Collapse of the *Arctoscopus japonicus* Catch in the Sea of Japan —Environmental Factors or Overfishing—

Kyuji WATANABE,[1] Kazumi SAKURAMOTO,[2] Hideki SUGIYAMA[3] and Naoki SUZUKI[2]

[1]*National Research Institute of Far Seas Fisheries, Fisheries Research Agency, Shizuoka-shi, Shizuoka 424-8633, Japan*
e-mail: watanabk@fra.affrc.go.jp
[2]*Department of Ocean Science, Tokyo University of Marine Science and Technology, Konan, Minato-ku, Tokyo 108-8477, Japan*
e-mail: sakurak@s.kaiyodai.ac.jp
[3]*Akita Prefectural Fisheries Promotion Center, Oga-shi, Akita 010-0531, Japan*
e-mail: sugipref@akita.lg.jp

Abstract

Sandfish (*Arctoscopus japonicus*) catch fluctuations both in Korea and Akita Prefecture, Japan, coincided closely until the mid 1970s, although each of the catch derives from different stocks. After that, however, the pattern of catch fluctuations in Akita was differed considerably from that in Korea, i.e., the amount of the catch has been very low since the mid 1970s. However, no mechanism behind the similarity and differences in catches between Korea and Akita has been demonstrated so far. The aim of this study is to investigate mechanisms behind these catch fluctuations using the information on ocean environment and catch forecasting model developed by Sakuramoto *et al.* (2001). The result is that the stock depletion occurring in the mid 1970s was due to environmental factors and after that the heavy decline in catches in Akita was due to overfishing. The important thing in managing a fish stock is to avoid putting pressure on fish by high fishing intensity, which has already been depleted, and to avoid losing a chance to recover abundance of fish depleted due to high fishing intensity.

Key words: Akita, catch forecasting, fisheries management, Korea, regime shift, sandfish, water temperature

1. Introduction

Northern 'Sea of Japan' sandfish, *Arctoscopus japonicus*, are one of the most important fish for the people of Akita Prefecture, Japan. Fishing for sandfish has been done in two areas (Fig. 1). One is offshore and the other, in coastal waters. The offshore fishing grounds are formed along a stratum of 200-300 m depth. A Danish seine fishery has been operating in the offshore fishing grounds throughout the year, except for the months in which fishing is closed. In the coastal waters, set net and gillnet fishing gears have been used for harvesting the spawning stock that migrates to the coastal waters mainly in December. The high season of the coastal fishing is, however, very short and lasts only a week in each coastal fishing area (Sugiyama, 1989, 1990, 1991, 1992).

The sandfish catch in the coastal waters off Akita Prefecture amounted to more than 10,000 tons from 1963 to 1975. From 1976, however, it began to decrease sharply and fell to only 74 tons in 1984. There

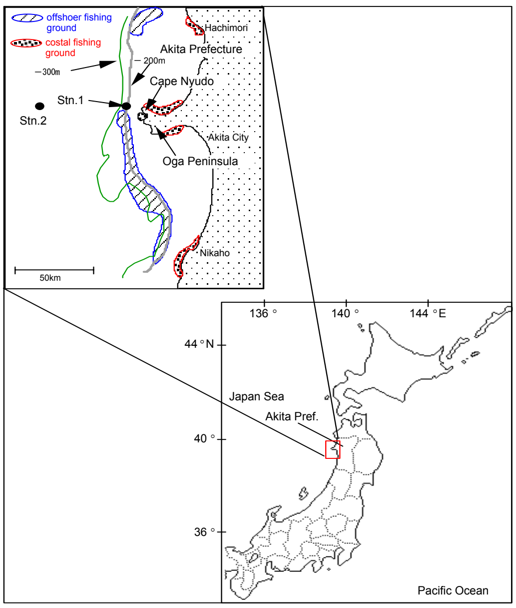

Fig. 1 Locations of fishing grounds for sandfish and sampling points for water temperature off Akita Prefecture.

