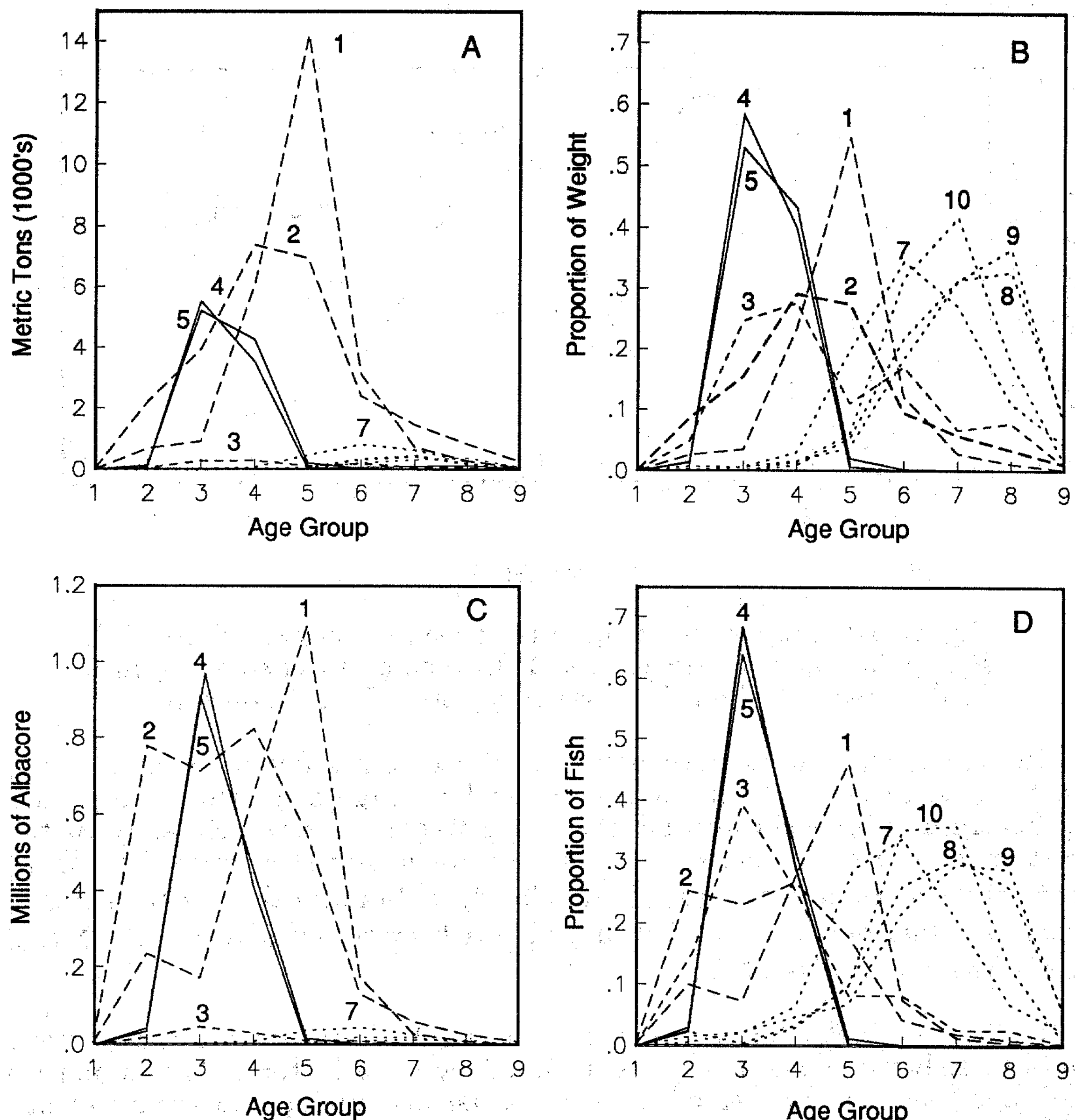

Figure 11. Average albacore age composition of the catches within each model area (1961-83). Age composition: A. by weight, B as a proportion of total weight in each age group, C. by numbers of fish, D. as a proportion of the total number of fish in each age group. Model areas as in Figure 10.

to the California Current; however, by age five they are again primarily located in the western Pacific with 95% of the catch of 5-year-olds occurring in the Kuroshio and Kuroshio Extension regions. The surface fisheries (i.e. baitboats and trollers) are the principal harvesters of the younger, mostly immature, fish and they are harvested primarily in the spring and summer. Peak landings occur earlier in the year in the western Pacific than in the eastern Pacific: May in the Kuroshio region, June in the

Kuroshio Extension region, and August in the California Current region (Figure 13).

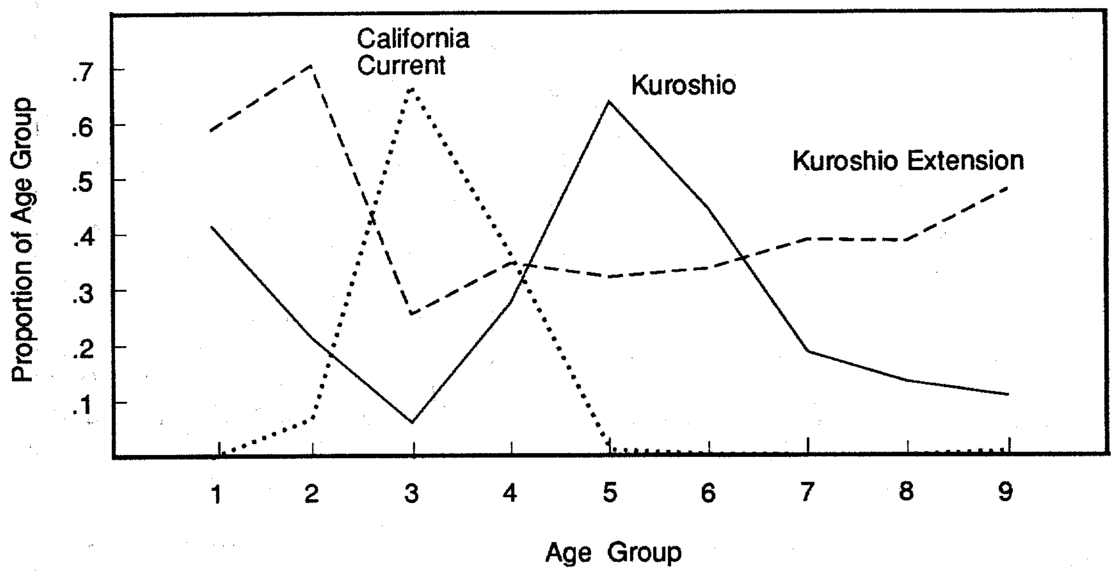

Figure 12. Proportion of age group caught by area (1961-83): Kuroshio region = Model area 1, Kuroshio Extension region = Model area 2, California Current region = Model areas 4+5.

In contrast to the surface fisheries, the longline fishery occurs in the winter (i.e. areas 7-10 in Figure 13) and it targets albacore which are approaching adulthood and adults. This fishery occurs primarily in the western two thirds of the Pacific. In November and December the fishery primarily occurs between 30° N and 35° N; in January the fishery spreads south to about 25° N and by February the fishery occurs between 25° N and 30° N (Lynn and Bliss 1982).

In the North Pacific, albacore are not available to the traditional hook and line fisheries for a large proportion of their life history. The immature fish, ages 2-5, are harvested almost exclusively during the spring to fall whereas the mature fish (ages 6+) are harvested essentially only in the winter. The immature fish are primarily harvested along frontal formations associated with the northern portion of the North Pacific Gyre; however, the age structure of the catch is very different in the Kuroshio, Kuroshio Extension and California Current regions. Mature fish are primarily harvested in the western two thirds of the Pacific at latitudes between 25° and 35° N; however, the breeding adults are lightly exploited. The longline fishery, which harvests adult age fish, does not target albacore in the winter spawning grounds (i.e. between 10° and 20° N). In the summer the spawning grounds extend north to about 30°, but there is no targeted albacore longlining in this region during the summer.

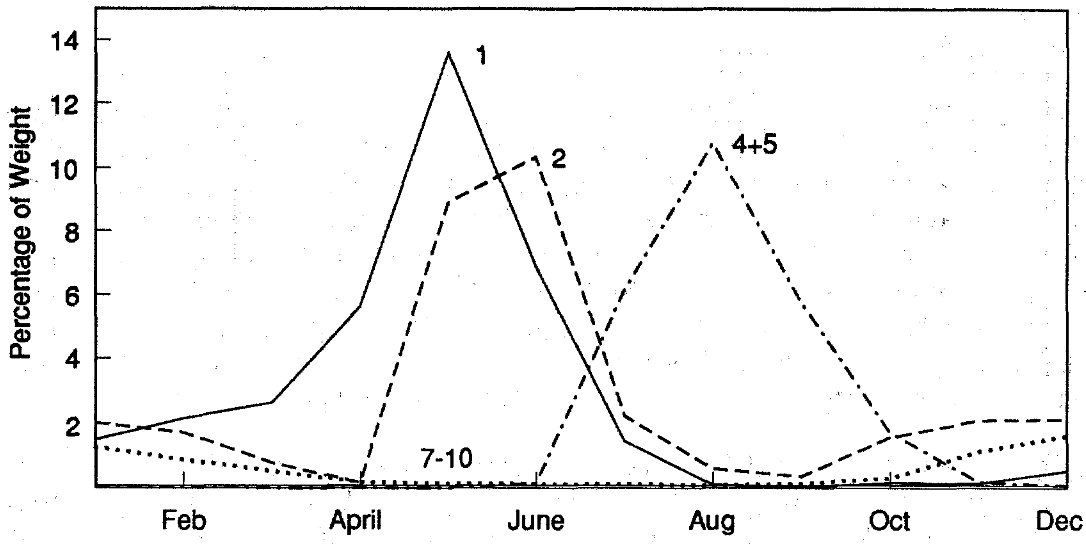

Figure 13. Seasonality of albacore catches by model areas (1961-83).

