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Introduction

The catch amount of swordfish in the north Pacific increased recently in response to the stock decline in the Atlantic (Anonymous, 1997). Nakano (1994) analyzed stock status of the swordfish in the north Pacific by using standardized CPUE of the Japanese longline fishery and reported recent declining trend of CPUE. The purpose of this report is to update the CPUE and improve the standardization method to see the stock status of swordfish in the north Pacific. Production model analysis was also tried to estimate parameters used in the stock assessment.

Materials and Methods

1) Stock structure

There is no definitive idea in the stock structure of swordfish in the Pacific Ocean. Sakagawa and Bell (1980) suggested two hypotheses which a single, Pacific-wide stock, and three separate stocks with center of concentration in the northwestern, southwestern and eastern Pacific Ocean based on the CPUE trends of the longline fishery and the distribution of larvae. Sosa-Nishizaki and Shimizu (1991) suggested the existence of two stocks in the eastern Pacific (off Baja California Peninsula and off south America) based on the monthly mean CPUE distribution pattern of Japanese longline fishery.

Yabe et. al. (1959) reported the Japanese catch records of juvenile and full matured swordfish by area and by month. Juveniles of swordfish were caught in May and June in the tropical area in the northwest Pacific, and in October and November around Caroline Islands and Solomon Islands. Full matured female were caught in April and May in the tropical area in the northwest Pacific, in October in Coral Sea and in the tropical area in the northeast Pacific (5° N, 135° E), and in June around Cook Islands. These results indicates that the swordfish in the north and south Pacific belong to the different stocks and also swordfish in the northeast Pacific would belong to the different stocks from that in the northwest Pacific.

Kume and Joseph (1969) analyzed catch and effort of Japanese longline fishery and survey data laying emphasis on size composition and sexual maturity of swordfish in the eastern Pacific, and suggested the outline of its life history. In the eastern tropical Pacific, matured and small sized (130cmEFL>) swordfish were apparently caught in offshore area (west of 100° W, 10° S～10° N) while almost of all fishes caught by coastal fishery were immature. They indicated that swordfish in the eastern Pacific spawn in the offshore area, migrate to coastal area as they grown and return to the offshore area when they start to mature.

Yokawa and Uozumi (1997) analyzed the length frequency data collected by Japanese longline fishery, training and research vessel. They reported that smallest mode (around 60cmEFL) appeared in the second quarter at the northwest Pacific and Hawaiian waters while small sized fishes (100cmEFL>) were caught in the forth quarter in the eastern and southwestern Pacific. This report also suggests that swordfish in the northwest Pacific belongs to the different stock from both the southwest and the northeast Pacific.

Taking into account of the results of these biological studies, it is reasonable to consider that swordfish in the northwest and the north central Pacific (NP) belongs to the different stock from that in the northeast Pacific. The present study assumes that swordfish in NP forms a single stock and set equator and 125 W as arbitrary boundary of the stock.

2) Standardization of CPUE of Japanese longline fishery

A. Data

The data for this study were obtained from the Japanese longline fishery statistics compiled at the National Research Institute of Far Seas Fisheries for 1952-1997. Two kinds of Databases were used. The Database-I has the information of catch number and number of hooks used which year, month and 5x5 blocks aggregated and raised to 100 percent coverage, while the new Database-II, from 1975 when Japanese deep longline fishery started in the Pacific, contains additional information for the gear configuration, i.e. the number of branch lines between floats.

Designation of subareas used for the CPUE standardization were done by comparing the level and the trend of nominal CPUE value of each 5x5 block, i.e. eliminated block which has less than 10,000 hooks in each year, and after that, collected blocks which had similar CPUE level and trend. Because of the apparent difference of effort distribution and the level of nominal CPUE value of each 5x5 block, the different subareas were set for the Databases-I and II (Figs. 1 and 2). Higashioki area and north of Hawaii area where major fishing grounds of swordfish area correspond to subareas 1 – 9 and 16 for the Database-I and subareas 1 – 8 and 6 – 7 for Database-II.

CPUE was calculated as catch number per 1,000 hooks. Observations with less than 1,500 hooks per month and per 5x5 blocks were excluded from analysis. Database-I from 1952 to 1975 and II from 1975 to 1997 were used for the GLM standardization and standardized CPUE of each area was multiplied by the relative size of the area and summed up to obtain the abundance index.

The standardization of CPUE were calculated for the two areas, one is the whole NP area and the other is the area north of 15° N in the NP where relatively high nominal CPUE were observed. In this document, later area called the temperate area of NP.