has been much debate why the catch has decreased so heavily. Some claim that it was due to overfishing (Mizuguchi & Shibata, 1992), and others argue that it was caused by environmental conditions (Sakuramoto *et al.*, 1997). Kawasaki (1983) implicitly noted the occurrence of a regime shift by showing that patterns of fluctuations in sardine catches in Europe, Chili, California and the Far East of Pacific were very similar to each other. Since then, the regime shift theory has become popular. A regime shift is defined as 'what occurs when the climate has abruptly changed within a shorter period than that of the population fluctuation (Yasunaka & Hanawa, 2002).' or 'basic global systems that are constructed as a result of shifts in climate (atmosphere), oceans and ocean-ecosystems in a decadal time scale' (Kawasaki, 1983). Some people believe that the ocean environment is the cause of catches fluctuations (Kawasaki, 1983; Noto & Yasuda, 1999; Oh *et al.*, 2002; Nihira *et al.*, 2003). However, there has been no explanation of why the sandfish catch in Akita Prefecture was heavily depleted.

The aim of this study is to elucidate the mechanism behind the fluctuation in the sandfish catch. In other words, we would like to clarify which is the main cause of the catch fluctuations, environmental factors or overfishing.

2. Materials and Methods

2.1 Catch data and environmental information used in this study

We used the following catch data, water temperatures and years of the regime shifts for the analysis.

1) The annual catches of sandfish by set net fishing and Danish seine fishing off Akita Prefecture from 1961 to 1998 (Anon., 1998).

2) The mean water temperature in depth strata of 0-50 m, 75-150 m and 200-300 m at Station 1 from April to December, from 1961 to 1998 (Anon., 1998). Station 1 is located along this 200-300 m depth contours at 9 km off Cape Nyudo (Anon., 1998) (Fig. 1).

3) Statistics on offshore trawl fishing in area off the Sea of Japan (Anon., 1978-1998).

4) The annual catches of sandfish by trawl fishing off the east coast of the Korean Peninsula from 1961 to 1998 (Anon., 1965-1998).

5) The annual catches of sandfish by gill net fishing and trawl fishing in the western Sea of Japan from 1961 to 1998 (Anon., 1989).

6) The years when the regime shifts occurred (Yasunaka & Hanawa, 2002).

The word 'Korean catch' used in this study indicates the sum of the catches harvested from Korean waters by Korean fishermen and those harvested from the western Sea of Japan by Japanese fishermen, because the sandfish caught in these areas are the same stock, called the 'Eastern Korean Peninsula stock' (Okiyama, 1970; Fujino & Amita, 1984; Watanabe *et al.*, 2003). In Korea, sandfish are not valuable and are landed only as a by-catch by the walleye pollack fisheries. Thus, from Korea there is little biological information such as migration patterns, the locations and depths of their habitats, the age-composition of landed fish, and so on. On the contrary, in Akita, plenty of biological studies on sandfish have been conducted. Therefore, our detailed investigation of the relationship between sandfish catches and environmental conditions will be conducted mainly using data collected in Akita.

2.2 Forecasting models

Using forecasting models developed by Sakuramoto *et al.* (2001), we forecasted the coastal and offshore catches. The coastal and offshore catches in years t, c_t, and o_t, are calculated as follows:

$$\mathbf{y} = \mathbf{A}\mathbf{x_c} + \boldsymbol{\varepsilon}_\mathbf{c} \tag{1}$$

$$\mathbf{z} = \mathbf{A}\mathbf{x_o} + \boldsymbol{\varepsilon}_\mathbf{o} \tag{2}$$

