

### **Chapter III**

## **AQUATIC RESOURCE AND PRODUCTION**

Ichiro AOKI, Kazuo OGAWA, Taku YAMAKAWA  
and Tomoyoshi YOSHINAGA

More than 70% of the Earth's surface is covered with water. Aquatic organisms have been collected and harvested since prehistory, and today, fish provides more than 2.9 billion people with at least 15 percent of their average per capita animal protein intake (SOFIA, 2008). In Japan, the share of fish proteins in total animal protein is about 40%, which is highest among animal foods. As the world's population grows, fish and shellfish are becoming increasingly important as a source not only of animal protein but also healthy lipids, and essential micronutrients.

Fisheries catch data are usually divided into capture fisheries and aquaculture. In 2006, capture fisheries accounted for 92 million tons (64%) and aquaculture for 52 million tons (36%) of the total global fish production. Aquaculture production is growing quickly and expected to soon exceed that of capture fisheries. Under the present trend, it is becoming increasingly important to sustainably manage the capture fisheries through resource management, conservation and stock enhancement as well as the development of new natural resources. To increase production in aquaculture will require reducing environmental burdens, establishing seed production technology for new species such as eel and tuna, developing feed that minimize the content of fishmeal, and producing new disease resistant species.

(Ichiro Aoki and Kazuo Ogawa)

### 1. FISHERIES PRODUCTION

#### *1.1 Japan*

In the annual fisheries and aquaculture statistics book of Japan, fisheries are divided into marine and inland fisheries. Marine fisheries comprise four divisions: distant water fisheries, offshore fisheries, coastal fisheries, and mariculture. Distant water fisheries operate on the high seas or within the 200-nautical-mile exclusive economic zones (EEZs) of other countries by gaining access to the fishing grounds through agreements with those countries. These include trawl

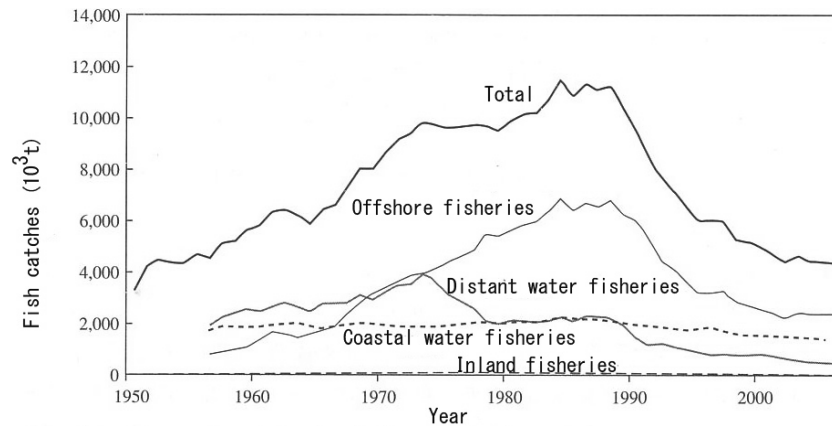


Fig. 3.1. Changes in catches by different fisheries category. Produced using data in annual statistics reports from the Ministry of Agriculture, Forestry and Fisheries.

fisheries, skipjack and tuna purse-seine fisheries, tuna long-line fisheries, skipjack pole-and-line fisheries, and squid jigging fisheries. The operation of fisheries in foreign EEZs are becoming difficult. The total catch from foreign EEZs in 2006 was  $50 \times 10^5$  tons, which was 9% of total catch of Japanese fishers and composed 11% of the total value. Offshore fisheries usually employ vessels larger than 10 tons operating mainly within Japan's EEZ. They include trawl fisheries, large- and medium-sized purse seine fisheries, adjacent sea skipjack pole-and-line fisheries, and Pacific saury stick-held net fisheries. The catch amount of offshore fisheries (40%) is the largest among the four divisions, but percentage in total value is lower than for coastal fisheries. Coastal fisheries employ vessels smaller than 10 t (some not powered) or no vessels at all and include set-net fisheries and beach-seine fisheries. Coastal fishing grounds are within a one-day trip from port, and most coastal fishers operate as independent businesses. Coastal fisheries account for a large share of the total number of management bodies and fishers. Their managements are relatively stable when compared with other fisheries. However, the catch amounts have been recently decreasing. Coastal fisheries catch various fishes including high-value fishes, and compose 25% (by weight) of the total Japanese fishery production and 31% of the total value.

Production in Japanese fisheries increased steadily during the 1950s through the early 1970s (Fig. 3.1). During 1960–73, production increased from 6 million tonnes to 10 million tonnes. As fishing grounds expanded offshore, catches in distant water fisheries reached 4 million tonnes in 1973, but then declined due to increased oil prices and regulation of fisheries in foreign EEZs. Catch amounts in offshore fisheries, such as large and medium purse seine fisheries, increased through the late 1980s largely due to increased catches of chub mackerel (*Scomber japonicus*) in the 1970s and sardine (*Sardinops melanostictus*) in the

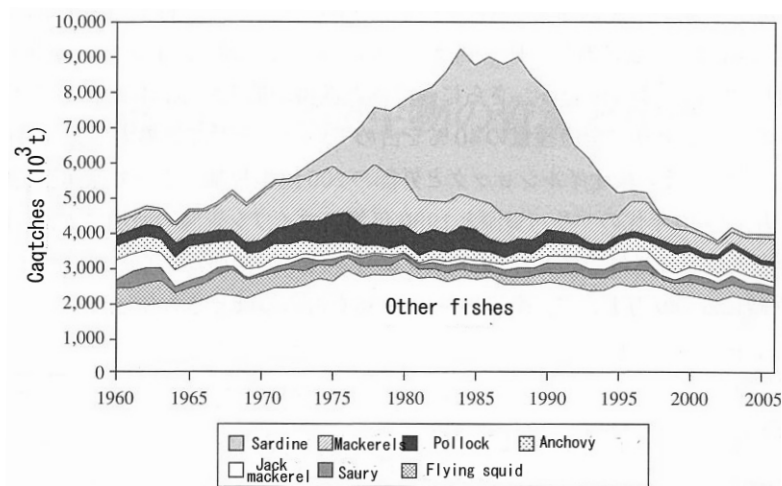


Fig. 3.2. Changes in catches of major fishes by offshore and coastal fisheries (produced from data in annual statistics report by the Ministry of Agriculture, Forestry and Fisheries).

1980s. The 1980s was a golden age for fisheries in Japan. Sardine catches peaked in 1988 at 4.49 million tonnes, which was about 40% of the total catch in Japan.

Total catch amounts since the 1980s have decreased. In offshore fisheries, the sardine resource rapidly decreased. In distant water fisheries, Japan was excluded from the EEZ of the United States, and regulation of EEZ in other countries became strict.

Although production of coastal fisheries has remained relatively stable, it also shows a gradual decline since the mid-1990s. Recently total catch amount by coastal fisheries have been around  $15 \times 10^5$  t.

Production in Japanese inland water fisheries has fluctuated around  $1 \times 10^5$  tonnes, and the value has recently decreased. They compose about 1–2% (by weight) of the total Japanese fisheries production.

More than 400 fish species around Japan are targeted by Japanese fishers, but ten major species make up about half of the total catch (Fig. 3.2). During 1970–95, the three main species were mackerel, Alaska pollock, and sardine. Much of the fluctuation in total catch was caused by fluctuations in these species, which periodically fluctuate with several ten years cycle. Annual catch amounts of all other species have remained fairly stable at around  $35 \times 10^5$  t.

Between 1980 and 2006, the total catch decreased about 30%, but catches of four species, including Pacific saury and anchovy increased. Salmon and scallop production also increased mainly as a result of stock enhancement projects.

In 2006, the species that contributed most to marine fisheries catches were mackerels ( $63 \times 10^4$  t), Japanese anchovy, skipjack, and scallop. Many of the abundantly caught species were pelagic migrating species. The total catch of

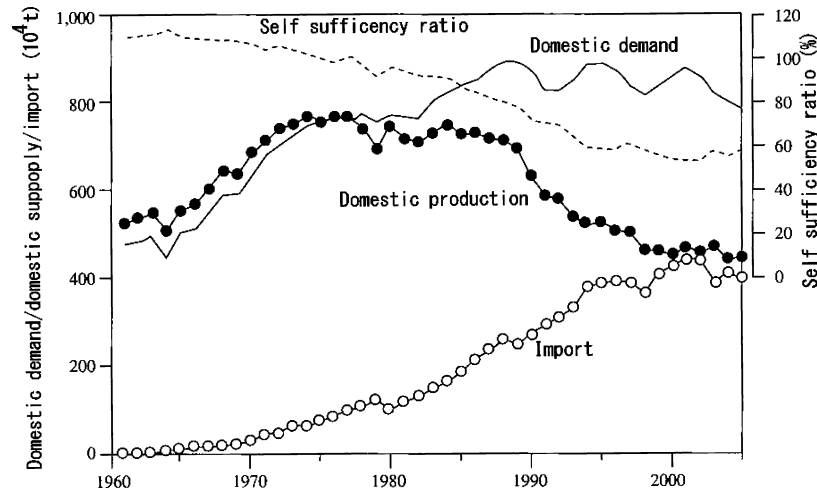


Fig. 3.3. Changes in demand and supply of fish and shellfish for food. Produced from annual fisheries white books.

sardine was  $5 \times 10^4$  t, which is less than 2% of peak catches in the 1980s.

Marine aquaculture production increased from  $28 \times 10^4$  t in 1960 to over 1 million tonnes in 1983. After 1988, the amount has been stable at around  $12\text{--}13 \times 10^5$  t. Inland aquaculture production was around  $9 \times 10^5$  t in the 1980s, but began to decline in the 1990s and is now about half of the peak in the 1980s.

The number of fishers and fish farmers in 1953 was about 800,000, but decreased to less than 300,000 in 1996. In 2006, the number was about 210,000. The population is aging: with 36% of the male workers being older than 65 yrs.

The average annual value of all Japanese fisheries and aquaculture production during 1976–98 was more than 2 trillion yen ( $2 \times 10^{12}$ ). In 1982–1985, it was 2.9 trillion yen. The amount decreased from 1999, and is now around 1.6 trillion yen.

With the changes in production, demand for fisheries products has also changed (Fig. 3.3). Through 1977, domestic production increased together with an increase in domestic demand, and the self-sufficiency ratio was more than 100%. But after 1977, domestic demand continued to increase, while domestic production stagnated, which caused the self-sufficiency ratio to gradually decrease. Since 1990, domestic demand has been 8–9 million tonnes, domestic production has decreased, and imports have increased. In 2005, the self-sufficiency ratio was 57%. The increase in imports appears to compensate for the decrease in domestic production, but much of the imported fishes are high-priced commodities such as shrimp and tuna, which were consumed in small amounts previously because of limited domestic production. In 2006, Japan was the top importer of fish and fisheries products (SOFIA, 2008). The shares in world fisheries products trade are 19% in value and 12% in amount. The major imported fisheries products include shrimps, tunas and billfishes, salmon and trout, and crab.

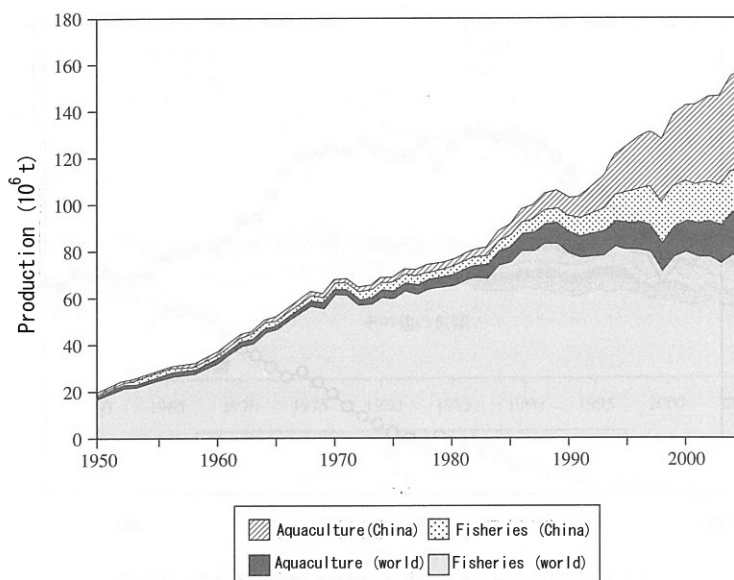


Fig. 3.4. Changes in world fisheries and aquaculture production. Data are expressed dividing production by China from world production. Produced using data in FAO FishStat.

In the early 1960s, the value of fisheries products was 100 billion yen, which was 5% of total value of exports from Japan. Exports then gradually increased, and Japan reached the top in the world in export value of fisheries products in 1976 (220.8 billion yen). Exports peaked in value in 1984 (303.3 billion yen) and in amount in 1988 (980,000 t) due to the production of sardine and skipjack. After 1988, exports decreased rapidly with the decrease of domestic production, though export has been improved from the worst record recently. In 2005, exports were 470,000 t and had a value of 170 billion yen.

### 1.2 Global production

Global fisheries and aquaculture production increased from 20 million tonnes in 1950 to 157 million tonnes in 2005. However much of the growth since 1990 has been due to dramatic increases reported by China. There are continued indications that since the early 1990s, China has over-reported its capture fisheries and aquaculture production statistics. Because of the uncertainty about Chinese production statistics, the FAO now discusses these data separately from those of the rest of the world. If China is excluded, world fisheries production has decreased since 1990, and the sum of the fisheries and aquaculture production has remained fairly stable (Fig. 3.4).

The recent stagnation in world fisheries production excluding China suggests that maximum wild capture fisheries potential from the world's ocean has



probably been reached. In 2007, about 28 percent of stocks were either overexploited (19 percent), depleted (8 percent) or recovering from depletion (1 percent). A further 52 percent were fully exploited and only about 20 percent were moderately exploited or underexploited. Compared to aquaculture, capture fisheries are in an unstable equilibrium.

China is by far the global production leader, accounting for 18% of the global production in capture fisheries, 70% of the global production in aquaculture, and about 40% of the global production in capture fisheries and aquaculture (Table 3.1). In 2005, Japan ranked fifth in terms of global production in capture fisheries and aquaculture, and seven of the top ten countries were in Asia.

In 2005, global finfish catches totaled 80 million tonnes (85% of total fisheries production), mollusk catches totaled 7.2 million tonnes (8%) and crustacean catches totaled 6 million tonnes (6%). Catches of other groups, such as sea urchins, was  $50 \times 10^5$  t, and the production of algae was  $13 \times 10^5$  t.

Major groups among the finfish included herrings and sardines (22 million tonnes, 24% of total fisheries production), small pelagic fish such as horse mackerels, mackerels, smelts and saury (11 million tonnes, 12%), cods (9 million tonnes, 9%), and large pelagic fish, skipjack and tunas (6.2 million tonnes, 7%).

In 2006, the species that contributed most to global catches was the Peruvian anchovy (7.0 million tonnes). Since 1960 the total catch by weight of Peruvian anchovy has exceeded that of any other single fish species in the world, but the annual catch has varied considerably. During 1962–71, annual yields averaged 9.7 Mt, but the catch dropped dramatically in 1972 and averaged only 1.3 Mt during 1976–85. A major cause of the large fluctuations in catch is El Niño.

Other species with high global catches included Alaska pollock, skipjack tuna, Atlantic herring, blue whiting and chub mackerel.

### *1.3 Fisheries technology*

Fisheries operations comprise several steps, including searching for target fish, selecting a fishing ground, and then capturing the fish using fishing gear. In several fisheries, fishers aggregate target fish before fishing using lights or feed.

#### *1) Classification of fishing gear*

Fishing gear is the equipment with which aquatic resources are captured, and the fishing method is how the gear is used. Both terms are closely linked, so in this text, the term “fishing gear” will also include the method in which it is used.

There are many types of fishing gear, but they can be classified into nets (a–f), angling gear (g), and others (h).

#### *a) Trawl nets (including Beam, Otter and Pair trawls)*

The trawl nets are cone-shaped nets which are towed by one or two boats along the bottom or in midwater. The cone-shaped body ends in a bag or codend. While the net is towed, its horizontal opening is maintained by beams, otter boards or by the distance between the two towing vessels (pair trawling). Target species include flounders and other flat fishes, shrimps, crabs, and shellfish. Towed nets are used in various fisheries using small and large vessels from coastal power boat trawl fisheries to distant water trawl fisheries.

*b) Seine nets (including beach seines and boat, Scottish/Danish seines)*

A seine net is a very long net, with or without a bag in the center, which is set either from the shore or from a boat for surrounding a certain area. It is operated with two ropes fixed to its ends. There are two main types of seine nets: beach seines and boat seines. Beach seine is towed from offshore to beach. The nets are landed on the beach. Beach seines were important fisheries before the establishment of modern fisheries. An example is sardine fishery at Kujukuri beach, Chiba Prefecture (Japan).

*c) Surrounding nets (including purse seines)*

Surrounding nets capture fish by encircling them, usually at the surface. The most common type is purse seines, which surround pelagic fish not only from the side but also from underneath, preventing them from escaping by diving downward. Major target species include sardines, horse mackerel, and mackerels. Distant-water purse-seine fisheries target skipjack and tuna. Surrounding nets can be operated by one or two vessels. Most catches come from one-vessel operations.

*d) Gillnets and entangling nets*

Gillnets and entangling nets are netting walls to entangle or enmesh fish. The nets hang vertically at the surface, in midwater or on the bottom, and have floats on the upper line (headrope) and weights on the ground-line. The structure of gill nets is simple, and these nets are widely used. Various species are targeted, including cods, salmon, trout, shrimps and crabs. The gear can be anchored to the bottom or left drifting, free or connected with the vessel.

*e) Lift nets*

Lift nets are horizontal square or circular nets that are submerged at a certain depth, left for a while to let fish aggregate over the net, then lifted out of the water. Fish are attracted over the nets using lights or food. Lift nets locally named “8 hands nets” or “stretch nets” were used in the past all over Japan for catching surface fishes such as sardine and mackerels. Today the only lift net commonly used in Japan is the saury stick-held dip net. Floats or poles are attached on the top of this net, and weights are attached on the bottom of the net. The net is set off from the side of a vessel by the poles and then lifted using a rope attached to the bottom line.

*f) Set nets*

Large stationary nets called set nets retain fish that swim into them, but are then hampered from escaping. Fish are lead along a fence net to a bag net or box net, and are collected by hauling up this part of the net. Set nets are fixed in a selected place on the coast for long period. Set nets that have a funnel-like pathway are called drop down net (Otoshiami). Most set nets today are drop traps. Set nets catch various species from pelagic migrating species to benthic species that migrate or live along the coast.

*g) Hooks and lines*

Hooks and lines attract fish by a natural or artificial bait (lures) placed on a hook fixed to the end of a line. The lines are attached to fishing rods, jigging machines, floats, or directly held by hand. Typical angling using a rod is the pole-and-line skipjack angling fishery. In automatic angling, machines operate the



angling lines. Automatic jigging is common in squid fishery. Trawl line is a angling method in which hooks and lines are towed by a vessel. Many branch lines are attached on the stem line from the rod. Generally trawl lines are used in fisheries for large pelagic fish like tunas, skipjacks and billfishes.

