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An Ecological Approach to Mariculture of Shrimp: Shrimp Ranching Fisheries

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Abstract Mariculture production in Japan has grown recently to nearly one million tons per year. Mariculture production in the shallow coastal waters of Japan mainly consists of eight species of finfish, six species of shellfish, and three species of algae.

Kuruma shrimp culture techniques are highly developed. Nevertheless, only 1,800 tons of kuruma shrimp can be produced yearly. There is a demand for this species but culture grounds have become limited and there is not enough space to raise shrimp. In 1980, 600 million postlarvae were produced but one-half had to be released to the sea. The released shrimp that survived and grew have formed a new basis for the "Sea Ranching Fisheries" industry. The trial releases of postlarvae have proven that sea ranching of shrimp can be successful.

To strengthen the foundation of sea ranching fisheries, there must be future research on ecological impact, as well as on physico-chemical water parameters. The life cycle, feeding habits, and predators of the shrimp must also be studied. Recent releases in Hamana-ko Lagoon, Shizuoka Prefecture, made by the research group of the Hamana-ko Substation of the Shizuoka Prefectural Fisheries Research Station have demonstrated the possibilities of sea ranching. This report discusses the research studies obtained at Hamana-ko Lagoon and the main problems of the use of this sea ranching method in mangrove swamp areas of Southeast Asia.

Introduction

Recent commercial mariculture production in the shallow coastal waters in Japan has grown to nearly one million tons per year. It is about 8.2% of total production or 940×10^4 tons and consists of yellowtail, sea bream, oyster, scallop, "nori" (*Porphyra*), and *Undaria* (Fig. 1; Table 1). There are more varieties of species cultivated as compared to Southeast Asian countries, for example: Philippines—milkfish, Malaysia—blood cockle, and Thailand—blood cockle and mussel. In Japan, the number of species for culture has been increasing. In the commercial mariculture of various species, the basic thing is to establish mass production techniques for seed supply. In hatcheries, techniques are studied and progressively being developed for various species. In 1981, the Japan Sea Farming Association and prefectural governments produced more than 2,400 million seed of finfish and shellfish to stock the open sea as shown in Table 2.

In the case of kuruma shrimp, *Penaeus japonicus,* techniques have been stabilized at a high level with production of about 513 million postlarvae in 1981, of which 60% were released to the sea. The released postlarvae that have survived and grown have formed a new basis for sea ranching fisheries. Many trial releases of postlarvae have proven that sea ranching of shrimp can be successful. To strengthen the foundation of sea ranching fisheries, much ecological knowledge is needed about the distribution, food habits, predation, population dynamics, etc. of the species to be restocked.

In this report, some problems in shrimp ranching fisheries are described based on results of trial releases of *P. japonicus* postlarvae in the Hamana-ko Lagoon, Shizuoka Prefecture, made by the research group of the Hamana-ko Substation, Shizuoka Prefecture Fisheries Research Station.

Fishing area

A brief topography of Hamana-ko Lagoon is shown in Fig. 2. It is one of the largest lagoons on the coast of Honsyu, main island of Japan. The water system is very simple in comparison with many mangrove areas in the Philippines (Motoh, 1981) and the Mexican coastal lagoon complex (Edwards, 1978a). Directly connected with the sea through a narrow neck 200 m wide, the lagoon has a surface area of 6,900 ha and maximum depth of 12 m in the inner part. Tidal range varies from 30 cm in the bottom part to 180 cm near the sea mouth. The water exchange due to tidal current is estimated to be about 42.3 million ton/day.

Subjected to tidal influence, salinity ranges from 18.56 ppt in January to 15.17 ppt in July near the sea mouth of the lagoon and from 16.98 to 14.22 ppt in the center. Water temperature ranges between extremes of 3.8 to 29.2°C in the center, and from 8.8 to 25.8°C near the sea mouth.

The lagoon bottom is silty clay mud in depths of more than 5 m and predominantly sand or muddy sand in shallower areas. These shallower sandy waters support a shrimp fishery of commercial importance. Recently, shrimp fisheries in the lagoon have developed steadily with production reaching 100 tons in 1984 due to restocking of the shrimp postlarvae. Shrimp fishing gear consisting of three types, drift gill net, traditional cover net, and small set net, contributes to the shrimp catches. The fishing grounds for set nets are shown in Fig. 3.

Table 1. Annual mariculture production (in tons) by species in Japan (after Fisheries Agency, Japan, 1984).

