Spatial and temporal CPUE trends and stock unit inferred from them for the Pacific swordfish caught by the Japanese tuna longline fishery

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ABSTRACT

The spatial and temporal trends of CPUE (No. of fish per 100 hooks) of the swordfish caught by the Japanese tuna longline fishery in the Pacific Ocean were described for the 1952-1985 period. The development of this fishery was summarized. CPUE values were used as a measure of relative abundance, and four areas of high CPUE values were described: a) off Japan, b) off Baja California Peninsula, c) off the western coast of South America, and d) off the eastern Australian coast and north of New Zealand. The possible use of this four areas in the discrimination of the Pacific Ocean swordfish stocks was discussed.

INTRODUCTION

The swordfish, *Xiphias gladius*, is a large pelagic species that attains a maximum size of 540 kg and is found in tropical, subtropical and temperate waters of the world's oceans and adjacent seas (Nakamura, 1985). The geographical distribution of swordfish varies with seasonal changes in water temperature, where the preferred range is from 18° to 22°C. They concentrate in areas where food is abundant, commonly along frontal zones where ocean currents or water masses intersect to create turbulence and sharp gradients of temperature and salinity. The fisheries for swordfish occur mostly in these regions of frontal zones, and in the Pacific Ocean there are five frontal zones (Sakagawa, 1989). However, from the tuna longline catch data, the swordfish is considered to be distributed in a Pacific-wide basis (Nakamura, 1985).

The objectives of this study are to describe the spatial and temporal variations of the swordfish relative abundance in the Pacific Ocean based on data from the Japanese tuna longline fishery and to discuss its possible use in the discrimination of swordfish stocks.

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MATERIALS AND METHODS

All the data for this study were provided by the National Research Institute of Far Seas Fisheries, Shimizu, Japan. For analysis of the catch per unit of effort (CPUE) we used only the catch records for the regular Japanese tuna longline boats with gross tonnage of 20 tons and larger (longline with 4 to 6 branch lines per basket) (Suzuki et al., 1977), where the swordfish is caught incidentally, and the data covered the 1952 to 1985 period. Each record consisted of a) date (year, month), b) geographical situation (by 5° squares), c) effort (number of hooks used), and d) swordfish catch in number of fish.

The CPUE was calculated by:

$$CPUE = (C/E) \cdot 100$$

where C is the number of fish, and E is the number of hooks. The CPUE is given as a measure of the relative abundance and used as a first approach to analyze the annual and monthly variations of the swordfish stock density distribution in the Pacific Ocean. Because the fishing effort (in number of hooks) used to obtain the CPUE is nominal, unstandardized effort, the CPUE values are not considered to reflect accurately the resource levels, and interpretations based on this analysis should be viewed with caution. Furthermore, for the 1952 to 1962 period data, it seems that the regular longline and night longline (longline which targets swordfish and is used during night operations as its name indicates) data have been reported together (Sakagawa, 1989). In this study any separation between the two types of gear was not able to do, hence they were analyzed together.

RESULTS

Fishing effort trends

In order to understand the actual distribution of the fishing grounds for the tuna longline fishery, we have to summarize the development of this fishery. The Japanese tuna longline fishery in the Pacific Ocean started to expand gradually to the east from Japanese coastal waters in the early 1950's. From that time, the development of the longline fishing effort including both the regular and deep longliners with gross tonnage of 20 tons and larger can be divided into four periods (Fig. 1). During the first period in order to target yellowfin tuna (*Thunnus albacares*) and albacore (*Thunnus alalunga*), the fishery expanded to cover all the Pacific reaching the American continent coastal waters (Ueyanagi, 1974), and the number of hooks used increased from around 100 million in 1952 to 340 million in 1963. By this time the fishery had extended throughout the tropical and subtropical waters and thus, covered most of the distribution range of the swordfish in the Pacific.

During the second period (1964 to 1975), the number of hooks used in the annual operations was reduced and fluctuated around 300 millions. The fishing area reached its maximum expansion during the latest 1960's and the beginning of the 1970's when the fishing grounds expanded to the high latitudes in the southern hemisphere. In this period the fishery started to focus on southern

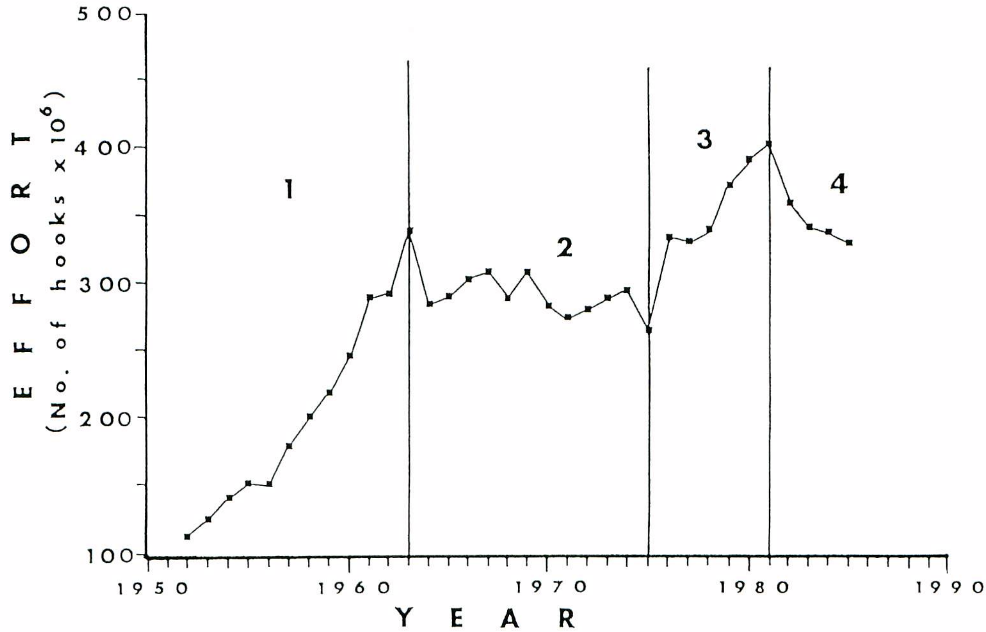

Fig. 1. Nominal fishing effort (millions of hooks) from the Japanese tuna longline in the Pacific Ocean, during the 1952 to 1985 period.