The vectors $\boldsymbol{y}$ and $\boldsymbol{z}$ are as follows:

$$\mathbf{y} = (\ln c_1 \;\; \ln c_2 \;\; \cdots \;\; \ln c_k\,)^T \tag{3}$$

$$\mathbf{z} = (\ln o_1 \;\; \ln o_2 \;\; \cdots \;\; \ln o_k\,)^T \tag{4}$$

Here, T and k denote the transpose of the vector and the number of data, respectively. The terms $\boldsymbol{\varepsilon}_\mathbf{c}$ and $\boldsymbol{\varepsilon}_\mathbf{o}$ denote the vectors of error terms and each element of $\boldsymbol{\varepsilon}_\mathbf{c}$ and $\boldsymbol{\varepsilon}_\mathbf{o}$ follows the normal distribution, with the mean of zero and variances σ_c^2 or σ_o^2, respectively. The variables $\boldsymbol{x_c}$ and $\boldsymbol{x_o}$ are also vectors with dimensions of two and four, respectively. The elements of vectors $\boldsymbol{x_c}$ and $\boldsymbol{x_o}$ are as follows:

$$\mathbf{x_c} = (\alpha_0\,\alpha_1\,\alpha_2\,\alpha_3\,)^T \tag{5}$$

$$\mathbf{x_o} = (\beta_1\,\beta_3\,)^T \tag{6}$$

The elements of matrices **A** and **B** are the catch and water temperature transformed by equations (9) – (11).

$$\mathbf{A} = \begin{bmatrix} 1 & u_{i,1} & u_{i,2} & u_{i,3} \\ 1 & u_{i+1,1} & u_{i+1,2} & u_{i+1,3} \\ & & \cdots & \\ 1 & u_{k,1} & u_{k,2} & u_{k,3} \end{bmatrix} \tag{7}$$

$$\mathbf{B} = \begin{bmatrix} u_{i,1} & u_{i,3} \\ u_{i+1,1} & u_{i+1,3} \\ \cdots & \\ u_{k,1} & u_{k,3} \end{bmatrix} \tag{8}$$

Here, k denotes the number of data. The elements of the matrices $u_{t,\bullet}$ are transformed as follows:

$$u_{t,1} = \ln(c_{t-1}\,) \tag{9}$$

$$u_{t,2} = \ln(c_{t-2}\,) \tag{10}$$

$$u_{t,3} = \ln(w_{9,\,t-1} + w_{9,\,t-2} + w_{9,\,t-3}\,) \tag{11}$$

Here, $w_{9,t}$ denotes the water temperature at station 1, at the depth of 200-300 m in September of year t. The parameter vectors $\mathbf{x_c}$ and $\mathbf{x_o}$ can be estimated by the least square method. Using $\mathbf{x_c}$ and $\mathbf{x_o}$ estimates, we can extrapolate the catch in the following year as follows:

$$\hat{c}_{k+1} = \exp(\begin{bmatrix} 1 & u_{k+1,1} & u_{k+1,2} & u_{k+1,3} \end{bmatrix} \hat{\mathbf{x}}_{\mathbf{c}}) \quad (12)$$

$$\hat{o}_{k+1} = \exp(\begin{bmatrix} u_{k+1,1} & u_{k+1,3} \end{bmatrix} \hat{\mathbf{x}}_{\mathbf{o}}) \quad (13)$$

Here, ^ denotes the estimated variable or matrices.

2.3 Simulation tests

As mentioned before, from 1976 to 1979, the catches in Akita and Korea drastically decreased, however, the catch in Korea increased again after around 1980. On the contrary, in Akita, the catch has continued at a very low level without recovery since around 1980. It is recognized, however, that the catch showed an increase from 1979 to 1980 (see allow in Fig. 2). Figure 3 shows that one to three years prior to 1979, the water temperatures changed from cool to warm. This would indicate that the environmental condition changed from a decreasing condition to an increasing condition, as Korean catch indicated. Thus, it is thought that the catch in Akita would have increased if the fishing had not continued so intensively. In order to demonstrate this, we conducted the seven following simulations. Scenarios 1-4 are cases in which fisheries were closed for one year, including both offshore and coastal fisheries. The year of closure is 1978 in scenario 1, 1979 in scenario 2, 1980 in scenario 3 and 1981 in scenario 4. Scenarios 5-7 are the cases when 10%, 20% or 30% catch reduction from 1978 to 1980 were conducted instead of one-year fishing closure. In these simulations, we assumed that the amount of catch by the coastal fisheries was proportional to the spawning stock biomass, because the coastal fisheries, which use, for example, set nets or gill nets, are passive fisheries and only fish migrating to the coast for spawning are harvested. If the fish could escape being harvested by the offshore fisheries, they would also migrate to the coast for spawning that year or the following year. Then, for simplicity, in this simulation we assumed that both the catches that escaped harvesting due to the closure were incorporated into the spawning stock biomass (SSB).

