Organization and Development of Stock Enhancement in Japan

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Introduction

In the 1960s, the Japanese economy was starting to industrialize. The rapid increase in business investment in new factories and equipment stimulated a yearly economic growth rate of approximately 12% (METI 1970). However, these developments have disrupted coastal landscapes through land reclamation and industrial effluents (Fishery Agency 1980a). Furthermore, overfishing has accelerated with increased consumer spending and demand for fish protein. Consequently, coastal fish resources such as red sea bream (*Pagrus major*), kuruma prawn (*Marsupenaeus japonicus*) and swimming crab (*Portunus trituberculatus*) have been depleted and income of coastal fisherfolk has decreased (Fishery Agency 1980b). Under such conditions, the Japanese government initiated the Stock Enhancement Program in 1963 (Fishery Agency 1980c, Imamura 1999).

The program initially targetted red sea bream and kuruma prawn in the Seto Inland Sea in southern Japan which covers almost 3,000 islands (Imamura 1999). Because the fundamental concept of stock enhancement programs was to compensate juvenile loss caused by high larval mortality in the ocean, development of mass juvenile production techniques was emphasized (Fishery Agency 1980a, Matsuoka 1989). Therefore, the release of juveniles became a typical form of stock enhancement in Japan.

The current number of target species for stock enhancement has increased to almost 80 species. Stock enhancement is undertaken by both the national government and local governments together with conservation of fishing ground and regulation of fish catches for resource management (Resource Association 1983a, Imamura 1999, Fishery Agency 2000, JASFA 2003a). This article reports the present status of stock enhancement in Japan from the organizational and technical viewpoints.

Organizations

At present, there are 16 national and 177 local hatcheries operated by national and local governments in Japan. The national hatcheries aim to develop stock enhancement techniques, and mainly target migratory species which are chosen based on their resource levels and local government requests (Fushimi 2001, JASFA 2003a). Local hatcheries carry out the stock enhancement programs for local species using techniques developed by the national hatcheries (Imamura 1999). In some cases, national hatcheries and neighboring local hatcheries cooperate to evaluate the effectiveness of stock enhancement (Fishery Agency 2002). Similarly, stock enhancement of sedentary species has also been promoted by the local hatcheries in response to requests from regional fisherfolk (Agatsuma 2005, Toba 2005, Maru and Kosaka 2005, Sasaki 2005). Consequently, such stock enhancement programs have covered 36 fish species, 15 crustacean species, and 20 mollusk species with annual releases of 80 million fish, 300 million crustaceans, and 14 billion mollusks (Tables 1 and 2).

Table 1. Fish and crustaceans targeted in the stock enhancement programs of Japan.

	Family	Scientific name	Common name
Fish	Branchiostegidae	*Branchiostegus japonicus*	Japanese tilefish
	Carangidae	*Pseudocaranx dentex*	Striped jack
		Seriola quinqueradiata	Yellowtail
	Clupeidae	*Clupea pallasii*	Pacific herring
	Gadidae	*Gadus macrocephalus*	Pacific cod
	Haemulidae	*Parapristipoma trilineatum*	Chicken grunt
	Lethrinidae	*Lethrinus nebulosus*	Spangled emperor
	Paralichthyidae	*Paralichthys olivaceus*	Japanese flounder
		Lateolabrax japonicus	Japanese seaperch
	Platycephalidae	*Platycephalus indicus*	Bartail flathead
	Pleuronectidae	*Pleuronectes herzensteini*	Littlemouth flounder
		Pleuronectes schrenki	Cresthead flounder
		Pleuronectes yokohamae	Marbled flounder
		Tanakius kitaharae	Willowy flounder
		Verasper moseri	Barfin flounder
		Verasper variegatus	Spotted halibut
	Sciaenidae	*Nibea japonica*	Japanese meagre
	Scombridae	*Scomberomorus niphonius*	Japanese Spanish mackerel
		Thunnus orientalis	Pacific bluefin tuna
	Scorpaenidae	*Sebastes inermis*	Black rockfish
		Sebastes oblongus	Oblong rockfish
		Sebastes pachycephalus	Spotbelly rockfish
		Sebastes schlegeli	Korean rockfish
		Sebastes thompsoni	Goldeye rockfish
		Sebastes vulpes	Fox jacopever
		Sebastiscus marmoratus	Japanese stingfish
	Serranidae	*Epinephelus akaara*	Hong Kong grouper
		Epinephelus bruneus	Longtooth grouper
		Epinephelus septemfasciatus	Convict grouper
		Plectropomus leopardus	Leopard coral grouper
	Sparidae	*Acanthopagrus australis*	Surf bream
		Acanthopagrus schlegeli	Black porgy
		Pagrus major	Red seabream
	Synanceiidae	*Inimicus japonicus*	Devil stinger
	Tetraodontidae	*Takifugu rubripes*	Ocellate puffer
	Trichodontidae	*Arctoscopus japonicus*	Sailfin sandfish
Crustaceans	Penaeidae	*Penaeus japonicus*	Kuruma prawn
		Penaeus semisulcatus	Green tiger prawn
		Penaeus chinensis	Fleshy prawn
		Metapenaeus ensis	Greasyback shrimp

