TOWARD A POSITIVE FEEDBACK BETWEEN FISH ABUNDANCE AND DENSE FOREST TO ENHANCE BIODIVERSITY: RESPONSIBLE FISHERIES FROM A VIEWPOINT OF NUTRIENT CYCLING

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ABSTRACT

Traditionally, fish has been considered as an item for direct or indirect human use (food, fertilizer, fishmeal and so on). Recently increasing number of studies on anadromous salmon in North America and Japan, however, suggest that fish could also support biodiversity. Marine-derived nutrients (MDN) are important contributors to maintain or enhance biodiversity in freshwater and riparian ecosystems. This can be rephrased in such a way that ocean helps to enrich terrestrial ecosystem. On the other hand, reevaluation of *uo-tsuki-rin* (fish breeding forest) has been under way in the last two decades or so in Japan. Women of fisheries cooperative associations and other environmentally-concerned people have been planting trees on coastal zone or sometimes on inland. Such activities are to attract fish to the water near such wooded areas. In this case forest is considered to furnish marine (or freshwater as well) fish with habitable environment by giving them shades, nutrients, shelters and so on. Based on these recent trends in research activities and popular actions, this paper characterizes responsible fisheries as a new approach to fisheries which allows a certain number of anadromous and other fish to freely make upstream and downstream migration and incorporates coastal and riparian afforestation in its practices. It then concludes that positive feedback between fish abundance and dense forest is the prerequisite for biodiversity both in terrestrial and marine environments.

Keywords: marine-derived nutrients (MDN), anadromous salmon, fish breeding forest, biodiversity, responsible fisheries, positive feedback

INTRODUCTION

This paper is not intended to define what responsible fisheries is. Rather, it proposes that the concept of responsible fisheries had better to include the viewpoint of nutrient cycling in its definition. The reason for this is that the nutrient cycling is the prerequisite for sustainability of marine and freshwater ecosystems and that sustainability of fishermen's livelihood, their community and fisheries industry is possible only when such ecosystems are fully alive with rich biodiversity.

Generally speaking, nutrient cycling has to be considered both horizontally and vertically. In this paper, however, we consider the vertical aspect of nutrient cycling. Our special attention here is on upward movement of nutrients by seabirds and anadromous fish and on downward movement of nutrients and other matters regulated by coastline and riparian forests.

Nutrient Cycling as Prerequisite for Biodiversity and Sustainable Economy

Due to the universal law of gravity, nutrients and other matters on terrestrial land mass tend to flow or sink down to various types of aquifers, and eventually to the ocean. If this is the only case, however, terrestrial ecosystems become poorer and poorer while rivers, lakes and oceans incur eutrophication of more and more severe kinds. Reversal transfer of sunken nutrients is an absolute requirement for terrestrial ecosystems to sustain themselves. Then the goal of environmental policy has to be the prevention of pollution on the one hand and prevention of oligotrophication on the other hand. As one possibility, compensations for the lost nutrients could be expected to come from the depths of the earth through geological processes such as ocean floor uplifts and volcanic eruptions. In fact, some people recently eyewitnessed a fantastic propagation of fish in a lake in Kamchatka after the volcanic eruption. It was the following event:

> "A Kamchatka eruption in this century gives us a small example of volcanic influence on nature. In 1956, during an eruption of Bezimyanny volcano, on the Arzhabachye Lake (you will see it in the Ust-Kamchatsky Region), heavy ash fell. The ashes brought with them a lot of highly soluble salts. After only a few months the amount of algae in the lake grew almost one hundred times. Algae provides food for crayfish which are the main food for young salmon. Of course, after the eruption, there was a large growth in the reproduction of this fish in the lake, one of the largest spawning grounds in Kamchatka." (*Kamchatka*, 1996, p. 13)

Though an anonymous author of this writing does not specify the name of salmon, his/her context suggests that it is quite likely to be sockeye salmon (*Oncorhyncus nerka*). This type of bonanza directly from the deep earth to terrestrial ecosystems does not, however, occur on a daily basis.

SEABIRDS AND HUMAN BEINGS AS COMPETITIVE PREDATORS ON MARINE FISH

Guano as a precious product of upwelling ecosystem

At the same time we know that terrestrial ecosystems, including human society, somehow have been managing their own survival if there were not such powerful, geological mixings of the deep earth and the surface earth. Nutrient cycling is the key to understand such ecosystems (Pomeroy, 1974; DeAngelis, 1992; Murota, 1998, and others).