Year	Finfish						
	Yellow-tail	Sea-bream	Horse mackerel	Hardtail (*Caranx*)	Fugu	Filefish	Others
1972	77,059	1,380	127		14	39	104
1973	80,439	2,741	378	—	16	40	150
1974	92,946	3,298	619	48	8	25	140
1975	92,407	4,462	920	22	9	8	170
1976	101,786	6,572	704	58	11	2	125
1977	115,098	8,245	743	61	15	10	238
1978	121,956	11,315	809	177	47	3	701
1979	155,053	12,253	1,461	304	73	—	1,178
1980	149,449	14,973	2,272	228	68	3	2,724
1981	150,907	18,243	3,195	158	162	3	2,235
1982	146,486	20,648	3,613	256	503	15	3,484
	Invertebrates						
	Oyster	Scallop	Pearl	Octopus	Japanese prawn	Ascid-ians	Others
1972	217,373	23,049	42	68	454	1,118	36
1973	229,899	39,397	34	56	659	4,675	289
1974	210,583	62,651	30	54	912	5,036	134
1975	201,173	70,313	30	41	936	6,313	114
1976	226,278	64,946	34	42	1,042	8,390	73
1977	212,779	83,213	39	16	1,124	7,463	92
1978	232,069	67,750	37	11	1,184	5,759	207
1979	205,509	43,622	40	22	1,480	5,287	173
1980	261,323	40,403	42	22	1,546	5,746	370
1981	235,241	59,106	46	8	1,666	6,909	481
1982	250,287	76,876	52	4	2,000	7,382	283

	Algae				**Grand total**
	Porphyra	*Undaria*	*Laminaria*	Others	(finfish, invertebrates and algae)
1972	217,906	105,695	3,340		647,905
1973	311,410	113,211	7,681	—	790,974
1974	339,314	153,762	10,201	—	879,761
1975	278,127	101,937	15,759	—	772,741
1976	291,050	126,701	22,096	—	849,909
1977	279,031	125,798	27,260	64	861,389
1978	350,471	102,665	21,890	194	917,244
1979	325,686	103,788	25,291	1,164	992,620
1980	357,672	113,532	38,561	2,904	991,843
1981	340,510	91,273	44,220	5,329	959,680
1982	263,312	118,338	42,978	1,888	938,680

Life history

There are many reports on the life history of penaeid shrimps, e.g., *Penaeus vannamei* (Lopez, 1967; Chavez, 1973), *P. japonicus* (Kurata, 1972), *P. monodon* (Motoh, 1981), *P. setiferus* and *P. aztecus* (Mock, 1966). *P. japonicus* (Kurata, 1972) and *P. monodon* (Motoh, 1981) have six life cycle history phases: embryo, larva, juvenile, adolescent, Subadult and adult. Each stage has its preferred habitats. Penaeids exhibit typical migratory behaviour—postlarvae migrate towards inshore waters on tidal currents and spend juvenile and adolescent phases in brackish waters like lagoon complexes, estuarine areas including mangrove and swamp areas, and interior portions of bays. At the end of the juvenile and adolescent phases, they migrate back downstream to the outside coastal waters.

Penaeus japonicus in Hamana-ko Lagoon also shows a typical life cycle pattern. The postlarvae metamorphose outside the lagoon, then move to the mouth part and enter the lagoon. The abundance of postlarvae (Fig. 4) was determined by plankton net sampling at approximately monthly intervals over a 12-month period in 1955-56. The postlarvae enter the lagoon mostly from July to September. The inshore movement of postlarvae continues during flood tides, noticeably decreases during ebb tides, and stops three hours after the commencement of ebb tide. *P. japonicus* spends juvenile, adolescent and Subadult phases in the lagoon. There is no evidence of occurrence of mature adults more than 37.5 g in body weight and 180 mm in body length. Migratory routes of the shrimp are shown in Fig. 5.

Growth and recruitment

Trial releases of postlarval *P. japonicus* in Hamana-ko Lagoon have been carried out by the Shizuoka Prefectural Government since 1978. The number of postlarvae released reached a total of 17.6 million over a period of five years. Table 3 shows the postlarvae released at the Shirasu area from August 1981 to November 1984. The method of release consists of three steps: hatchery production, nursery culture and release. Hatchery-produced postlarvae of 14-15 mm body length are cultured in an enclosure with an average area of 6,000 m^2 at a stocking rate of 270 individuals/m^2 fed on artificial diets for 16.8 days. They grow to 29.6 mm body length with 49.7% survival rate. Some 9.7 million postlarvae have been released at the Shirasu area over three years (Table 3).

To obtain growth estimates of the released stocks and naturally recruited populations, continuous sampling at 5-day intervals during the fishing season (April to early December) was done. Specimens were collected from shrimps caught in set nets in offshore Shirasu, Shonai-ko as shown in Fig. 3. The length frequency distribution was analyzed by Cassie's method (1954). Each population could be extracted from these polymodal length frequencies in spite of continuous recruitment and release. Weight (W) in grams was calculated using the formula:

$W = 1.9001 \times 10^{-5} \times L^{2.8927}$ (mm), R = 0.9984 for females

$W = 2.0239 \times 10^{-5} \times L^{2.2748}$ (mm), R = 0.9992 for males

The results are shown in Fig. 6 and Table 4. The potential stocks of 1983 in the lagoon consisted of five populations