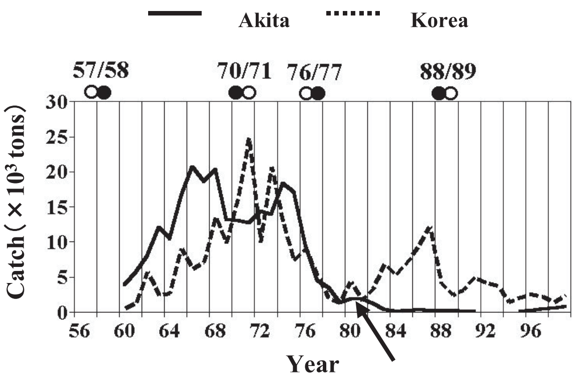

Fig. 2 Trajectories of catches harvested in Akita and Korea. Circles indicate the years when regime shifts occurred. The allow indicates a year when the catch in Akita seemed to have an increasing tendency.

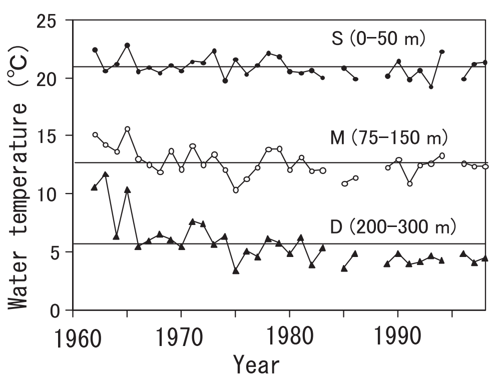

Fig. 3 Trajectories of water temperatures in the depth strata of 0-50 m, 75-150 m and 200-300 m at Station 1 from April to December from 1961 to 1998 (Anon., 1998). The horizontal lines indicate the mean water temperature in each depth layer.

For the simulation trials, we define the following notations:

N_t ; number of fish at year t
R ; ratio of migrated fish to the coast for spawning
$R \cdot N_t$; number of migrated fish to the coast for spawning
$(1-R)N_t$; number of fish stay in the offshore waters
E_o ; exploitation rate in the offshore waters
E_c ; exploitation rate in the coastal waters
NS_t ; number of spawning stock in the coastal area in year t
ef_c ; effective factor due to catch regulation in the coastal waters when a reduction rate of catch is d
ef_o : effective factor due to catch regulation in the offshore waters when a reduction rate of catch is d

For simplicity, we assumed that R, E_o and E_c are constant regardless of year. The catch in the coast and the number of spawning stock are calculated by equations (14) and (15).

$$c_t = E_c R \, N_t \quad (14)$$

$$NS_t = (1-E_c)\, R \, N_t \quad (15)$$

From equations (14) and (15), we obtain,

$$NS_t = \frac{1-E_c}{E_c} c_t \quad (16)$$

We define the effective factor in the coastal waters as follows:

$$ef_c = \frac{d \cdot c_t}{NS_t} = \frac{d \cdot E_c}{1-E_c} \quad (17)$$

Here, d=1.0 indicates the complete closure of fishing, and d=0.1, d=0.2, and d=0.3 corresponds to the cases in scenarios 5, 6 and 7, respectively. That is, ef_c is scaled with the amount of catches that protected by closure or catch reduction comparing to the NS_t when the fishing is operating without fisheries closure or any regulation. On the offshore waters, we defined the effective factor as follows:

$$ef_o = R\frac{d \cdot o_t}{(1-E_o)\ (1-R)N_t} = R\frac{d \cdot E_o}{1-E_o} \quad (18)$$