Table 1 (continued from p. 92)

Family	Scientific name	Common name
Pandalidae	*Pandalus kessleri*	Hokkai shrimp
	Pandalus hypsinotus	Humpback shrimp
Palinuridae	*Panulirus japonicus*	Japanese spiny lobster
Lithodidae	*Paralithodes brevipes*	Spiny king crab
Majidae	*Chionoecetes opilio*	Snow crab
Cheiragonidae	*Erimacrus isenbeckii*	Hair crab
Portunidae	*Scylla paramamosain*	Mud crab
	Scylla serrata	Mangrove crab
	Portunus trituberculatus	Swimming crab
	Portunus pelagicus	Flower crab
Grapsidae	*Eriocheir japonicus*	Mitten crab

From Fishery Agency et al (1993-2003)

Fish and crustaceans

Among 36 fish species, the major ones are the Japanese flounder (*P. olivaceus*) and red sea bream (*P. major*) with annual releases of about 25 and 20 million seedlings, respectively (Fig. 1). Stock enhancement programs for these two species are mainly promoted by local hatcheries and have attained commercial success in limited areas (Imai 1996, Fujita et al 1993). Besides, the stock enhancement effectiveness of those species has been jointly evaluated by the local hatcheries with the financial aid of the Japanese government (Imai 1996, Fishery Agency 2002). Recently, such joint evaluation has been applied to the Pacific herring (*C. pallasii*), ocellate puffer (*T. rubripes*), and Japanese Spanish mackerel (*S. niphonius*) (Fishery Agency 2002).

Among 15 crustacean species, the greatest focus is on the kuruma prawn (*M. japonicus*). Over 200 million individuals are released annually mainly in southern Japan (Fig. 2). In particular, local institutions around the Sea of Ariake have undertaken initiatives for the stock enhancement of the prawn (Morikawa et al 2003). In addition, the swimming crab (*P. trituberculatus*) and greasyback prawn (*M. ensis*) have been released by national and local hatcheries in the Seto Inland Sea and the Sea of Ariake (Fishery Agency et al 1993-2003).

Mollusks and other species

Only local hatcheries promote the stock enhancement of mollusks. Among 20 mollusk species, the numbers of individuals released annually are huge for scallop (*Patinopecten yessoensis*) and Japanese littleneck clam (*Ruditapes philippinarum*) - 3 and 10 billion, respectively (Fig. 3). The scallops are released only in the coast of Hokkaido and in Mutsu Bay by local hatcheries, and the littlenecks mainly in Tokyo and Ise Bays by fisherfolk unions (Resource Association 1983b, 1983c, Maru and Kosaka 2005, Toba 2005). These stock enhancement programs have been successful in each stocking region (Maru and Kosaka 2005, Toba 2005). The littlenecks are sometimes released for recreational shellfish gathering of visitors (Toba 2005). Besides, six of the 20 mollusk species are abalones which have high market value

Table 2. Shellfish, sea urchins, sea cucumbers, and cephalopod targeted in the stock enhancement programs of Japan.

