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Proceedings of the First U.S.-Japan Meeting on Aquaculture at Tokyo, Japan October 18-19, 1971

Under the Aquaculture Panel, U.S.-Japan Cooperative Program in Natural Resources (UJNR)

Panel Chairmen:
WILLIAM N. SHAW - United States
ATSUCHI FURUKAWA - Japan

SEATTLE, WA
February 1974

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WILLIAM N. SHAW (Editor)

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PREFACE

The United States and Japanese counterpart panels on aquaculture were formed in 1969 under the United States-Japan Cooperative Program in Natural Resources (UJNR). The panels currently include specialists drawn from the federal departments most concerned with aquaculture. Charged with exploring and developing bilateral cooperation, the panels have focused their efforts on exchanging information related to aquaculture which could be of benefit to both countries.

The UJNR was started by a proposal made during the Third Cabinet-Level Meeting of the Joint United States-Japan Committee on Trade and Economic Affairs in January 1964. In addition to aquaculture, current subjects included in the program are desalination of seawater, toxic microorganism, air pollution, water pollution, energy, forage crops, national park management, mycoplasmosis, wind and seismic effects, protein resources, forestry, and several joint panels and committees in marine resources research, development, and utilization.

Accomplishments include: Increased communications and cooperation among technical specialists; exchanges of information, data, and research findings; some 30 missions involving over 300 scientists and engineers; seven meetings of the Conference, a policy coordinative body; administration staff meetings; exchanges of equipment, materials, and samples; several major technical conferences; and beneficial effects on international relations. Because of the importance of natural resources in this cooperation, the Secretary of State asked the Secretary of the Interior to serve as U.S. Coordinator of the UJNR.

William N. Shaw - United States
Atsushi Furukawa - Japan

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REMARKS AT FIRST MEETING UJNR PANEL ON AQUACULTURE, 18-19 OCTOBER 1971

ROBERT W. HIATT[1]

The initial meeting of the UJNR (United States-Japan Natural Resources) Aquaculture Panel is a significant event in the most comprehensive bilateral cooperative program between our two countries. This meeting brings together technical representatives of an ancient but still far from scientifically mature endeavor in any country, and it is especially significant that this initial meeting takes place in the country acknowledged to be in the vanguard of the "art" of aquaculture.

My personal interest in this field is great, as my professional background in marine ecology has involved studies of Hawaiian fish ponds as well as attempts at rearing zoeal stages of crabs. My feeling for the field thus enables me to sympathize with those who have labored long and hard at aquacultural problems, and my interest has led me to visit many of the aquacultural activities of Japan during my brief period of residence in this country.

Japanese panel members have spent much time and effort on the conference program which should not only give each delegation a summary review of aquacultural activities in each country, but will sift through the problems of the field and thus establish principal points for the agenda of the next panel meeting to be held in the United States. Field trip organization has been both elaborate and detailed so that special interests of the U.S. participants can be fulfilled.

Aquaculture in the Western world most likely dates from the early Roman period when oysters were brought under cultivation. Whether or not Asian aquacultural activities antedate those of the West I do not know, but there is little doubt that Japan's mariculture is the most varied and successful in any country today. Unlike aquaculture in Southeastern Asia which deals with few species in mass production systems, Japan's objective has been to produce variety and to sustain a large group of seashore residents in gainful economic activity. In the last few decades the mass production of exportable products such as oyster spat has sustained not only a host of Japan's mariculturists but those of the western United States and other areas of the world as well. Recently, a news item indicated that 15 planeloads of seed oysters from Sendai will be shipped to Bordeaux, France, via New York to replenish the declining oyster breeding farms there. Each plane will carry approximately 243 million seed oysters.

Mariculture, like most other industries, makes major surges when breakthroughs in technology occur. Most of these breakthroughs have occurred in Japan, indicating that the world renowned "green thumb" of the Japanese is based on substantial scientific observation, experimentation, and deduction.

Everyone is well aware of the great strides in mariculture being made in Japan, both with plant and animal species. Special mention should be made of very promising success in marine cultivation of rainbow trout, which ultimately may replace our diminishing salmon supply on the world's tables. One need only to let his mind wander a bit to realize what potential lies in the selection of rainbow trout for rapid growth, a la Lauren R. Donaldson of the University of Washington, combined with the greatly accelerated growth rate of trout reared in seawater.

During the field trips the impact of Japan's industrialization and urbanization on mariculture will be most apparent. Many of these problems are also being experienced in the United States. I hope that during the course of these and future joint panel meetings an assessment can be made of this threatening environmental circumstance so that agencies in

[1] Scientific Attache, U.S. Embassy, Tokyo, Japan.

each country, recently established for environmental affairs, can bring proper action to bear on preserving the basic environment for aquaculture. We all realize that pollution of inshore waters may not be all bad. We have not really attempted to utilize controlled eutrophication or warmed water from power plants to increase maricultural production. Theoretically these are viable concepts and should receive attention very soon.

We all look forward to an outstanding series of meetings and field trips. I should like to take this opportunity, on behalf of the U.S. Government, to thank the Japanese panelists for an outstanding job of organization.

PRESENT STATUS OF MAJOR MARINE CULTIVATION AND PROPAGATION IN HOKKAIDO AND SOME PROBLEMS OF THE RESEARCH ACTIVITIES

YOSHIO HASEGAWA and YUKIMASA KUWATANI[1]

GENERAL FEATURES OF THE WATERS AROUND HOKKAIDO

Hokkaido is the northernmost island of Japanese archipelago. It has a long shoreline extending about 2,700 km, which corresponds to about 10% of the Japanese coastline. The island is surrounded by three different seas—the Japan Sea, the Pacific Ocean, and the Okhotsk Sea. The coastline of Hokkaido is influenced by two warm currents, the Tsushima and the Kuroshio, and one cold current, the Oyashio (Fig. 1). The seasonal fluctuations of these warm and cold currents considerably influence the oceanographic conditions in each local region. Therefore, Hokkaido has many specific ecological features as a result of these oceanographic, as well as topographic, conditions.

Japan Sea Region

The Japan Sea coast of Hokkaido can be divided into two regions by the Shakotan Peninsula: The northern region is characterized by simple sandy beaches, while the southern region, including the Shakotan Peninsula, is characterized by a rough, rocky shoreline. Along this coast, the warm Tsushima Current flows northward. In addition, some upwelling of cold water-masses from the lower layers of the Japan Sea occurs both in the offshore waters and the inshore area of the Tsushima Current. This intermingling of warm and cold water-masses complicates the oceanographic conditions of the area. Moreover, strong northwest winds bring stormy weather conditions to this region during the winter. Therefore, because of the oceanographic conditions, stormy winters, and open topography, it is very difficult to establish and maintain artificial equipment (rafts, longlines, etc.) for marine cultivation.

Pacific Region

The Pacific coast can also be divided into two regions by Cape Erimo. In the eastern region, there are many small bays or inlets in the Akkeshi area, but the largest embayment, Uchiura Bay, is found in

Figure 1.—Sea currents and isothermal lines in Japanese waters during August.

[1] Hokkaido Regional Fisheries Research Laboratory, Yoichi, Hokkaido, Japan.

the western region. The whole coastline of the Pacific region, except in the area of Tsugaru Strait, where wide, rocky shores are found, is made up of simple, sandy beaches. The fundamental water system of this region consists of two warm currents, the Kuroshio and the Tsugaru, and one cold current, the Oyashio. In the western region, the warm Tsugaru Current and the cold Oyashio Current interchange alternatively by seasons; therefore, the oceanographic conditions of this region are quite variable. On the other hand, in the eastern region, the coastal area is affected entirely by the cold Oyashio Current throughout the entire year. Dense sea fogs often occur during the summer (June to August), especially in the eastern part. There are, on the average, 58 foggy days per year.

Okhotsk Sea Region

The Okhotsk Sea coast can be divided into two regions by the Shiretoko Peninsula: The northern region is characterized by a flat sandy beach; in the southern region, a big embayment is formed between the Shiretoko Peninsula and the Nemuro Peninsula. In addition, some of the Kurile Islands are located in the entrance of this embayment. The channel lying between Hokkaido and Kunashiri Island is called the Nemuro Strait. This region is characterized by many large and small brackish lakes along the coast. The warm Soya Current (a branch of the Tsushima Current) flows southward along the Okhotsk Sea coast and a cold East Sakhalin Current runs along the outside and parallel with the Soya Current. Considerable freezing of seawater, especially in lakes and inlets, and drifting ice occur from December to April in this region. Because of these icy conditions, fishing activities as well as maintaining artificial equipment for marine cultivation are greatly restricted during this period.

PRESENT STATUS OF THE PRODUCTIVITY OF IMPORTANT MARINE ORGANISMS

The major species which are artificially cultivated and propagated in Hokkaido are restricted in numbers because of environmental conditions of this region. Almost all are northern forms which have their major distributional range in Hokkaido (Table 1). Recently, the cultivation of fishes and other marine organisms has become of major interest in Hokkaido, and it has become necessary to establish seed production systems for some of the most impor-

Table 1.—Catch statistics for main fishing species as the subject of the cultivation and propagation in Hokkaido in 1969, and show it related percent to the total Japanese landings.

	Species	Japan (A)	Hokkaido (B)	($\frac{B}{A} \times 100$)
				%
Fish	*Oncorhynchus* spp.	100,799 tons	78,870 tons	(78.24)
	Clupea pallasi	31,644 tons	20,664 tons	(65.30)
	Flounders	168,296 tons	58,389 tons	(34.69)
	Pleurogrammus azonus	107,085 tons	101,898 tons	(95.15)
Crab	*Paralithodes camtschatica*	4,794 tons	4,761 tons	(99.31)
	Chionoecetes opilio elongatus	26,291 tons	13,515 tons	(51.40)
Shellfish	*Patinopecten yessoensis*	14,642 tons	8,618 tons	(58.85)
	Mactra sachalinensis	3,980 tons	3,689 tons	(92.68)
	Haliotis discus	6,574 tons	634 tons	(9.64)
Sea urchin		26,873 tons	12,204 tons	(45.41)
Marine algae	*Laminaria* spp.	145,696 tons	129,114 tons	(88.61)
	Undaria pinnatifida	91,885 tons	8,005 tons	(8.71)
	Porphyra spp.	5,522,918,000 sheets	11,575,000 sheets	(0.21)

tant northern forms. The species listed in this article are presently being cultivated in Hokkaido.

The present status of some important invertebrates and seaweeds is as follows:

Scallop ***(Patinopecten yesoenssis)***

Sea scallops are distributed along the whole coast of Hokkaido. However, in recent years, the major areas of production have been limited to the Okhotsk Sea region, especially in the southern half of the northern region and the Nemuro Strait area in the southern region. Scallop production in Hokkaido reached its peak in 1934, when 78,674 tons were harvested. Since then, production has been declining, with accompanying wide annual fluctuations. A low of 3,843 tons was recorded in 1968. However, in 1969, production rose to 8,618 tons. This increase may be due to the gradual development of the artificial cultivation and the use of underwater off-bottom techniques in Lake Saloma and Uchiura Bay, and the stocking of seed scallops along the Okhotsk Sea coast. It is not clear whether the remarkable reduction in production was caused by overfishing or by a decrease in the amount of scallop setting as a result of some adverse oceanographic conditions.

Japanese surf clam ***(Mactra sachaliensis)***

This clam is found along the entire Hokkaido coast. Major areas of production are the Pacific coast region and the Nemuro Strait. In Hokkaido, the annual production of surf clams is nearly 5,000 tons. Commercial-sized clams range in age composition from 4 to 10 yr old, and it is doubtful that the resource would recover if overfished. At present, the clam resource is being carefully managed by regulating the size of the catch, fishing seasons, fishing grounds, and minimum shell size. Transplanting of juvenile clams has been attempted for the purpose of preserving this resource.

Abalone ***(Haliotis discus)***

Abalone are limited to the Japan Sea coast, the Tsugaru Strait, and Uchiura Bay: it has never been found in other areas. This restriction in its geographical range may be attributed mainly to the low seawater temperatures during the winter season. The number of abalone per unit of area is considerable in Hokkaido. Because of cold waters, the growth rate is slower than in the southern part of Japan. Accordingly, Hokkaido has played an important role as a source of seed abalone for southern Japan. Growth rates vary considerably along the Hokkaido coast and successful transplants have been made from poor growing grounds to good growing grounds.

Sea urchin ***(Strongylocentrotus intermedius*** **and** ***S. nudus)***

Hokkaido's species of the sea urchins differ from those of the southern part of Japan. They are of commercial importance in Hokkaido and are found along all coasts. Recently, effective management of sea urchin populations has been carried out and, as a result, the annual catch has shown a rising tendency. In managing the populations, severe regulations have been established on the fishing grounds, designated fishing seasons, and minimum carapace size. Also, young individuals (those with immature ovaries) have been transplanted to productive grounds rich in seaweeds.

Kelp ***(Laminaria*** **spp.)**

Laminaria growing along the coast of Hokkaido are classified into several species, namely *L. japonica, L. religiosa, L. ochotensis, L. diabolica, L. angustata*, and *L. angustata* var. *longissima*. The classification is based on their morphological characters. However, from the taxonomical as well as distributional viewpoints, it is appropriate to divide the above-mentioned *Laminaria* into two major groups—*Laminaria japonica* group (including *L. japonica, L. ochotensis*, and *L. diabolica)* and *Laminaria angustata* group (including *L. angustata* and *L. angustata* var. *longissima)*. The former group is found in Uchiura Bay, the Tsugaru Strait, the Japan Sea, the northern part of Okhotsk Sea region, and along the coast of Shiretoko Peninsula. The latter group grows along the coast of the Pacific Ocean. Since 1955, the annual production of *Laminaria* in Hokkaido has fluctuated between 100,000 and 150,000 tons in fresh weight. The most abundant harvests were recorded, based on a 5-yr cycle, in 1957, 1962, and 1967. Since the 19th century, various attempts have been made to increase *Laminaria* production. These include the planting of stones and rocks and the blasting of rocky reefs. In the recent years, cultivation of *Laminaria*, especially forced cultivation, by a longline type or rope-curtain type, was popularized, as in *Undaria* in southern Hokkaido.

Brown algae *(Undaria pinnatifida)*

The distributional range of *Undaria* in Hokkaido is generally the same as that of abalone. In recent times, the annual production of *Undaria* in Hokkaido has been constant at about 10,000 tons in fresh weight.

Red algae *(Porphyra* spp., mainly *Porphyra yezoensis)*

Hokkaido is still an underdeveloped area for the cultivation of *Porphyra* because there are many obstacles hindering its growth, such as heavy windstorms along the Japan Sea coast, freezing of sea waters, and floating drift ice in the inlets along the eastern part of the Pacific coast and the Okhotsk coast. However, since 1953, the cultivation of *Porphyra* has increased gradually in Uchiura Bay, Akkeshi Bay, and the northern part of the Japan Sea coast. In the former two places, the algae are not damaged by the above obstacles, while in the latter place, they are protected by special breakwater fences.

IMPORTANT PROBLEMS OF THE RESEARCH ACTIVITIES

As in many agencies, organization, staff, budgets, and facilities are problems affecting research activities. However, these are omitted from this discussion for want of space. The problems to be solved in future studies are as follows:

All species being artificially propagated

1) Identification of food organisms and developing best methods for their mass production.

2) Determination of an adaptive environmental condition for each species.

3) Determination of the size and the quality of seed to be stocked and places where stocking will be done.

4) Explanation of an annexing effect to the natural stocks as an important problem in the future.

Scallop

1) Clarification of the major factors causing the decline in populations on both the Japan Sea coast and the northern part of the Okhotsk Sea coast.

2) Establishment of a large-scale, dependable system for the mass production of seed (target is 800 million individuals).

Japanese surf clam

Establishment of a large-scale, dependable system for producing seed both naturally and artificially.

Abalone and sea urchin

Establishment of a technique for artificially planting seaweeds and clarification on the ability of abalone and sea urchin to propagate following planting.

Laminaria

1) Investigation of methods of growing high quality *Laminaria* (2-yr old plants).

2) Improvement of methods for the forced cultivation of *Laminaria* (1-yr old plants).

3) Study how to protect the cultured *Laminaria* from the noxious bryozoan, *Membranipora serrilamella*.

Porphyra

1) Identification of the new local species and the breeding of *Porphyra*.

2) Study the adaptation of each local species to its environmental conditions.

3) Establishment of a suitable culture technique for each local condition.

MARICULTURE OF SEAWEEDS AND ITS PROBLEMS IN JAPAN

SHUNZO SUTO[1]

INTRODUCTION

The change in annual production of seaweeds in Japan is shown by species in Table 1, where the production from cultivation and harvest of wild populations are mentioned separately.

Japanese and people in East Asia consume most of the seaweed harvested for human food, and its use in industrial materials is comparatively less. The situation differs clearly from that in the other areas of the world. Japanese taste for "nori" *(Undaria, Laminaria, Monostroma,* etc.) is quite developed, and the shortage of its supply and resulting rise of its price have encouraged efforts to increase its production from the natural beds and also the development of its cultivation on the surface of the sea.

Of course, the progress of cultivation depends on social economic factors and the techniques to make it profitable. Nori cultivation, it is said, started about 300 yr ago and harvested quantities are increasing every year. The cultivation of *Undaria* (a member of Laminariaceae) has recently grown to an industry and the one for *Laminaria* has just begun. *Monostroma* has been cultivated for 30 yr, and in the past 10 yr, the amount of its harvest has kept a constant level, satisfying the consumers' demands.

The amounts of *Laminaria, Undaria, Gelidium,* etc. harvested from their natural beds have not increased much from year to year. Little increase in *Undaria* production seems to come from overharvesting. Many efforts have been made to increase its production, but so far none has proved to be effective on the whole; though in some local grounds successful attempts have been reported—by setting stones to enlarge seaweed bed substrate, by blowing up shallow beds with dynamite to lower their level, or by removing useless weeds which will otherwise occupy the substrate of the species being cultivated.

Another problem is found in the natural production. Sometimes, a local decay of seaweeds, often lasting more than several years, causes not only the decrease in the algal production, but also the decrease in the abalone catch, which feed on seaweeds, and also affect the catch of coastal fish, owing to the lack of production of juvenile fishes that grow around the seaweed beds. The reasons why the decay of seaweeds occur and why seaweeds cannot recover soon are being studied at the present.

NORI *(PORPHYRA)*

Cultivation of Nori

Historical Reviews

The cultivation of nori started about 300 yr ago around the coast of Tokyo Bay and developed gradually in many localities on the bays facing the Pacific coast of Japan, where this culture can find protection from strong surf and an adequate tidal range necessary for growth.

Nori grounds were limited in those days to the shallow waters around the mouth of rivers, on the basin of which cities and rice farms developed, supplying rich nutrients to nori grounds.

Bundles of twigs of trees such as oaks, cherry, etc. were set in rows on the ground in the fall as the collectors, to which nori spores attach themselves and grow. In the winter, grown nori plants are harvested, made into dried products similar to sheets of paper, and are sold to consumers, mostly city dwellers.

The cultivators were mainly farmers in the coastal regions. Gradually product dealers controlled and exploited the cultivators, whose income was very low, which in turn held back the industry from rapid progress.

[1] Mariculture Division, Tokai Regional Fisheries Research Laboratory, Arasaki, Nagai, Yokosuka, Kanagawa-ken, Japan.

Table 1.—Change in annual amount of seaweed production.
[Wet basis: 1,000 tons.]

Seaweed	Harvested from	1936-40	1941-45	1946-50	1951-55	1956-60	1961-65	1966-70	Consumed in
Nori	Cultivation	27	33	36	18	45	61	169	Food
(Porphyra)	Natural bed						7	7	Food
Wakame	Cultivation						4	66	Food
(Undaria)	Natural bed	37	31		48	51	57	57	Food
Monostroma	Cultivation					12	14	15	Food
Laminaria	Natural bed	305	132	139	148	142	144	167	Food. A part. alginate material
Gelidium	Natural bed	12			17	15	13	18	Agar material
Gracilaria	Natural bed				12	12			Agar material
Iridaea and *Chondrus*	Natural bed				8	8			Mostly plastering
Gloiopeltis	Natural bed	5	4		2	2	2	2	Starch for silk clothes
Ecklonia and *Eisenia*	Natural bed		118						A part. alginate material

The nori harvest increased only gradually, amounting to 1 billion sheets—a sheet is a paperlike product of nori, of about 20 × 20 cm in size and about 3 g in weight—just before World War II.

Advances in the culture techniques were also poor. Old collectors (twigs from trees of oak, cherry, etc.) were replaced by bamboo twigs, promising more harvest than the old ones. Modern net collectors were found more effective to increase the harvest, but they were adopted only in limited localities because of the higher cost than the old collectors.

It should be mentioned here, that the nori cultivation in Korea had a rapid growth 10 years prior to World War II by introducing new techniques which produced about the same amount of nori as in Japan.

After World War II, nori cultivation in Japan made rapid progress. The amount of the harvest doubled in 1945, became four times in 1955, and is now six times that of the prewar level.

Social economic reasons for this abrupt rise are:

1) Increase in the demand by consumers. The food rationing system during and after World War II supplied nori to all of the people in Japan, making many new consumers. The increase of consumers and the halt of the import of nori from Korea brought about a severe shortage of nori and the rise of market price.

2) Innovation of fisheries systems after the War. Nori cultivators organized themselves in cooperative unions, which shut out the capital control of dealers and established a cooperative selling system that raised the rate of net income from about 30% in the prewar times to an income of 60-70%.

Rise of the market price of nori and increase of the net income made the nori cultivation the most profitable fishery. This was followed also by the rapid expansion of the industry throughout Japan, making strong demands on the advances of culture techniques.

3) Expansion of the nori grounds. Increase of population, fertilization of rice fields, and the progress of industry made the coastal waters richer in nutrients, making cultivation possible to spread away from areas adjacent to river mouths where nori often suffers from declining salinity during rainy weather.

Under these circumstances, the following culture techniques were pushed forward at a rapid advance:

1) Techniques to find new grounds suitable for nori culture. Conditions required are a) sufficient exchange of water by currents and waves, b) sufficient supply of nutrients, and c) protection from freshwater inflows and strong surf.

2) Improvement of collectors. Old collectors were replaced by a net made of palm fiber string and then of synthetic fiber string of 2-3 mm in diameter. The strings are netted in a mesh of about 20 cm, and the standard size of a net is 18.2×1.3 m^2. The nets are set stretched horizontally into the sea and are tied to bamboo poles set in two rows on the shallow sea. The net collector has many advantages over the old ones in rearing nori. It is far easier to deal with, surf resistant and more productive. The replacement made possible a wider culture, spreading from the limited waters near the mouth of rivers to deeper waters of rougher wave action, as the waters became more nutritious.

The net collector made possible the cultivator's control on the growth of nori. Elevating the net a little from its standard level slows the growth of nori but controls the growth of weeds, such as *Enteromorpha* and diatoms which may overcome the nori and decrease the harvest. Lowering the net accelerates the nori growth, but the nori often becomes weak by disease; *Enteromorpha* and diatoms grow vigorously on the net, displacing the cultured nori, if the weather in winter is calm and not too cold. Nori cultivators can then control the net level height as well as the nori growth, protecting against diseases and injurious weeds.

3) Seed control. Soon after the findings of K. M. Drew on the "Conchocelis phase" in the life history of *Porphyra*, its whole history was made clear in Japan, being followed by the artificial control of nori spores. In 1955-60, nori producers cultured a necessary amount of Conchocelis for themselves through the summer and produced nori spores to start its culture. The technique removed the shortage of natural spores which had limited the growth of the cultivation especially in the western Japan.

It can be said, that the replacement of old collectors by net doubled the production of pre-World War II time, also doubling the seed control.

It should be mentioned that a change of species in nori occurred with the change of culture techniques. *P. yezoensis* became dominate in place of *P. tenera*, the former seems to adapt more readily to higher salinities and to easier cultivation of spores. The change increased the harvest but produced a low-grade product with decreased odor and hardening when tasted.

General View of Actual Nori Cultivation

At present, nori is cultivated in most bays and inland seas along the Pacific coast of Japan. Nori grounds are about 60,000 hectares in area, producing about 5-6 billion sheets of nori a year worth 70-80 billion yen. Fishermen's cooperative unions obtain prefectural government sanction to set nori grounds and manage them. About 60,000 fishermen set their own collectors, harvest grown nori on them, and produce dried paperlike products. The products are sold through the cooperative unions to the dealers.

