Stock Assessment and ABC Calculation for Japanese Sardine (*Sardinops Melanostictus*) in the Northwestern Pacific under Japanese TAC System

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Abstract

Stock assessment for the Japanese sardine (*Sardinops melanostictus*) in the northwestern Pacific was conducted based on VPA and biomass surveys independent from commercial fisheries data. The stock size of Japanese sardines in the northwestern Pacific has shown a continuous decrease from 1987 to 2003 and the stock biomass estimate for 2003 was about 130 thousand tons. The spawning success (RPS: number of recruits/spawning biomass) has been 22 inds./kg in average and fluctuated between 5 and 61 inds./kg during the recent 10 years. From the historical perspective, the current stock status would not be in the conditions for rapid stock recovery. The acceptable biological catch (ABC), that is the biological criterion for the TAC, is set to rebuild the spawning biomass at least to the level at which the recruits are expected to be comparable with those of 1996 year-class. Some hypothetical scenarios for controlling the catch amount were explored, in order to avoid intensive fishing efforts on dominant recruits.

Key words: acceptable biological catch, Japanese sardine, *Sardinops melanostictus*, spawning success, virtual population analysis

1. Japanese TAC (Total Allowable Catch) System

An entry limitation approach, which restricts fishing efforts, such as the number of vessels, period or area of fishing operations, has been traditionally employed in the Japanese fisheries management system. However, with the ratification of the United Nations Convention on the Law of the Sea, an approach to controlling catch amounts directly by setting a total allowable catch (TAC) was additionally introduced into the Japanese fisheries management system in 1997.

TACs have been set for eight marine captured species in the Japan EEZ: the Japanese sardine (*Sardinops melanostictus*), jack mackerel (*Trachurus japonicus*), chub mackerel (*Scomber japonicus*), spotted mackerel (*Scomber australasicus*), Pacific saury (*Cololabissaira*), walleyepollock (*Theragra chalcogrammus*), Japanese common squid (*Todarodes pacificus*), and snow crab (*Chinoesetes opilio*). TACs for the chub mackerel and spotted mackerel are combined, with a common TAC set for both mackerels because they are not separated in catch statistics. Under the TAC system, the National Fisheries Research Institutes carry out stock assessments and ABC calculations for 19 stocks of TAC species in the Japanese EEZ.

2. Distribution and Current Status of the Pacific Stock of Japanese Sardine

The spawning area of the Pacific stock of the Japanese sardine covers a wide stretch of the waters off Honshu and Shikoku islands. Juveniles are broadly distributed in the Kuroshio/Oyashio Transition Zone during spring as far east as 180° longitude (Fig.1, Kinoshita, 1999). The distribution of adult sardines extends to the central Pacific and the southern areas of the Okhotsk Sea and Western Subarctic Gyre during periods of high abundance.

The Japanese catch of the Japanese sardine peaked in 1936 and 1988 and fell to record lows in 1965 and 2004. Watanabe *et al*. (1995) attributed the collapse of the stock in the late 1980s to successive recruitment failures caused by extremely low survival after the

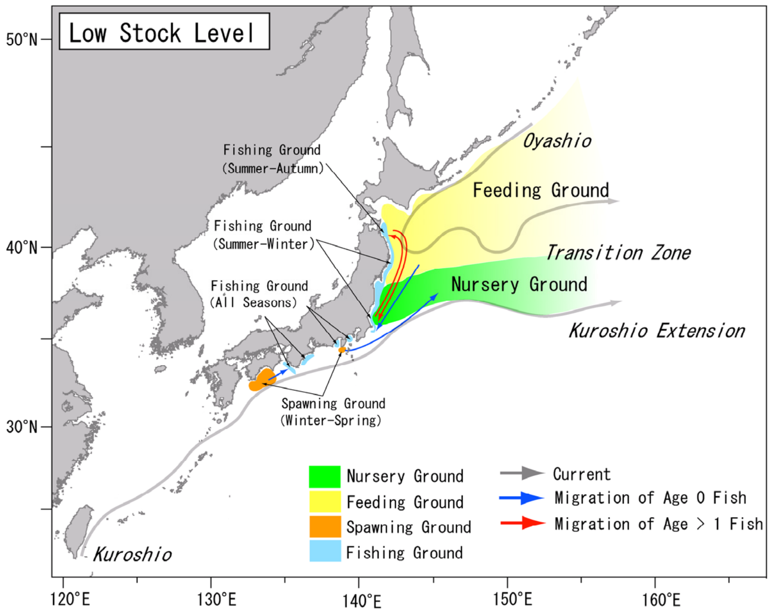

Fig. 1 Distribution and migration of the Pacific stock of the Japanese sardine. The spawning area of the Pacific stock of the Japanese sardine covers a wide stretch of the waters off Honshu and Shikoku islands. Juveniles are broadly distributed in the Kuroshio/Oyashio Transition Zone during spring. The distribution of adult sardines extends to the central Pacific and to the southern areas of the Okhotsk Sea and Western Subarctic Gyre.