That is, the potential catch that is necessary to forecast the catch in the following year is calculated by equation (19). After a one-year closure, it is assumed that the surplus catch that would be incorporated into the SSB decreases with the survival rate S, which is including a fishing mortality. In this case, we extrapolated the potential catches, using equations (12) and (13), which would have been harvested when no regulation was enforced. In order to extrapolate the catch in the following year, c_t' is calculated by equation (19), i.e., during and after the year of closure, c_t' is used instead of c_t in equations (9) and (10).

$$\begin{aligned} c_t' &= \hat{c}_t & t &< K \\ c_t' &= \hat{c}_t\ (1+ef_c) + \hat{o}_t\ ef_o & t &= K \quad (19) \\ c_t' &= \hat{c}_t + c'_K\ S^{t-K} & t &\geq K \end{aligned}$$

In the case of scenarios 5-7, i.e., the cases when 10%, 20% or 30% catch reduction from 1978 to 1980 were conducted instead of one-year fishing closure, c_t', is calculated by equation (20)

$$c_t' = \hat{c}_t \qquad t < 1978$$

$$c_t' = \hat{c}_t + d\sum_{i=0}^{t-1978} \{\hat{c}_t\ (1+ef_c) + \hat{o}_t\ ef_o\}\ S^i \qquad t = 1978,\ 1979,\ 1980$$

$$c_t' = \hat{c}_t + [d\sum_{i=0}^{1980-1978} \{\hat{c}_{1980-i}\ (1+ef_c) + \hat{o}_{1980-i}\ ef_o\} S^i]\ S^{t-1980} \qquad t > 1980 \quad (20)$$

For simplicity, in the simulations, we assumed that $R = 0.5$, $E_o = 0.3$, and $E_c = 0.5$. Then the average exploitation rate for offshore and coastal waters is 0.4, and if natural mortality coefficient per year is assumed to be 0.3, the average survival rate becomes S = exp(–0.9).

3. Results

3.1 Comparison of the catches between Akita and Korea

Table 1 shows some part of parameters estimated by least square method. Figure 2 shows the respective catch trajectories in Akita Prefecture and Korea. The catch in Akita shown here denotes the total catches, the summation of the catches harvested by coastal and offshore fisheries. The pattern of catch trajectories in Akita and Korea are very similar to each other before the 1980s. That is, the catches increased from the 1960s, and became maximum around 1970. After that the catches decreased steeply. However, after the mid 1980s, the pattern of these two trajectories behaved differently. That is, the catch in Korea increased again after the beginning of the 1980s; however, that in Akita remained low.

Table 1 Parameters estimated and the years that the data are used for estimation.

Year	α_0	α_1	α_2	α_3
1964-1970	–1.1121	0.3732	0.3473	1.2313
1964-1971	2.7663	0.3164	0.2104	0.5672
1964-1972	2.8884	0.3163	0.2067	0.5374
1964-1973	2.7046	0.3133	0.2185	0.5717
1964-1974	2.8726	0.3049	0.2143	0.5542
1964-1975	0.3392	0.2725	0.3389	1.0942
⋮	⋮	⋮	⋮	⋮
1964-1997	0.9953	0.7208	–0.1929	1.1170

The black and white circles shown in Fig. 2 indicate years when regime shifts occurred (Yasunaka & Hanawa, 2002). The Korean catch fluctuations coincided well with these regime shifts. That is, the first regime from 1958 to 1970 and the third regime from 1977 to 1988 correspond to increasing phases of the catch. The second regime from 1971 to 1976 and the fourth regime starting from 1989 correspond to decreasing phases of the catch. The catch fluctuations in the first increasing and first decreasing phases also coincided well with the catches in Akita, but differ sharply from the Korean catch after the end of the 1970s. Why did this difference occur? We will discuss this later.