Coastal waters of 0-5 m in depth are available for nori grounds of classic net systems, setting the nets by spreading them between two rows of bamboo poles. By the actual development of the new floating net system, cultivators have been able to turn waters 20-m deep into profitable grounds.

Usually a net, in a cultivating set, has a spread of $18.2 \text{ m} \times 1.3 \text{ m}$. Now 5 million sets are prepared for all the grounds. About 10 million nets are used per year, i.e., in a set two nets are spread one after another during a harvesting season, from November to next March or April.

Every fisherman has equipment for harvesting nori plants and also for manufacturing them into paperlike products. Generally the cooperative unions prepare cold storage for preserving nets with young buds in living condition. These unions sometimes have equipment for culturing Conchocelis and also for manufacturing nori products.

Paperlike products are gathered by unions and sold to the dealers, who preserve the products and sell them to consumers. Each Japanese eats an average of 50-60 sheets of nori per year. Nori is rich in vitamins, and two sheets of nori can supply one daily dose of them.

Processing in Actual Nori Cultivation

Seed.—Present cultivation depends completely on the spores from cultured Conchocelis. The culture is done by each fisherman or by his cooperative union. The culture begins at the end of the last season. Many cleaned oyster shells are spread on the bottom of shallow tanks filled with seawater. Cut pieces of mature nori plants are put on the water, so that the carpospores released from the plant will attach themselves to the shells and develop to the Conchocelis phase on them. Shells with Conchocelis are hung down in other tanks 0.5-1.0 m in depth, where they are kept throughout the summer. The water in the tanks is changed if it becomes dirty. Light in the tanks is controlled so that Conchocelis grows well without getting ill. At the end of summer, the Conchocelis matures and produces many spores which develop into nori buds.

In the fall, when the seawater temperature goes down below 24°C, fishermen prepare the cultivation. Twenty to forty nets are set in a layer in the sea. Shells with fertile Conchocelis are put into many vinyl bags, and these are hung just under the nets in order to have the spore find the collector as they come out of the bag. Sometimes the net layer is put into a large polyethylene bag with Conchocelis and left floating on the surface of the sea. This method prevents the cultivator from wasting spores and can also be done in deeper waters. After several days, when the spores have fixed themselves to the nets, these nets are taken out from the bag and are tied to the poles for spore development.

Bringing up of young buds.–A set of 20-40 layered nets is separated into sets of 5-6 layered nets, which are then separated into single nets, as the buds grow. In the process of separation, when the buds are 5-50 mm in length, the necessary amount of nets with buds are taken out of the water, dried and stored in refrigerators set at −20°C. Here the buds are kept alive, preparing for the recovery of crops when the planted nori suffers from a prevailing disease or a heavy storm. Fishermen always control the level of nets as the climate and the tide changes, so that the buds do not suffer from severe drying out in low tide and also from growth of weeds and diatoms.

Rearing of nori plants and their harvest.–About 50 days after budding, nori plants grow to 15-20 cm in length and then are harvested. After the first harvest many buds remain on the nets, promising another harvest in 15-20 days. In this way harvesting can be repeated several times from a net throughout the nori season. But generally the crop decreases in repeating harvests; sometimes the crop may die from the diseases of nori or by some accident. Then, the cultivators replace these nets with the refrigerated ones that can replace the crop in 15-30 days.

Harvesting is done by using machines which make the labor at sea more comfortable and efficient.

Manufacturing paperlike dried products from cropped nori.—Cropped nori plants are cleaned by washing with seawater. Then they are chopped and spread on screens made of fine twigs of bamboo or of fine plastic rods and finally dried in a dryer with an old burner. Drying has to be done quickly at low temperatures, commonly in 2-3 hr with the temperature lower than 50°C. In these conditions nori is kept alive until the end of the drying procedure. This makes the product glossy, tasty, and sweet smelling, and retains all vitamins.

Recent Advances in Culture Techniques

Recent yearly changes of nori production is shown in Figure 1, with changes of numbers of cultivating sets, of nets used, and of nets stored in refrigerators. The overall nori production has increased year by year but show sharp fluctuations. In these days progress in culture techniques has tended towards 1) new methods on how to expand the nori grounds, 2) how to prevent sharp declines in the yearly production, and 3) how to reduce labor in cultivation and to make laborers more comfortable.

Techniques to prevent sharp declines in the yearly production.–Of course, nori growth is affected by certain conditions, especially by the climate in the growing season. But the sharp drops in production were caused by severe outbreaks of diseases which occur successively in important grounds. It was found that the disease occurs in connection with overpopulation of the plants on the grounds—setting of too many nets for greater harvest. This finding led to the development of the techniques to get a far more stable crop by controlling the amount of nets to be set on a ground.

The technique to store live nori buds in cold storage was first applied in 1965, making it possible for crops to recover when the planted nori become severely damaged by disease or by some accident. Nets with young buds are dried until the water content of the nori comes down to about 20-30%, are packed in polyethylene bags, and are stored in refrigerators at about −20°C, in which buds can be kept alive for more than 6 mo and capable of recovering normal growth whenever they are returned to sea. Even wet buds can endure the cold storage for a short period, while many of the weeds and diatoms are killed. Also a parasitic fungus, which often causes disease on nori, loses its ability to reproduce by this treatment.

The number of nets with young buds stored in refrigerators has increased in the past 5 yr, as shown in Figure 1. This brought about new difficulties in bud rearing, because cultivators have to rear the buds with doubled amount of nets. In 1966-70, when too many nets are set during bud rearing, these nets often caused severe damage to the buds, resulting in a sharp decline in harvest. This problem is now solved by reducing the nets to a reasonable and manageable amount on each ground.

Techniques to expand nori grounds.–By using the net collectors, nori culture has developed the

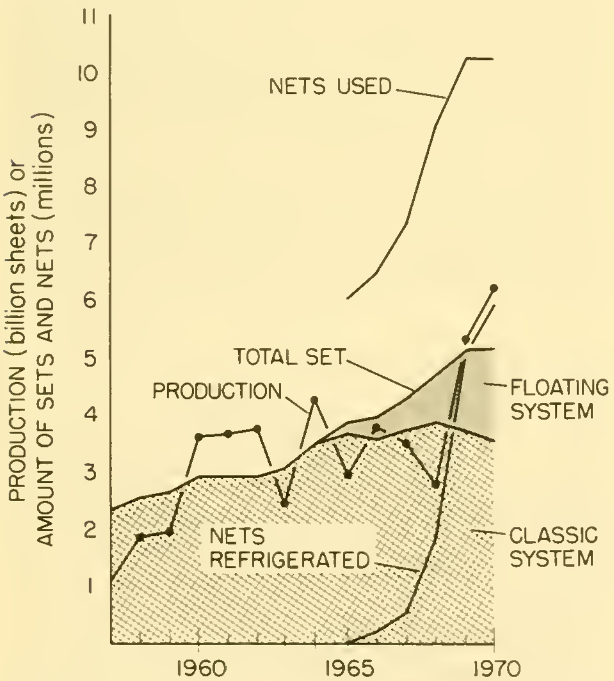

Figure 1.—Change in annual amount of "nori" production and in the amount of cultivating sets and nets used. Generally a net is spread in a set.

grounds in the new areas after the old grounds were destroyed by polluted waters and so on until 1965; after that the development and loss came into balance. However, nori grounds are still showing an overall increase by using a new rearing system, i.e., a floating-net system, which can make profitable grounds out of waters of about 20 m deep and with strong wave action.

Generally a square frame of synthetic rope is set floating on the surface of the sea with the help of buoys and anchors, and 20 nets with small buoys can be set in it. Waters with currents faster than 30 cm/sec or with somewhat strong wave action are convenient for rearing nori by this system. The frame systems can resist the impact of a wave 4 m in height without any damage to nori.

Mechanization of processes in nori cultivation.—Labor shortages and culture enlargement demanded the mechanization of each process of production. It turns culture labor into a comfortable and profitable one, keeping the young labor force from flowing out into land industries. This is an exception to the labor shortage situation for all fisheries. For instance, oyster culture appears more profitable in some localities than nori cultivation, but labor in oyster culture is far more severe and dirty, causing an outflow of young labor from the culture industry. This loss of labor is making the culture fall behind the nori cultivation.

Introducing engineering principles to make or to improve nori grounds.–From about 1965 engineering principles have been introduced in nori cultivation. For example, concrete or iron piles were set to decrease wave action in order to have nori culture possible behind them. On the grounds in shallow waters, water ways were dug to better the exchange of water and to increase the harvest, and now in several old grounds digging works are planned. Here the connection between the biological and engineering techniques have to collaborate closely to make the effort effective for production increment.

Problems in Nori Cultivation

The demand for nori by consumers, which is supposed to increase year by year, was estimated at about 5-6 billion sheets a year in 1970. The import of nori from Korea is now politically limited to 200 million sheets a year, but it may increase to 1 billion sheets in the future. Cultivation in Japan produced 6 billion sheets in 1970, satisfying the amount of consumers' demand, and Japan is capable of increasing its supply with the increase of the consumers' demand, if the following technical problems are solved: 1) How to prevent a bad crop, and 2) how to improve the quality of the products.

There is another problem which has arisen, the spreading of industrial pollution. Coastal waters became polluted and nori products became contaminated with cadmium, mercury, etc. We are afraid we may need hygienic control in the future if pollution increases.

The most important problem in nori culture is found in its administration. Income of the cultivators increased more quickly than that of city laborers, but in recent years this is not so. The increase came from the rise in nori prices and also from the increase in the harvests. In the future the rise in the prices can be expected, but the increase in the harvest will cause oversupply. The mechanization of the culture processes is raising the cost of nori, especially in the case of small-scale operations.

The technique to store live nori buds in cold storage is also used for cropped nori plants. This will inevitably stimulate the development of factories which store cropped nori and make it into products far more efficiently than each fisherman can. Until now, the income of a cultivator was the sum of harvest plus manufacturing, and if the latter is removed, he must recover his loss by production increase.

In the near future nori cultivators will be divided into two groups, the majority going into mass production using the floating system and the minority going into small-scale operations producing nori of special quality.

The number of cultivators has been kept at a level of 60,000 in the past 20 yr, but this level will decrease with the scale-up of each operation. Substitution of cultivators will occur, and cultivators who combine farming will decrease and ones who combine fishery will increase.

Under these changes of circumstances, the technical problems will be:

1) How to prevent cultivation from a bad crop? A bad crop is generally caused by outbreaks of diseases, and techniques to forecast and prevent the outbreak of diseases are expected.

2) How to simplify each culture process? The present processes were developed for small-scale operations. They have to be modified to fit the need of a large-scale operation.

3) How to improve the qualities of the products? Development of an effective fertilizing technique will be expected.

4) Breeding of nori and introducing foreign *Porphyra* will be helpful for items 1-3—nori with more resistance to diseases, nori of higher productivity, perhaps of not maturing under winter's short-day conditions, and nori of higher quality, making the product more glossy, with more odor and better taste. A variety of *P. tenera* is highly productive and resistant to diseases but of lower quality.

5) Techniques for mass manufacturing of crop products.

WAKAME *(UNDARIA)*

Biology

"Wakame" is a seaweed peculiar to Japan and Korea, and 60,000 tons of this raw seaweed are landed annually, 10,000 tons in dry weight. Currently cultivation extends the seaweed industry to the northern areas, now including many districts all over Japan. The output from cultivation was over 60,000 tons in 1970.

The seaweed grows from beginning of winter to spring, then dies out after liberating zoospores. Within 20-40 days several hundred million spores come out from one plant. The spores germinate immediately to a microscopic filamentous alga, which lies dormant during the summer. In the fall, when the water temperature goes below 20°C, egg and spermatium are produced, germinate, and grow into the wakame plant. This seaweed grows to several millimeters long in 1 mo, 10 cm in 2 mo, and 1-2 m long in 3-4 mo. The temperature at the northern limit of distribution is 2°C in the winter and at the southern limit, 14°C.

Cultivation

Historical Reviews

In 1935 Kanda found that the life history of wakame was almost the same as that of *Laminaria*. Its cultivation started in the 1940's along the coast of southern Manchuria, together with that of *Laminaria*, where their natural growth is almost zero.

After World War II, the industry was introduced into China which produced 30,000 tons of raw product a year, most of which is *Laminaria*. Meanwhile in Japan, the cultivation did not develop because of sufficient supply of natural products.

However, with increase in population, shortages in the supply of wild wakame occurred in the 1960's, stimulating the development of its cultivation. A new product, salted wakame, was developed and welcomed by consumers for convenience in cooking, and this product did a great deal for increasing consumption.

Under these circumstances wakame cultivation had an abrupt growth mainly in northern districts of Japan. The annual production was almost zero in 1963 and was over 60,000 tons in 1970, which exceeds the harvest from natural beds.

Processes in Cultivation

At the end of the season, wakame becomes mature and develops zoospores, at the time fishermen start to prepare the "seed strings" for the next season.

For collecting spores, strings of 2-3 mm in diameter made of synthetic fiber are used. The 100-m long strings are reeled over a frame made of vinyl plastic tube of 2-3 cm in diameter. A tank is filled with fresh seawater. Mature sporophylls of wakame are put into the tank after half drying. Enormous numbers of spores are released into waters, when the vinyl frames with strings are set in the tank so as to catch the spores. Several sporophylls are necessary for seeding a 100-m string. After 1-2 hr the frames are taken out and are put into culture tanks of about 1 m deep, where they are kept through the summer under controlled light intensity. It is desirable to keep the water temperature lower than 25°C. Favorable light intensity over them is 500 lux at 25°C and 1,000 lux at 20°C.

Germlings of wakame develop in the fall when the water temperature goes below 20°C. When young buds grow to about 1 mm in length, the frames with strings are put into the sea hanging from a raft, so as to accelerate their growth.

In northern waters, where invasion of fouling seaweeds and animals is less, the seeded strings are often cultured in the sea.

Management and Harvesting

The cultivation starts when the seawater temperature becomes 15°C and fouling organisms become scarce. A synthetic rope of 100 m long and of 8-10 mm in diameter is floated into the sea with the help of buoys and anchors. Often many branch ropes are hung from the rope. Seed strings with young buds of wakame are rolled up to the rope. Sometimes seed strings are attached to the ropes at 10-cm intervals after being cut into pieces of about 10 cm long.

In waters which are too rough or with many floating *Sargassum* plants, the rope is set at a depth of 1 m, where the buds can escape being damaged by wave action or by rubbing off by *Sargassum*.

Wakame grows quickly in winter. The optimum temperature for its growth may be about 10°C. The longer the period of lower than 15°C, the greater the harvest. However, temperatures lower than 5°C may injure the plant and may decrease the crop. Fast current and strong wave action are favorable for growth of the alga, if they do not damage the cultivation set.

Harvest is done by cutting the weed which has grown to about 1 m in length. Most of it is dried under the sun or in a drier. Some of it is sold raw to meet local demands. The yield from 1 m of cultivating rope in a season is about 10 kg in wet weight in the northern areas and about 5 kg in warmer districts.

The amount of labor work in wakame cultivation is far less than that in nori cultivation. The set of the former is more resistant against rough waves than that of the latter. For these conditions the former is more profitable in northern open coast than the latter. However, the amount of consumption is now limiting progress of the industry.

With the spreading of the cultivation, new problems are occurring, i.e., damages caused by bacterial diseases and by the eating of young buds by isopods and gastropods.

Harvest of Wild Wakame

The amount of production changes every year primarily because of the variations in water temperature. The low temperature in the growing season, winter to spring, brings about a good crop except at the north limit.

Elimination of harmful seaweeds in wakame beds is found to be effective in increasing production during the season. The bed is likely to be taken over by other perennial weeds, *Phyllospadix* in the north and *Sargassum* and *Ecklonia* in the south. The best time to control the weeds may be during the germinating season of wakame buds.

We have never produced a favorite culture area by throwing stones into the sea, which is effective in the case of *Laminaria* and *Gelidium*. Limiting the amount of the harvest and transplanting mature plants were found ineffective for producing a better crop the following year.

Wakame is an annual plant and there is an enormous mortality in the microscopic phase in the summer. These conditions may cause the ineffectiveness of the foregoing techniques. However, after germination the plant grows to maturity with a little mortality. If some devices are used to plant young buds in large quantities, the efficiency will be quite reliable. Trials of this method are now underway.

LAMINARIA

Biology

Important species are *Laminaria japonica* and *L. angustata*. *L. japonica* is the best quality though not much is produced. Half of all *Laminaria* harvested is *L. angustata* var. *longissima*.

Laminaria mature in the fall. Some hundred million zoospores, each having two cilia, come out from a frond. A germling is a microscopic filiment. When the water temperature goes to 10°C or below in winter, the germling gives rise to spermatia and eggs. A fertilized egg germinates and grows into a *Laminaria* plant. The filaments do not fruit at water temperature over 10°C and for this reason *Laminaria* grows only in northern Japan.

Young plants are seen in early spring, then grow rapidly, but start to decay from the top of the frond in the autumn. In the second year, a growth at the top of the stipe develops and becomes a second year's blade. The growth in the spring is good at 5°-15°C, but never takes place at over 20°C in the summer. The second year's blades are the main parts of the plant harvested because the first year's blades are of unsuitable quality for consumption in Japan.

Harvesting

The harvesting season is from July to August. A drying process after harvesting is important to get an excellent product. Hokkaido is subjected to foggy days frequently; therefore, the drying by a drier is useful for increasing production and for improving quality.

Culture Techniques

Shinran-shonin, an old famous Buddhist priest, is said to have been the first to propagate *Laminaria* in 1718. At present a large amount of the national expenditure is invested in Hokkaido.

Throwing stones into the sea for propagation improvement has been practiced for many years with good results. The yield rate in the area where stones are thrown is roughly the same as the one in natural growing districts. The area in which this technique is used should not be one in which the bottom is altered by the movement of sands. Use of a short cylinder of concrete which was thrown into the sea was practiced on a large-scale basis at Nemuro, Hokkaido. The expense is supposed to be recovered in 7-8 yr.

The reefs which are too high to drain the even surface are dynamited so that *Laminaria* plants are able to grow. To eliminate harmful weeds such as *Phyllospadix* from the bed bottom explosives are also useful. An explosive equivalent to 150-300 g of dynamite has an effective area of about 4 m^2.

Cultivation

China is said to produce 30,000 tons of *Laminaria* annually due to the recent progress in cultivation to produce a dietary balance.

In Japan the emphasis has been on increasing the production of *Laminaria* plants which grow naturally in the sea, because it supplied sufficient amounts for the demand of consumers. With increase of consumption and rise of market price, cultivation has been attempted.

There are some obstacles preventing a breakthrough in *Laminaria* cultivation, especially the fact that the plant takes 2 yr to grow into a desirable market product for Japanese consumers, i.e., 2 yr plants. Research is now going on to reduce this period.

GELIDIUM (AND OTHER AGAR WEEDS)

Introduction

The production of raw seaweeds for agar-agar in recent years has been 6,500 tons dry weight and 5,500 tons are imported. The latter, sold at a cheap price though not of good quality, replaced the ones raised in Japan. Agar output was 5,500 pounds in 1963. Korea which exported raw materials in prewar days is now producing more agar-agar every year and soon is going to exceed Japan's production.

Biology

Raw seaweeds for producing agar belong to the families of Gelidiaceae and Gracilariaceae. Of these, *Gelidium amansii* is the most important species. It grows between low tide level and 20- to 30-m depth. They are found in areas which are influenced by warm currents. More than 60% of the total production comes from Izu Peninsula and Izu Islands, where the rock of the andesite, clear water, and warm current are located and where the transparency of the water is high which enables *G. amansii* to grow. In the Izu Islands, plants do not appear in large amounts in the region directly washed by the warm current, but grow in good amounts in the waters with an upwelling of bottom water. They also do not grow in muddy water, or on rocks covered with fouling organisms, but grow well on rocks on sandy bottom.

G. amansii reach 10 cm high in 1 yr and 20 cm in 2 yr. The span of the lifetime of a plant seems to be 2 yr, but a holdfast remains several years and produces new plants. The crop largely depends upon the plants that developed from these holdfasts.

The plants are able to grow in densities up to 1 kg/m^2 at Izu Peninsula, the most favorable bed. At harvesting, plants up to 0.2 kg/m^2 are usually left to grow because these plants grow back to 1 kg/m^2 within 2 mo after harvesting. Harvesting is done three times in a season, the yield per square meter is well over 2 kg.

Sometimes in vast areas most algae except *Sargassum* disappear and calcareous algae take over. The cause of this phenomenon, "Isoyake" in Japanese, is still obscure. All trials, such as adding stones and transferring plants, to bring about recovery of the vegetation have been unsuccessful.

Harvest

Harvest is done under the control of a Fishermen's Cooperative Association that manages the ground. A rest period is required during the harvesting season to save labor and increase yield in the fruitful years. Plants remaining at the end of the fishing season do not thrive the next year. Therefore, the plants should be cropped as many times as possible.

Culture Techniques

Gelidium is a perennial with a slow rate of growth. The most reliable technique for propagation is to produce more places in favorable areas by throwing stones into the sea. The elimination of harmful weeds, such as *Ecklonia* and *Eisenia* that grow in *Gelidium* beds, is effective for 1 or 2 yr.

Cultivation is not an efficient way for increasing production because the spores take 2 yr to grow and reach harvesting size. Branches of plants attached to a rope, which is hung into the sea, grow well. However, the costs of plants for seed are high, and the cost of the large labor force, which is needed for setting seed plants on the rope, leaves little for profit.

In order to expand the growing area, stones should be placed on the sandy bottom in and around the growing areas. Stones weighing 20-100 kg are used since they are not moved by wave action and do not embed into the sand. Soon after calcareous algae such as *Lithothamnion* appear on the stones and spores of *Gelidium* grow on them.

It does not make much difference if the stones are set at the best time so far as production is concerned, but does make a big difference whether it is a suitable place or not. Production on new substrate provided along the Izu Peninsula is almost the same as that of natural populations, i.e., 1-2 kg/m^2. The expenditures for setting stones is recovered in 4 yr. In regions where production is less than 0.3-0.4 kg/m^2, it is not recommended that stones be added because the costs cannot be recovered.

Introduction of a gradually dissolving lump of fertilizer into the bed is said to be effective in restoring both color and growth during the summer. It has not been clear whether it is profitable or not.

CONCLUSION AND PROBLEMS

There are two different ways to increase seaweed production: 1) to increase harvest from its natural ground and 2) to cultivate in or near the surface being completely independent from its rocky natural ground.

Problems in Propagation Protection

Many attempts to increase natural crops by increasing the size of the seaweed bed by setting stones or concrete blocks on sandy bottoms around the seaweed ground have proved to be quite effective. Annual growth on these stones was the same as the ones grown nearby on natural substrate.

Expenditures for setting stones is recovered within 4-5 yr with *Gelidium* and in 5-8 yr with *Laminaria* on the most favorable grounds. Regions of low production cannot be recommended for setting stones in the sea. For *Iridaea* and *Chondrus*, the period of cost recovery would be 20 yr; therefore, this attempt for habitat improvement is not a profitable one.

In *Porphyra*, a concrete cover on rugged rocks increased their harvest. This investment is recovered in 3-4 yr on profitable beds.

However, even in a good ground, a project of setting stones or a concrete cover could not be an object of investment from a private enterprise. In Japan, the privilege to harvest seaweeds is reserved for Fishermen's Cooperative Association, who in return is responsible to manage and protect this resource by means of propagating seaweeds and enlarging their substrate. This association has worked on substrate enlargement by stone setting with government aid of 100 million yen per year, an amount too small to improve their total production.

Other attempts to improve the production from natural beds are found to be not so effective. Elimination of injurious weeds may sometimes improve production in 1 to 2 yr. Also, trials to recover from decreased production in "Isoyake" waters by stone setting proved to be ineffective.

On the seaweed grounds, the fauna and flora have interrelations with each other depending on environmental conditions. Due to the difficulties in changing the environment with a limited budget, the way to increase production or recover from production declines is to change the succession mechanisms of flora and fauna.

For instance, in waters where seaweed population has decreased by some accident, starved abalones, top shells, and other gastropods may eat up and consume the young seaweed buds, decreasing the flora recovery. Therefore, to protect these buds, it is necessary to put a large amount of transplanted seaweeds sufficient enough to feed gastropods and other grazers, preventing the ingestion of buds needed for the vegetation to recover.