B. Selection of the model

Selection of the factors included in the model as main effects were followed by Nakano (1994) except for CPUEs of other species which were excluded from main effects in the present study because of a constant trends were not observed in them (Anonymous, 1997a).

The multiplicative model was selected. For Database-I is:

$$\ln(CPUE_{ijk}+const)=\ln(\mu)+\ln(YR_i)+\ln(QT_j)+\ln(AR_k)+\ln(INTER)+\varepsilon$$

and for Database-II is:

$$\ln(CPUE_{ijkl}+const)=\ln(\mu)+\ln(YR_i)+\ln(QT_j)+\ln(AR_k)+\ln(GE_l)+\ln(INTER)+\varepsilon_{ijkl}$$

where ln: natural logarithm, $CPUE_{ijk}$: nominal CPUE (catch in number per 1,000 hooks, in year i, quarter j, area k), const: 1/10 of overall mean, μ : overall mean, YR_i: effect of year i, QT_j: effect of quarter j, AR_k: effect of area k, GE_l: effect of gear l, INTER: any combination of two way interaction, and ε : normal error term. Analysis was made though the GLM procedure of computer software, "SAS Ver. 6.11".

3)Stock assessment

Non-equilibrium production type of analysis was done by using computer program "ASPIC Ver. 3.6x". Input data for the ASPIC were abundance index which obtained by the standardized CPUE of the Japanese longliners and the total catch amount in the NP. Catch amount of swordfish by the Japanese distant water and offshore longline fishery was calculated from the catch and effort statistics compiled by the NRIFSF by multiplying the average weight for various time and area strata by number of fish caught in these strata. Swordfish catches by other Japanese fishery than distant and offshore longline fishery were obtained by Annual report of catch statistics on fishery and aquaculture (Ministry of Agriculture, Fishery and Forestry Japanese Government. 1952-1996). The catch of US was obtained by logbook data. The catches of all other nations were taken from FAO Fishery Statistics Year books (FAO. 1952-1996).

Result

1. Catch trend of Japanese distant and offshore longline fishery

The swordfish catch of Japanese distant and offshore longline fishery have consisted about 70 – 90 percent of total Japanese swordfish catch in the NP (Fig. 3). Figures 4, 5 and 6 show the swordfish catch number, effort and CPUE of swordfish by gear configuration (number of hooks between floats, NHF), respectively. As it was indicated by Uosaki and Takeuchi (1997), surface longline fishery whose numbers of hooks between floats were 3 and 4 recorded high catch rate and occupied high percent of total catch after late 1980's, while before late 1980's, catch by other type of fisher whose numbers of hooks between floats were 5 and 6 accounted for high percent of total though its CPUE were not so high as surface longliners during that period.

Figure 7 and 8 shows average swordfish catch number (number per year) and effort (x1000 hooks per year) distribution of Japanese distant water and offshore longliners. Large number of swordfish catch were obtained in the temperate area (between 20° N and 40° N) in the north Pacific. The effort of surface longliners (NHF are 3 – 4, swordfish direct fishery) was limited in the north of 20° N and west of 180° E (Higashioki area) and the surface longliners attained large number of catch in that area. Large number of swordfish catch were also observed by other gear forms such as NHF was 5 – 6 in the Higashioki area and the area north of Hawaii islands, and NHF was 7 – 9 in the area north of Hawaii islands, while the effort distribution of these two gear forms spread over the north Pacific. The effort distribution of the longliners whose NHF was 10 – 15 also spread over the north Pacific and the effort distribution of the deep longliners (NHF was over 16) was limited to the tropical area (south of 10° N). The catch levels of them were relatively low in everywhere in the north Pacific.

2. Standardization of CPUE of Japanese distant water and offshore longline

1) Model used for the standardization

The standardization of CPUE was done with Database-I (1952 – 1975) and Database-II (1975-1997). Only Database-II has information about gear configuration. The model in each Database includes all main effect and two way interactions. For the Database-II, terms of two way interactions which produced the lowest value of Akaike's Information Criteria were selected as an appropriate model (Table 1). For the Database-I, terms of two way interactions with no missing cell in the period between 1952 and 1997 were included into the model.

The models used in each Database are as follows,

Database-I:

$$CPUE= \mu + Year+Area+Quarter+Area*Quarter+Year*Area+Year*Quarter+e.$$

Database-II:

$$CPUE= \mu + Year+Area+Quarter+Gear+Area*Quarter+Quarter*Area+Quarter*Gear+Year*Area+e.$$

As Year*Area interactions were significant in both Database, the weighted mean of CPUE in each year by the size of subareas is used as abundance index.