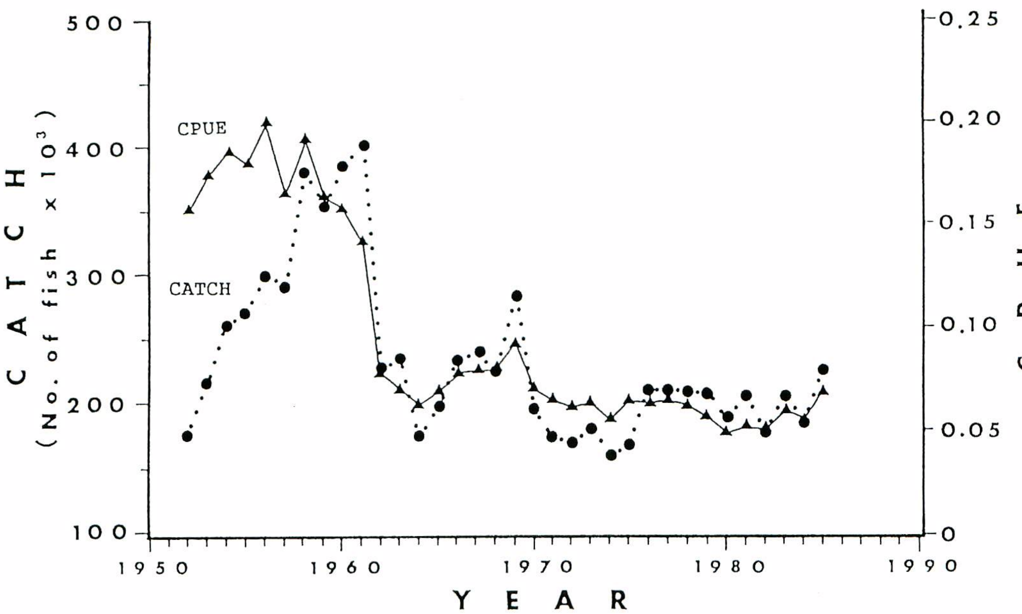

Fig. 2. Annual swordfish catch (No. of fish, circles), and CPUE (No. of fish per 100 hooks, triangles) from the Japanese tuna longline in the Pacific Ocean, during the 1952 to 1985 period.

bluefin tuna (*Thunnus maccoyii*) in waters near Australia and New Zealand, on bigeye tuna (*Thunnus obesus*) (Suzuki, 1989) in temperate and tropical waters of the central and western Pacific, and on striped marlin (*Tetrapturus audax*) (Ueyanagi, 1974) in waters off Mexico. A second increment happened during the third period from 1976 to 1981, when a total of 400 million hooks level was reached. By this time the fishing effort started to decrease substantially in the coastal waters off Mexico and concentrated into tropical waters at the central Pacific, principally because of the success in catching the highly priced bigeye tuna (Suzuki, 1989). After this peak, fishing effort declined during the fourth period from 1982 to 1985, and leveled off at around 330 million hooks (Fig. 1). This decrease in fishing effort is attributable to the concentration of fishing effort in the Central Pacific and the 20% fleet reduction policy taken in the tuna longline fishery during the 1981-1982 period (Ueyanagi et al., 1989).

CPUE

Inter-annual trends

In Figure 2 the annual variations of the swordfish catch and the CPUE are shown for the regular longline fishery. During the first 10 years of the 1952-1985 period, the swordfish catch from the regular longline (including an unknown percentage of night longline operations), showed a sharp increment, from 177 thousand fish caught in 1952 increased to 403 thousand fish caught in 1961. This catch in 1961 has been the greatest throughout the period (Fig. 2). During this period the CPUE values were the highest and they were fluctuating between 0.15 and 0.20. The catch fell down to 226 thousand fish in 1962 and this was reflected in the CPUE values, which dropped from a value of 0.14 in 1961 to the half of its value, 0.07, in 1962. This sudden fall in the relative abundance index does not necessarily mean a depletion of the swordfish in the Pacific. Sakagawa (1989) considered it to be a result from the changes in the fishing strategies (from night longline to regular one) in order to target tunas with higher prices in the sashimi market. After 1962 the CPUE values fluctuated around 0.07 till the late 1960's. However in 1969, reached the 0.09 level, reflecting the good swordfish catch in that year. Although the CPUEs fluctuated around 0.06 during the 1970's, at the end of the decade and the beginning of the 1980's, they slipped down slightly to 0.05. But, in the last three years of the period, a slightly upward trend can be seen. With those results, we can affirm that the annual relative abundance in the Pacific Ocean, estimated from the regular longline fishery shows a stable state after the 1960's.