3.2 The relationship between water temperature and catch in Akita

Figure 3 shows the trajectory of water temperatures in depth strata 0-50 m, 75-150 m and 200-300 m at Station 1. The three horizontal lines show the mean values in each respective depth layer. Figure 3 demonstrates that in the 1960s, many years showed water temperatures higher than average, but, in the middle of the 1970s, the water temperatures suddenly decreased. After the 1980s, not so many cases of high water temperatures were recognized and the temperature were rather low. These patterns of water temperatures and catches coincided well.

3.3 Fishing intensity

Figure 4 shows the ratio of the catch harvested by the offshore fisheries to the total catch harvested by

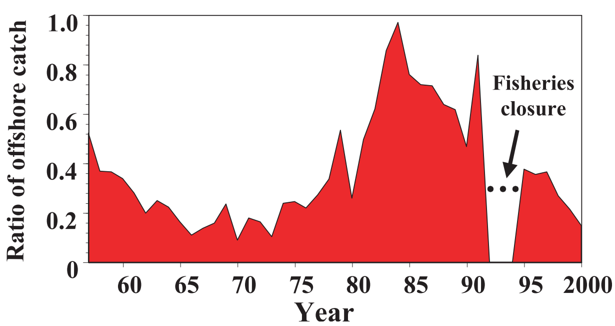

Fig. 4 The ratio of catch harvested by the offshore fisheries to the total catch harvested by the offshore and coastal fisheries combined.

offshore and coastal fisheries. The ratio has steeply increased since 1975, when the amount of the catch drastically decreased. The target fish for the coastal fisheries is only the spawning stock migrating to the coast, but, the offshore fisheries harvest immature and mature fish before they migrate to the coast for spawning. Thus the abrupt increase in the ratio means that overfishing had occurred in the offshore area and this prevented the population from recovering from low stock levels.

3.4 Results of simulation tests

We show the results of scenarios 1- 4 in Fig. 5 and scenarios 5-7 in Fig. 6. Table 2 shows the tons of catch protected due to the fisheries closure or 10%, 20% or 30% catch reductions. For instance, in the case of scenario 1, the forecasted catch in 1978 was 3,533 tons, and the one-year closure meant that everyone forfeited this amount of catch. This means that a great number of fish could escape harvesting and spawn their eggs. Catch trajectories in both Akita and Korea showed that the catches in 1980 were greater than those in 1979 (see Fig. 2). This indicates that the oceanographic conditions were conductive to population rehabilitation. Thus, as is shown in the upper left of Fig. 5 (scenario 1), the catch recovered rapidly by 5,000 tons. However, in the case of scenario 2, the forecasted catch in 1979 was small, only 1,389 tons. This meant that oceanographic conditions were not so good, and furthermore, the number of fish that could escape harvesting was very a few. As a result, the catch could not recover, as shown in the lower left of Fig. 5 (scenario 2). The same explanation holds for both scenarios 3 and 4. The trajectory of the catch derived from scenario 1 was similar to that observed for the Korean catch.

Figure 6 shows the cases when catch reduction was conducted instead of closure, because it is generally very difficult to achieve complete fisheries closure. When a 10% catch reduction was conducted from 1978 to 1980, the effect of the reduction was not so high. However, when a 20% catch reduction was conducted from 1978 to 1980, the effect of the reduction was high enough, and almost the same as that of the one-year closure commencing in 1978. In this case, the total catch reduction was 1,800, much smaller than that for scenario 1. The effect of a 30% catch reduction was higher than that of the 20% catch reduction.