	Family	Scientific name	Common name
Shellfish	Haliotidae	*Haliotis aquatilis*	Japanese abalone
		Haliotis diversicolor	Variously colored abalone
		Haliotis discus discus	Disk abalone
		Haliotis discus hannai	Ezo abalone
		Haliotis madaka	Giant abalone
		Haliotis gigantea Gmelin	Disk abalone
	Trochidae	*Tectus niloticus*	Commercial trochus
	Turbinidae	*Turbo cornutus*	Horned turban
		Turbo marmoratus	Great green turban
	Buccinidae	*Neptunea polycostata*	Ezo neptune
		Balylonia japonica	Ivory shell
		Fusinus perplexus	Perplexed spindle shell
	Arcidae	*Scapharca broughtonii*	Ark shell
	Pectinidae	*Patinopecten yessoensis*	Yezo scallop
	Tridacnidae	*Tridacna crocea*	Crocea clam
	Veneridae	*Meretrix lamarckii*	Hard clam
		Ruditapes philippinarum	Japanese littleneck
	Mactridae	*Pseudocardium sachalinense*	Sakhalin surf clam
		Tresus keenae	Trough shell
	Solecrutidae	*Sinonovacula constricta*	Razor clam
Sea urchins	Arbacia	*Tripneustes gratilla*	Collector urchin
		Pseudocentrotus depressus	Red seaurchin
	Echinoidea	*Anthocidaris crassispina*	Hard-spined sea urchin
	Strongylocentrotidae	*Hemicentrotus pulcherrimus*	Elegant sea urchin
		Strongylocentrotus intermedius	Intermediate sea urchin
		Strongylocentrotus nudus	Naked sea urchin
Sea cucumber	Holothuroidea	*Stichopus joponicus*	Japanese common sea cucumber
Cephalopod	Octopodidae	*Octopus vulgaris*	Common octopus

From Fishery Agency et al (1993-2003)

in Japan (Table 2). They are released by local hatcheries in all coastal areas of Japan due to strong requests from regional fisherfolk (Sasaki 2005). Sea urchins and sea cucumbers are important target species of regional stock enhancement programs with approximately 80 million seedlings released annually by 50 local hatcheries (Fishery Agency et al 1993-2003).

Technical Process

The technical aspects of stock enhancement can be classified into several phases, namely; spawning, seed production, tagging, release, and survey. Among these, seed production and survey of effectiveness of stock enhancement techniques have developed

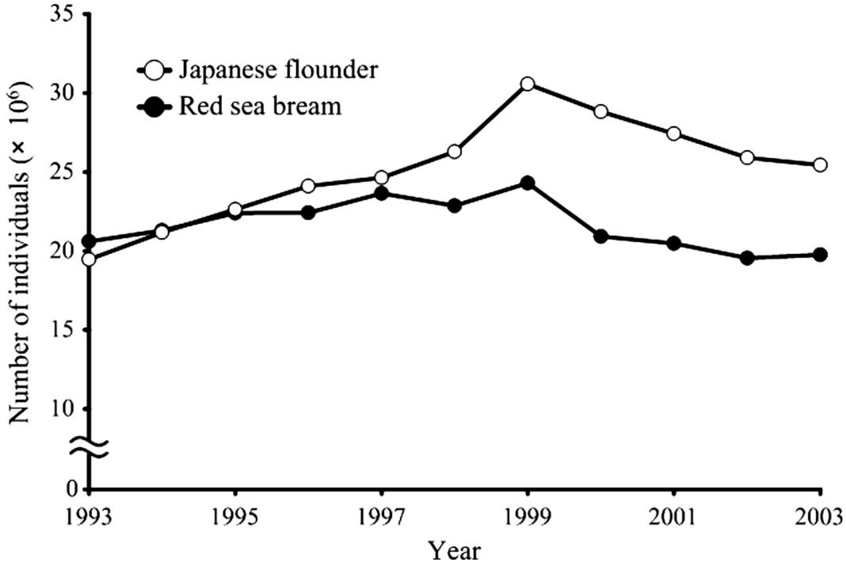

Fig. 1. Annual numbers of released individuals of Japanese flounder and red sea bream in Japan (data from Fishery Agency et al 1993-2003).

remarkably in the past two decades. Moreover, disease prevention and conservation of genetic resources in seedling populations have become recent issues.

Spawning, seed production and release

Wild fish and crustaceans from the management area of a stock enhancement program are used as broodstock (Mushiake et al 2003, Yano 2005). Most wild fish need to be reared for several months or years before they are induced to spawn by hormonal treatment, control of water temperature, and/or control of photoperiod (Hirose 1991, Mushiake et al 2003). Artificial fertilization is performed according to the need of each stock enhancement program (Mushiake et al 2003). Among crustaceans, mature females that have mated are obtained from the wild to supply fertilized eggs (Yano 2005, Hamasaki 2005). Spawning of females is synchronized by regulating water temperature (Yano 2005, Hamasaki 2005).

Mass seed production is usually performed in 50– to 350– mt concrete tanks with air and water supply systems and water heating equipment. Generally, 10,000 to 20,000 eggs per mt are placed in the tank for mass seed production (K. Teruya, personal communication). Water flow in a tank is controlled by means of aeration to distribute eggs and larvae uniformly (K. Teruya, personal communication).