Intra-annual trends

The monthly trends of the CPUE values presented a remarkable variations during the first ten years of the 1952 to 1985 period (Fig. 3). During those years the lowest values of CPUE were observed between May and October, especially during July and August. After those years, the variations were smaller, resulting in almost no significant variation in the monthly trends in the latest years. As indicated by the annual CPUE distributions (for the annual CPUE values distribution see Sosa-Nishizaki, 1990), the seasonal variations shown during the first ten years of the 1952

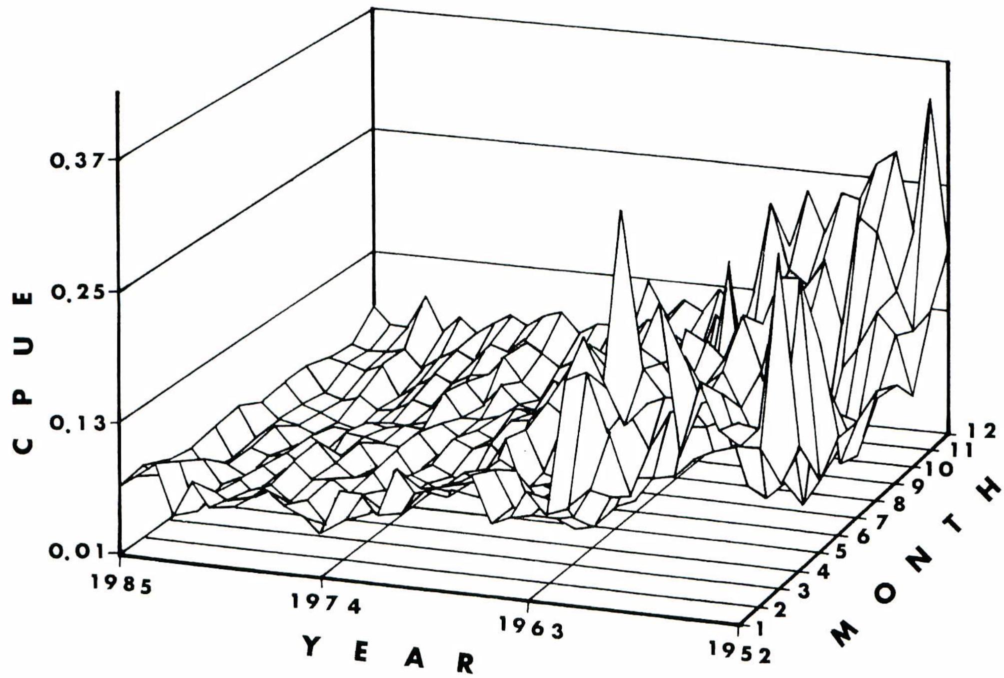

Fig. 3. Three dimensional representation of the annual and monthly trends of the swordfish CPUE (No. of fish per 100 hooks), from the Japanese tuna longline in the Pacific Ocean, during the 1952 to 1985 period.

to 1985 period (Fig. 3) are mostly related with the dimension of this northwestern distribution. The remarkable fluctuation of the monthly CPUE during the first ten years, therefore, appears to have been caused by relatively restricted coverage of the fishing ground.

Monthly spatial distribution

As described above, there have been several changes in the Japanese tuna longline fishery such as fishing grounds, fishing methods and target species which will give bias to the CPUE calculated from nominal fishing effort to be used as relative abundance index. However, the fishing seasons and fishing grounds for swordfish caught by the Japanese tuna longline fishery still remain more or less the same throughout the whole period from 1952 to 1985. Therefore, the catch and effort data for the whole period were used in computing average CPUE to investigate the distribution pattern of swordfish.

The monthly spatial distributions of high (>0.16), medium (0.051-0.16), and low (<0.050) CPUE values per 5° squares in the Pacific Ocean are shown in Fig. 4. In waters off Japan, 5° areas with high values of relative abundance concentrate between the 140°E and west of 140°W and between 45°N and 25°N, during January. After that month, this distribution moves to the south and separates from the Japanese coast, reaching the 20°N and it is reduced to west of 150°W during