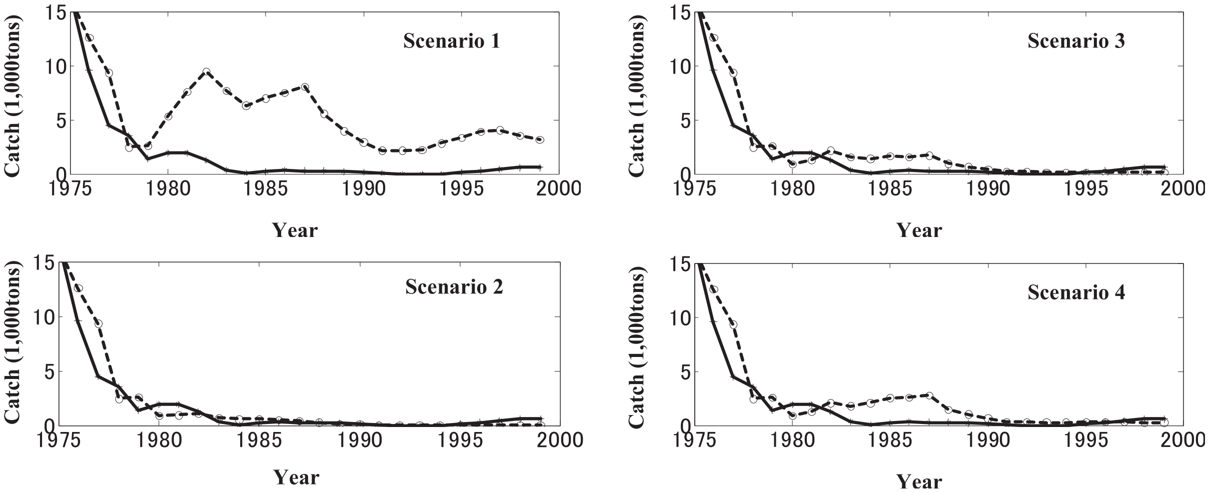

Fig. 5 Results of simulation tests when one-year fisheries closures were enforced.
Solid and broken lines indicate the observed and simulated catch trajectories, respectively.

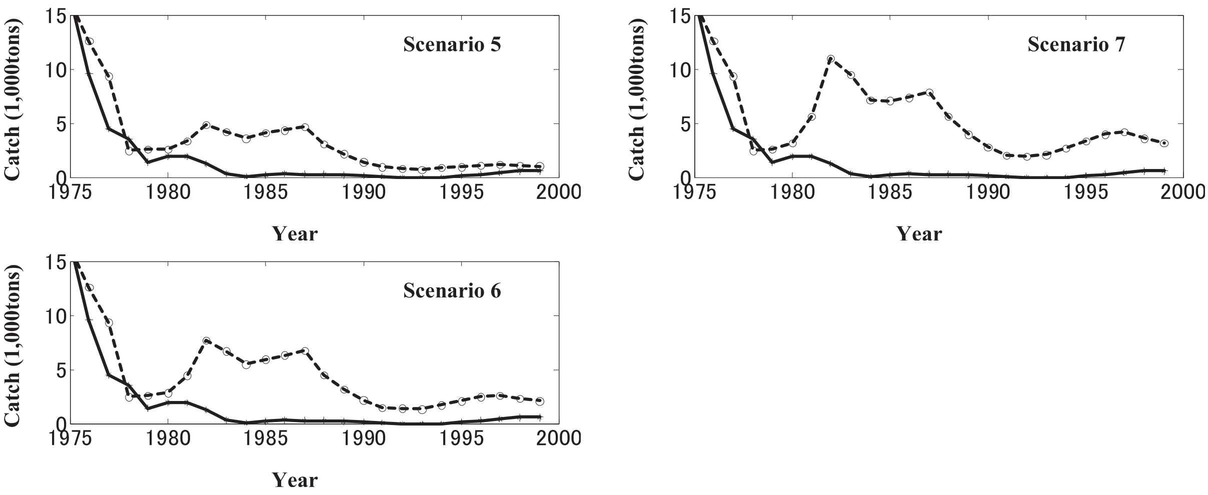

Fig. 6 Results of simulation tests when three-year catch reductions were enforced.
Solid and broken lines indicate the observed and simulated catch trajectories, respectively.