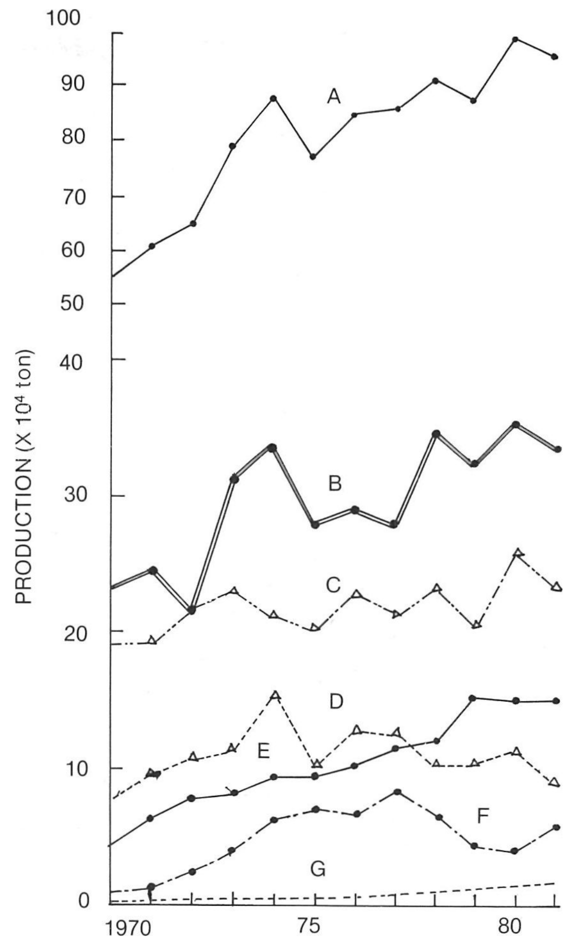

Fig. 1. Annual mariculture production by species. A, total; B, *Porphyra*; C, oyster; D, *Undaria*; E, yellowtail; F, *Pecten*; G, sea bream (Fishery Agency, 1983).

Table 2. Annual seedling production (× 10^3 invividuals) for mariculture in Japan (after JASFA, 1984).

Species	No. of seedlings produced				No. of seedlings released in the sea			
	1978	1979	1980	1981	1978	1979	1980	1981
Fish								
Pagrus major	6,942	11,594	13,457	16,120	5,109	8,600	10,359	12,044
Acanthopagrus schlegelii	443	2,113	2,386	2,867	407	1,267	1,314	1,955
Gadus macrocephalus	1,100	1,834	1,209	2,350	1,100	2,113	1,209	2,350
Limanda yokohamae	1,795	1,601	1,693	1,727	1,215	401	733	815
Paralichtys olivaceus	379	1,051	3,203	3,688	297	898	2,370	1,156
Fugu rubripes	602	1,615	445	454	550	615	442	454
Sebastiscus marmorata	68	325	75	127	48	25	75	57
Seriola quinqueradiata	0.3	105	230	216	—	21	120	63
Lateolaborax japonicus	56	36	325	104	53	31	25	104
Invertebrates								
Penaeus japonicus	448,864	534,634	599,853	513,111	280,075	337,229	297,842	302,138
Metapenaeus ensis	10,960	32,516	29,301	39,144	10,595	25,141	12,483	19,193
Neptunus trituberculatus	10,280	18,070	16,041	18,352	7,870	12,171	11,519	11,212
Patinopecten yessoensis	1,798,315	1,822,143	2,131,713	2,055,439	1,566,655	1,699,127	1,525,333	2,127,447
Anadara broughtonii	1,490	11,932	11,854	6,766	651	2,764	5,187	3,137
Haliotis spp.	10,863	11,724	16,471	18,881	7,205	8,597	10,690	12,485
Meretrix lusoria	390	1,500	2,530	35	395	2,158	10,348	2,860
Babylonia japonica	65	109	177	3,240	50	109	212	2,627

Table 3. Release of postlarval *Penaeus japonicus* (ave. body length 14.1 mm) at Shirasu area, Hamana-ko Lagoon (after data from Hamana-ko Substn., Shizuoka Pref. Fish. Res. Stn.).

Year and group	Nursery culture				Release	
	No. stocked ($\times 10^3$)	Period (days)	Survival rate (%)	Body length (mm)	No. ($\times 10^3$)	Date
1981 RS_1	2,567	14	43.5	33.1	1,374	Aug. 12
RS_2	500	10	32.8	30.9	164	Sep. 9
RS_3	1,742	24	66.7	29.1	1,162	Oct. 31
1982 RS_1	500	16	3.3	28.5	50	Aug. 7
RS_2	500	13	57.1	26.3	285	Oct. 9
RS_3	2,092	18	49.7	26.1	2,150	Nov. 6
1983 RS_1	2,038	14	42.6	30.3	1,652	Aug. 10
RS_2	377	16	42.8	33.0	522	Sep. 24
RS_3	4,388	27	52.6	29.0	3,308	Nov. 2
Total/Ave.	14,704	16.8	49.7	29.6	9,667	—

derived from natural recruitment (groups $82N_4$ and $83N_{1-4}$) and five released populations (groups $82RS_{1-3}$ and $83RS_{1-2}$). The females released in August 1982 (group $82RS_1$) were caught in set nets, attaining 5.4 g average body weight in early October and 20.2 g in mid-December (Table 4). Some appeared to emigrate to the outside sea but those that remained in the lagoon contributed to the next year's catches with average body weight of 27.2 g after overwintering in the lagoon. The groups of $82RS_2$ and $82RS_3$ released in October and November 1982, respectively, were not found in the 1983 catches due to smaller size. All of them overwintered in the lagoon and contributed to the 1983 catches with sizes of 6.6-15.9 g in early April to early June for group $82RS_2$ and 4.1-13.5 g in late April to late June for group RS_3.