A commonly used angling gear is the longline. Many branch lines are attached on a long stem line, and hooks are attached on the end of branch line. In distant water tuna longline fishery, the length of stem line can reach more than 100 km. Longlines are used at the surface to target tuna and near the bottom to target bottom fish such as Alaska pollock.

*h) Other gear*

Other commonly used gear include traps (e.g., octopus pots, crab baskets and conger eel tubes), grappling and wounding gear (e.g., spears and harpoons for sea cucumber, octopus and billfishes), nipper or twister for shells and algae and dredges for shellfish.

*2) Fisheries machines and equipment*

Various machines and equipment are used to operate the fishing gear and to monitor fish and the ocean. These machines and equipment are called auxiliary fishing gear, in contrast to the principle fishing gear described above. Increased production in fisheries today largely depends on developing auxiliary fishing gears as well as the development of vessel size and speed.

*a) Gear-handling equipment*

Gear-handling equipment is used to set and retrieve nets, as well as operate angling gear. They include capstans, haulers, winches and automatic jigging machines. Capstans include net haulers used for gill nets and surrounding nets, and power blocks for surrounding nets. A longline hauler is used for hauling of stem line. The setting and retrieving of trawls is done using winches. A purse winch is a special machine for hauling the ring line on the bottom of a purse seine net, and a multistage winch is used in the stick held net fishery for hauling the net bottom. Squid jigging is conducted using automatic jigging machines, and unmanned anglers are used in some skipjack pole-and-line fisheries.

*b) Fish detection instruments*

Fish detection instruments, such as echosounders and netsounders, are used to search for fish during the fishing operation. Acoustic equipment is used to monitor fish schools and fishing gear in the sea. Echosounders find schools of fish using sound signals. Echosounders send out a signal in one direction, and scanning sonars shoots supersonic beams in multiple directions in half or all circumstances to monitor around the vessel. In purse seine fisheries, fish schools are located and followed using scanning sonars. Fishing locations and operation plans are decided after getting information on the shape, direction of movement, speed, depth, and size of a school using scanning sonar. After nets are set, the condition of net and fish school are also monitored using sonar.

*c) Fishing lights*

Light are used at night in some fisheries to attract species such as sardine, house mackerel, mackerel, Pacific saury, lance and squid. The lights are usually attached to a vessel above the water surface, but underwater lights are also used.

Fishing lights are used in purse seine, stick held net, scoop net, and squid net fisheries. Light emitting diodes (LEDs) are now being developed to reduce electric power consumption.

*d) Other auxiliary equipment*

A water sprinkler (shower) is used in the skipjack pole-and-line fishery to stimulate the sense of sound and vision of skipjack, resulting in the aggregation of skipjack.

*3) Fisheries information*

Target fish are not homogeneously distributed in the sea. They tend to aggregate in certain places and at certain times in places that become fishing grounds. The formation of fishing ground and the abundance of fish depend on ocean conditions such as water temperature, currents and bottom topography. Fishers can improve their fishing efficiency by using information on ocean conditions before they begin fishing. In the past, fishers made decisions based on their experience and gut feelings, whereas today's, fishers often rely on computers and information-communication technology.

Several fisheries and oceanic condition information systems exist. Some target wide areas, while others target the coasts in each prefecture. Data collected include temperature by fishing vessels and other ships, temperature at coastal observation stations, isothermal charts of sea surface temperature using satellites, current charts, fishing-ground locations and fishing conditions. These data are usually collected daily and sent by internet, mobile phone, or facsimile to fisheries organizations.

#### *1.4 Fisheries management systems*

*1) Fishing acts in Japan*

Fisheries in Japan are regulated in several ways for resource conservation and coordination among fishermen. From an institutional viewpoint, fisheries in Japan can be classified into fishing right fisheries, licensed fisheries, and open access fisheries.

Fishing right fisheries occur in an appointed site of coastal area depending on fishing right. There are three types of fishing rights. The Set-net Fishery Right is the right to perform large scale set net or set net for salmon. The Demarcated Fishery Right is the right to engage in specified aquaculture in a specified area. The Joint Fishery Right is issued only to fishery cooperatives for fishing in coastal areas. This type of fishery occurs in most areas along the Japanese coast. The cooperative should manage the fishing area communally.

Fisheries that operate under fishery right are defined by the fishing method used. Fishers can operate particular fisheries in particular area licensed by governor of the prefecture exclusively. In fishery right, the location of the fishing ground, area, fishing period, target species and fishing and aquaculture method are regulated.

Licensed fisheries require a license from either the Minister of Agriculture, Forestry and Fisheries or the prefectural government. These fisheries generally

use larger fishing gear, fish in larger areas, and catch more than the fishery right fisheries. The major fisheries in Japan are licensed fisheries.

*National licensing system*

A national fishery license is required for fisheries to operate on a nation-wide scale or in international waters. There are two categories in the national license: Designated Fisheries (*Shitei-gyogyo*) and Permitted Fisheries (*Kyoka-gyogyo*). There are 13 Designated Fisheries, including the offshore trawl fishery, large and medium type purse seine fishery, and distant-water tuna fishery. The size of vessels, operation area, operation period, and number of vessels are regulated. There are five Permitted Fisheries, including the snow crab fishery. In addition, notification fisheries are not minister licensed fisheries de jure, though fishermen should notify the minister for implementation of notification fishery as government manages the notification fisheries. Notification fisheries are four types of fisheries including small squid fishery.

*Prefectural licensing system*

A prefectural license is required for fisheries operated in coastal area and offshore areas. These fisheries are classified into official governor licensed fisheries and other governor licensed fisheries. The maximum number of vessels in official governor licensed fisheries in each prefecture is regulated by the governor. There are five official governor licensed fisheries, including the mid-size purse seine and small scale power boat trawl. The other governor licensed fisheries are small scale fisheries mainly in coastal areas. They are managed by ordinance of the local governments depending on the local situation. Small scale surrounding nets, small scale power boat trawl, gill net are included in other governor licensed fisheries, with large variations depending on locality.

Fisheries that do not fall in any of the above categories and do not require a license or permission are open access fisheries. These fisheries have little problem in conservation and coordination of operation among fishermen are out of regulation. They include small scale angling, longline, and trawl line.

In addition to the above mentioned regulatory system, the Law Regarding Conservation and Management of Marine Living Resources provides regulation relating to the total allowable catch (TAC) system and total allowable effort (TAE) system.

The United Nation Convention on the Law of the Sea (UNCLOS), which came into force in 1994, gives the coastal nations the right to establish an exclusive economic zone (EEZ), where each state has special rights over the marine resources. UNCLOS also obligates coastal nations to implement adequate actions for the conservation and management setting allowable catch amounts in the zone. Japan ratified UNCLOS in 1996, and the convention became effective in 1996.

The TAC system began in 1997. Catch control through the TAC system is implemented for seven major fishery species (sardine, mackerel, jack mackerel, Pacific saury, Alaska pollock, Japanese common squid, and snow crab), which are called primary specified marine biological resources. These are most important species for fisheries in Japan. The TAC system sets the upper limits of annual

allowable catches for each fish species in the EEZ, and allowable catches are determined from an allowable biological catch (ABC) amount that is assessed from analyses of data obtained by biological resource surveys.

The TAE system sets an upper limit on the number of fishing days and the number of operating vessels in a specific area within the EEZ. TAE target species are called secondary specified marine biological resources, and are the target of resource restoration plans. There are nine target species, including flathead flounder (Akagarei, *Hippoglossoides dubius*), Japanese sand lance (Ikanago, *Ammodytes personatus*), Japanese Spanish mackerel (Sawara, *Scomberomorus niphonius*), and tiger puffer (Torafugu, *Takifugu rubripes*). TAC and TAE are used in national licensed fisheries and prefectural licenced fisheries for each fishing method in each operation area.

#### 2) *International fisheries management*

Fisheries beyond Japan's EEZ are regulated by domestic law and bilateral agreements with other countries or multilateral agreements among countries. Fish resources that need international agreements include shared stocks, which occur in multiple EEZs, straddling stocks, which occur within both an EEZ and the high seas, and highly migratory stocks, which migrate widely, like skipjack and tuna.

Skipjack and tuna fisheries are managed and regulated under five international regional fisheries management organizations: the International Commission for the Conservation of Atlantic Tunas (ICCAT), Inter-American Tropical Tuna Commission (IATTC), Western and Central Pacific Fisheries Commission (WCPFC), Commission for the Conservation of Southern Bluefin Tuna (CCSBT), and Indian Ocean Tuna Commission (IOTC). The upper catch limit for each country is set by these organizations. Other regional fisheries management organizations operate in the Central Bering Sea, Northwest Atlantic Ocean, Mediterranean Sea, and Antarctic Ocean. Whales are under control of the International Whaling Commission. Japan is a member of all these organizations.

A serious issue in international resource management is IUU (illegal, unregulated, and unreported) vessels, which operate without observing international rules on resource conservation. Products from IUU fisheries are being eliminated from international trade as a countermeasure.

The United Nations Fish Stock Agreement, which was enforced in 2001, increases the role of regional fisheries management organizations in managing high-seas stocks and accelerating cooperation between coastal countries and high sea fisheries countries.

Japan has bilateral fisheries agreements with Russia, South Korea and China. Each country agrees on the fishing quota and other operation provisions. Because the EEZ boundary between Japan and Korea and between Japan and China is not clearly defined due to territorial issues, there are provisional waters and a halfway zone. In the agreements, it is agreed that stocks in these regions are managed cooperatively between the two countries. However, fisheries in those areas are free fisheries without any regulation from partner country.

### *1.5 Responsible fisheries*

Operation of fishing gear not only results in catch of target species but also has an impact on the sea ecosystem. Increase in fisheries products in the later half of 20th century means an increase in operation of fisheries activity such as enlargement of vessel size and increase of vessel number. Similar to human production activity on the land, impact of fisheries activity on the environment and ecosystem cannot be neglected any more. Code of Conduct for Responsible Fisheries was adopted by the FAO in 1995. Its aim is to ensure effective conservation and management of living aquatic resources considering their impacts on ecosystems and biodiversity. Sustainable fisheries should not only maintain stock of target species but also consider their impact on the global environment and ecosystems.

#### *1) Bycatch, discards and ghost fishing*

When harvesting fish from the sea, fishers sometimes catch things they did not intend to, such as a different fish species, sea turtles or seabirds. The term for animals caught unintentionally by fishing gear, including non-target species and undersized fish, is “bycatch”. Much of this catch is discarded at sea.

In 1994, the FAO estimated annual global discards in marine fisheries to be about 27 million tonnes, but a more recent study estimates the yearly average discards during 1992–2001 to be 7.3 million tonnes. Trawl fisheries for shrimp and demersal finfish account for over 50 percent of total estimated discards. Shrimp trawl fisheries alone are responsible for around one third of the world’s discarded bycatch, despite producing less than 2% of global seafood. For every 1 kg of shrimp they collect, they also collect 5 kg of bycatch. Dumping of bycatch is wasting of stocks that simultaneously affects fishing sustainability from the view point of maintenance of ecosystem and biodiversity.

Methods being used to reduce bycatch include enlargement of mesh size and attachment of escape equipment for untargeted species. Tuna longline fisheries, which often have high bycatch of sea turtles and seabirds, are now using improved hooks and operating methods.

Ghost fishing is the term used for lost or abandoned fishing gear that continues to catch fish. Like bycatch, it is environmentally detrimental, and the fish caught is wasted. Ghost fishing usually occurs with passive fishing gear such as longlines, gill nets, traps and pots, rather than active fishing gear. Methods being used to reduce ghost fishing include introducing gear made with biodegradable plastic or natural material that is strong, but will easily decompose if the gear is lost.

#### *2) Ecolabelling*

Ecolabelling is the voluntary granting of labels by a private or public body to inform consumers and thereby promote consumer products which are determined to be environmentally more friendly than other products.

When a consumer purchases an ecolabeled product, he or she supports fishers who makes efforts in the activities for sustainable fishing, so the labels create a market-based incentive for environment-friendly production.

Eco label accreditation system is a system to enable support from consumer

to sustainable fisheries. Consumer can recognize by the label that the item is a product of the fisheries considering the impact on fisheries resources and ocean environment. This leads to sustainable fisheries and consumers can continue eating the fisheries products forever.

The ecolabel certification program of the Marine Stewardship Council (MSC) is well known around the world. The program began in 1997, and by 2007, about 860 seafood products with the MSC ecolabel were available in 34 countries. Products with the MSC ecolabel first appeared in Japan in 2006. The first fisheries in Asia certified to received the MSC ecolabel were the Kyoto Danish Seine Fishermen Federation's snow crab (*Zuwaigani*, *Chionoecetes opilio*) and flathead flounder fisheries.

In 2007, the Japan Fisheries Association (JFA) established a Japanese certification system for fishery products called the "Marine Ecolabel Japan" (MEL). The first fishery accredited for production, processing and transport was the red snow crab ("benizuwaigani", *Chionoecetes japonicus*) fishery.

More recently, the sakura shrimp two-boat trawl fishery based in Shizuoka Prefecture and the Jusanko freshwater clam fishery in Aomori Prefecture were also certified. Since Japan is a top consumer of fisheries products in the world, this system is expected to contribute towards establishment of sustainable fisheries.

(Ichiro Aoki)

## 2. STOCK FLUCTUATIONS

Fishery resources share three characteristics: they are renewable; they fluctuate, so stock assessment is not easy; and they are *bona vacantia* ("ownerless goods") before they are caught. These characteristics give us a basic stand point to consider how these can be used and how fisheries should be developed sustainably.

### 2.1 Stock dynamics

Life history characteristics play an important role in management and assessment of species. Figure 3.5 shows the typical life history cycle of a fish species and the factors that regulate stock size. The figure is for fish, but the same ideas apply to invertebrates. Larval fish hatch and grow until they are large enough to be fished. Growth in a population occurs as fish increase their lengths and weights. This influence the total population biomass (total weight of fish alive at a particular time). Recruitment is defined as the number of individuals that reach a specified stage in the life cycle (e.g., settlement or joining the fishery). It is one of the most important fisheries population parameters to estimate. After maturing, the fish reproduce and the population increases in numerical abundance. With new growth, the population increases in weight. As deaths occur, the population decreases in number and in weight. Fisheries science separates mortality into two components—fishing mortality, which encompasses

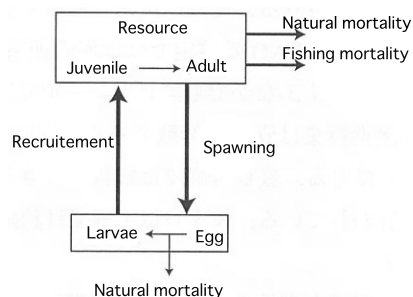


Fig. 3.5. Life cycle of resource organisms and factors relating to the resource ecology. Resource amount increased by recruitment and growth and decreased by natural mortality and fishing mortality. Amount of recruitment is determined by spawning amount and survival of eggs and larvae.

all deaths from fishing activities, and natural mortality, which is the loss of fish from a population due to all causes other than fishing.

The abundance of aquatic species fluctuates in space and time. In classic theory, it was assumed that stock would be in equilibrium condition if there is no fishing by the balance of increase and decrease. In some case amount of recruitment is fixed at a steady value or determined only by amount of spawning in other case. Optimal fishing strategies are theorized and practiced actually under these hypotheses. However, those theories gradually have shown their limitation caused by unrealistic hypotheses. Off California, the abundance of Pacific sardine and northern anchovy have changed dramatically over 1700 years long before they were fished (Baumgartner *et al.*, 1992). And it was clarified that wide fluctuation occurred even in a certain spawning amount and the amount of recruitment was not determined uniquely by spawning amount (Fig. 3.6).

For many stocks, there is a relationship between the size of the spawning stock (number or biomass of mature fish) and the number of fish that recruit into the fishery. This is called the stock-recruitment or spawner-recruit relationship and is important because it describes the ability of a stock to maintain its abundance in response to fishing pressure.

Stock-recruitment relationships can be written in many ways. The two most commonly used models are the Beverton-Holt model and the Ricker model. The most simplified expression of the relation is as follow:

$$\begin{aligned} \text{number of recruits} &= \text{number of spawned eggs} \\ &\quad \times \text{survival rate between spawning and recruitment.} \quad (1) \end{aligned}$$

The spawning amount is considered to be relative to amount of spawning individuals (in weight). However, per weight spawning amounts of a female sometimes fluctuate depending on environmental condition and per weight spawning amount of young individuals is often smaller than old individuals. We

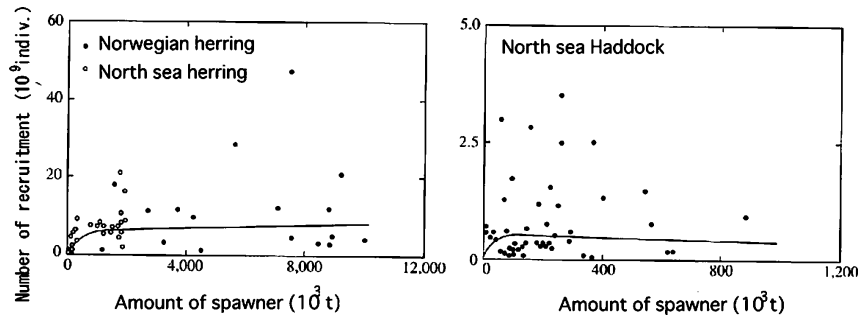


Fig. 3.6. Relation between amount of spawner and amount of recruitment. Circles indicate observed value and lines indicate calculated value by reproduction model (modified from Rothchild, 1986).

have to take care of these points in actual assessments. An important information to be mentioned here is that number of spawning individuals can be controlled by fishing. When the number of spawner decrease to less than required level, recruitment clearly decrease. On the other hand, the equation explains that increase in amount of spawning not necessarily cause increase of recruitment.

Survival rate is the key factor. In the classic theory of stock-recruitment relationship described above, it was presumed that survival rate was determined by the spawning amount. In this theory, survival rate decreased with an increase in spawning amount or spawning fish. This is called density dependency. The solid lines in Fig. 3.6 show calculated value using the theory. The distance between solid line and actual amount of recruitment (solid points in the figure) means part of recruitment that was determined by factors independent from density. Conclusively the figure shows that recruitment is not controlled only by spawning amount, but strongly controlled by environmental conditions before recruitment resulting in recruitment fluctuation of the stock.