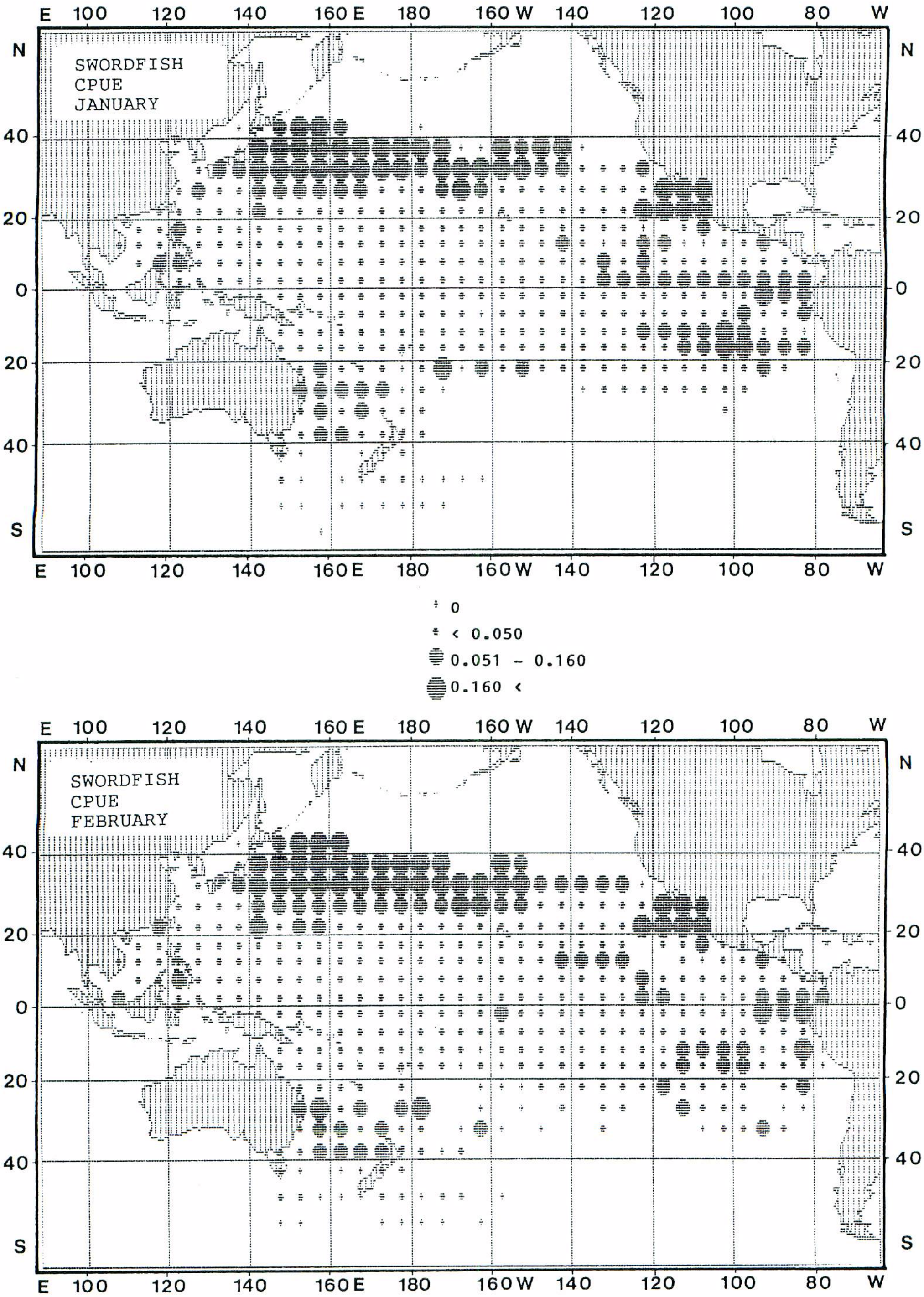

Fig. 4-1. Average monthly swordfish CPUE (No. of fish per 100 hooks) distribution per unit of area (5° squares) from the Japanese tuna longline fishery in the Pacific Ocean, during the 1952 to 1985 period combined.

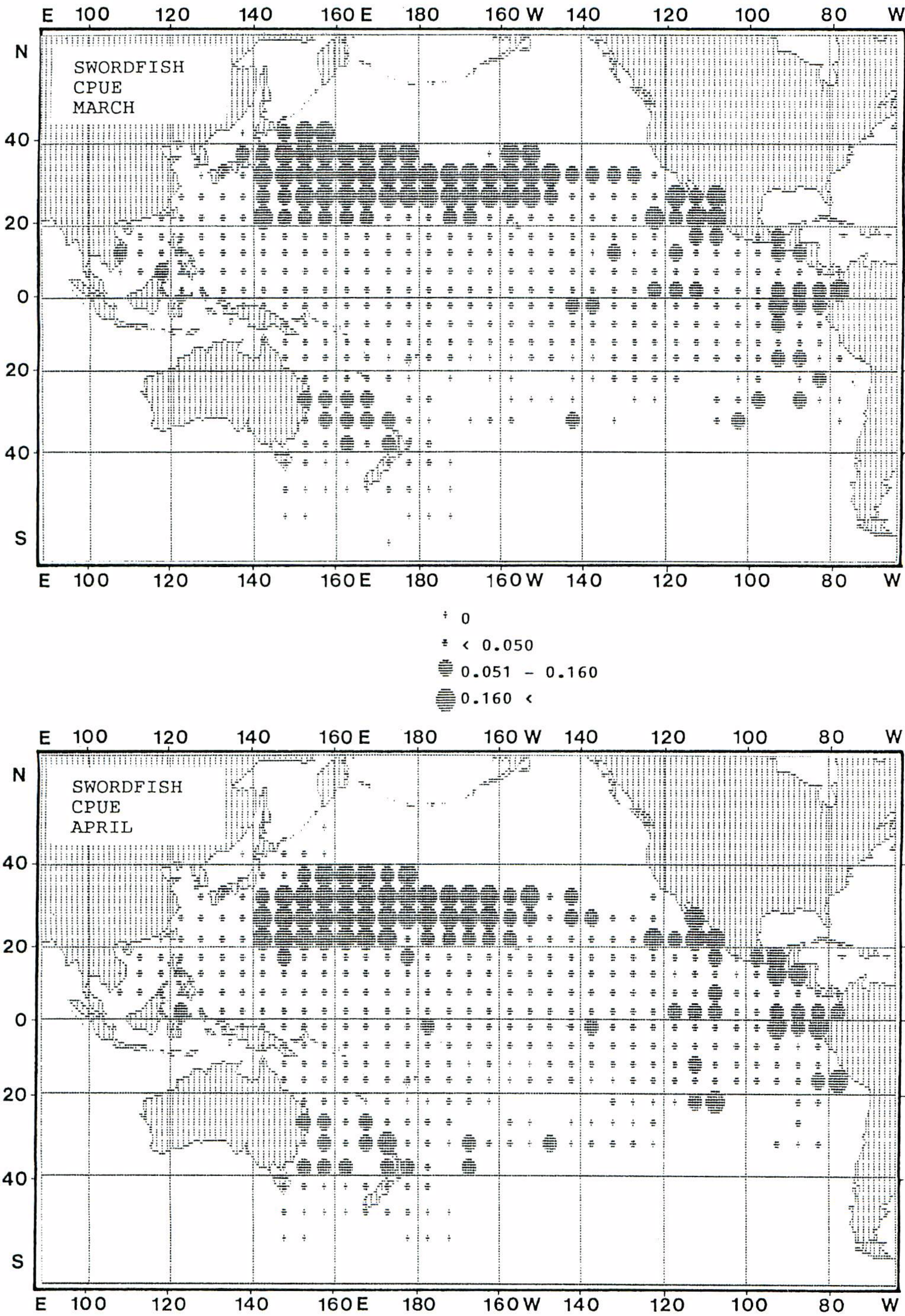

Fig. 4-2. Average monthly swordfish CPUE (No. of fish per 100 hooks) distribution per unit of area (5° squares) from the Japanese tuna longline fishery in the Pacific Ocean, during the 1952 to 1985 period combined.