The first larval diets consist of rotifers and brine shrimp; the more advanced stages are fed artificial diet (Fushimi 2001, JASFA 2003b). The nutritional value of rotifers and brine shrimp is usually enhanced by feeding highly unsaturated fatty acids (HUFAs) including docosahexaenoic acid (DHA) (Fushimi 2001). Besides, three different-sized rotifer species - *Brachionus plicatilis*, *B. rotundiformis*, and *Brachionus* sp. - are used according to the mouth size of larvae (Hino et al 2000). Conditions in the rearing tanks are checked daily including water temperature, pH, dissolved oxygen, food intake of the seed and swimming activity of rotifer. Rotifer supply is considered to be crucial for the success of mass seed production.

Seeds which have grown large enough for release are transported by boat or truck

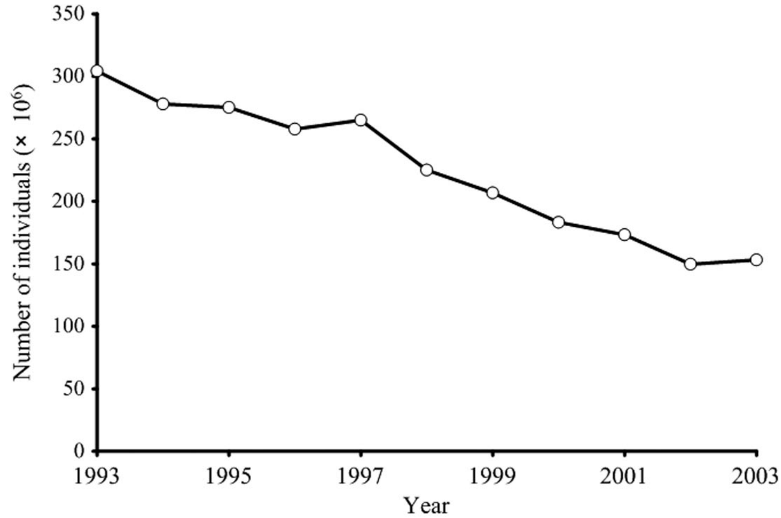

Fig. 2. Annual numbers of released individuals of kuruma prawn in Japan (data from Fishery Agency et al 1993-2003).

to a release point. The seed are sometimes acclimatized to the natural environment in net cages settled in the ocean for several days or months prior to release (Tanida et al 2003, JASFA 2003b). In striped jack (*Pseudocaranx dentex*), continuous feeding of artificial diets after release is useful for such acclimatization by regulating their dispersal from the release area to the ocean (Kuwada et al 2004).

Tagging and survey

Various tags have been used in stock enhancement programs. External tags, such as fin or caudal appendage cuttings, branding iron, dart tag, and disc and ribbon type tags, are commonly used to examine the distribution of released fish and prawns (Achiha 2004, Tanida et al 2003, Fujimoto et al 2001, Takeno et al 2001). The effectiveness of stock enhancement is usually evaluated by the fin or caudal appendage cuttings and the branding iron because these tags are relatively stable and easy to use. Similarly, Alizarin complexone (ALC) is used by many cooperative stock enhancement programs as an internal tag to distinguish the source of the released fish seed (Takemori et al 2005, Sasaki et al 2002, Okouchi 2003).

Cost effectiveness of stock enhancement is estimated based on the price and the number of marked seedling sold in fish markets (Kitada 2001). The daily number of recaptured seedlings is checked for several years in all the fish markets which sell fishery products from the stocking area (Kitada 2001, Okouchi 2003). Information on fishing grounds and fishing gears are also collected to standardize fishing effort among the markets (Kitada 2001, Okouchi 2003). Such information can sometimes contribute to the improvement of stock enhancement technology.

Disease prevention

While mass seed production has been successful in many species, infectious diseases have often caused mass mortality of larvae (Muroga 1995). In particular, viral diseases, such as Viral Nervous Necrosis (VNN) in striped jack and some other fishes, White Spot Disease (WSD) in kuruma prawn, and viral ascites in yellowtail have caused major damage to the stock enhancement programs of the host species (Munday 2002, Satoh et al 1999, Sorimachi and Hara 1985). Many bacterial diseases such as vibriosis, pasteurellosis, gliding bacterial infection, and bacterial enteritis