## 2.2 Fluctuation of recruitment

The number of eggs a female fish or shellfish produces over time is referred to as fecundity. Most fished marine fishes have high fecundities of thousands to millions per female per year. Much of the variance around the stock-recruitment relationship is due to high and largely unpredictable variation in egg and larval survival (Fig. 3.7). In sardine, 99% of spawned individuals die before reaching 10 mm in body length (10–15 days after hatching) and only 0.1% survive to reach 20 mm in body length (20–30 days after hatching). The group born in a year is called a cohort or year class, and the magnitude of the year class is called year-class strength. We can recognize the magnitude of recruitment of each year as year class strength of each year. Figure 3.7(b) shows how mortality rates during the early life history affect recruitment variability. In case when strong fishing pressure does not exist, the fluctuation of survival after recruitment is probably



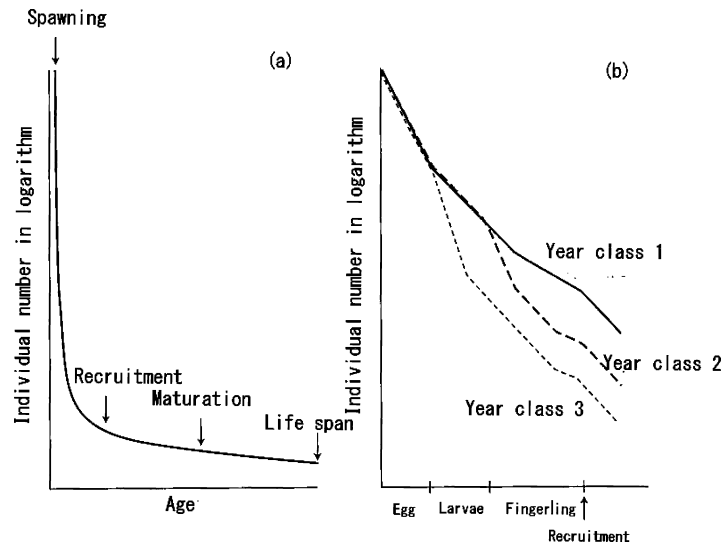


Fig. 3.7. Pattern diagram of survival curve of fish. Vertical axis is expressed in logarithm scale. (a) Survival in whole life. (b) Changes in survival in early stage among year class.

small. The survival of a year class is also known as year-class strength, and a year class with high survival is called a strong year class or dominant year class. In sardine, the 1972 and 1980 year classes were dominant year classes and basis of high stock levels in later years. Development and mortality rates are closely linked. Development includes growth (changes in size or abundance of existing features) and ontogeny (appearance of new features).

Two factors that affect recruitment include larval starvation and predation. In starved condition, fish may be easily eaten by predators. Data from the field show that larvae of Japanese anchovy (*Katakuchiiwashi*, *Engraulis japonica*) in the stomachs of predators are smaller than those living in surrounding water. Smaller individuals are culled from year class and well grown individuals survive selectively in the group. When the growth of larvae and juveniles is high, we can expect high recruitment.

Factors that affect growth include water temperature and prey availability. Growth generally increases with increasing temperature to a maximum, after which it decreases as temperatures continues to increase. Suitable temperature for growth differs among species. The optimal temperature for growth is 16°C in Japanese sardine and 21°C in Japanese anchovy (Fig. 3.9).

Prey availability also affects the growth of fish. Fish larvae and juveniles typically feed on tiny zooplanktons. It is difficult in actual sea to observe whether plankton that can be eaten by fish is rich or poor in the surrounding space of the fish. Mutual relations between zooplankton biomass sampled by plankton net and fish growth are hardly observed in field survey. Predator-prey interaction in the

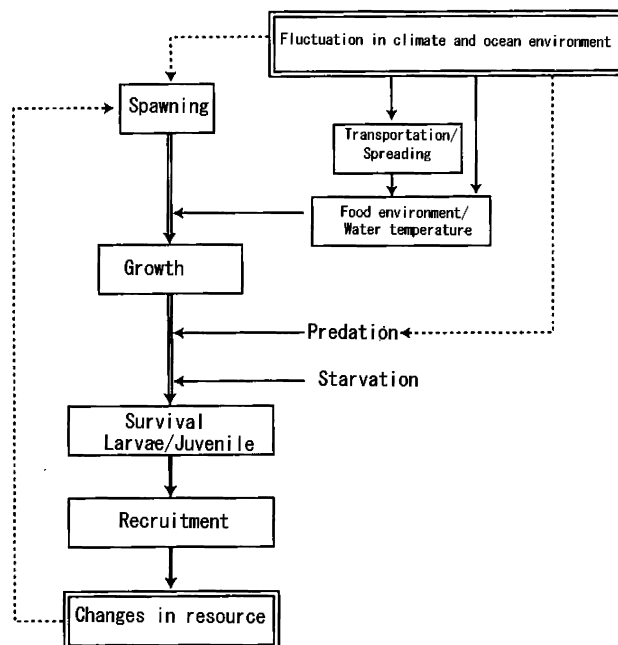


Fig. 3.8. Biological process and environment relating to resource fluctuation.

huge ocean is a very small, mm or cm scale event. Zooplankton distribution in the sea is spatially and temporally nonhomogenous. This means that actual food environment for larval and juvenile fish is not the average biomass of plankton in large space and is rather the density of plankton in small space, and the importance for larvae is the possibility of encounter in space at proper moment. This is the basic idea for considering the biological process involved in fluctuation of recruitment. Several hypotheses have been proposed to explain this biological process.

1) *Critical period hypothesis*

Fish larvae hatch from their eggs with a yolk supply that lasts a few days to several weeks. Before the yolk is exhausted, the larval fish must be able to capture live plankton. A critical point in a fish's life occurs during the larval stage when it must capture its first meal of plankton. In Japanese anchovy larvae, the yolk is exhausted within 3 days after hatching, and the larvae dies if unable to feed within two days after yolk absorption. This starvation threshold is usually measured as the point of no return (PNR), the time at which starved larvae become too weak to feed and recover.

2) *Match-mismatch hypothesis*

In temperate latitudes, there is usually spring phytoplankton bloom, which is followed by the proliferation of zooplankton. Fish larvae feed on the zooplankton

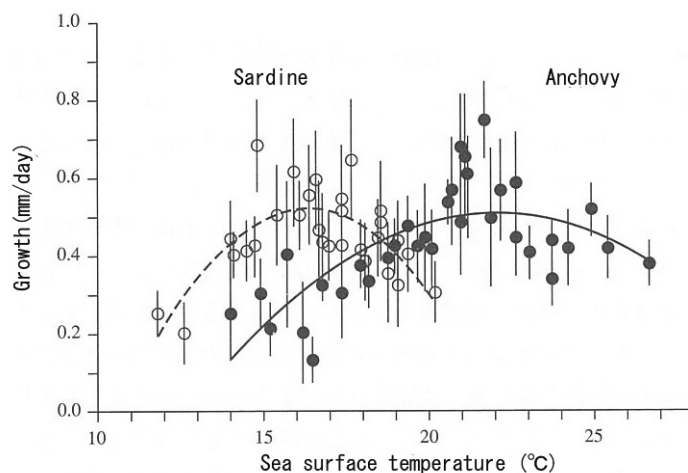


Fig. 3.9. Relations between water temperature and growth rate observed in field samples of sardine and anchovy larvae.

and zooplankton larvae. The timing of this production cycle can annually vary by several weeks, and the strength of the match between the zooplankton bloom and the spawning time would determine the quantity of food available to the larvae. The match-mismatch hypothesis states that the variable timing of the seasonal phytoplankton bloom in relation to a fixed period of spawning generates interannual differences in the match between the zooplankton production cycle and the period of fish larval feeding. If there is a mismatch in space or time, the larvae may not encounter sufficient food and reach the point of no return.

### 3) *Ocean stability hypothesis*

The stable ocean hypothesis states that stable conditions are needed to generate high local concentrations of food. It was developed by Lasker (1981), who observed that northern anchovy larvae off California starve during periods of unstable oceanographic conditions. When the sea is calm and stable, patches of high zooplankton concentration can form, and fish larvae in those patches can feed effectively. However when the sea is rough, the zooplankton prey are dispersed, and their density becomes too low to support the larvae. High densities of food organisms are required for feeding of many larval fish, so aggregations of food can be important for survival. Such aggregations often form at fronts and at the thermocline (the layer between warm upper water and cold lower water).

### 4) *Turbulence hypothesis*

This hypothesis is almost the opposite of the ocean stability hypothesis; increased turbulence enhances the encounter rate between fish larvae and their prey. Thus, years of increased wind mixing and areas of strong tides should improve larval feeding success and generate relatively higher survival rates. This

hypothesis is supported by a report that food intake of larval cod increases when wind velocity increases.

5) *Transport-retention (or member-vagrant) hypothesis*

Eggs and larvae drift in currents, so their survival will depend on if the currents transport them to areas suitable for survival. This hypothesis emphasizes the role of physical rather than biological factors in governing spawning or year-class success.

In reality, all the processes described above are important and will interact. The dominant factors vary depending on the fish species and sea area. Larval and juvenile fish which can grow rapidly by getting sufficient good food can survive by escaping from predation. The crucial period is not limited in beginning of feeding stage. Feeding capacity and moving capacity increase with the growth from larvae to juvenile and possibility of suffering predation decrease. The survival is thought to be determined by the sum of impacts during larval and juvenile stages.

### 2.3 Regime shifts

1) *Climate variability and species replacement*

Around 1977, zooplankton, invertebrate and fish populations in the North Pacific underwent a rapid change in distribution, productivity and abundance. The changes, or shifts, observed in marine ecosystems were evident on a large geographic scale (mainly the whole North Pacific) and persisted for a decade. The co-occurrence of these shifts in ecosystems around the North Pacific suggest that ecosystems were responding to a common factor, namely changes in climate or ocean conditions.

In the 1990s the issue of rapid and major shifts in climate, ocean conditions and ecosystems became a hot topic of interest to marine scientists. As a result, there has been much research on this topic, and scientists from many fields have contributed to the development of the concept of what are now commonly referred to as regimes and regime shifts. A regime is a period of several years (often a decade or more) in which the state, or characteristic behavior of the climate, the ocean conditions, or an ecosystem is steady. A regime shift refers to a relatively rapid change (occurring within a year or two) from one regime to another.

Ecosystems respond to changes in climate and ocean conditions, so several climate and ocean indices have been developed and used to determine when regime shifts have occurred. A commonly used index in the North Pacific is the Aleutian Low Pressure Index (ALPI) developed by Beamish *et al.* (1997, 2000), which is a measure of the Aleutian low, a semi-permanent, subpolar area of low pressure located in the Gulf of Alaska near the Aleutian Islands. Figure 3.10 shows fluctuations of the strength of Aleutian low and catch amounts of Japanese sardine and Japanese anchovy. We can recognize strong relations between them. When the Aleutian low is strong, temperature in Japan becomes cold because of strong north winds, and has warm winter when Aleutian low is weak. During

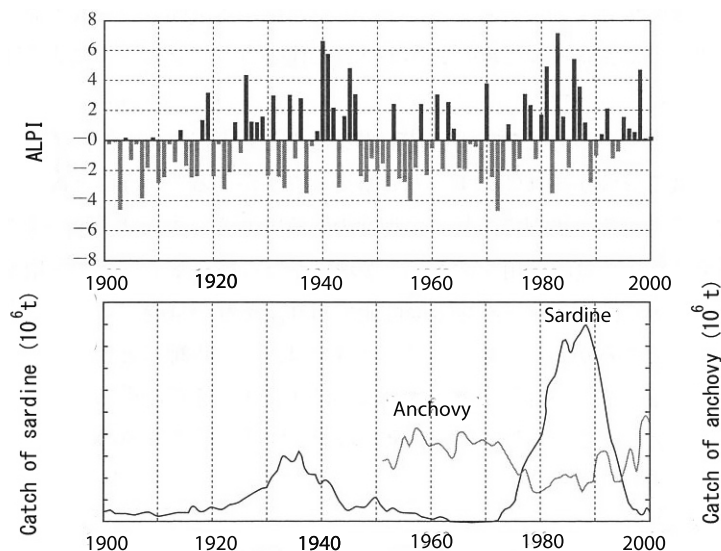


Fig. 3.10. Long term fluctuation in Aleutian Low Pressure Index (ALPI) and catch of sardine and anchovy. ALPI were calculated from data in website of Fisheries and Ocean Canada. Aleutian low pressure is strong when ALPI is positive value (from Beamish *et al.*, 1997).

1926–1946 and 1977–1988, the Aleutian low was strong, and catches of Japanese sardine were high. Japanese anchovy showed the opposite pattern—catches were high when the Aleutian low was weak. The fluctuations of both species occurred alternatively. In cold regime, sardine increased, while anchovy increased in warm regime. This is called species replacement.

Sardine species in the genus *Sardinops* are distributed off Japan as well as off Pacific coasts of North and South America. The species distributed far from Japan represent long wave fluctuation synchronously with fluctuation of Japanese sardine (Fig. 3.10). Species replacement between sardine and anchovy occur globally in seas where the genus are distributed. Species replacement with sardine is not only with anchovy but also with house mackerel, squid and saury. In comparison of spawning temperature, these species belong to warm temperature fish species similar to anchovy.

Several hypotheses have been proposed for the mechanism from climate variability to stock fluctuation or fish species replacement, though the clarification of the mechanism is still being studied. A proposed mechanism for the process is shown in Fig. 3.8. Climate and ocean changes work on growth and survival of larvae and juvenile fish indirectly through transportation and distribution or directly by alteration of food environment and temperature in this process.

The relations between water temperature and the growth rates of Japanese sardine and Japanese anchovy are parabolic in both species (Fig. 3.9). The growth

rate is highest for sardines at 16°C and for anchovy at 22°C. The curves intersect at a temperature between 16°C and 22°C. Increase of water temperature works negatively to sardine and positively for anchovy in this temperature zone. The difference in optimal temperature between the species corresponds to the fact that water temperature in Northeast Pacific Ocean was low from late 1970s to late 1980s when catch of sardine was high. It is also known that the Oyashio Current flowed to lower latitude in those days than in recent days. From these facts, we can speculate that cold-warm regime shift was a cause of fish species replacement through the difference in temperature dependent growth of both species.

The biomass of zooplankton in Japan Current and Oyashio Current show long-term fluctuations. An important food organisms of sardine and anchovy are copepod eggs, larvae and adults. Anchovy tend to eat slightly larger food than sardine. So change in size distribution may benefit one or the other species. This presumption is supported by the fact that large size copepods are rare and smaller size copepods are dominant during the period of 1976–1989 in the long term fluctuation of species composition of copepods in Japan Current in winter season. Generally it is difficult to obtain data representing the relation between the amount or species composition of zooplankton with the growth of larval and juvenile fish. However, as described in the previous paragraph, clarification of the predator-prey relationship is important also for understanding the mechanism of species replacement.

#### 2) *Regime shifts and fisheries*

Multi-decadal fluctuations in fish-population abundance have been known for centuries in many species, including herring, salmonids, cods, flatfishes, and shellfish. Understanding these regime shifts is important to fishery management, but also complicated because the abundance of fish populations is driven by both environmental forcing and fishing. From the difference in climate regime and pattern of synchronization, the fish are categorized into two groups. One is represented by sardine and the other is represented by anchovy.

It is the reality in modern times that each fish species have unique way of utilization and market value. However, it is important for management of fisheries to know that if there is a decreasing stock, there necessarily exists an increasing stock. If this fact is the fundamental of nature in ocean biological production and fundamental mechanism of fluctuation, it is reasonable to consider utilization combining multiple species in order to prevent monomaniac utilization of a species. It is impossible for human being to directly control the long term fluctuation of fish stocks, though it is possible and important to make proper counter measures to the fluctuation. When a stock is large, it is agreeable to catch sufficient volume of the stock, though for a small stock, we have to take care not to give additional impact to disadvantage species living in poor environment. We can find and catch increasing stocks alternating the disadvantaged stock. This is the way to enable the long term sustainable utilization of stocks and development of fisheries.

(Ichiro Aoki)

### 3. SUSTAINABLE RESOURCE USE

The three characteristics of fisheries stock were listed in Section 2. Among these proper use of “renewability” is important for future sustainable utilization of stock. When we leave fisheries in free competition, overfishing necessarily happens by fishing race in “first come, first served” basis, because fish are “bona vacantia” and the risk of failure always exists because of “uncertainty”. We have to discuss how we can manage fish stocks for sustainable utilization of fisheries resource considering the above described characteristics.

#### 3.1 Unit of resource fluctuation and population

For fisheries resource management, it is necessary to specify the management target. This originated from the requirement of specification of space where the unit group that represents same stock fluctuation distributes and the necessity of homogeneity of the target group when we apply population dynamics model.

In the analyses of quantitative fluctuation of organisms, the target of the analyses is generally an internally homogeneous group independent from other groups. The term population, which is commonly used in ecology, corresponds to this unit. A population is a biological unit referring to individuals of a species living in the same area. A fish stock is a management unit grouped by genetic relationship, geographic distribution, or movement patterns. Approaches to stock identification include distribution and abundance, marks and tags, meristics and morphometrics (scale pattern, number of fin rays, number of vertebra), calcified structures and scales, genetics (isozyme pattern, DNA sequences) and life-history parameters (differences in growth or maximum size).

#### 3.2 Russell's equation

Russell expressed the possibility of sustainable fisheries using reproductive function of fisheries resource by the following simple equation:

$$S_2 = S_1 + (R + G) - (M + F). \quad (2)$$

Where  $S_2$  and  $S_1$  are the biomass of the stock at the start of two successive time periods (usually one year apart),  $R$  is the recruitment of new individual,  $G$  is tissue growth,  $M$  is natural mortality and  $F$  is fishing.  $R$  and  $G$  add to the biomass, and  $M$  and  $F$  reduce the biomass, so when the two brackets are equal, the fishery will be in balance, or equilibrium. The yield of a fishery in this condition are called sustainable, and the largest average catch that can be taken from a stock over time without negatively impacting the reproductive capacity of the stock is called the maximum sustainable yield.

Russell's simple equation summarizes what causes stocks to fluctuate. If we can express each term by a mathematical model and estimate the parameters in the models, we can use the equation to establish a fisheries management strategy.

### 3.3 Surplus production models

The concept of surplus production describes a population's capacity to produce more than is needed to replace itself. The extra, or "surplus" production is what is left over and available for harvest. This concept is the foundation of fisheries management.

To understand surplus production, you must first define the limits of possible population sizes. A population can range from a minimum (zero i.e., extinction) to a maximum, which is referred to as the carrying capacity. In theory, the population size of an unexploited species will vary around its carrying capacity due to variations in natural processes. A stock fished below its carrying capacity has the ability to generate surplus production that can be sustainably harvested over time. Surplus production models are used to search for the largest fishing mortality rates that can be offset by increased population growth.

#### 1) Process of population growth

Growth rate of a population at time  $t$  is expressed as follows:

$$\frac{dB}{dt} = f(B) \cdot B. \quad (3)$$

Where,  $B$  is biomass,  $f(B)$  is function expressing increasing rate when biomass is  $B$ . In the case  $f(B) = r$  (constant), the solution of (3) is  $B = B_0 e^{rt}$ . This equation means the biomass increases without limit. The parameter  $r$  is the intrinsic rate of natural growth when there is no density effect.

