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An Assessment Of The Pacific Swordfish Resource

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The swordfish *(Xiphias gladius)* is cosmopolitan in its distribution, found in all tropical to temperate oceans. In the Pacific Ocean, swordfish are generally distributed from Asia to the Americas and from 50 degrees north to 50 degrees south latitude. Swordfish are taken by many countries with various gears. For a complete discussion of Pacific swordfish fisheries and their trends the reader is referred to Sakagawa (this volume). These fisheries are both coastal and high-seas in nature. Data available from these fisheries provide the basic information from which to draw inferences about the state of the swordfish stocks, in this chapter the condition of the Pacific swordfish resource.

We have chosen two stock structure hypotheses which are consistent with previous reviews of the condition of the resource (Sakagawa and Bell 1980). One hypothesis envisions a single Pacific stock, under the rationale that the resource appears to be contiguous, with zones of local high catches due to high abundance or high vulnerability, and the assumption that the population is sufficiently mobile to make the concept of local depletion on an annual basis a non-issue. Our second hypothesis is to separate out 3 general areas of apparent high abundance in the northwest, southwest and east Pacific, made contiguous by a broad region of lower catches.

Data and Rationale

Each country and fishery reports different data ranging from estimated total catch to detailed catch and effort by area. A review of all available Pacific swordfish data indicates that only the Japanese longline fishery data are suitable in their detail and time period covered to provide a basis for a catch-per-unit-effort (CPUE) assessment of the Pacific swordfish stock. This conclusion was reached by others who previously investigated the swordfish resource (Sakagawa and Bell 1980, Shomura 1980). The available longline data contain both catch in numbers and nominal hooks fished by 5 × 5 degree squares and by month. These data can provide a measure of CPUE for a useful time series. The absence of reliable size sample data (length-frequency or weight-frequency) for the time series precludes the use of age-structured assessment techniques such as cohort analysis for the stock structures assumed.

Total Catch

Table 1 shows Pacific swordfish catches in weight by country. Figure 1 shows both the Japanese longline catch and the estimated Pacific total catch in weight. The Japanese longline catch represents a large proportion of the annual catches throughout the time series. Note from Table 1 that estimates of catch for many countries are available only for the second half of the time series. As a result, the total catch for the first half of the time series is underestimated by an unknown but presumably significant amount. These catch estimates are from the FAO (1971-1987) and published and private sources within various countries. After 1970, when all countries shown in Table 1 are represented, the Japanese longline catch has maintained a relatively constant and high proportion of the total catch.

Catch and Effort

The Japanese catch-and-effort series of data, 1952 to 1980 (Fisheries Agency of Japan 1965-1982, Agricultural Resource Agency of Japan 1953-1964), have changed within the time series, due mostly to substantial changes in the way the fishery is operated (Shomura 1980, Sakagawa et al in press, Ueyanagi 1974). During

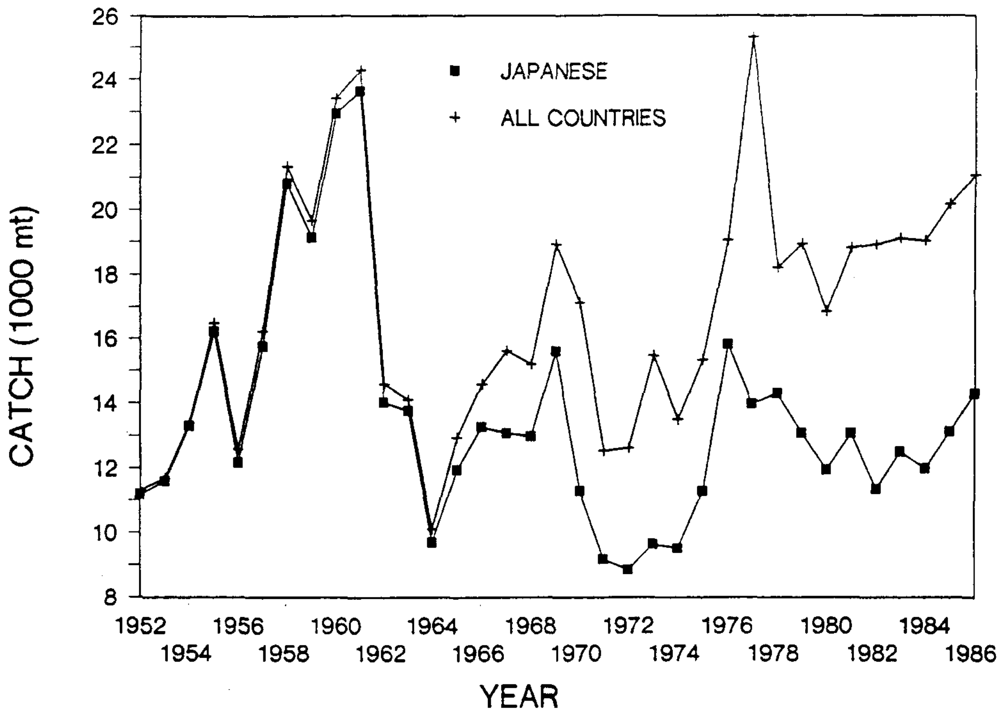

Figure 1. Japanese longline catch and the estimated catch of all countries fishing for swordfish in the Pacific Ocean.

the period 1952 through about 1962, swordfish were specifically targeted in some areas by fishing at night with squid for bait. The fishery changed substantially in the early 1960s (approximately 1962 — 1964). Day operations with mixed bait types became the norm, which has continued to the present. The strategy of Japanese longlining tuna changed at about this same time, de-emphasizing albacore *(Thunnus alalunga)* and emphasizing sashimi grade tunas (Sakagawa et al in press), mostly bigeye tuna *(T. obesus)*, bluefin *(T. thynnus)*, and yellowfin *(T. albacares)*. Thus, the data series is broken in two in the early 1960s. To further complicate matters, portions of the fleet began "deep longlining" in 1974 to increase the catch rate on bigeye tuna (Suzuki and Warashina 1977). The effect was that the CPUE of the deep longline operations was about 80% as efficient as the standard operations for albacore, swordfish, and yellowfin tuna. The different operations are not distinguished in the published data, and therefore cannot be compensated for in the calculations without additional information, but must instead by considered qualitatively in the results.

Previous assessments of Pacific billfish and swordfish in particular have relied on "Honma's method" (Honma 1973, Shiohama 1971) to calculate the portion of the total effort fished in any particular area that is presumed to be effective for the species of interest. Because of the changes in the fishery and qualitative differences in the data with passage of time and the fact that swordfish appear to be a target species in a few areas and a true incidental catch in others, we suspect that the assumptions required to implement Honma's method for swordfish are not fully met. Consequently, we have chosen to use nominal CPUE and a data stratification which allows the separation of target or high catch rate areas from areas where swordfish appear as incidental catches. This procedure is done to account for the spatial distribution of populations, a concept presented by MacCall (1983).