The results of ANOVA are shown in Tables 2 and 3. The models for both two Databases in each period and area were highly significant. The distributions of residuals for both two Databases in each period and area are shown in Figs. 9 and 10. The shapes of these distributions are roughly close to the normal and symmetric one.

2) Gear effect (Database-II) and Area effect

Figure 11 shows the effect of gear configuration by area on the swordfish CPUE. All the values in the figure were derived from the least square mean of CPUE on gear*area effect obtained by the GLM procedure in the CPUE standardization with the Database-II. Because Fig. 11 does not show detailed effect of gear with NHF larger than 9, another GLM procedures were conducted with the subareas and periods having enough number of data to see the effect. Figure 12 shows the results of it. The data of subareas 2 –12 and the period between 1985 and 97 were used.

Negative correlation observed between CPUE and NHF in subareas north of 20° N (Higashioki and north of Hawaii area) except for subarea 1 where surface longliners often targets not swordfish but sharks. In subareas south of 20° N, no apparent negative correlation observed between CPUE and NHF and positive correlation observed in subarea 12 by the gear with NHF between 7 and 17.

Figures 13 and 14 show the affect of subarea by year on the swordfish CPUE. All the values in the figure were derived from the least square mean of CPUE on area*year effect obtained by the GLM procedure in the CPUE standardization with the Databases-I for 1952 - 75 and II for 1975 - 97. High CPUE observed in subareas north of 20° N through the period analyzed.

4) Standardized CPUE

Figure 15 shows the standardized and nominal CPUEs of swordfish. All the values of CPUEs expressed as the relative value of the value in 1975 set at 1.0.

The shapes of the standardized CPUEs were very flat on the whole. Highest CPUE obtained in 1987 which was 2.7 times higher than lowest CPUE observed in 1952. The standardized CPUE showed a consistent declining trend after 1987 but the value of 1997 is still 85 percent of the average of whole period.

The nominal CPUE and the standardized CPUE were very different in the period of 1952 – 1970 while they showed similar trend after 1970. The nominal CPUE were 2 – 6 times higher than the standardized CPUE in the period of 1952 – 70.

5) Relation between standardized CPUE, standardized effective effort and catch

The relationships among the standardized CPUE and effective effort for the area of whole

NP estimated total swordfish catch (ton) from NP are shown in Figures 16 – 18. Estimates of effective effort were obtained by dividing total catch by the standardized CPUE (scaled to the value of 1975 set at 1.0).

The relationship between the effective effort and total catch exhibited a linear trend and these two indeces showed a similar trend during the period after late 1950's. The total catch had no correlation with the standardized CPUE.

6) Production model analysis

Figure 19 compares trend of the standardized CPUE and total catch (ton) in NP and these two values were used for parameter estimation of production model. The meaning abbreviations of r, B1-ratio, B-ration used in this document are as follows,

r : poplulation's intrinsic rate of increase

B1-ratio : the ratio of biomass at the starting year to the biomass at which can attain MSY as a sustainable yield (B_{MSY}).

B-ratio : the ratio of biomass in a certain year to B_{MSY}.

For the fitting procedure of ASPIC, three data sets were used. One of them was the set contained all the historical data (1952 – 97) and other two sets were the ones in which the historical series divided into two phases at the year of 1976. After numbers of trial with these three data sets, it was found that every fitting trial could not obtain normal convergence without fixing one of four parameters (K, r, q, and B1-ratio). As a result of that, the values of B1-ratio or r were fixed to conduct fitting procedure. In every case, the value of r fixed at 0.4 which was estimated by the production model analysis on the swordfish stock in the north Atlantic in 1996 by International Commission for the Conservation of Atlantic Tunas (Anonymous, 1997b). The values of B1-ratio was fixed at 2.0 for the data sets starting in 1952 as no large scale swordfish fishery existed in NP before 1952 and fixed at 1.5 for the data set starting in 1976.

The results obtained by the ASPIC runs are shown in Table 6 and the trajectories of B-ratio are shown in Figs. 22 – 24. In all cases, shapes of trajectories of B-ratio were more or less flat on the whole but the values of B-ratio were largely different by data set and fixed parameter.