Shrimp from the population originating from the fourth recruitment in 1982 (group $82N_4$) attained 3.6 g body weight in mid-October and 11.9 g in mid-December 1982. All of them appeared to winter and were caught with the size group 14.7-21.6 g from early April to late May 1983. Shrimp from the first to third natural recruitments in 1983 (groups N_{1-3})

Table 4. Estimated growth of *Penaeus japonicus* in Hamana-ko Lagoon in 1982-83 based on statistical analysis of samples caught in set nets in Shonai Inlet. N_{1-4}: population from natural recruitment; RS_{1-3}: population from postlarvae released at Shirasu area, Shonai Inlet (after data from Hamana-ko Substn. Shizuoka Pref. Fish. Res. Stn.).

Group	1982 Estimated body weight		1983 Estimated body weight		Remarks
	Start	End	Start	End	
Female 1982 $82N_4$	4.6 g late Aug.	27.6 g mid-Dec.			Emigration in 1982
$82RS_1$	5.4 g early Oct.	20.2 g mid-Dec.	27.2 g mid-Apr.	29.6 g late May	
$82N_4$	3.6 g mid-Oct.	11.9 g mid-Dec.	14.7 g early Apr.	21.6 g late May	Emigration to the sea in 1983
$82RS_2$	Released early Oct. (W)		6.6 g early Apr.	15.9 g early Jun.	
$82RS_3$	Released early Nov. (W)		4.1 g late Apr.	13.5 g late Jun.	
1983 $83N_1$			3.6 g late Jun.	14.4 g mid-Aug.	Emigration to the sea in 1983
$83N_2$			5.7 g late Jun.	12.5 g late Aug.	
$83N_3$			5.2 g mid-Aug.	26.3 g mid-Oct.	
$83N_4$			5.4 g early Sep.	25.4 g early Dec.	Wintering in the lagoon
$83RS_1$	Released mid-Aug. 1983		6.4 g late Sep.	16.3 g early Dec.	
$83RS_2$	Released late Sep. 1983		4.9 g late Oct.	9.5 g early Dec.	
$83RS_3$	Released early Nov. 1983				
Male 1982 $82N_3$	4.7 g late Aug.	17.7 g mid-Dec.			Emigration to the sea in 1982
$82RS_1$	5.4 g early Oct.	19.4 g mid-Dec.			
$82N_4$	4.1 mid-Oct.	12.2 g mid-Dec.	11.9 g early Apr.	16.1 g late May	Emigration to the sea in 1983
$82RS_2$	Released early Oct. 1982 (W)		6.8 g early Apr.	13.6 g early Jun.	
$82RS_3$	Released early Nov. 1982 (W)		4.3 g late Apr.	11.8 g late Jun.	
1983 $83N_1$			6.5 g mid-Jun.	10.6 g early Aug.	Emigration to the sea in 1983
$83N_2$			5.7 g late Jun.	11.8 g late Aug.	
$83N_3$			6.1 g mid-Aug.	18.2 g mid-Sep.	
$83N_4$			5.6 g early Sep.	18.9 g early Dec.	
$83RS_1$	Released mid-Aug. 1983		6.1 g late Sep.	13.1 g early Dec.	Wintering
$83RS_2$	Released early Sep. 1983		4.5 g late Oct.	9.5 g early Dec.	
$83RS_3$	Released early Nov. 1983				