Problems in Seaweed Cultivation

In cultivation, seaweeds grow on a net, a rope, or a raft set or floating at or near the surface of the sea. This means the cultivation is done free from the bottom conditions, on which natural growth of seaweeds largely depends. The cultivation can be done anywhere on any species, if techniques and water conditions make it profitable. The problems are:

1) Whether demand of consumers and techniques make the cultivation of a seaweed to be profitable or not.

2) How many water areas can be made into profitable grounds.

When these terms are met, the amount of production can increase enormously, as it has in the cultivation of *Porphyra*, *Monostroma*, and *Undaria*, and that of *Laminaria* will follow them in the near future. This is in contrast to the difficulties in increasing production from natural beds, being limited by bottom conditions.

However, the cultivation of *Gelidium*, *Gracilaria*, *Iridaea*, and *Chondrus* has yet not developed, because it is not profitable. This stems from the fact that these crops are too small or that their cultivation requires too much labor. Here an epochal improvement in techniques is expected in making their cultivation practical.

In the already industrialized cultivation of *Porphyra* and so on, the problems are:

1) How to save labor in its cultivation and make it more comfortable. Mechanization of the work is being done. However, it will result in a reorganization of the management, from fishermen's private ones to their cooperative operation.

2) How to change water areas of rough waves into profitable grounds; that is to say, how to improve the culture apparatus to make it more resistant to waves and how to reduce wave action by some engineering techniques.

3) How to protect cultivated plants from diseases, which cause large fluctuations in yearly production.

4) How to improve the quality of products, especially in *Porphyra*, to meet better the consumers' demands. An effective fertilizing technique is expected to develop.

5) Breeding is expected to be useful to answer some of these problems. Looking for more favorable species abroad will be of consequence in the breeding.

SOME TECHNICAL PROBLEMS IN FRESHWATER FISH CULTURE IN JAPAN

HIROSHI KAWATSU[1]

INTRODUCTION

During the past 10 yr, considerable attention has been paid to fish culture in various countries, especially in the United States and Japan. In our country, freshwater fish culture has a long history, but the recent remarkable improvement of culture techniques has brought on a great change in production methods.

PRESENT STATUS OF FRESHWATER FISH PRODUCTION

Four major species of freshwater fishes are cultured in Japan: 1(rainbow trout, *Salmo gairdneri*, 2) common carp, *Cyprinus carpio*, 3) eel, *Anguilla japonica*, and ayu, *Plecoglossus altivelis*. From 1959 to 1969, production of cultured fish for food increased from 15,000 to 52,000 tons, for a percent increase of 236. This can be compared to an increase of only 26% for wild fish from inland waters in this same period (Table 1).

Government statistics on fish culture in Japan classify the culture methods into four categories, namely, 1) standing-water pond, 2) running-water pond, 3) irrigation pond, and 4) net culture in lakes. Running-water ponds give the highest production per unit area for all species; net culture is second. Harvest from irrigation ponds is slightly higher than from standing-water ponds, because the larger water area of the former is more favorable to the growth of fish.

In 1968, the number of ponds utilized in various types of fish culture was 35,239 in number and 8,500 hectares in area. A total of 7,518 of these ponds were used to produce food fish. The number of fish farms classified by water area are listed in Table 2. Almost all the rainbow trout and ayu are cultured in running-water ponds, and eel in standing-water ponds. In the case of carp, both standing- and running-water ponds are used. Number and area of ponds per fish farm are shown in Table 3. These

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Table 1.—Annual catch and crop in inland waters, 1959-69.

Year	Natural waters	Cultured fish for food			
		Total	Carp	Eel	Trout
	tons				
1959	43,658	15,481	4,562	5,663	2,643
1960	43,916	15,940	4,629	6,136	2,670
1961	47,188	18,990	5,142	8,105	3,023
1962	49,194	20,230	6,344	7,572	3,507
1963	48,349	23,371	6,592	9,918	3,936
1964	50,781	29,780	7,557	13,418	5,412
1965	53,423	33,096	7,971	16,017	5,745
1966	49,294	36,375	9,827	17,015	6,231
1967	50,683	41,852	10,886	19,605	7,882
1968	52,110	51,932	14,460	23,640	9,454
1969	54,918	52,044	13,971	23,276	10,254

Source: Bureau of Statistics (1969).

Table 2.—Number of management units by size of water area in freshwater fish culture, 1968.

Water area (m^2)	Carp				Eel				Rainbow trout			Ayu	
	Standing water	Running water	Irrigation pond	Net culture	Standing water	Running water	Irrigation pond	Net culture	Running water	Irrigation water	Net culture	Running water	Net culture
< 100	157	648	59	16	18	1	1	—	281	5	—	20	1
100 - 200	121	241	48	8	21	—	3	—	156	4	—	30	1
200 - 300	106	117	38	3	26	2	1	—	102	2	—	32	—
300 - 500	124	157	75	8	36	—	4	—	128	2	—	68	—
- 1,000	198	170	115	6	60	—	4	—	183	2	—	98	—
- 3,000	204	125	227	1	183	1	4	—	214	—	1	88	—
- 5,000	71	31	108	3	337	1	1	—	39	—	—	15	—
- 10,000	37	12	194	1	449	—	1	—	21	—	—	5	—
- 30,000	22	7	251	—	390	—	3	1	12	—	—	—	—
- 50,000	5	1	76	—	79	—	—	—	1	—	—	—	—
- 100,000	7	1	62	—	43	—	—	—	1	—	—	—	—
> 100,000	3	2	52	—	12	—	—	—	—	—	—	—	—
Total	1,055	1,512	1,305	46	1,654	5	22	1	1,138	17	1	356	2

Source: Bureau of Statistics (1969).

Table 3.—Number and area of pond per fish farm, and average area of pond in each of the types.

Fish species	Number of fish farm	Number of pond per fish farm	Total water area per fish farm	Average area of pond			
				Standing water pond	Runing water pond	Irrigation pond	Net culture
			m^2	m^2	m^2	m^2	m^2
Carp	3,918	2.8	8,957	718	280	12,939	143
Eel	1,682	4.3	12,247	3,061	91	7,410	367
Rainbow trout	1,156	8.3	1,100	328	127	589	200
Ayu	358	7.2	1,777	461	461	15,062	28

Source: Bureau of Statistics (1969).

tables indicate that the fish farms in Japan are run on a small scale.

As shown in Table 4, private farms predominate in fish culture in Japan. Most of them produce vegetables and crops as well as fish. The proportion of farms engaging in monoculture is only 3% in carp culture, 28% in eel culture, 10% in ayu culture, and 6% in rainbow trout culture. The increase of monocultural fish farms will be desirable in the future. On the other hand, the reduced demand for rice may increase the culture of fish as a sideline in the rice producing area.

Table 4.—Classification of fish farms.

Fish species	Total number of farms	Private	Company	Others
Carp	3,918	3,431	76	411
Eel	1,682	1,371	217	94
Rainbow trout	1,156	918	75	163
Ayu	358	249	30	79

Source: Bureau of Statistics (1969).

As shown in Figure 1, carp culture farms are distributed from Hokkaido to Kyushu regions. Most eel farms are centered in four prefectures: Shizuoka, Aichi, Mie, and Tokushima. They account for 78.6% of all eel culture farms. Ayu culture farms are distributed in the southern part along the Pacific

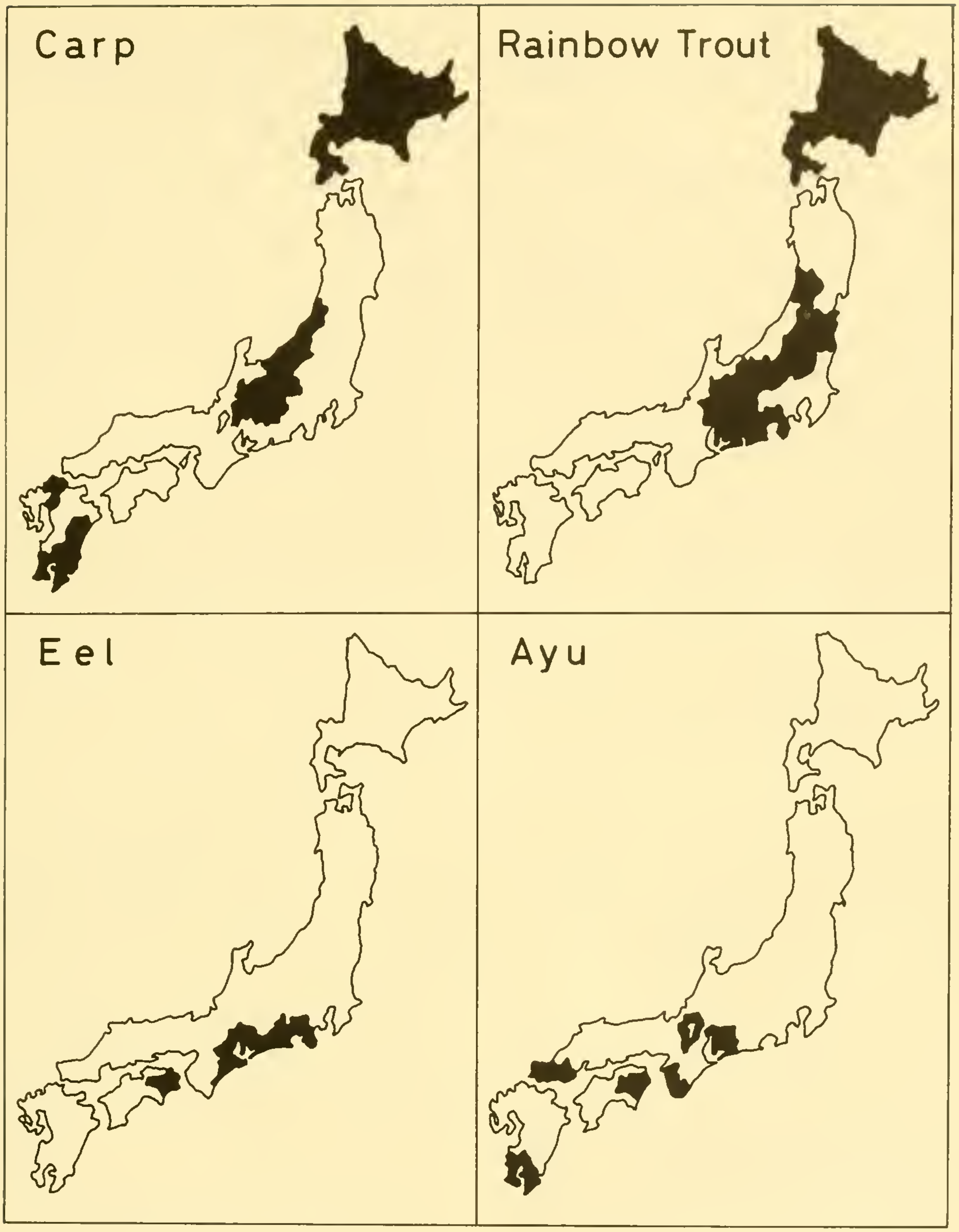

Figure 1.—Distribution of fish farms.

coast. Rainbow trout farms are distributed in all parts of the country. However, fish farms which produce fish for export are centered in Shizuoka and Nagano Prefectures.

SOME TECHNICAL PROBLEMS IN FRESHWATER FISH PRODUCTION

Many technical problems have arisen in freshwater fish production. While many of the same problems occur with all species, their relative order of importance differs by species as follows:

Carp: 1. Improvement of breed.
Eel: 1. Stabilization of elver supply.
 2. Prevention of epidemic diseases.
Rainbow trout:
 1. Prevention of epidemic diseases.
 2. Improvement of breed.
Ayu: 1. Mass production of fry.
 2. Prevention of epidemic diseases.
Other fish species:
 1. Culture of native trout fingerlings for stocking in natural waters.
 2. Transplantation of foreign species suitable to the tastes of Japanese.

Carp

No urgent problems are found in carp culture at present, but in the future, improvement of the breed will be desirable. The selective breeding of strains considered to have desirable characteristics has been started by several institutions.

Eel

In eel culture, elvers are collected along the Pacific coast from December to April. Eel culturists are often troubled with scarcity of young eels because of fluctuations in abundance from year to year. The demand for elvers has rapidly increased in recent years proportionally with the increase of culture ponds. Three counterplans have been adopted to solve the problem: 1) improvement of survival rate of elvers, 2) importation of elvers from foreign countries, and 3) establishment of spawning techniques.

Heating apparatus to increase winter temperatures in ponds is proving to be effective for improving the survival of eels. This apparatus includes two main systems, heating and a circulating filter system. In the latter, the water is filtered and recirculated back to the culture ponds. In the process of circulation, the water is heated to a constant temperature. Although this apparatus entails high costs, survival rates often reach 95%.

Recently, elvers of other eel species have been imported from various countries such as France, Philippines, and New Zealand. In 1969, 25.2 tons of elvers were stocked in Shizuoka Prefecture, of which 9 tons were imported from various countries. Foreign species have different habitat needs than native species; therefore, satisfactory results are not always obtained. Culture methods suitable for them are being developed.

Establishment of spawning techniques is an extremely difficult problem because the physiology and spawning behavior of adults and the life history of hatchery fry are not well understood. Several public institutions are wrestling with this problem, under the guidance of T. Hibiya, Professor of Faculty of Agriculture, University of Tokyo.

The prevention of epidemic disease is another important problem in eel culture. It is difficult to keep accurate records of mortalities in eel culture, because turbidity of the pond water inhibits finding or seeing dead fish. Attempts at estimating losses in Shizuoka Prefecture have revealed a seasonal pattern. That is, the mortality begins to increase in March and reaches its peak in April or May. Figure 2 shows these seasonal changes of mortality in Shizuoka Prefecture in 1968. In that year, most of the loss in the spring was due to fungus disease, while in summer bacterial gill disease caused the most mortalities.

In 1970, eel production suffered heavy losses. During the first half of the year, crop mortality totaled 2,600 tons in Shizuoka Prefecture (Table 5). This was due to a new epidemic disease, branchionephritis, named by S. Egusa, Professor of Faculty of Agriculture, University of Tokyo. Fortu-

Table 5.—Loss of eel in Shizuoka Prefecture.

Year	Amount of loss
	tons
1964	492
1965	200
1966	522
1967	199
1968	449
1969	205
1970	2,639

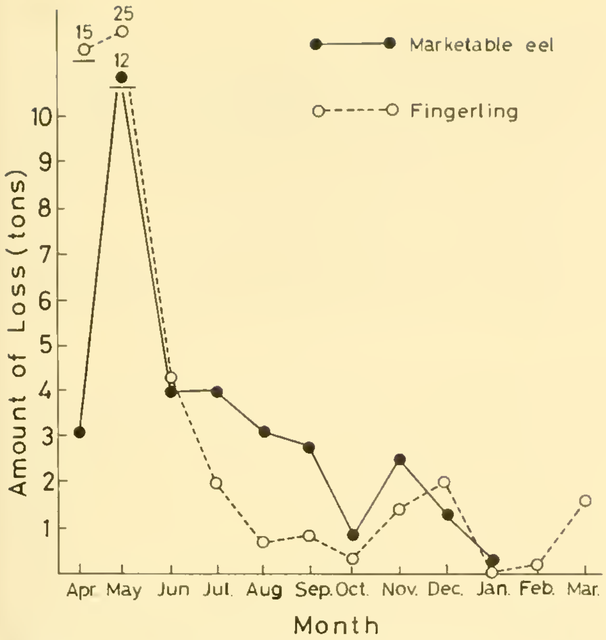

Figure 2.—Seasonal change of loss in eel culture ponds in Shizuoka Prefecture, in 1968.

nately, this epidemic did not return last winter (1971).

Rainbow trout

Prevention of epidemic disease is also the most important problem in trout production. Infectious pancreatic necrosis (IPN), *Vibrio* infection, bacterial gill disease, and *Hexamita* infection are the principal diseases in Japan. Among them, IPN is most harmful. Fortunately, viral hemorrhagic septicemia (VHS) and whirling disease, *Myxosoma cerebralis*, have not yet been discovered in Japan. However, preventive systems against these two epidemics have been in effect since 1967. These preventive systems display the power in epidemiological surveys in other epidemic diseases. For example, they estimated the critical temperature as 12°C for outbreak of IPN.

Recently, the net culture of rainbow trout in shallow seawater has begun in the northern part of Japan. All attempts resulted in failure in southern Japan, because the water temperature is too high for rainbow trout to survive in seawater. The upper limit for survival in seawater is estimated to be 22°-23°C (72°-73°F). Water temperatures above 23°C lead to bacterial infections. An analogous phenomenon is observed in ayu reared in seawater.

Ayu

Ayu is familiar to the taste of Japanese and is also the most important game fish in inland waters. Most fingerlings for culture are caught in Lake Biwa and along the seashore. Fingerlings from Lake Biwa are of good quality; however, the supply is limited by the natural standing crop. The catch from the seashore is also limited for the same reason. Attempts at artificial production of ayu fry have been started in several prefectures. At present, two systems of fry production are used, one type uses salt water and the other fresh water. At present, saltwater culture gives better results. In both types of culture, *Rotifera* are used as the starting feed. *Brachionus plicatilis* is used for seawater culture and *B. calyciflorus* for freshwater culture.

Vibrio and *Glugea* infections are the principal diseases of ayu culture. *Vibrio* infections annually occur in Shiga and Tokushima Prefectures. This disease also is observed in wild populations in Shiga Prefecture. Disinfection of fingerlings is widely practiced in many culture farms.

PRODUCTION OF NATIVE TROUT FINGERLINGS FOR STOCKING IN NATURAL WATERS

With the development of game fishing, it has been requested to propagate the populations of cold-water game fishes in natural streams. Rainbow trout are not suitable for this purpose, because these fish do not remain in the stocking area. The native trouts on the other hand appear to be very suitable for this purpose. Prompted by this information, many prefectural trout hatcheries have carried out the experimental production of native trout fingerlings. Large-scale production will be realized in various parts of the country.

TRANSPLANTATION OF FOREIGN SPECIES SUITABLE TO THE JAPANESE TASTES

Concurrent with the reduction of rice production, part of the fields will be changed to fish ponds. As this occurs, demand for a variety of cultured fish will increase. In anticipation of this situation, various foreign species have been experimentally introduced into our country. Examples are bluegill sunfish, whitefish, German carp, and channel catfish. Channel catfish attracts much attention because of the ease of production; its taste is also suitable to the Japanese people.

REFERENCES

BROWN, E. E.

1969. The freshwater cultured fish industry of Japan. Univ. Georgia, Coll. Agric. Exp. Stn. Res. Rep. 41, p. 57.

EGUSA, S.

1970. Branchionephritis prevailed among eel populations in farm ponds in the winter of 1969-1970. Fish Pathol. 5(1):51-66.

BUREAU OF STATISTICS, OFFICE OF THE PRIME MINISTER, JAPAN.

1969. Fisheries. [In Japanese and English.] *In* Bureau of Statistics, Japan statistical yearbook, p. 145-166.

1971. Inland fisheries. [In Japanese and English.] *In* Bureau of Statistics, Japan statistical yearbook, p. 160.

SHIZUOKA PREFECTURAL FISHERIES EXPERIMENT STATION, HAMANAKO BRANCH.

1969. Hamana. Shizuoka Prefectural Fisheries Experiment Station, Hamanako Branch, No. 98.

1970. Studies on the disease of eel culture. Shizuoka Prefectural Fisheries Experiment Station, Hamanako Branch, No. 152, p. 26.

THE PRESENT STATUS OF SHELLFISH CULTURE IN JAPAN

HISASHI KAN-NO[1] and TOMOO HAYASHI[2]

INTRODUCTION

In 1969, shellfish production (including pearl oysters) in Japan was 561,132 tons worth 58,444 million yen (Table 1). Types of shellfish products landed during the past decade have changed because of certain effects on the environment and changes in commercial demands. Shellfish, like *Meretrix*, which live along the coastal area, have decreased remarkably in production because of the loss of their habitat from industrialization. In 1969, the oyster industry in the Seto Inland Sea area was seriously affected because the oysters were heavily fouled by the calcareous tube worm, *Hydroides norvegica*. For the past several years, production in the pearl industry has declined because of reduced demand for pearls. On the other hand, landings of scallops, abalone, and top shell, so-called high grade products, have been increasing yearly both in tonnage and value because of the demand by the consumer for fresh marine products. Production through aquaculture has remained commercially stable in Japan.

In the past, shellfish aquaculture in Japan was limited, strictly speaking, to oysters and pearls. Recently, both scallops and abalone are being grown using aquaculture techniques. In general, aquaculture requires three important techniques: 1) to catch the juveniles in desirable places with collectors, 2) to produce seed for culture using hatchery (artificial) techniques, and 3) to cultivate the seed to market size in the field. Aquaculture techniques are being utilized to grow oysters, pearls, and scallops, and it is expected that abalone will also be produced in the near future through aquaculture.

In my presentation at the first UJNR (United States-Japan Natural Resources) Aquaculture Panel meeting, I would like to explain briefly about the present status of shellfish aquaculture in Japan and its prospects for the future.

Table 1.—Shellfish production in Japan, 1969.

Shellfish	Landings in tons	Value in million of yen
Abalone *(Haliotis discus hanai, H. discus, H. gigantica, H. sieboldi)*	6,463	5,692
Top shell *(Turbo cornetus)*	8,459	1,715
Hard clam *(Meretrix meretrix, M. lusoria)*	7,081	966
Short-necked clam *(Venerupis semidecussata)*	116,572	3,025
Common scallop *(Patinopecten yessoensis)*	14,644	1,833
Surf clam *(Spisula sachalinensis)*	4,050	948
Ark shell *(Anadara subcrenata)*	38,289	1,918
Other molluscs	114,281	9,920
Oyster *(Crassostrea gigas)*	245,458	8,149
Pearl	97	22,600
Pearl mother shell *(Pictada fucata)*	5,738	1,678
Total	561,132	58,444

OYSTER CULTURE

Production of oysters *(Crassostrea gigas)* has rapidly increased since the 1950's because of the development of hanging culture. Strings of oysters are hung from racks, rafts, or longlines, depending on water depth. Hanging culture makes good use of the water column and is not limited by depth or nature of bottom. In 1969, production was 245,458 tons (including shell) valued at 8,149 million yen (Table 1).

The first operation in oyster culture is to catch the juveniles (seed). Strings of shells are suspended during the summer spawning season from racks placed in coastal areas such as bays and inlets. After setting, the seed is hardened, a process of draping the strings over racks so that they are out of water for a

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considerable period of time during each tidal cycle. Hardening results in an increased percentage of survival, better growth rates, and less fouling. In northern Japan, almost all commercial oyster seed production takes place in Miyagi Prefecture. At present, oyster seed production supplies not only domestic uses, but also supplies some 30,000 to 50,000 cases of seed per year to the Pacific coast of the United States and to parts of Europe, principally France.

Two methods of hanging oyster culture are usually practiced in southern Japan. In the first method, seed oysters are transplanted to the rafts about 1 mo after setting to grow; no hardening is done. These oysters are harvested at the end of 1 yr. This method is characterized by a short growing period and low labor costs. In the second method, seed oysters are hardened until autumn or early winter. They are then transferred to the rafts to grow and are not harvested until the following year (known as 2-yr culture).

The best oyster producing area in Japan is in the Seto Inland Sea where calm conditions exist. Here there are wide areas which enable the growers to use large size rafts, 20 m long by 10 m wide. The Tohoku region of northern Japan is also favorable for oyster culture and longlines are used in some of the rough water areas. It takes 2 yr for the oysters to grow to market size.

Oyster production is expected to remain stable over the next few years. New species of oysters such as the European flat oyster, *Ostrea edulis*, and the Portuguese oyster, *Crassostrea angulata*, may enter commercial production in the future if the problem of pollution along the coastal areas can be overcome.

SCALLOP CULTURE

The aquaculture of scallops, *Patinopecten yessoensis*, has recently been developed in Japan. The production of scallops on natural grounds has remained poor during the past decade with annual landings fluctuating between 5,000 and 15,000 tons. Since the development of the hanging method for catching seed and culturing scallops, production has increased rapidly during the past few years and will continue to do so. Because considerable quantities of seed are being caught in Aomori and Hokkaido areas of northern Japan, the scallop fishery is currently expanding. The seed is not only being cultured in nets to market size but also released on the bottom where good returns are being obtained 2 to 3 yr later. In 1969, 14,644 tons worth 1,833 million yen were harvested from natural grounds and approximately 5,000 tons were produced from hanging culture.