Daily, yet massive upward transfer of nutrients occur in association with upwelling in certain parts in the world ocean. A visible product of such upwelling is guano, i.e., accumulation of seabirds' droppings. Upwelling of cold seawater from the depth of ocean brings up nutrients to shallow layer of ocean where sunlight penetrates. Meeting of nutrients with sunlight results in phytoplankton bloom, which in turn brings about zooplankton growth. Fish of various kinds predate on such planktons. The number of fish which can be supported by such a mechanism are usually enormous. The abundance of fish nourishes a great number of seabird population. Quite a number of seabirds then drop their excrements on rocky islands, or coral reefs, or the like. The final product of such an upwelling ecosystem is guano (Schneither and Duffy, 1988; Crawford and Jahnke, 1999).

The guano formation in small islands off Peru is most well known. It is the product of massive, strong upwelling associated with the Peru Coastal Current. It is said that the people under the Inca civilization used guano as a highly effective fertilizer for their agriculture in lofty mountains. An old anecdote of indigenous people there says: "Guano, though not an angel, reveals a miracle."

Herein arises the ocean-mountain continuum concept. If we confine our attention on guano to the age of the non human settlement in South America, nutrients in deep, cold ocean eventually assume the form of guano on islands, and that is the end. But human beings uploaded it to the Andes mountain and fertilize the soil by applying it there. This can be generalized as follows: Mountains and lowlands as well tend to lose nutrients down to ocean. It could come back, however, to terrestrial ecosystems if certain conditions were satisfied. In this sense, ocean and mountain could be a continuous entity through nutrient cycling. The river continuum concept presented by Vannote et al.(1980) can now be seen as a part of such an ocean-mountain continuum.

ANADROMOUS SALMON AS MARINE-DERIVED NUTRIENTS UPLOADER

A question then arises if there are possibilities of such ocean-mountain continuum in the high latitude areas in the Northern Hemisphere. To this question, anadromous fish may be a key. Certain parts of the Northern Pacific and Northern Atlantic used to be highly abundant in fish thanks to the upwelling due to seawater convection. In the ocean of high latitudes the surface gets cooled by super chilled air and the cooled water with relatively high density sinks down into deep ocean.

To compensate such sinking water, deep water upwells with an enormous amount of nutrients toward the ocean surface. This, coupled with sunlight, accelerates primary production in the shallow part of the water column. It then causes zooplankton propagation. This brings about large population of fish and sea mammals. Pacific salmon and Atlantic salmon predate on small fish and their bodies become the masses of marine-derived nutrients (MDN) and energy sources. Their anadromy means a possibility of such nutrients and energy being uploaded onto terrestrial ecosystems in association of their upstream migration for spawning in the freshwater rivers.

Maximum Distance and Altitude Salmon Make Upstream Migration

Salmon spawn near a river mouth if they find good freshwater environment to dig redds. But some go up more. How far do they make upstream migration from a river mouth at a maximum ? Figure 1 shows the representative cases of such maximum distance and altitude of spawning runs of Pacific and Atlantic salmon in major salmon rivers in the world in the historical and contemporary context. The cases of Yukon River and Frazer River are the contemporary ones. The cases of Columbia River and Rhine River are only the historical ones. Figure 1 does not contain the case of Elbe River in Europe. But Atlantic salmon historically made some 1,000 km migration in that river (McCrimmon and Gots, 1979).

