JAPANESE CREATIVITY IN ECO-SYSTEMS MANAGEMENT: THE CASE OF FISHERIES MANAGEMENT DURING 1975-1988

MATSUDA Hiroyuki

Kyushu University

INTRODUCTION

Until the Meiji Restoration of 1868, the Japanese used to eat fish almost every day. Japanese had developed the culture of eating rice and fish during their history as a nation. While their dietary habit has since changed considerably with meat becoming more important, the Japanese still eat fish far more frequently than the people in the West. In fact, Japan is the largest importer of marine bioresources (2,850 thousand tons and 1,687 billion yen in 1991). What I propose to do in this paper is to discuss Japanese creativity as it relates to the problem of fisheries.

Japanese creativity in fisheries is exhibited, first, by the wide range in their use of marine bioresources. In fact, the Japanese are the people who eat the largest number of bioresources in the world. They eat fishes, shrimps, crabs, squids, octopi, bivalves, laver and kelps. They eat almost all species of fish: tuna, swordfish, salmon, sea bream, cod, flatfish, flying fish, mackerel, sardine, anchovy, pike, and others. They sometimes eat snails, sea urchins, sea cucumber, sea hare, sea squirt, and others. These are not favorite food for just a few Japanese. They also eat almost all species of plankton-feeding pelagic fishes: sardine, anchovy, chub mackerel, spotted mackerel, Pacific saury, horse mackerel, herring, and others.

People do not always eat all species of bioresources that they catch near their country. For example, Americans rarely eat the Pacific saury, despite the fact that this species is abundant in the Northern Pacific Ocean. On the other hand, baked Pacific saury is one of the favorite menu for the Japanese, as is raw Pacific saury.

Japanese creativity is also exhibited in the use of wild fishes rather than cultured ones. About one third of the catch amount in Japanese fishery was sardine in 1987. Recently, modern whaling overexploits some species of whales — blue whales, sperm whales, and others. In addition, the Japanese government has promoted cultured fishery in stead of harvesting wild fishes, partly because cultured fishes are not expected to fluctuate very much in biomass. In this paper, we recommend harvesting plankton-feeding wild fishes as another "creative" use of bioresources — a creative method, as a matter of fact, which is in line with the spirit of sustainable development.

Some wild bioresources often exhibit permanent fluctuations. Economic theory is less familiar with use of non-equilibrium resources. The Japan Fishery Agency usually constructs an economic model based on a stationary stock abundance. Almost all fishing companies do not take account of non-equilibrium bioresources either. The non-equilibrium nature of stock abundance suggests that purse-seine-net fisheries should change their target depending on the stock abundance of each pelagic fish. When the sardine is abundant, fishermen should catch, and consumers should eat, the sardine. On the other hand, when the anchovy is abundant, they should use the anchovy in stead of sardine. The idea is that people should use a fish that is currently abundant. However, Japanese fishermen, fish-meal companies and consumers still use the sardine after the sardine population has drastically decreased.

The third area in which Japanese creativity is exhibited is the existence of health-oriented consumers. The average per capita rate of calorie intake for the Japanese (2,864 kcal/person in 1986) is lower than that of almost all developed countries. And the Japanese have the longest life expectancy at birth in the world — 76.2 years for men and 82.5 years for women, according to a government report in 1994. The Japanese always look for fresh food, making sure the date produced is as recently as possible. Although the Japanese live in a "rabbit hutch" as one European Community reports put it, they rarely skip lunch as some Americans do.