Stock Structure

The determination of stock structure in albacore is of particular importance due to the wide geographical distribution and extensive migrations which occur in the species. A wide range of research activities was used to address this subject. The most direct approach involved biochemical, population-genetics analyses, utilizing mitochondrial DNA. In this work, Graves and Dizon (1989) found no significant genetic differences between albacore taken in the North Pacific and off South Africa. A second approach using chromosomal analysis techniques found that the method apparently does not have sufficient resolution to determine genetic differences within individual tuna species (Ratty et al. 1986).

In contrast to the genetics studies, there is a a growing body of evidence (Brock 1943; Laurs and Lynn 1977; Laurs and Wetherall 1981, and Wetherall et al. 1987) that imply that North Pacific albacore are not as homogeneous as previously thought (Clemens 1961; Otsu and Uchida 1963). Results from a number of studies, including the cooperative NMFS/AFRF albacore tagging studies, suggest that there are two subgroups of albacore in the North Pacific. These subgroups appear to have different migratory patterns (Laurs and Nishimoto 1979) modal sizes in the U.S. fishery (Brock 1943; Laurs and Lynn 1977; Laurs and Wetherall 1981), growth rates (Laurs and Wetherall 1981), and birth months (Wetherall et al. 1987). While the subgroups are differentiated by geographic dissimilarities in biological or fishery statistic criteria, they are not believed to be genetically distinct. Nevertheless, there is evidence that suggests that the North Pacific albacore population may have "fishery stock" boundaries, which may require that the population be managed as putative stocks.

Migration and Stock Structure

North Pacific albacore make extensive movements during their lifetime. The degree of migration appears to be geographically most expansive in the pre-adult ages, between about 2 and 5 years, when fish may conduct trans-oceanic migrations in temperate/subtropical waters between the eastern and western or central North Pacific. On the other hand, spawning adults, above ages of about 6 years, appear to undertake more limited movements, mostly within the tropical/subtropical regions between about 10° to 30° N (Laurs In Prep). However, there has not been a sufficient number of adults tagged to assess the movements of this segment of the population.

Tagging results show that the northern subgroup exhibits a different migration pattern than the southern subgroup. Fish which have been released in North American coastal waters north of 40° N have 28% of their recoveries in the same general area as released, 54% west of 180° W, 13% in coastal waters off North America south of 40° N and about 5% in the central eastern Pacific or unknown area of recovery. In contrast, fish which have been released in coastal waters off North America south of 40° N have 78% of their recoveries in the same general area as release, only 9% west of 180° W, 9 % in coastal waters off North America north of 40° N, and about 5% in the central eastern Pacific or unknown area of recovery (Laurs In prep a). These results indicate that the northern subgroup is primarily exploited by the Japanese surface fishery in the western Pacific, the Asian longline fishery and the North American fishery north of about 40° N. The southern subgroup appear to be exploited by the North American fishery south of about 40° N, the Asian longline fishery and, only limitedly, by the Japanese surface fishery.

Unlike the movement patterns of skipjack, which tend to be diffusive in nature (Anon. 1981), those of albacore are more migratory. The fish appear to follow well-defined routes during inter-seasonal and inter-fishery migrations. A relatively high proportion of fish tagged off North America has been recovered within 150 miles of where they were released after being at liberty until the following, or up to three fishing seasons later. These fish had, presumably, in the meantime migrated into the central or western Pacific (Laurs and Nishimoto 1974). For example, one tagged fish was recovered only 39 miles from where it had been tagged nearly 2 years earlier. Also, albacore tagged off the Pacific Northwest, and in the western North Pacific, and recovered in the Japanese surface fishery show a pattern indicative of a directed, well-defined migration route (Laurs In Prep).

Growth Variation and Stock Structure

Two continuing needs in North Pacific albacore research are the development of validated age and growth models and the elucidation of stock structure. These goals are interdependent. An accurate aging method is essential for growth modeling, and will provide a key to describing and interpreting variation in such processes as spawning and migration. Similarly, knowledge of growth variation can be useful in defining stock heterogeneity.

Recent research has been directed at both of these areas. Due to the difficulty in aging albacore with traditional methods, aging was attempted by reading daily increments on otoliths. Growth models were then developed based on the otolith data and tag return statistics. In both sets of information, geographical variation was explored to elicit hypotheses on stock structure. Recent work involved analysis of daily increment counts on 225 albacore (98 from the northern group, 127 from the southern group), and tag release and recapture data from 521 fish (257 from the northern group, 264 from the southern group). Stochastic von Bertalanffy models were fitted to the daily increment data, and other (composite) von Bertalanffy models were estimated using a combination of the tagging data and otolith increment counts on albacore under about 45 cm. Earlier experiments had demonstrated conclusively that albacore between about 50 cm and 100 cm deposit one increment per day and that increments deposited as an albacore grew from 50 cm to 100 cm could be read accurately on whole otoliths (Laurs, Nishimoto and Wetherall 1985). However, when the 225 otoliths were read completely, from the otolith margin to the nucleus, it was found that the number of increments counted was far fewer than the number expected based on growth of tagged and recaptured fish. Thus the otolith data predict much faster growth than do tag data.

Various explanations may be advanced for the discrepancy between otolith and tag-based growth models. For example, it is conceivable that tagged albacore grow slower than ordinary ones, but recent studies with southern bluefin tuna suggest such an effect would be negligible (Hampton 1986). Further, growth increments of tagged and recaptured fish are generally consistent with length frequency statistics and the assumed one year interval between length modes. Another possibility is that on albacore shorter than 50 cm, the increment deposition rate is less than one per day, but this seems unlikely based on experience with other species. It should also be noted that Francis (1988) has recently suggested that growth parameters estimated from tagging and age-length data are not comparable.

One source of error in the aging data seems to be a systematic undercounting of increments deposited during early life. When a whole otolith is viewed under the microscope, newer increments partially hide those laid down earlier, closer to the nucleus. Despite constant, careful refocusing during the otolith examination, obscured increments may well be missed. If the composite growth models are correct, the implied degree of increment undercounting would be about 15% for a 50 cm albacore and 20% for a 70 cm fish. On an 85 cm albacore, the total increments missed would amount to roughly 50% of all those deposited during the first 2 years.

Although the otolith and tag return growth models predict different lengths at a given age, they both indicate faster growth for albacore in the southern group than in the northern group (Figures 14, 15, and 16). Differences in growth are conceivable if albacore in the northern and southern groups have different migration routes and foraging areas, as implied by the spatial criteria used in defining the groups. Note, however, that in both types of data there is considerable overlap between groups, and the statistical significance of the differences between the groups has not yet been estabished.

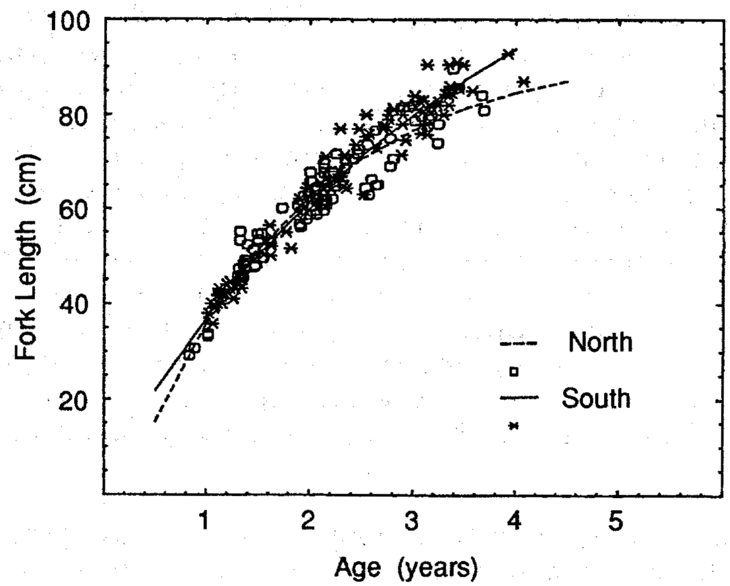

Figure 14. Estimated von Bertalanffy growth models for "north" and "south" groups of North Pacific albacore, and observed length-at-age, based on otolioth data.

Interestingly, a difference in tag return patterns between northern and southern groups becomes more distinct with size. Because the larger albacore are approaching maturity, the apparent differences in their migration behavior suggest that the northern and southern groups have different spawning areas and/or seasons.

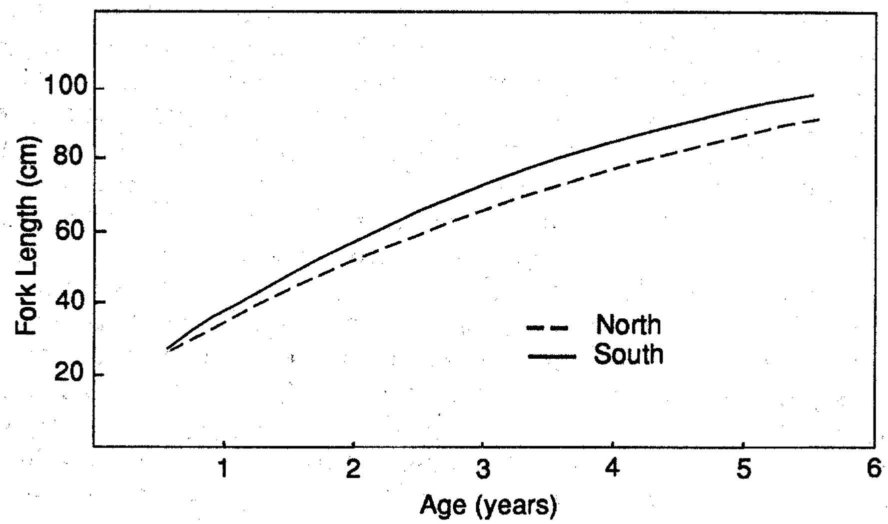

Figure 15. Estimated von Bertalanffy growth models for "north" and "south" groups of North Pacific albacore, based on tag return data. Locations of curves with respect to age axis fixed using estimates of mean length of 1-year-old fish computed from otolith daily increment counts on small albacore.