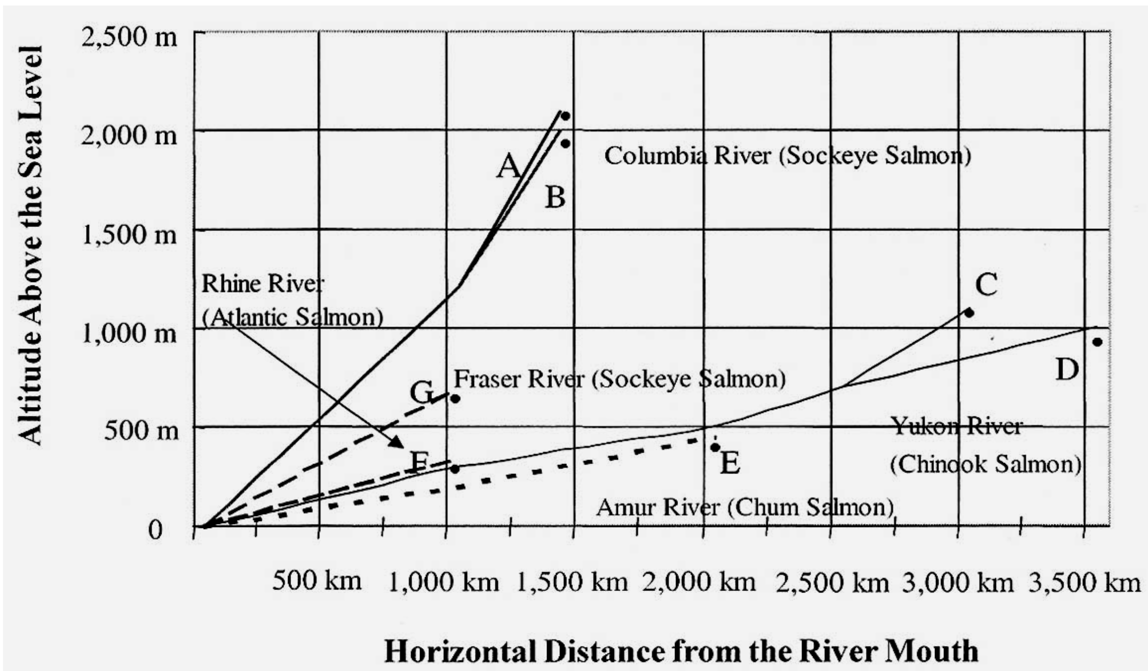

Figure 1. Maximum Fresh Water Distance and Altitude of Spawing Runs of Salmon
Source) Reproduced from Murota (2003, p. 24).

It has been historically known that chum salmon have ascended Amur River as long as 2,000km. I had not been sure, however, if they do so even now. In August 8, 2003, I had an opportunity to make an interview with Mr. Herman Novomodnyi at the Pacific Fisheries Research Center (TINRO) of the Russian Federation in Khabarovsk. He told me and my Russian co-researcher that it is still true that some chum salmon ascend up to the confluence of Silka River and Arguni River, i.e., the area where those rivers change the name to Amur River and that it is 2,000km from its mouth facing the Sea of Okhotsk. In the same month, other Russian scientists told us that Anadir River salmon make upstream migration of some 1,000 km in Chukotka Automous Oblast in Russia. The results of the interviews are summarized in Khantashkeeva and Murota (2004, pp. 56-57).

Such long distance journeys of salmon mean that they have been and are supporting the lives of a whole variety of invertebrates, birds, and mammals in the long range of watersheds of salmon rivers.

Accumulation of Nutrient Uploading Research on Pacific Salmon

The scientific research on this possibility has two pioneers, Chancy Juday in the United States and K. M. Krokhin in the former Soviet Union (Juday et al., 1932; Krokhin, 1957, 1967). Their early researches did not have immediate follow-ups by other scientists. The situation, however, started changing around 1980.

The Pacific coastal areas of Canada has many oligotrophic lakes and rivers. Such aquifers cannot support large number of parrs and smolts of salmon. Some fisheries managers then experimentally sprayed chemical fertilizers over such lakes. In the meantime it occurred to some scientists' minds that salmon carcasses after spawning might contribute to the creation of good habitat for salmon parrs and smolts. More than that, such spawned-out salmon may be predated by certain species of birds and mammals. Spawning runs of Pacific salmon(*Oncorhyncus*, spp.) may even be contributing to give nutrients subsidies to the riparian forest growth, if not directly but indirectly.
Northwest Fisheries Science Center in the US describes the critical situation as follows:

> "Declines in salmon abundance over the last century have resulted in decreased deposition of marine-derived nutrients from salmon carcasses in streams. The effect of this nutrient subsidy reduction on freshwater habitat productivity in the Columbia River watershed must be evaluated. Impacts on freshwater habitat productivity due to the loss of nutrient subsidies from salmon carcasses pose a significant restraint on recovery of threatened and endangered Pacific salmon.
>
> The Columbia River Basin streams have long been starved for the essential nutrients from salmon carcasses and this nutrient starvation has impaired salmonid productivity.
>
> It is necessary to determine minimum nutrient levels needed to maintain optimum salmon production"(Web site: Northwest Fisheries Science Center).