Seed scallops are caught in the spring. Several kinds of cultch materials are used: vinyl fibre (used gill net), vinyl film, branches of trees, etc. These are suspended from rafts or longlines. Three months after setting, the young scallops are transferred to nets where they grow to 3-4 cm by autumn. The culture of scallops can then go one of two ways: Either the seed can continue to grow in nets for 1½ yr to market size or they can be released on the natural grounds. As high as an 80% return has been obtained from released seed on the coastal area of Hokkaido.

In the near future, a large-scale bottom farming of scallops can be expected along the coast of Okhotsk Sea, Hokkaido. This project will be made possible because large amounts of scallop seed are available. The site once produced 60,000 tons of scallops annually. To make the program successful, systematic engineering and newly developed harvesting machines such as suction dredges and underwater bulldozers will be utilized.

ABALONE CULTURE

Considerable interest has developed in the culturing of abalone (*Haliotis discus hanai* in cold waters and *H. discus* in warmer waters). These are very important commercial species along the rocky sea bottom both in quantity and quality. Production has remained relatively stable over the past years as a result of good management practices such as the transplanting of natural sets to areas of poor setting. In 1969, abalone landings totaled 6,463 tons valued at 5,692 million yen (Table 1).

Two approaches are planned in the aquaculture of abalone—mass production of seeds in hatcheries and the artificial production of food in the field by seaweed afforestation. Artificial seed production was developed in the 1960's. Seed production is expected to expand as studies are completed on the conditioning of abalone for spawning and as commercial hatcheries are developed. Good returns can be expected from released seeds, 2-3 cm in shell length, when they are harvested 3-4 yr later.

There is a lack of knowledge about the food conditions in the abalone's natural habitat. For this reason, research was initiated in afforestation in the field. Afforestation could produce about 40 tons of food that could feed up to 4 tons of abalone. The seeds for this program will come from hatcheries.

PEARL INDUSTRY

The pearl industry first began in 1906. The industry has developed rapidly after World War II and reached its peak of production in 1967 when 130 tons of pearls were produced by 4,701 culturist (called management units). The increase was related to techniques in artificially collecting seeds and rearing the mother shells (*Pinctada* sp.). The mother shell industry has grown rapidly since 1952. In 1965, 11,000 tons of mother shells were harvested from 69,000 rafts operated by 7,859 management units.

A rapid increase in the number of management units occurred from the postwar era to 1964. These were mostly small-scale units using less than 30 rafts. In recent years, the number of units has not been increasing and many units are using more rafts, indicating an enlargement of the individual industry units.

The everlasting aim of the industry is to improve the quality of the cultured pearl. In the 1920's, pearls were small but, after developing successful techniques of transplanting mantle pieces in the gonad, bigger pearls were produced. Between 1952 and 1969, the production of small pearls (less than 6 mm) decreased from 67% of the total production to 24%; those in the medium size range (6.0-7.6 mm) and large pearls (7.6 mm) increased in total production from 24 to 58% and from 9 to 18%, respectively.

As the industry developed, culture grounds spread rapidly over the middle and southeastern parts of Japan. These areas were used mainly for the production of mother shells. In 1956, 82% of all pearls produced in Japan came from the middle Pacific region; 73% of these came from rafts. Recently, however, production in this area has declined because of overcrowding and deterioration of culture grounds. In 1964, 20% of the total pearl production came from the Seto Inland region but, recently, production dropped to 10%. On the other hand, production in the southern Pacific and East China regions has been on the increase, and over half of the total Japanese pearl landings now comes from these two areas.

Until 1963, yields from pearl rafts were stable but, thereafter, production per raft has gone down. Reasons for this decline have been related to crowded conditions and to the use of unsuitable culture grounds. In the Seto Inland region, the deterioration of the waters caused by man-made pollution has caused a drop in yields from certain culture grounds. Special provincial laws have been undertaken to regulate production, recover the balance of supply and demand, and effectively utilize suitable culture grounds. The success of these regulations will insure the steady foundation of the industry and the production of better quality pearls.

FISH FARMING AND THE CONSTRAINTS IN JAPAN

MASARU FUJIYA[1]

INTRODUCTION

Geographically and historically, utilization of marine products. which has been quite significant to the Japanese people and fisheries, is one of the most important industries of the Nation.

Before the World War II, Japan expanded her fishing area and Japanese fishermen worked all over the world to obtain their foods. The catch was mainly consumed as the protein source for nutrition of the people, and the expansion of production was most important. This situation continued until about a decade ago.

During recent years the situation has changed remarkably. The Japanese people have demanded greater variety of fishery products of high quality with improvement of their living standard. However, high-quality species occur along the coast of our homeland, and these stocks had decreased because of overfishing and/or water pollution. Under these circumstances, fish farming has become necessary.

ESSENCE AND SIGNIFICANCE OF FISH FARMING

In 1962, the Seto Inland Sea Farming Fisheries Association was established, and by 1966 five operation centers were completed and began operation. At present, the tasks of fish farming are expanding as scheduled, but some problems remain. Through cooperative research, biologists and fish farming specialists are searching for solutions to these problems in order to advance the operations. Fish farming is somewhat different from ordinary aquaculture. The differences are explained briefly and some constraints are discussed in this paper.

When the Seto fish farming operation was started, it was planned to release the larvae following the procedures used with salmon and trout. At that time the Inland Sea was regarded as a fish culture pond, and early stages of larvae were released directly from the operation centers without any care because no effective technique had been developed for rearing marine fish through their larval stages in captivity.

Subsequently, it became apparent that more effective utilization of artificially produced larvae was required, and some new techniques were developed for larval culture and for acclimation to natural waters. Also, procedures were developed for maintaining a brood stock in captivity for earlier production of seedlings and production of more healthy seedlings. As a new idea, some civil engineering techniques were proposed to rehabilitate growing and releasing grounds.

Thus, the present farming fisheries are really equivalent to agriculture in water areas. Artificially produced seedlings are held or planted in shallow coastal regions, and these seedlings utilize natural productivity of these waters for their growth. Recapture or harvest occurs within a certain period (Fig. 1) when the products are ready for market.

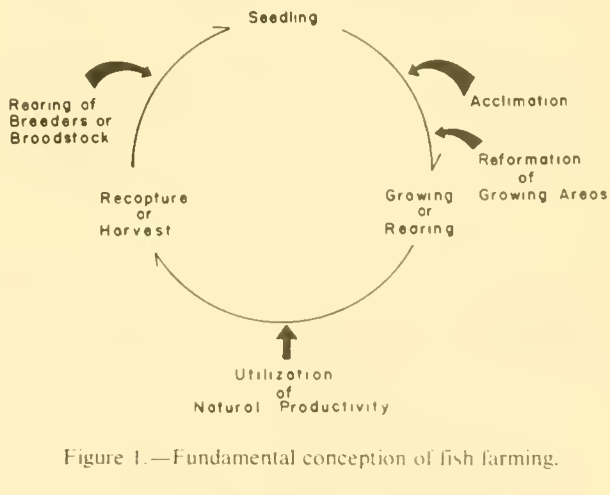

Figure 1.—Fundamental conception of fish farming.

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In this process, the utilization of natural productivity is an indispensable condition for farming fisheries which is different from ordinary aquaculture in which the growth of species, such as trout and eels, depends almost entirely upon introduced foods.

The following items are considered in selecting suitable organisms for farming:

1) They should adapt easily to farming operation.
2) Their growth rate should be high.
3) They should have a reasonably high market value as a product.
4) The seedlings can be supplied easily from a hatchery or from natural reproduction.
5) The feeding habits of larvae and/or young should be clearly known ecologically and physiologically.
6) Foods for the organisms should be readily available and cheap.
7) They should be resistant to diseases, or disease-control methods should be available.

The satisfaction of these requirements is especially significant for a successful operation. However, if demand for a species is great and the market value is high, greater efforts to develop farming techniques for the species will be justified, even though that species would be difficult to farm. The most important consideration in planning of fish farming may not be the technical problems, but the development of an economical system. Composite planning will be required from both technical and economical points of view.

As a special case, geographical transplantation of organisms is ideal for some species. Rapid growth and greater production can be expected when northern species are transplanted to southern regions. Some places isolated from a source of organisms sometimes have few native species, but have food and space capacity for additional species. So, when the investigation for farming is carried out, the idea of introducing a new species should be considered.

TWO TYPES OF FISH FARMING

Present and/or proposed farming fisheries could be classified into two types: 1) stock recruitment and 2) artificial control, as shown in Figure 2.

Stock Recruitment Type

In stock recruitment type of farming, the seedlings are transferred from the operation centers or hatcheries to a temporarily constructed acclimation facility. This procedure allows the seedlings to adapt to the environmental conditions of the receiving waters and to naturalize their behavior while protected from predators. After certain periods, they are released into natural waters for growth. In this case, the planting sites are determined from the results of scientific investigation of the environments and distribution and behavior of natural stocks.

For example, when a shrimp release program is planned, investigations are carried out in advance to determine the suitability of various places for shrimp growth and the best place is selected for the planting. Places where natural shrimps thrive are likely to be satisfactory release sites.

When environmental conditions in an area are acceptable for the planned species and when results of scientific investigations show that the adaptation and the naturalization are unnecessary, seedlings are released directly into the waters. Otherwise, acclimation techniques are applied. In the case of shrimp, the seedlings are acclimated in net enclosures for 1-3 wk depending upon the situation.

The stock recruitment type of farming is practiced at present with prawn, blue crab, and several species of fin fish.

Artificial Control Type

The artificial control type of farming is usually smaller in scale than the stock recruitment type, and frequently some facilities or mechanical equipment

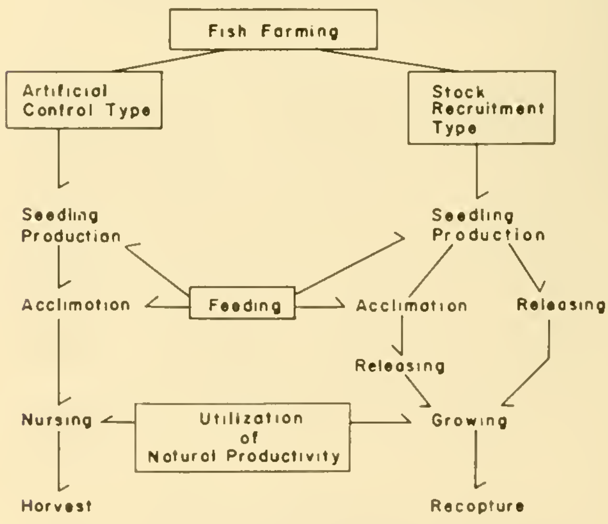

Figure 2.—Brief diagram of fish farming in Japan.

are involved. The farming of oyster, abalone, clam, algae in Japan, and of milkfish in South Asian countries are of this type.

A new experiment in the culture of red sea bream is based on conditioning the fish to respond to sounds. The seedlings, 20-50 mm in total length, are kept in floating cages and trained with sound and feeding of pellets. Within 2-8 wk, they are adapted to sound of certain frequency (100-600 Hz) and develop the habit of gathering around a feeding place every time the sound discharges. After they obtain this habit, the fish are liberated into natural waters, and most of them retain the habit and do not scatter. Although a small amount of pellets is necessary to feed them, they can eat more natural foods for their growth. Therefore, this idea could be categorized as a fish farming.

SEEDLING PRODUCTION

The first step and one of the key points of fish farming process is the seedling production. At the incipient period, zygotes, larvae, and young fish collected from natural waters are mainly used as seedlings, but artificial seedling production techniques have been developed for important species and these techniques are applied for the actual farming operations. The process is briefly shown in Figure 3.

Matured adults from wild stocks are still used to obtain eggs and sperm in most cases, but research to develop techniques for obtaining eggs from adults reared to maturity in captivity are in progress.

In order to obtain zygotes, stripping and artificial spawning methods are sometimes used, but most species can be induced to spawn naturally in artificially controlled tanks. Matured adults are put in a tank of water, and the zygotes are collected after spawning and fertilization occur. Then, the eggs are transferred into a rearing facility such as a tank or aquarium. For some species, matured adults are put directly into the larval rearing tank and removed after spawning.

The zygotes are reared in tanks of still water, but slow running water can be used for larvae after they reach certain sizes. With some species, the larvae are transferred to floating cages until they reach seedling size, but with shrimp, the larvae are kept in the same tank till they reach seedling size. In this case, control of population density to achieve the desired numbers of final stage is important. The size of seedlings varies depending on the purpose and environmental conditions of receiving waters.

The planned numbers of seedlings to be produced in five centers in 1971 fiscal year are shown in Table 1. The prefectural centers are also producing some seedlings, but their main purpose is the development of culture methods.

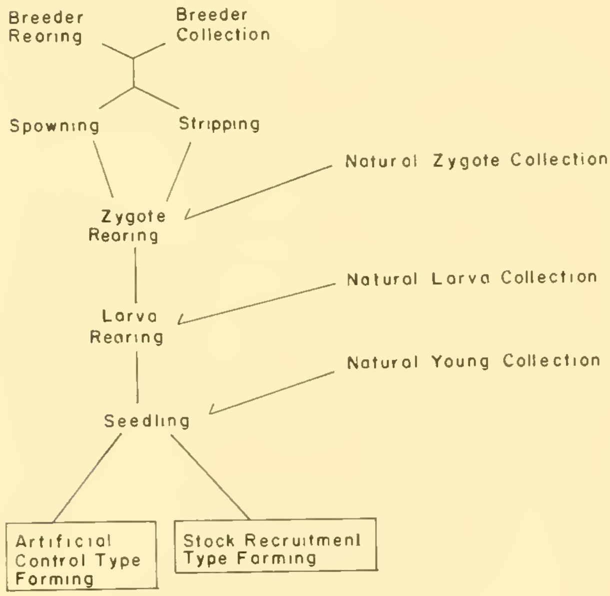

Figure 3.—Seedling production process.

Table 1.—Planned production of seedlings in five centers of Farming Fisheries Association in 1971.

Organisms		Season	Number of production	Size
Prawn	*Penaeus japonicus*	May-Aug.	140×10^6	0.01-0.02 g
Blue crab	*Portunus trituberculatus*	June-Aug.	30×10^6	Megalopa
Red seabream	*Pagrus major*	May-July	500×10^3	0.01-0.1 g
Flounder	*Paralichthys olivaceus*	Jan.-Mar.	600×10^3	0.1 g
Rockfish	*Sebasticus marmoratus* *Sebastes inermis*	Dec.-Mar.	1.5×10^6	0.07 g

CONSTRAINTS AND PROBLEMS

Although fish farming is in progress in Japan, some problems and constraints remain.

Technical constraints include problems concerning seedling production, nutrition of larvae, disease and parasite control, and feeding. Among these, seedling production techniques are being developed rapidly, and experience with the successful culture of several species should be applicable in the future to other species. Among other problems, however, fundamental research for the advancement of techniques for nutrition of larvae and control of disease and parasites are the most important. Aquatic organisms go through several larval stages with selective food habits, and the most suitable food has to be found for each stage. At present, phytoplankton and zooplankton cultured and/or collected from natural waters are fed to the larvae, but the supply frequently becomes the limiting factor for seedling production. Thus, the development of a stable supply of foods for larval stages is necessary for the advancement of seedling production. The development of artificial foods is especially needed.

As the history of aquaculture has shown us, disease and parasite control is also significant. In fish farming, disease control for larval stage will have to be developed. Usually, larvae are weaker than adults, and contagious diseases are most serious. It is not unusual to have several millions of larvae killed during a short-time period in actual farming.

In aquaculture, practical methods for treatment of diseases and parasites have been developed. For instance, chemotherapy has assisted the treatment and prevention of fish diseases. These kinds of advanced techniques should be applicable to fish farming, but some fundamental problems such as resistant strains and human public health considerations remain.

As an effective method for preventing disease mortality, it may be possible to breed resistant strains but little research has been done for this purpose.

The most significant constraint concerning the utilization of seedlings is the hypothesis that artificially reared seedlings are equal to those from natural reproduction. As mentioned before, the release of seedlings is based on the results of preliminary investigations on the environmental conditions of planting area and the behavior of natural organisms. In most cases, the suitability is estimated from the presence of natural larvae indicating a fundamental hypothesis that artificially produced seedlings are equivalent to natural larvae. However, the results of farming trials along the coast of the Inland Sea and surrounding districts have been variable. Successful results have not always been obtained in spite of the determination, based on preliminary investigations, that these places were suitable for farming. These circumstances raise doubts concerning the validity of this hypothesis.

The larvae reared under the artificial conditions are pampered. They are kept in optimal environmental conditions as far as possible, with adequate food supply, and protected from competitors and predators.

On the other hand, larvae in natural waters must survive the fluctuation of environmental conditions, effects of competitors and predators, and, in addition, they must find food for themselves. Thus, they are hardened in nature. Therefore, it is likely that there are some differences in the biological characteristics of natural larvae and artificially produced seedlings as diagrammed in Figure 4.

In order to obtain more successful results of farming, evaluation of suitability of the receiving waters should include consideration of biological characteristics of seedlings.

There have been suggestions that comparative research should be carried out to define the difference in biological characteristics between natural and artificially produced larvae. However, this is sometimes impractical because of the difficulty in collecting samples of natural larvae. In some species, the natural larvae have not been observed and, with the present state of knowledge, could not be identified even if some larvae could be found. The best method is to experimentally establish expected environmental conditions and to observe the effect of these conditions on biological characteristics, such as, resistance to the fluctuation of environments, physiological activity, avoidance reaction from predators, and ability of shrimp and crab to bury themselves in the bottom sediments.

Techniques for acclimating artificially produced seedlings should be varied with the species and the results desired. At present, almost standardized facilities and methods are used for acclimation of seedlings without adequate consideration of objectives. These include net enclosures and net cages for shrimp and crab and floating cages for fish, in which seedlings are kept with feed for several weeks. Although this procedure is helpful for adaptation to natural water conditions, it does not train the seed-

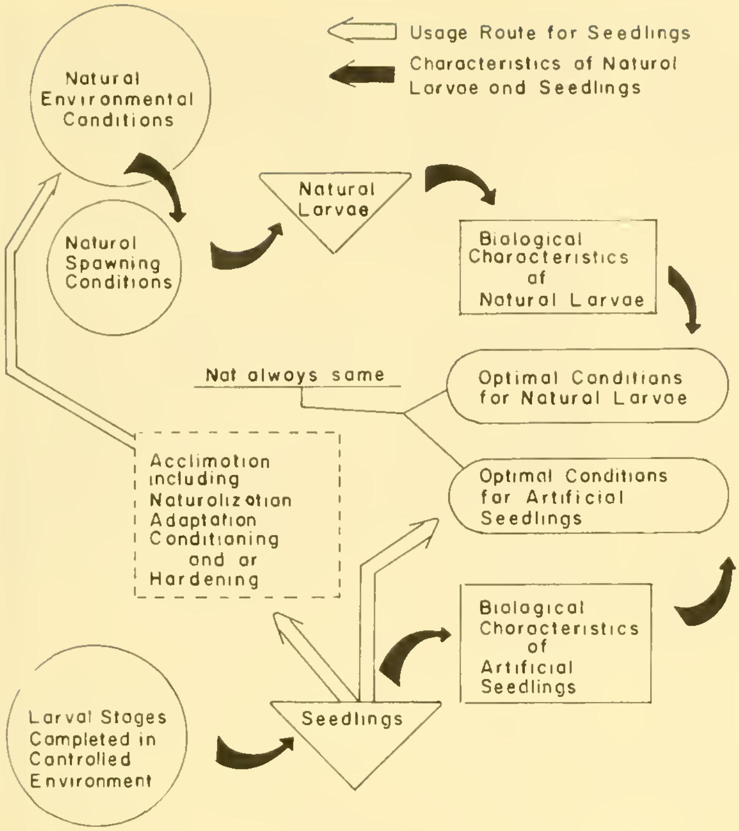

Figure 4.—Some differences in the biological characteristics between natural larvae and seedlings and artificial seedlings.

lings to find natural foods or to avoid predators. Conditioning and training, based on biological requirements to achieve the intended purpose, should be tried in the acclimation facility; otherwise, successful acclimation cannot be expected.

The greatest problem connected with the future of fish farming is the pollution of natural waters. Although water pollution is a matter of concern among the people and plans for pollution control are being developed, the adverse effect on fish farming is not fully recognized.

Some aspects of this biological problem have been investigated to find ways to reduce the effects of pollutants on fisheries, and water quality criteria and water quality standards have been described for some aquatic organisms. However, most of the research data are on adult organisms.

In fish farming, the situation is more severe. For example, the period of larval development is the weakest stage of the life history of organisms, and even seedlings have lower resistance to pollution than adults. Brood stocks require a high quality of water to maintain healthy adults which will produce active larvae.

As the mass production of seedlings is possible, a limited number of hatcheries can supply the demand for seedlings. Places chosen for hatching facilities should have the best environmental conditions in unpolluted regions. Farming, especially of the stock recruitment type, requires extensive areas of unpolluted water for the production of large amounts of fish or shellfish. Complete water pollution control will be needed to keep released organisms safe. For this purpose, the cooperative research will have to be carried out by fishery biologists and specialists on pollution control. Without this cooperation the advancement and expansion of fish farming will be hopeless.

CONCLUSION

The history of aquaculture in Japan is quite long. Mariculture of oysters and algae was started sometime before the beginning of science. Procedures were established by fishermen, and the techniques have been developed and reformed year by year based on their experiences.

Since the beginning of fisheries science about a century ago, the scientists have verified the suitability of techniques developed by fishermen, though some technical contributions have been offered. Therefore, it cannot be said that scientists have developed the fundamental concepts for the advancement of aquaculture.

Considering the period in which it was developed, the idea of fish farming should be esteemed highly as an epochal accomplishment. At the present time, however, ancient and new ideas of aquaculture in Japan are mixed together. These ideas should be reorganized systematically to establish efficient operation plans and research projects.

Among the old aquaculture techniques, there are some helpful ideas and methods for the development of new farming fisheries. For example, an artificial fish shelter of concrete blocks is an effective method to build a new fishing ground. A larger scale shelter would form an "artificial bank." If the technology of artificial shelter or bank and fish farming could be combined, greater fish production may be expected. Therefore, the combination of differently categorized ideas or techniques will accelerate the advancement of practical fish farming.

Fish farming is becoming of global interest and Japan is considered as the most advanced country in this field. People concerned with fish farming and aquaculture expect to obtain the information from Japan, and sometimes they are apt to apply the Japanese methods and techniques directly. Biological techniques are so complicated, however, that direct application in other environments may be unsuccessful and some modifications will be required. Certainly fish farming should be encouraged on a universal basis, but many problems remain to be solved. Greater advancement can be expected with the international cooperation of experts in this specialized field.

LARVAL CULTURE OF PENAEID SHRIMP AT THE GALVESTON BIOLOGICAL LABORATORY[1]

CORNELIUS R. MOCK[2]

PRELIMINARY EXPERIMENTATION

The first larval culture experiments at the National Marine Fisheries Service Galveston Laboratory were conducted to aid the identification and description of the larval stages of penaeids found in the Gulf of Mexico. By 1966 the three commercially important penaeid shrimp (white shrimp, *Penaeus setiferus;* brown shrimp, *P. aztecus;* and pink shrimp, *P. duorarum*) had been reared to the postlarval stage. The basic techniques used to culture larval shrimp were similar to those described by Hudinaga (1942) and Hudinaga and Miyamura (1962).

During this period the following organisms were tested individually as foods for the larval shrimp: *Skeletonema costatum*, *Eucampi* sp., *Gymnodinium splendens*, *Tetraselmis* sp., *Thalassiosira* sp., a euglenoid protozoan, and *Artemia* sp. As a result of this work, two suitable food organisms were selected for use in subsequent experiments. These were *Skeletonema costatum*, because it could be cultured easily, and *Artemia* sp., because it was readily available (Cook and Murphy, 1966; Cook, 1967).

Following the initial phase of this work, research was directed toward developing methods of rearing penaeid larvae en masse in order to supply shrimp grown under known conditions for physiological studies and for experimental pond culture. A variety of specialized equipment was designed and tested in an attempt to perfect larval culture techniques.