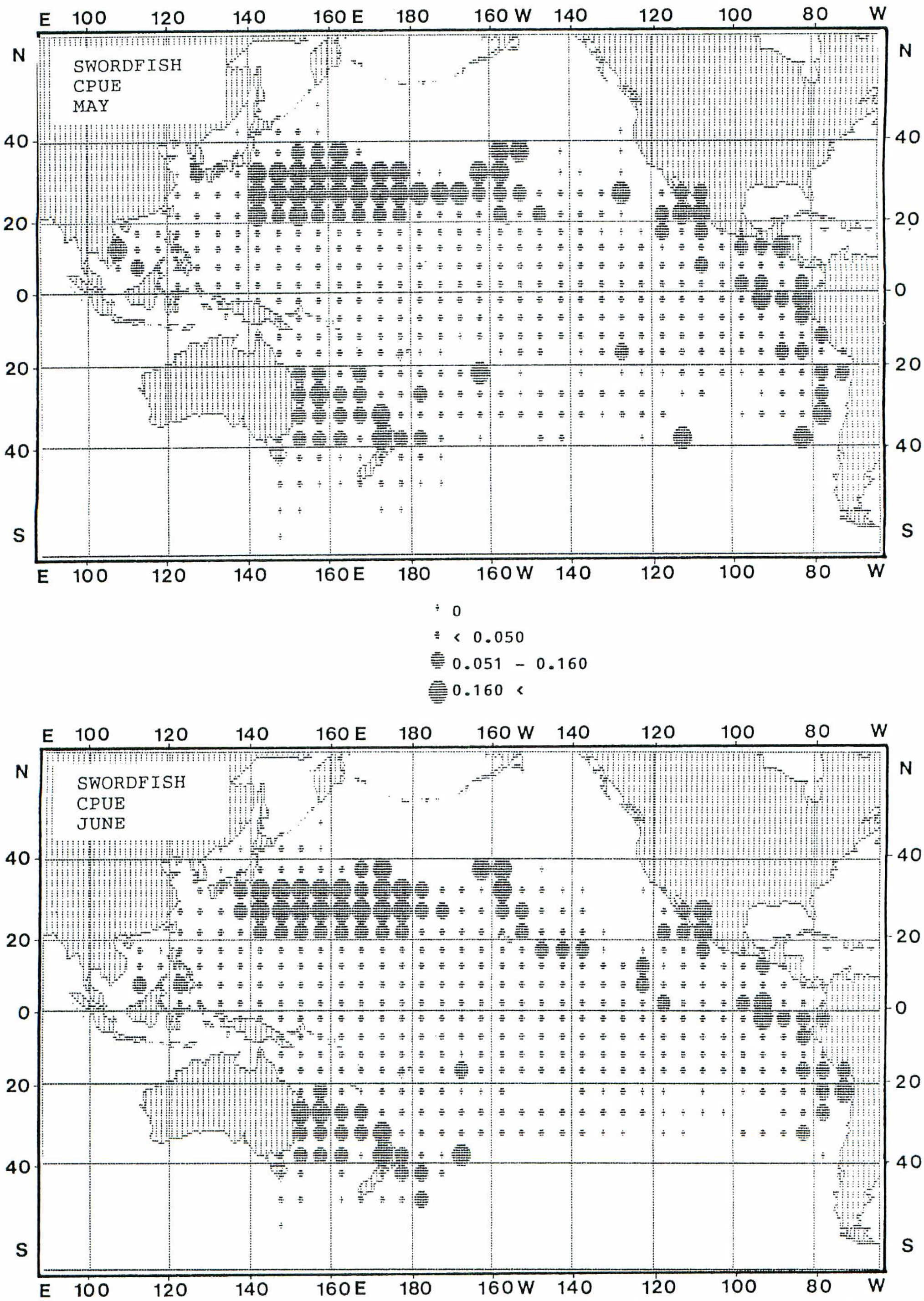

Fig. 4-3. Average monthly swordfish CPUE (No. of fish per 100 hooks) distribution per unit of area (5° squares) from the Japanese tuna longline fishery in the Pacific Ocean, during the 1952 to 1985 period combined.