Prompted by the feelings similar to this line of thought, a great number of research have been conducted and many published papers are already available to confirm the fact that Pacific salmon do fertilize terrestrial ecosystems. Salmon carcasses from hatcheries have been often used for experiments. Stable isotope analysis has become an already established tool to find the pathways through which MDNs are incorporated into the terrestrial ecosystems. Among such studies, one can find Cederholm et al.(1989), Kline et al.(1990), Bilby et al.(1996), Hilderbrand et al.(1996), Ben-David (1997), Johnston et al.(1997), Cederholm et al. (1999), Wipfli et al.(2003), Reimchen et al.(2003), Darimont, et al. (2003), Stockner (2003), Zhang, et al. (2003) and many others. The work in the context of Russian Far East is also important (Utekhina, et al., 2000).

Status of Atlantic Salmon

Compared with the studies on MDN associated with Pacific salmon, similar studies on Atlantic salmon(*Salmo salar*) have been only a few. But we should not hastily conclude that Atlantic salmon are insignificant for biodiversity. Semelparity is not the character of Atlantic salmon. After the first spawning they become kelts (black salmon) to go back to the sea. Yet many die soon after spawning. About this point, one finds that: "All members of the genus *Oncorhyncus*, the Pacific salmon, die after their first spawning and about 74 per cent of the individuals of the Atlantic salmon, *Salmo salar*, do so. The massive Danube salmon, Hucho hucho, on the other hand, which clearly has a high probability of survival, may continue to spawn for 20 years or so"(Baker, 1978, p. 808).

Did Atlantic salmon decrease because of being predated by other living organisms including human beings? If there are many species of predators, however, one may be able to argue that Atlantic salmon also contribute to biodiversity. As far as a body of recent research is concerned, it is addressed to the question of asking if such predators bring Atlantic salmon to extinction. Gannettes, merganser and a few other birds have been mentioned in this regard. Otters predate on Atlantic salmon in a river in Scotland (Kruuk, 1995; Carss, et al., 1990). Seals in Maine, US have been known to occasionally eat adult Atlantic salmon, but it is not their common habit. Predation on Atlantic salmon was also discussed by Boss and Richardson(2002) and Dieperink et al.(2002).

Predation on Atlantic salmon may be seen in two opposite direction; negative in the sense that it can drive salmon into extinction, and positive in the sense that salmon support the lives of many species. But I rather argue that it is more important for fishermen and fisheries scientists to face the fact that the decrease in the number of spawning runs of Atlantic salmon has been largely due to the anthropogenic destruction of river ecosystem such as dam construction and so on in many salmon rivers in the northern hemisphere as in the case of Pacific salmon.

REVIVRD INTEREST IN FISH BREEDING FORESTS IN JAPAN

Anadromous salmon (both Pacific and Atlantic) are potentially uploaders of marine-derived nutrients(MDN) onto the terrestrial ecosystems. But their habitait is endangered everywhere in the Northern Hemisphere. Watersheds of potentially salmon rivers have to be the ones to be able to welcome such MDN's upstream flow. On the other hand, terrestrial ecosystems, in turn, are essentially important to marine lives.

Uo-tsuki-rin was considered to be precious for fishermen and be protected in the Yedo ear (1603 and 1867) in Japan. The modern forest law was enacted in 1897 under the new Meiji government. Article 25 of this law stated that uo-tsuki-rin had to be protected as a type of protection forest among many other types of protection forests. This means that the government recognized its importance. The area of such forests increased in the pre-war times, and then their importance was almost forgotten in the post-war times except some excellent research works such as Inukai (1951, 1965) and Miura (1955). But some people came to recognize its importance again. In Hokkaido, women in the fisheries cooperatives started planting trees along the coast in the 1980s. This movement spread all over Japan afterward. The reason why forest is important had been debated in the pre-war period. But now its importance is widely recognized. According to the translation by the Forestry Agency, the Ministry of Agriculture, Forestry and Fisheries, Japan, *uo-tsuki-rin* is 'fish breeding forest.'

Newly revived planting started in 1988 in Hokkaido. In Hokkaido, where the Ainu people used to live and still live, herring fishery is one of the major industries in the Yedo era (1603-1867) and the early times of the Meiji period (1868-1912). Herring was boiled in a big pan and then dried on the beach to become important source of fertilizer in the western part of Japan where agriculture had been highly developed around such big cities as Osaka and others. In order to boil massive amount of herring caught in their spawning season, shoreline trees were felled for firewood. This process continued years and year so that shorelines tended to lose forests. The degree of dependence of agriculture on herring of Hokkaido decreased in the 20th century. Shoreline trees, however, continued to be felled for other development purposes in the same century.