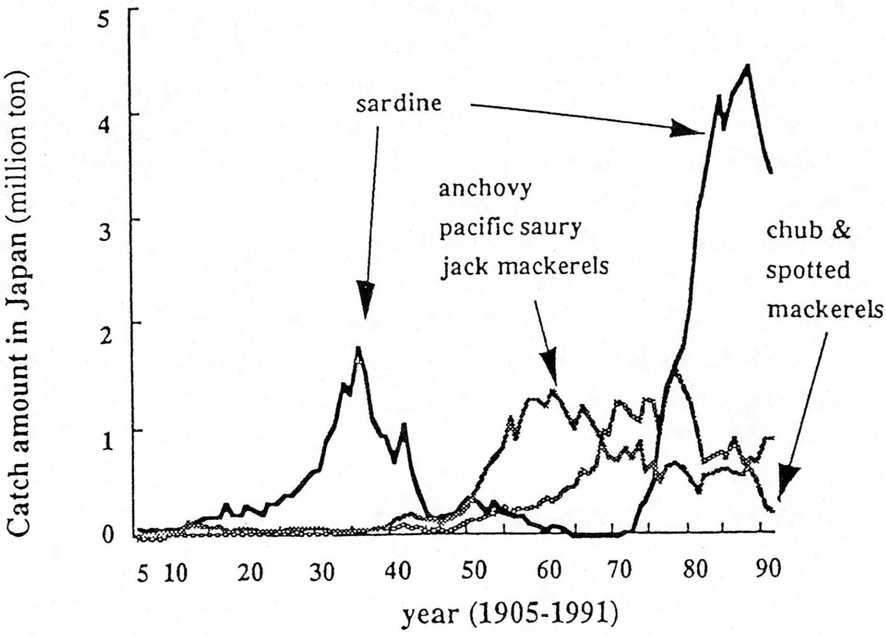
However, there are problems in Japanese fishery. Like other industries, the fishery industry also looks for stable income and stable development. For this purpose, fish companies invested in the construction of large boats. The government promoted cultured fisheries and marine fish farms. These resulted in reduced recruitment of fishermen, over fishing, and sea water pollution.

I consider an economic model with the assumption of stable bioresources to be unrealistic. In the 21st century, we need to pay attention to fluctuations in the natural environment. In this paper, we consider an appropriate harvesting policy of a wild fish whose stock abundance greatly varies from generation to generation. We also discuss some problems in eco-systems management.

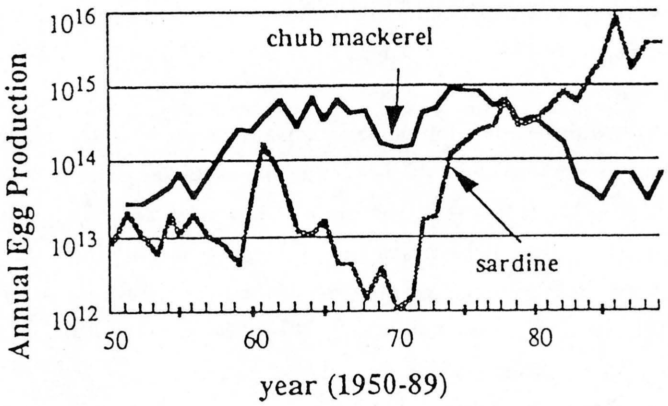
SOME CHARACTERISTIC FEATURES OF PELAGIC FISHES

The first characteristic feature of pelagic fishes is a large amount of stock abundance. According to the number of eggs surveyed by the Japan Fishery Agency and some prefectural stations, the adult population size during the second half of 1980s was about 10 times larger than the catch size. This suggests that the cause of the sardine stock reduction after 1990 was not over-fishing. Fishermen follow a management policy of the government not because of avoiding over-fishing but because of avoiding a slump in fish market. The sardine is cheap and healthy if people eat it directly. However, we usually use sardine as food for domestic animals and cultured fishes.

I consider it possible to catch the Pacific saury at least 10 times the amount we are catching now (about 298,000 tons in 1988). Although the chub mackerel and the sardine are scarce now, I consider that we can catch 10 times the amount we used to catch when they were abundant. If we use these pelagic fishes as a source of protein, they should satisfy a large part of the necessary protein for the Japanese.



Figur 1. Catch amount of some pelagic fishes in Japan during 1905-1991, compiled by Japan Ministry of Agriculture, Forestry and Fisheries (see also et al. 1992c)



Figur 2. The long-term fluctuations of estimated annual egg production of the sardine and chub mackerel in the Pacific ocean off Japan (compiled by Japan Fisheries Agency, see also Matsuda et al. 1992a)

The second characteristic feature of pelagic fishes is the huge fluctuations in their stock abundance. The annual catch of sardine varied from a low of 10,000 tons in 1965 to a high of 4,490,000 tons in 1988 (see Figure 1). The estimated annual egg production (i. e., the estimated number of eggs oviposited by all adults during a year) of the sardine varied from a low of 1.0×10^{12} in 1970 to a high of 0.9×10^{16} in 1986 (see Figure 2). Because fishermen tend to put more effort into fishing at a low stock level than at a high stock level, fluctuations in the catch amount usually underestimate fluctuations in the stock abundance. Other species of pelagic fishes also greatly fluctuate from decade to decade. The sardine population fluctuated at least since 300 years ago (Tsuboi, unpublished manuscript). This is not because of over-exploitation, but probably because of environmental fluctuations or the intrinsic instability of the ecosystem (Matsuda et. al., 1991). In spite of large fluctuations, the Japanese have caught many species of fishes that were abundant.