This approach to segmenting or stratifying the population is based on the premise that different portions of the population may react differently to exploitation and should be examined independently. An example of different reactions expected might include a shrinking of the areal distribution and decline in CPUE of low density areas as the stock is reduced and the remaining population continues to concentrate itself in higher density areas. Fortunately, this approach appears robust with respect to strata chosen, as our analysis was unaffected by several different choices of strata. We have chosen three strata, a high density or CPUE stratum (target areas), a low density or CPUE stratum (incidental catch areas), and an intermediate or buffer stratum. The primary purpose of the latter is to separate the signals from high and low CPUE strata by minimizing the subjectivity in defining the high and low strata.

Stratification

The annual distribution of catch in numbers by 5 × 5 degree square shows 3 areas or regions of concentrated catches. These 3, northwest (N.W.), east (E), and southwest (S.W.) Pacific, appear year after year in the data series. Figure 2 shows the catch distributions for 4 years chosen throughout the time series. Of interest is the fact that the exact squares producing high catches may shift slightly from year to year. This presumably mirrors the shift in fish distribution caused by environmental or oceanographic changes, etc. A great portion of the area fished

Table 1. Pacific Ocean catches (metric tons) of swordfish

YEAR	JAPAN	TAIWAN	KOREA	USA	CHILE	PERU	PHIL	OTHERS	TOTAL
1952	11182			157					11339
1953	11604			85					11689
1954	13301	77		14					13392
1955	16220	185		80					16485
1956	12167	254		163					12584
1957	15771	250		222					16243
1958	20815	247		279					21341
1959	19136	262		265					19663
1960	22944	273		192					23409
1961	23636	432		218					24286
1962	14037	544		23					14604
1963	13775	300		58					14133
1964	9703	300		109					10112
1965	11955	300		194	200	300			12949
1966	13283	600	41	277	200	200			14601
1967	13083	838	47	181	200	1300			15649
1968	12983	974	55	118	200	800		100	15230
1969	15612	1023	89	610	300	1200		100	18934
1970	11301	1053	115	558	200	2400	1400	100	17127
1971	9182	1149	115	91	200	200	1500	100	12537
1972	8846	1111	115	157	100	600	1600	100	12629
1973	9644	1269	115	363	400	1900	1700	100	15491
1974	9517	1157	115	383	218	270	1848	3	13511
1975	11274	1099	115	510	218	158	1976		15350
1976	15843	856	444	49	13	295	1558		19058
1977	13997	8197	265	301	32	420	2103		25315
1978	14333	779	198	1536	56	436	890		18228
1979	13091	1060	365	346	40	188	3845	7	18942
1980	11953	1459	329	706	104	216	1716	380	16863
1981	13078	909	257	674	294	91	1940	1575	18818
1982	11350	1107	194	989	285	154	3468	1365	18912
1983	12511	1268	135	1534	342	225	2974	120	19109
1984	11986	1387	54	2878	103	298	2277	47	19030
1985	13125	1429	56	3064	342	92	2036	18	20162
1986	14295	1357	37	2131	764	33	2089	350	21056
1987				1580					1580

produces relatively low annual catches of swordfish.

The proportion of swordfish to all tunas and billfish in the total catch in each 5 × 5 degree square (Fig. 3) reveals broad areas of very low representation which generally correspond to areas of low total catch, described above, and appear to be indicative of incidental catch areas. Squares with a high proportion of swordfish in the catch correspond with areas of higher catches.

As stated previously, two stock structure hypotheses are considered. These correspond to the areas described above (Fig. 4) and are approximately the same as those used in previous assessments (Sakagawa and Bell 1980). The exact boundaries chosen are not critical because of the stratification concept employed.

The index of abundance chosen, mentioned previously, is nominal annual CPUE in numbers of fish per 10,000 hooks fished for each 5 × 5 degree square. To separate high abundance or possible target squares from lower abundance squares where swordfish are an incidental catch, the CPUE for all squares in the Pacific receiving effort in a year were combined into 3 strata. The first stratum, "high CPUE," contains 15% of the total squares fished which produced the highest CPUEs. The second stratum, "low CPUE," contains 50% of those squares fished which produced the lowest CPUEs. The third stratum, "middle CPUE," contains those squares which produced the 35% intermediate values between the first and second groups.

The rationale for this accumulation scheme is that high abundance squares — possible swordfish target areas or centers of high concentrations — are sought by the fishery year after year and produce the bulk of the catch. The squares are not fixed in number of spatial location. This circumstance accounts for spatial shifts in the resource, which happen from year to year. A key assumption is that the fishery will shift to an adjacent square as the resource shifts. An examination for year-to-year shifts (Fig. 5) shows these squares to be in the same

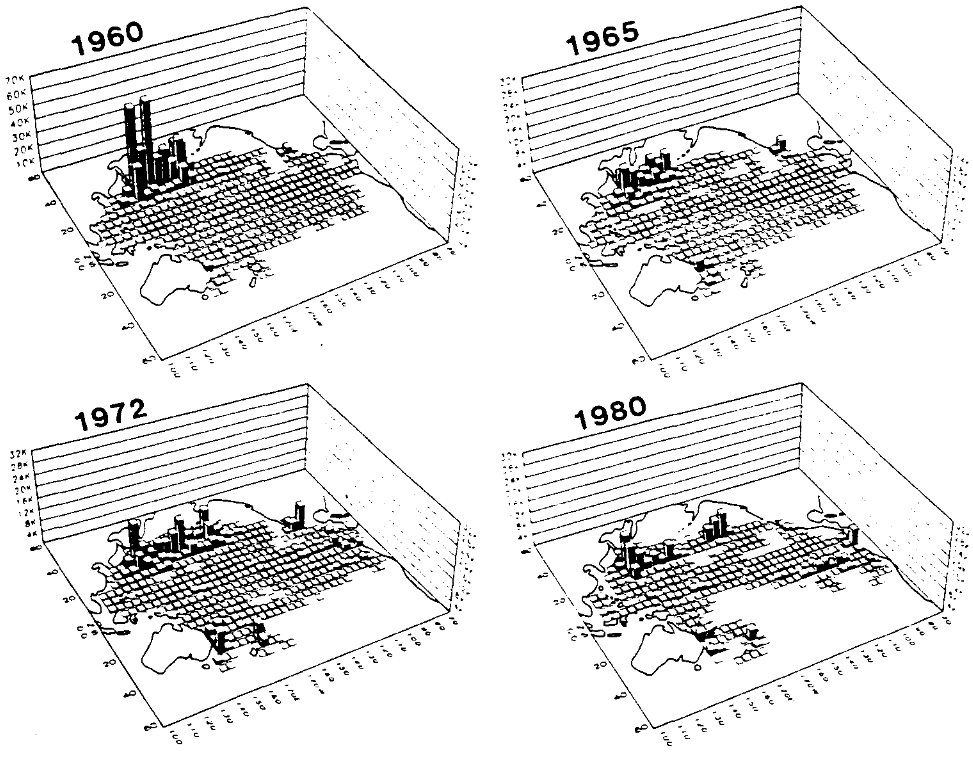

Figure 2. Geographical distribution of Japanese longline swordfish catches in the Pacific Ocean.