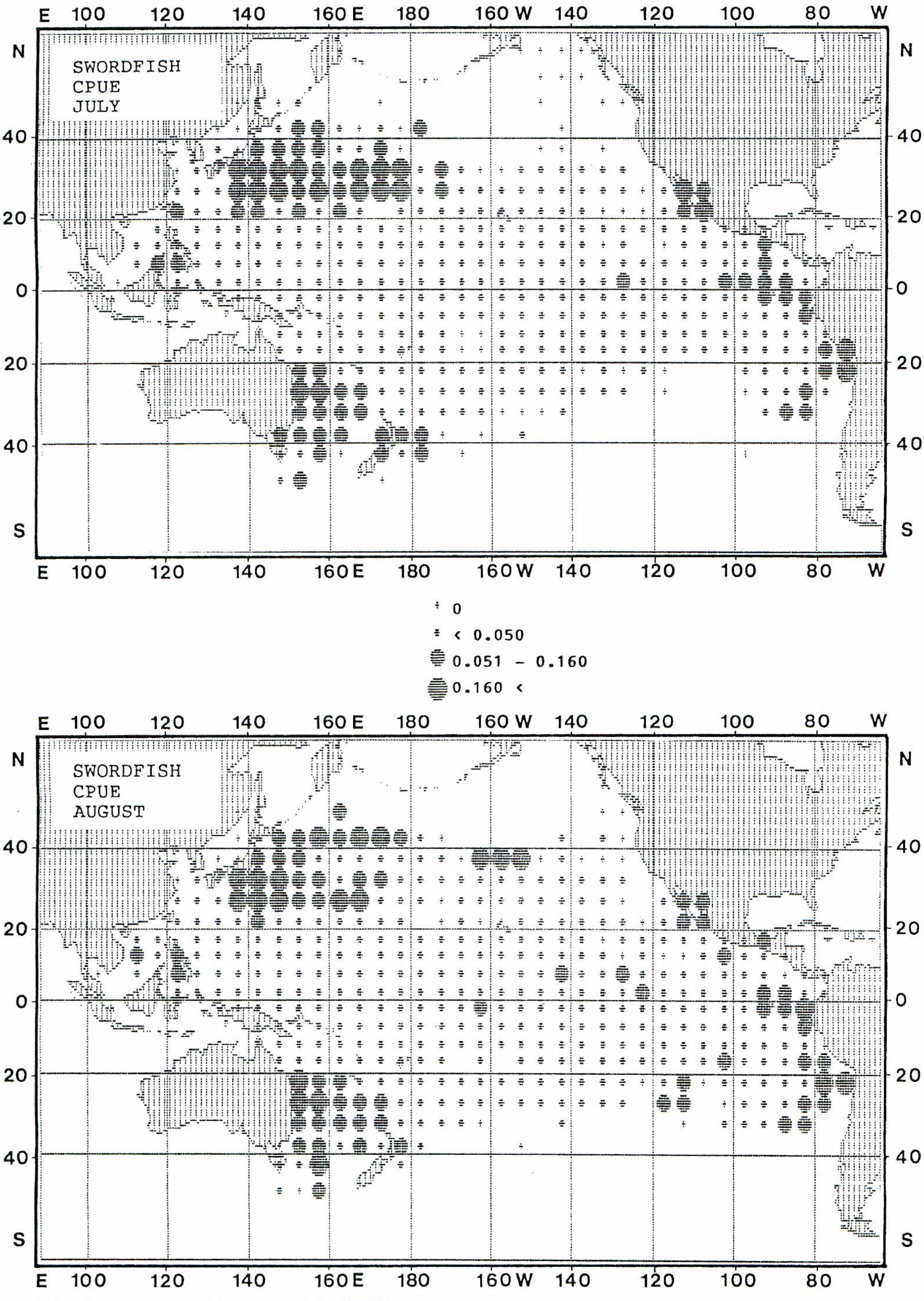

Fig. 4-4. Average monthly swordfish CPUE (No. of fish per 100 hooks) distribution per unit of area (5° squares) from the Japanese tuna longline fishery in the Pacific Ocean, during the 1952 to 1985 period combined.