Actually in biological phenomena, endless population growth is not possible, because density effects such as food and space deficiency, degradation of environment caused by accumulation of metabolic products, epidemics of disease, and increase of predation or cannibalism caused with increase of population density. Generally, biomass reaches a plateau with the increase and the relation with time represents sigmoid curve (Fig. 3.11). We will consider the case in which the increasing rate decrease linearly to the increase of biomass as the result of density effect in following paragraph as an example.

$$f(B) = r \cdot \left(1 - \frac{B}{K}\right). \quad (4)$$

$f(B)$  is equal to  $r$ , intrinsic rate of natural growth, when  $B = 0$ , and decreases with increase of  $B$ . It becomes 0, when  $B = K$ . When we put Eq. (4) in Eq. (3), Eq. (3) expresses quadratic function of  $B$  and shows parabola. A solution of the differential equation is as follow.

$$B = \frac{K}{1 + e^{-r(t-t_0)}}. \quad (5)$$



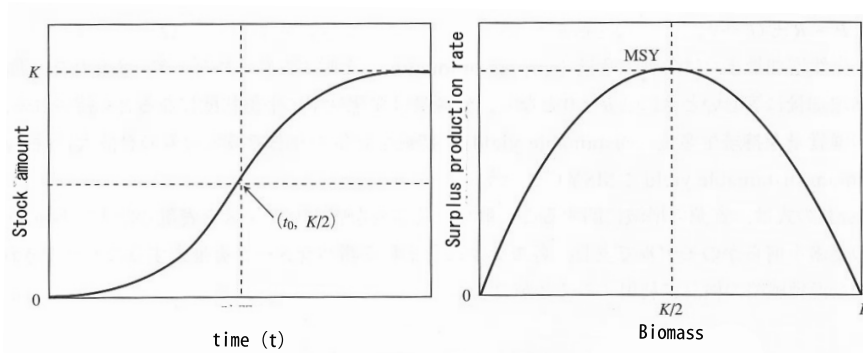


Fig. 3.11. Population growth by logistic model (left) and relation between biomass and population growth rate in Scherfer's surplus production model (right).

This is a logistic equation. The logistic curve has an inflection point at  $t = t_0$ ,  $B = K/2$ , and the increasing rate is maximum at this point.  $B$  converges to  $K$  as  $t \rightarrow \infty$  and the growth will stop.  $K$  is called carrying capacity.

#### 2) Surplus production model

When we put the term of fisheries yield,  $Y$ , in the above described model of natural increase, the equation is as follows.

$$\frac{dB}{dt} = r \cdot B \cdot \left(1 - \frac{B}{K}\right) - Y. \quad (6)$$

This equation is called Schaefer's surplus production model, and is similar to the model that expresses  $P (=R + G - V)$  in Russel's equation by a parabolic curve of  $B$ . By the regulation of  $Y$  to fulfill  $Y = r \cdot B \cdot (1 - B/K)$ , that means catching of equal amount of natural increase, we can make  $dB/dt = 0$  and equilibrium conditions will be obtained.  $Y$  in this condition is sustainable yield,  $Y_e$ .  $Y$  is maximum when  $B = K/2$ . Conclusively, maximum sustainable yield (MSY) is achieved by controlling catch amount to keep stock at half of the carrying capacity  $K$ . The author will introduce catchability coefficient ( $F$ ) and catch effort ( $X$ ) in later parts of this chapter. We can calculate  $F_{MSY}$  and  $X_{MSY}$ , which are the mean fishing amount and fishing effort to achieve MSY.

The Schaefer's model of population growth is based on the logistic equation. Other production models include Pella-Tomlinson model and the Gompertz model.  $B_{MSY}$ , which gives MSY, differs among models, though assuming the existence of carrying capacity and density effect, the speculation that there is an optimum fishing level between over-catching and over-protection is acceptable. It is easy to understand by imagining that in the case there is no parent, there will be no offspring and limitless increase is impossible on infinite Earth.

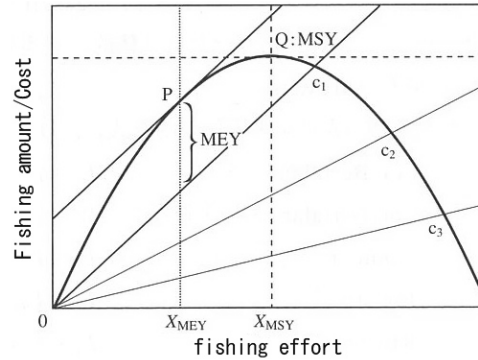


Fig. 3.12. Relations between fishing effort and fishing amount (heavy curve) and fishing cost (thin line) in the economic model. MSY is obtained at Q and MEY is obtained at P. Costs and benefits are equivalent at  $c_1$ ,  $c_2$ , and  $c_3$  depending on each cost performance.

### 3) Maximum economic yield (MEY) and optimum yield (OY)

The maximum economic yield (MEY) is a socio-economic way to approach fisheries management. It is the value of the largest positive difference between total revenues and total costs of fishing (including the cost of labor and capital). The optimum yield from a fishery is the yield that provides the greatest overall benefit, with particular reference to food production and recreational opportunities; it is based on MSY as modified by economic, social or ecological factors.

When we include production cost in a surplus production model, presuming that catch amount (price) is proportional to catch volume (weight) and production cost is a variable cost proportional to catch effort, the relation between the catch amount and production cost is as shown in Fig. 3.12. Profit is expressed as the difference between catch amount and production cost. Point P in the figure, the contact point of the parallel line of production cost and catch amount line, gives the MEY. The catch effort gives the MSY at point Q. The effort level producing maximum economic yield (MEY) is always lower than the effort level producing MSY.

The Gordon (1954) model shows the relationship between fishing effort, revenue and cost (Fig. 3.12). In an unregulated fishery, fishing continues until revenue = costs (point  $c_1$ ,  $c_2$ ,  $c_3$  in Fig. 3.12), while the greatest profits are made at  $X_{MEY}$ . The model suggests that if the costs of entering the fishery and catching fish were low, then the fishery would develop well beyond its biological limits and the stock would become depleted. In addition, the fishery would become economically inefficient. This model thus provides an explanation for why open-access fishery would be expected to expand to a size greater than that which gives the highest yield and profit.

Countermeasures to prevent this situation include 1) privatization of a stock dividing it to individual ownership, 2) privatization of stock to ownership of

fishermen group and cooperative utilization of the stock, 3) shifting the stock to public domain and detailed management by official body, and 4) Introduction of new taxation system to control catch effort to optimum level (Gordon, 1954). Among his proposals, 1) corresponds to individual catch quotas (IQ) and individual transferable quotas (ITQ), 2) corresponds to fishing right system in coastal fisheries in Japan, and 3) corresponds to management by integration of total allowable catch (TAC) and other license systems used today.

In summary, surplus production models are among the simplest stock assessment models used by fisheries scientists to model population dynamics and track biomass. They are designed to characterize the dynamics of a stock in terms of changes in total biomass without regard to age or size structure, and one disadvantage of these models is they cannot provide possible explanations for changes in abundance, because the changes in standing stock biomass, recruitment, and mortality are all examined together.

However, reality of the presumption that parameter  $r$  and  $K$  are definite and stock is always in equilibrium condition is still suspicious. For example, when a regime shift occurs, we cannot expect stable relationships to occur. Responding to the criticism, recently, models that do not assume equilibrium conditions (non-equilibrium production model), and models in which parameters  $r$  and  $K$  change secularly with the long term fluctuation in environment have been developed. In those models, MSY does not mean only fixed amount of balanced catch volume. It is used as pursuance of optimization in dynamic utilization of stock.

### 3.4 Dynamic pool model, reproduction model

As noted above, four factors influencing population biomass must be in balance for a stock to be exploited sustainably: reproduction, body growth, fishing mortality and natural mortality. Surplus production models group these together and ignore age structure, but models that keep these components separate are called dynamic pool models. They describe individual growth and survival of population in each process of the life history (Section 2, Fig. 3.7(a)).

#### 1) Growth

Equations used to express the individual growth of organisms include the following (Fig. 3.13):

von Bertalanffy growth equation

$$L_t = L_\infty \left(1 - e^{-k(t-t_0)}\right). \quad (7)$$

von Bertalanffy cubic equation

$$W_t = W_\infty \left(1 - e^{-k(t-t_0)}\right)^3. \quad (8)$$

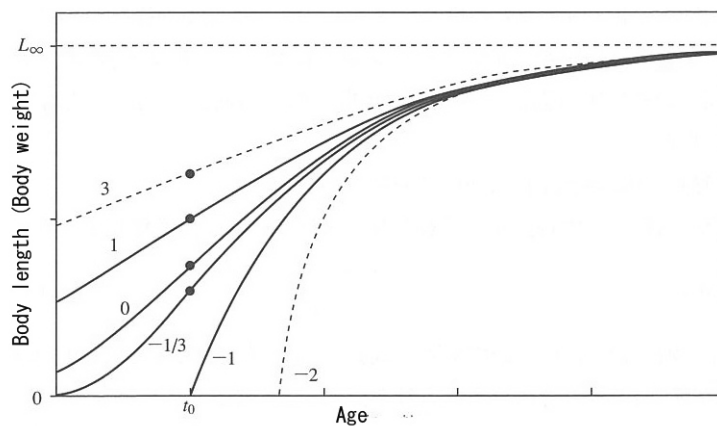


Fig. 3.13. Richards' equation. Numbers in the figure represent  $r$  value. The curve represents third power equation of von Bertalanffy's, Gompertz's equation and logistic equation when  $r = -1, -1/3, 0$  and  $1$ , respectively.

Gompertz's equation

$$L_t = L_\infty e^{\left(1 - e^{-k(t-t_0)}\right)}. \quad (9)$$

Logistic equation

$$L_t = \frac{L_\infty}{1 + e^{-k(t-t_0)}}. \quad (10)$$

Richards's equation

$$L_t = \frac{L_\infty}{\left(1 + e^{-k(t-t_0)}\right)^{1/r}}. \quad (11)$$

Where  $L_t$  and  $W_t$  are body length and body weight at time  $t$ , respectively.  $L_\infty$  and  $W_\infty$  is asymptotic body length and body weight, and  $k$  is the growth coefficient. In Eq. (7),  $t_0$  is the time when length would have been zero on the modeled growth trajectory. Equations (8), (9), (10) and (11) are sigmoid curves that have inflection points at  $t_0$ . At the reflection point, the body length is  $L_\infty/2$  in Eq. (9) and is  $L_\infty/e$  in Eq. (10). Equation (11) is all-inclusive equation of growth. When  $r = -1, -1/3, 0, 1$ , the equations correspond to the von Bertalanffy equation, von Bertalanffy cubic equation, Gompertz's equation and logistic equation,

respectively. Using Eq. (11) continuous variation can be expressed. To estimate the equation model, the following are used: 1. Rearing, 2. Tagging and recapture method, 3. Temporal changes in body length histogram and 4. Age trait.

### 2) Survival

In stock assessments, the removals from a fish stock are divided between natural mortality ( $M$ ) and deaths caused by fishing (fishing mortality,  $F$ ). The sum of fishing mortality and natural mortality is termed total mortality ( $Z$ ), that is,  $Z = F + M$ .

In a “closed stock” (i.e., one with no emigration or immigration), after recruitment, survival is considered to be relatively stable. Changes in stock number can be expressed as

$$\frac{dN}{dt} = -ZN. \quad (12)$$

The contents of  $Z$  are divided into natural mortality by disease and predation and depletion of catch by fisheries and is expressed as  $Z = F + M$ . Here  $F$  is fishing coefficient and  $M$  is natural mortality coefficient. From this model, number of catch expressed

$$\frac{dC}{dt} = FN. \quad (13)$$

The solution of Eqs. (12) and (13) is as follows:

Survival model

$$N_t = N_0S = N_0e^{-Zt} = N_0e^{-(M+F)t}. \quad (14)$$

Catching equation

$$C = EN_0 = \frac{F}{M+F} \{1 - e^{-(M+F)t}\} N_0. \quad (15)$$

Where,  $S$  is survival and  $E$  is the exploitation rate. Here,  $Z$ ,  $F$ , and  $M$  are definite and independent from  $t$ . Equation (15) shows that the catch number can be obtained by allocation of total decrease number  $N_0 = \{1 - e^{-(M+F)t}\}$  by the proportion of  $F$  and  $M$ .

In fish stock management, it is convenient to consider fishing effort  $X$  and express  $X$  as a function of  $F$ . Commonly,  $X$  is presumed to be proportional to  $F$ .

$$F = qX. \quad (16)$$

The catchability coefficient ( $q$ ) is the portion of a stock caught by a single unit of

fishing effort, and expressed as the ability of fishing gear to catch fish. Fishing effort  $X$  is input for fisheries such as investment and working time.  $X$  is expressed as measurable specific value of fisheries operation. More specifically, total number of operated vessels, total tonnage of operated vessels, operation days, total operation duration and etc. are used as  $X$ . For trawl fisheries, total number of operation times and total operation duration, for purse seine, total exploration time, for gill net, number of net and operation period is often used as  $X$ .

### 3) Yield per recruit (YPR or $Y/R$ )

Catch amount  $Y$  can be calculated by introducing body weight obtained by equation of growth to the survival and fishing processes described above:

$$Y = \int_{t_c}^{t_d} N_t F W_t dt. \quad (17)$$

Where  $t_c$  is the first age of catch, and  $t_d$  is the life span. By dividing both sides of the equation by number of recruits  $R$ , we can obtain yield per recruit (YPR). YPR is used as an indicator for establishment of fishing strategy after recruitment.

Growth overfishing occurs when fish are removed from the population while they are relatively small, or when they are removed at such a high rate they cannot reach size at maturity. In this situation, the YPR is below the possible YPR because of too early catching age or a too heavy fishing coefficient. Recruitment overfishing occurs when fish are removed at a rate jeopardizing the ability of the population to replace itself. Management based on YPR maximizes use of a stock using recruited stock as a seed by prevention of growth overfishing, in which recruitment is treated as a given amount and enormous and unstable early stage mortality is not considered. Management to keep the number of spawning fish to prevent recruitment overfishing is called reproduction management.

Contours connecting equal YPR points, with initial age of fishing on the  $Y$  axis and fishing coefficient on the  $X$  axis, are called Beverton and Holt's iso-fishing volume chart or management chart for stock management (Fig. 3.14). We can express the situation of a fishery as a plot on the contour. We can judge whether the fisheries is being overfished or not in one glance at the contours. The direction of modification, reduction of  $F$  or pull up of  $t_c$ , is easily concluded. It is possible to draw iso-fishing amount chart and iso-profit chart by price function and expense rate for establishment of fishing and management strategies.

### 4) Reproduction

The relationship between spawner and recruit abundance is commonly called the stock-recruitment or spawner-recruit relationship. Curves expressing this relationship are called reproduction curves. They are often expressed by the relation between parental stock and recruitment or spawning amount and number of recruits. The two most commonly used models are the Beverton-Holt model, and the Ricker model. Generally the curves either approach an asymptote (as in the Beverton-Holt model), or peak and decrease at high spawning stock sizes (as in the Ricker model) suggesting a limited availability of resources to support large recruitments beyond stock sizes at the peak. In the curve of the relation

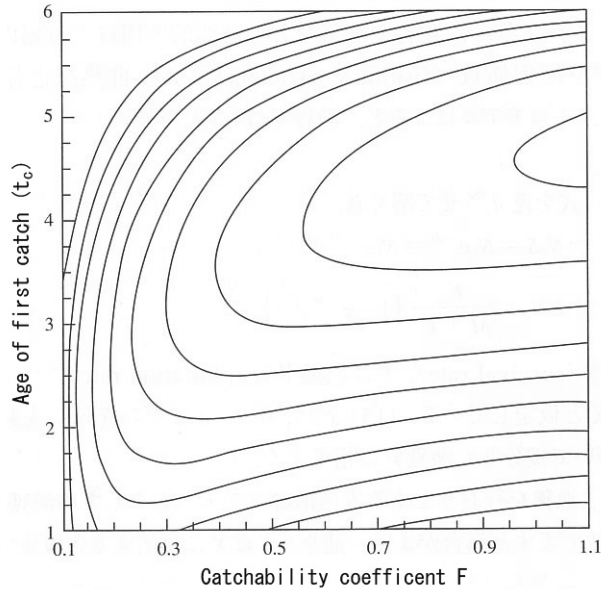


Fig. 3.14. Beverton and Holt's isogram of fish catch.

between the number of parent age and number of next generation at same stage in life history, such as relation between recruitment of parental age and that of next generation, intersecting point of the curve and 45° slope line passing origin ( $Y = X$ , displacement line) gives equilibrium condition. By fishing in the upper part of displacement line, we can prevent recruitment overfishing.

Common spawner-recruitment models include the following (Fig. 3.15):  
 Beverton-Holt model:

$$R = \frac{\alpha S}{1 + \beta S} \tag{18}$$

Ricker model:

$$R = \alpha S e^{(-\beta S)} \tag{19}$$

Generalized equation:

$$R = \frac{\alpha S}{(1 + r\beta S)^{1/r}} \tag{20}$$

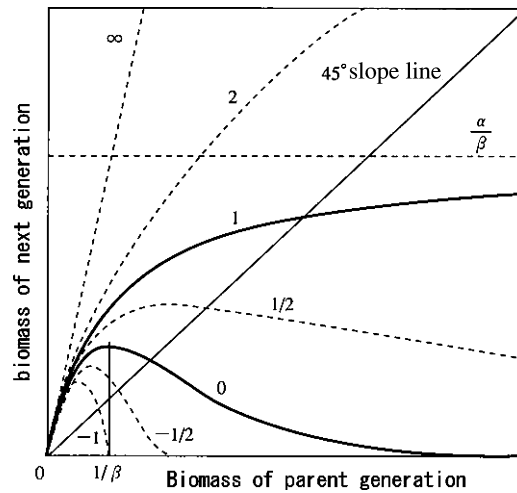


Fig. 3.15. Reproduction curve (general formula). Numbers in figure represent  $r$  value. When  $r = 1$ , the curve represents Beverton-Holt type reproduction curve, and when  $r = 0$ , the curve represents Ricker type curve.

Where  $R$  is recruit abundance, and  $S$  is spawner abundance. The right side of all equations are multiplication of proportional value of quantity of parental generation ( $\alpha S$ ) and density effect ( $1/(1+\beta S)$ , or  $e^{-\beta S}$ ). In Beverton-Holt model,  $R$  approaches  $R = \alpha/\beta$  (carrying capacity) at  $t \rightarrow \infty$  and approaches an asymptote. In the Ricker model,  $R$  peaks at  $S = 1/\beta$ . Equation (20) is a generalized equation that corresponds to the Beverton-Holt model when  $r = 1$  and the Ricker model when  $r = 0$ . Slopes at origin are  $\alpha$  in all equation and  $\alpha$  is related to intrinsic rate of natural increase  $r$ .

Data concerning reproduction have large variance due to the influence of environmental factors in actual stocks (Fig. 3.6). For this reason, in stock simulations, models which consider random fluctuations are used. In some models, water temperature is introduced as a variable. In others,  $\alpha$  and  $\beta$  fluctuate in long term by the influence of regime shifts.

By adoption of reproduction relations, we can draw whole life history cycle of fish, recruitment-growth and survival-spawning-hatch-recruitment, can be predicted. We can calculate MSY from these models and perform various numerical simulations for optimum utilization of the stock.