feeding larval stage and before recruitment to fisheries at age 1. Recruitment anomalies were negatively correlated with SSTs in the Kuroshio Extension (Noto & Yasuda, 2003). The SST anomalies were preceded by shifts in the mixed-layer depth in the Kuroshio Extension three years earlier (Yasuda *et al*., 2000). The winter mixed-layer depth in the Kuroshio Extension between 1967 and 1985 was deeper than the long-term mean. Thus, sardine dynamics were associated with the 1970 and 1988 shifts in the SST field (Yasunaka & Hanawa, 2002). In 1970 in particular, when SSTs in the Kuroshio Extension were below average, zooplankton biomass in the Oyashio waters also increased (Odate, 1994), which may have been caused by intensified vertical mixing in winter associated with wind stress (Sugimoto & Tadokoro, 1997). Increased production in the lower trophic levels in the Oyashio region may have enhanced the early growth and survival of sardines.

Despite poor recruitment, fishing mortality of the Japanese sardine has increased drastically since the early 1990s owing to strong incentives to continue fishing for sardines (the landing price of sardines increased relative to the more abundant Japanese anchovy) (Yatsu *et al*., 2003).

3. Biomass Estimation for the Pacific Stock of the Japanese Sardine

Stock assessment for the Japanese sardine (*Sardinops melanostictus*) was conducted based on a virtual population anlysis (VPA). An age-structured stock assessment was applied to fishery-dependent and fishery- independent biomass surveys to derive estimates of population abundance and age-specific fishing mortality rates. Fishery-independent data include egg abundance as an index of spawners abundance, juvenile and 1-year-old fish biomass survey.

At first, for the estimate of age-specific selectivity, VPA using Pope's (1972) equation, was conducted based only on catch at each age. Age was classified ranging from 0 to 5 years and over. The monthly catch at each age was estimated from catch-by-size data using the monthly age-length key. The yearly total catch at each age from 1976 to 2003 was used for VPA.

$$N_{a,y}=N_{a+1,y+1}\exp(M)+C_{a,y}\exp(M/2)$$

$$N_{a,2003}=C_{a,2003}\exp(M/2)\,/\,(1-\exp(-F_{a,2003}))$$
(the most recent year, in this case y =2003)

$$N_{4,y}=(C_{4,y}N_{5+,y+1}\exp(M)\,/\,(C_{5+,y}+C_{4,y})+C_{4,y}\exp(M/2) \quad \text{(4-year-old fish)}$$

$$N_{5+,y}=(C_{5+,y}N_{5+,y+1}\exp(M)\,/\,(C_{5+,y}+C_{4,y})+C_{5+,y}\exp(M/2) \quad \text{(5-year-and-over fish)}$$

$$F_{a,y}=-\ln(1-(C_{a,y}\exp(M/2)\,/\,N_{a,y}))$$

$F_{a,2003}$=average value between $F_{a,1998}$ and $F_{a,2002}$ (most recent year, in this case y=2003)

$F_{5+,2003}$=average value between $F_{4,1998}$ and $F_{4,2002}$ (5-years-and-over fish in 2003)

$F_{5+,y}=F_{4,y}$ (4-year-old and 5-years-and-over fish)

Where N and C represent the number of fish and catch, respectively, a their age, y the year, F the fishing mortality coefficient and M the natural mortality coefficient (=0.4/year in the case of the Japanese sardine). F for the 5-years-and-over (5+) is assumed equal to that of 4-year-old fish. The average value of F between 1998 and 2002 was used for the 0-4 years-old fish in the most recent year 2003. F for the age group 5+ in 2003 was set equal to F for the 4-year-old fish in 2003. Based on this calculation, age-specific selectivity was estimated and this result was used in the next step as follows.

The next step, $F_{a,2003}$ was derived by minimizing

$$\sum_i \sum_y \{\ln(I_{i,y}) - \ln(q_i P_{i,y})\}^2$$

The terms in the objective function (to be minimized) included the sum of squared differences in the observed and predicted estimates from the catch at each age and various sources of data used for tuning VPA. I represents each fishery-independent abundance index and effective fisheries effort data, as follow; i, the index number; y, the year q; the proportional coefficient; and P, the predicted estimates linked to each index.