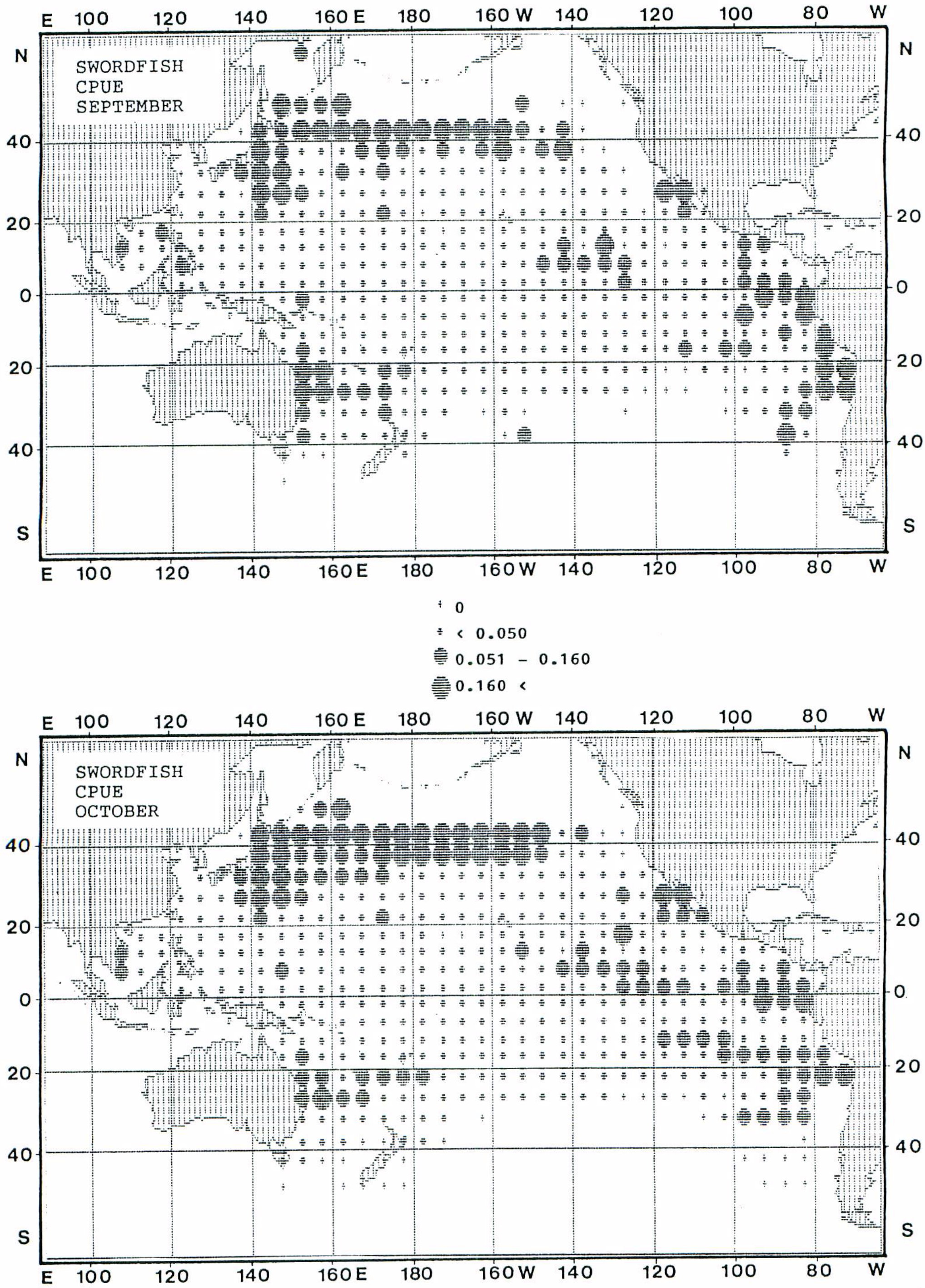

Fig. 4-5. Average monthly swordfish CPUE (No. of fish per 100 hooks) distribution per unit of area (5° squares) from the Japanese tuna longline fishery in the Pacific Ocean, during the 1952 to 1985 period combined.

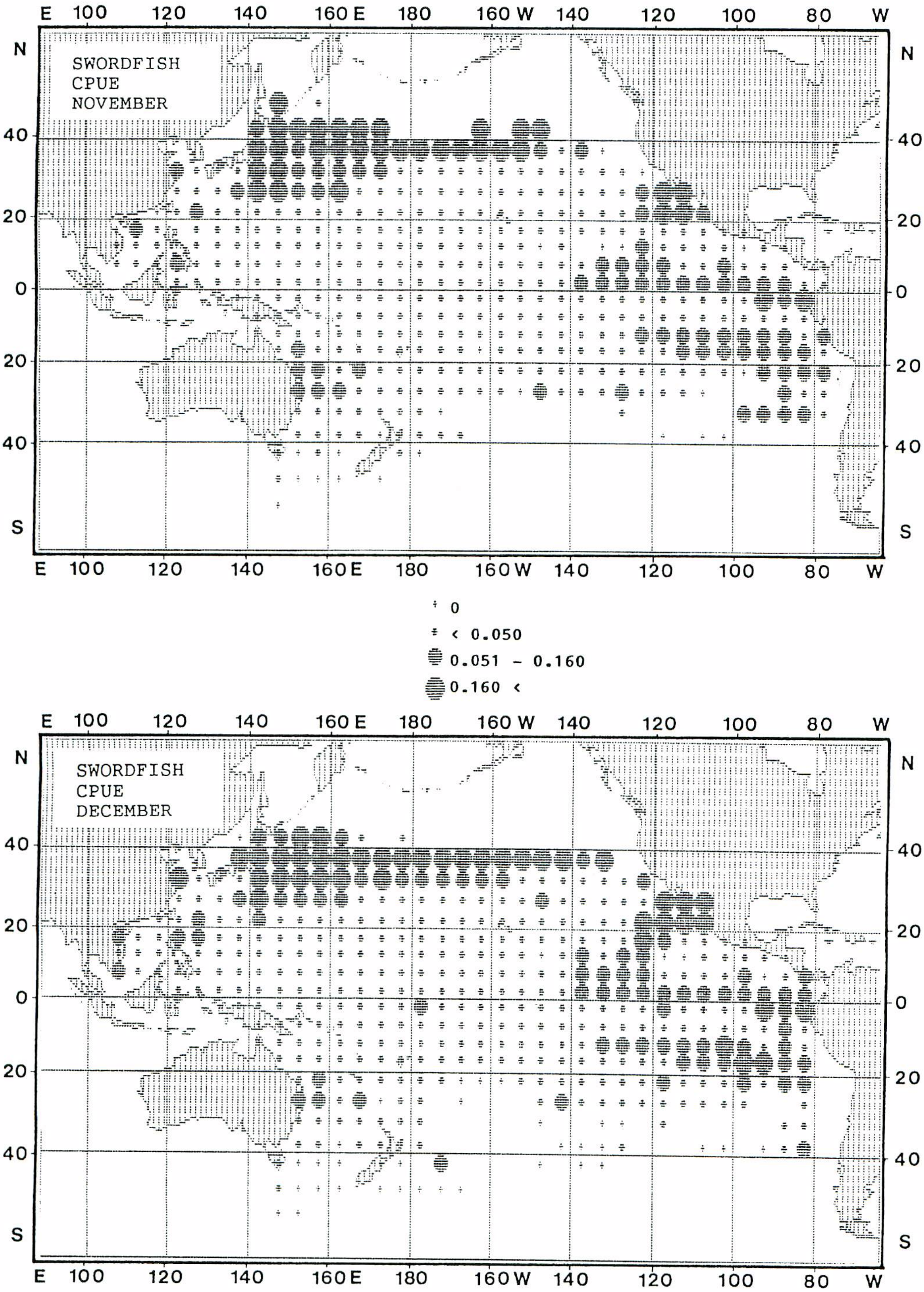

Fig. 4-6. Average monthly swordfish CPUE (No. of fish per 100 hooks) distribution per unit of area (5° squares) from the Japanese tuna longline fishery in the Pacific Ocean, during the 1952 to 1985 period combined.

April to June. During July and August, the distribution with high CPUE is reduced to its minimum, covering the areas between Japanese coastal waters and west of 180°. In September, this distribution moves to the north reaching the 50°N and extending its eastern frontier to waters west of 140° W and north of 40°N. Yabe et al. (1959) also described the same distribution pattern and indicated that swordfish were extensively fished in this area, the so-called North Pacific fishing grounds, which lie between the Polar Front and the Subtropical Convergence. In December, this distribution extends throughout the north Pacific Ocean in waters between the 35°N and 40°N, though the distribution in northern waters can not be evaluated, because the 40°N line was the limit of the fishing operation during this month in this region.