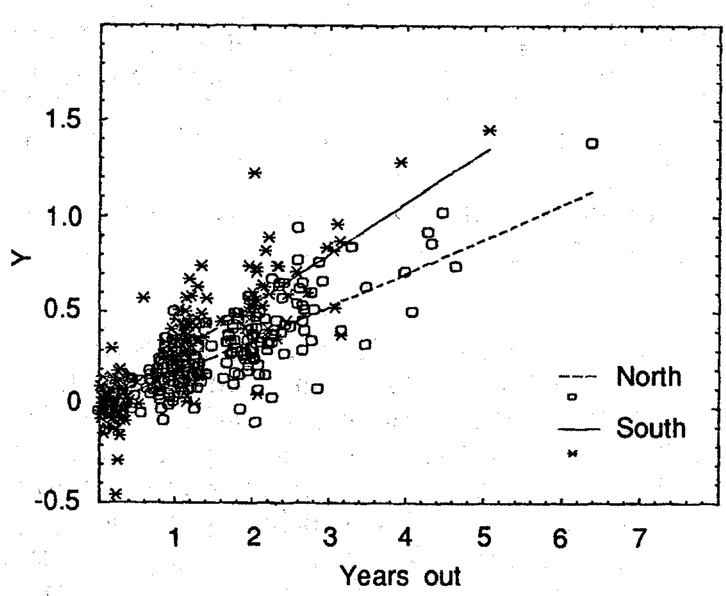

Figure 16. Growth rate variable (Y) as a function of days at liberty for "north" and "south" tag returns, and expected values based on fitted von Bertalanffy models.

Birthdate distributions for the northern and southern groups were estimated using the tag release and return data and the composite growth models. Each of the 521 albacore provided two estimates of its birth date, one based on its release length and date and another on the corresponding recapture statistics. The resulting distributions indicate spawning throughout the year, but suggest the northern group are born primarily during the April-November period, with a peak in July, whereas the southern fish are born mostly between November and June with a peak in February. The peak of northern birthdays follows the southern peak by about 5 months (Figure 17). The breadth of the overall spawning season is consistent with observations on ripe albacore and the occasional occurrence of early juveniles in samples. Of course, systematic errors in the growth curves would bias these birthdate distributions. In particular, if otolith increments from small albacore used in the composite growth model were undercounted, peaks of the spawning periods would occur earlier than indicated.

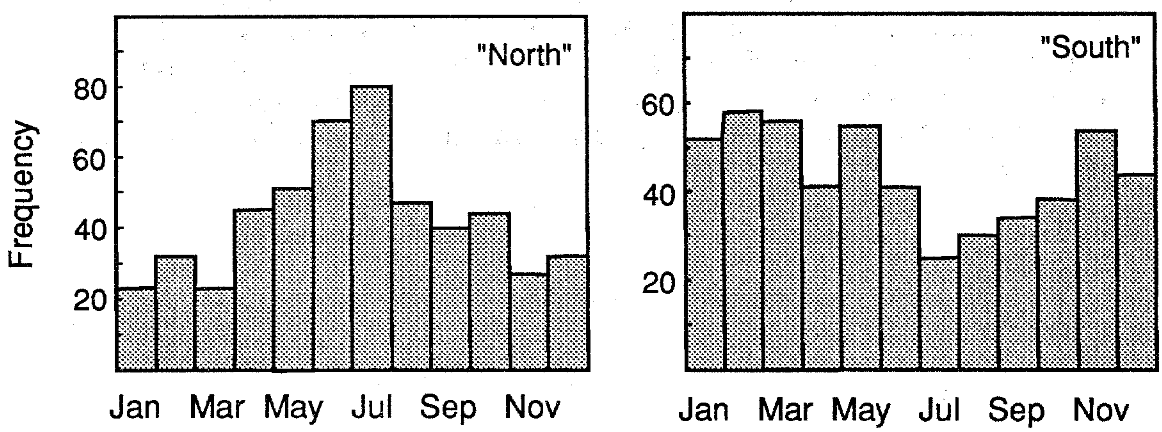

Figure 17. Estimated birth-date distributions for "north" and "south" groups of North Pacific albacore.

Another way to estimate spawning periods is to assign ages to modes in catch length frequency distributions. This was done using the composite growth model and historical length-frequency statistics for the U.S. fishery during 1972-78. Aggregate length distributions (Figure 18) were compiled for the northern area (90,956 fish) and the southern area (49,920 fish). This analysis estimated the interval between the primary modes in each group at about 1 year. However, it also suggested that corresponding modes in the northern and southern groups were roughly 6 months different in age, suggesting spawning seasons peaking 6 months apart (summer spawning for northern fish and winter spawning for southern fish).

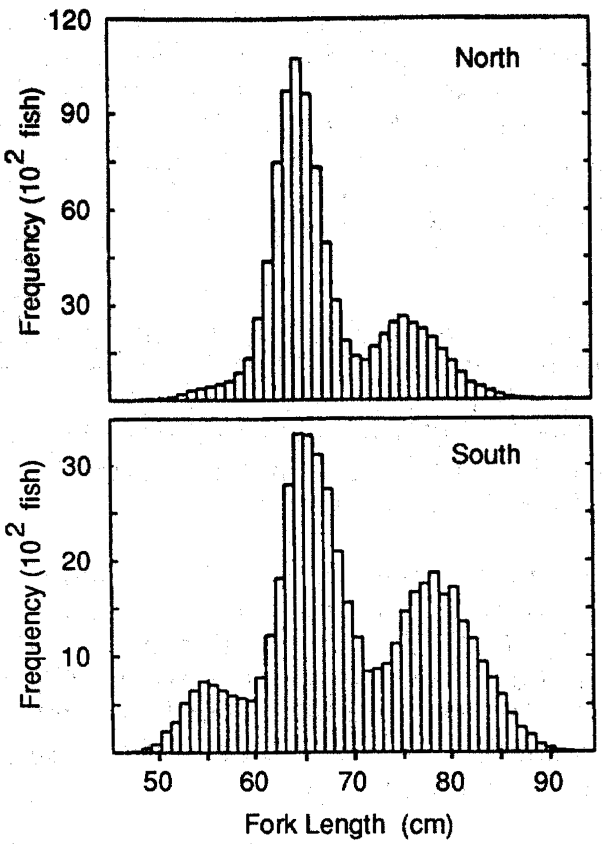

Figure 18. Composite length-frequency distributions for North Pacific albacore caught north and south of latitute 38° N off the U.S. west coast during the 1972-78 fishing seasons.

Habitat Definition

Most of the present level of understanding of albacore habitat has been gained through studies at sea using multidisciplinary approaches including physical and biological oceanography, satellite oceanography, fish tracking and physiological investigations. The results of these studies have revealed that the migration, distribution, availability, and vulnerability of the immature albacore which dominate the surface fisheries are markedly influenced by oceanographic conditions in the North Pacific Ocean, notably oceanic fronts.

Albacore surface fishing grounds in the western Pacific have been linked to oceanic fronts (Uda 1973). Also, the seasonal migration of albacore into North American coastal waters has been found to be associated with the North Pacific Transition Zone waters and its frontal boundaries (Laurs and Lynn 1977). Oceanographic conditions also play an important role in the local concentrations and movements of albacore in coastal waters off North America. Albacore tend to aggregate on the warm side of upwelling fronts and move away from the locations where the fronts had occurred when upwelling breaks down (Laurs et al. 1977). Satellite images of ocean color and sea surface temperature and concurrent albacore catch data clearly show that the distribution and availability of albacore off California are related to coastal upwelling fronts and that albacore are most abundant in warm, clear, blue oceanic waters near temperature and color fronts at the seaward edge of coastal water masses (Laurs et al. 1984).

It is presumed that albacore aggregate in the vicinity of upwelling fronts to feed on forage organisms which are plentiful in these areas (Blackburn 1969; Laurs et al. 1977; Fiedler and Bernard 1987). Yet, it remains unclear what physical factors inhibit albacore from penetrating these fronts in order to reach what would likely be the highest potential forage biomass (Blackburn 1969; Laurs unpublished results).

Thermal-physiological mechanisms have been thought to be the main reason why tunas generally do not cross sea surface temperature gradients into cooler waters. Past studies have stressed confinement to a physiological optimum temperature range (Thompson 1917; Clemens 1961; Sund et al. 1981). Neill (1976) has postulated that tunas, which can perceive temperature changes as small as 0.1^{o} C (Steffel et al. 1976), utilize frontal gradients for behavioral thermoregulation.

However, explanations for environmental preferences of albacore are changing as new knowledge is acquired. For example, the recent finding that albacore can regulate their body temperatures (Graham and Dickson 1981) suggests that temperature regulation, while on the cool side of a thermal front, should not be limiting. Moreover, an investigation of albacore swimming behavior in relation to ocean thermal structure, using acoustic telemetry to measure movements of free-swimming albacore and coincident oceanographic sampling, has shown that albacore did not cross from the warm side to the cool side of an upwelling front which had a sea surface temperature gradient of about 2^{o} C over a few kilometers. However, the fish routinely passed through vertical temperature gradients up to 10^{o} C within a 20 minute period while undergoing extensive vertical excursions up to several hundred meters (Laurs and Dotson In prep.).

These findings clearly document that albacore aggregation on the warm, clear side of sea surface temperature fronts is not exclusively related to thermal-physiological mechanisms. Recent research involving acoustic telemetry of free-swimming albacore, satellite measurements of ocean color and temperature, and oceanographic sampling of water optical and other characteristics, indicate that water clarity as it affects the ability of albacore to detect prey is an important mechanism underlying the aggregation of albacore on the warm, clear sides of upwelling fronts (Laurs In prep b).

Based on physiological research findings, the normal habitat of albacore is within a temperature range of 10°-18° C (Graham and Dickson 1981) with a dissolved oxygen saturation greater than about 60% (Graham and Laurs 1982). While individuals may temporarily move into waters outside of this range, thermoregulation and respiration functions will be adversely affected. Acoustic tracking of free-swimming albacore (Laurs and Dotson In prep) has demonstrated that immature albacore customarily live within the depths of the thermocline, rather than the upper mixed layer as has been generally presumed.