PROGRESS BETWEEN 1966-1969

From 1966 to 1969, considerable effort was directed toward growing mass cultures of algal foods in natural seawater. Although samples of seawater were tested prior to each experiment with several types of fertilizers to determine which combinations of nutrients should be used with that batch of seawater for best algal growth, satisfactory growth did not always occur. It soon became apparent that a more reliable medium than seawater was needed. A number of media made with synthetic sea salts and tap water were tested. "Instant Ocean"[3] was chosen from those tested for use at the Galveston Laboratory along with a complement of nutrients, trace elements, and vitamins (Mock and Murphy, 1971). With this medium dense unialgal cultures can be grown and maintained. For example, 300 liters of *Skeletonema costatum* can be cultured from an 8-liter starter culture to a density of 4-5 $\times$ 10^6 cells per milliliter in 4 days.

Additional algal foods fed experimentally included *Cyclotella nana*, *Isochrysis galbana*, and *Cerataulina* sp.

Based on observations made during this experimentation the following conclusions were made: 1) the responses of *Penaeus aztecus* larvae to different light intensities were inconsistent; 2) a temperature range of 28°-30°C (82°-86°F) and a salinity range of 27-35‰ were most satisfactory for penaeid larval culture; 3) addition of several algal foods gave better survival than additions of only a single species when comparable concentrations were used; 4) the omission of antibiotics from the larval culture media was possible when the chelator EDTA (ethylenediaminetetraacetic acid) was substituted at concentrations of 0.01 g per liter of seawater; and 5) postlarvae could be shipped successfully either by motor vehicle or air when placed in plastic bags filled with oxygen and seawater (Cook, 1965, 1966, 1968, 1969).

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[3] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

RECENT EXPERIMENTATION

Beginning in 1969, the major objective of the research at Galveston was to develop methods whereby larval shrimp could be cultured more efficiently and economically. It was realized that the economic success of shrimp culture was largely dependent upon the costs of producing larval shrimp in quantity. Two key problems contributing to the costs were: 1) costs of food production and 2) costs of labor. Research was initiated that was designed to reduce the investment required for the construction of a shrimp hatchery, to increase the efficiency of algal and larval culture procedures, and to reduce the amount of labor required in the hatchery.

The approach used has been to grow unialgal cultures separately from the larval shrimp and to add only that number of algal cells needed to maintain the shrimp population. However, when algal densities were low, large volumes of the culture had to be transferred to the shrimp rearing tanks. This resulted in changes in the temperature of the larval culture media which frequently caused mortalities. In addition, the medium in which the diatoms were grown was slightly toxic to the larval shrimp. For these reasons, it was decided to separate the cells from their culture medium.

Separation with a centrifuge has been successful with several types such as a table model, a continuous centrifuge, or a large cream separator. When a continuous centrifuge or cream separator is used, the algal concentrate accumulates within the centrifuge and is removed by disassembling the machine. If the speed of the centrifuge is adjusted so that the cells are not damaged, the resulting concentrate is a satisfactory food. The cells are then suspended in a known volume of water and a series of counts made to determine cell density. The concentrate is then measured into a number of suitable containers in volumes predetermined to provide appropriate feeding levels in the larval rearing tanks.

Experimentation with methods of preserving algal concentrates was initiated in an effort to increase the reliability of the larval culture procedure.

In the past it had been necessary to begin algal cultures several days before the gravid female shrimp were captured to insure adequate volumes of the culture for feeding. Often cultures were ready, but gravid shrimp could not be captured, or if gravid shrimp were captured, the algal cultures failed.

Refrigeration has been used successfully to hold the concentrates for periods of 96 hr. For storage under refrigeration the concentrate is placed in a plastic container and diluted to a volume of 6 to 8 liters, then held at 5°C and aerated gently.

Freezing in a deep freeze at −19° to −22°C has also been a suitable method of holding algae. Frozen algal concentrates have been held 7 mo without apparent damage to the cells. Research has also been done on algal foods which are freeze-dried alone or in the presence of protectants. Brown (1972) reported that freeze-dried diatoms are suitable foods for larval shrimp, although they are inferior to live diatoms.

The final modification in procedures made possible by the concentration of algae is the use of a continuous feeding device consisting of a small peristaltic pump. Either freeze-dried, frozen, or fresh concentrated algae is suspended and diluted slightly so that it can be pumped into a larval culture at rates as slow as a few milliliters per hour. Larval densities of 100-500 per liter have been maintained in tanks up to 1,800-liter capacity using this technique (Mock and Murphy, 1971).

The entire procedure of centrifuging, freezing, and feeding automatically has been performed with cultures of *Skeletonema*, *Tetraselmis*, *Thalassiosira*, and *Cyclotella*. Single species and mixed species of algal concentrations have been tested. In every case the algae used were reared in unialgal cultures. Each step in this procedure contributes to a more efficient hatchery operation, and the freezing and automatic feeding reduce the labor requirements of the operation significantly.

TYPICAL EXPERIMENTAL RESULTS

For purposes of demonstrating the value of research conducted in small tanks, the results of two experiments conducted in 1971 are presented below. The results of these experiments were not particularly outstanding, but they can be used to illustrate the type of information which can be obtained using this procedure.

Experiment I

Data are presented for a single tank from Experiment I conducted March 31, 1971 (Table 1). This was the first use of frozen algae as food during the protozoeal stages at the Galveston Laboratory. The spawn from two brown shrimp were placed in a 1,520-liter fiber glass tank (1.8 m in diameter, 0.9 m high, with a flat bottom) in a greenhouse. Twelve

Table 1.—Experiment I. Use of frozen *Skeletonema costatum* (S), *Cyclotella nana* (C), and freshly hatched and frozen *Artemia* by larval and postlarval brown shrimp, *Penaeus aztecus.*

1971			Larval stage	Larval count	Algae		*Artemia*	
Month	Day	Hour			Residual	Feed	Residual	Feed
					No. cells/ml	*No. cells fed/ml*	*No./ml*	
March	31	2145	Spawn					
April	1	0900	Egg nauplii					
		1120	Hatching					
April	2	0830	Nauplii III-IV	304,000				
		1500	Nauplii IV-V					
		2400	Nauplii V			124,600 S		
April	3	0900	Protozoea I		27,000 S			
					210,000 C			
					[1] 10,000 N			
		1000				152,100 S		
						272,300 C		
		1500		307,290	48,000 S			
					19,000 C	187,000 S		
						876,000 C		
April	4	0900	Protozoea I	304,000	145,000 S			
					220,000 C			
					10,000 N			
						200,000 S		
						500,000 C		
		1700		297,061	231,000 S			
					845,000 C			
					5,000 N			
April	5	0800	Protozoea II		30,000 S			
					217,500 C			
					15,000 N			
						250,000 S		
		2000			62,500 S			
					195,000 C			
					12,000 N			
						250,000 S		
						500,000 C		
April	6	0800	Protozoea II	301,244	92,500 S			
					275,000 C			
					30,000 N			
		1130				217,100 S		
		1630			22,500 S			
					232,500 C			
					32,500 N			
						147,100 S		
		2100	Protozoea III		37,500 S			
					197,500 C			
					47,500 N			
						349,000 S		
						353,250 C		
April	7	0800	Protozoea III		70,000 S			
					277,500 C			
					15,000 N			
						194,000 S		
		1415	Protozoea III	304,000		194,000 S		
		1545	Protozoea III		65,000 S			
					322,000 C			
					10,000 N			

Table 1.—Continued.

1971			Larval stage	Larval count	Algae		*Artemia*	
Month	Day	Hour			Residual	Feed	Residual	Feed
					No. cells/ml	*No. cells fed/ml*	*No./ml*	
April 7—continued								
						300,000 S		
		2045	Mysis I		187,500 S			
					445,000 C	312,000 S	3.0	
April	8	0800		289,000	45,000 S			
					507,500 C			
		1130				231,000 S		
		1600					0.2	4.0
		2115					3.5	
								5.0
April	9	0800					3.4	
		1700					1.4	
								5.0
April	10	1100					3.8	
								5.0
		1900					3.4	
								[2] 8.0
April	11	0900					5.2	
		1700						[2]20.0
April	12	0800	Postlarvae I	131,000			18.6	
							N 14.9	

[1] N = *Nitzschia* sp.
[2] Frozen *Artemia* (*Artemia* did not hatch).

airstones along the side and one in the middle of the tank aerated the water.

The food used initially was the diatom *Skeletonema costatum;* however, live *Nitzschia* sp. and *Cyclotella nana* were also present. Because this experiment was conducted in a greenhouse, the additional species, which were introduced inadvertently, grew in the tank. Since *C. nana* had also been frozen and was present in the tank, it was added to the experiment. Frozen cultures of *Nitzschia* sp. were not available, so it was decided to only monitor its presence.

Examination of Table 1 will reveal that at times the uneaten cells remaining in the tank were at a higher level than that fed. These discrepancies are due to counting error.

Aliquot counts of the population on 8 April showed that 95% of the larvae had advanced to mysis I stage. Unfortunately, because two successive days—10 and 11 April—of poor hatches of *Artemia* occurred, frozen *Artemia* were used as food. The frozen *Artemia* sank to the bottom, deteriorated rapidly, and caused apparent decline in water quality. Before fresh seawater could be exchanged and before freshly hatched *Artemia* could be added, a number of the larval shrimp perished. Only 42% of the population survived to the postlarval stage.

A second rearing experiment was performed in May 1971 using two 1,893-liter (500-gal) fiber glass tanks with conical bottoms. Average length of the shrimp that spawned was 191 mm, and the average number of eggs spawned was 231,000 per shrimp (range 71,000-380,000) with an individual hatching success of about 12.8% (range of 0.5-35.7). The spawn from each shrimp was divided into equal parts and each part was poured into one of the rearing tanks.

Experiment II

In Experiment II, Tank I (Table 2), two species of concentrated frozen algae, *Skeletonema costatum* and *Tetraselmis* sp., were used, the latter being introduced during the advanced protozoeal II stage.

Table 2.—Experiment II, Tank I. Use of frozen *Skeletonema costatum* (S), *Tetraselmis* sp. (T), and *Artemia* by larval and postlarval brown shrimp, *Penaeus aztecus*.

1971			Larval stage	Larval count	Algae		*Artemia*	
Month	Day	Hour			Residual	Feed	Residual	Feed
					No. cells/ml	*No. cells fed/ml*	*No./ml*	
May	20		Spawn					
May	21	0730	Egg nauplii					
		1300	Nauplii I					
May	22	0700	Nauplii III	84,000				
		1800	Nauplii IV					
		2000	Nauplii V			250,000 S		
May	23	0800	Protozoea I	84,000	230,000 S			
		2000	Protozoea I		144,000 S	346,000 S		
May	24	0800	Protozoea I	82,300	132,000 S	350,000 S		
		1615	Protozoea I		250,000 S			
		2130	Protozoea I		170,000 S	270,000 S		
May	25	0800	Protozoea II	77,800	110,000 S			
		1000	Protozoea II			210,000 S		
		1545	Protozoea II		147,500 S			
		1630	Protozoea II			297,500 S		
		2130	Protozoea II		149,800 S			
		2300				449,800 S		
May	26	0800	Protozoea II	70,800	137,000 S			
		0930	Protozoea II			15,000 T		
		1530	Protozoea II		132,000 S			
					6,250 T	14,050 T		
		2200	Protozoea III		100,000 S	250,000 T		
					13,750 T	21,550 T		
May	27	0730	Protozoea III		217,500 S			
					23,700 T			
		1630	Protozoea III		225,000 S			
		1700	Protozoea III		7,500 T	27,500 T		
		2130	Protozoea III		36,250 S	136,250 S		
May	28	0800	Protozoea III		57,500 S			
					25,500 T			
		0900				35,000 T		
		1330	Protozoea III	60,000	67,500 S			
		1630			16,250 T	36,250 T		
		2130	Mysis I		66,250 S			
					16,875 T			
		2245	Mysis I			47,875 T		3.0
May	29	0800	Mysis I		48,750 S		0.9	
		1045	Mysis I		13,750 T			
						148,750 S		
						63,750 T		3.0
		2215	Mysis I		21,250 S		2.9	
					17,500 T			
		2320	Mysis I		321,250 S			6.0
						87,500 T		
May	30	0800	Mysis II		57,500 S		6.0	
					55,000 T			
		1115	Mysis II			157,500 S		
		1130				85,000 T		
								9.0
		2000	Mysis II		37,500 S		7.3	
					30,000 T	137,500 S		
		2200	Mysis II			90,000 T		

Table 2.—Continued.

1971			Larval stage	Larval count	Algae		*Artemia*	
Month	Day	Hour			Residual	Feed	Residual	Feed
					No. cells/ml	*No. cells fed/ml*	*No./ml*	
May	31	0800	Mysis III		35,000 S 33,750 T		5.0	
		1030	Mysis III					8.0
		1045	Mysis III			135,000 S 89,750 T		
		2000	Mysis III		27,500 S 38,750 T		6.8	
		2100	Mysis III			127,500 S 86,750 T		8.8
June	1	0800	Postlarvae I	40,000	37,500 S 21,250 T		8.0	

Of the 84,000 nauplii which hatched, 71% reached the mysis stage. Once again, owing to a buildup of algal food on the bottom, water fouling caused high mortalities. From mysis I to mysis II, those *Artemia* fed to the shrimp were eaten; however, from mysis II to postlarvae I, the *Artemia* begin to graze quite heavily on phytoplankton and some grew so rapidly that the larval shrimp could not eat them. It was then necessary to build the *Artemia* level higher in order to have enough available to feed the young shrimp.

Not only was fouling on the bottom a problem, but from the mysis stage on, the shrimp tended to accumulate at the bottom of the tank where the fouling was occurring, thus increasing the stress upon the population. Only 48% of the initial population reached the postlarval stage.

The second of the two tanks was used to test a small peristaltic pump set up for feeding continuously the algal concentrate into the larval culture tank (Table 3). Unfortunately, enough *Skeletonema* had not been concentrated and frozen for this tank, so concentrated frozen *Skeletonema* was used in the continuous feeder and concentrated fresh *Skeletonema* was used for the initial feeding and for supplemental feedings needed to raise the standing cell level. At times the automatic feeder was pumping too fast, so it was shut off or the food concentration was reduced.

On 28 May, it was necessary to transfer about half of the population from this tank for an additional experiment, leaving 42,750 mysis I's in the tank. Survival was good from mysis I to postlarvae II. However, when this tank was harvested, an accumulation of debris had built up on the bottom of the tank, with dark areas of decomposition, indicating hydrogen sulfide production. In more recent work using airlift pumps to keep the debris suspended, the problems related to the accumulation of debris on the bottom have been solved.

By careful measurement of the abundance of the larval shrimp populations as well as the densities of food organisms at regular intervals, biologists have been able to learn much concerning the survival, behavior, and environmental requirements of larval shrimp. While these methods may or may not have commercial applications, they are a useful research tool.

LITERATURE CITED

BROWN, A., JR.

1972. Experimental techniques for preserving diatoms used as food for larval *Penaeus aztecus*. Proc. Natl. Shellfisheries Assoc. 1971, 62:21-25.

COOK, H. L.

1965. Rearing and identifying shrimp larvae. *In* M. J. Lindner and J. H. Kutkuhn (editors), Biological Laboratory, Galveston, Tex., fishery research for the year ending June 30, 1964, p. 11-13. U.S. Fish Wildl. Serv., Circ. 230.

1966. Identification and culture of shrimp larvae. *In* M. J. Lindner and J. H. Kutkuhn (editors), Annual Report of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, Fiscal Year 1965, p. 12-13. U.S. Fish Wildl. Serv., Circ. 246.

Table 3.—Experiment II, Tank II. Use of fresh concentrated and frozen concentrated *Skeletonema costatum* and *Artemia* by larval and postlarval brown shrimp, *Penaeus aztecus*.

1971			Larval stage	Larval count	Algae			*Artemia*	
Month	Day	Hour			Residual	Fresh	Frozen	Residual	Feed
					Cell/ml	*Cells/ml*	*Cells/ml/hr*	*No./ml*	
May	20		Spawn						
		0730	Egg nauplii						
		1300	Nauplii I						
May	22	0700	Nauplii III						
		1800	Nauplii IV-V						
		2000	Nauplii V	171,000		250,000	10,000		
May	23	0800	Protozoea I	167,500	280,000				
		1000							
		2000	Protozoea I		205,000		20,000		
May	24	0800	Protozoea I	127,000	347,500		10,000		
		1130	Protozoea I				5,000		
		1650	Protozoea I		360,000		Turned off		
		2130	Protozoea II		177,000	202,000	10,000		
May	25	0800	Protozoea II	142,500	107,500				
		1000	Protozoea II			157,000			
		1415	Protozoea II		217,500				
		1545	Protozoea II		195,000				
		1630	Protozoea II				20,000		
		2130	Protozoea II		113,000	288,000			
May	26	0830	Protozoea II	119,000	208,750				
		1010	Protozoea II-III						
		1030	Protozoea II-III				30,000		
		1530	Protozoea II-III		232,000				
		2200	Protozoea II-III		235,000		33,300		
May	27	0730	Protozoea II-III		344,500				
		1230	Protozoea II-III		114,800				
		1630	Protozoea II-III		251,500				
		2130	Mysis I		178,750		20,000		2.0
May	28	0800	Mysis I		302,500		10,000	1.1	
		1300	Mysis I	93,500	(½ population transferred for another experiment)				
		1645	Mysis I	42,750	300,250			0.5	3.5
		1715	Mysis I		200,250				
		2130	Mysis I		220,000			3.3	
May	29	0800	Mysis I		93,750			3.1	
		0930	Mysis II			193,750	20,000		
		1120	Mysis II						6.2
		2215	Mysis II		125,500			5.7	
		2300	Mysis II				30,000		
May	30	0800	Mysis III		128,750			5.3	
		1130	Mysis III						8.3
		2000	Mysis III		240,000			8.8	
		2200	Mysis III				32,000		
May	31	0800	Postlarvae I		117,500			8.9	
		1100	Postlarvae I				35,000		
		2000	Postlarvae I		197,500			4.8	
		2100	Postlarvae I				30,000		8.0
June	1	0800	Postlarvae I		146,250			7.2	
		1630	Postlarvae I		81,250				
June	2	0800	Postlarvae II	42,400					

1967. Identification and culture of shrimp larvae. *In* M. J. Lindner and R. E. Stevenson (editors), Report of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, Fiscal Year 1966, p. 6-7. U.S. Fish Wildl. Serv., Circ. 268.

1968. Taxonomy and culture of shrimp larvae. *In* M. J. Lindner and R. E. Stevenson (editors), Report of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, Fiscal Year 1967, p. 7-8. U.S. Fish Wildl. Serv., Circ. 295.

1969. Larval culture. *In* M. J. Lindner and R. E. Stevenson (editors), Report of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, Fiscal Year 1968, p. 5-6. U.S. Fish Wildl. Serv., Circ. 325.

COOK, H. L., and M. A. MURPHY.

1966. Rearing penaeid shrimp from eggs to postlarvae. Proc. Conf. Southeast Assoc. Game Comm. 19:283-288.

HUDINAGA [FUJINAGA], M.

1942. Reproduction, development and rearing of *Penaeus japonicus* Bate. Jap. J. Zool. 10:305:393.

HUDINAGA, M., and M. MIYAMURA.

1962. Breeding of the "Kuruma" prawn (*Penaeus japonicus* Bate). (In Japanese, English abstract.) J. Oceanogr. Soc. Jap., 20th Vol., p. 694-706.

MOCK, C. R., and M. A. MURPHY.

1970. Technique for raising penaeid shrimp from egg to postlarvae. Proc. Annu. Workship World Mari. Soc. 1970, p. 143-156.

AQUACULTURE IN THE NATIONAL SEA GRANT PROGRAM

ROBERT D. WILDMAN[1]

INTRODUCTION

The National Sea Grant Program was created by an Act of the Congress of the United States to accelerate the development and optimum utilization of our marine resources. This was to be accomplished through the support of research and development, education and training, and advisory service activities. Major emphasis was to be placed on the conduct of these programs through the establishment and operation of Sea Grant Colleges, the ocean equivalent of our Land Grant Colleges which were instrumental in making the United States one of the greatest agricultural nations of the world.

The Sea Grant Program, originally a part of the National Science Foundation, is now in the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce. Several requirements, restrictions, and methods of operation affect the Program in important ways. Sea Grant funds may not be used for construction or maintenance purposes, or for vessel rental. Any recipient of Sea Grant support must provide at least one-third of the total cost of the project from non-Federal sources. All grantees are encouraged to develop cooperative programs with other scientists from universities, government agencies, and/or private industry. Many of our programs have, in fact, operated in this way. When the National Sea Grant Program was created by the Congress, aquaculture was one of the few fields of research specifically identified for emphasis. In carrying out this mandate, the Sea Grant Program has provided more support to this one area of research than to any other. At the present time over 20% of our research funds go into aquacultural efforts. As of 30 June 1971, we were supporting over 50 projects directly related to aquaculture. The total cost of these projects was nearly $5 million with over $3 million coming from our Program. The remainder of the funding is being provided by the universities, state agencies, and private industrial organizations participating in these Sea Grant Programs.

Due to the low level of past activity in the aquaculture field in the United States, very few research groups had any capability or experience on which to base an expanded effort. As a result, much of the early work under Sea Grant support has been devoted to the establishment of trained, experienced groups who are equipped and capable of conducting the type of research necessary to solve the many and varied problems encountered by anyone in aquaculture as a business venture. This includes studies on economics and law, environmental quality, engineering, and seafood technology as they relate to aquaculture. Such studies are not described in this paper even though they may ultimately provide the solution to the most critical problem faced by one or more aquaculture ventures.

For the purpose of this paper, the Sea Grant aquaculture projects will be described by type of organism being studied, except for a few projects of a general type.

CRUSTACEANS

Shrimp

The first aquaculture project to be supported by Sea Grant, the University of Miami program continues to be one of the most advanced in experimental shrimp culture. Begun in cooperation with Armour and Company, the United (Fruit) Brands Company, and Florida Power and Light Company, the main objectives have been 1) to rear large numbers of shrimp from eggs to postlarvae (about 1 cm long) and 2) to grow these postlarvae to marketable size quickly and at low cost. Since the first objective has been achieved for the most part, emphasis is now given to the problems associated with the second. Specifically, the work is now devoted to the further development of satisfactory foods and feeding methods which will provide rapid growth, high sur-

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vival and yields in ponds, tanks, and cages, and to further develop techniques for pond management, including procedures for assuring adequate oxygen supply and optimization of other pond conditions such as bottom material, depth of water, and fertilizer regimen. Other efforts are underway on rapid and efficient harvesting techniques, cage culture, and testing of the important variables in the culture system such as food types, stocking density, and feeding methods.

A new rotatable cage for high density culture has been designed. It is intended to solve the problem of fouling of the mesh. Every portion of the cage is out of the water for about half the time where it is exposed to sunlight and drying and can be easily cleaned. It is not necessary to handle the animals in order to clean the cage. Harvesting will also be greatly simplified by this design.

In a related project at Miami, attempts are being made to induce maturation of ovaries and oocytes in pink shrimp, *Penaeus duororum*. This is a necessary step in the control of the life cycle of the animals in captivity which will relieve the commercial culturist from his dependency on wild populations for gravid females as the source of fertilized eggs. The research to date has included efforts to develop various measures of maturation and investigation of factors (light, temperature, salinity, and hormones) which enhance maturation by inhibiting molting.

Another project at Miami, aimed at the general objective of life cycle control of shrimp, involves the development of techniques to attain in vitro fertilization of ova and sperm removed from ripe animals. Included in this investigation are in vitro studies of maturation of oocytes and ovaries, effects of hormones and ovarian extracts on maturation of ovarian cells, and development of cryogenic techniques to preserve viability of ova and sperm, fertilized eggs, and cultured ovarian cells. Biochemical studies of gonad maturation are underway using electrophoretic profiles to assess maturity.

Aquacultural research at Texas A&M University is aimed at shrimp farming as a commerically feasible operation. Twenty ½-acre ponds (0.2 hectares) are used for study of artificial feeds, shrimp stocking rates, mortality, and growth rates. Some ponds are stocked with hatchery-reared postlarval brown shrimp, *P. aztecus*, supplied by the Dow Chemical Company. Yields from 1970 harvests averaged 250 pounds of shrimp per acre (280 kg/ha), with some ponds exceeding 450 pounds per acre (504 kg/ha). The wholesale market price of the shrimp at harvest ranged from $0.65 to $0.85 per pound, heads on (465-608 yen/kg). In cooperation with Ralston Purina, new feed rations have been developed. Harvesting of the 1971 crop, now in progress, should also reveal effects of pond fertilization on growth rates and survival.