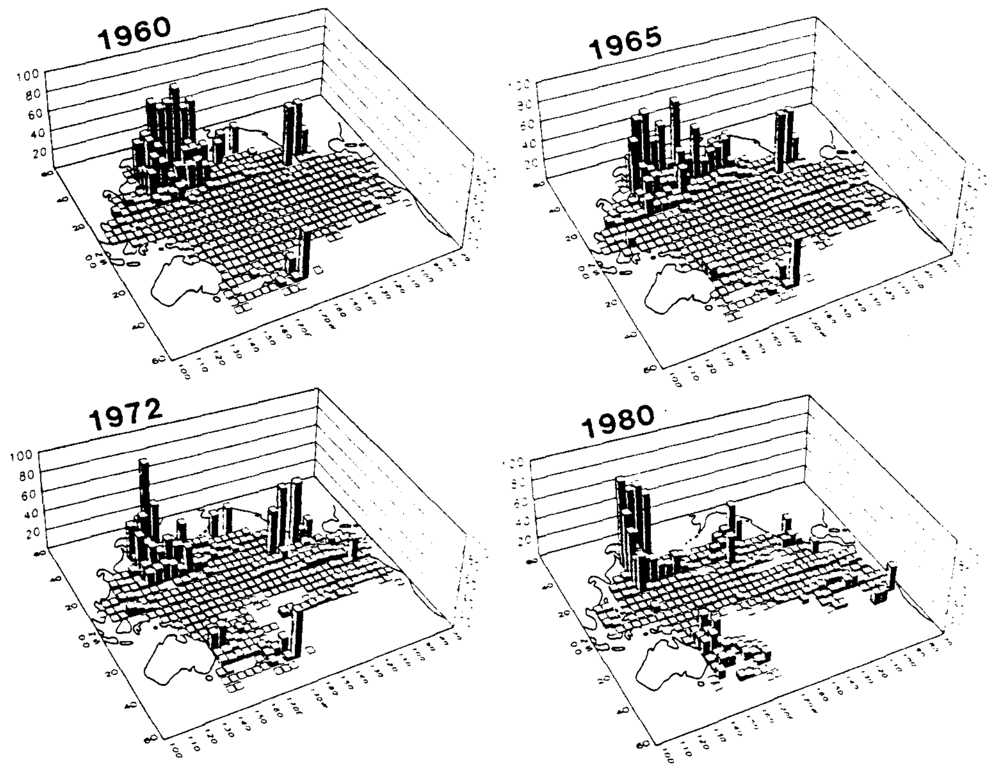

Figure 3. Geographical distribution of Japanese longline percent of swordfish in the total catches of billfishes and tunas in the Pacific Ocean.

general area year after year. The number of squares producing the top catch rates varies for several reasons. The total number of squares fished in the Pacific (Fig. 6) and the concentration of fish, or vulnerability, in each square throughout the entire Ocean varies from year to year. Interestingly, the actual number of squares included in the top catch-rate group each year is remarkably stable. The use of an annual CPUE value removes the effect of seasonality from the data. Although the procedure does lower peak CPUE values, it is consistent throughout the time series.

The stratum of the low catch-rate squares (lower 50%) captures broad areas of the Pacific, mostly contiguous, where low catches, low proportion of swordfish in the overall catch, and low catch rates make swordfish an incidental catch. Figure 7 shows the distribution of these squares for several example years. Figure 6 shows the number of squares contained in the grouping over the time series.

The last stratum of squares, those with the middle 35% of the catch rates, serves two functions. First, it captures into a relatively narrow group those squares where it is uncertain whether swordfish are a target. Second, and more importantly, it serves as buffer separating the high and low catch-rate groups. This buffering obviates the requirement to define precisely the strata where "target" fisheries begin and end. We need only be concerned that the high CPUE stratum has a high enough threshold and that the low CPUE stratum has a low enough one. This condition implies that the CPUE values in the high and low groups will track relative abundance in their designed strata. The benefit is that signals or trends in each extreme have a low probability of becoming confused or distorted by subjective judgment used to separate high CPUE areas from low CPUE areas.

Results and Discussion

Whole Pacific Stock

Figure 8 shows catch over time aggregated by the three CPUE strata. The high CPUE stratum, the top 15%, presents an increasing trend in catch through 1961 and a drop to a lower level in 1962, during the period of changed longline operations described previously. The catch is erratic following the 1962-1964 period, but has stabilized following a few peak catch years in the late 1960s. The other 2 strata, low CPUE and middle CPUE, show relatively smooth, slowly increasing catch trends. Note from Figure 1 that the Japanese longline catch is a relatively constant proportion of the total catch after 1970, when catch estimates became available for most countries.

Figure 9 presents total effort over time for the 3 strata. Effort in the middle and low CPUE strata shows a continuously increasing trend. Effort in the high CPUE stratum approximately follows the pattern of catches.

Figure 10 presents CPUE for the 3 strata for the Pacific-wide case. CPUE in the high stratum shows a slight increasing trend through the early 1960s, a drop to a new plateau following the longline operational changes in the early 1960s, and a stable almost level trend through 1980. This pattern is similar in pattern to that seen in the previous analysis reported by Sakagawa and Bell (1980). Note that effort in the last few years is approximately the same as in the late 1950s, although longline catch and CPUE are lower. This can indicate lower abundance or a reduction in catchability in the later period. Given the operational changes reported, and the relative stability in CPUE in the two periods, the latter explanation seems more plausible. The increase in reported total catch (Fig. 1) since the mid-1970s, however, may have depressed the longline CPUE somewhat. The absence of available longline data for the more recent years precludes further examination.