Physiological/ecological investigations on albacore conducted by the SWFC in cooperation with several universities and research foundations have increased knowledge of specializations of albacore for active migration. They have also provided information useful in defining albacore habitat, and have enlarged the understanding needed to define causal mechanisms responsible for natural fluctuations in the North Pacific albacore resource in response to variations of its oceanic environment. Findings demonstrate that the albacore is a highly advanced teleost with many specialized adaptations. It is capable of thermoregulation (Graham and Dickson 1981), has a high metabolic rate (Graham and Laurs 1982), an advanced cardio-vascular system (Breich et al. 1983; Lia et al. 1987; White et al. in press), and specializations in the circulatory system and blood/gas exchange systems (Laurs et al. 1978; Alexander et al. 1980; Cech et al. 1984; Graham et al. in press). Albacore have also been found to have distinctive enzyme and complement systems (Morrison et al. 1978; Giclas et al. 1981; Dyke et al. 1987; Dickson 1988), and high energetic costs for migration (Sharp and Dotson 1977) which may be partly met by utilization of stored fat (Dotson 1978).

MODELING STUDIES

The Albacore Model

A significant proportion of recent NMFS albacore research has centered around the development of a simulation model of the North Pacific albacore population and fisheries. The development of the model was carried out concurrently with the work of research planning for albacore. Decisions concerning the architecture of the model and the direction of the modeling effort were made in consultation with members of the albacore task force. A technical description of the necessary data processing leading to the model is given by Kleiber and Baker (1986), and details of the design of the model are given by Baker and Kleiber (1987a). The spatial resolution of the model was based on the principal geographical fishing zones with 10 areas described for the North Pacific (Figure 10).

The first purpose of the modeling effort was to make a tool for evaluating the possible effects of various manipulations of the albacore fishery, in case management of the albacore fisheries should become necessary.

The international North Pacific albacore fishery is carried out by fisheries utilizing different gear types. Each fishery has a different geographical range and seasonality and each fishery exploits a different size distribution of albacore. The model therefore requires gear type, area, seasonal, and fish size resolution. The model must respond correctly in the face of simulated management actions and it must be tuned to produce a nominal behavior against which the various fishery simulations can be compared. The nominal behavior does not have to be a simulation of actual historical events, but can be some kind of average behavior. A crucial component of the model involves simulating the migrations of albacore between the separate geographical fishing zones. Therefore, a workshop was held to develop the current conceptualization of the age dependent migration patterns of albacore into migration coefficients usable by the model. The values obtained can be viewed as average or typical and are used for assessing nominal model behavior; in the absence of environmental driving functions, they cannot capture historical variation in migration.

To simulate management action, it is necessary to know how the proposed management will affect size specific catchabilities and the deployment of effort in time and space so that equivalent model manipulations can be made. In some cases this may be relatively straight forward, such as with quotas or size limitations, but other cases may be more involved such as those which would occur with model manipulations to determine the effects of license arrangements or fuel subsidies.

The model simulated recruitment, growth, movement, natural mortality and harvest of albacore by three fishing fleets: the Japanese baitboat fleet, the Japanese longline fleet, and the United States jig fleet. The model must begin with starting values of the population of fish at large and the disposition of those fish both geographically and by size of fish. The model then predicts population and catch by each fleet as a function of time on the basis of a time series of effort values by fleet and geographic area and a large set of parameters for recruitment, growth, movement, natural mortality, and harvest.

To demonstrate the kind of results the model can produce, it was used to address a potential concern of fishermen and fishery administrators, that of interaction among fishing fleets (Kleiber and Baker 1987b). For these simulations the nominal behavior of the model was based on a typical, or average, year in the fishery which was produced by multi-year simulations with constant recruitment and a constant seasonal pattern of fishing effort for each fleet type and model area. Thus the results were not dependent on precise starting values. The nominal yearly catch of each of the fleets was then compared with the resulting catch when the effort in one of the fleets was either doubled or halved. At the current level of exploitation, the largest interaction was an 8% loss of longline catch due to a doubling of baitboat effort (Figure 19, Table 2)

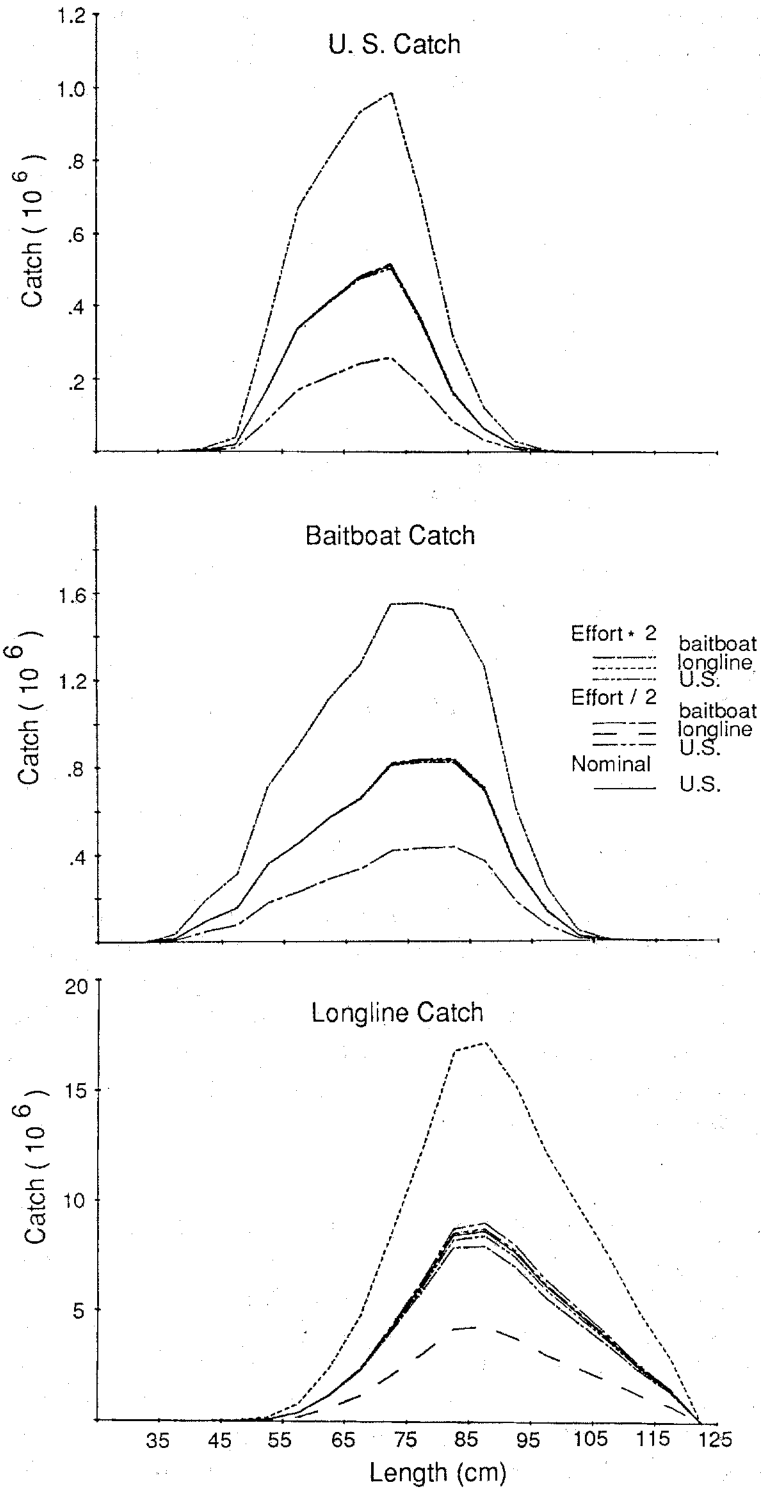

Figure 19. Fishery interactions between the three major albacore fisheries. Catch in numbers of fish. (from Kleiber and Baker 1987b).

Table 2. Average albacore annual (1970-80) catch in numbers and metric kilotons (kt) by baitboat, longline and U.S. fleets plus annual catch from model after at least 10 years of simulation under nominal conditions and under various condition of altered fishing effort (from Kleiber and Baker 1987b).

		Baitboat		Longline		U.S.	
		(10^6)	kt	(10^6)	kt	(10^6)	kt
Average catch		6.29	57.52	0.68	13.30	2.65	19.56
Nominal effort		6.87	55.12	0.66	9.47	2.67	18.32
Baitboat	X 2	12.89	102.00	0.62	8.76	2.63	18.05
effort	/ 2	3.55	28.69	0.69	9.86	2.69	18.46
Longline	X 2	6.85	54,91	1.32	18.79	2.67	18.30
effort	/ 2	6.88	55.23	0.33	4.75	2.67	18.33
U.S.	X 2	6.80	54.43	0.65	9.23	5.19	35.41
effort	/ 2	6.90	55.49	0.67	9.59	1.35	9.32

The model has not been used to evaluate the effects of management actions because no such actions have been proposed for the North Pacific albacore fisheries. In the event such proposals do appear, the model could be used to evaluate the effects of the management actions by predicting the behavior of the fishery in relation to nominal behavior based on an assumed set of input data. Thus we could predict likely trends in catch per effort or other resource measures, and we could predict if the trends are likely to be large or small. Such results are useful in evaluating management policies even without quantitative prediction of the actual future levels of the resource.

Quantitative long-term prediction by the model of absolute levels of CPUE or other measures of the resource is very unlikely. Such prognostication would depend on knowledge of the future deployment of effort in all fleets, future recruitment and possibly future environmental data if such are incorporated into the model. In addition, the prediction would depend on accurate starting values for the current size and geographical distribution by size of the population at large. Precise current information of this type is not available with the present state of our data gathering systems.

The second purpose of the model was to establish whether oceanographic and climatic data can be incorporated into a fishery simulation model and thereby improve the predictive ability of the model. If a model which takes account of the albacore's response to fluctuations in the environment can be developed, this could provide additional insight into the mechanisms of environmental actions on the fishery and would result in better evaluations of the observed fluctuations in the various albacore fisheries.