Each index is as follows.

(1) Egg abundance during 1978 to 2003 were used to develop the following time series of spawning stock biomass. These data were derived from NORPAC-net egg surveys performed by the Prefectural Fisheries Experimental Stations and National Fisheries Research Institutes.

(2) Effective fisheries effort data (Japanese Fisheries Information Center) during 1994 to 2003 were used to develop the time series of F-bar (averaged F for all age group)

(3) Fishery independent 1-year-old abundance survey data during 2002 and 2004 was used to develop a time series of the stock number of 1-year-old fish. These data were derived from surface-midwater trawl survey data in January (wintering area for young Japanese sardines).

Among these indices, (2) was double-weighted, the other two indices were single weighted. So, in this case, $F_{a,2003}$ was derived by minimizing,

$$\sum_y \{\ln(I_{1,y}) - \ln(q_1 P_{1,y})\}^2 + 2\sum_y \{\ln(I_{2,y}) - \ln(q_2 P_{2,y})\}^2 + \sum_y \{\ln(I_{3,y}) - \ln(q_3 P_{3,y})\}^2$$

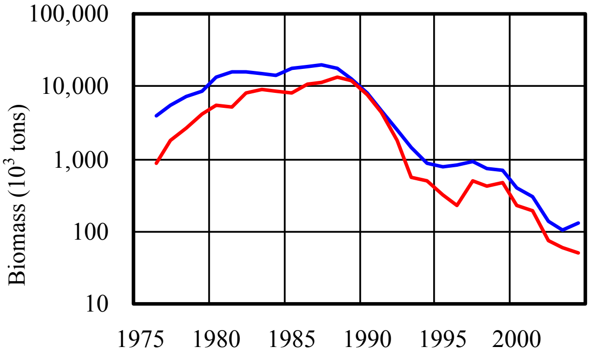

Fig. 2 Total stock biomass and spawning biomass estimated for the Pacific stock of the Japanese sardine between 1976 and 2003. Blue line shows the total biomass, and red line shows the spawning biomass, respectively. The stock size of the Japanese sardine has shown a continuous decrease from 1987 to 2003 and the stock biomass estimated in 2003 was 130 thousand tons.

Total biomass and spawning stock biomass estimates based on the VPA are shown in Fig.2. The stock size of the Japanese sardine in the northwestern Pacific has shown a continuous decrease from 1988 (1,950 thousand tons) to 2003 with yearly fluctuations, and the stock biomass estimate in 2003 was about 130 thousand tons. Stock biomass estimates from the assessment conducted in 2004 have indicated the sardine population has remained at a lower abundance level than 1980s.

4. Spawning Success (Number of Recruits/ Spawning Biomass) of the Pacific Stock of The Japanese Sardine

For calculating spawning biomass, maturation of each age group was estimated as follows. Maturation rate of age-zero is 0; age-one, 0.1-0.2 during 1976 and 1996 (Wada & Kinoshita, unpublished data), 0.5 during 1997 and 2003; and ages two to five and over, 1. The relationship between recruits and the spawning biomass is shown in Fig.3. It is clear that successive poor spawning success between 1988 and 1991 caused the collapse of this stock (Fig.3, left panel). In the past 10 years, the spawning success (RPS: number of recruits/spawning biomass) has been 22 inds./kg in average and fluctuated between 5 and 61 inds./kg (Fig.3, right panel). This value is nearly as the same level as the early 1980s, so the current stock status is considered in the condition for stock rebuilding. In the early 1970s, the RPS level was 100-1,000 inds./kg (Wada & Jacobson 1998), and it was an order of magnitude higher than in 1980s and 1990s. Considering the historical perspective, it would appear that the current stock status would not be in the condition for rapid stock recovery.