CPUE trends for the middle and low CPUE

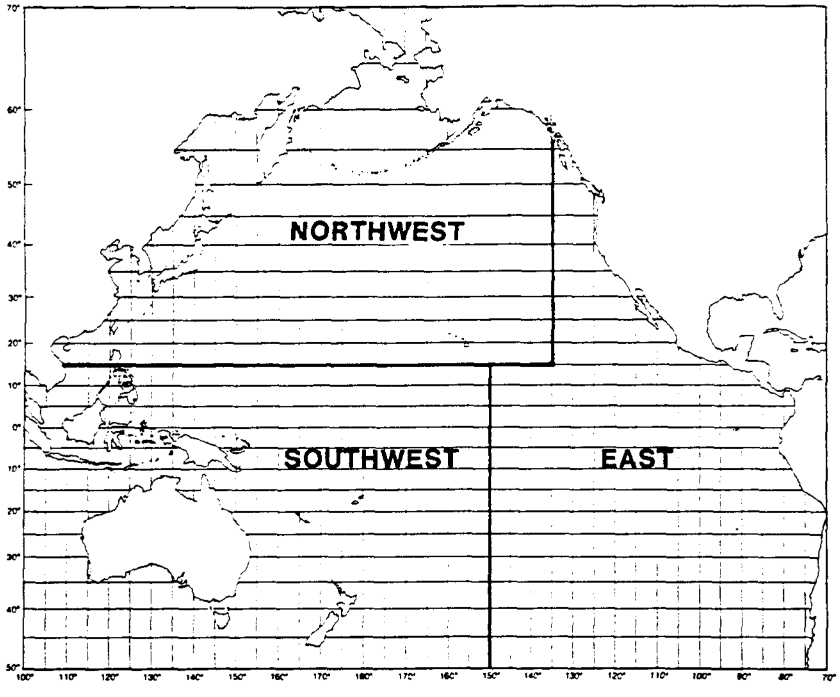

Figure 4. Geographical regions of the Pacific Ocean used as hypothesized stock boundaries.

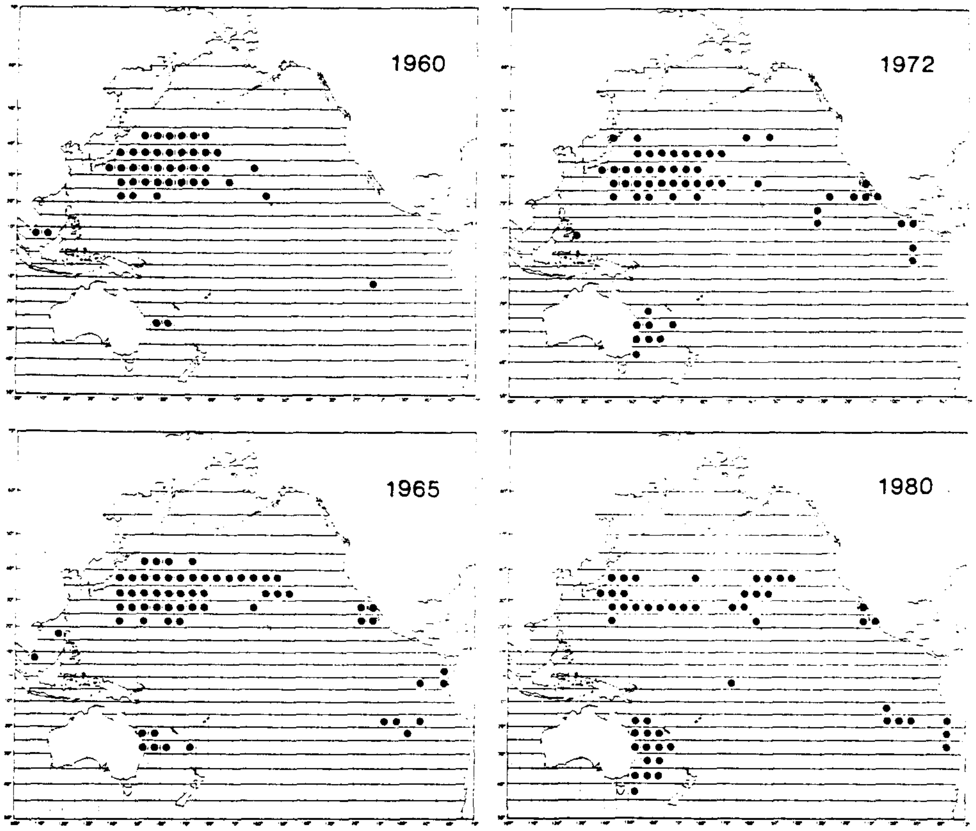

Figure 5. Geographical distribution of 15% of the squares fished by the Japanese longline fishery in the Pacific Ocean that produced the highest CPUEs annually for swordfish.

strata are quite stable and nearly constant, particularly since the mid 1960s. The stable CPUE trends and slowly increasing catch trends are complemented by an increasing trend in effort and does not indicate a decrease in relative abundance over the time series. The large absolute difference in CPUE values between the low CPUE stratum and the high CPUE stratum suggests that swordfish abundance in the lower strata is either considerably lower or that catchability of swordfish in the low CPUE stratum is lower, due to the operational characteristics of the gear. As mentioned preceding, Suzuki and Warashina (1977) indicated that deep longlining techniques used in much of the area covered by the low CPUE stratum reduced catchability of swordfish by approximately 25%. Thus, the effects of deep longlining may affect CPUE values to an unknown degree. If deep longlining effort has increased in proportion to regular effort between 1974 and 1977, as was indicated by Suzuki and Warashina (1977), then catchability of swordfish should be reduced for the deep effort and calculated CPUE will be biased low for the years after 1974. Unavailability of data after 1980 precludes confirmation.

The distribution of squares, or area occupied by the stock in the low CPUE stratum, shows no signs of declining over the time series. The percentage of total squares fished annually from 1960 through 1980 which produced no swordfish is rather stable, ranging from 7% to 13% with most observations at 9%. Any changes in the distributions of catch appear to be due to the complete elimination of effort from areas in the south-central Pacific near island states which produce mostly tropical tunas.

Three-Stock Case

The designation of the 3 stocks or fishery areas shown in Figure 4 was guided by the criterion that the purpose of this stratification is to be able to examine the trends in the high CPUE stratum, described previously, independent of influences of the high catch-rate squares in other areas. This can be useful if swordfish tend to remain in each of the 3 areas after recruitment, thus making location reductions in abundance a possible issue. As mentioned previously, the actual boundaries chosen are arbitrary because there are no firm, documented critieria available. While it is valid, therefore, to compare CPUE trends for the high catch-rate strata between areas which are isolated, it is not valid to compare CPUE trends for the middle and low catch-rate strata because CPUE values and trends can be biased by the choice of area or stock boundaries. It appears more reasonable to use the whole Pacific case as the abundance trend for the incidental catch areas.

The distribution of the 15% of the 5 × 5 degree squares fished each year having the highest CPUEs in the 3 areas in the Pacific is shown in Figure 11. In the northwest area (N.W.), the number of squares rapidly peaks in 1963 and then declines. From 1969 through 1980, the number of squares shows no strong trend, with about 30 squares per year. In contrast, the number of squares in the eastern area (E) shows an increase from 1963 through the early 1970s. The trend has been level since then, at about 10 squares per year. In the southwest area (S.W.), the number of contributing squares has remained small but has increased over the time series to approximately 10.