To see if the model responds correctly to real historical environmental events, such as El Niño, the model must predict a real historical series of population size and catch. To do that, it is necessary to have accurate starting values for the size and geographical distribution of the fish population. The appropriate environmental data must be assembled and submodels dealing with the effects of the environmental parameters must be coded into the model. Furthermore, either a historical series of recruitment estimates or a submodel dealing with the effect of parental stock size and environment on recruitment is necessary.

Early on, a workshop was convened with taskforce members and others to consider environmental inputs to the model. Candidates for relevant environmental parameters were proposed and their potential applications within the model were discussed. The consensus of the group was that more research needed to be accomplished before environmental driving functions could be included in the model. This second aspect of the modeling effort has remained shelved, partly because of continued need for more understanding of environmental effects, but also because of technical problems in obtaining good starting values and a good historical series of recruitments which are necessary for the model to generate a historical series of catch estimates.

The modeling effort has served as a focus for planning of albacore research by illuminating gaps in our knowledge and helping to organize the various albacore research endeavors. We are considering using the model as a basis for developing two new methods of data analysis, both taking advantage of the built-in geographic structure and migration features of the model. One would be a geographically heterogeneous form of cohort analysis and the other would be a quantitative evaluation of migration from tagging data.

Albacore Predictive Models

A separate modeling effort was initiated to examine the possibility of forecasting CPUE on time and space scales (fortnight and one degree squares) which could be used in real time by albacore fishermen (Mendelssohn and Husby In prep). The study examined contemporaneous and prior environmental conditions within the traditional U.S. albacore fishing grounds to determine if real time, or near real time, environmental information can be used to assist fishermen in predicting albacore catches. The CPUE time series used in the study was developed from information derived from the albacore log book program and included information from 1961-79. Environmental time series of SST and wind were developed from weather information derived from ship logs, ship weather reports and data buoys; this information is maintained by the National Climatic Data Center.

Twenty-four one degree squares that had from 100 to 200 fortnights in which some fishing occurred were selected for study. Multivariate, nonlinear models were estimated relating CPUE at time t to CPUE, SST, and wind at different time lags. For all 24 areas the estimated r squared for the models based on contemporaneous environmental conditions (lag 0) were much less than those based on the previous fortnight (lag 1). Models based on lags 0,1 and lags 1,2 had r squared values not greatly different than those based on lag 1. Models based on the previous fortnight environmental conditions had r squared values ranging from 0.49 to 0.74.

Transformations for SST suggest a threshold of about 12-13^{o} C below which albacore are not found by the jig boats. CPUE increases to a maximum at around 16-17^{o} C and then decreases at temperatures above this. However, there is a north-south gradient with both the threshold and maximum CPUE occurring at lower temperatures in the north. Transformations of the north-south and east-west components of the wind suggest that optimal conditions for catching albacore will be when 2 weeks earlier the wind was from the north and west at a speed of about 7-10 m/sec. Off California this type of wind is usually associated with upwelling and offshore Ekman transport. The estimated transformations, especially for wind, are highly nonlinear and this may explain why linear techniques have failed to date. The combination of conditions defined by all three environmental variables appears to be necessary to make accurate forecasts which suggests that these variables act as proxies for an underlying oceanographic process rather than being direct influences on albacore.

The entire area of study was then divided into nine regions, based on the relative homogeniety of the one degree square areas within a region. Functional forms for the nonlinear transformations were determined for SST, the northwest-southeast (alongshore) and southwest-northeast (inshore-offshore) components of the wind in each region. These estimated functions are being used to develop forecasting models at different levels: locally by region, then a space-time model using all nine regions, and then by an aggregation-disaggregation scheme, down to each of the original one degree square areas.

The ability of the models to predict CPUE for albacore at each level of spacial resolution will be tested using cross-validation and diagnostic measures and then by examining the behavior of the models on 4 years of data not included in the estimation stages.

ECONOMIC STUDIES:

Four economic analyses concerning north Pacific albacore were conducted by NMFS personnel during the period covered by the current operational plan. Three of these dealt with the commercial fishery and one with the recreational fishery.

Vessel Characteristics and Performance

Carlson and Herrick (1985) conducted this investigation to provide baseline information on the structure, operations, and performance of the harvesting sector of the North Pacific albacore fishery. The coastwide data base (CWDB) was used to examine the fishing activity of vessels that participated in the fishery from 1974 through 1976.

Annual landings of albacore ranged from a high of 24,400 tons in 1974, to a low of 16,500 tons in 1976. Corresponding ex-vessel values ranged from $18 million to $15 million. From 1974 through 1976, 4,585 different domestic vessels landed albacore at U.S. Pacific coast ports, with the numbers of vessels in the fishery averaging 2,169 annually for each of the 3 years. A relatively small proportion of these vessels accounted for the bulk of albacore landings in each year: 10% of the vessels landed 40% of the albacore and 20% of the vessels landed 60% of the albacore in each of the 3 years.

Of the total number of vessels that landed albacore over the three-year period, 780 landed albacore in all three years (i.e. the permanent fleet). In any one of the years 1974-76, the permanent fleet accounted for approximately 60% of the total annual tonnage of albacore landed. The permanent fleet was mainly composed of vessels in the 35 to 55 foot length range and most, over 78%, reported using troll gear for part of their fishing operations. Vessels that were active in the albacore fishery during this period also landed salmon, crab, groundfish, shellfish, and other tuna. The dominant species combination for the permanent fleet, in terms of number of vessels, was albacore-salmon-groundfish. Vessels landing this species combination accounted for the largest percentage, 24%, of the annual albacore landings by any species combination group in the permanent fleet. Vessels in this fleet also reported using purse seine nets, crab pots, trawl gear and longline gear. In the permanent fleet, the percentage of total revenues derived from albacore varied from 38% to 55% over the 3 years.

For a vessel in the permanent fleet during this period, it is possible to construct the following profile:

> The vessel was between 35 and 54 feet in length, and used trolling gear in its albacore fishing operations. The vessel had average albacore landings of 18 tons which accounted for 45% of its total landings Its average earnings from albacore were $13,983 which contributed 47% to its total ex-vessel revenue. Along with albacore, it most likely landed salmon and groundfish which together contributed an average 5.61 tons of additional landings and $9,118 in additional ex-vessel earnings. Its total ex-vessel revenue was in excess of $26,000.

Budget Simulation Model

In the second analysis, Herrick and Carlson (1986) designed a model to monitor and predict the financial and economic performance of specific vessels or classes of vessels making up the North Pacific albacore troll fleet. ALBSIM (a computer based, budget simulation model) is essentially a collection of regression equations that predict a vessel's revenues and expenditures according to the structure of a net cash flow account. The model components are as follows:

Vessel Revenue
- landings, ex-vessel price

Operating Costs
- fuel and oil
- other

Labor Costs
- payments to crew
- payments to skipper
- payroll taxes

Fixed Costs
- interest payments
- scheduled maintenence
- moorage and rent
- insurance
- fees (professional services, property taxes permits, and other)

Net Cash Flow

ALBSIM is capable of generating budgetary information for west coast albacore trollers when the values of key variables describing vessel characteristics, fishing activities, and costs of inputs (e.g. fuel) are specified. This makes the model a particularly useful analytical tool for evaluating events that affect the fleet's operating environment.

The simulation model has been designed so that fleet-wide economic analyses can be conducted, and is also designed so that it can be used by individual fishermen as a financial decision making tool.

Fishery Switching Model

This work, which is currently in progress, is an effort to model the within season decision-making behavior of U.S. troll fishermen for whom the North Pacific albacore fishery is an operating alternative. The purpose of this work is to identify conditions under which fishermen will switch from one type of fishing activity to another, and provide a means of predicting shifts in the time/area/species distribution of troller fishing effort in response to changes in these conditions.

Each fisherman intuitively has his own objective function, set of constraints, and means for solving it. The objective function is the maximization of profits and the constraints are: vessel hold capacity, distance traveled, days at sea, relative fish abundance, length of season, unknown fish location, etc. with each variable weighing differently over time for each fisherman.

By observing actual behavior over the course of several seasons, the relative importance of various conditions can be assessed. For example, the relative abundance of albacore is separable from fisherman specific variables; fishermen who operate smaller, less mobile vessels with little remaining hold capacity place higher weight on local conditions than those with larger vessels. Leaders versus followers have differing attitudes toward uncertainty and different needs and uses for information. By formulating and estimating a model that yields the probability of a fisherman's choices given certain conditions and information, the optimization behavior underlying his actions is revealed.

Albacore Sportfishing Economic Study

The demand for California albacore angling was analyzed by Hanemann, Strand, and Wegge (1986). The work provides estimates of the net economic value from albacore angling, and the effect on angler economic benefits and participation rates from marginal changes in access prices, the individual's socio-economic circumstances, angling quality factors, and real or perceived changes in albacore availability.

Based on data collected during a 1983 survey of southern California anglers, the demand for albacore angling off the southern California coast was analyzed, and the gross and net economic values of this activity were estimated. Several economic modeling techniques were used to analyze the demand for party/charter boat and private boat angling for albacore. Variations of the travel cost method of estimating recreational values were employed to estimate the net economic values of albacore sportfishing.

For party/charter boats fishing for albacore, the average length of a fishing trip was 2.07 days and the average albacore catch was 7.5 fish per angler. Trip expenditures which include boat fees, food, beverages, lodging, tackle, licenses, fish cleaning and processing, and transportation to and from the dock site averaged $231.66 per angler per trip. The net economic value, or the value to the angler above and beyond actual expenditures, was estimated at $123.00 per trip. The total amount the angler would be willing to pay for the albacore party/charter boat fishing trip was therefore approximately $354.00.

The net benefit of albacore party/charter boat angling from six southern California sites was also estimated. Because albacore party/charter boat trips from San Diego represent such a significant share of the total number of trips (81 percent of all trips originated from San Diego), the net benefit of

San Diego sites for albacore fishing accounts for approximately 95 percent of the total annual benefits accruing to albacore anglers utilizing party/charter boats in southern California.