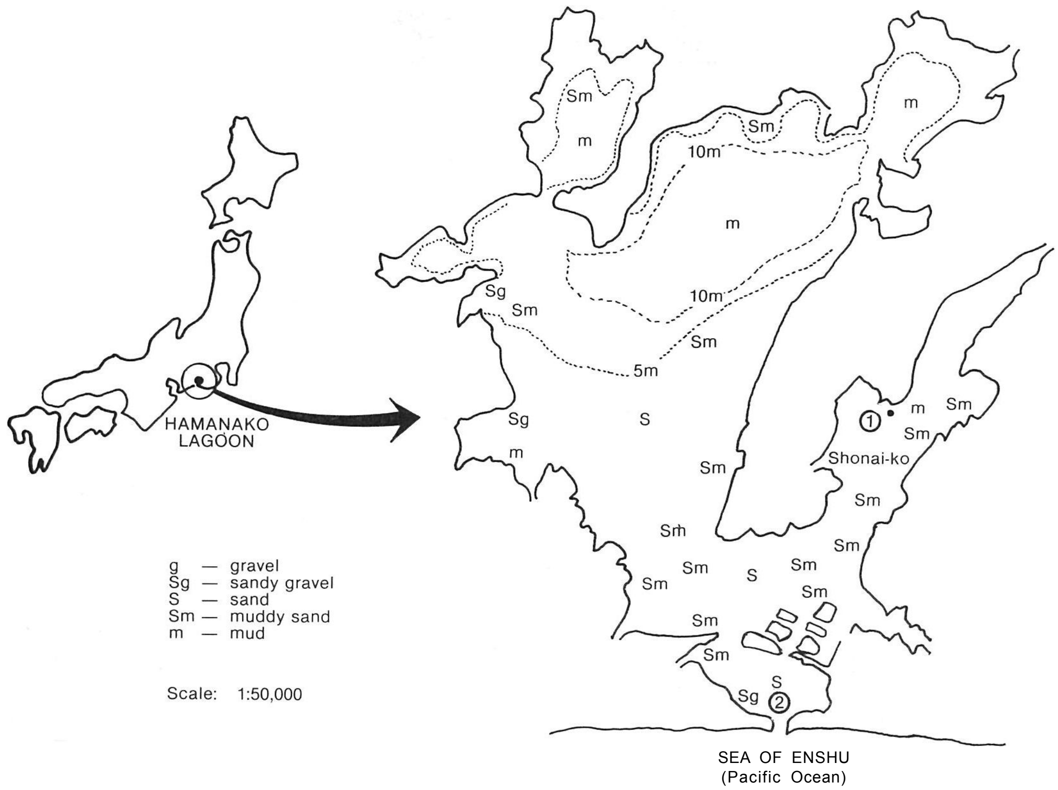

Fig. 2. Topography of Hamana-ko Lagoon showing bottom conditions and depth. 1, site of enclosure for nursery culture; 2, mouth of lagoon (Imakiriguchi).

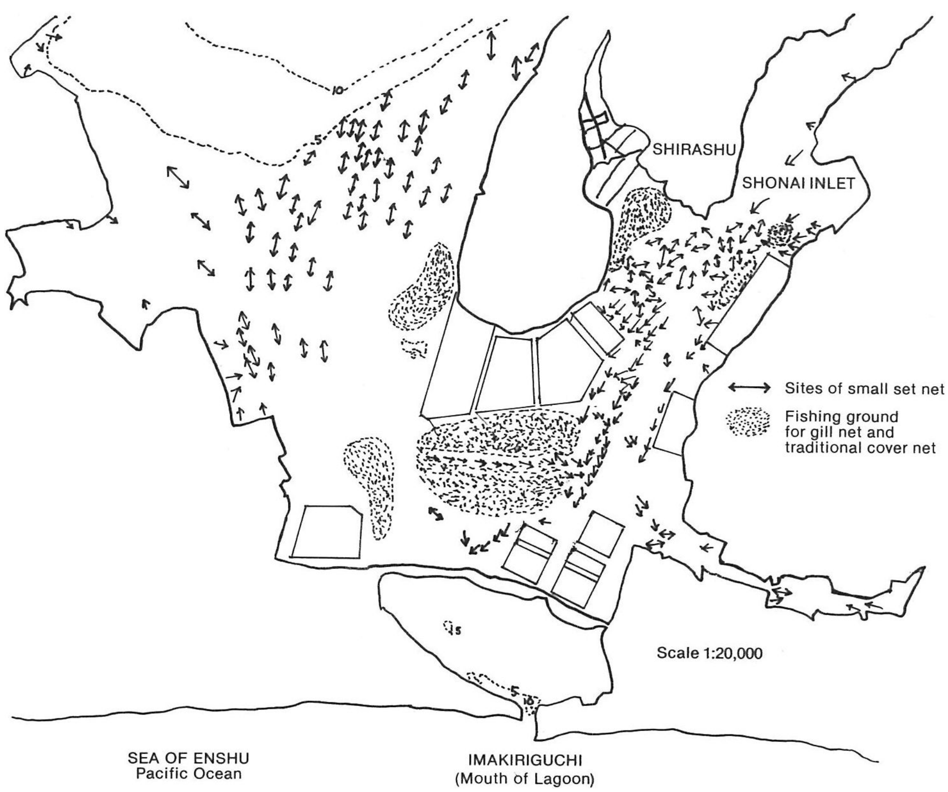

Fig. 3. Fishing grounds of kuruma shrimp, *Penaeus japonicus,* in Hamana-ko Lagoon. Figures denote depth in m.