Other shrimp research at Texas A&M includes studies on temperature and salinity effects on postlarvae and feeding behavior, and diet preference of postlarvae. To date one phase of this research has provided information regarding upper incipient lethal temperature, acclimation rate to temperature change, and the influence of environmental salinity on heat tolerance of postlarval brown shrimp. Present work will extend results to include white shrimp *P. setiferus*, postlarvae. Differences have been demonstrated between the responses to diets of postlarval brown and white shrimp. It was shown that shrimp responses to foods, including initial diet preference, survival, growth, and resistance to high temperature may vary independently.

The 4,700 square miles (12,173 km^2) of brackish to marine marshlands and 1,600 square miles (4,144 km^2) of bays, estuaries, bayous, and canals in southern Louisiana are potential sites for impoundments for mass culture of brown and white shrimp without supplemental feeding. A research program being conducted by biologists from Francis T. Nicholls State University has been attempting to solve the many problems involved in demonstrating that such a system is feasible. Two shallow, 10-20 acre (4-8 ha) impoundments containing water and *Spartina patens* marsh are being used to determine the basic productivity (shrimp production) and for measurements of the effect of fish and crab predator control on shrimp production. Natural stocking of ingressing postlarval shrimp occurs on nighttime flood tides across weirs in the impoundments. Large shrimp and predators are prevented from entering by hardware cloth screening.

Predator control is exercised in the larger, test impoundment by rotenone application for fish and baited wire traps for blue crabs. Efficient harvesting of the ponds consists of draining surface water at night across the weir into a net. Shrimp of commercial size rise to the surface and migrate out of the estuarine areas and into the Gulf at night during ebb tides. With predator control the brown shrimp grew to 34 count (heads on) in 75 days and to 12 count in 200 days; the white shrimp grew to 34 count in 60 days. The total harvest of both species for one season was 125 pounds (57 kg) of 34 count shrimp per acre. In the pond with no predator control, the total harvest was 44 pounds (20 kg) of 70 count shrimp per acre, which is probably about the natural productivity of unmanaged marshes.

In a study of the penaeid shrimp, *Penaeus marginatus*, aimed at developing techniques for intensive cultivation under manipulated environmental conditions, investigators at the University of Hawaii have successfully spawned females and reared the larvae through all stages. A new, intensive-culture enclosure is being built that will boost production by vertically arranging the shrimp in small cages on frames, so as to allow the use of the entire water column. Also, a shrimp nutrition study is underway. This project is to provide the technical information needed for a commercial-scale operation to be established and operated by a community group in Hawaii.

Biologists and food scientists at Louisiana State University are developing new rations (foods) for crustaceans in culture. Emphasis has been on the utilization of products such as crustacean meals, single-cell protein (torula yeast), food processing "waste" fiber and cellulosic products, and other products of the fishery processing industries. Special attention is being given to the evaluation of the nutritional value of sun-dried shrimp meal and other shrimp meal prepared by various processing procedures. These rations will be tested for feeding efficiency rates, durability and acceptability, and the effect of various attractants to stimulate shrimp feeding will be identified. A suitable ration which uses alginates as a pellet binder has been developed and is being evaluated under a range of environmental conditions. Other hydrocolloids and modified starches are also being evaluated as pellet binders. Experimental samples are being made available to investigators for testing on a range of economically valuable crustacean species, i.e., penaeid shrimp, freshwater shrimp, and crawfish.

A part of this project includes work to prepare the feeds developed as microcapsules in varying sizes and densities according to the stage of development of the animal. For example, the feed for the nauplius, zoea, mysis, and early postlarval stages will be small and have near-neutral buoyancy, whereas that for the late postlarval and juvenile stages would be larger, would sink, and exhibit good water stability. Although the microcapsules are expensive initially, they should result in healthier animals and greater survival through provision of all nutritional requirements and controlled amounts of expensive sophisticated chemicals (hormones, antibiotics, stimulants, etc.). Use of the microcapsules will also relieve the culturist from the tedious and expensive algal cultural systems now employed in most aquaculture operations.

Another study into the environmental and nutritional requirements of shrimp in culture is being carried out at the Skidaway Institute of Oceanography in Georgia. Following a series of experiments which established a suitable water flow rate, type of substrate, oxygen level, stocking density, and light intensity, preliminary nutritional studies using purified pelleted diets were conducted. Eighteen different diets which varied in level and quality of protein, carbohydrate, lipid, vitamins, and minerals were evaluated by growth rate and percent survival. Rates of ingestion under given environmental conditions, rates of assimilation of specific biochemical entities and calorie-protein relationships are now being investigated. To date, a semipurified diet, containing about 70% shrimp meal and 8% anchovy meal, fed at a rate of 15% of the total biomass daily has produced the best results (164% increase in weight with 95-100% survival during a 3-mo period).

Crabs

Mass culture techniques to produce large numbers of larval stone crabs, *Menippe mercenaria*, and blue crabs, *Callinectes sapidus*, have been achieved in a project at the University of Miami. However, techniques must be improved to reduce and control the problem of cannibalism among larval stone crabs. The stone crab matures, copulates, and spawns viable eggs under conditions of captivity. F_2 offspring of blue crabs have also been attained in captivity. Investigations are now underway to improve techniques of larval culture and to test feasibility of rearing crabs to marketable size in cages placed in natural waters.

A Samoan or mangrove crab, *Syclla serrata*, has been studied at the Hawaii Institute of Marine Biology. The Samoan crab has been maintained in cages suspended from rafts and its growth rate measured. This study indicated this crab could attain marketable size of 1 - 1½ pounds (0.5 - 0.7 kg) in about 1½ yr at ambient temperatures (24°C). Tests at higher temperatures (27°C) indicated that the time to reach market size could be reduced to 1 yr. Also, a diet of artificial food resulted in faster growth than natural foods.

In another crab culture project, efforts are underway at Humboldt State College in northern California to develop methods of growing the Dungeness crab, *Cancer magister*, using locally produced fish wastes as food. The studies are being conducted in two different environments in Humboldt Bay, in pens—one using heated effluents from an electric power plant and the other in bay ponds at ambient temperatures. The diet preference, condition, and growth are determined and evaluated. This project could provide a cheap source of food for an aquaculture operation as well as make use of what is now a waste disposal problem. Early results indicate that a food mixture of rockfish, sablefish, Dover sole, and shrimp offal produced the best results.

Research is underway at East Carolina University on the reproductive cycles and fungal parasites of the blue crab and will begin shortly on the American lobster, *Homarus americanus*. Studies to date on the crab have included observations of the condition of the ovary as seen through the carapace, condition of eggs of ovigers, and occasion of spawning by certain individuals. The crabs which ovulated were successfully induced to attach their egg mass, something not previously reported for the blue crab. Attempts to date to isolate *Lagenidium callinectes* or other fungal parasites of crab eggs have been unsuccessful.

In laboratory studies at Texas A&M University with young blue crabs (5-40 mm), a sand plus oyster shell substrate supported significantly better survival than did either sand alone or bare glass. The suitability of various temperatures and salinity levels were also evaluated.

Lobster

One of the most highly prized seafood organisms in the world, the American lobster, *Homarus americanus*, is being studied by geneticists at the University of California at Davis. The intent is to develop the technology necessary to grow large numbers of edible quality lobsters, to marketable size, in a short period of time, at less cost than the market value. The project is being conducted in cooperation with the State of Massachusetts Lobster Hatchery on Martha's Vineyard Island. The work includes the improvement of culture facilities; development of an economically feasible form of food; studies of the effect of selected environmental parameters on growth; application of genetics techniques for the selection of fast growing lobsters; evaluation of biochemical methods for controlling cannibalism, mating, molting, and disease; and physical methods to control cannibalism. Research, already completed has shown that it is possible to produce a 1 pound (0.45 kg) lobster in 2 yr time instead of the 7-8 yr it takes in the sea, by growing them at 20°C and feeding them daily.

Work on the American lobster at the University of Rhode Island is also directed toward reducing the time required to grow the animal to market size. Here the effort has resulted in the development of methods for accelerating the hatching of eggs and the mass culture of larvae to juveniles under controlled conditions. Work is now in progress for maximizing the growth rate of juveniles to market size under optimum conditions.

Several parts of a multifaceted program of research at San Diego State College on spiny lobster, *Panulirus interruptus*, and American lobster involve aquacultural work. Juveniles of spiny lobster have been studied with respect to the effects of elevated temperatures (20°, 22°, 26°, and 28°C) on growth and metabolic energy budget. Studies of American lobster in progress are providing a comprehensive evaluation of the biological and economic feasibility as well as the potential benefits and dangers of establishing this species as a fishery resource in California waters. Part of this work is concerned with developing and evaluating lobster culturing techniques, with the primary aim of producing large numbers of young suitable for stocking.

Crayfish

In a project to develop crayfish culture in the Pacific Northwest, biologists at Oregon State University are developing husbandry methods in controlling environments. A system for holding and breeding adult crayfish in captivity has been developed.

Juveniles are raised singly in small cells to avoid cannibalism of soft-shelled animals. Several natural and artificial diets have been tested and research on nutrition is now centered around a simulated natural diet versus a high protein vegetable pellet diet. The role of temperature and salinity on growth and survival is also under study.

MOLLUSCS

Oysters

In a large multidisciplinary effort, scientists at the University of Delaware are working to improve our techniques in shellfish culture. A variety of problems are being attacked in both open and closed culture systems. Over 500 million oyster larvae were reared at least to the straight hinge stage in 51 separate cultures during the past year. These larvae, the results of 40 spawning attempts, were used in a variety of rearing and setting experiments. The algal culture facilities can now provide food on a year-round basis and are capable of producing 150 liters of dense algal culture every 24 hr. Research on the feeding of adult oysters in being conducted to show how the oyster utilizes available food energy. Preliminary experiements have determined the caloric content of cultured algae and have shown that an oyster can assimilate at least 85% of the energy content in the food that it consumes. Research is also being conducted on the bacteria associated with supplemental feeding of oysters in closed systems, and efforts to produce viable offspring from hybridization of the Eastern (or American) oyster, *Crassostrea virginica*, and the Pacific oyster, *C. gigas*, are continuing.

A pilot-scale oyster hatchery at Newport, Oreg., is producing seed from Pacific and Kumamoto *(C. gigas)*, Olympia *(Ostrea lurida)*, and European *(O. edulis)* oysters on a routine basis. Peak production in the pilot hatchery approaches 1 million juveniles per month. The seed is being raised by growers in Oregon and Alaska, and is being used in a variety of studies by Oregon State University researchers.

Heritability studies have been completed on the Pacific oyster, and parentage is controlled to selectively breed for rapid growth, high meat production, and low mortality. The growth of hatchery seed oysters in warmed ocean water from power plant effluents is under evaluation. Successful cryogenic preservation of oyster sperm at -196°C has allowed self-fertilization of the Pacific oyster after natural sex reversal for genetic studies. Improved larval feeding schedules and diets have increased the success of setting in the hatchery.

In their program to advance the state-of-the-art in oyster culture, biologists at the Virginia Institute of Marine Sciences have developed two new methods for obtaining free oyster spat (cultchless), one for relatively clear estuarine areas and one for areas which have heavy siltation problems. In the first method, the spat must be removed from the substrate before sufficient new shell for permanent attachment has been produced. The set takes place in fiber glass salmon-egg hatching trays in complete darkness, using filtered river water. The spat are removed from the tray bottom, to which they have temporarily attached, by a strong stream of river water, yielding cultch-free spat.

The second method delays the removal of the newly set spat from the substrate for 18-21 days. Setting is induced on Frosted Mylar[2] or Herculene. A new setting tray was designed to hold the mylar upright. The spat set on the upright mylar sheets, thus avoiding most of the siltation and organic detritus. The spat is removed from the mylar sheet by simply shaking it over a container of river water. It is then dipped up and down in the container, washing the loose spat off.

A team of researchers at the Darling Center, University of Maine, is investigating the feasibility of culturing several species of marine organisms in the colder waters of that region. Although research is being conducted on the deep sea scallop and blue mussel, most of the experiments to date in this new program have been with cultchless European and American oysters. Trays of the cultchless oysters have been placed at many different locations in the Damariscotta estuary (24 km long) and at 14 sites along the coastline. These were selected to provide as good a geographic and ecological spread as possible and are being monitored for growth, survival, and presence of fouling organisms. In the first year, growth response of European oysters was excellent (to 10 cm) in even the most exposed coastal locations. The data will be utilized to develop a predictive model allowing assessment of the potential of the Maine coast for economically competitive oyster culture. A cooperative pilot hatchery is being started at Newcastle which may result in the establishment of a commercial operation.

The Departments of Agricultural and Mechanical Engineering of the University of Maine are working on oyster rafting systems which will be adaptable to this environment and compatible with multiple use concepts. A pilot model of a submersible raft has been constructed and will be field tested in 1972.

Several problems inherent in the culture of oysters and clams are being investigated at the University of Washington. The optimal horizontal spacing of oyster cultches suspended from rafts in relation to growth, mortality, and condition is being determined and the local variation in the degree and type of fouling organisms evaluated. The investigators are also attempting to determine if bacteria are responsible for some of the summer oyster mortalities. They are particularly interested in *Vibrio* and other types

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[2] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

of pathogenic bacteria which may be associated with these mortalities. In related work, the gonadal development of the Manila clam, *Venerupis japonica*, is being studied. Also, seed of this clam species is being planted in commercial growing areas to determine the best annual planting density and minimum length of time seed must be held in the hatchery to give optimum yields to the clam grower.

In a companion program, a prototype continuous phytoplankton culture unit is being developed at the University of Washington to provide nutritious, efficiently grown feeds for the clam and oyster farm. The prototype can produce at least 14 liters per day of *Monochrysis lutheri* with a total yield of 2×10^{11} cells, consisting of 6.8 g ash-free dry weight, which is 22% protein.

Clams

A new hard clam culture method has been developed at the Virginia Institute of Marine Sciences. The new method involves spreading shell, gravel, or other material (aggregates) over the sand or mud bottoms before planting the seed. This type of bottom protects the young clams from their chief predator, the blue crab, and other predators, such as other crabs, boring snails, bottom-dwelling fish, and waterfowl. Other methods of protection tried in the past included planting the young clams in screened trays or boxes, within fenced enclosures, under sheets of netting or hardware cloth, in saltwater tanks, and intertidally. These techniques were unreliable and expensive, caused silting and slow growth, and thus are unsuitable for commercial use.

Other work on molluscs at the University of Hawaii has included efforts to develop pond culture of the Japanese littleneck clam which was introduced to Hawaii, but whose natural populations are declining. Research to date has identified proper substrate as a key parameter with sand substratum yielding normal growth. Spawning was achieved through temperature elevation (30°-31°C) and addition of sperm.

Scallops

The hatchery techniques of conditioning, spawning, and rearing the bay scallop, *Aequipecten irradians*, have been developed at the Virginia Institute of Marine Sciences. The scallop has been raised to market size (5-6.5 cm) with the final growth phase taking place in wooden, rectangular floats (2.1 m × 0.6 m × 15 cm) whose tops and bottoms are covered with fiber glass window screen or plastic netting. In one experiment, the scallops were grown from 1.3 to 5.7 cm in a net enclosure directly on a relatively hard mud-sand bottom. The total growth time from egg to market size was 6-7 mo. Work is continuing to determine optimum stocking densities and optimum depth for holding the scallop floats and to develop other methods for holding scallops from about 2.2 cm to market size.

Abalone

The culture of four commercially important species of abalone is under study at the Scripps Institution of Oceanography, University of California. Studies of spawning phenomena, early development, settlement, growth of settled juveniles, and hybridization are being conducted. Approximately 200,000 young red abalone, *Haliotis rufescens*, were reared by the chief investigator in a commercial venture. This resulted in the identification of the problems being attacked in this research program. Primary attention is being given to the influence of temperature on larval development and juvenile growth, and to the behavioral problem of substrate selection by settling larvae. Other efforts are being devoted to determine the causes of larval mortalities and to identify micropredators of newly settle juveniles.

Octopus and Limpets

Two rather unusual species of molluscs are being studied by University of Hawaii scientists. Work on large limpets, which are in great demand for Hawaiian luaus and which sell for as much as $70 per gallon (6,000 yen/liter), is concentrating on the development of an acceptable food source. Eggs have been obtained from females and artificially fertilized successfully with the females producing several thousand eggs each. However, further ecological work is necessary to ascertain conditions under which the early larvae can be reared to acceptable size.

Research on the Day Octopus, another specialized food that is highly prized in Hawaii, has indicated a rapid growth rate with the animal reaching the marketable size of 1 pound (0.45 kg) in about 3 mo and growing to 3-4 pounds (1.36-1.8 kg) in only 4-5 mo. Current efforts are directed toward the development of an artificial food. Mating occurs readily in captivity with the females producing an average of 500,000 eggs. Difficulty has been experienced in the rearing of larvae since, while they are active and feed, they do not grow.

FINFISH

Salmonids

One of the oldest research efforts in the United States directed toward developing improved strains of seafood organisms is that at the University of Washington under Lauren R. Donaldson. Over a period of 40 yr, through a selective breeding program, several species of salmon and hybrids of trout have been developed, and eggs from this program have been provided to organizations all over the world. Currently Donaldson and his co-workers are working with rainbow trout, rainbow-steelhead hybrids, and chinook and coho salmon, *Oncorhynchus tshawyscha* and *O. kisutch*. Millions of eggs are produced each year. some being used in the breeding program, some irradiated for studies of the effects of radiation exposure, and others used or provided to other organizations for other types of research or for aquaculture.

In an associated program, other University of Washington fisheries biologists are attempting to demonstrate the practicality of rearing salmonids in floating pens, in brackish water ponds, and in saltwater estuaries. In this work, which is being conducted cooperatively with private industry, the salmon are being reared for two uses: 1) direct marketing and 2) release at an advanced stage for support of sport and commercial fisheries. This same project also includes studies of the effects of environmental parameters on the success of rearing salmonids in seawater, the training of salmon to come to an underwater sound source for effective feeding and harvesting, and feasibility studies on enhancing production of 20 species of flatfishes indigenous to Puget Sound by improved cultural techniques.

A team of researchers at Oregon State University is investigating several problems associated with salmon culture. New hatchery methods which simulate natural spawning beds are being developed. The system involves raising salmon alevins (larvae) in darkness on a gravel substrate instead of on screened trays or smooth tank bottoms. Water velocity is similar to that in good quality natural spawning beds. Several hundred thousand chum salmon, *O. keta*, are being produced annually by this method at an experimental hatchery located at Netarts Bay. The fry from the gravel incubator are considerably larger than fry from standard hatchery incubators and do not exhibit malformed yolks which are common in hatchery chum salmon alevins. In the laboratory at Port Orford, chinook salmon are being exposed in rearing tanks to increasing salinities to determine the feasibility of releasing juveniles directly to seawater after only a brief period of adaptation. If successful this could significantly reduce the mortalities which now occur in freshwater areas.

Other work at Oregon State University on salmon includes attempts to: improve certain strains through hybridization and selective breeding; develop methods for rearing in power plant effluents; determine the effects of infection by the trematode, *Nanophyetus salmincola;* and develop techniques for cryopreservation of gametes. Sperm frozen for 7 days at $-196°C$ were thawed and used to fertilize 80% or more of fresh eggs from coho salmon and steelhead trout, *Salmo gairdneri*.

Seafood scientists at Oregon State University are working with several salmon diet formulations in order to develop new rations, as well as to learn more about the nutritional requirements of the salmon. Experiments now completed indicate that a pelleted fish food utilizing 40% dewatered and comminuted shrimp wastes provide results as good as those obtained with the commonly used Oregon moist pellet. Thus, a use for large quantities of raw shrimp wastes has been identified.

Coho and chinook salmon are being reared in net enclosures in the open waters of Puget Sound in a project being conducted by a private firm, Ocean Systems, Inc. This project is an outgrowth of work by the National Marine Fisheries Service whose scientists continue working on associated problems. Assistance has also been received from the Washington State Department of Fisheries and the University of Washington. The eggs were hatched and the fingerlings placed in a freshwater pond. When they reached the desired size, the fish were transferred by truck to small net enclosures ($7.5 \times 7.5 \times 4.5$ m) in the Sound and later transferred to four larger ($15 \times 15 \times 7.5$ m) growing pens which are attached to an anchored raft. The enclosures are covered by a net to protect the fish from bird predators and surrounded on four sides and the bottom by a 6.4-cm stretch mesh gill net to protect the fish from dogfish and other predators.

At the present time, approximately 230,000 coho and 270,000 chinook salmon are growing in the pens. They are fed a dry salmon pellet ration which is hand-cast over the enclosure. Although some of the salmon have reached potential market size in 8 mo, the average weight was 0.06 kg. The company, working with the National Marine Fisheries Service, will begin test marketing the 0.2-0.34 kg fish shortly after the beginning of the year. Current efforts also include an evaluation of the potential environmental effects of a large-scale operation of this type.

In northern California, at Humboldt State College, fisheries biologists are in the early stages of testing the efficacy of enriching brackish water and saltwater rearing ponds with sewage effluents for the rearing of salmon and trout. The fish are released as fry and fingerlings into two ponds, one a control seawater pond and the other contains a seawater and sewage effluent mixture. The scientists hope to determine if it is possible to rear fish to migrant size more cheaply by this method than with standard fish culture techniques. Harvest for human use would occur after the fish had been released and continued their growth in the natural environment.

At the present time there are 40,000 coho salmon (10,000 of them marked) and 2,500 steelhead trout divided between the two ponds. Growth and mortality studies are being conducted to evaluate the success of this technique.

Scientists at the University of Rhode Island are attempting to develop a new form of aquaculture, based on a closed cycle, controlled environment system, which will have almost no environmental impact and be compatible with other demands on coastal resources. Salmonids; Atlantic salmon, *Salmo salar;* pink salmon, *Oncorhynchus gorbuscha;* rainbow trout, bluefish, *Pomatomus saltatrix;* and striped bass, *Morone saxatilis,* are being grown in the project. The work is intended to provide information which will increase the operating efficiency and capacity of present day salmon hatchery and smolt production facilities as well as improve diets for fish in culture. Nutritional and physiological studies are underway, with one study the effect of the level of dietary protein and different lipids on the nutrition of rainbow trout adapted to an intermediary salinity (16‰) just completed.

Studies are being conducted to determine the requirements for rapid activation of biological filters in both marine and freshwater systems. Also, alternatives to biological filters for water purification in the closed circuit system are being evaluated.

One key part of this work is aimed at solving the problems resulting from the accumulation of nitrogen waste products in the closed system. Another part of this program is an analysis of the economic feasibility of commercial salmonid culture for food fish markets. A projection of production costs for a model salmonid aquaculture facility has just been completed.

Striped Mullet

In an effort to develop a controlled culture system for striped mullet, *Mugil cephalus,* scientists at the Oceanic Institute in Hawaii have devoted considerable effort, with success, to the induction of spawning. Successful breeding of wild, adult fish has been accomplished with injections of salmon pituitary in conjuction with Synahorin, or with low doses of a partially purified Pacific salmon gonadotrophin. Spawning was also induced in captive animals using a controlled photoperiod regime followed by injections. Larval rearing studies are also underway using copepod adults and nauplii and gastropod veliger larvae as food. The veliger larvae appear to be preferred by the striped mullet larvae and are produced in the laboratory.

In a companion project, the problems associated with rearing the striped mullet in coastal ponds are being studied. Artificial seaweeds ("X" sheets of plastic) are anchored in the ponds. Algae grow on this plastic "grass" and are eaten by the fish, thus providing a cheap source of food for the fish in culture.

Young striped mullet have been studied at Texas A&M University to determine high temperature resistance and acclimation rates in laboratory tests. Salinities of 1 and 10‰ were more suitable than 20 and 30‰ for temperature acclimation and heat resistance of young mullet. These findings may be useful in the development of pond stocking guidelines. A two-factor laboratory study on the effects of salinity and temperature on survival and growth of striped mullet has recently been completed. Statistical analysis of the results has not been completed, but the data suggest that striped mullet are tolerant to broad ranges of both factors.