For private boats fishing for albacore, the average length of a fishing trip was 10.8 hours, and the average albacore catch was 6.0 fish per angler. Trip expenditures, which include boat fuel, food and beverages, lodging, tackle, licenses, fish cleaning and processing, and transportation to and from the launching site, averaged $130.89. The net economic value was estimated at $26.00 to $89.00 per trip, with the higher value resulting from the inclusion of boat fuel only as a fishing-related cost. The total willingness to pay for albacore private boat sportfishing was estimated at $156.00 to $219.00 for a typical trip.

FISHERY DEVELOPMENT

Distant Water Fisheries Development

The U.S. fishery for albacore began in the early 1900s in relatively nearshore waters off southern California (Scofield 1914). It soon enlarged southward, eventually to about central Baja California. It also gradually extended northward around Point Conception, but remained restricted in the north to waters within a few hundred miles off California until the late 1930s. Large catches of albacore were made off Oregon and landed in Astoria in 1938, after which the fishery rapidly expanded to waters off the Pacific Northwest. The geographical extent of the fishery remained virtually unchanged, with vessels operating within several hundred miles of the coast between central Baja California to British Columbia during summer and fall months, through the late 1970s.

In the early spring of 1975 three U.S. jigboats, receiving a fuel subsidy from the American Fishermen's Research Foundation (AFRF), carried out albacore trolling exploration across the North Pacific. Substantial catches were made by these vessels in the general vicinity of the Emperor Seamount chain (Laurs 1976). Encouraged by these results, additional albacore exploration was conducted in the central and western Pacific during 1976, 1977, and 1978 by two or three vessels chartered with funds from the AFRF and from Saltonstall-Kennedy (S/K) funds awarded to the Pacific Trust Island Development Foundation (Laurs 1977a and 1977b; Laurs and Nishimoto 1979). These albacore trolling explorations demonstrated the potential for U.S. vessels to operate profitably in areas over 2000 - 3000 miles off the coast of North America during spring months. As a result of the distant water fishery development investigations, the U.S. albacore fishery expanded operations across the North Pacific into the central and western portions. Since about 1980, approximately 30 % of the total U.S. catch has been caught by the distant water fleet operating across the North Pacific.

U.S. fishermen have traditionally used surface fishing methods (mostly trolling feathered jigs, pole-and-line bait gear and occasionally purse seines) to catch albacore (Dotson 1980). Efforts were undertaken in 1981-1985 to evaluate the feasibility of extending the U.S. albacore fishery through the winter months using longline fishing techniques. Exploratory albacore longline fishing and research operations were conducted by one to six vessels chartered with S/K funds awarded to the AFRF and working in cooperation with the SWFC. The investigations demonstrated that the U.S. albacore fishery could be extended to operate during winter months using all monofilament longline gear (developed during the course of the investigation) in an area about mid-way between the coast of central California and the Hawaiian Islands (Laurs et al. 1981; Laurs et al. 1982; Laurs and Dotson 1983; Dotson et al. 1984). Because of the cannery closures in the U.S. and decreases in the the ex-vessel prices for albacore which occurred in 1984 and 1985, vessels abandoned plans to enter the longline fishery. However, as a result of the recent increases in ex-vessel prices paid for albacore and the increased demand for specially handled albacore for the fresh, fresh/frozen, and the sushi/sashimi markets, several U.S. vessels are expected to enter longline fishing.

Fishery development research conducted in 1986 and 1987 indicated that the prospects for establishing a U.S. troll fishery in the South Pacific appeared excellent. The albacore trolling exploration was conducted by two to five U.S. jigboats, which received fuel subsidies from S/K funds awarded to the Pacific Fisheries Development Foundation in collaboration with the Western Fishboat Owners Association. The fishery exploration/research, which was conducted in cooperation with the SWFC, resulted in high catch rates and high total catches. The excellent fishing success, combined with relatively good weather conditions and the infrastructure in the South Pacific for selling catches and supporting vessel needs, indicated that it was economically feasible for U.S. albacore fishing vessels to operate there (Laurs 1986; Laurs et al. 1987). The development of a U.S. albacore fishery in the South Pacific began in earnest in 1988 with 43 U.S. fishing vessels participating in the fishery; catch rates in this fishery were high (252 fish per day) and a total of 3,527 MT of albacore was caught. The development of the South Pacific fishery will allow U.S. vessels to operate year around by fishing in the summers of both hemispheres.

Processing, Product Development and Marketing

Historically the U.S. albacore fishery has marketed its product almost exclusively to canneries. The distant water nature of the fishery, the reliance on the cannery market, and the recent great reduction in local canning of tuna has resulted in a situation where it has been necessary to develop new markets for U.S. caught albacore. The new market development centered on establishing a fresh and fresh/frozen market for resturants and retail stores, and export of high quality frozen albacore for canning in Japan and Europe. Much of the funding for the development of the fresh and fresh/frozen market was supported by U.S. Government grants. The export market development was funded entirely by the industry.

The principal mechanism used by NMFS to assist the albacore fishery regain economic stability has been through grants to industry-sponsored programs. Seven S/K grants ($403,750) were used to assist in the development of new markets for albacore. Four of these grants concerned market development ($279,350) and three were concerned with onboard processing methodology, quality control and new product development of albacore ($124,400). In addition to the above seven grants, there were an additional five S-K grants for albacore fishery development ($433,000); these are described in the previous section. To the extent that part of the rationale for these five grants was to assist in the expansion from a seasonal to a year-around fishery, they were also part of the effort to aid in the economic development of new markets for the U.S. albacore fishery.

Grants for market development were awarded to the Western Fishboat Owners Association, the West Coast Fisheries Development Foundation, NWR Restaurant Market Development and Tennyson and Associates. These grants were intended to assist in the major Albacore Alternative Marketing Program which was organized by the Western Fishboat Owners Association. This program included a wide range of activities most of which could best be characterized as education. Fresh tuna had not been available to U.S. consumers and people within the entire food delivery system from fisherman to retailers or restaurants did not know how to handle fresh tuna nor did the consumer know how to utilize it. The marketing program was therefore concentrated on three linked problem areas: improving on board product quality, improving product quality at the processing and distribution level and improving the recognition of a quality product at the retail and food service level. The description of the problems and the efforts made to solve them is well described in Tennyson's (1986) and Western Fishboat Owners Association's (1985) final S/K reports.

Product quality at the on-board level is a problem with a historical base. Albacore have long been considered the premium tuna in the canned market. In the past, U.S. fishermen were able to sell as much albacore as they could land as long as the product quality met the standards necessary to produce a good canned product. These standards do not result in a product quality which is high enough to meet the additional demands required to get fresh or frozen albacore to the consumer. The two most important problems appear to be the appearance of the fish and the increase in salt content caused by brine freezing. Methodology developed under the S/K grants for on-board processing clearly demonstrate that product quality can be greatly increased (Vanderpool 1985; Jacoby 1985; Price and Melvin 1989). These studies show that quality is greatly enhanced by proper bleeding and eviscerating techniques, care in avoiding bruising the fish, and blast freezing. Price and Melvin's (1989) study clearly demonstrates the importance of immediate refrigeration and it provides on-board handling techniques for producing high quality fresh fish and high quality frozen fish.

PRESENT STATUS

Evaluations of the status of a fishery resource are often confounded with the status of knowledge of the resource. Albacore is not an anomaly in this regard. Although there is a huge amount of information on albacore in the North Pacific, there are a number of areas in which gaps in our knowledge limit the reliability of resource evaluations. The three most important factors involve stock structure, the age structure of the population, and population parameters for the spawning portion of the resource. Given these limitations, the evaluation of the resource is based on a large amount of consistent information derived from the juvenile portion of the resource, trends in fishery statistics, fishery monitoring, tagging studies, population modeling and biological information on the adults of other scombrids.

The Question of Stock Structure

To evaluate the stock structure of the albacore population, genetic analyses, utilizing mitochondrial DNA, were carried out. Results from this work (Graves and Dizon 1989) demonstrate that albacore from the North Pacific are genetically indistinguishable, with presently available methodology, from those off of South Africa. This implies that it is possibile that there is only a single fishery stock of albacore in the entire Indo-Pacific. Conversely, it does not rule out the possibility that there is more than one fishery stock in the North Pacific. Spawning populations which exchange 1% of their populations per generation would be genetically indistinguishable, but would still have to be considered independent fishery stocks for management purposes. Therefore, the genetic analyses carried out as a part of the albacore research program do not reveal the fishery stock structure of albacore in the Pacific.

Unfortunately, the stock structure question is a major factor confounding our knowledge of the status of the albacore resource To date all of the population analyses of the North Pacific albacore have been based on the assumption of a single North Pacific stock; however, there is circumstantial evidence which can be interpreted to suggest that there are two fishery stocks in the North Pacific. The principal pieces of evidence which can be used to assess the one and two stock hypotheses are as follows:

1. Tagging results suggest that there is more exchange between the albacore in the Kuroshio (and Kuroshio Extension) and fish in the northern portion of the California Current than with fish in the southern portion of the California Current (p. 20).
2. Fish from the northern group have lower growth rates than those from the southern group, based on otolith studies and tag recovery growth models (p. 22).
3. The northern fish are primarily born in the summer and the southern fish are primarily born in the winter, based on birthdate distributions derived from daily otolith counts (p. 24).

4. Albacore larvae occur throughout the year; however, the distribution of larvae is about 10 degrees of latitude further north in the summer than in the winter (p. 16).
5. There is essentially no directed fishery on spawning adults. The winter longline fishery, which primarily harvests adults and fish which are approaching adulthood, occurs in the northern portion of the summer spawning grounds but larvae are not present in this region during the period of the fishery (p. 18).
6. The winter longline fishery has about the same recovery rates (ie. about 5%) from fish tagged in the northern and southern areas of the California Current (p. 20).

There are two opposing ways to interpret the above information; however, the lack of a directed fishery (and tag returns) on spawners severely limits the interpretations. First, there is only one stock in the North Pacific, spawning occurs year round, and seasonal differences in ocean circulation causes the fish born in the summer have a more northerly distribution as juveniles and pre-adults (i.e. 1 to 5 years old) than those which are born further south in the winter. Second, there are two stocks, one spawning in the summer and one spawning in the winter, and the two stocks have different geographical distributions. Although there is little supporting evidence for other alternatives, it is possible that there is only one fishery stock in the entire Pacific, that there are more than two stocks in the North Pacific or that the entire fishery stock concept is not applicable to albacore.