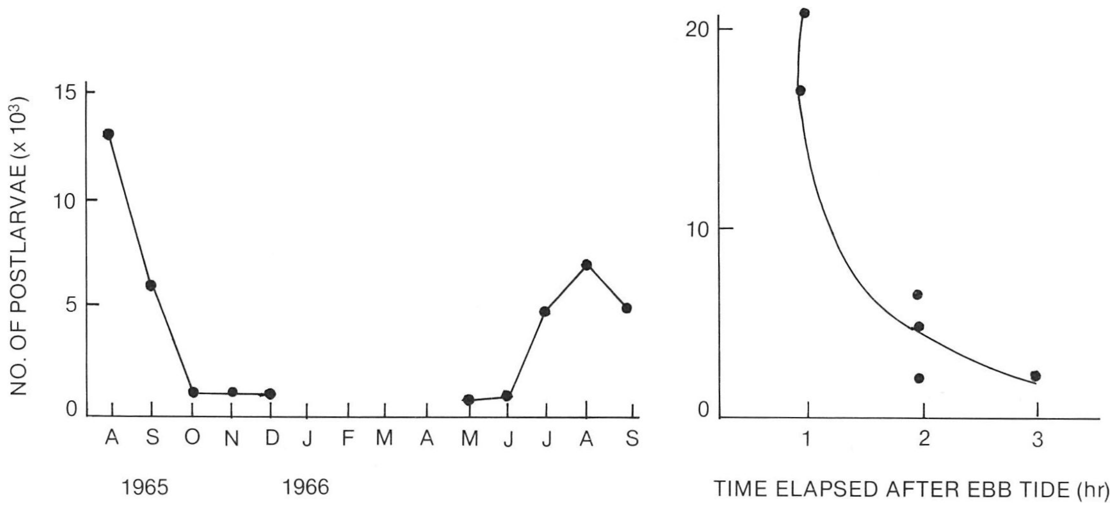

Fig. 4. Variation in number of postlarval *Penaeus japonicus* by month and in relation to ebb tide at the mouth portion of Hamana-ko Lagoon in 1973. (After data from Hamana-ko Substn., Shizuoka Pref. Fish. Res. Stn.)

were caught with the sizes 3.6-14.4 g from late June to mid-August for N_1, 5.7-12.5 g from late June to late August for N_2, and 5.2-26.3 g from mid-August to mid-October for N_3. The remaining shrimp appeared to emigrate to the outside sea. The group $83N_4$ could not be caught in this year due to smaller size. They could contribute to the catches for next year as described in the case of $82N_4$.

Estimated growth in body length based on size distribution data is 0.62 ± 0.16 mm/day with a range of 0.41-0.87 mm for females and 0.53 ± 0.17 mm/day with a range of 0.26-0.80 mm for males. Growth rate of 0.87 mm for females and 0.80 mm for males were derived from group $83N_3$ and $83N_2$, respectively, which were caught in summer. Minimum growth rate of 0.41 mm for females and 0.26 mm for males were derived from groups $82RS_1$ and $82RS_2$ caught in spring after overwintering.

There are many reports on growth rates of *Penaeus* spp. — *P. aztecus* (Cook and Lindner, 1970), *P. setiferus* (Williams, 1955), *P. vannamei* (Sato, 1979; Edwards, 1977) and *P. stylirostris* (Menz and Bowers, 1980). Direct comparison of growth rates of *P. japonicus* with those of other species is difficult because of different ways of data presentation. The present results indicate that the sizes of *P. japonicus* that immigrate to the lagoon in summer are greater than those in spring and autumn with differences between males and females.

The catch curve (Ricker, 1975) was obtained according to the variation of catch per unit effort calculated at 5-day intervals throughout the 1983 fishing season and the annual catch for each naturally recruited and released population. Results are shown in Table 5.

A total of 6.98 million postlarval *P. japonicus* (30 mm size) were stocked in the Shirasu area (fishing ground ca. 200 ha) and production was 2.4 times greater than catches in natural waters.

Application of sea ranching to Southeast Asia

The activity of releasing postlarval *P. japonicus* has recently become extensive in Japan, reaching 302 million postlarvae released in 1983. The main sites for releases are inlets and open or semi-open waters. The trial in the Hamana-ko Lagoon is the first successful one. After many studies on the feasibility of stocking open waters with shrimp postlarvae, it has been proven that this system provides three advantages: 1) increased production, 2) stabilized

Table 5. Estimated annual catch for each population of *Penaeus japonicus* in the Shirasu area, Shonai Inlet, Hamana-ko Lagoon. 1983.

Group	Annual catch		Body wt. (g)	Percentage	Remarks
	Number	Wt. (kg)			
Natural population					
$82N_4$	24,048	370.1	15.4	5.15	Wintering
$83N_{1-4}$	276,192	2,533.5	9.2	35.14	
Total	300,240	2,903.6		40.39	
Released population					
$82RS_{1-3}$	386,483	4,030.0	10.4	56.05	Wintering
$83RS_{1-2}$	29,551	256.1	8.7	3.56	
Total	416,083	4,286.1		59.61	
Grand total	716,278	7,189.7	10.9*	100.10	