A symbolic example of the result from such deforestation was the disaster which hit the kelp industry around Cape Erimo in Hidaka region after the World War II. The coastline near Cape Erimo had had a reputation as high quality kelp producing region. But the very region totally stopped producing kelp of good quality. It was obvious to the eyes both of fishermen and national forest administrators that the desertification of the coastline was the cause of such a disaster. They then made tremendous efforts to spray seeds of grasses over the beach and cover them by valueless kelp and so on to prevent the grass seeds from flying away by strong wind. After the beach became a grass land, they planted trees there. Such labors were spent in several decades in the post-war age. Kelp of high quality is now back to the Cape Erimo region.

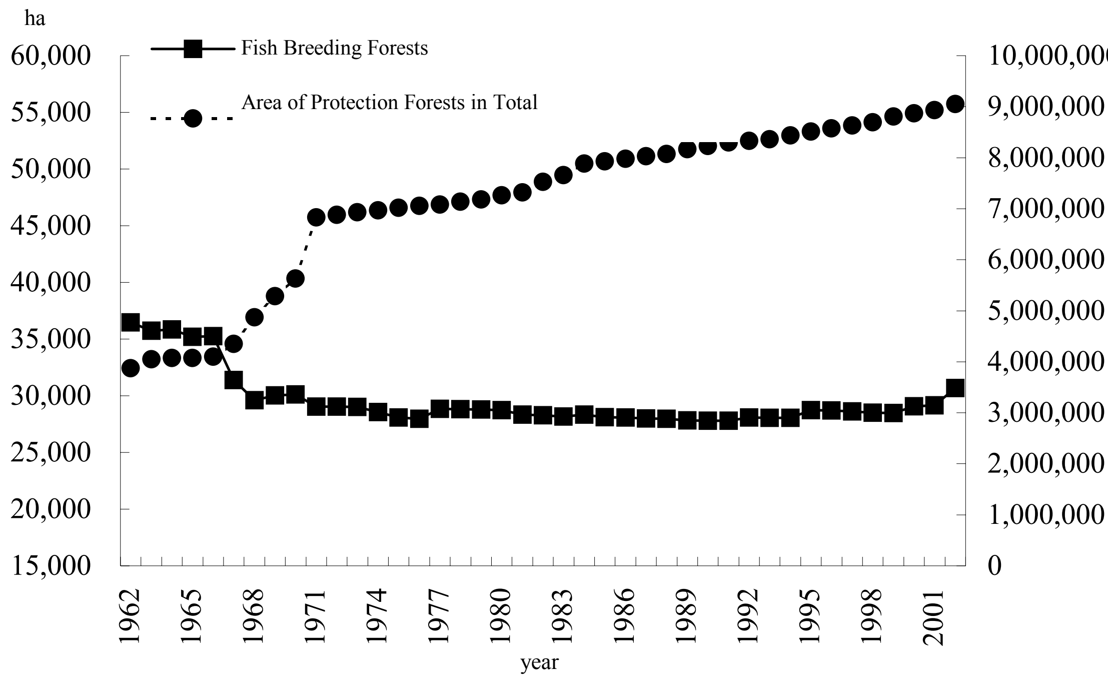

Figure2. Area of Protection Forests in Total and Fish Breeding Forests

Source) This figure was made by Norie Tamura based on the data of the official statistics of protection forests in Japan.

But the critical situation was not only seen in that particular region but in many other places in Hokkaido. Fish catches declined in some places and kelp harvests did so in other places. Fisheries women's actions have been the positive actions to prevent such a total crisis. Their actions are based on the bitter experience of deforestation in Hokkaido. This movement is very strong because there are 138 women's branches of fisheries cooperative associations (FCA) in Hokkaido and their membership is 20,000. Not only that, it spread to many other parts of Japan as documented in Yanaginuma(1992).
In Miyagi Prefecture in mainland Japan, oyster fishermen of Karakuwa Bay together with environmentally-minded citizens in the area began to plant trees on Murone mountain, which locates some 30km upstream from the bay. This movement of making forest for oysters started in 1988, the same year when the actions in Hokkaido began as documented in Hatakeyama(1994) and Saito(2003).