### 3.5 Stock management

#### 1) Procedures of stock management

Management of fisheries stock can be compared with health management of human being. They have a similarity in the procedure in which treatment (management) should be done after proper diagnosis. First of all, biological



Table 3.2. Categorization of major fisheries regulation methods.

|                                 | Quantitative regulation   | Qualitative regulation   |
|---------------------------------|---|--|
| Input control                   |   |  |
| Fixed equipment<br>(fixed cost) | Fishing capacity (fishing efficiency)<br>a) Size of vessel<br>b) Power of engine<br>c) Size of gear                         | Fishing gear and method<br>k) Selectivity of gear<br>l) Prohibition of fishing method  |
| Operation<br>(variable cost)    | Fishing effort<br>d) Number of vessel<br>e) Operation days, times, period<br>f) Number of gear<br>g) Allowable effort (TAE) | Operation area and time<br>(ban during spawning and nursery season)<br>m) Closed area<br>n) Closed season  |
| Output control                  | Catch volume<br>h) Allowable catch (TAC)<br>i) Individual quota (IQ)<br>j) Individual transferable quota (ITQ)              | Qualitative regulation of caught fish<br>(ban for catch of small fish and mature female)<br>o) Size regulation<br>p) Regulation depending on sex |

nature such as age and growth, stock characteristics such as stock volume and fishing rate are estimated (stock assessment). Comparing the results of assessment with management goal, stock diagnosis including evaluation of stock condition and specification of cause, in case if the condition is not preferable, is done. Based on the certification of diagnosis, stock management treatment such as fisheries regulation is performed aimed at recovery to target stock conditions and rational utilization of the stock.

To achieve the target goal of stock management, in fisheries, social and economic activities must be controlled. Stock management and fisheries management are inextricably linked and actually are performed together. Stock management is a successive procedure including stock assessment, setting of target goal, establishment of strategies, selection of a method, implication and assessment of outcomes for recovery or maintaining desirable condition of target stock through regulation of related fisheries.

## 2) Classification of fisheries stock management methods and their characteristics

Methods of fisheries stock management are classified in Table 3.2. One criterion for the classification is whether the control is performed at the input or output stage. The other criterion is quantitative control or qualitative control. Further, input control can be divided into control of fixed capital equipment such as vessels and fishing gears, and contents of operation.

### a) Input controls (Table 3.2a–g)

Input controls, also known as effort controls, limit the activities of fishers, the type of gear they use and the amount of time they can use the gear. The aim of input control is to reduce the catching power of fishers and thus reduce fishing mortality. In input control, decrease of effect of management caused by fluctuation

of stock is small. This implies, input control is strong to uncertainty of stock assessment. However, there are possibilities of loopholes in another item when one item is restricted. In order to control total fishing pressure at an adequate level, a proper combination of restriction in several items is needed. In case of insufficient control, irrational economic behavior is possibly induced such as overinvestment in equipments.

*b) Output controls (Table 3.2h–j)*

Output control, or catch control, try to control fishing mortality by limiting the weight of catch that fishers can take. These include total allowable catch (TAC), and individual quotas (IQ).

Under TAC management, a fishery closes when the total catch volume reaches the annual catch recommended by a management authority for a species or group of species. This management tends to rush the fishers in maximizing their share of the TAC.

Under the IQ system, the catches of individual fishers are restricted. If the IQs can be bought and sold, they are known as individual transferable quotas. Under the IQ and ITQ systems, fishers receive a quota and can fish at their own pace. This tends to result in improved catch quality and a more stable supply to markets.

More economically efficient and rational fisheries will be established in society by pursuance of economic rationality through dealing between management bodies. However, the risk of oligopoly by overconcentration of capital is possible under the ITQ system. The IQ and ITQ systems also tend to induce high grading and dumping of low market value fish.

Accuracy of stock assessment should be improved for effective management by output control. When the estimation error is large, output control is less effective than input control.

*c) Technical measures (Table 3.2k–p)*

Technical measures are qualitative restriction of the size and sex of fish that are caught, gears used, the times when, and areas where fishing is allowed. Technical measures at the entry side restrict the operation of the fishery, while those at the exit side restrict the aspects of fishing products. Restrictions for body length and sex are technical measures at the exit side, due to which, landing or selling of smaller fish and matured female is restricted. Technical measure implemented as a routine after introduction of the system with a detailed operational plan can reduce the cost for management and prevent fluctuation of stock.

*3) Harvest control rules*

At what stock level should catch restrictions be imposed? To what degree should fishing be restricted? How much can we catch when a stock is increasing in size? When can we increase the catch volume? These questions can be answered by using control rules, which are agreed upon management actions that may be triggered by changes in the status of the stock. Control rules are also known as decision rules or harvest control laws and can specify how yield should vary with biomass. An example of a control rule is shown in Fig. 3.16, which

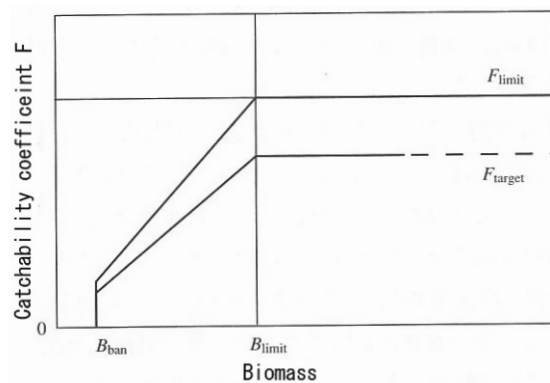


Fig. 3.16. An example of fishing regulation rule (ABC calculation rule of Japan in 2007).

shows how allowable biological catch (ABC) used as a base for setting the TAC in Japan is calculated. When a stock size is sufficiently large, fishing under definite fishing coefficient ( $F_{\text{limit}}$  and  $F_{\text{target}}$ ), which is calculated from a biological reference point (BRP) such as  $F_{\text{MSY}}$ , is proposed. When biomass  $B$  decreases below a limit set as the lowest acceptable by some specified criterion ( $B_{\text{limit}}$ ), a stock recovery operation is invoked, and  $F$  is reduced. When  $B$  drops below  $B_{\text{ban}}$ , a fishing ban or other operation pursuant to a ban will be invoked. Rules used in Europe, the United States and in international committees are approximately similar to this rule, though more restraint rules including proper safety ratio are often applied introducing the idea of precautionary approach to respond to the risk of uncertainty.

Consideration for desirable harvest control rule eventually results in the following two work operations. 1. Setting object functions based on concrete measurable indicators for most efficient achievement of agreed upon management goals, 2. Determining what is the most adequate rule for optimization of the objective functions under a given condition. This is the solution of the constrained optimization problem. To solve this, operating model (OM, described below) is used.

Control rules were originally composed from biological management criteria. However, many felt that sustainability of catch amount and volume should be included in management goals other than achieving MSY considering fisheries as economic activities. Furthermore, desirable rules differ depending on the range of uncertainty such as estimation error in stock assessment. The consideration for the uncertainty should be expressively included in the rule.

#### 4) Response to uncertainty and feedback management, adaptive management

Various simulation models have been developed using computer-related technology for various future assessments. Introduction of new concepts, such as regime shifts, deeper our understanding of ocean dynamics. However, no matter

how sophisticated the models are, they all include uncertainty. For the implementation of risk-free stock management, establishment of management strategy primarily including consideration for existence of uncertainty in the future prediction is required.

Feedback control is one of those management systems in which the effect of management on a system is sequentially monitored to adjust the contents and extent of the management adaptability. Mis-prediction of an assessment is preliminarily premised in the management system. Response of the output to an input is monitored, and the input is modified corresponding to the response as ex-post countermeasures in feedback control. Methods which manage systems by predicting future dynamics are called feed-forward controls. If the prediction is correct, feed forward control will show a prominent effect, though when the prediction is incorrect, there is high risk of an adverse effect.

Tanaka's method is a simple feedback method, in which fishing volume is increased when the stock size is larger than the target size and is decreased when the stock size is smaller than the target size. Adaptive management, a more generalized concept of management including feedback control, has been established in recent years for conservation and management of ecosystems. Feedback control, which is used for management responding to medium to long-term shifts of stock rather than short-term fluctuations, is attracting attention as a countermeasure to regime shifts.

#### 5) *Operating Model (OM) and Management Procedure (MP)*

Uncertainty caused by insufficient knowledge of stock condition and dynamics and impossibility of inspection, which can be done in other sciences by experiment to confirm the adequacy of models and hypotheses, are often pointed out as the reason for the difficulty in management of fisheries stock. Recently, trials to explore adequate measures by virtual-reality experiments using operating model constructed on computers have been performed. In computer simulation, we know the state of the stock virtually, so we can judge the success or failure of stock assessment and management, and can evaluate the capacity of a total management system. Moreover, we can apply models to various situations to develop a management system that can deal with uncertainty. The management systems developed by these simulation methods are called management procedure (MP). Control rules and feedback control systems can be evaluated and their performance improved by operating model.

(Taku Yamakawa)

## 4. STOCK ENHANCEMENT

### 4.1 *Contents of aquatic stock enhancement*

Fisheries stock propagations are human activities for management or improvement of biological production system of fisheries organisms in natural water bodies in order to obtain higher catch volumes sustainably. The methods of propagation can be divided largely into three categories, namely, protection of

Table 3.3. Major method for stock enhancement.

---

|  |
|--|
| Protection of propagation  |
| Regulation of fisheries  |
| Season, Fishing area, Fishing gear, Fishing method, Catch size, Catch volume |
| Regulation of transplanting  |
| Regulation for removal of element for propagation of fisheries organisms     |
| Regulation of abandon and dispose materials harmful for fisheries organisms  |
| Establishment of protection area   |
| Protection of migratory fish   |
| Setting of migration route (fish-way)  |
| Prohibition of fishing of salmon in fresh water area                         |
| Promotion of propagation–Environment improvement                             |
| Improvement of spawning and wetting environment                              |
| Construction of spawning ground  |
| Production of calm current area  |
| Improvement of nursery for larvae and juvenile                               |
| Creation or repairment of sea grass bed                                      |
| Creation or improvement of tidal flat  |
| Artificial beach   |
| Creation of fishing ground   |
| Artificial fish shelter, Artificial reef, Stone introjections, Reef crash,   |
| Production of concrete wall surface  |
| Acceleration of sea water exchange   |
| Open channel, Construction of water route, Construction of leading bank      |
| Improvement of bottom condition  |
| Admixture of soil, Covering of bottom, Tilling                               |
| Vanishing wave   |
| Construction of dike, Subsurface dike  |
| Nutritional support  |
| Fertilizer, Construction of sea grass bed                                    |
| Regulation of biological community   |
| Removal of competitor and predator   |
| Promotion of propagation–Direct supplement of stock                          |
| Transplantation  |
| Release of natural seed  |
| Release of artificially produced seed (culture based fisheries)              |

---

propagation; protection of fisheries stocks from adverse impacts caused by human activities such as overfishing and environment destruction, improvement of environment. Improvement of environmental factor limiting stock increase to more suitable condition for fisheries organisms, and stock supplement; direct enhancement of stock such as stocking with young of target species when spawning amount or development and growth of eggs and larvae is limiting factor for transplantation of fish species when target organism does not exist in the environment. Operations which combine mass stocking of artificially produced seed and protection and improvement of environment are called cultivating fisheries. Encouragement of propagation is a terminology combining improvement

of environment, transplantation, stocking and cultivating fisheries used as a term in contrast to protection of propagation (Table 3.3).

#### *4.2 Protection of propagation*

Restrictions on fishing season, fishing ground and fishing size, fishing method and gear, and number of fishing vessels are imposed for the protection of spawning and larval individuals from adverse effects on stocks by fisheries. Transplantation of harmful organisms for stock, dumping or leaving of deleterious materials including chemicals, and harvesting or elimination of functional elements for nursing of fisheries organisms such as algae and rocks used as substrates by attaching invertebrates and shelters are also restricted. Protected areas are designated, where alteration of the environment by dredging and digging of gravel and catching of target species by specified fishing methods and gears can be restricted and banned.

Construction of obstacles in rivers that interfere with movement of fish such as dam and weir is restricted, as installation of fish way for keeping migration route of fish is mandatory in order to protect anadromous fish like salmonids and ayu. Fishing of mature chum salmon is prohibited in inland water bodies in Japan.

#### *4.3 Environmental improvement*

Various measures to actively improve the habitat environment of aquatic organisms are implemented as more progressed countermeasures than restriction-based protection of propagation. When we summarize the measures in order of developmental process of organisms, improvement of environment for increasing the amount of emerging eggs and larvae, improvement of growth environment for hatched larvae and juveniles, improvement of habitat such as settling place and substrate for sessile organisms can be observed. Various techniques have been devised from long ago. Recent improvements are implemented by integration of such techniques.

##### *1) Improvement of spawning and settling environments*

Various arrangements of environment are carried out for increasing the amount of emergence of organisms, such as the construction of fish spawning grounds and substrate for settlement of planktonic larvae of invertebrates. For example, spawning beds are paved with gravels of size suitable for adhesive eggs of ayu, and breakwaters are constructed to weaken water current behind it for easy settlement of larval crabs and shrimps.

##### *2) Improvement of nursery ground of larvae (seaweed bed and tidal flats)*

Survival of larvae of fisheries organisms is commonly very low and maintenance of nursery ground such as seaweed bed and tidal flats are important for their survival. Several types exist in seaweed bed. Sea grass beds are formed as clumps of flowering plants in sea on shallow sandy beaches, sargassum beds and sea oak, and sea trumpet beds (sea forest) are formed on rocky shores as clumps of sargassum and mixed communities of sea oak and sea trumpet. In seaweed beds, organisms can easily escape from its predator and can get rich food

organisms such as small crustaceans. These are considered to be the reasons why seaweed beds are preferable nursery grounds for many larvae and juveniles. Drifting seaweed provides a good nursery for larvae and juveniles of migrating fish species. Sea oaks and sea trumpets are good food for various fisheries organisms such as abalones. Tidal flats are muddy or sandy shore produced in intertidal zones of estuaries. Large predators cannot enter these areas, and food organisms such as polychaetes are abundant. Tidal flats function not only as nursery ground, but also provide a place for laver aquaculture, fishing grounds of short neck clam, habitats of birds and a place for recreation such as clam digging. Water cleanup function of both seaweed bed and tidal flat is high and thus serve an important function in conservation of coastal environment.

Recently, disappearances of sargassum bed and sea forest throughout the year without relation to season have been frequently reported and the phenomenon called "Isoyake" (meaning rocky-shore denudation), which is partial or total withering of the seaweed growing in certain areas is observed. The cause of Isoyake is not fully understood, though various factors are seemingly involved. Creation and recovery of seaweed beds, input of substrate such as rock and concrete block, input of substrate with attached seaweed, cleaning of the surface provide new substrate for attachment and capture of harmful seaweed eaters are implemented (Taniguchi (ed.), 1999).

Various methods are being implemented to enhance the productivity of tidal flats where the surface mud is scraped away and exposed to air for long period due to the high ground level. Surface soil is tilled and ditches are constructed to keep water exchange in tidal flats, when water exchange become inactive in soil due to drying. Artificial tidal flats and beaches are constructed as nurseries for short neck clam and places for tourism by construction of dikes and filling up of sand.

### *3) Construction of fishing grounds*

Artificial structures made of concrete and abandoned vessels are placed on sea bottom to create habitat for fisheries organisms. Various fish and crustaceans prefer hard structures such as rocks located adjacent to such structures, for shelter and protection from strong current. These natures of aquatic organisms are utilized in construction of fishing grounds. These structures also provide places for attachment of seaweed and invertebrate. In administrative terminology, structures targeting finfish are called "artificial fish bank" and those targeting seaweed and invertebrate are artificial shore or dumping of stones.

Blasting of rocky reefs and construction of concrete surface are carried out to make new substrate for attaching of seaweed and to enlarge intertidal zone for laver, respectively.

### *4) Acceleration of seawater exchange*

In areas where the substrate is rich in organic substances, oxygen in the water is consumed with decomposition of organic substances and anoxic water is generated. Aquatic organisms cannot live in such environments. Especially in summer, warm and low density water floats at the surface (stratification), and mixing of water between upper layer and lower layer is low. As a result, bottom conditions become anoxic, and toxic substances such as ammonium and hydrogen

sulfite are frequently produced. To improve these oxygen depleted environments, various construction and civil engineering works are carried out such as the construction of open channels, bottom channels and training walls to introduce oxygen-rich water. To promote mixing between the surface and bottom water, aeration and pumping up of bottom water are implemented.

5) *Improvement of bottom condition*

To make bottom conditions suitable for habitation of aquatic organisms, admixture of soil suitable for survival of bivalves and shrimps, tilling of hardened bottom, covering of bottom containing harmful substance with sand and dredging of harmful slime from water bottom are implemented.

6) *Wave suppression*

Shores directly washed by waves are not preferred by invertebrates such as crabs and shrimps. Breakwaters are constructed for suppressing waves. However, breakwaters sometimes interfere with water exchange and deteriorate the water quality. To avoid such cases, submerged breakwaters are constructed to allow water exchange above the breakwater and maintain preferable water quality.

7) *Nutritional support*

Fertilizers are applied for the growth of seaweed such as *Laminaria (konbu)*. The so called deep seawater, which is pumped up from depths of 200–300 m and is rich in nutrient, is used as a fertilizer. Seaweed beds are constructed to give nutritional support to the abalones and top shells.

8) *Regulation of biological community*

Organisms harmful for survival and growth of fisheries organisms and their natural predators are removed or exterminated from the environment. For propagation of useful algae such as *Laminaria* and *hiziki*, competitive algae are removed to help the attachment and growth of spores of the useful algae. For stock enhancement of scallops, short neck clams and abalones, their predators, such as starfish, are eliminated. Recently, bullnose rays, which prey on short neck clams, have been eliminated in several clam nurseries, and rabbit fish, which prey on seaweed have been eliminated as a causative animal of “Isoyake” phenomenon.

#### 4.4 *Transplantation and release*

Transplantation is the introduction of new aquatic species to water body not originally inhabited by the species. Transplantations have been performed in inland waters like lakes and ponds. Most of Japanese smelt currently inhabiting the dam lakes and mountain lakes have been expanded by transplantation. Himemasu (landlocked kokanee) in the Shikotsu, Towada, Chuzenji, Sai and Motosu lakes in Japan have been stocked by transplantation. Recently, transplantation of exogenous species such as largemouth bass and bluegill have seriously damaged indigenous species and caused a serious social issue. In addition, transplantation is not recommendable for prevention of the spread of pathogens, and currently transplantation is not used as a measure for stock enhancement in natural water bodies.

Release is different from transplantation. Mass release of juveniles of indigenous species aimed at stock enhancement is “release”. Naturally captured



seeds as well as artificially produced seeds are used. Recently, release of artificially produced seed is dominant because of development of mass seed production technologies. A method for stock enhancement by the release of mass-produced seed is called “culture based fisheries”.

#### 4.5 Culture-based fisheries

Survival of aquatic organisms living in natural environment is generally very low during the egg and larval stages. Culture-based fisheries are a method for stock enhancement, in which seeds are produced under human management in artificial environments during the low survival stage, intermediately cultured to juvenile size and massively released in water body. Approximately 1,800 million individuals of salmon, 20–30 million individuals of sea bream and flounder, 100 million individuals of kuruma prawn, 3,000 million individuals of scallop are annually released in Japan. Culture-based fisheries are carried out also for many fish and shellfish species in Japan other than the species listed above. After the release, various techniques for protection of propagation and improvement of environment are performed to support the growth and survival of released juveniles. Assessment of the effect of the release is also commonly implemented.

Basic technologies for mass production of seeds such as maturation inducement of parental individuals, inducement of spawning, rearing of larvae, production of food organisms, and various techniques are developed for use in target species.