Discussions

The swordfish targeting operation have been existed before 1950's (Kikawa, 1958). Uosaki and Takeuchi (1998) revealed that the operations with NHF 3 – 4 among the Japanese distant water and offshore longline fishery were targeting swordfish. The standardized and the nominal CPUE of this surface longliners was considerably higher than the operation with other deeper longline (Figs. 4 and 11) but the operation area of the surface longliners was limited in Higashioki area (Fig. 7). The amounts of swordfish catch (number) and effort (number of hook) of the surface longliners were low in the period between 1975 and 1985 when the bulk of the swordfish catch obtained by the operation with NHF 5 – 6 (Fig. 4). The nominal and the standardized CPUEs of the operation with NHF 5 - 6 were about one second or third of the surface longline but still higher than the other operations with NHF larger than 7. It seems that the part of the operation with NHF 5 – 6 would target on the swordfish. Because of the operation with this gear form catch a sizable number of swordfish in both of Higashioki area and north of Hawaii where two major swordfish fishing ground in the north Pacific (Fig. 7), further analysis about the operation pattern and target species of this gear form would contribute to obtain more accurate abundance index.

Negative correlation between NHF and swordfish CPUE observed in this study was supported by the result of Suzuki (1977) and Nakano (1994) but conflict with the result obtained in the Indian and the Atlantic Ocean (Uozumi, 1998) where the positive correlation observed. The reason of this contradiction is unknown but more precise analysis between gear effect and the oceanographic condition and the telemetry study will answer to it.

Large difference between the standardized and the nominal CPUE in the period between 1952 and 1963 was not reported in the former same kind of work done by Nakano (1994). Major differences between the present standardization and that by Nakano (1994) are the subarea stratification and the model used for the standardization. The subarea stratification has high influence for the calculation of the abundance index in case that year*area interaction, which Nakano (1994) did not include in the model, is significant. Nakano (1994) allocated only four relatively large size subareas in the Higashioki area where main swordfish fishing ground of Japanese surface longliners, but the pattern of operation of Japanese longliners in this area are more complicated, i.e. the size of subarea 5 for the Database-I which recorded highest CPUE (Fig. 13) during 1950's was only 8 percent of the total Higashioki area. Fine subarea stratification used in the present study accounted for such concentration of catch and leveled down the values of CPUEs. Another reason would be the change of fishing effort distribution. Figure 23 shows the ratio of the amount of fishing effort of the subareas in the Higashioki area and in the tropical area (south of 20° N) to the amount of all subareas. The ratio of Higashioki area was 1.5 – 3 times higher than that of tropical area before 1961 while the ratio of Higashioki area was less than that of tropical area after 1960. Change of distribution of fishing effort from the area where high swordfish CPUE obtained to the area where the CPUE of swordfish was low would be another major reason of the difference (Figs. 24 - 26).

The fitting procedure of ASPIC did not converge in case all four parameter estimated. The calculated B-ratios were almost constant over the period analyzed when one of four parameter fixed and the level of B-ratio fluctuated largely depend on the period analyzed and fixed parameters. The reasons of this were flat trend of standardized CPUE and high linear correlation between the standardized CPUE and estimated total catch (Fig. 17). The high linear correlation between the standardized Japanese longline CPUE and estimated total catch can attribut to,

a) Decline of the exploitation ratio of the Japanese longline fishery ; The exploitation ratio of Japanese longline had been larger than 70 percent before 1970, but its decline to 50 - 60 percent during 1970's and 1980's. It shows further decline after 1989 down to 30 percent.

b) Influence of the effects other than used in this study; The values of R-square were 0.42 – 0.60. Part of the reason could be explained by other effects such as the change the gear material and sort of bait which were not considered in the present study. These cryptic effects might mask the real trend of the CPUE.

d) low quality of catch data ; If total catch number used in this study were different from the real one, ASPIC program run would not converge normally. Accuracy of data should be checked.

e) Assumption of the production model ; Two of three cases of ASPIC run in the present study estimated relative high and constant B-ratios (Figs. 20 – 21). If catch did not have a influence on the stock and the level of stock only fluctuate in response to the change of environmental condition, the production model can not give a proper answer.

f) Possibility of the existence of multiple populations in NP; Figure 27 shows the trend of the abundance index of the sum of subareas west and east of 180° W. Trends of the abundance indexes between west and east area are different. It should be interesting to clarify whether the reason of this difference between west and east came from the difference of stock or difference of fishing pattern of Japanese longliners.

In the present study, the production type of analysis did not produce adequate answer. The best way, however, to overcome this problem would be to introduce information about catch at age to the analysis, more detailed check both of logbook data of Japanese longline fishery and the biology of swordfish in NP should be necessary before enough amount of data about catch at age of swordfish in NP.

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