Figure 12 shows the catch over time from the 3 years. In the early years, the N.W. area contributed the vast majority. Following the fleet changes in the 1960s, the S.W. and E areas contributed greater amounts to the longline catch.

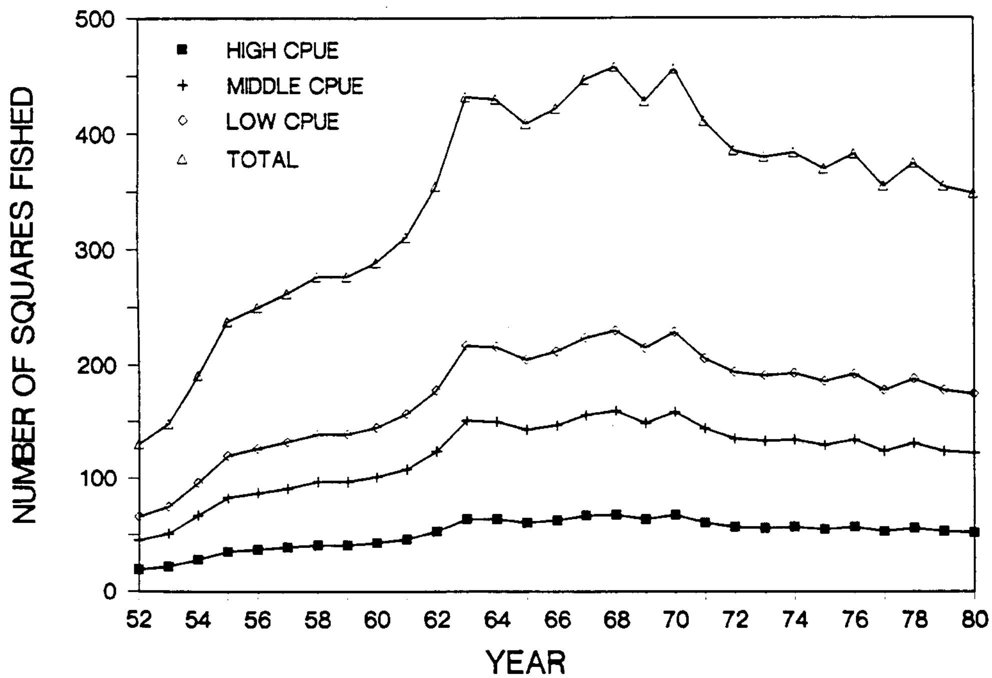

Figure 6. Total number of squares fished annually by the Japanese longline fishery in the Pacific Ocean for three CPUE strata: the top 15% of the squares fished producing the highest CPUEs (HIGH CPUE), the next 35% of the squares fished producing the middle CPUEs (MIDDLE CPUE), and the last 50% of the squares fished producing the lowest CPUEs (LOW CPUE).

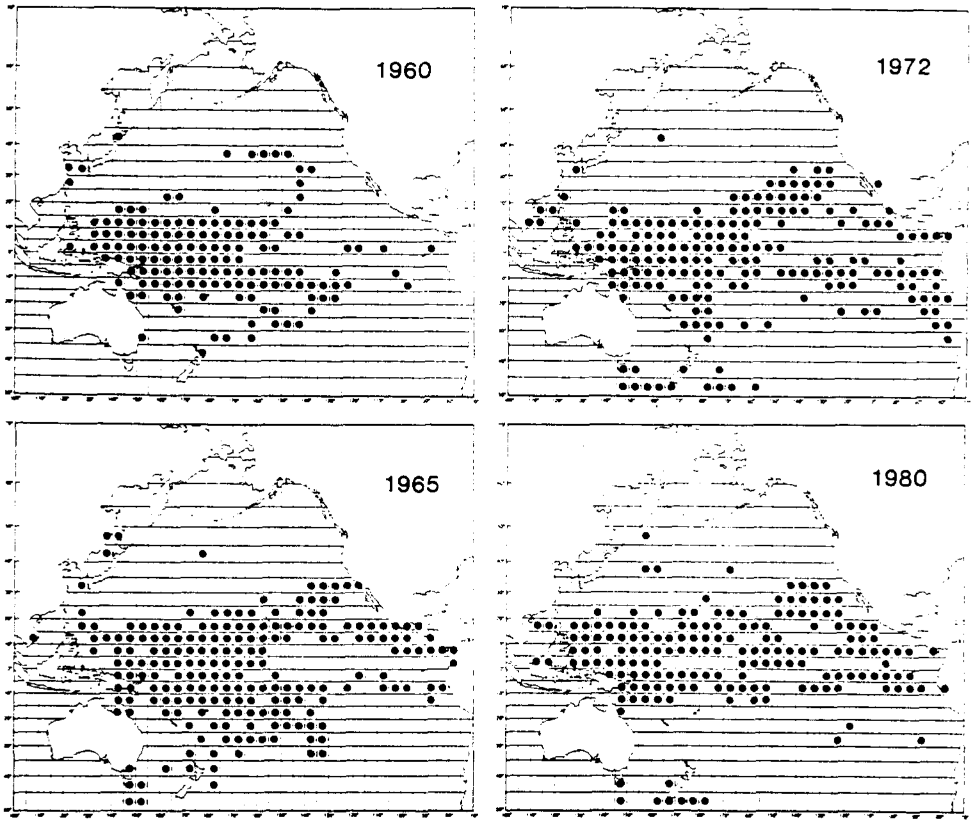

Figure 7. Geographical distribution of 50% of the squares fished by the Japanese longline fishery in the Pacific Ocean that produced the lowest CPUEs annually for swordfish.

CPUE trends for the 3 areas are shown in Figure 13. The pattern in the N.W. is similar to the pattern for the whole Pacific. This similarity is due to the fact that the N.W. area contributes the majority of the catch. The trend in CPUE for E area has been constant or level since the late 1960s, although some of the peak CPUEs are greater than in the rest of the Pacific. This situation also prevailed for the S.W. Pacific. The CPUE trends in the 3 areas in recent years are flat and do not indicate a change in the resource.

Conclusions

The analysis and examination of data leads us to several conclusions, some of which are not qualitatively different than those from previous examinations.

Data for swordfish have changed little since the last Pacific-wide look at swordfish. Many of the data are generally not adequate for assessment purposes, the notable exception being the Japanese longline fishery data through 1980. Total estimated catches in weight appear to be at about the same general level seen in the late 1950s; however, there appears to be incomplete reporting of catches in years prior to the mid-1960s. The historical catch-and-effort data for the Japanese longline fleet were affected by major changes in both the operation of the gear — reduction in night sets and bait changes, and in the strategy of fishing operations — changing from albacore to tunas for the internal Japanese sashimi market.