In the northeastern Pacific, an area of high relative abundance was found all the year round in waters off the coast of the Baja California Peninsula. The size of this area begins to diminish from April, stays small in August and September, and expands again from October to reach its maximum in December. Seemingly corresponding to the decrease in the size of this area, a new area of high relative abundance appears in April in waters off the coast of southern Mexico, south to 20°S around 90°W and stays there diminishing its size till July.

In waters off Ecuador, a concentration of medium relative abundance was found also all the year round. This distribution expands in longitude from Ecuador's coastal waters up to the 140°W, and is located always around the equator. During November and December, in waters between the 140°W and 120°W, there appears to be an interaction with the high CPUE area of the Baja California since both areas almost become continuous.

In the eastern Pacific, another medium and high CPUE concentration can be seen from May, between the 10°S and 40°S in Peruvian and Chilean coastal and offshore waters. These areas stay in coastal waters until September, then move northward, north of 35°S and in the region between the 20°S and 10°S, and it reaches waters east of 120°W in October staying in this region until January, when it starts to be less clearly distributed.

In the southwestern Pacific, a concentration of 5° squares with medium and high values is distributed between the 25°S and 40°S region mainly in waters between off the south eastern coast of Australia and north western coast of New Zealand during the first months of the year. In June it expands to the east of New Zealand, and to the south reaching the 45°S. In July and August, this southern expansion can be seen also in waters off the south east Australia. In September it moves northwards to the central part of Australia, almost disappearing from New Zealand waters. In October, it concentrates only in the central Australian waters, between the 30°S and 20°S. And in December it is reduced to its minimum, into waters off the central Australian eastern coast.

DISCUSSION

There are very few studies on population structure of swordfish in the Pacific Ocean. In order to assess the Pacific Ocean swordfish resources, in one of the most recent study Bartoo and Coan (1989) considered, mostly from the similar information on the Japanese tuna longline data, two stock structure cases : 1) one Pacific-wide stock and 2) a three stock structure. However, the present study is based on more detailed analysis of the monthly CPUE changes than the previous work based on yearly CPUE changes. The results of the spatial and temporal trends of the relative abundance here presented showed that the Pacific swordfish population could be more complex in its structure than it has been thought before. The monthly distributions of high relative abundance shown in Fig. 4 indicated seasonal trends and principally were allocated in: a) off Japan, in the northwestern and central Pacific, b) off Baja California Peninsula, c) off the western coast of South America, and d) off the eastern Australian coast and north of New Zealand. These areas changed seasonally expanding and contracting either latitudinally or longitudinally or both, but always seemed to be separated. However, during northern autumn and winter, a distribution which seems to be continuous from the northeastern Pacific to the southeastern part can be also recognized. Studies on seasonal and geographical changes of swordfish gonad index in the eastern Pacific do not indicate any clear separation of the high index areas between the northern and southern hemispheres (Kume and Joseph, 1969; Shingu et al., 1974; Miyabe and Bayliff, 1987). From tagging experiment in the Atlantic Ocean (Miyake and Rey, 1989), no transoceanic movements have been observed. Beckett (1974) from the recovery of one tagged swordfish near the point of release, even after several years at large, suggested that after a spawning migration the swordfish return to the same part of the summer feeding area in subsequent years in the northwestern Atlantic. Those results have been interpreted to imply homing behavior if we assume that these fish are migrating regularly the same route (Carey and Robinson, 1981). Furthermore, the distribution of the areas of high relative abundance in the northeastern and in the southeastern Pacific during the months except the October-January period presented an evidence of a clear independence.

Since the turn of the century, unit stocks have been recognized and labeled as such based on the species physical characteristics. In addition, biological difference in growth and age at maturity have been considered. More recently, genetic methods have become common. Observations on the distribution often form the initial basis for the hypotheses, but the evaluation of tagged fish is often required for more definitive conclusions to be drawn. In all cases some indication of significant geographical separation at spawning is required to support biological bases for separate stocks (Brown et al., 1987). There are some indications for the Pacific swordfish that suggest the separation of the spawning grounds. The occurrence of larval swordfish appears to show at least two large areas with high density, one in the northwestern and northcentral Pacific, the other in the southwestern Pacific (Nishikawa et al., 1974). In addition, Yabe et al. (1959) showed that the occurrence of small juveniles (body length from 10 to 30 cm) found in the stomach contents of tunas and billfishes tended to be separated to the northwestern and southwestern Pacific which roughly corresponds to the two areas with the high larval density in the previous study. Further, Sosa-Nishizaki (1990) reported some differences in spawning activity among these four areas which support the present hypothesis.

Skillman (1989) stated that setting boundaries and identifying stocks is, in effect, determining what part of the total species population is going to be assessed and managed. Here we propose that the four areas mentioned above (a to d) could be centers of unit stocks, based on the temporal and spatial distribution differences among them, occurrence of the larval and small juvenile swordfish and the migration patterns of swordfish in the Atlantic Ocean. However, in order to make a complete discrimination of the stocks, more biological information is needed.

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日本のまぐろはえなわ漁業で漁獲された太平洋のメカジキに関するCPUEの時空間的変化およびそれから推論した系群単位

オスカー・ソーサニシザキ・清水　誠

摘　　要

太平洋における日本まぐろはえなわ漁業によるメカジキのCPUE(釣獲率)の時空間的変化を、1952年から1985年の資料により検討した。相対資源量指数と考えたCPUEの分布から、本海域を以下の4つの水域にわけることができた。すなわち、a) 日本沖、b) バハ・カリフォルニア半島沖、c) 南アメリカ西岸沖、d) オーストラリア東沖およびニュージーランド北部沖である。太平洋のメカジキ資源はこれらの水域に対応した4つの系群により構成されると推論された。