Figure 2 shows the historical trend of the area of fish breeding forest in contrast to the area of protection forest in total during the period of 1962 through 1999. From this, we understand that the area of fish breeding forests had been in a declining trend until very recently while protection forests as a whole steadily increased in the post-war Japan. From the late 1990s, however, fish breeding forests started increasing. Figure 3 is the graph covering longer term from 1915 to 2002. It clearly shows that the area of fish breeding forest significantly increased in the pre-war times and that it was rapidly decreasing in the 1950s and in the age of rapid economic growth. We also understand from Figure 3 that it is now increasing again.

As of 2003, Japan has 29,000ha of fish breeding forests in 9,300 places. 80 % of this type of forests are in private forests and 20 % in national forests. But scientific evidences have not been enough to fully support that the so-called fish breeding forests are really fish breeding or not. With regard to this question, the studies on riparian vegetation such as Beechie and Sibly (1997), Boss and Richardson (2002), Nakano, et al. (1999), Roni, et al. (2002), Schlosser (1991), Vannote, et al. (1980), and Wang, et al (2003) seem to give us good hints.

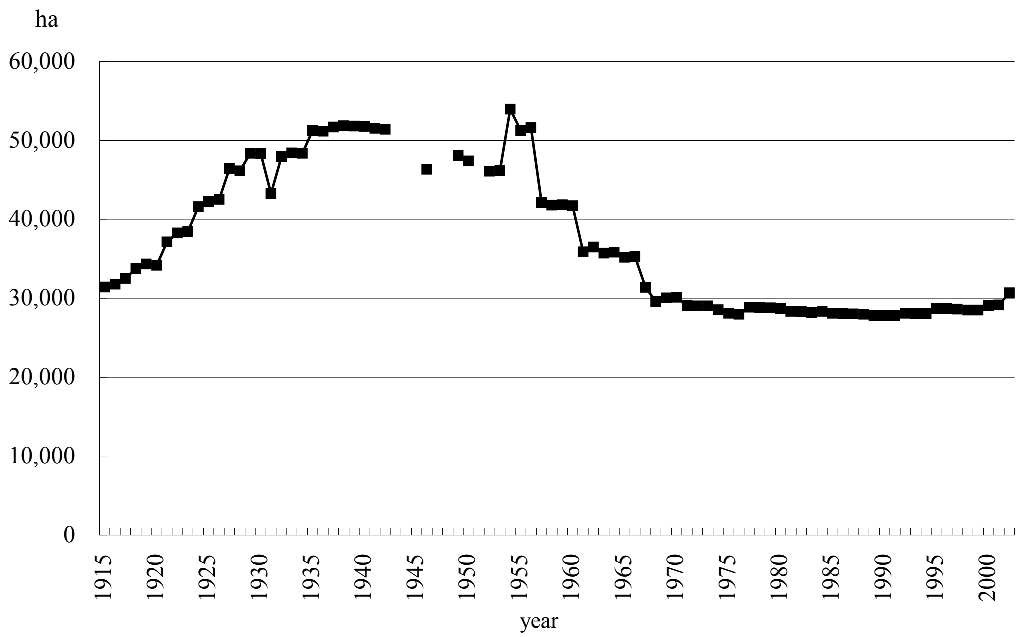

Figure3. Area of Fish Breeding Forests in Japan

Source) This figure was made by Norie Tamura based on the data of the official statistics of protection forests in Japan.

WATERSHED MANAGEMENT FOCUSED ON RIPARIAN VEGETATION

The Roles of Riparian Vegetation

Mills (1989, pp. 248-250) points out the importance of streamside vegetation for freshwater ecosystem in the context of Northern Atlantic countries, especially in the context of Atlantic salmon rivers. According to him, the reasons why it is important are as follows: The streamside vegetation

(a) shades water, stream bed and stream bank from the sun's heat,
(b) provides energy to the stream through leaf fall, terrestrial insect drop and dissolved nutrients,
(c) gives protective cover for fish,
(d) protects the stream banks from channel erosion, erosion from overland runoff, and the erosive effects of precipitation impact,
(e) acts as a buffer against debris from overland runoff, and
(f) intercepts toxic materials from spraying.

Mills also notes that "removal of streamside vegetation can facilitate increases in the temperature of streams which may then reach a lethal point for salmon and trout"(ibid., p. 248).

In the context of northern Australia, Pusey and Arthington (2003, pp. 1-2) list up the factors of importance of riparian zone as follows.