The third characteristic feature of pelagic fishes is the existence of "species replacement". Catch statistics shown in Figure 1 suggests that the fluctuation in the sardine stock depends on the stock abundance of other pelagic fishes. The sardine was abundant in 1930s and 1980s. The anchovy, the horse mackerel and the Pacific saury were abundant in 1950s and 1960s. The chub mackerel was abundant in 1970s. The catch amounts of these species were low in 1940s due to World War Ⅱ.

MERITS OF WILD PLANKTON-FEEDING PELAGIC FISHES

I recommend people to eat wild fishes, especially plankton-feeding pelagic fishes for the following reasons: (1) Plankton-feeding pelagic fishes are very abundant as shown in Figure 1. Cultured fishes are less efficient from the energetic viewpoint. We feed the sardine to cultured fishes. It is known that about 100 kg of the sardine produces 10 kg of the yellowtail fish. In addition, marine fish farming usually has some problems of the sea pollution. Therefore, wild plankton-feeding pelagic fishes show a good cost-performance for consumers. (4) Fishermen easily catch them, since they form a school and a purse-seine-net fish boat catches the whole school of fish in one time.

We know that the plankton-feeding pelagic fishes are one of the most healthy foods. They contain rich decosa-hexaenoic acid (DHA) and eicosa-pentaenoic acid (EPA), kinds of unsaturated fatty acids. Most Japanese find these fishes very tasty. There are many ways of cooking them: raw fish, baked fish, boiled fish, fish cake and others. Although it has been difficult to keep them fresh, we can keep frozen for a long time due to recent advances in technology. We believe that a wild fish meal is healthier than a meal of cultured fishes or domestic animals. These plankton-feeding pelagic fishes have low risk from biological concentrations, while tunas and other fish-feeding fishes contain a high concentration of heavy metals due to biological concentration.

A few problems do exist in the purse-seine-net fishery, however. (1) Because of the huge fluctuations in stock abundance, the fishery may lead to over-exploitation when it is rare (see below). Of course, fishermen can change their target when they change the mesh size of purse-seine-nets. (2) These fishes are poor cost-performance on the supply side. Consumer demands do not change enough to cause variations in the annual catch.

All in all, eating more wild fishes would be a creative use of bioresources. I therefore recommend people to put more reliance on wild fishes. Although the sardine off Japan is decreasing now, we can catch some kinds of plankton-feeding pelagic fishes: the anchovy, the Pacific saury and the horse mackerel.

SOME HYPOTHESES FOR SPECIES REPLACEMENT OF PELAGIC FISHES

There are several models for species replacement of pelagic fishes: (1) single population model, (2) prey-predator model (Collie and Spencer, 1995), (3) 2-competing-species model (Shirakihara and Tanaka, 1981), (4) environmental fluctuation model, and (5) cyclic advantage model (Matsuda et al, 1992c). Matsuda et al (1991) investigates whether these models can explain some characteristics of fluctuations in the stock abundance of pelagic fishes.

A biological population often attains a stable population density, which we call the carrying capacity. This is because the per capita rate of reproduction decreases with the population density. On the contrary, some mathematical models predict that a biological population can fluctuate permanently due to a strong density effect on the per capita rate of reproduction. A permanent oscillation forms a periodic cycle or a non-periodic fluctuation even under a constant environment. Mathematicians call the latter "chaos" May (1975) introduced this term into ecology. However, these single species models predict that the density over the carrying capacity does not continue for more than one generation, while the high stock level and low stock level in pelagic fishes continue for several generations.

On the other hand, if species A defeats B due to a stronger competitive ability, B defeats C, and C defeats A, then a mathematical model predicts that these 3 species permanently fluctuate (May and Leonard, 1975). I call this model "cyclic advantage hypothesis" for the species replacement of pelagic fishes. I consider that the sardine is stronger than the chub mackerel, the chub mackerel is stronger than the anchovy, the horse mackerel and the Pacific saury, while these species are stronger than the sardine. This model predicts what the next dominant species is, since A will be dominant after B is dominant. Therefore, this hypothesis is testable by a long-term replacement pattern (Matsuda et al, 1992c).

Cyclic advantage relationship is familiar with Japanese and East Asian people. They usually play the "scissors-paper-stone" game, while Europeans use the coin-toss. In Japanese, cyclic advantage among three players is expressed by one word: *"san-sukumi"*. The widespread use of the "scissors-paper-stone" game suggests that the cyclic advantage hypothesis could be interpreted as another manifestation of Japanese creativity.