Swordfish appears to be a target or very important species in at least 3 areas of the Pacific.

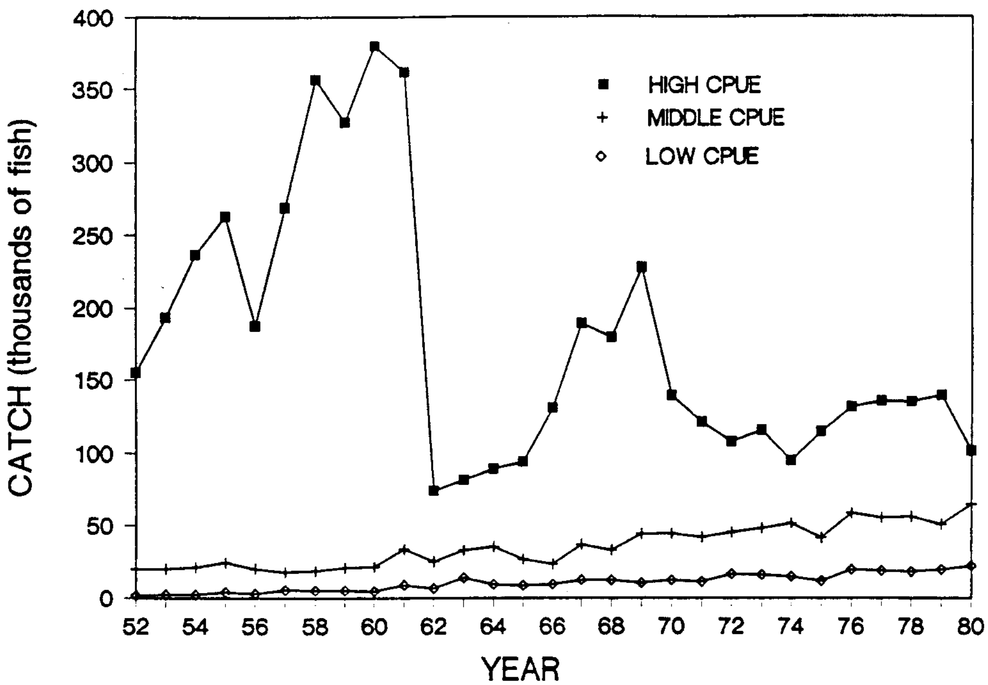

Figure 8. Annual Pacific Ocean swordfish catches from the Japanese longline fishery in three CPUE strata: the top 15% of the squares fished producing the highest CPUEs (HIGH CPUE), the next 35% fo the squares fished producing the middle CPUEs (MIDDLE CPUE), and the last 50% of the squares fished producing the lowest CPUEs (LOW CPUE).

the northwest, east, and southwest. Consistently, year to year, high catch and CPUE areas are fished in each area. Additionally, swordfish appear to be an incidental catch taken in relatively small numbers in a broad contiguous area of the Pacific associated with tropical tuna operations.

When considered as a single, Pacific-wide stock with several high catch-rate areas, the CPUE in the target areas showed a slowly increasing trend through the early 1960s. In the early 1960s, CPUE values dropped by about ⅓ and have remained about the same since. The drop in CPUE coincides with the change in longling operations. The CPUE trend in the area where swordfish are an incidental catch is stable, slowly increasing throughout the time series. The change in operations is not seen in this data series.

If considered as 3 stocks, the northwest stock high catch-rate stratum follows the same CPUE pattern as the total-stock case, mostly because the N.W. stock provides the bulk of the catch. In the eastern stock, CPUE has shown considerable highs and lows since the late 1960s, but the trend is level and this stock yields about ⅕ the catch of the N.W. stock. The southwestern stock also yields about ⅕ that of the N.W. stock and has shown an erratic but level trend in CPUE since 1970. In all 3 areas, the actual CPUE values are similar, with the S.W. area tending to be slightly higher.

The effects of those fisheries with increased reported catches in the latter half of that time series, such as the U.S.A., Peru, and Philippines, is unknown. The longline catches used, however, are based on approximately the same reporting rate throughout the time series and should not be affected by the changes in reporting rates. The CPUE indices developed here show no declining trends. Nothing definitive can be said about yield-per-recruit realized by the various fisheries or about optimum size for capture due to the lack of published size data. As a cursory measure, we note that weight per fish in the Japanese longline fishery has been about the same since 1977 (total weight/total catch in numbers).

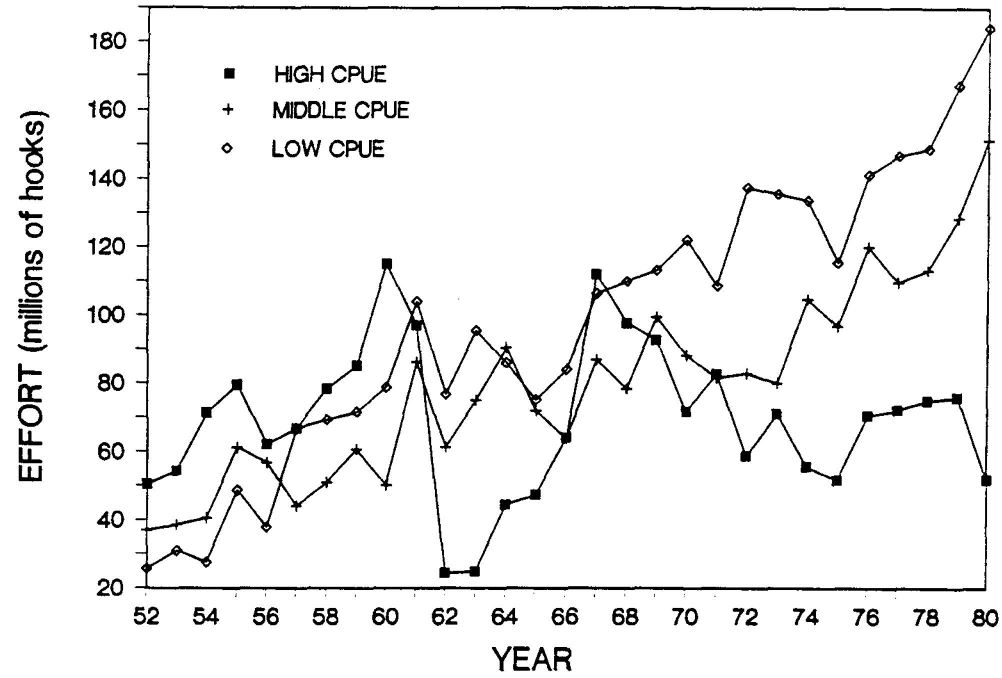

Figure 9. Annual Pacific Ocean hooks fished by the Japanese longline fishery in three CPUE strata; the top 15% of the squares fished producing the highest CPUEs (HIGH CPUE), the next 35% of the squares fished producing the middle CPUEs (MIDDLE CPUE), and the last 50% of the squares fished producing the lowest CPUEs (LOW CPUE).