##### 1) Seed production of marine fish

Control of day-length and water-temperature are commonly used to induce maturation. In some cases, hormonal drugs are administered. Fertilized eggs are collected from surface water of culture tanks, where eggs are spawned and fertilized naturally from multiple numbers of parental fish. In seed production from multiple spawning, fish such as sea bream and flounder produce separate floating eggs. For semelparous fish, such as salmon and puffers, artificial fertilization is performed using eggs and sperm artificially obtained from parental fish.

Eggs of marine fish are very small, so the yolk sack of hatched larvae is also small. The larvae must feed soon after hatching when the digestive tract is still not fully developed. To prevent the discharge of larvae, water exchange rate should be kept at a low level. Therefore, the required characteristics of food for larvae are (1) having physical property in size, shape and distribution to be eaten by larvae, (2) digestibility by larvae, (3) little impact on water quality, (4) mass scale availability. Brackish water rotifers, *Brachionus plicatilis* (Fig. 3.17A) and *B. rotundiformis* which satisfy the above required conditions are commonly used as food organisms.

Brackish water rotifers are zooplankton belonging to the phylum Rotifera. Their lorica length is approximately 300  $\mu\text{m}$ , and the shape is round or urceolate. Most marine fish larvae can eat *B. plicatilis*. Its swimming velocity and swimming behavior are preferable for fish larvae. Fish with mouths too small to eat *B. plicatilis*, such as the serranids, are fed *B. rotundiformis*. The gastric gland in

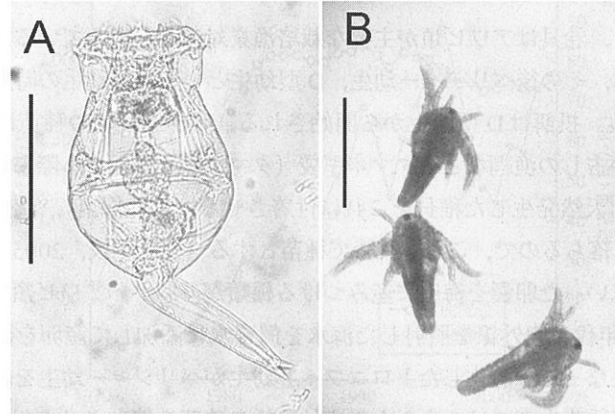


Fig. 3.17. Rotifer *Brachionus plicatilis* (A) and *Artemia nauplii* (B). Bars are indicating 200 µm (A) and 500 µm (B).

larval fish just after hatching is still not sufficiently developed to excrete pepsin. The larvae can digest proteins only to a colloid, and the epithelial cells of the digestive tract absorb the colloid and digest it to amino acid by intracellular digestion. Therefore, they cannot digest altered proteins in formulated feed. On the contrary, rotifers contain digestive proteins. Rotifer is given to larvae in living condition. Uneaten rotifer can survive in the rearing water and will not spoil the water quality.

In early days, rotifers were cultured with mass cultured *Nannochloropsis* sp. After that, culture method of rotifer by baker's yeast, which is easily obtainable without culture, was established. Nowadays, industrially produced freshwater chlorella is generally used for the culture of rotifers. Continuous culturing method for rotifer using freshwater chlorella has been developed. Based on the development of these technologies, stable mass production methods for rotifer have been established (Japan Sea Farming Association, 2000).

Mass mortalities of larval fish once occurred due to nutrient deficiency of rotifer cultured by baker's yeast. This was the momentum for the studies on nutrition requirement of fish larvae. It was clarified that highly unsaturated fatty acid (HUFA), such as IPA (icosapentaenoic acid) and DHA (docosahexaenoic acid) was essential. Baker's yeast and freshwater chlorella contain little amount of HUFA. Supplementation of oils containing HUFA to baker's yeast became common for rotifer production. Nowadays, rotifer produced by freshwater chlorella is used as feed for larvae after enrichment of HUFA and other nutrients.

As a common protocol for feeding of marine fish larvae, newly hatched artemia (brine shrimp) nauplii are fed to larvae after rotifer eating stage when the larvae grow large enough to eat the nauplii, and, subsequently formulated feed or minced fish meat is fed. Resting eggs of artemia, tolerant to drying, are available commercially and the nauplii can be obtained by incubating the egg in seawater.

## 2) *Seed production of crustaceans*

Kuruma prawn is a representative species of artificial seed production of crustaceans. Most crustacean females store sperm from males in their body and fertilize eggs at the moment of spawning. Generally in kuruma prawn seed production, wild females which have a well developed ovary are caught in natural environment, and eggs spawned from the females are used. Recently a method to artificially induce maturation by eye stalk ablation was developed, and cultured parents can be used for seed production.

Nauplii hatch from the fertilized eggs discharged outside. The larvae grow to juvenile shrimp with repeated molting through zoea and mysis stages. Planktonic diatoms are used for food of early stage and rotifer, artemia nauplii, and formulated feed are serially used depending on the development of shrimp larvae (Yano, 2005).

## 3) *Seed production of bivalves and gastropods*

Scallop and abalone are representative target species of bivalves and gastropods, respectively, for culture based fisheries in Japan. Bivalves hatch as trocophores and grow to settling stage on substrates or bottom through planktonic phases called the veliger stage and D-shaped larval stage. Feeding start from the D-shaped larval stage. Scallop seeds are collected from natural environment in the season when planktonic larvae are in high density using spat collectors made by putting used fishing net in mesh bags. The collector is submerged in the sea, and larvae attach to the net. With the growth of larvae, they lose their attaching ability and drop down to the bottom of the bag. The shells in the bags are collected and used as seed (Maru and Kosaka, 2005).

Although many gastropods spawn egg capsules containing fertilized eggs on the bottom, abalone eggs are fertilized in water. Spawning inducement technology by flowing ultra-violet irradiated seawater in spawning aquarium had developed in the 1970s, and this method triggered seed production of abalones. The larvae attach to the substrate after swimming trochophore and veliger stages. Feeding starts after attachment. In seed production of abalones, plastic corrugated boards on which attached diatoms flourish as food organisms are used as substrate for attaching shells. The boards are replaced with new boards depending on the condition to feed new diatom. In later stages, formulated feed and natural sea algae are used for feeding (Sasaki, 2005).

## 4) *Seed production of Echinoderms*

Sea urchins are also target species for culture based fisheries. Eggs and sperm are obtained by stimulation with potassium chloride solution and inseminated in seawater. Echinoderms start eating from the planktonic stage, and feed on planktonic diatoms during the planktonic phase, and on *Ulvella lens* (awabimo) or diatoms grown over plastic boards, after attachment. When they grow up to the stage which can digest cell wall of algae, algae or formulated feed are fed to them (Azuma, 2005).

## 5) *Intervening culture*

The possibilities of survival and growth of the artificially produced seed are low when released directly into the natural environment from cultured condition.

Intervening cultures in semi-natural environment are performed to increase the possibility of survival after release. The purpose of intervening culture is not only growth in size to prevent predation but also adding more proper morphological and physiological characteristics in natural environment such as resistance to starvation, developing natural behavior for obtaining food organisms and escape from predation. In the case of intervening culture only aimed at increase of the size, large rearing tanks or cages are used in the sea. However, culturing in natural environment enclosed by net or dike are often used for intervening culture of sea bream and flounder. In such cases, fish are cultured in low density, and feeding of formulated feed is repressed to enforce utilization of natural food organisms.

#### 6) *Managements after release*

Protected areas for released seed are generally established or restriction of fishing size are carried out as management after release. In culture based fisheries of scallops, 4 to 5 fishing areas are installed. Before releasing of juveniles, natural enemies of scallop are eliminated from the area and fishing is banned for 3–4 years. Fishing is allowed after the ban by rotation. This system is called rotation fishing system (Maru and Kosaka, 2005).

#### 7) *Assessment of stocking efficiency*

Marking of juveniles before release and estimation from increase of catch are used for the estimation of stocking efficiency. Fin cut, partial remove of fin ray and tagging are used as marking methods. Marking of juveniles for release requires high cost and labor and sometimes has a negative impact on the survival of released juveniles. In addition, tags have risk of drop-off after release. Moreover, reporting rates of recapturing of released individuals are low. Morphological aberrations, which occur in high percentages in artificially produced seed, are used as markers of artificial seeds. Partial tanning of underside of flounder, lack of inter nostril epidermis in sea bream and discriminative color of a part of the shell produced during seed production in gastropods are used as natural makers, and released individuals are easily recognized by these characteristics.

Accurate quantitative assessment of the effect by comparing catch volume between before and after release is difficult, because catch volumes fluctuate even in original condition before release. However, in salmon and scallops, the catch volumes prominently increased after the beginning of releasing activities and sufficient effects of release are recognized (Fig. 3.18).

### 4.6 *Laws and regulations for stock enhancement*

Most of stock enhancements are performed in official open water and the target species do not belong to private ownership (*bona vacantia*). Therefore, stock enhancements are implemented by public institutions such as state, local government and fisheries association under laws. In Fisheries Basic Act of Japan, the most fundamental rule of public administration of fisheries establishes the obligation of state to implement necessary action to propagate, and to conserve and improve environment for the growth of fisheries animals and plants. Actual projects for protection propagation are implemented under the Act on the

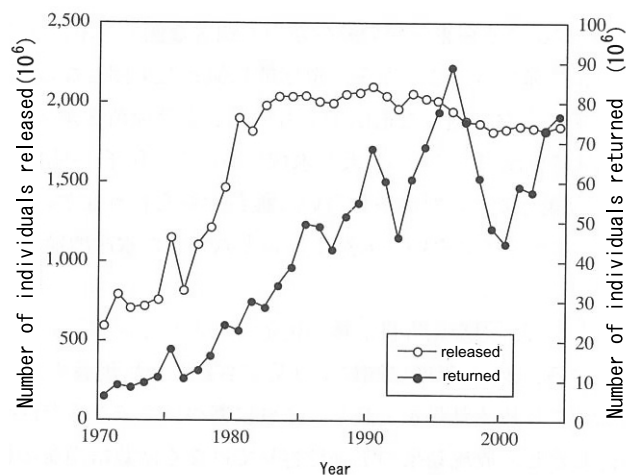


Fig. 3.18. Changes in numbers of salmon released and returned in Japan. Data are obtained by Fisheries Research Agency.

Protection of Fisheries Resources. Improvements of environment are carried out under the Act on Development of Fishing Ports and Grounds. Projects relating to culture based fisheries are performed under Coastal Fisheries Grounds Enhancement and Development Program Act. For determination of necessary guideline, plan, regulation and restriction, the administrative organization should hear the opinion of Fishery Policy Council under Fisheries Basic Act and Fisheries Adjustment Commission under Fisheries Law.

#### 4.7 Contemporary issues of stock enhancement

Stable ecosystem is established by complicated relationship among huge number of species in natural water bodies. On the other hand, activities of stock enhancement are actions to enhance particular useful species and the relation with other species are rarely considered. As a result, there is a possibility that activities of stock enhancement sometimes disturb total ecosystem. Typical prominent examples are the decrease of endogenous species of largemouth bass and blue gill by transplantation. Artificially produced seeds are offsprings of limited number of parental organisms and the release has a risk of creating genetically biased population. There is a possibility of unconscious selection of a particular gene that suits artificial environment of seed production. Mass release of artificially produced seed has risk of genetic disturbance of natural population. Efforts to prevent risk such as use of large number of parental fish are done today, though the fear of the risk is not cleared. Development of policy and methodology for harmonized stock enhancement with natural ecosystem is expected.

Project of stock enhancement is implemented by government and local government using tax. Opinions claiming payment of beneficiaries are becoming

popular. The basic guideline for culture based fisheries formulated by government in 2005 requests assessment to prove the effect of release and possible payment of beneficiaries based on the effect. However, the proof of effect is not actually easy. Except the release of salmon, scallop, sea bream and kuruma prawn in particular area, the effects are rarely proven. In addition, optimum place, season, releasing size and releasing amount are still unclear. It is necessary to implement studies for development of method for assessment of effect as well as the technologies of releasing method.

(Tomoyoshi Yoshinaga)

## 5. AQUACULTURE

### 5.1 *What is aquaculture?*

Aquaculture is the culturing of aquatic organisms in particular facilities under ownership of a particular person for the purpose of marketing. In Japan, various animals and plants are cultured, such as fish, crustacean, mollusks (shell), echinoderm, protochordates, crawler (soft shelled turtle) and algae. In aquaculture, exist complete aquaculture, in which whole life history is controlled under human care, and incomplete aquaculture. Carp and rainbow trout fertilized eggs are obtained from cultured parental individuals and reared to market size, and are cultured by complete aquaculture. On the other hand, seeds for culture are obtained from natural environment through incomplete aquaculture. Large amount of seeds for yellowtail (mojako) are obtained by catching juveniles under drifting seaweeds. In eel culture, technology to provide large amount of seed as not yet been established. In aquaculture, organisms are reared to marketable size from seed. Storage is different from aquaculture, where organisms are kept for short periods aiming to increase the price. In storage, organisms are sometimes fed, though the purpose of feeding is not growth of individuals.

Fish, crustacean and crawler (soft shelled turtle) are fed without some exceptional case (feeding culture). In contrast, oyster and scallop grow feeding small organisms or organic particles in natural environment. Algae can grow by absorbing nutrients from seawater, and algal culture do not need feeding. Such culturing systems are non-feeding aquaculture. In aquaculture, organisms are reared in high density in a limited area. The environment of adjacent area of aquaculture sites are often polluted by residual foods and waste from cultured organisms. Previously, raw and frozen fish were used as feed in the culture of marine fish, which led to serious problems of pollution the inner bays. After that, use of formulated foods have been popularized, and the environment has prominently improved. However, pollution by aquaculture is not negligible. Undoubtedly, the impact of non-feeding aquaculture to the environment is smaller than that of feeding aquaculture, while labor required is smaller in non-feeding aquaculture.

Products of aquaculture are mainly used as food. Several fishes are cultured for ornamental use.

## 5.2 History of aquaculture

It is thought that irrigation ponds and ditches were used for raising freshwater fish in Japan around 100 B.C. The first shellfish aquaculture recorded was in the Seto Inland Sea in the middle of the 16th century. At the start of the 17th century, commercial growing of red sea bream began and carp culture was conducted. Carp culture using silk worm pupa started near Saku in the beginning of the 19th century. Paddy carp culture started in the Meiji period (1868–1912). Oyster culture began in the Aki domain (Hiroshima prefecture) in the late 17th century as a bottom-sowing culture method. Eel, ayu, and rainbow trout culture originated in the Meiji period, and yellowtail and sea bream culture began in the Showa period (1925–1989). With the promotion of culture-based fisheries, technologies for mass production of artificial seed of fish and shells were developed in the late 1960s. The seeds produced for release were also provided for aquaculture. As a result, the culture of flounder and puffer became common, and diversification of aquaculture progressed.

Recent total production of aquaculture in Japan has been about 1.2–1.4 million tonnes. The relative importance of aquaculture is expanding because of stagnated production in capture fisheries. A source of misgiving for future development of aquaculture is decreasing the trend of freshwater aquaculture production.

World aquaculture has grown dramatically in the last 50 years to about 51.7 million tonnes in 2006. While capture fisheries production stopped growing in mid-1980s, the aquaculture sector has maintained an average annual growth rate of 8.7 percent and is expected to exceed the production of capture fisheries in future. Of the world aquaculture production, China is reported to produce 67 percent of the total quantity and 49 percent of the total value.

## 5.3 Aquaculture species

In Japan, cultured species include about 20 freshwater fish species (e.g., eel, rainbow trout, ayu and carp), about 30 marine fishes (e.g., yellowtail, sea bream, greater yellowtail, coho salmon, flounder, tiger puffer, jack mackerel, white trevally), crustaceans (e.g., kuruma prawn), shellfish (e.g., pacific oyster and Yesso scallop), echinoderms (e.g., sea urchin and sea cucumber), algae (nori, konbu, wakame), and other animals such as soft shelled turtle and sea squirt (Table 3.4). Production has recently increased, especially for marine fishes. Productions of major aquaculture species are shown in Table 3.5.

## 5.4 Aquaculture technologies

Water, seed and feed are the three major elements of aquaculture and most important factors for rearing of fish.

### 1) Culture system

Based on the method for utilization of water, freshwater fish culture can be classified into stagnant water system, running water system, cage culture system and circulation system. Stagnant water systems are used to culture fish in ponds.

Table 3.4. Major cultured fish in Japan (except ornamental fish).

|                 |   |
|-----------------|---|
| Freshwater fish | Eel, Rainbow trout, Ayu, Seema, Red spotted masu trout, Char, Japanese huchen, Coregonus, Kokanee, Kawachi-buna, Catfish, American catfish, Loach, Pejerrey, Tilapia, Japanese fluvial sculpin  |
| Seawater fish   | Yellowtail, Red sea bream, Purplish amberjack, Coho salmon, Marbled flounder, Tiger puffer, Japanese jack mackerel, White trevally, Pacific bluefin tuna, Amberjack, Almaco jack, Cobia, Striped beakfish, Spotted Knifejaw, Spotted halibut, Brown sole, Barfin flounder, Thread-sail filefish, Rockfish, Marbled rockfish, Stone fish, Kurosoi rockfish, Sevenband grouper, Grouper (Yaitohata), Orange spotted grouper, Longtooth grouper, Red spotted grouper, Japanese black porgy, Goldlined seabream, Chub mackerel, Chicken grunt, Japanese seabass, Common Japanese conger |
| Crustacean      | Kuruma prawn  |
| Shellfish       | Japanese scallop, Pacific oyster, Japanese rock oyster (Iwagaki), Ezo abalone   |
| Echinoderm      | Green sea urchin, Ezo green sea urchin, Sea cucumber  |
| Algae           | <i>Porphyra yezpensis</i> , <i>Undaria</i> , <i>Laminaria</i> , <i>Porphyra tenera</i> , <i>Cladosiphon okamuranu</i>   |
| Others          | Sea squirt (urochordata), Soft shell turtle (crawler)   |

Typical stagnant water system is water reservoir culture of carp and eel in outdoor pond. In running water systems, river water is brought or river bed water is pumped up to ponds or aquarium, and fish are cultured in running water. Salmonid fishes such as rainbow trout and ayu are cultured by this method. In Kasumigaura Lake, carp are cultured in cages floating on the surface of the lake. This system is intermediate between a stagnant water system and running water system. Residual feed and excretory substance accumulate in the pond in stagnant water system. It is necessary to keep the balance of accumulation of organic substances and decomposition by bacteria and phytoplankton in the pond. Therefore, the stocking density should be repressed. Phytoplankton called *aoko* (blue green algae and green algae) are constantly propagated. This is called *mizuzukuri* (water preparation). *Aoko* use dissolved nutrient and oxygen is provided to the water by photosynthesis of *aoko* during daytime. Oxygen is provided by mixing the water using a water mill at night. Stocking density could be increased by this method which originated in Japan. It is possible to increase the stocking density far higher than in stagnant water system because oxygen is constantly provided by new water and residual of feed and excretory products are removed with outflow of rearing water or after precipitation. When enough amount of water is not obtainable, water is reused by a circulation system. In contemporary eel culture, a circulation system called house eel culture is dominant. The water is heated during winter, and ponds are covered by a plastic sheet like in the green house for vegetable. Rearing water is circulated between rearing pond and sedimentation pond. Supplement of new water is repressed to minimum level. Residuals of feed are removed in sedimentation pond and ammonium



Table 3.5. Production of major aquaculture species in Japan (ton) (FAO Fishstat, 2006).

| Freshwater fish              |        | Seawater fish             |         | Crustacean   |       | Molluscs |         | Algae                |         |
|------------------------------|--------|---------------------------|---------|--------------|-------|----------|---------|----------------------|---------|
| Eel                          | 20,733 | Yellowtail <sup>(1)</sup> | 155,004 | Kuruma prawn | 1,745 | Oyster   | 208,182 | Laver <sup>(2)</sup> | 367,678 |
| Rainbow trout <sup>(3)</sup> | 7,583  | Seabream                  | 71,141  |              |       | Scallop  | 212,094 | Undaria              | 59,092  |
| Ayu                          | 6,270  | Coho salmon               | 12,046  |              |       |          |         | Laminaria            | 41,339  |
| Carp                         | 3,306  | Flounder                  | 4,613   |              |       |          |         |                      |         |
|                              |        | Tiger puffer              | 4,371   |              |       |          |         |                      |         |
|                              |        | Jack mackerel             | 3,300   |              |       |          |         |                      |         |

<sup>(1)</sup>Salmonids are included in seawater fish depending on culture site.