Dolphin

Work is underway by North Carolina State University biologists to determine the feasibility of commercial propagation of the dolphin, *Coryphaena hippurus.* Successful efforts, being conducted at Hatteras, N.C., and Bimini, Bahamas, have been directed toward developing artificial spawning techniques by use of sex hormones. Capturing and transporting techniques have been developed, and growth studies have yielded an average weight increase of 1 pound (0.5 kg) per week with a maximum growth of 7¾ pounds (3.5 kg) in 6 wk. Larval rearing techniques will be developed as dependable spawning is realized.

Miscellaneous

Several species of finfish (see appendix for names of species) have been studied at the Hawaii Institute of Marine Biology on Coconut Island to determine their potential for aquaculture. They were selected on the basis of their acceptability as food or bait and their ability to grow in captivity. Eggs, larvae, juveniles, or adults were collected according to their availability, and attempts were made to ascertain their environmental requirements in a variety of situations including small tanks, floating rafts, ponds, etc. Investigations were made on nutrition, growth, reproduction, and diseases of the various species.

Research at Louisiana State University has been directed toward determining the various parameters controlling growth of several species of finfish in culture. The effects of salinity and other water quality parameters on channel, blue, and white catfish *(Ictalurus punctatus, I. furcatus,* and *I. catus)* and on Florida pompano *(Trachinotus carolinus)* have been identified. One notable effect of brackish water on the catfish is that it prevented outbreaks of the protozoan parasites, *Ichtyophthirius multifilis*, which is frequently a serious problem in freshwater catfish culture. Other studies have examined growth, development, and survival of the pompano and the Atlantic croaker, *Micropogon undulatus*, in culture.

For the past 6 yr, Louisiana State University (LSU), in cooperation with the Louisiana Wild Life and Fisheries Commission, has screened a number of species for suitability for culture including: three species of freshwater catfish (blue, channel, and white), pompano, mullet, croaker, crawfish, and redfish. These species are also being stocked in various combinations, polyculture. In one study, the mullet-channel catfish combination showed promise. Total production in ponds was increased. The mullet, acting as a biological filter, helped to clean up solid wastes produced by catfish, as well as adding to total production. LSU has consistently produced over 1 ton of channel catfish per acre in ponds with salinities up to 10‰ total salinity.

The sheepshead minnow, *Cyprinodon variegatus*, a valuable bait fish in Texas has been studied at Texas A&M University to determine the effect of salinity on high temperature resistance and acclimation rates in the laboratory. At 10 and 20‰ these fish fared better than at 1 or 30‰.

SEAWEEDS

Red Algae

One of the most advanced programs in seaweed culture in the United States is being conducted by phycologists at the University of Hawaii. The program consists of the development of techniques for growing the red alga, *Eucheuma* (three species), as a carrageenan source. Small, pilot-scale farm operations have been established and successfully demonstrated in the Philippines, the Trust Territory, and other Pacific areas. Hopefully, this project will lead to full-scale commercial operations which will provide a reliable supply of raw material for the U.S. carrageenan industry.

Other seaweed projects at the University of Hawaii are investigating the culturing of other red and green algae *(Gracilaria, Hypnea, Cladophora,* and *Ulva)* and their potentially useful extracts.

Two projects aimed at expanding the source of commercially valuable seaweeds in the United States are underway at the University of South Florida. One is a field and laboratory study of the carrageenan source, *Eucheuma isiforme*, which involves studies of growth, reproduction, morphology, and carrageenan content of tagged plants growing naturally in the ocean, plants suspended from lines 2 ft above the bottom, and plants under laboratory culture. Results to date suggest that in the ocean, growth rates are highest in the cooler months, whereas carrageenan content is highest in the warmest months. Morphology does not appear to be easily influenced by environmental changes, such as would occur in transplantation, but may be greatly influenced by nutrient levels. Reproduction appears to be limited to very brief times and may not even occur yearly.

The other project consists of experimental cultivation of about a dozen species of south Florida red marine algae in various habitats, during different seasons of the year, using three procedures: 1) vegetative growth in net-covered frames or in, or upon, other forms of substrata; 2) the "seeding" of selected substrata with a given species, and obtaining either gametophyte or sporophyte plants as desired; and 3) the placing of solid substrata in areas suitable for algal growth but lacking the necessary substrata.

The most promising results with a potential for direct application in the production of quantities of raw material for industry have come from the first procedure. Growth of *Hypnea musciformis* and *Gracilaria folifera* in net-covered cages, floating just 15 cm under the surface, during the warmer months of the year was very rapid, often doubling their weight in 1 day. These plants, growing in a very favorable environment and protected from grazers, increased their weight from 10 to 100 g in 10-14 days. The culture of *Eucheuma isiforme* and *E. acanthocladum*, using some of these techniques, will be emphasized during the next year.

Methods to culture both benthic and planktonic marine algae are being developed at the University of Washington. The phycologists have demonstrated that *Iridaea cordata*, *Gigartina exasperata*, and *Agardhiella tenera* var. *pacifica* can be successfully transplanted to habitats in which they have not previously grown, and have grown these three species, plus *Sarcodiotheca furcata*, in laboratory cultures. In a related effort, the investigators have completed a study on extracellular, water-soluble polysaccharides produced by various marine diatoms and isolated in axenic culture the unicellular red alga, *Rhodosorus marinus* for subsequent growth experiments.

A multidisciplinary team at the University of California at Santa Barbara is studying some of the varied problems encountered by the seaweed industry in the United States. Biologists and engineers are studying the settlement and growth of spores, including the effects of water motion on spore settlement and on reproductive stages. Transplants of *Gelidium*, *Gracilaria*, and *Macrocystis* are being made for studies of growth and colloid production.

As part of this program, economists are surveying the present and future status of the U.S. seaweed industry. An economic model is being developed for the agar weed *Gelidium*, which considers growth, loss, and reproduction rates; production problems; and agar content.

Future work will include an evaluation of harvesting methods and packaging operations and the development of a "breeding stock" of rapidly growing forms.

Brown Algae

One of the oldest programs in the United States in seaweed management is the kelp research now being conducted at the Marine Laboratory of the California Institute of Technology. During their early attempts of restoring the kelp beds off southern California, the researchers simply transplanted adult plants from an existing bed to an area where a new bed was to be established or a disappearing bed strengthened. The adult plant then released spores which produced new plants. At the same time quicklime was spread over the bottom to kill the heavy grazing sea urchins. Attempts were also made to protect the young plants from grazing fish with net covers.

Recent work has been devoted to the development of techniques for raising *Macrocystis* plants in mass culture from liberated zoospores, through the gametophyte to the embryonic sporophyte. The embryonic sporophytes which develop on an artificial substrate are scraped free and dispersed close to the bottom in areas suitable for kelp growth. Preliminary estimates indicate that about 10^5 embryos must be dispersed to yield one attached *Macrocystis* juvenile about 15 cm tall.

The culture system now in use can produce 10^5 to 10^6 embryos per cm^2 of culture substrate. Thus, the low survival rates following dispersal do not prohibit the use of this system for developing new kelp stands. Out of five areas in which this technique was attempted, young *Macrocystis* developed in three of them with hundreds to thousands of plants resulting in two of the areas.

MARINE PATHOLOGY

Several institutions have directed research efforts toward the diseases and parasites of seafood organisms, usually looking at several different kinds of animals. Most of the animals examined are being cultured, at least experimentally, in the United States. Texas A&M University has established an Aquatic Animal Medicine Laboratory on its campus and is working with a wide variety of finfish and shellfish, looking for many types of bacteria, viruses, and other infectious agents. They have identified the microbial flora of Gulf of Mexico and pond-grown shrimp and developed new techniques for detecting certain agents and diseases in finfish and shellfish.

Microbiologists at Georgetown University have been examining several Chesapeake Bay organisms for the bacterium, *Vibrio parahaemolyticus*, responsible for many cases of food poisoning in Japan and some recent cases in the United States.

This bacterium has been isolated from dead and dying blue crabs from Chesapeake Bay and was isolated from dead and dying cultured shrimp taken from Texas A&M University's ponds.

Several other universities, including Oregon State, Miami, Rhode Island, and Washington, have programs in marine pathology in which both wild and cultured animals are being studied. While it will be difficult, if not impossible, to solve disease and parasitic problems in wild populations, this work could lead to solutions of problems with pathogens encountered in aquaculture.

NEW AQUACULTURE SITES

Two projects are underway at the University of California to explore the potential of selected environments for aquaculture. The first, at the Santa Barbara campus, involves the study of a California coastal lagoon to determine its usefulness as a manageable ecosystem for aquaculture. The investigators believe that it may be possible to increase productivity by shortening the normal food chains, reducing predation and/or artificially fertilizing this ecosystem. Initial efforts are devoted to a study of the basic ecology of the lagoon, including meteorological measurements, physicochemical determinations, and biological sampling.

The second, at the Scripps Institution of Oceanography, is examining the feasibility of a large-scale seafood production unit utilizing the nutrients contained in deep oceanic waters to enrich a marine food chain. The pilot study is being carried out on Eniwetok Atoll in the Marshall Islands, where the deep water may be brought up by drilling into the coral reef rather than by using a submerged pipe. Work is in progress toward establishing ecological and productivity baselines on the trophic systems in two nuclear craters that are washed over by the tides and have become invaded with marine organisms. In preparation, moreover, are efforts to assess the water yield capacity of the reef and what changes the nutrients undergo during the seawater's passage through the coral formation.

In a somewhat related program, a team of scientists from the Lamont-Doherty Geological Observatory of Columbia University is working on St. Croix in the U.S. Virgin Islands to demonstrate the feasibility of using deep, cold ocean water for aquaculture and, later, for other uses. The total system could involve multi-usage of the water: sea thermal power production by the Claude process, air conditioning, ice-making, cooling of electric power and desalination plants to avoid thermal and brine pollution, and condensation of atmospheric moisture for freshwater production. The experimental work to date, however, has been restricted to the aquaculture portion of the total system.

A pilot-plant operation was established in which water was pumped into small ponds from a depth of 830 m through an 1,800-m long polyethylene pipeline of 7.5-cm internal diameter. The ponds are used to grow diatoms (mainly *Cyclotella nana*) which are fed into tanks containing trays of Eastern oysters, *Crassostrea virginica*, and hard shell clams, *Mercenaria mercenaria*. Results to date have shown the system to produce unusually fast growth rates for both types of shellfish. However, some oyster mortalities have been experienced. The culture of other types of seafood organisms utilizing this technique will be examined later and an expanded experimental system is planned.

APPENDIX

National Sea Grant Aquaculture Programs

(By organization)

California Institute of Technology
Pasadena, CA 91109
Project:
Restoration, propagation and management of marine algae *(Macrocystis pyrifera)*. Wheeler J. North, Department of Engineering and Applied Science.

University of California at Davis
Davis, CA 95616
Projects:
1. The culture, selective breeding and genetics of the lobster, *Homarus americanus*. Robert Shleser, Department of Genetics.
2. Habitats for rearing of lobsters *(Homarus americanus)*. Robert Shleser, Department of Genetics.

University of California at San Diego, and
Institute of Marine Resources
La Jolla, CA 92037
Sea Grant Program Director, Dr. George Shor; telephone (714) 453-2000, ext. 1094.
Projects:
1. Abalone culture methodology and larval ecology. *(Haliotis rufescens* (red), *H. corrugata* (corrugated), *H. fulgens* (green), and *H. sorensensi* (Sorensen).) David L. Leighton, National Marine Fisheries Service Laboratory, La Jolla.
2. Enhancement of natural marine productivity by artificial upwelling. Walter R. Schmitt, Scripps Institution of Oceanography, La Jolla.

University of California at Santa Barbara
Santa Barbara, CA 93106
Project:
1. Continued studies of seaweed resource management (cultivation). *(Gelidium, Gracilaria,* and *Macrocystis.)* Michael Neushul and Alexander Charters, Department of Biological Sciences; and Walter J. Mead, Department of Economics.
2. Ecosystem studies and mariculture potentialities of a coastal lagoon. Robert W. Holmes, Department of Biological Sciences.

Columbia University
Lamont-Doherty Geological Observatory
Palisades, NY 10964
Project:
Artificial upwelling. Oswald A. Roels, Chairman, Biological Oceanography.

University of Delaware
Newark, DE 19711
Sea Grant Program Director, Dr. William Gaither, Dean, College of Marine Studies; telephone (302) 738-2841.
Projects:
1. System engineering and development of commerically valuable marine shellfish. *(Crassostrea virginica* and *C. gigas.)* Donald Maurer, Department of Biological Sciences.
2. Closed environmentally controlled systems for aquacultural production. Oscar R. Harmon, Department of Agricultural Engineering.
3. System engineering for shellfish production. Frederick A. Costello, Department of Mechanical and Aerospace Engineering.
4. Investigation of new shellfish species for closed cycle mariculture. *(Mercenaria mercenaria, Callinectes spaidus,* etc.) Charles Epifanio, College of Marine Studies.

East Carolina University
Greenville, NC 27834
Project:
Studies on reproduction and fungal parasites affecting reproduction in the lobster, *Homarus americanus*, and the blue crab, *Callinectes sapidus*, in North Carolina waters. Edward P. Ryan and Charles E. Bland, Department of Biology.

Georgetown University
Washington, DC 20007

Project:

Vibrio parahaemolyticus in Chesapeake Bay - isolation, incidence and pathogenicity. Rita R. Colwell, Department of Biology.

University of Hawaii
Honolulu, HI 96822, and
Hawaii Institute of Marine Biology
Coconut Island

Sea Grant Program Director, Dr. Jack Davidson. Director of Sea Grant Program; telephone (808) 944-7331.

Projects:

1. Production of food colloids from tropical marine algae. Maxwell S. Doty, Department of Botany, Honolulu.
2. Seaweed agronomy. Maxwell S. Doty, Department of Botany.
3. Algal food for aquatic organisms. Maxwell S. Doty, Department of Botany.
4. Tropical animal aquaculture: Finfish - omaka *(Caranx mate)*, yellow ulua *(Gnathanodon speciosus)*, moi *(Polydactylus sexifilis)*, Japanese yellowtail *(Seriola quinquiradiata)*, Nehu or Hawaiian anchovy *(Stalephorus purpureus)*, iao *(Pranesus insularum)*, freshwater threadfin shad *(Dorosoma petenense)*. Molluscs - opihi or limpets *(Cellana exarata* and *C. sandwicensis)*, Japanese littleneck clam *(Tapes philippinarium)*, Day Octopus *(Octopus cyanea)*. Crustacea - Samoan or mangrove crab *(Scylla serrata)*, white or haole crab *(Portunus sanguinolentus)*, opae lolo *(Penaeus marginatus)*.

Humboldt State College
Arcata, CA 95521

Sea Grant Program Director, Richard Ridenhour, Academic Vice President; telephone (707) 826-3632.

Projects:

1. Sewage fertilization of brackish and saltwater fish ponds for rearing salmon and trout. *(Oncorhynchus kisutch* and *Salmo gairdneri.)* George H. Allen, Department of Natural Resources.
2. The utilization of fish wastes for rearing of crabs in salt and brackish water *(Cancer magister)*. James P. Welch, Department of Natural Resources.

Louisiana State University
Baton Rouge, LA 70803

Sea Grant Program Director, Jack Van Lopik, Office of Sea Grant Development; telephone (504) 388-1558.

Projects:

1. Culture of fish and crustaceans *(Penaeus* sp. and *Trachinotus carolinus)*. James W. Avault, School of Forestry and Wildlife Management.
2. Nutrition of penaeid shrimp. Samuel P. Meyers, Department of Food Science and Microbiology.

University of Maine
Orono, ME 04401, and
Ira C. Darling Center
Walpole, ME 04573

Sea Grant Program Director, David Dean; telephone (207) 563-3146.

Projects:

1. Laboratory spawning and rearing of deep sea scallops *(Placopecten magellanicus)*. Herbert Hidu, Darling Center, Walpole.
2. Adaptation of known cultural techniques for the european oyster *(Ostrea edulis)* to the Maine environment. Herbert Hidu, Darling Center, Walpole.
3. Engineering assessment of hatchery mechanization; design and testing of submersible rafts for oyster culture. Richard Rowe, Department of Agricultural Engineering; and Walter Schneider, Department of Mechanical Engineering, Orono.

University of Miani
Miami, FL 33124

Sea Grant Program Director, Wendell Mordy, P.O. Box 9178, Coral Gables, FL 33124; telephone (305) 350-7468.

Projects:

1. Commerical culture of brachyuran crabs *(Menippe mercenaria* and *Callinectes sapidus)*. W. T. Yang, School of Marine and Atmospheric Sciences.

2. Cryobiological preservation of shrimp sperm and ova. *(Penaeus duorarum.)* J. L. Runnels, School of Marine and Atmospheric Sciences.
3. Commercial culture of penaeid shrimp. *(Penaeus duorarum* and others.) Charles W. Caillouet, School of Marine and Atmospheric Sciences.
4. Induced maturation of ovaries and oocytes in *Penaeus duorarum* in vivo. Charles W. Caillouet, School of Marine and Atmospheric Sciences.
5. Virology and protective factors. M. M. Siegel, Department of Microbiology.

Francis T. Nicholls State University
Thibodaux, LA 70301

Project:

Effects of water exchange and blue crabs control on shrimp production on Louisiana salt-marsh impoundments. (Brown shrimp, *Penaeus aztecus*, and white shrimp, *P. setiferus.)* Alva H. Harris, Department of Biological Sciences.

North Carolina State University
Raleigh, NC 27607

Project:

Abundance, exploitation, migration and propagation of the dolphin, *Coryphaena hippuras*. William W. Hasler, Department of Zoology.

Oceanic Institute
Waimanalo, HI 96795

Projects:

1. Food resources studies of mullet *(Mugil cephalus)*. Ziad H. Shehadeh, Food from the Sea Division.
2. Feasibility pilot project for a method of open water fish farming. Ziad H. Shehadeh, Food from the Sea Division.

Ocean Systems, Inc.
Reston, VA 22070

Project:

Pacific salmon aquaculture program. *(Oncorhynchus tshawytscha* and *O. kisutch.)* Jon M. Lindbergh, Route #8, Box 8485, Bainbridge Island, WA 98110; telephone (206) 842-5098.

Oregon State University
Corvallis, OR 97331, and
Marine Sciences Center
Newport, OR 97365

Sea Grant Program Director, Herbert Frolander, Department of Oceanography; telephone (503) 754-2714.

Projects:

1. Physiology of developmental processes. Ronald H. Alvarado, Department of Zoology, Corvallis.
2. Culture of Pacific salmon. William J. McNeil, Department of Fisheries and Wildlife, Newport.
3. Culture of bivalve molluscs. Wilbur P. Breese, Department of Fisheries and Wildlife, Newport.
4. Culture of crayfish, shrimp, and prawns. John R. Donaldson, Department of Fisheries and Wildlife, Corvallis.
5. Control of pests on oyster grounds. Raymond E. Millemann, Department of Fisheries and Wildlife, Newport.
6. Field culture of bivalve molluscs. Howard F. Horton, Department of Fisheries and Wildlife, Corvallis.
7. Heritability in oysters. Raymond C. Simon, Department of Fisheries and Wildlife, Corvallis.
8. Cryogenic preservation of salmonid and molluscan gametes. Howard Horton, Department of Fisheries and Wildlife, Corvallis.
9. Hybridization of salmon. William J. McNeil, Department of Wildlife and Fisheries, Newport.
10. Culture of algae for mollusks. Harry K. Phinney, Department of Botany and Plant Pathology, Corvallis.
11. Nutrition and waste utilization. Russell O. Sinnhuber, Department of Food Science and Technology, Corvallis.

University of Rhode Island
Kingston, RI 02881

Sea Grant Program Director, Niels Rorholm; telephone (401) 792-2550.

Projects:

1. Nutrition of salmonids and other selected

species. (Chinook salmon, *Oncorhynchus tshawytscha;* coho or silver salmon, *O. kisutch;* striped bass, *Morone saxatilis;* and American lobster, *Homarus americanus.)* Thomas Meade, Marine Experiment Station.
2. Commerical aquaculture of American lobster. Akella Sastry, Graduate School of Oceanography.
3. Chemistry and microbiology of recirculating aquaculture systems. John Sieburth, Graduate School of Oceanography.
4. Marine pathology. (Protozoal infection of ocean pout, *Macrozoarces americanus;* fin rot in salmonids; epitheliocystis disease of striped bass, *Morone saxatilis,* and white perch, *Morone americana;* effects of nitrosamines on marine fish tissue.) Richard Wolke, Graduate School of Oceanography and Department of Animal Pathology.
5. Economic analysis of salmonid aquaculture. John M. Gates, Department of Food and Resource Economics.

San Diego State College
San Diego, CA 92115
Sea Grant Program Director, Glenn A. Flittner, Bureau of Marine Science; telephone (714) 286-6523.
Projects:
1. Studies of recruitment and growth of puerulus and juveniles of the California spiny lobster. *(Panulirus interruptus.)* Deborah M. Dexter, Division of Life Sciences.
2. Investigation and development of an American lobster *(Homarus americanus)* fishery in California. Richard F. Ford, Division of Life Sciences.

Skidaway Institute of Oceanography
Savannah, GA 31406
Projects:
1. A study of the nutritional, environmental and economical requirements for the intensive aquaculture of penaeid shrimp. *(Penaeus setiferus, P. aztecus,* and *P. duorarum.)* James W. Andrews, Life Sciences Division.
2. Experimental rearing of flounder to marketable size in tidal flushed ponds. James W. Andrews, Life Sciences Division.

University of South Florida
Tampa, FL 33620
Projects:
1. Experimental cultivation of red algae of economic value in Florida marine waters. (12 species of red algae.) Harold J. Humm, Director, Marine Science Institute, St. Petersburg, FL 33701.
2. Ecological and culture studies on the red alga, *Eucheuma isiforme.* Clinton J. Dawes, Department of Botany and Bacteriology.

Texas A&M University
College Station, Texas 77843
Sea Grant Program Director, John C. Calhoun, Vice President; telephone (713) 845-3854.
Projects:
1. Mariculture of commerical crustaceans and fishes on the upper Texas coast. *(Panaeus aztecus, P. setiferus, Callinectes sapidus,* and *Mugil cephalus.)* Kirk Strawn, Department of Wildlife Science, College Station.
2. Mariculture pond demonstration. *(Panaeus aztecus* and *P. setiferus.)* John E. Hutchison, Director, Cooperative Extension Service, College Station.
3. Shrimp culture research. *(Panaeus aztecus* and *P. setiferus.)* William F. McIlhenny, The Dow Chemical Company, Freeport, TX 77541.
4. Bacterial and viral diseases and cell cultures of marine fish and shellfish. George W. Klontz, Department of Veterinary Medicine, College Station.

Virginia Institute of Marine Sciences
Gloucester Point, VA 23062
Sea Grant Program Director, William J. Hargis, Jr., Director; telephone (703) 642-2111.
Projects:
1. Develop and demonstrate improved methods of producing hard clams and investigate the possibility of reviving the bay scallop industry. *(Mercenaria*

mercenaria and *Aequipecten irradians.)* Michael Castagna, Eastern Shore Laboratory, Wachapreague; and William T. Duggan, Gloucester Point.
2. Management of larvae, supply of food. John L. Dupuy, Gloucester Point.

University of Washington
Seattle, WA 98105
Sea Grant Program Director, Stanley R. Murphy, Division of Marine Resources; telephone (206) 543-6600.
Projects:
1. Expanded program in salmonoid aquaculture. *(Oncorhynchus kisutch,* etc.) Lauren R. Donaldson, College of Fisheries.
2. Aquaculture of Puget Sound fishes. *(Oncorhynchus tschawytscha,* etc.) Ernest O. Salo, College of Fisheries.
3. Development of a clam and oyster farm at Big Beef Harbor. *(Venerupis japonica* and *Crassostrea gigas.)* Kenneth K. Chew, College of Fisheries.
4. Algal culture as aquaculture feed. Frieda B. Taub, College of Fisheries.
5. Aquaculture of marine algae. *(Iridaea cordata, Gigartina exasperata, Agardhiella tenera,* and *Sarcodiotheca furcata.)* Richard E. Norris, Department of Botany.