OPTIMAL HARVESTING POLICY FOR A FLUCTUATING BIORESOURCE

Whatever may be the factors that produce huge fluctuations in stock abundance, we must find an optimal harvesting policy for a biosphere. Matsuda et al (1992a, b) estimated long-term fluctuations in reproduction rates in the sardine and the chub mackerel from the data on the annual catch and estimated annual egg production. In this paper, we ignore the interaction between species in stock fluctuation (See Matsuda et al, 1991, for management policy under the cyclic advantage hypothesis).

We investigated temporal fluctuations in the reproduction index of chub mackerel in Japan for the period 1972-1985, when the stock abundance of chub mackerel varied from a high to a low level. Because the chub mackerel matures at three years and oviposits eggs every year, we consider a model with two stages: the number of eggs and the number of adults. We know the estimated annual egg production each year (denoted by E_t, where t refers to year) and the annual catch amount in biomass (C_t). We considered the following assumptions: (1) The survival probability of an adult (S) is constant; (2) The stock of adult fish in biomass (N_t) is proportional to the egg production of the year (E_t); (3) The fecundity of adult per biomass is constant; (4) The maturation age is constant (i. e., 3 years); and (5) The survival rate from egg to maturation (R_t) varies with the environmental condition when it was born (b_t) and decreases with the number of eggs in the same cohort (E_t, or the number of adults, N_t). In population ecology, the survival rate is often formulated by the Ricker equation: $R_t = exp\{b_t\text{-}kN_t\}$, where k is the strength of the density effect on population growth and b_t varies with time, which is affected by some environmental conditions, e.g., the average water temperature where and when the egg was born.

The stock level each year is determined by the estimated egg production. We can calculate the survival rate from egg to maturation, R_t or b_t. From these assumptions and the data on E_t and C_t, we can implicitly obtain the reproduction index, R_t:

$$N_t = SN_{t-1} + R_{t-m}N_{t-m} - C_t$$

where m means the maturation age. We obtained the reproduction index of the chub mackerel population from 1972 to 1985 (Matsuda et al., 1992b). The reproduction index greatly varied from year to year. In addition, if the reproduction index, b_t, is fixed irrespective of the catch, we can evaluate the final stock abundance and the annual catch under any harvesting policy. We may expect that there is a tradeoff between increasing total catch and stock conservation. If the annual catch is higher than the actual catch for every year, the final stock is lower than the actual stock level. However, too much exploitation will decrease the total catch, since the stock level decreases too much.

Suppose a wild fish population that approaches its carrying capacity under zero-catch. If we catch a constant yield from the population every year, the population usually approaches a stable equilibrium stock level that is lower than the carrying capacity. The equilibrium stock level decreases as the annual catch amount increases. If the annual catch is larger than a critical level (called the maximum sustainable yield, or MSY), the population decreases and goes into extinction.

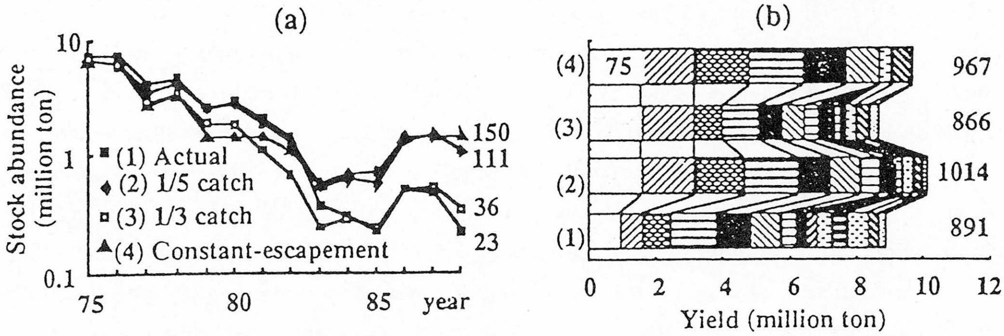
The MSY policy is not guaranteed by conservation biology but derived from economic considerations. If people used a bioresource permanently, over-exploitation by which the resource goes into extinction is not efficient economically. However, there are some factors that may lead to over-exploitation (Clark, 1976). For example, (1) under-development of the economy. That is, one who catches all the resource and invests the benefits in other economical fields may receive a larger interest every year than one who permanently uses the resource under the MSY policy. (2) Uncertainties in the stock level of a bioresource: Stock versus reproduction relationship and future environmental condition may lead to over-exploitation, since the present yield seems to be more important than future yields. (3) If anyone can catch a common resource, over-exploitation is rarely prohibited. If one catches a resource too much while others keep their catch quota, the former can receive a much larger benefit than if the former keeps its quota too. In that case, the latter will lose both the present income and future sustainable yields. Cooperation for the MSY policy is more difficult as the number of fishermen increases. Hardin (1968) called this situation the "tragedy of the commons".