Based on our examination of the Japanese longline CPUE data, and our interpretation of the changes which occurred in the fishery over time, we conclude that the stocks do not appear to have been exploited heavily enough to cause a declining trend in CPUE and, by extension, in abundance, through 1980. It is actually possible that CPUE may have trended upward slightly since 1974 as the practice of deep longlining increased and estimated CPUE was biased downward, an unknown amount. In an attempt to confirm our conclusions we have examined total swordfish catch and total effort data for the Taiwan and Korean longline fleets. The Taiwan data cover the period 1975 through 1985, with 1980, 1981 and 1982 missing. The Korean data cover the 1975 through 1982 period. The calculated CPUE values for both fleets are very low, less than 1.2 fish per 10,000 hooks. The trend in CPUE is realtively stable, varying between 0.4 and 1.2, similar to that observed for the Japanese fleet's low CPUE stratum over the entire time series (1952 — 1980).

Summary

The Pacific swordfish resource is assessed using catch-per-unit-effort (CPUE) realized by the Japanese longline fleet as an indicator of abundance. Lack of data for other fisheries, and absence of reliable size sample, limits the assessment to CPUE trends and comparisons. A time series of data from 1952 through 1980 is used. This series of data is not consistent throughout due to changes in the fishery and fishing strategy. Attempts to standardize or calculate effective fishing effort are rejected because of changes which occurred in the fishery and because swordfish are, depending on location, both a target species and an incidental catch. Nominal CPUE (numbers of fish caught per 10,000 hooks fished) is used in conjunction with a stratification methodology which separated high catch-rate "target" areas from low catch-rate incidental catch areas. Two stock structure cases were considered: 1. Pacific-wide and 2. three stocks: northwest, east, and southwest.

Results for the whole-Pacific case show that CPUE for target areas increased slowly from

the early 1950s through the early 1960s, then dropped by approximately ⅓ in the 1963 — 1965 period and has remained level since. The change in CPUE levels in the early 1960s corresponds to operational changes in the longline fleet. The CPUE for incidental catch areas shows a very slow long-term increase without the abrupt change noted in the target area CPUE.

Results for the three-stock case show that the CPUE pattern in target areas in the northwest Pacific follows the total-Pacific case because this area produces the bulk of the catch. The CPUE in the east Pacific was very erratic in the early fishery years. Increased effort and operational changes after 1965 reduced some of the CPUE variability and produced a near level trend in CPUE. The CPUE trend in the southwest Pacific is erratic (more so in the earlier years of the fishery) but flat since 1970.

The conclusion reached is that none of the data examined indicates that the stock(s) have been exploited heavily enough to cause a noticeable decline in CPUE through 1980. Sketchy data for Taiwan and Korean longline fleets covering the 1975 to 1985 period show an extension of the Japanese data trends for the low CPUE stratum. The conclusion that no decline is evidenced by data examined may be conservative. The increase in deep longlining since 1974, when corrected for, may possibly elevate CPUE values in the last part of the time series. The inclusion of detailed Japanese data from 1980 — 1988 could be useful in confirming these conclusions.

Acknowledgment

We acknowledge and thank those people who helped prepare the text and figures, including Roy Allen, Lorraine Prescott, Henry Orr, and Ken Raymond. Thanks to our colleagues David Au, Dave Holts, Gary Sakagawa, and James Squire for their reviews and suggestions. Special thanks to Alec MacCall for his help.

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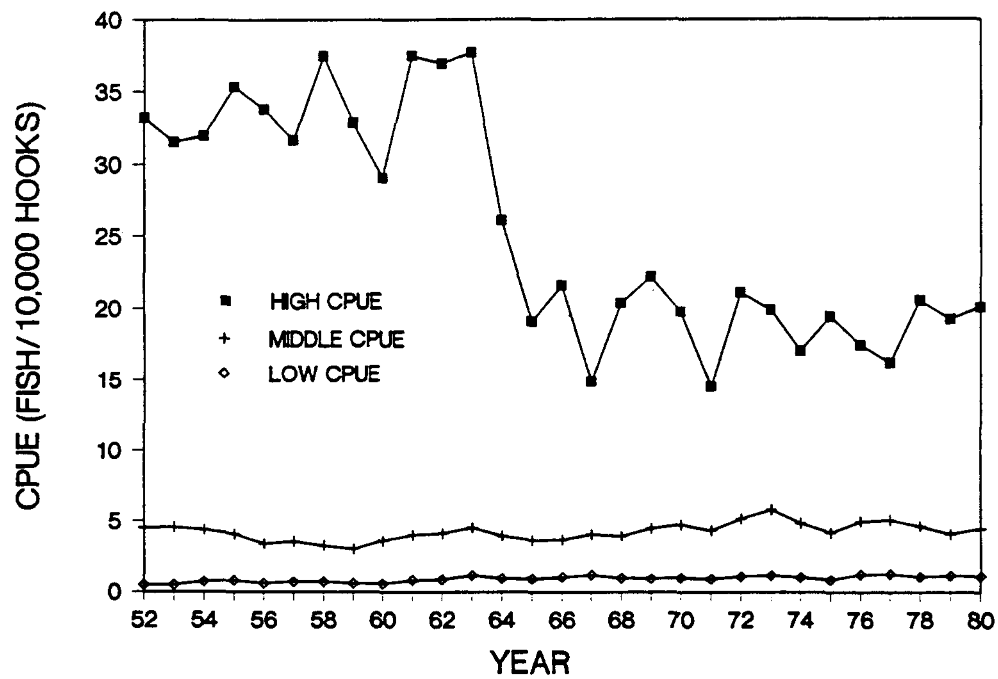

Figure 10. Annual Pacific Ocean catch-per-unit-effort for the Japanese longline fishery in three CPUE strata: the top 15% of the squares fished producing the highest CPUEs (HIGH CPUE), the next 35% of the squares fished producing the middle CPUEs (MIDDLE CPUE), and the last 50% of the squares fished producing the lowest CPUEs (LOW CPUE).