(1) Terrestrial primary production derived from riparian zone and floodplains as a vital source of energy in riverine food webs,
(2) Terrestrial secondary production as a significant contribution of energy to riverine food webs,
(3) Thermal buffering,
(4) The provision of shade and its influence on in-stream primary production,
(5) Nutrient interception, storage and release,
(6) Enhancement of bank stability,
(7) Provision of coarse woody material as habitat and substrate for fish, invertebrates and microalgae,

(8) Mediation of changes in channel morphology and habitat diversity, and
(9) Refuge from disturbance variety of scales from that of the particle (i.e. individual pieces of wood) to that of the watershed.

The factors (1) through (f) of Mills and the factors (1) through (9) may be reread as the factors which coastline forests contribute to the formation of good habitat for marine fish. This is a hypothesis to be tested in the future.Interception of toxins by riparian vegetation is also emphasized by Lin, et al.(2002) in the context of Taiwan.

It is worth noting that the Japanese scientist, Tetsuo Inukai(1897-1989), emphasized that not only riparian but mountain forest is important for a productive sea because mountain forest ultimately control the water flow of a river in the senses of volume of flow, transparency, and water temperature (Inukai, 1951).

It is also important for us to study implications of fish breeding forests in parallel with mangrove forests in tropical and subtropical regions of the world. The cases of mangrove planting in the Philippines (Walters, 2003) seems to have some common aspects to

CONCLUSION : IMPLICATIONS FOR FISHERIES MANAGEMENT POLICY

Anchovy fishing became too intense. This meant a competition between two major predators on fish, i.e., fishermen and seabirds. The formers with engine-driven boats had the advantage. The number of seabirds became less. This in turn resulted in the decrease in guano formation. Only a few tens of thousand tons are annually harvested in Peru in recent years. A large part of the harvested fish by fishermen has been transformed into fish meal to feed mainly chicken. As far as guano islands in Peru are concerned, they are under strict state control so that harvest should continue in a sustainable manner.

As far as anadromous salmon is concerned, a possibility of positive feedback can be pointed out. If the watershed become livable for anadromous fish, many number of them will make upstream migration. This in turn help tree growth. If riparian vegetation becomes good, more fish will come up.

Necessity to Establish Escapements Goals of Anadromous Fish

A balance between catches and escapements must be established in such a way that not only human beings but other terrestrial lives can enjoy feeding on the MDN uploaded by anadromous fish. In this context, a caution must be paid upon an excessive degree of salmon hatchery. Powell (2003) points out that 1 kg of farm fish including salmon is the product of 2-5 kg of other fish. From this, he argues that fish should be vegetarian.

Though we neither claim that all fish should be vegetarian nor propose that all hatchery business should be abondoned, we at least argue that a certain number of anadromous fish must be allowed to freely make their own spawning runs deeply into the terrestrial ecosystems.

From this point of view, the status of salmon in Sakhalin is interesting and worth mentioning. There, upstream migration of salmon is free at night, i.e., from 23:00 each day to 9:00 in the next morning (Khantashkeeva and Murota, 2004). About a half of the total spawning runs are left for bears and other animals.

Knowler et al.(2003) conducted an economic evaluation of salmon river. Such a study should be extended to the direction of incorporating some kind of biodiversity indicators in the evaluation.

Caution on Circulation of Toxic Chemicals in Ecosystems

Continued deaths of beluga was seen in the esturian upwelling area at the mouth of St. Lawrence River in Canada in the 1980s (Murota, 1998). This is now known to have been caused by endocrine disrupters. While nutrient cycling is essential to all living beings, chemical and radioactive toxins must be separated from such cycling.

Fisheries and Forestry Together to Enhance Biodiversity

In an enlightening book on biodiversity, one finds the following passage:

"An understanding of food webs and nutrient cycles makes it possible to indicate the chain between some species targeted for conservation and the species, communities or systems on which the target species depends. Similarly, an understanding of the structure of metapopulations makes it possible to identify colonization pathways between individual populations that may be at risk"(Perrings, et al., 1995, p. 336).

It is important to note that human beings themselves are a species in this context of nutrient cycling. Fish abundance in the sea means that it attracts many seabirds, mammals, and so on there. Abundance of animals fed on fish in turn drop MDN on terrestrial ecosystem. Such MDN helps trees grow to form dense forests. Riparian and mountain forests create good habitat for fish. Human beings can be a good part of such nutrient transfer between fish and forest.

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ENDNOTES

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