<sup>(2)</sup>Including purplish amberjack and amber jack.

<sup>(3)</sup>*Periphyra yezoensis*.

nitrogen is oxidized to nitrate nitrogen by nitrobacteria. This system enabled the increase of stocking density to ten times of outdoor pond culture. Water temperature is kept higher than 30°C, and the rearing period is shortened to 6–12 months.

In marine fish culture, culturing is largely carried out in cage placed in quiet coastal area or by pumping up seawater to rearing tank on the land. In early days, cove and small bays were used as culture facilities by partitioning the open mouth of the bay with a net (net partitioning system). This system is rarely used today. Major marine fish such as yellowtail, sea bream, coho salmon, tiger puffer are cultured in square cages 10 m on side. Material of net is generally chemical fiber. Styrofoam floats are attached on the top of the cage and fixed by anchor. This is called the Kowari system (small partition system), because the size of the cage is small. Number of small cages are connected to each other in this system. Detailed observation of cage is possible in this system and management is relatively easy. In Pacific bluefin tuna culture, large cages more than 30 m on a side are used. Various animals and plants (sessile organisms) attach on the mesh of the cage and water exchanging rate through the net decreases due to the attachment of sessile organisms. The nets are periodically exchanged. Circular cages are also used for Pacific bluefin tuna. The net of the circle cage is made with metal and is not changed. Cost for pumping up of seawater is required for land based tank though it suits the benthic fish like flounder. For offshore aquaculture, a water circulation system can be used. Culturing of flounder and tiger puffer is possible, although still not popular because of high maintenance cost for facilities and management.

In kuruma prawn culture, banking system and land based tank system are exist. In banking system, coastal area is separated by construction of bank and the shrimp is cultured inside the bank. Rearing water is pumped up from the sea. There is semi-banking system in which water is taken and discharged using tidal difference. Land base tank system use circular tank constructed along coast. Seawater is pumped up to the tank and water is discharged from the bottom with residual feed and excretory products. Kuruma prawn prefer to hide in the bottom sand. Sand is paved on the bottom of the rearing pond and tank in both systems. Production is high though the running cost is also high in land based tank system. Therefore, banking system is commonly used for culture of kuruma prawn. The culture starts in summer and shrimps are harvested by winter at the market size of 20 g.

Pacific oysters and scallops are cultured by the hanging method (Table 3.6). Oysters are placed in the intertidal zone after seed collection in summer till next spring for repression of growth to have resistance to the environmental change. After that, oysters are hanged up from raft or rack for growth and harvested in next autumn or winter. Scallops are cultured by hanging method from next February to April after the seed collection. In the hanging method scallop culture, shells are hung in a basket or directly by a thread, pin or rope piercing on the hinge. The shells are harvested after one or two years of hanging culture.

In nori culture, seeded nets by *Porphyra yezoensis* are unrolled on sea surface by support pole in shallow area, or by buoy in deeper area after autumn (Table 3.6). The pedalia grow more than 10 cm within a month. Nori is harvested

Table 3.6. Culture systems.

| System                | Species   |
|-----------------------|---|
| Feeding culture       |   |
| Stagnant water        | Carp (water reserver), Eel (out door pond),<br>Kuruma prawn (pond inside of dike) |
| Running water         | Rainbow trout, Ayu, Flounder (land-based tank),<br>Kuruma prawn (land-based tank) |
| Cage culture          | Yellowtail, Sea bream, Carp (lake)  |
| Circulation system    | Eel (green house)   |
| Non-feeding culture   |   |
| Hanging method        | Oyster, Scallop, <i>Laminaria</i>   |
| Floating, pole method | Laver   |
| Long line             | <i>Undaria</i>  |

4 or 5 times after that at an interval of about one week. In wakame culture, seeded threads by *Undaria pinnatifida* are tied with ropes and placed in the sea by hanging method or as a long line from October. Wakame are harvested when they reach more than 1 m from February to May. In konbu culture *Laminaria japonica* is the main cultured species. Seeded threads of konbu are tucked on ropes and the ropes are hung in the sea from October. The konbu are managed by thinning and water depth regulation and harvested from next July to August.

## 2) Seeds

Aquaculture begins by taking seeds to the culture farm. Culture seeds should be healthy and free from pathogens, obtainable on a mass scale and cheap. Procurement of seed satisfying the required condition in quality, quantity and price is of utmost importance for the success of aquaculture. The term "seed" used in this chapter includes not only young and juveniles but also fertilized eggs such as salmon eggs imported from North America.

Seeds are classified as natural seeds and artificially produced seeds (Table 3.7), or domestic seeds and imported seeds. If seeds are introduced to a farm when they have already reached a large size, the seeds are called intermediate seeds. Some of these aquacultures are quite similar to storage.

As formally described, seed for eel culture is the glass eel caught in natural environment. On the other hand, seed for carp culture and rainbow trout culture are artificially produced seeds. In ayu culture, natural seeds caught on the process of migration to river from coastal area (marine seed) or Lake Biwa (lake seed), or seeds produced from parental stock of marine or lake seed are used. Lake seeds sometimes have the pathogen for bacterial cold water disease (*Fravobacterium psychrophilum*) and fall sick during culture, and hence culturists preferring to use produced seeds are increasing.

Production of yellowtail seed is possible, though the use of produced seeds is not popular because the price of natural juveniles (mojako) is cheaper than artificial seed, and natural seeds do not include malformed fish. About 40 million

Table 3.7. Types of seed.

| Type of seed                          | Major aquaculture species   |
|---------------------------------------|---|
| Wild seed                             | Eel, Ayu <sup>(1)</sup> , Amberjack, Pacific bluefin tuna   |
| Artificially produced seed            | Carp, Salmonid, Ayu <sup>(1)</sup> , Flounder, Sea bream <sup>(2)</sup> , Tiger puffer <sup>(2)</sup> |
| Raising after collection of wild seed | Oyster, Scallop, Laver, <i>Undaria</i> <sup>(3)</sup>   |
| Raising artificially produced seed    | Laver, <i>Laminaria</i> <sup>(3)</sup> , <i>Undaria</i> <sup>(3)</sup>                                |

<sup>(1)</sup>Both wild and artificially produced seeds are used.

<sup>(2)</sup>Artificially seeds were used after establishment of seed production technology.

<sup>(3)</sup>Both collection of seed in natural environment and artificial environment are performed.

juveniles are caught in coastal areas of Japan in a year as seeds for yellowtail culture, though negative impact on stock condition of yellowtail is not observed at the present moment. Most of the seeds for greater amberjack culture are imported from China. Each year 10–20 million seeds are imported. Recently, the import of intermediate seeds larger than 1 kg has increased. Other seeds imported from China include seeds for three line grunt, amberjack, and Chinese sea bass. Seed production of Pacific bluefin tuna was established, though natural seeds caught by angling (yokowa) are still commonly used.

In early times of marine aquaculture, only natural seeds were used. Even in sea bream culture, natural seeds were used by the 1970s and large amount of imported seeds from Hong Kong were used in the 1980s because of their low price. From late 1980s, artificial seeds were popularized and most of the seeds used today are artificially produced. In coho salmon culture, seeds are produced from artificially fertilized eggs. Only imported fertilized eggs had been used previously though only seeds produced from cultured parent stock are used today because of its safeness from drag-in of pathogen from foreign countries. In tiger puffer, flounder and striped jack (*Pseudocaranx dentex*) culture, artificial seeds have been used from the 1980s. The establishment of seed production technology enabled the industrialized flounder and striped jack culture, of which natural seeds cannot be provided on a mass scale.

Seeds of kuruma prawn and scallop culture are produced by the same method for the production of seed for stock enhancement. Except particular seeds such as the seeds for triploid oyster culture, all seeds for oyster culture are natural. For the collection of natural seeds for oyster culture, so called spat collectors (mostly shells of scallop) are used as substrate for attaching larvae in adjacent water of oyster culture ground when the density of oyster larvae increase. After that the collectors with the larvae are left in the intertidal zone for development and selection of seeds.

In nori culture, tricores (conchotheris) are cultured on oyster shells in summer. Conchospore discharged from the tricores are collected on the threads of net. Thallus (weed) from the spore are cultured to 2 or 3 cm size and used as seeds for culture. The seeds are preserved by freezing and used for the culture in

the sea depending on the sea condition. In konbu and wakame culture, zoospore discharged from matured thallus are collected by collectors made from coil of threads. Male and female gametophytes are produced from zoospore and larval sporophytes produced by fertilization of male and female gamete are cultured to several cm size and used as seed (Table 3.7).

### 3) Feeds

In early times of freshwater fish culture, raw fish were used as feed for eel and rainbow trout, pupa of silk worm were used for carp and rainbow trout (Table 3.8). These feed were excellent at nutritional level, though they had problems in preservation, especially fat of pupa was easily oxidized and spoiled. Early studies on nutrient requirement of rainbow trout were carried out in USA and formulated feed for rainbow trout of which major component was fish meal was developed based on these studies and was sold in Japan from 1960. After that formulated feeds have been popularized in other cultured freshwater fish and are used in all freshwater fish today (Table 3.8). All formulated feeds for freshwater fish except eel are hard pellets which are produced by powderization and mold of materials. For carp and rainbow trout, extruder pellets (EP) that are heat formed after extrusion are used. EP are porous pellets whose buoyancy can be controlled. Crumbled feeds from formulated pellets are used for ayu. Formulated feed for eel is powder feed containing  $\alpha$ -starch as bond. For feeding, the powder feed is added in proper amount of water and kneaded to make sticky paste.

In marine fish culture, raw fish obtained from surrounding area were used as feeds in early times (Table 3.8). The provision of raw fish from surrounding water was not stable, but after freezing facilities were introduced, the fish were used as feeds after thawing. Raw and thawed fish produced large volume of liquid waste and polluted the surrounding environment, and fatty acids contained in raw and thawed fish were easily oxidized and caused nutritional problems. In addition, the cost for the maintenance of freezing facilities was high. In the 1980s, moist pellets (MP) developed in USA were in practical use in Japan. MP is a granular feed produced by mixing of minced fish flesh with formulated feeds. MP needs refrigerating facilities and can not be preserved for long periods. Regardless of the disadvantages, MP was popularized because of its advantage of less feeding loss in water, easiness of addition of nutrients and high preference by the fish. It is said that the popularization of MP decrease the environmental impact to two third of former level. Now EP is rapidly becoming popular. EP for yellowtail in which fat contents are increased for the replacement of fish meal and floating EP for flounder is under development.

Kuruma prawn were fed raw feed. In the 1970s, formulated feeds were marketed. The most popular feed used today is high protein EP, which contains squid and krill meal with fish meal. The stickiness of the EP is increased to match the feeding behavior of the prawn, which needs a long period to ingest food.

From the 1990s, the catch volume of sardine decreased. Sardine had been the major material for fish meal, which was later replaced by anchovy produced in Chile and Peru. Simultaneously, a global epidemic of bovine spongiform encephalopathy (BSE) increased the interest to ichthyophagy, and demand for

Table 3.8. Various food types.

| Type            | Food  | Culture species   |
|-----------------|---|---|
| Raw food        | Raw fish (including frozen fish)                              | Yellowtail, Amberjack, Sea bream, Tiger puffer  |
|                 | (Sardine, Anchovy, Japanese sand lance, Chub mackerel)*       |   |
|                 | Japanese littleneck, Squids, Euphausia<br>Pupa of silk worm** | Kuruma prawn<br>Carp, Rainbow trout   |
| Formulated food | Hard pellet   | Carp, Salmonids   |
|                 | Moist pellet (MP)   | Yellowtail, Amberjack, Sea bream, Tiger puffer, Flounder  |
|                 | Extruder pellets (EP)   | Carp, Salmonids (freshwater), Yellowtail, Amberjack,<br>Sea bream, Tiger puffer, Flounder, Kuruma prawn |
|                 | Crumble   | Ayu   |
|                 | Mash  | Eel   |

\* Actually rarely used today after conversion to pellet.

\*\* Actually rarely used today.

cultured fish increased in Europe and USA. This caused a worldwide deficiency in the supply of fish meal. The contents of the fish meal in formulated feed vary among fish species, though the average has been about 55%. The use of alternative protein source to decrease the content of fish meal is under development.

#### 4) *Breeding*

Desirable characteristics for aquaculture species are high growth, high food conversion, ease of rearing, and high tolerance to disease. To improve the characteristics, selective breeding of strains which have preferable characteristics for many generations and cross breeding among related species have been implemented. In culturing sea bream, the period for shipping is decreased from three years to one and a half years by selective breeding of faster growing individuals. The use of marker gene linked to the genes controlling the preferable character enables the detection of the preferred gene and its use in selective breeding (Chapter 4, 1.7.6). Establishment of tolerant cultivar to lymphocystis disease, a virus disease of flounder, was succeeded by selection of the gene linked with tolerance to lymphocystis disease.

Triploid oyster and rainbow trout produced by chromosome manipulation are sold in the market. Triploid can be made larger than diploid because of lack of deterioration with maturation. Triploid hybrids between tetraploid rainbow trout and diploid brown trout have been commercialized. This is an example of application of benefits from chromosome manipulation and crossbreeding. Productions of clone succeeded in carp, rainbow trout, flounder, sea bream and so on by chromosome manipulation and shipping of high quality homogenous cultured fish became possible. Studies for breed improvement by gene transfer are rapidly developing. Production of high growth strains by inducing growth hormone gene into chromosome by gene manipulation of fertilized eggs of the target fish and shells is now possible. However, the use of gene modified organisms are not realized because of the concerns over its safety as food and impact on gene disturbance.

### 5.5 *Disease and prevention of epidemics*

Epidemics of disease are unavoidable for cultured fish that are kept in high density in an environment different from the natural. The loss of cultured fish by disease is not negligible. The fluctuation among years is wide, though the amount of the loss reaches about 5% of total value of production and 1,500,000,000 yen in a year. There are various categorization of disease. The authors classify the disease by the cause of infectious and non-infectious diseases.

#### 1) *Variety of disease*

Infectious diseases are classified to viral disease, bacterial disease, parasitic disease and fungal disease. In Table 3.9, diseases causing high damages are listed. In fish culture, diseases are diversified with the increase of cultured species. Crustaceans suffer heavy damage from viral and fungal diseases. Protozoan and fungal diseases are dominant in oyster and algal culture, respectively. After 1980s, infectious diseases have often occurred in fish and shellfish in seed production process. Diseases occurring in seed production facilities tend to be

Table 3.9. Major diseases of aquaculture species and pathogen.

| Pathogen               | Fish  | Crustacea                            | Bivalves                                | Algae  |
|------------------------|---|--------------------------------------|---|--|
| Virus                  | IHN (salmonids)   |                                      |   |  |
|                        | KHV (carp)  | PAV (WSD)<br>(kuruma prawn etc.)     |   |  |
|                        | Iridovirus disease of red sea bream (sea bream)   |                                      |   |  |
|                        | VNN (striped jack etc.)<br>Lymphocystis disease (flounder etc.)   |                                      |   |  |
| Bacteria               | Furunculosis (salmonids)  | Vibriosis<br>(kuruma prawn etc.)     |   |  |
|                        | Vibriosis (ayu etc.)  |                                      |   |  |
|                        | Edwardsiellosis (eel)   |                                      |   |  |
|                        | Streptococcal infection (yellowtail etc.)   |                                      |   |  |
|                        | Pseudotuberculosis (yellowtail etc.)  |                                      |   |  |
| Fungi                  | Saprolegniasis (salmonids)  | Black gill disease<br>(kuruma prawn) |   | Chytrid disease (larver)<br>Red rot disease (larver) |
| Protozoa               | Ichthyobodo disease (salmonids)   |                                      |   |  |
|                        | White spot disease (freshwater fish, seawater fish)<br>Glugeosis (ayu)  |                                      | Hypertrophy of ovary<br>(oyster)        |  |
| Mycosporea             | Gill myxobolosis (carp)<br>Kudoasis amammi (yellowtail, amberjack)  |                                      |   |  |
| Macro parasite         | Anchor worm disease (freshwater fish)   |                                      |   |  |
|                        | Skin fluke disease (yellowtail, amberjack)  |                                      |   |  |
|                        | Gill fluke disease (tiger puffer)   |                                      |   |  |
|                        | Blood fluke disease (amberjack)   |                                      |   |  |
| Non-infectious disease | Vitamin B <sub>1</sub> , E deficiency (seawater fish)   |                                      | Boring by Polydora<br>(scallop, oyster) |  |
|                        | Pigment abnormality (flounder)<br>Gas disease (freshwater fish)<br>Methemoglobinemia (eel)<br>Body color abnormality (flounder) |                                      |   |  |



different from those in culture ground and implementation of proper countermeasures are difficult because of the weakness of the larvae and juveniles.

Contamination and parasitism of organisms sometimes cause degradation of commercial value or problems in food safety. In yellowtail culture in Amami and Ryukyu Island, visible cysts of genus *Kudoa* (myxosporea) are sometimes formed (*kudosis amami*). Parasitism of microsporidia in muscle of eel cause concave shapes on the surface of the body by melting of tissues. This symptom is called "Beko disease". A serious case in food hygiene is poisoning of cultured shells. Scallops sometimes accumulate paralytic shellfish poison or diarrheal shellfish poison by ingestion of toxic dinoflagellates. The shipping of cultured scallops in polluted area is banned for a definite period in such case. Norovirus sometimes accumulate in cultured oysters and infect people who eat the oyster and cause diarrhea in winter. Eating of Ayu cultured in river water is dangerous, because metacercaria of *Metagonimus yokogawai* and *M. miyatai* (trematoda) make cysts in the scales or muscles.

There are also various non-infectious diseases. Typical nutritional disease is vitamin deficiency. When yellowtails are fed solely with anchovy, the growth of the fish decreases finally leading to death. The cause of the disease is decomposition of vitamin B<sub>1</sub> by vitamin B<sub>1</sub> degrading enzyme contained in anchovy. Unsaturated fatty acid in fish feeds and fish meals are easily oxidized and changed to lipid peroxide. Feeding of rancid lipid causes various diseases. Addition of vitamin E in feed as antioxidant agent is effective to prevent oxidation of lipid. Vitamin B<sub>1</sub> and E are added to the formulated feed for the prevention of diseases today. Albinism of eye side of flounder in artificially produced seed is related with deficiency of DHA and vitamin A. The larval fish are fed with DHA supplemented food organisms from 10 to 20 days after hatching.