If there is only one stock in the North Pacific, the available evidence on year class size suggests that prior to 1980 the stock was moderately exploited and that the population size and recruitment were remarkably stable. For example, the catch of the 1959-78 year classes, as estimated from the age composition analysis, varied by only a factor of four (Figure 20). The year classes with maximum catches were generally those occurring during the late 1960s and early 1970s, in association with the peaks in fishing effort of the North American and Japanese surface fisheries, which suggests that much of the variation in catch to that time was due to variations in effort rather than year class size. However, size composition data from the Japanese fisheries have not been made available to U.S. researchers after the 1982 season. Therefore, the last year class for which we have adequate information was born more than a decade ago and it is not possible to evaluate the size or age composition of the catch during the more recent period, which is characterized by low CPUE in the surface fisheries and the rapid increase in the Asian drift gill net fisheries.

The standardized CPUE's of the major fisheries vary by factors of about 2.6 in the two Japanese fisheries and 3.6 in the North American fishery and there is a significant correlation (0.01%) between the 1961-86 CPUE's in the Japanese and North American surface fisheries (r=0.679). However, the North American fishery is much more remarkable for its geographical variation than its interyear variation in catch or CPUE. In fact, the relatively low interyear variation of CPUE in the North American fishery is unusual as this fishery is heavily dominated by a single year class (age three) and such fisheries are often characterized by very large interyear variability.

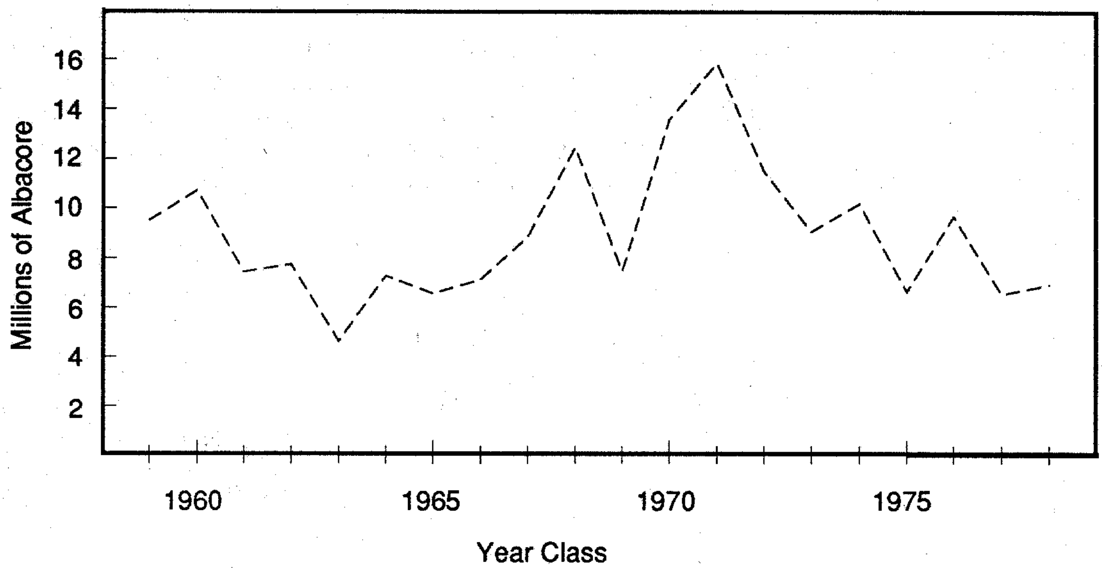

Figure 20. Total North Pacific catch of the 1959-79 year classes in the Japanese surface fishery, Japanese longline fishery, and the North American surface fishery.

Simulations with the albacore model which were made under the assumptions of a single stock, constant recruitment, and average (1970-80) exploitation parameters show very little interaction among the three major fisheries. This suggests that, under these assumptions, the stock was not heavily exploited.

Finally the size composition in the catches in the area where the largest albacore are taken, the area the Japanese refer to as the main spawning area (i.e. between 10^{o} N and 25^{o} N and between 140^{o} W and 140^{o} E), remained nearly constant from 1965 to 1981 (Shiohama 1985). Again, more recent data are not available.

If there are two stocks in the North Pacific, either the recruitments or the migrations of these stocks to the California Current region must be extremely variable. In addition, the pattern of landings in the California Current region (i.e. multiyear series of northern or southern dominance) implies that the variations in the two stocks are negatively correlated (Figure 2). The two-stock concept also suggests that the northern stock provides the major component of the North Pacific landings as it is presumably the principal stock in both the Japanese surface fishery and the northern portion of the North American surface fishery.

The sharp declines in the landings of the Japanese and North American surface fisheries since the mid 1970s imply that, if there are actually two stocks in the North Pacific, there is a strong possibility that the stock size of the northern stock greatly decreased from the mid 1970s to the late 1980s (Figure 21). An alternative explanation is that the availability or geographical distribution of the northern stock has altered due to environmental conditions associated with the warming trend which occurred from 1976-87. Under the two stock scenario it would be assumed that the stock harvested off California and Baja California is quite small and that it is highly variable on the decade time scale with catches from this stock not exceeding 10,000 MT since the early 1970s (Figure 2).

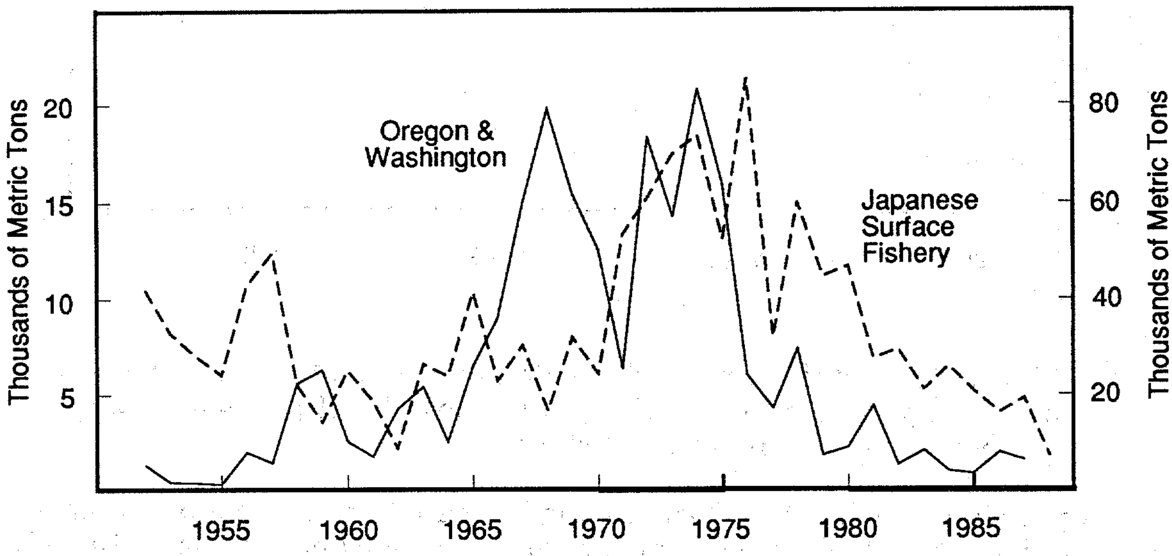

Figure 21. Catches in the Japanese surface fishery (right margin) and the Oregon-Washington region of the North American surface fishery (left margin).

Age Structure and Population Parameters

The second factor which limits analyses of the North Pacific albacore resource is the lack of information on the age structure of the population. The size/age structure of North Pacific albacore is highly geographically dependent. One and 2 year olds are concentrated in the Western Pacific, 3 and 4 year olds are common north of 30° N across the entire North Pacific, 5 and 6 year olds are concentrated between 25° and 35° N in the Western Pacific and older adults are primarily found in the Western and Central Pacific between 10° and 25° N. This geographical dependence makes assessment of the age structure of the population an intractable problem as any assessment is biased by the spacial distribution of sampling. Lack of information on the true population age structure also prevents any accurate estimate of natural mortality and severely limits the evaluation of year class sizes.

The third limitation in our knowledge concerns information on the spawning population of albacore in the North Pacific. Our information is sparse primarily due to two factors. First, the spawning population is lightly exploited and this exploitation primarily occurs in the higher latitude edge of the adult habitat. Second, the difficulty in aging adult albacore has resulted in a situation in which there are no reliable estimates of the age structure, maximum age or mortality rates of adult albacore. The combination of these factors also precludes a reliable cohort analysis, an estimate of the adult biomass, and the development of a stock-recruitment relationship. Information on the spawning portion of the resource is extremely difficult for U.S. researchers to develop due to the fact that the mature segment of the population is not harvested by U.S. fishermen and the adult habitat lies outside of the geographical regions normally surveyed by U.S. fishery research vessels.

Recent information from skipjack tuna (Hunter et al. 1986) shows that when their gonads are active they spawn nearly every day. Assuming a similiar pattern in albacore, this information (when coupled with the fact that albacore larvae occur in the spawning grounds all year) suggests that the reproductive potential of albacore is very large. When coupled with the observed (1959-78) stability of year class strength in the North Pacific albacore fisheries and the observed stability (1965-81) of the size composition of albacore in the spawning grounds, it appeared that exploitation levels on North Pacific albacore had not been large enough to reduce recruitment. However, recent information from the Japanese fisheries (Warashina, Honma, and Watanabe 1989) shows that lower recruitment has occurred and that a very weak year class (1984) has just passed through the Japanese surface fishery, resulting in the lowest catch in our records (1952-88), and it is just entering the longline fishery . This year class, at age three, also produced the lowest North American catch since 1937. Warashina et al. (1989) also predict that the density of 3 and 4 year old albacore will be reduced in the 1989 surface fishery (i.e. the 1985 and 1986 year classes). In 1990 and 1991 this string of poor year classes will, probably for the first time since the fishery began, result in a sharp decrease in the spawning biomass of albacore in the North Pacific.