In addition, almost all bioresources, especially pelagic fishes, do not approach their equilibrium. However, we know an optimal harvesting policy which supports sustainable development for a non-equilibrium bioresource. Reed (1969) found the optimal harvesting policy under a fluctuating environment with no auto-correlation as the constant-escapement policy, under which the catch is prohibited if the stock falls below a critical level, N_{crit}; otherwise the catch is the subtraction of the critical stock level from the stock before the fishing season.

We consider an optimal harvesting policy for a chub mackerel population, as a typical example of uncertainty in future environmental conditions. An optimal harvesting policy is defined as one that maximizes the long-term catch of a biosphere. To estimate the effect of various harvesting policies on stock conservation and the long-term catch, we consider four harvesting policies: (1) the actual catch data during 1975-88, (2) a constant 1/3 rate of exploitation (i. e., fishermen exploit 1/3 of adult fish every year), (3) a constant 1/5 rate of exploitation, and (4) a constant escapement of 1.5 million tons. We further assume the maximal annual catch to be 1.5 million tons irrespective of the stock abundance under all policies.

Thus, we can estimate the final stock level in 1988 and the long-term catch during 1975-88 under the various harvesting policies. Under (1)-(4) policies, the final stock level was respectively 23, 36, 111 and 150 tons (see Figure 3a), whereas the total catch was 891, 1014, 866 and 967 million tons respectively(see Figure 3b).

Under (1) the actual catch data and (2) a constant 1/3 rate of exploitation, the final stock level is very low. The actual catch policy gives the worst result of these policies because the resultant rate of exploitation at low stock levels was much larger than 1/3. These policies over-exploited the resource when it was rare. The two policies — (3) a constant 1/5 rate of exploitation and (4) constant escapement — maintained the final stock abundance at a much



Figur 3. Performances of various harvesting policies: (a) Change in stock abundance and (b) annual catch from 1975 to 1988. Components of annual catch are discriminated by hatching patterns in (b).

higher level.

Under (1) the actual catch and (3) a constant 1/5 rate of exploitation, the total catch was less than 9 million tons whereas it was more than 9 million tons under (2) a constant 1/3 rate of exploitation and (4) constant escapement policy. However, (4) constant escapement policy had a long prohibition of fishing from 1981 to 1985 and a large variation in the annual catch. Furthermore, the stock level during prohibition still decreased from 1981 to 1982. Fishermen are unlikely to accept this policy. Under (3) a constant 1/5 rate of exploitation, the catch in 1988 would be almost the same as the actual catch, because a constant 1/5 rate of exploitation would maintain a higher stock level.

WHAT TO DO IN THE NEAR FUTURE?

Although we have considered a policy that maximizes the long-term catch, fishermen are usually interested in increasing short-term benefits from fishing. The price of fish definitely increases as the catch decreases, and the price elasticity of demand is a strong factor that leads to over-exploitation. The most favorable policy for fishermen depends on the market conditions. Recently, we have been able to save frozen fish for more than one year, thus enabling the Japanese to import chub mackerels from Norway. As a result, the price of the chub mackerel in recent years depends less on the annual catch than it did several decades ago. A short-term prohibition may not be critical for the market.

If we support fishermen who refrain from fishing when the fish stock is low, a constant escapement policy may be more easily realizable. For example, if the government employs fishermen as government employees, their income does not depend on their harvesting yield. They do not work so hard as to lead to over-exploitation but work for supplying a sufficient amount of protein resource to people under a catch quota decided by the government.

Needless to say, the problems of fisheries management are not resolved only by fishermen. The problems are strongly connected with the fish market system, including consumers. Fisheries scientists usually say that managing fishermen is more difficult than managing fish populations. Despite the fact that there are many examples of over-exploitation in fisheries, including whaling, we can still exploit much more plankton-feeding pelagic fishes. The Japanese have a tradition of eating pelagic fishes in many ways of cooking. I believe that such a Japanese creativity will help the future shortage of food-supply in the world by showing how an eco-system can be managed while promoting sustainable development.

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