Table 2 The amount of catch forfeited due to fisheries closure or catch reduction.
Total catch reduction donotes the total catch forfeited during the three year peroid. Figures in scenarios 1- 4 and the first figures in the parentheses in scenarios 5-7 were forecasted catch using the forecasting model.

	1978	1979	1980	1981	Total catch reduction
scenario 1	3,533				
scenario 2		1,389			
scenario 3			1,898		
scenario 4				1,935	
scenario 5	353 (= 3533*0.1)	259 (2591*0.1)	260 (2597*0.1)		872
scenario 6	706 (= 3533*0.2)	518 (2591*0.2)	576 (2878*0.2)		1,800
scenario 7	1,060 (= 3533*0.3)	777 (2591*0.3)	950 (3165*0.3)		2,787

4. Discussion

In this study, we assumed that the exploitation rate in the coast is 0.5. However, the true rate would be much higher than this assumption. If E_c is grater than 0.5, the ef_c becomes greater than 0.5 $d/(1-0.5)$, i.e. the effect of regulation would be higher than the case presented in the simulations. Therefore, the result of the simulation shown here would be an under-evaluation of the catch regulations. Equally, if E_o is grater than 0.3, the ef_o becomes grater than $0.3Rd/(1-0.3)$, i.e. the effect of regulation would be higher than the case presented in the simulations. However, in the case of offshore fisheries, there is a possibility that the E_o is smaller than 0.3. If E_o is smaller than 0.3, the ef_o becomes smaller than $0.3Rd/(1-0.3)$, i.e. the effect of regulation would be smaller than the case presented in the simulations. However, the difference would not be so large. If R is grater than 0.5, the effect of catch reduction will be grater than the case shown in the simulations, and vice versa.

The idea of regime shift has gained popularity and is a useful tool for explaining populations and catch fluctuations. However, as was shown in this study, it is also very important to evaluate the effect of harvesting. The results of this study are summarized as follows:

1) The catch fluctuations in Korea occurred due to environmental factors. These coincided well with the regime shifts that occurred in 1957/58, 1970/71, 1976/77 and 1988/89, i.e., the first regime from 1958 to 1970 and the second regime from 1971 to 1976 corresponded to increasing phases, while the third regime from 1977 to 1988 and the fourth regime starting from 1989 corresponded to decreasing phases.
2) The catch fluctuations in both Korea and Akita coincided well before the middle of the 1970s, i.e., before the second regime ended in 1976. After that, however, the pattern of catch fluctuations in Akita differed from those in Korea. In Akita, the amount of the catch has been very low since the middle of the 1970s.
3) The ratio of the catch harvested by the offshore fisheries to the total catch harvested by the offshore and coastal fisheries combined has increased steeply since 1975, when the amount of catch drastically decreased. This means that high intensity of fishing had injected in the offshore area and this prevented the population from recovering from a low stock level.
4) The results of the simulation tests indicated that if catch reduction had commenced during the beginning of the third regime, the catch would have increased again and the trajectory of the catch in Akita would have been similar to that in Korea.
5) The important thing about catch reduction is its timing. If it is conducted in the year when the environmental conditions are not so good and stock abundance is very low, the effect of management is low. Thus it beans repeating that catch reductions or fisheries closures should be commenced during years when environmental conditions are good, before stock abundance has been heavily depleted.

The conclusion of this study is that the stock depletion occurring in the middle of the 1970s was due to the environmental factors, and the heavily reduced catch in Akita after that year was due to overfishing. The important thing when we manage fish stocks is to avoid putting pressure on the fish which are already depleted due to high fishing intensity, and to avoid losing a chance to rebuild their population level.

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