Status of the Resource

Prior to the recent North Pacific Albacore Workshop (May 1989), most of the available information suggested that the North Pacific albacore resource had not been over exploited . The single exception to this was dependent upon a scenario in which the Japanese surface fishery and the northern segment of the North American surface fishery are dependent upon a separate stock. In this case, there was a possibility that the biomass of this stock is significantly smaller than it was in the mid 1970s.

This position has been sharply altered by the recent updates of information on the Japanese surface and longline fisheries and Kleiber's

(1989) reanalysis of CPUE in the North American fishery (Figure 4) which clearly demonstrate that the status of the resource was at a lower level in the late 1980s than it was in the early 1970s. In addition, there is a continuing lack of information on the rapidly developing Asian gill net fisheries, we do not know the effects of the decade of global warming on albacore abundance or availability, and it now appears that a series of poor year classes is passing through the North Pacific albacore fisheries; this will soon result in a significantly smaller spawning biomass .

Status of the Fishery

Two of the four goals established for the NMFS Pacific Albacore Program were to increase the U.S. harvest of albacore to 35,000 tons annually by 1995 and to assure economic stability of the U.S. fishery. It is clear that we are presently further from these goals than we were when they were established in 1983.

Fishing effort and catch in both the Japanese and North American surface fisheries have, within the last 2 years, declined to about one tenth of their peaks. The decline in both fisheries was associated with an extended period of reduced CPUE. The Japanese surface fishery, which is primarily for skipjack tuna, has also been affected by a transformation from a baitboat to a purse seine fishery, to more effectively harvest skipjack. This change in fleet composition has also contributed to recent decreases in effort and landings of albacore. In the U.S. fishery adverse economic factors including increases in fuel costs, increases in the cost of (and difficulty in acquiring) insurance, and competition from imported albacore has further depressed the fishery. In contrast, recent landings and fishing effort in the longline fishery have been relatively constant and there has been a very rapid development of Japanese and Taiwanese gill net fisheries that take large numbers of juvenile albacore in the North Pacific

Although there is still considerable doubt concerning what catch levels the North Pacific albacore resource could support on a sustained basis, the most recent information suggests that catches in the next few years will be at very low levels. There are a number of factors which are associated with the decline in the North Pacific albacore fisheries, but the relative importance of these factors is unknown. The record catches in the 1970s may have been above MSY, the developing gill net fisheries (which take large numbers of small albacore) may be adversely affecting the resource, and global warming (which coincides with the period of reduced CPUE) may have reduced recruitment and altered availability. Whatever the cause, the decreased CPUEs which occurred from the late 1970s to the mid 1980s have combined with a series of unfavorable economic factors to produce a severely depressed North Pacific albacore fishery.

RECOMMENDATIONS

Recommendations for Research

In comparison to other fisheries there is a very large amount of information available for Pacific albacore; however, our ability to assess the status of the resource is limited by several major gaps in our knowledge.

First, the age structure of the population and particularly that of the adult segment is unknown; in fact, there is not even a valid estimate of the maximum age of albacore. Consequently, no good estimate of the adult natural mortality rate exists and any evaluation of the population dynamics of the resource is, therefore, highly speculative. The first step in the solution to the lack of information on age structure and adult mortality rates is to expand current aging studies by including a good sample of the adult segment of the population. This could require special efforts to sample the Japanese longline fishery and it may require a research vessel to take large, adult albacore in both the summer and winter spawning grounds.

Second, the biochemical genetic studies strongly suggest that there is only a single genetic stock of albacore in the Pacific. This implies that albacore in the North Pacific are not isolated from those in the South Pacific, at least on longer time scales; however, this does not necessarily imply that there is only one fishery stock in the North Pacific. Conversely recent work on the juvenile segment of the population has shown regional differences in several population dynamics factors; however, these differences do not necessarily imply that there is more than one fishery stock of albacore in the North Pacific. Thus, the fishery stock structure of albacore in the Pacific remains a mystery. The only apparent solution of the stock structure problem appears to be increased emphasis on tagging studies. However, it should be noted that tag recoveries from the albacore's spawning grounds have been very sparse. This is primarily due to the fact that there are presently no directed albacore fisheries in the region where albacore spawn all year nor are there directed albacore fisheries during the summer in the summer spawning grounds. It is, therefore, likely that the stock structure problem will prove to be intractable due to the low rate of exploitation on the spawning grounds and it is recommended that current tagging studies should be re-evaluated.

Third, the lack of information on the length frequency distributions from the Japanese surface and longline fisheries since the 1982 season and the often several years delay in receiving the most recent information on their catches and CPUEs is bound to result in inaccurate analysis of the current status of the resource. In addition, it is important that the methodology and assumptions used to calculate standardized catch and effort statistics for the various fisheries should be assessed. An international research team should be formed to determine the status of catch and effort data and standardization procedures.

Fourth, there is very little information on the rapidly developing gill net fisheries of Taiwan, Japan and South Korea. Landings from these fisheries may dominate the North Pacific albacore fishery in the next few years and very little information has been available about them. The Liu and Hsu (1989) report on the 1988 Taiwan tuna gill net fishery is a good example of the information that is needed. Further efforts need to be made to ensure that data for all components of the fishery are available to researchers. We note that the effort and catches in the North Pacific albacore gill net fisheries has been growing rapidly at the same time that the traditional Japanese and North American surface fisheries were rapidly declining. This problem is not unique to the North Pacific as albacore gill net fisheries are growing even more rapidly in the South Pacific, South Atlantic and Indian Oceans.

As noted above, the goal of a 35,000 MT U.S. albacore fishery will not be achieved with present trends. There appear to be two arenas in which research could assist the industry in achieving higher profits; 1) product and market development to increase the average price that fishermen receive for albacore, and 2) development of environment-dependent forecast models which could increase the efficiency and CPUE of vessels operating in the traditional North American fishing grounds. A considerable amount of effort has recently been placed on product and market development and it is recommended that the results of this work should be evaluated before similar work is funded. Very recent research in forecasting albacore catch rates, utilizing environmental data, suggests that it is likely that CPUE can be forecast on time scales of one to two fortnights. It is recommended that efforts should be made to verify the forecast models which have been developed and, if it turns out to be practical, to develop operational forecast models and modes of dissemination of the information to albacore fishermen.

In the absence of any formal international forum, coordination of fishery monitoring and research has been carried out by an informal, multilateral series of workshops. These workshops have primarily been conducted by staff from the United States and Japanese fisheries agencies; however, they have also included personnel from the fisheries agencies of Canada, Taiwan and South Korea, as well as private citizens. The current level of North Pacific albacore landings is lower than at any time since 1952 and this decline has contributed to a situation in which the albacore fisheries were no longer considered important enough to maintain annual workshops Therefore, it is highly recommended that the present cooperative, international monitoring programs, data exchanges, and workshops be continued on, at least, the present level.

Recommendations for Management

If an international management entity existed for North Pacific albacore this report would have recommended that fishing effort for North Pacific albacore should be decreased due to a long series of years with reduced CPUE in the surface fisheries and the alarming appearance of a series of poor year classes in the fishery.

The fact that there is no international entity responsible for management of the North Pacific albacore resource does not mean that fishery management actions are not affecting albacore; in fact, Japanese fishery management has significant impacts on albacore. Japan primarily regulates its distant water fisheries by limiting the number of vessels (by gear type) which can fish in an area. For example, the Japanese limit the numbers of baitboats (which fish for skipjack and albacore) and longliners (which fish for tropical tunas and albacore). The number of gill netters (which fish for squid and albacore) is not limited. These three Japanese fisheries have dominated the North Pacific albacore fishery; however, albacore is a secondary species in each of the three. The North American albacore fishery also has a large, seasonal multispecies component and while the fleet is subject to fishery management on many of the other species it harvests, it is not subject to management for albacore. The principal U.S. Government response to the reduced CPUE in the traditional U.S. albacore fishing grounds has been to work with the industry in the development of distant water albacore fisheries, first in the central and western North Pacific and more recently in the South Pacific.

Decreases in the North Pacific albacore landings and fishing effort since the mid-1970s have been almost entirely due to reductions in the traditional surface fisheries which exploit juveniles. These declines were associated with extended periods of reduced CPUE in the surface fisheries, whereas the CPUE in the longline fishery did not exhibit a decline and there was no alteration in the size composition of albacore caught in the main spawning area. This suggested that the albacore spawning population had not been greatly reduced.

In fact, until very recently, the available information, analyses, and modeling all suggested that the North Pacific albacore resource was not heavily exploited by the present, reduced fishing effort. However, there was insufficient evidence to either determine the potential yield the resource is capable of sustaining or to determine the natural variability of the resource. In particular, the fact that the adult habitat is not exploited by American fishermen makes it impossible for NMFS to monitor the adult biomass. In this regard we note that the latest size composition data from the Japanese fisheries which were available for the preliminary version of this report was for 1982 and the latest fishing effort and CPUE data were for 1983. Size composition for the post 1982 Japanese surface, longline, and gill net fisheries , CPUE data for the gill net fishery and even the gill net catch from the North Pacific are still not available.

The preliminary version of this report was substantially revised when more recent Japanese catch and effort data, the magnitude of the combined Japanese, Taiwanese gill net fisheries, and a reanalysis of the U.S. jigboat catch and effort data was presented at the May 1989 North Pacific Albacore Workshop held in La Jolla. The overall tone of the status section of the document went from:

> The combined North Pacific albacore fisheries may have exceeded the productivity of the resource, but in the absence of an international management regime fishing effort has declined.

to:

> The resource has suffered its first observed recruitment failure, its long term viability is in danger, and there is no international management policy for North Pacific albacore.

RECOMMENDATIONS FOR IMMEDIATE ACTION;

1. The countries presently harvesting Pacific albacore should develop a new strategy regarding future international monitoring, research and management of this resource.

2. An international research effort should be quickly organized to examine catch and effort standardization procedures and, where necessary, to reanalyze the data to determine the past and present status of all of the North Pacific albacore fisheries.

3. There is a critical need to develop a research project to evaluate the effect of the rapidly expanding gill net fisheries on the world's albacore resources.

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