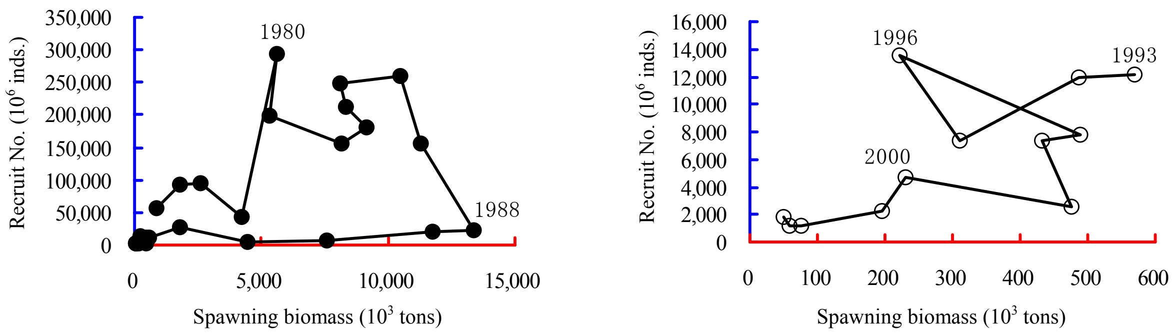

Fig. 3 The relationship beween spawning biomass and recruits. Successive poor spawning success between 1988 and 1991 caused collapse of this stock (left panel). The spawning success (RPS: number of recruits/spawning biomass) has been 22 inds./kg in average and fluctuated between 5 and 61 inds./kg during the recent ten years.

5. ABC Calculation for the Pacific Stock of Japanese Sardine

To set the ABC for 2004 based on the stock status in 2003, it is necessary to forecast stock estimates for each year after 2004. Stock numbers for each age group in 2004 were calculated as follows.

$$N_{0,y}=SB_y\ SS_y$$

$$N_{a,y}=N_{a-1,y-1}\exp\{-(F_{a-1,y-1}+M)\}$$

$$C_{a,y}=N_{a,y}\{1-\exp(-F_{a,y})\}\exp(-M/2)$$

$$SB_y=\textstyle\sum_a M_{a,y}N_{a,y}$$

SB and SS represent spawning biomass and spawning success (recruits per spawning biomass), respectively. *M* represents the maturation rate for each age. Actually, for SS and *F*, the average value between 1999-2003 was adopted.

In the present TAC system, ABC levels are set to maintain or rebuild stocks to a 'suitable yield level realized under the suitable control rule.' Since 2000, Japanese managers have set TAC levels in accordance with harvest control rules based on precautionary and risk averse approaches. The basis for this rule was discussions in the United Nations, especially in FAO (Food and Agriculture Organization). Japanese scientists and managers examined case studies in the United States and the North Atlantic areas, and since 2000 have adopted the general harvest control rule (ABC-rule) for each stock of TAC species. Figure 4 shows the ABC-rule which has been adopted since 2004 (Fisheries Agency and Fisheries Research Agency of Japan, 2004). In the ABC-rule, *B* limit, *F* limit and *B* ban have to be set for each stock. When a stock biomass is below the *B* limit, the stock is assumed to be overfished. In this case, *F* limit is the fishing mortality rate for stock rebuilding. When fishing mortality exceeds the *F* limit, overfishing is considered to be occurring and reduction of the current *F*

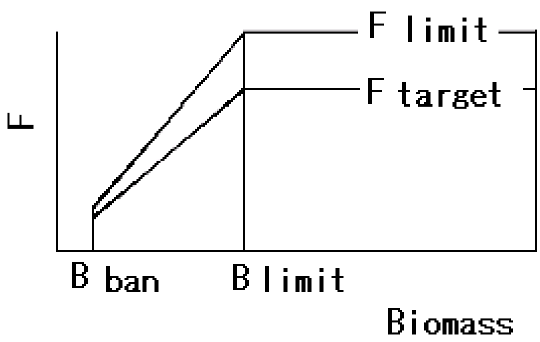

Fig. 4 General harvest control rule (ABC-rule) for each stock of TAC species. In this rule, *B* limit, *F* limit and *B* ban have to be set for each stock. When a stock biomass is below the *B* limit, the stock is assumed to be overfished. In this case, *F* limit is the fishing mortality rate for stock rebuilding. When fishing mortality exceeds the *F* limit, overfishing is considered to be occurring and reduction of the current *F* might be proposed. The *B* ban is the minimum biomass open to fishing and threshold where fishery might be prohibited.

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In the case of the Pacific stock of the Japanese sardine, the minimum spawning biomass for abundant recruits was considered to be that of 1996 in a decade of low stock abundance. The acceptable biological catch (ABC), that is the biological criterion for the TAC, is set to rebuild the spawning biomass at least to the level at which the recruits are expected to be comparable with those of 1996 year-class. Based on such a stock rebuilding idea, the ABC proposal for 2005 was 25,000 tons ('ABC limit' in Nishida *et al*., 2004) . Here, *B* limit was set to the spawning biomass in 1996 and *F* limit was set to rebuild the stock to *B* limit level in five years.