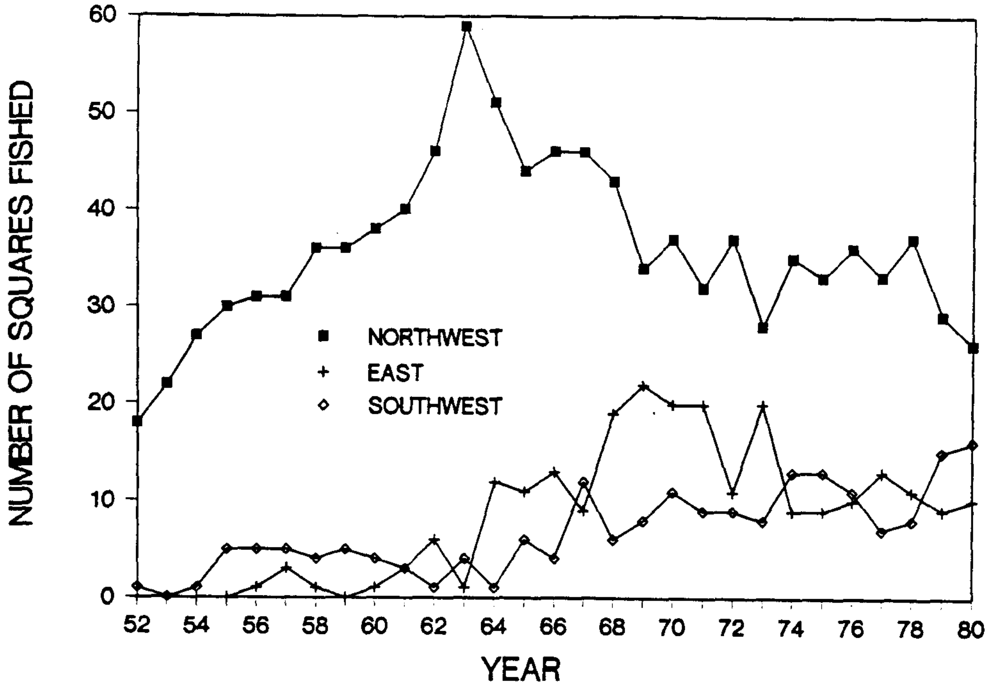

Figure 11. Annual distribution of 15% of the squares fished by the Japanese longline fishery in the Pacific Ocean producing the highest swordfish CPUEs in three hypothesized stock regions, northwest, southwest, and east.

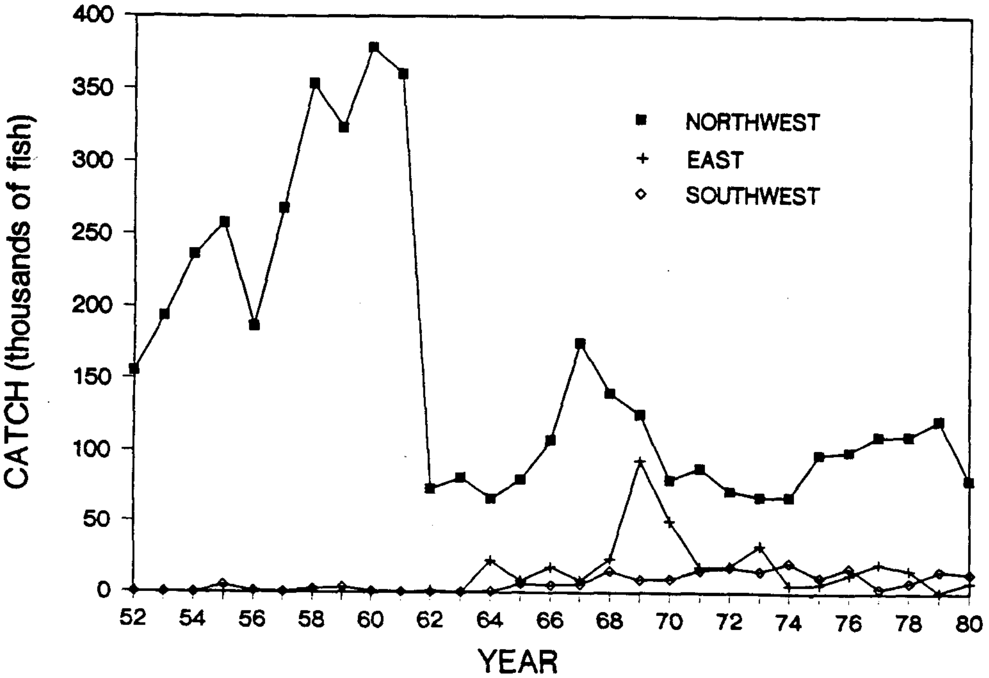

Figure 12. Annual distribution of swordfish catches from the Japanese longline fishery in the Pacific Ocean for squares fished that produced the highest swordfish CPUEs in three hypothesized stock regions, northwest, southwest, and east.

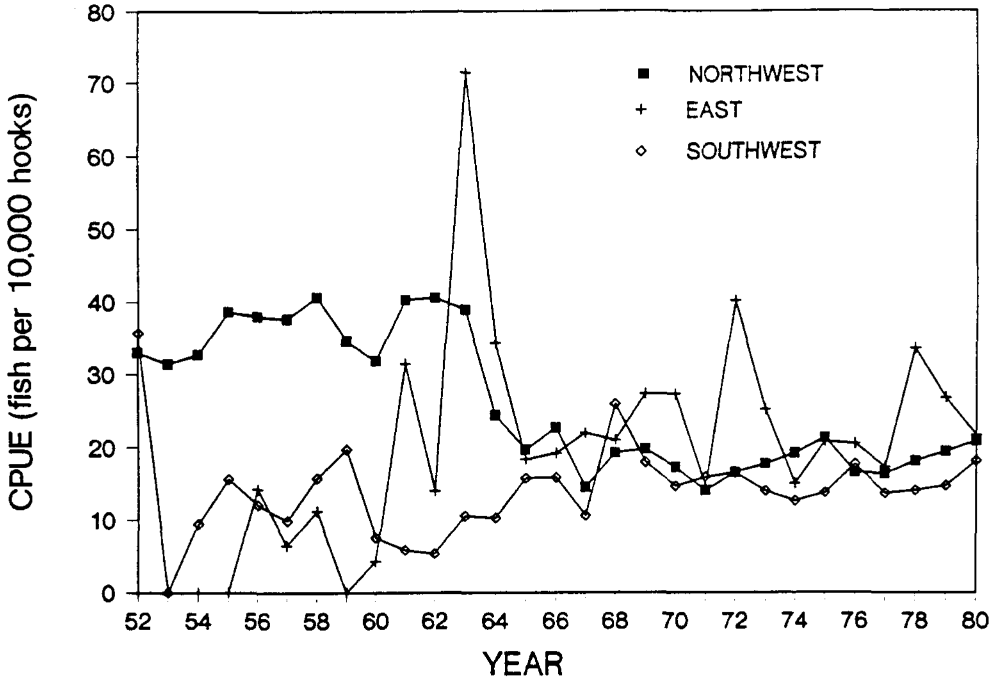

Figure 13. Annual distribution of catch-per-unit-effort by the Japanese longline fishery in the Pacific Ocean for squares fished that produced the highest swordfish CPUEs in three hypothesized stock regions, northwest, southwest, and east.

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