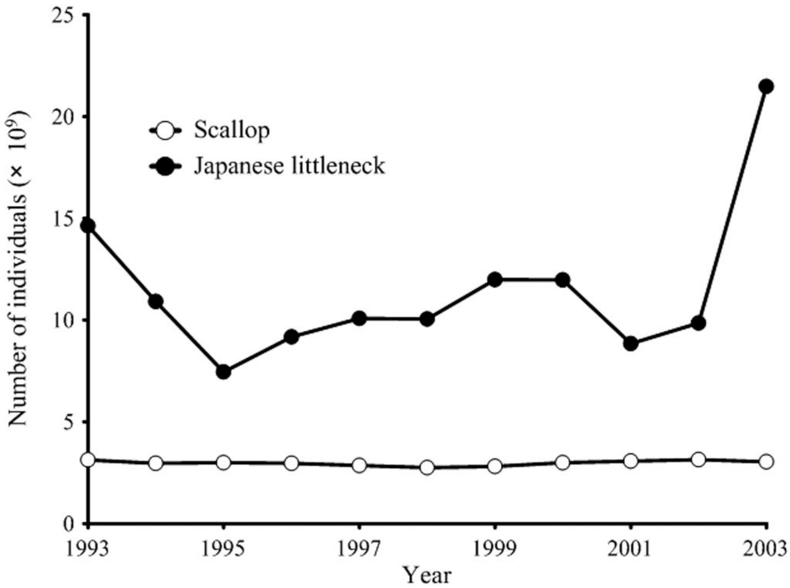

Fig. 3. Annual numbers of released individuals of scallop and Japanese littleneck clam in Japan (data from Fishery Agency et al 1993-2003).

with *Vibrio* sp. are additional obstacles in mass seed production (Muroga 1995). Sterilization by ozone or ultraviolet rays of the seawater used for production has become popular in recently established hatcheries to keep out disease agents from the ocean. At the same time, there is growing awareness that sanitary supervision, e.g., strict assignment of tools and workers to a given tank, is important to prevent and control diseases in the hatchery.

However, seawater sterilization has not always been effective for viral diseases because they can be transmitted by the broodstock. For example, VNN and WSD are known to occur in larvae and juveniles via vertical transmission (Munday 2002; Satoh et al 1999). Therefore, recent seedling production has selected broodstock based on diagnosis by polymerase chain reaction (PCR) techniques (Nishizawa 1994, Satoh 2001, Mori 1998). PCR diagnosis checks for the presence of viral nucleic acids in ovarian eggs or the thelycum (Mori 1998). Moreover, such molecular biological techniques are now being applied to epidemiological analysis in the hatchery (Sugaya et al 2005).

Prevention of disease transmission from hatchery fish to wild fish is very important for responsible stock enhancement. Therefore, hatcheries check for the presence of disease agents and viruses in seedlings before their release.

Genetic variability

In many target species for stock enhancement program, the seedlings have usually low genetic variability and altered genetic composition relative to the wild population due to limited numbers of broodstock. Such phenomenon has led the concern that released seedlings might decrease the genetic variability of the wild populations and disturb the locally adopted gene pools (FAO 1993, Campton 1995).

From this points of view, most hatcheries gather from the stocking area 50-200 wild individuals for broodstock of Japanese flounder (*P. olivaceus*) and red sea bream (*P. major*) to reflect the regional genetic composition and variability (T. Nishioka, personal communications). These broodstock are partially replaced every 3-5 years (Mushiake et al 2003). Furthermore, recent development of highly polymorphic DNA markers, such as microsatellites DNA and mitochondrial DNA markers are about to bring a new strategy for the genetic management of the broodstock. The selective breeding according to the minimal-kinship criterion, which can be evaluated by pedigree analysis based on DNA markers, has been reported to be effective for the genetic conservation even in small number of broodstocks (Sekino et al 2003, Taniguchi 2004, Ortega-Villaizán Romo et al 2006).

Future Directions

The stock enhancement program activities that started in the Seto Inland Sea have been expanded in the last four decades to cover the rest of Japan. Mass seed production techniques have been established in almost 80 species and have contributed to the expansion of the stocking program. In several species such as scallop, kuruma prawn and red sea bream, stock enhancement has been successful economically in some areas. In contrast, the effectiveness of stock enhancement has not been evaluated for many other target species because of the complexity of the fishery and fluctuations in the natural populations of the species.

Current stock enhancement in Japan has recently improved with the development of the fish market survey method to estimate effectiveness of stock enhancement. Joint studies have been organized among local and national hatcheries for the precise estimation of stock effectiveness using the marker survey method. Although there are still difficulties in this method due to the complexity of the fishery, these studies will supply valuable information about stock enhancement effectiveness. Furthermore, the information might contribute to more effective combination of stock enhancement, conservation of fishing ground and regulation of fish catches for proper resource management.

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