6. Examination of Some Catch Amount Scenarios for the Purpose of Avoiding Intensive Fishing Efforts on Dominant Recruits

The major problem of the present TAC system is that TACs are sometimes considerably larger than ABCs. Under the present legal system, marine capture fisheries are managed by the minister and prefectural governors. Therefore, many management bodies exist for each stock, particularly if the stock is distributed widely beyond prefectural jurisdictions. Each management body considers economic and social factors, which tend to increase each individual TAC allocation and the sum of the TAC allocations for each stock.

A solution of this problem might be to modify the present management framework to include all stakeholders, administrators, and scientists who provide scientific, economic and social information needed for making decisions and executing management plans.

Under the present system, ABC calculation is conducted based on stock assessments mainly relying on catch data from two years prior to the TAC year, and so uncertainty in the fluctuation of recruits in the two years (ABC calculation year and TAC year) is another major problem in ABC calculation.

Here we propose catch amount control with the purpose of avoiding intensive fishing efforts on dominant recruits. We examine the performance of two types of hypothetical scenarios for catch amount control. In this case study, a retrospective analysis was made of stock numbers in the past years, so calculation of past stock numbers under catch amount control was forecasted as follows.

$$N_{a,y}=N_{a\text{-}1,y\text{-}1}\exp(-M)-CL_{a\text{-}1,y\text{-}1}$$

$$N_{0,y}=SB_y\,SS_y$$

CL represents catch amount limit adopted in the hypothetical scenario. *SB* and SS represent spawning biomass and spawning success (recruits per spawning biomass), respectively. In this hypothetical scenario, simulations were done with observed annual SS values (i.e., where the density-dependent effect was ignored due to reduced abundance. See Fig.3) .

Figure 5 shows the observed trajectory of the stock biomass and catch of the Pacific stock of the Japanese sardine under two types of the hypothetical control scenario. The upper panel shows the case of the limitation of total catch set to 180 thousand tons since 1997 for avoiding intensive fishing efforts on relatively dominant year-classes in 1996. 180 thousand tons is the same as the landing in 1996. The lower panel shows the case of the limitation of total catch set to 200 thousand tons between 1999 and 2001, and set to 100 thousand tons since 2002, as recruit abundance had dropped to a level lower than before 2000.

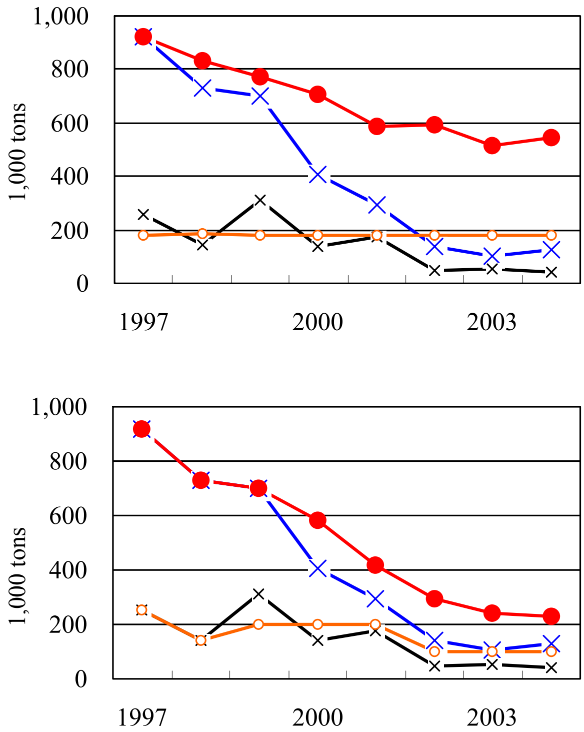

Fig. 5 The observed trajectory of the stock biomass and catch of the Pacific stock of the Japanese sardine. Red line: stock biomass under the scenario, blue line: actual stock biomass, orange line: catch under the scenario, black line: actual catch.
The upper panel shows the case of the limitation of total catch set to 180 thousand tons since 1997 for avoiding intensive fishing efforts on relatively dominant year-classes in 1996. 180 thousand tons is the same as the landing in 1996. The lower panel shows the case of the limitation of total catch set to 200 thousand tons between 1999 and 2001, and set to 100 thousand tons since 2002, as recruit abundance had dropped to a level lower than before 2000.

In both cases, the speed of the stock biomass decrease was not as fast as the actual. The observed and predicted trajectory of the stock biomass and catch of the Pacific stock of the Japanese sardine are shown in Fig.5. The simulated catch was less than the actual catch in the first year of controls, however the total catch after two or more years was higher than the actual catch. It appears that intensive fishing on the Japanese sardine probably prevented recovery of the population, as was also the case with the Pacific stock of the chub mackerel *Scomber japonicus* (Kawai *et al.*, 2002).

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