*Average

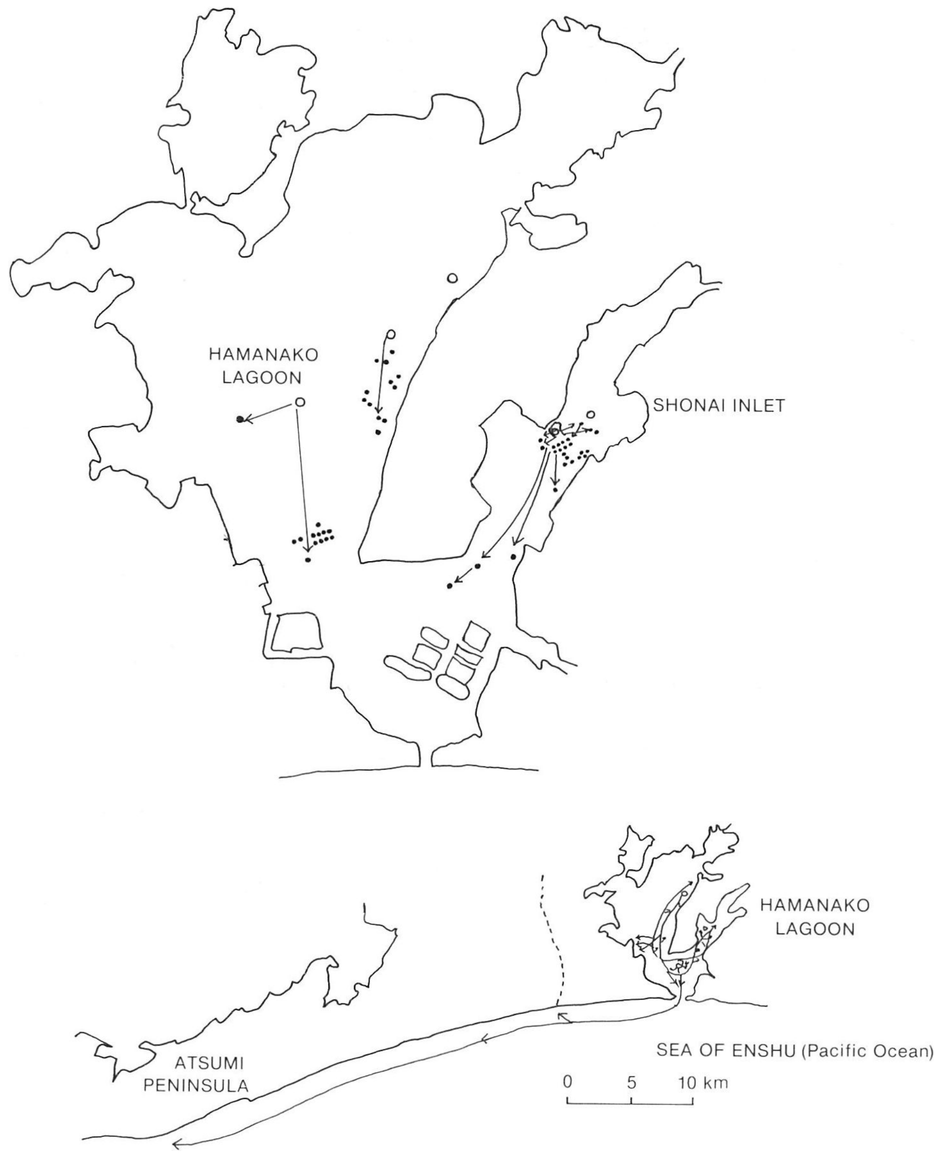

Fig. 5. Migration of kuruma shrimp in Hamana-ko Lagoon and the open sea based on tagging experiments in 1973-74; ● release site: → migration route. (After data from Hamana-ko Substn., Shizuoka Pref. Fish. Res. Stn.)

production through adjustment of the time postlarvae are released, and 3) addition of shrimp not caught to the natural breeding population. In the case of the Hamana-ko trials, it becomes clear that the released postlarvae survived and grew, contributing to fishery catches and forming a new basis for sea ranching fisheries.

The author proposes the application of this sea ranching system to the shallow coastal zones of Southeast Asian countries for the development of large-scale prawn culture. There are very large areas suitable for commercially important penaeid prawn species such as *Penaeus monodon*, *P. merguiensis*, *P. indicus*, *P. brevicornis*, *P. semisulcatus*, *Metapenaeus ensis*, etc. Among all these species, *P. monodon* has been most closely investigated as a suitable species for culture. Pond cultivation of prawns in coastal zones is rapidly developing in the countries of Southeast Asia. In other words, the traditional method of building ponds in mangrove swamps now causes the destruction of mangrove areas and the gradual disappearance of the mangrove ecosystem.

It is well known that mangroves have both a land-building and coast-protecting function (Davis, 1940). These backwater areas are a complex combination of swamps, creeks, rivers and mangrove forests where salt water and fresh water gradually mix. They are an important buffer zone between freshwater and marine environmental conditions.

From the ecological point of view, these mangrove areas are natural nursery ponds for juveniles of many organisms including penaeid prawns (MacNae, 1974). This brackish-water zone has abundant shelter and the decomposition of leaves and other organic matter, and inorganic nutrients carried by river floods provide a rich supply of detritus as food for the benthic community.

In order to preserve the mangrove ecosystem and still make use of this large productive coastal area, a new approach to culture like sea ranching is needed. Penaeid prawns come into mangrove and estuarine areas as juveniles and remain there until they reach Subadult size. Then they emigrate offshore to deeper waters where they mature and reproduce. In the case of *P. monodon*, they remain in the coastal area up to a size of about 30 g in body weight. This means that the mangrove coastal habitat is most suitable for this stage of their life cycle. It is possible to enclose large coastal areas, *P. monodon* and other penaeid species could be kept in such enclosures of several hundred hectares. This type of enclosure could be constructed in the same way as the fish pens in Laguna de Bay (Delmendo and Gedney, 1974). They could be used to enclose shallow water areas along the coast and river estuaries as well as mangrove areas. Harvesting would be done by trapping prawns as they try to emigrate offshore after growing to Subadult size. Trapping methods are well documented for the Pacific coast of Mexico (Edwards, 1978b) and Adriatic coastal lagoons (Ravagnan, 1978). The process of harvesting would be continued and stocking of hatchery-produced fry would be timed through adjustment of release dates to stabilize and increase the potential stock relying on natural fry which enter the enclosed areas. With such a stocking system, some supplementary feeding may be necessary. In this way, coastal areas could be used for prawn production without the need to construct ponds thereby preserving the basic mangrove areas.