"Gas disease (air bubble disease) occurs in freshwater fish. When fish are reared in nitrogen or oxygen over saturated water, sometimes the absorbed dissolved gas vaporizes in the body. Gas disease shows a symptom of formation of air bubbles on the surface of the body. When the bubbles blocks the blood vessel, the fish will die. By the strong aeration of the water, the fish will recover.

Nitrite poisoning occurs when eels are cultured in excessive density in green house. Ammonium excreted from eels is oxidized to nitrate by the function of bacteria. However, when the amount of ammonium is excess, reaction rate cannot catch up to the excretion rate and nitrite is accumulated in pond water. Increased nitrite in the water absorbed in the blood of the fish oxidizes the hemoglobin to methemoglobin (methemoglobinemia). The symptom can be rapidly recovered by replacement of pond water with new water.

Natural enemies also cause damages. Polydora, a borer annelid, makes hole in the shell of the scallops and oyster. Parasitism of polydora weaken the shell and sometime the hosts will die.

## 2) Countermeasure for diseases

Countermeasure for infectious disease are prevention and treatment (Table 3.10). Prevention is basically to interrupt the contact with pathogen to escape from infection (epidemic prevention). For this purpose, culture of pathogen free

Table 3.10. Countermeasures for disease.

| Category                        | Method  |
|---------------------------------|---|
| <b>Prevention</b>               |   |
| Epidemic control                | Pathogen free seed, Restriction of transportation of fish, Sterilization of rearing water, Removal of intermediate host |
| Acquisition of immunity         | Vaccination   |
| Enhancement of natural immunity | Administration of physiological active substance  |
| Improvement of environment      | Prevention of high density culture, Feeding of high quality food  |
| Genetic improvement             | Breeding of disease resistant varieties   |
| <b>Treatment</b>                |   |
| Environment control             | High temperature treatment for bacterial cold water disease infected ayu, Removal of exoparasite by fresh water bathing |
| Chemical therapy                | Administration of antibiotics   |
| Biotherapy                      | Administration of bacteriophage (under development)   |

seed in sterilized, and disinfecting of facilities with sterilized water is a fundamental strategy. Prevention of introduction of fish and shells contaminated with pathogens is also important. Cutoff of life cycle of parasite is included in epidemic prevention. Introduction of immunity to cultured organisms beforehand is an effective method of epidemic prevention. The use of vaccine to cultured fish was first approved in 1988. Variety of the approved vaccine is still small (Table 3.11), though effects for epidemic prevention are prominent and the popularization of vaccine are rapid. Injection method of vaccine increases labor load and is difficult to use in larvae, though it has superiority in efficacy and lasting effect. Substances which enhance the nonspecific immunity by administration with feed are called immunostimulant. Various vitamins, cell wall components of bacteria, indigenous bacteria in intestine etc. are used as immunostimulant. Efforts to breed varieties that have tolerance to specific diseases are tried (see p. 159). However, regardless to these new technologies, keeping good environment is a fundamental in prevention of diseases. For sufficient effectiveness of vaccine, rearing of cultured organisms in low stress environment is important.

As treatment, environmental manipulation the environment inadequate for survival of pathogen is a useful method. Shift of osmotic pressure within non-harmful range to cultured organisms is a useful method of environmental manipulation. Salmon fry infected with bacterial gill disease are soaked in 5% salt water. For the disinfection of skin fluke, marine fish are administered fresh water bathing. Temperature control is another effective method of environment control. Ayu infected by bacterial cold water disease are treated keeping water temperate higher than 25°C. Most common treatment for bacterial diseases is chemotherapy. Using antibiotics and synthetic antibacterial agents are used for killing of bacteria or depression of growth of bacteria. 20 antibiotics or synthetic antibacterial agents, 5 anthelmintics are approved in Japan as medicinal drugs for aquaculture. Medicinal drugs for aquaculture can be used without prescription by veterinarian. Adherence of regulation of target pathogen, target cultured species (order level),

Table 3.11. Approved vaccine for aquaculture species in Japan.

| Disease (Pathogen)  | Target species                                     | Method of medication | Licensed year |
|---|--|----------------------|---------------|
| Vibriosis ( <i>Vibrio anguillarum</i> )   | Ayu, Salmonids,                                    | Immersion,           | 1988          |
|   | <i>Seriola</i> spp.                                | Injection            |               |
| $\alpha$ -hemolytic lactococcosis<br>( <i>Lactococcus garvieae</i> )            | <i>Seriola</i> spp.                                | Oral administration, | 1997/2000     |
| $\beta$ -hemolytic streptococcosis<br>( <i>Streptococcus iniae</i> )            | Flounder   | Injection            | 2005          |
| Iridovirus disease of red sea bream<br>(RSIV)                                   | Sea bream,<br><i>Seriola</i> spp.,<br>Striped jack | Injection            | 1999          |
| Pseudotuberculosis<br>( <i>Photobacterium damsela</i> subsp. <i>piscicida</i> ) | Yellowtail   | Injection            | 2008          |

dose regime is a requirement. Erythromycin can be used for  $\alpha$ -hemolytic streptococcus infected perciform fish in prescribed dosage (50 mg titer/kg body weight/day) by oral administration. The shipping of the treated fish is allowed from 30 days after the treatment. Uses for other diseases, other species than perciform, in other dosage regime or shipping before 30 days after the treatment are punishable by pharmaceutical law. Before the popularization of vaccine, countermeasures strongly depended on chemotherapy and emergence of drug resistant bacteria caused by excessive use of drugs was a serious issue. As an example of biotherapy, administration of bacteriophages to fish so that the phage can infect the pathogenic bacteria has been tried.

Only limited effect can be obtained by a single countermeasure for disease prevention. Holistic countermeasure combining several methods is useful such as improvement of environment after administration of vaccine or replacement of the cage net attached by fluke with new net after the disinfection of fluke.

### 3) Quarantine system

Many pathogens (viruses, bacteria and parasites) of cultured fish and shellfish are not originated in Japan. Major diseases caused by exotic pathogens are listed up in Table 3.12. Most of them have invaded Japan through seed for aquaculture. It is very difficult to exterminate pathogens completely after invasion. The invaded exotic pathogens will continuously provide damages to aquaculture in Japan. Some pathogens transmit from original host species to new host species. This phenomenon is called host alternation. Pathogens with low host specificities such as penaeid acute viremia (white spot disease) virus of kuruma prawn and *Neobenedenia girellae*, parasite of marine fish, the infection propagates among various species and causes serious damages by host alternation.

Until very recently, legal system for quarantine of aquatic animals was not consolidated in Japan. Fish Resource Protection Law was amended in 1996 to protect invasion of exotic pathogens. In 1997, the Act on Maintenance of Sustainable Aquaculture Production was established to prevent the spread of pathogens.

Table 3.12. Major exotic disease in Japan.

| Disease (or pathogen)                   | Type of pathogen     | Year of first confirmation | Estimated carrier                | Origin              | Host in Japan                                |
|---|----------------------|----------------------------|----------------------------------|---------------------|--|
| Infectious hematopoietic necrosis (IHN) | Virus                | 1971                       | Fertilized egg of sockeye salmon | USA (Alaska)        | Salmonids                                    |
| Red spot disease                        | Bacteria             | 1971                       | European eel seed                | Europe              | Eel, Ayu                                     |
| Bacterial kidney disease                | Bacteria             | 1973                       | Fertilized egg of coho salmon    | USA (Pacific coast) | Salmonids                                    |
| Epitheliocystis disease                 | Bacteria             | 1984                       | Red sea bream seed               | Hongkong            | Red sea bream                                |
| Erythrocytic inclusion body syndrome    | Virus                | 1986                       | Fertilized egg of coho salmon    | USA (Pacific coast) | Coho salmon                                  |
| Bacterial cold water disease            | Bacteria             | 1990                       | Fertilized egg of coho salmon    | USA (Pacific coast) | Salmonids                                    |
| <i>Neobenedenia girellae</i>            | Parasite (Monogenea) | 1991                       | Amberjack seed                   | China               | Marine fish<br>(Tiger puffer, Flounder etc.) |
| Penaeid acute viremia (=WSD)            | Virus                | 1993                       | Kuruma prawn seed                | China               | Crustacean                                   |
| Neoheterobothrium hirame                | Parasite (Monogenea) | 1993                       | Southern flounder                | USA (Pacific coast) | Flounder                                     |
| <i>Limnatrachelobdella sinensis</i>     | Parasite (Hirudinea) | 2000                       | Carp or crucian carp*            | Far east Asia       | Crucian carp                                 |
| Koi herpes virus (KHV)                  | Virus                | 2003                       | Carp*                            | Asia?               | Carp   |

\*Not confirmed.

Table 3.13. Specified fish disease in the Fish Resource Protection Law, which need permission for import.

| Aquatic animal  | Specified disease   | Year of specification        |
|---|---|------------------------------|
| Carp  | Spring viraemia of carp (SVC)   | 1996                         |
| Gold fish, Other crucian carps, Silver carp, Bighead carp, Grass carp, Black carp | Koi herpes virus (KHV)<br>SVC   | 2003<br>2004                 |
| Salmonids (eyed egg, juvenile)  | Viral hemorrhagic septicemia (VHS)<br>Epizootic hematopoietic necrosis (EHN)<br>Piscirickettsiosis<br>Enteric redmouth disease  | 1996<br>1996<br>1996<br>1996 |
| Shrimps in genus <i>Marsupenaeus</i>  | Nuclear polyhedrosis baculoviruses (Infection of <i>Baculovirus penaei</i> )<br>(Infection of monodon type baculovirus)<br>Yellow head disease<br>Infectious Hypodermal and Hematopoietic Necrosis (IHHN)<br>Taura syndrome | 1997<br>1997<br>1997<br>2004 |

In the Fish Resource Protection Law, import of aquatic animal needs permission and target animals of the law are specified. In the Act on Maintenance of Sustainable Aquaculture Production, diseases which have potential of invasion to Japan and risks of serious damages are specified (specified disease in Table 3.13). With the specification, attachment of certification issued by the government of exporting country proving that the animals are not infected with specified disease (disease free certification) is obligated, when seeds for aquaculture are imported. After the application of the act, quarantine inspections are not performed on each import because the variety and number of imported fish and shellfish are huge to implement inspection at each import.

Governor of the prefecture can issue order by the action for implementing proper measures to prevent epidemics of diseases in case specified or unknown serious diseases invade Japan. More specifically, aquaculture bodies such as fisheries cooperatives have obligation to make plans for the improvement of aquaculture environment and qualified persons appointed by governor (fish health protection officer) can implement onsite inspection and order restriction of transportation and sterilization of cultured animals.

Weakness of the system in Japan is that unspecified fish and shellfish in the Fish Resource Protection Law, particularly marine species, are not the objectives of the permission system. There is no regulation for import of unspecified species. In addition prediction of epidemics of new diseases caused by pathogens alter the host. For the solution of the issues, all seeds for aquaculture in Japan should be shifted to domestic seeds and establishment of aquaculture not depending on the seed from outside is needed. Further development of seed production technologies is expected.

(Kazuo Ogawa)

## CONCLUSION

In the early phase of development of new fisheries resources, generally, catch volumes of the resources rapidly increase due to the accumulation of new information and development of new fishing method and gears. The establishment of fishing methods stabilizes the income from fisheries. New investments are invited and further developments are possible in that phase. However, the catch effort exceeds with time and resources decrease. The catch volume decreased and the operation of the fisheries became unstable. Further, fishing efforts put in place to compensate the decrease of catch volume accelerate the decrease of the resource. If the situation is allowed without any countermeasures, the fisheries will be collapsed or will continue at low level. On the contrary, when the fishing effort and catch volume are repressed consciously, the resource recover in time, catch volume will be increased and the operation of the fisheries industry will be stabilized. Peaking of the total volume of fish catch in the world and the fact that nearly half of the fisheries resources in Japan are low level indicate that the fisheries in the world are now at a turning point in history. Fisheries resources

fluctuate and are finite. To consider how we can utilize the resources effectively keeping sustainability of the resources is an urgent issue for us. For the solution of the issue, we have to integrate organically the results obtained by individual discipline such as studies on the mechanism of resource fluctuation, ecologies of resource organisms, resource environments, stock assessment and evaluation methods, management technology and system, fisheries policy and socio-economy toward a “wise use of resources”.

Not only by the resource management, but also by the regulation of fisheries, Japan has progressively promoted addition of resources and improvement of fishing ground under the name of fisheries resource enhancement. Particularly, “culture based fisheries” based on mass release of artificially produced seeds has been implemented following the leadership of the government from the 1960s. The project has enabled the mass productions of marine fish seeds which had been impossible before the project. There may be no objection to pride the technologies. However, after nearly half century from the start of the project, culture based fisheries comes to the period for the revision from the view point of economic efficiency and the impacts on natural organisms. It is the reality that there exist sharp criticisms in our society from the view point of expense burden to the stock enhancement by improvement and construction of fishing ground. Who should pay the cost? Inland water body and coastal zone, the main target places of the stock enhancement are not the places only for fisheries. Their importance as a place for the recreation of citizen and natural educations are increasing. The technologies developed for the fisheries can be utilized for the recovery of natural environment such as sea grass beds and mud floods. It is desirable to establish the direction and framework to utilize the technologies developed in fisheries science and fisheries industry for the entire benefits of citizen globally.

Aquaculture industries in the world are growing 6–10% in a year. The rapid growth rate is making various issues to be considered such as provision of feed and seed, pollutions and epidemic of diseases. In aquaculture, organisms are reared in high density. Occurrence of disease is inevitable regardless of feeding or non-feeding. Deficiency of fishmeal for formulated feeds is becoming a serious problem recently. The deficiency accelerate development of feed that has high ingestion rate and food conversion rate minimizing the use of fish meal. It can be expected that the development of the feed minimizing the content of fish meal will also contribute to the decrease of environmental impact and risk of disease. We should consider that problems of feed, seed, environmental pollution and diseases do not exist alone and are closely related. For disease prevention, several serious diseases may be prevented by use of vaccine, though on the other hand, new diseases are continuously on the rise. Most of the causes of the diseases are exotic pathogens introduced with imported seeds. It is impossible to depress the epidemics of new disease by present quarantine system. Several bold measures are needed to solve the issue, such as changing all seeds for aquaculture to domestic seeds. Such innovative change will increase the traceability of cultured fish and shellfish and heighten the credibility of consumer to aquaculture products. Establishments of seed production are requested for the eel and tuna

culture which depend on the natural seed. The development of the technologies will contribute to the problem of decreasing resource. For the development of sustainable aquaculture, technology revolutions in various fields are needed.

(Kazuo Ogawa, Taku Yamakawa and Tomoyoshi Yoshinaga)

#### CITED LITERATURE

- Azuma, I. (2005): Sea urchins. p. 339–366. In *Propagation and Aquaculture System III—Shells, Crustaceans, Sea Urchins and Algae*, ed. by K. Mori, Kouseisha-Kouseikaku, Tokyo.
- Baumgartner, T. R., A. Souta and V. Ferreira-Bartrina (1992): Reconstruction of the history of Pacific sardine and northern anchovy population over the past two millennia from sediments of the Santa Barbara Basin. *CalCOFI Rep.*, **33**, 22–40.
- Beamish, R. J., C. E. Nevile and A. J. Cass (1997): Production of Fraser River sockeye salmon (*Onchyrhynchus nerka*) in relation to decadal-scale changes in the climate and the ocean. *Can. J. Fish. Aquat. Sci.*, **54**, 543–554.
- Japan Sea Farming Association (2000): Sea farming training project. Basic theory course text book XIII “Culture technique of rotifer”, 152 pp.
- Maru, K. and Y. Kosaka (2005): Scallops. p. 131–170. In *Propagation and Aquaculture System III—Shells, Crustaceans, Sea Urchins and Algae*, ed. by K. Mori, Kouseisha-Kouseikaku, Tokyo.
- Rothschild, B. (1986): *Dynamics of Marine Fish Populations*. Harvard Univ. Press, 277 pp.
- Sasaki, R. (2005): Abalones. p. 85–120. In *Propagation and Aquaculture System III—Shells, Crustaceans, Sea Urchins and Algae*, ed. by K. Mori, Kouseisha-Kouseikaku, Tokyo.
- Takasuka, A., Y. Oozeki and I. Aoki (2007): Optimal growth temperature hypothesis: why do anchovy flourish and sardine collapse of vice versa under the same ocean regime? *Can. J. Fish. Aquat. Sci.*, **64**, 768–776.
- Taniguchi, K. (ed.) (1999): *Mechanism of “Isoyake” and Recovery of Sea Weed Beds*. Kouseisha-Kouseikaku, Tokyo, 120 pp.
- Yano, I. (2005): Kuruma prawn. P. 229–238. In *Propagation and Aquaculture System III—Shells, Crustaceans, Sea Urchins and Algae*, ed. by K. Mori, Kouseisha-Kouseikaku, Tokyo.

#### REFERENCE BOOKS

- Aoki, I., A. Nihei and A. Yatsu (2005): *Regime Shift and Aquatic Resource Management*. Kouseisha-Kouseikaku, Tokyo, 143 pp.
- Hiroyosi, K. and M. Sano (2008): *Fisheries Economy Studying by Point Arrangement*. Hokutoshobo, 285 pp.
- Kawai, T. (1995): *Fisheries in Japan*. Iwanamishoten, 218 pp.
- Kumai, H. (2005): *Marine Fish “Propagation and Aquaculture System I”*. Kouseisha-Kouseikaku, Tokyo, 323 pp.
- Matsuda, O., K. Furuya, K. Taniguchi and A. Hino (2002): *Aquatic Environment Conservation and Recovery Function in Fisheries Industry*. Kouseisha-Kouseikaku, Tokyo, 131 pp.
- Matsumiya, Y. (2000): *Increase Fish with Fishing*. Seizandoshoten, Tokyo, 174 pp.
- Mori, K. (ed.) (2005): *Propagation and Aquaculture System III—Shells, Crustaceans, Sea Urchins and Algae*. Kouseisha-Kouseikaku, Tokyo, 396 pp.
- Ogawa, K. and K. Muroga (2008): *(Revision) Outline of Fish Disease Science*. Kouseisha-Kouseikaku, Tokyo, 192 pp.
- Ooshima, Y. (ed.) (1992): *Source Materials for Aquatic Propagation and Aquaculture*. Japan Sea Farming Association, 338 pp.
- Sakuramoto, K. (1998): *ABC for Fisheries Management*. Seizandoshoten, Tokyo, 200 pp.
- Takashima, F. and M. Murai (2005): *Propagation and Aquaculture System II—Freshwater Fish*. Kouseisha-Kouseikaku, Tokyo, 362 pp.
- Takeuchi, T., H. Nakata, T. Wada, H. Ueda, T. Arimoto, S. Watabe and A. Nakamae (2004): *Handbook for Fisheries Oceanography*. Seibutukenkyuusyaya, 654 pp.
- Tanaka, S. (2001): *Talk about Fisheries Resource*. Kouseisha-Kouseikaku, Tokyo, 153 pp.