In order to develop large-scale prawn culture based on the system of sea ranching, much basic ecological information is needed about population dynamics, life history, and biotic and abiotic parameters of the ecosystem. Furthermore, several engineering and biotechnical points need investigation for the layout of such large-scale enclosures. These include the most suitable enclosure area, optimum water level within the enclosure, construction of a low dike to maintain water level at low tides, and increasing the tidal pool water area within the mangrove swamp to act as nursery pools.

It will be necessary to establish some legal framework such as fishing rights and licenses to promote large-scale aquaculture using mangrove areas while preserving their natural conditions by not building fishponds. As the utilization of mangrove areas for this kind of culture will greatly affect the villager's small-scale fisheries and community life in general, some form of administration is needed to settle conflicts of interest. Moreover, if the use of mangrove areas is limited to just a few individuals, the disparity of income among villagers may increase to the extent of disturbing the peace of communities. In order to prevent such negative results, it is advisable to work out a legal system with fixed rules for the use of mangrove areas that will benefit large sections of coastal communities.

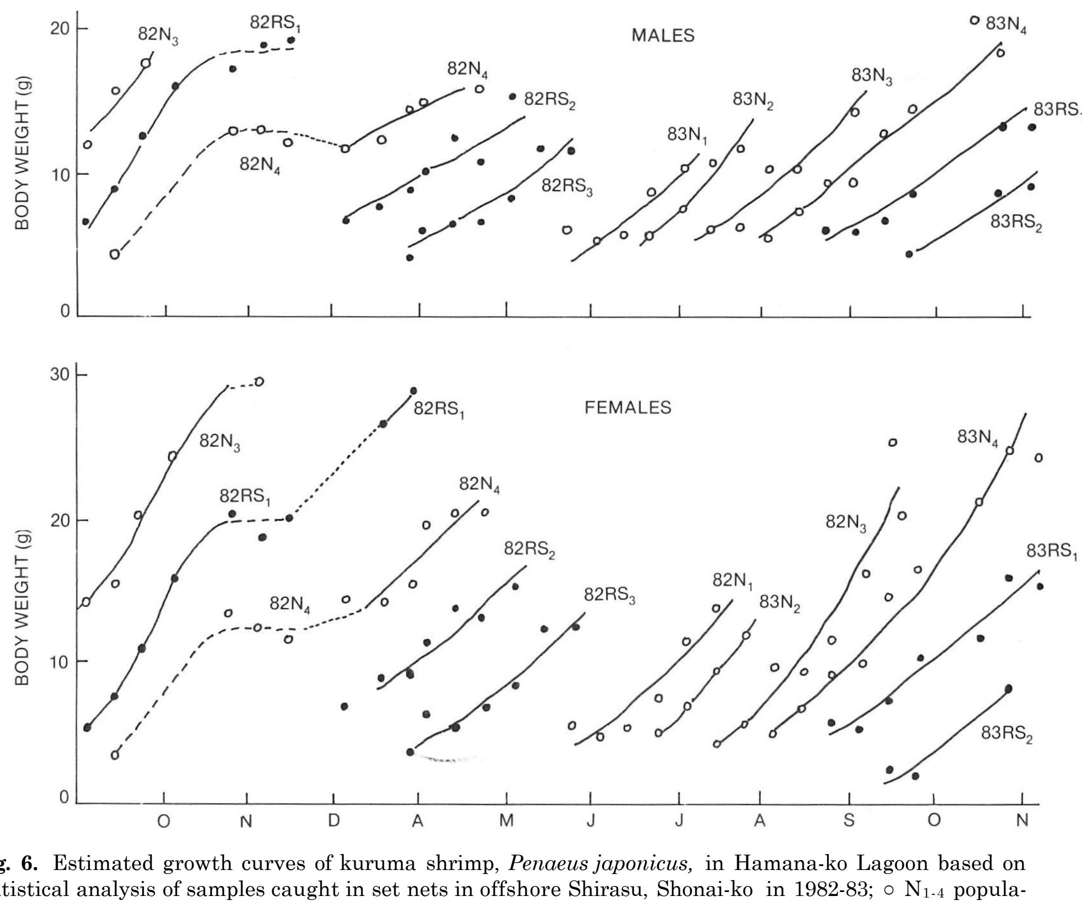

Fig. 6. Estimated growth curves of kuruma shrimp, *Penaeus japonicus,* in Hamana-ko Lagoon based on statistical analysis of samples caught in set nets in offshore Shirasu, Shonai-ko in 1982-83; ○ $N_{1\text{-}4}$ population from natural recruitment; ● $RS_{1\text{-}3}$ population from postlarvae released at Shirasu. (After data from Hamana-ko Substn., Shizuoka Pref. Fish. Res. Stn.)

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