AQUACULTURE OF MOLLUSCS ALONG THE UNITED STATES ATLANTIC AND GULF COASTS

WILLIAM N. SHAW[1]

INTRODUCTION

Today I would like to take you on a tour of the east and gulf coasts of the United States to review the past and present status of molluscan aquaculture. Robert D. Wildman has already reviewed the current molluscan aquaculture projects under the Sea Grant Programs for this area, so I will cover these projects only briefly in my presentation. Because of the limited time, I plan to center my discussion around the culture of three species of molluscs, the Eastern oyster, *Crassostrea virginica;* the hard clam, *Mercenaria mercenaria;* and the bay scallop, *Aequipecten irradians.* Although there are other important commercial molluscs found along our east and gulf coasts, such as the surf clam, *Spisula solidissima;* ocean quahog, *Artica islandica;* sea scallop, *Placopecten magellanicus;* sunray venus, *Macrocallista nimbosa;* calico scallop, *Aequipecten gibbus;* and the soft-shell clam, *Mya arenaria,* these species are being hunted. Little or no attempt is being made to farm these species at the present time.

I will review the fishery for the oyster, hard clam, and bay scallop and describe past and present attempts to farm each species.

THE EASTERN OYSTER

The Eastern oyster, *Crassostrea virginica,* (also called the American or Virginia oyster) ranges along the entire east and gulf coasts. Peak of production, near 170 million pounds, was reached in the 1890's. Since then, landings have been on the decline with an apparent leveling off in the 1960's—around 50-60 million pounds (Engle, 1966). Unlike Japan, oysters along the east and gulf coasts are grown almost entirely on the bottom. The national average is reported to be only 0.004 tons per acre per year, while the best yield on the bottom is 2.0 tons per acre per year (Ryther and Bardach, 1968). These yields are extremely low when compared to those of Japan where 23.3 tons per acre per year are being harvested using off-bottom methods.

Not only are most of the U.S. methods of growing oysters extremely primitive, but so are our ways of harvesting. In Maryland, the state that has the largest annual production of oysters, oystermen catch oysters with hand tongs and patent tongs and in dredges pulled along the bottom by sailboats. Laws in this state prevent the use of more mechanical means such as the hydraulic dredges, except on private leases.

Realizing that the production of oysters has been on the decline, many private companies, state and federal agencies, and universities have in recent years initiated programs in an attempt to modernize the oyster industry. I would like to review some of these programs at this time.

New Hampshire

Under the U.S. Government's Federal Aid Program the State of New Hampshire has for 3 yr (1966-69) investigated the possibility of producing seed oysters and growing oysters using off-bottom techniques (Ayer, Smith, and Acheson, 1970). New Hampshire is at the northern limit of the oyster's natural range, and because of the cold waters, growth is slow. Still in certain areas, like Great Bay, the water warms sufficiently so that the natural oyster populations can spawn and setting does occur. It appears from their studies that a limited amount of seed could be produced annually, but intensity would vary greatly from year to year.

Massachusetts

Production of oysters in Massachusetts is small and only 72,100 pounds of meats were harvested in

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1970. Yet, during the 10-yr period from 1910 to 1919, an annual yield of 1.2 million pounds was realized. Up to recent times, all oysters were grown on leased bottoms. Because of the cold waters, it takes up to 5 yr for oysters to reach market size. Massachusetts oysters are of excellent quality and are eaten raw on the half shell. The wholesale price is as high as $22.00 per bushel (7,920 yen, 250 oysters to the bushel).

In 1956, the Bureau of Commercial Fisheries (now the National Marine Fisheries Service) initiated studies on the off-bottom culture of oysters in Massachusetts. Because of the oyster's high price, it was felt that this method of culture may be commercially feasible.

A log raft was constructed and moored in Oyster Pond River, Chatham, Mass. Oyster and scallop shells, containing seed oysters, were strung on #14 galvanized wire, each shell separated by a 3-inch piece of plastic tubing. The strings were suspended from the log raft for 1 yr, and then the oysters were removed and planted on the bottom for an additional year.

The results of the study showed that oysters grew almost twice as fast as those on the bottom. Survival of raft oysters was about 6 times greater than for the bottom grown oysters. Meat quality was excellent. Finally, the results indicated that raft culture appeared commercially feasible in Massachusetts (Shaw, 1962).

Similar raft studies were conducted by Matthiessen and Toner (1966) on Martha's Vineyard, Duke's County, Mass. These results showed that suspension techniques offered a promising method of oyster culture in the county. The authors felt that further refinement of suspended materials was needed and that rafts which could be conveniently submerged below the surface should be developed because many areas were exposed to storms and moving ice.

It was not until 1970 that off-bottom culture was attempted commercially in Massachusetts. Aqua Dynamics Corporation, Wareham, Mass. has begun to grow oysters suspended from iron-pipe racks (10 ft × 7½ ft × 5 ft) that rest on leased bottom. This year they plan to have 575 racks. Each rack contains 154 5-ft strings which will yield approximately 60 bushels of oysters. The corporation hopes to market their oysters, which will measure from 2 to 2½ inches, in 1½ yr. In a cooperative study with the National Marine Fisheries Service, Division of Marketing, it was learned that these small oysters have excellent consumer acceptance on the half shell.

An 8-ft high tower has been constructed adjacent to the Wareham River for growing oysters (Zahradnik and Johnson, 1970). A series of 4 ft × 4 ft tray-pallets containing up to 50 bushels of oysters are in the tower. Water is supplied to the tray-held oysters through a pipe running up the center of the tower. It is planned to operate the tower for 1 yr, including a winter season.

Rhode Island

In 1910 over 15 million pounds of oyster meats were harvested from Rhode Island. In 1970 only 146 pounds of meats were landed. Although many factors have contributed to this decline, pollution of Narragansett Bay is the probable leading factor.

At present, one company is attempting to grow oysters suspended from rafts (patent pending) in a small tidal pond. This is a small operation and only 800 bushels were expected to be harvested annually.

Connecticut-New York

In the late 1800's, Connecticut was producing over 10 million pounds of oyster meats annually. In 1970, only a little over 125,000 pounds of meats were landed. Set failures have contributed greatly to the drop in production. Loosanoff (1966) reported that during the years 1925-60, a good commercial set has occurred only 8 times. In addition, factors such as slow growth, predators, siltation, pollution, and hurricanes have all contributed to the decline of this once prosperous industry.

In an attempt to help the oyster industry of this area, a center for shellfish research was established by the Bureau of Commercial Fisheries at Milford, Conn. The Milford laboratory has become world renown for its work in developing shellfish hatchery techniques (Loosanoff and Davis, 1963). Shellfish hatcheries are now located throughout the United States and in many foreign countries. The use of lime and Polystream[2] for predator control was also developed at the Milford laboratory. Unfortunately, because of the current feelings about dumping chem-

[2] A polychlorobenzene product produced by Hooker Chemical Corp., Niagara Falls, New York. Polystream is a registered trademark. (Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.)

icals in the water, the license for using Polystream has not been renewed.

In 1968, the American Cyanamid Company of Stamford, Conn., developed a report entitled, "New Engineering Approaches for the Production of Connecticut Oysters." They attempted, through a search of published literature relating to oysters, to develop an oyster factory. The general conclusion was that more research was needed (Calbo et al., 1968).

In New York, over 24 million pounds of oyster meats were landed in 1911. Since then production has steadily declined and reached an all-time low in 1967 of only 101,000 pounds. From 1968 to 1970, production has risen slightly to 534,000 pounds in 1970. New York like Connecticut has faced seed shortages. Three interesting developments have taken place in recent years in an attempt to alleviate this problem. At Fisher's Island, N.Y., seed oysters are being caught on scallop shells suspended from rafts in a 23-acre brackish water pond (Matthiessen, 1970a). In 1969, 150 rafts were moored in the pond and roughly 68,000 strings were suspended. This year approximately 100,000 strings were used. In 7 yr of operation, only once was there a set failure. A portion of the shells bearing the oyster spat are stripped from the strings, loaded upon oyster boats, and planted upon private grounds in Long Island Sound. The remainder of the shells are transported to Massachusetts and suspended from the iron-pipe rack described earlier in the talk.

Second is the development of commercial shellfish hatcheries in the Long Island Sound area. One of the largest is operated by the Long Island Oyster Farms, Inc., in cooperation with the Long Island Lighting Company. The hatchery is utilizing a 4-acre pond which receives warm-water discharge from a fossil-fuel power plant. The young trayed oysters are placed in the pond for various periods of time before being planted on the bottom in the natural waters of the Sound. Because of the quicker growth rates in the heated pond, the oysters reach market size in a year or so sooner. A marine museum adjacent to the hatchery has been constructed for the viewing public.

Third is the New York State Department of Environmental Conservation project supported by federal funds (PL 88-309) to produce seed oysters in a natural pond in East Hampton, Long Island. To date, little success has been obtained in their attempts to catch seed on shells suspended from rafts or placed on the bottom.

New Jersey-Delaware

The leading area of oyster production in the New Jersey-Delaware area is Delaware Bay. The once productive oyster beds in the Bay have been devastated by increasing pollution, freshwater abatement, increased predation problems, and, most recently, by massive mortalities from the disease, "MSX" *(Minchinia nelsoni)*. Landings in 1970 totalled only 869,000 pounds. In 1950, the two states produced over 9 million pounds of oyster meats. The bay can be divided into two areas—the upper seed beds and the lower leased growing grounds. Shells are planted on the seed beds and later transplanted by the private planters to their leased bottoms. Following the heavy mortalities in 1957 and 1958, New Jersey initiated a large shell planting program to rehabilitate the oyster industry. Recently, heavy oyster sets on these shells suggests that the oyster industry may recover.

Both Rutgers University and the University of Delaware have been investigating disease resistance of oysters to MSX. Also, at the University of Delaware, extensive studies on the feasibility of semi-closed and closed systems for culturing oysters are now underway. This aspect of research is supported under the Sea Grant Program described earlier by Robert D. Wildman.

Maryland-Virginia

Chesapeake Bay is one of the leading oyster producing areas of the world. In 1880, nearly 125 million pounds of meats were harvested from the Bay. In 1970, production was just under 35 million pounds or about one-half of the total U.S. production for that year. Yet, methods of oyster culture are extremely primitive with little or no change in either culturing or harvesting methods since the turn of the century.

In Maryland, for example, the majority of oysters harvested come from public bars. The tools used to harvest these oysters include hand tongs, patent tongs, and dredges pulled by boats under sail. Management consists mainly of planting up to 5 million bushels of shells for catching seed oysters and improving or enlarging public oyster bars. Following setting, the seed is replanted on public oyster bars where it remains until harvested by oystermen, 3 or 4 yr later.

There have been several attempts in recent years to demonstrate new methods of oyster culture that may be applied in Chesapeake Bay. These include hatchery systems, raft production of seed oysters, and culture of oysters to market size using off-bottom techniques. Two commercial shellfish hatcheries have been built, one at Urbanna, Va., and the other on West River in Maryland. Both are producing cultchless oysters. Unfortunately these single oysters are very vulnerable to predators and the handling of the juveniles is a formidable problem (Matthiessen, 1970b). The former company is attempting to grow them to market size while the latter is selling the small spat to private growers. There are also two research agencies, Virginia Institute of Marine Science (Andrews and Mason, 1969) and the Chesapeake Biological Laboratory (Hidu, 1971; Hidu et al., 1969), working on hatchery techniques.

Two agencies, the Maryland Department of Natural Resources (Otto, 1969) and the National Marine Fisheries Service (Shaw, 1970), have been studying raft production of seed oysters. Shells, either on strings or in chicken-wire bags, are suspended from rafts. Excellent sets are being obtained using the off-bottom techniques, but to date it has not been adapted commercially in Chesapeake Bay.

The National Marine Fisheries Service has also been studying the off-bottom culture of oysters (Shaw, 1969, 1970, 1971). Methods being tested include raft, longline, and rigid-structure. Strings of spat-laden shells are suspended from each floating device and maintained in suspension until the oysters reach market size—about 2½ yr from time of set. It is estimated that 11.9 tons of oyster meats per acre per year could be produced using off-bottom techniques.

In Virginia the majority of oysters are grown on private leases. Power dredging is the common method used for harvesting although hand tonging is also practiced. The majority of seed for the private bed cultivation comes from the James River. Unfortunately, in the late 1950's and early 1960's, heavy mortalities from MSX occurred among the oysters in the high salinity waters which included the spawning stocks for James River seed. Since then little or no setting has occurred in the James River.

The Virginia Institute of Marine Science has been working on developing disease resistant stocks using hatchery techniques. In addition, spat collecting shells are being planted in Great Wicomico, Piankatank, and other rivers (Bailey and Biggs, 1968). It is hoped that through the development of disease resistant stocks and managing around the disease, the oyster industry of Virginia can come back to productive levels.

North Carolina, South Carolina, and Georgia

The total production for the three south Atlantic states—North Carolina, South Carolina, and Georgia—was estimated to be 1.4 million pounds in 1970. Methods of culture in these three states are primitive, harvesting by hand is not uncommon. Little attempt has been made, until recently, to investigate new aquaculture techniques. In North Carolina, a seed collecting project was undertaken under the federal aid PL 88-309 program. Several varieties of cultch were tested. Because of heavy fouling, the cultch was lifted out of the water periodically. Using the airing technique, good quantities of seed and commercial size oysters were produced, but because of the excessive expense involved in the methods tested, it did not appear commercially feasible (Marshall, 1969).

The Coastal Zone Resources Corporation is attempting to grow oysters caught on passenger car tire beads (David Adams, pers. comm.). Eighty tons of eight bead configurations (about 14,000) have been planted in an area where oysters have the reputation for high quality and rapid growth. Each configuration is anticipated to yield about one-half bushel of oysters in 30 mo.

Beginning in 1944, extensive studies were conducted in South Carolina on the cultivation of oysters in ponds. Initially (1944-45), excellent results were obtained and marketable single oysters were produced in 2 yr. In 1950, drought conditions developed and salinities in the ponds rose. A sudden mass mortality among pond held oysters developed probably by *Dermocystidium*. It was concluded that as long as wild oysters are available to the industry, it is unlikely that pond culture will be economically practicable (Lunz, 1956).

In Georgia, two members of the Japanese panel, Atsushi Furukawa and Hisashi Kan-no, assisted in an attempt to develop off-bottom oyster culture techniques. Many problems were encountered including fouling, heavy siltation, erosion, and retardation of growth. It was felt that because of the current low price of oysters, off-bottom culture did not appear commercially feasible in Georgia at the present time (Linton, 1968).

Florida

In 1970, Florida produced about 3.8 million pounds of oyster meats. The majority of oysters comes from the west coast of Florida. Oysters are harvested from public reefs either by tongs or picked by hand, with dredging allowed on leased beds. The future of the Florida oyster industry lies in the cultivation of the private leases (Ingle and Whitfield, 1962).

The Florida Department of Natural Resources has several research projects related to oyster aquaculture (Florida Department of Natural Resources, 1970)—one is oyster nutrition and the other is oyster reef modification. Some success has been obtained in fattening oysters with finely ground cornmeal. These studies are continuing in conjunction with learning optimal conditions (temperature, salinity, and other parameters) for fattening oysters.

Florida is presently studying the modification of natural reefs to improve their oyster production. Artificial gaps are being cut in the reefs. Oysters planted in these cut-out areas have shown excellent growth. Florida, through federal aid PL 88-309, is also constructing artificial oyster reefs using oyster shells and limestone slag. Some excellent sets have been obtained on the planted cultch.

One commercial company at Cedar Key, Fla., is attempting to grow strings of oysters from rigid structures (Robinson, 1971). Some problems have occurred resulting from the oysters falling off the strings. To solve this problem, portable racks have been built with bottoms to catch the oysters that fall off.

Similar to studies in North Carolina, attempts are being made to catch and grow oysters on tire beads at Cedar Keys, Fla. In this case the tire beads and configuration have been patented. It is not known if the operation is successful.

Alabama

The oyster industry of Alabama is based upon natural repopulations of public reefs which include about 3,064 acres (May, 1971). In addition, there are approximately 2,000 acres of private bottoms, but they yield only 12% of Alabama's total oyster production (annual average from 1948 to 1968 was 1.2 million pounds of meats). Lack of seed has kept private production down. All of the oysters from public reefs are harvested with hand tongs; however, harvesting from private beds can be accomplished with dredges.

Very little attempt has been made to try to modernize the Alabama oyster industry. May (1969) investigated the feasibility of off-bottom oyster culture. Both rack and raft methods were tested. Although excellent growth was obtained, he found the off-bottom culture was not economically feasible because of high production costs and low market value. The Alabama Marine Resources Laboratory at Dauphin Island constructed a ¼-acre tidal pond to study the commercial rearing of oysters. In 1968, oysters were placed in the pond and after 12 mo the oysters had increased in height from 18 mm to 101 mm. Ninety-one percent were legal size after 8½ mo of growth. It is not known if studies were continued.

Mississippi

The entire Mississippi oyster production comes from public reefs (about 3,000 acres), there are no private leases (Maghan, 1967). Annual production fluctuates considerably because of adverse weather conditions, leveeing of the Mississippi River, predators, and disease. As an example of these fluctuations, production in 1968 was 3.8 million pounds of meats while in 1970 only 547,000 pounds were landed. Except for extensive plantings of shells and seed oysters, there has been little attempt to modernize the oyster industry of Mississippi.

Louisiana

In 1970, Louisiana produced 8.1 million pounds of oyster meats, second in the nation to Maryland. Roughly 70-80% of the oysters are canned (Matthiessen, 1970b). Louisiana has a well-managed industry based on privately owned or leased bottoms, approximately 83,000 acres, plus state-owned areas (450,000 acres) set aside as a source of seed oysters (St. Amant, 1964). Growers are allowed to gather wild seed for planting on their leased grounds. All oysters are grown on the bottom and no attempt has been made to try off-bottom techniques.

The Louisiana Marine Laboratory on Grand Terre Island has several projects (federal aid PL 88-309) related to oyster culture. These studies include the reestablishment of historical seed grounds and control of the Southern oyster drill, *Thais haemostoma*. Both projects are still in progress so final results are not available.

At Grand Terre Island, 16 ¼-acre ponds were constructed on existing marsh floor. The levees were enclosed by two asbestos bulkheads that were supported by creosote posts and tied together by galvanized steel rods. Besides oysters, brown and white shrimp plus selected fishes are being cultured in these ponds. Preliminary results with oysters were not promising when high water temperatures resulted in excessive mortalities (Matthiessen, 1970b).

Texas

In 1970, 4.6 million pounds of oyster meats were harvested from Texas. The center of production is Galveston Bay. Harvesting has been confined almost entirely to the 22,000 acres of natural reefs (Hofstetter, 1959), although there are some 3,000 acres of leased bottom. Lack of good bottom for leasing has been a deterrent to oyster cultivation.

Considerable interest has developed recently in the pond culture of oysters (More and Elam, 1970). At Palacios, Texas, the Parks and Wildlife Department has built 21 artificial ponds ranging in size from a quarter of an acre to 4 acres. Studies on disease resistance to the fungal parasite *Labyrinthomixa* sp. are being conducted. Attempts are also being made to relate water depth and type of pond construction to oyster growth and survival.

THE HARD CLAM

The hard clam, *Mercenaria mercenaria*, (also called quahog, quohog, and quahaug) is distributed along the Atlantic coast and the Gulf of Mexico. They reached their peak of production in 1950 when 21 million pounds were harvested. Production then dropped until 1955 when 14.2 million pounds were landed. Since then, production has remained fairly stable fluctuating between 13.3 and 15.8 million pounds, and in 1970 approximately 15.4 million pounds of meats were produced. New York is the leading producer (7.9 million pounds) while five states—Virginia, New Jersey, New York, Massachusetts, and Rhode Island—accounted for 91% of the total U.S. landings. The entire fishery comes from wild stocks although some attempts are being made to utilize hatchery stocks.

In New York the center of the resource is on the southern shore of Long Island in the sheltered bays such as Great South Bay. Many types of gear have been used to harvest clams. These include tongs, rakes, dredges, by hand, hoes, and grabs. In 1967, New York harvesting was divided among three types of gear—dredges, 2.6 million pounds; tongs, 2.5 million pounds; and rakes, 1.9 million pounds. Introduced into this industry in recent years was the hydraulic escalator dredge which harvests clams with surprisingly little damage (Engle, 1970) to either the clams or the clam beds. This gear is also used in Chincoteague Bay, Md.

The hard clam fishery appears to be in excellent condition although there is some concern over the increasing threat of pollution. In New York there are an estimated 450,000 acres of potential shellfish producing bottoms of which 156,892 acres or approximately 35% of the total are uncertified. Considerable effort has been devoted by the New York Conservation Department to develop depuration techniques. A PL 88-309 project entitled, "Operation of a depuration plant for hard clams (*Mercenaria mercenaria*)," was completed in 1969 (MacMillan and Redman, 1971). Results of the study, using a "pilot" scale depuration system, indicated that the depuration of hard clams is feasible, both economically and bacteriologically when such shellfish are harvested from restricted growing areas (Median Coliform MPN range: 70-700). The successful operation is greatly enhanced utilizing seawater obtained from a saltwater well. It was estimated that hard clams could be depurated at a cost of $1.76 per bushel.

The most intensive efforts towards propagation on a commercial scale have been made on Cape Cod and Long Island (Miller et al., 1970). Clams are artificially spawned to setting using methods described by Loosanoff and Davis (1963). The seed clams are held in especially designed hatcheries and then transplanted to controlled growing areas. Heavy losses from predation have been a serious problem following planting on the growing grounds. To solve this problem the Virginia Institute of Marine Science has developed the use of aggregates on the bottom to protect the seed clams from predators (Castagna, 1970). Three types of aggregates were found successful: 1) crushed oyster shell, 2) crushed stone, and 3) stream bed gravel (pea gravel).

An average of more than 80% of the seed clams planted with aggregates survived compared to 16-30% survival on plots without any aggregates. Clams should be at least match-head size before planting and should be scattered over the aggregate at a rate of about 25-50 per square foot.

One of the largest clam hatcheries is located in North Carolina (Tyler, 1970). Since early 1970, Coastal Zone Resources Corporation has been engaged in producing hard clam sets using hatchery techniques (David A. Adams, pers. comm.). Approximately 4 million clam larvae are produced each week. Metamorphosis occurs in about 2 wk. They are then placed in shallow 2 ft × 4 ft plywood trays mounted vertically in banks of 10 trays each. Here the set stays for an additional 8 wk. When the clams are about 10 wk old, they are transferred into running seawater concrete raceways. Under ideal conditions, the seed clams measure 1-2 cm at about 14 wk of age. When the clams reach 2.5 cm, they are either sold as seed clams or planted by the corporation on nearby mud flats to grow to commercial size.

THE BAY SCALLOP

The bay scallop, *Aequipecten irradians*, ranges from Maine to the Gulf of Mexico (Belding, 1910). Principal areas of abundance are the southern New England states; Peconic Bay, Long Island, N.Y.; and the bay and inlets of North Carolina (Gutsell, 1931). In 1970, approximately 865,000 pounds, valued at 1.2 million dollars (dockside value $1.39/lb) were landed in two states, New York and Massachusetts. The bay scallop rarely lives beyond 2 yr (Merrill and Tubiash, 1970). Because of its short life span and high value, this species is highly suitable for aquaculture. Yet, very little attempt has been made to farm this animal.

Wells (New York Conservation Commission, 1927) was one of the first to artificially rear bay scallops. Since then others including Loosanoff and Davis (1963) and Castagna and Duggan (1971) have successfully spawned and reared the larvae to setting stages.

Several programs are presently underway in an attempt to farm the bay scallop. Under a federal aid project PL 88-309, the State of New York has just begun studies on the growth of scallops during the fall, winter, and spring in heated waters. Scallops will be subjected to 40°, 50°, 60°, and 70°F respectively, and periodic growth measurements will be taken. It is also planned to place scallops in cages placed in the effluent discharge from LILCO Electric Power Station at Port Jefferson, N.Y.

Under a Sea Grant Program described earlier by Robert D. Wildman, the Virginia Institute of Marine Science is rearing bay scallops to market size under controlled conditions (Castagna and Duggan, 1971). Scallops collected from Virginia and North Carolina were conditioned and spawned in the laboratory. Following setting, juveniles were held in plastic trays in the laboratory for 1 wk. They were then moved to outdoor tanks with flowing unfiltered seawater. They remained there until they were 2 mm in width. The scallops were then moved to natural waters and placed in plastic coated wooden floats. They reached an average minimum market size of 50 mm in 12-13 mo. The authors felt that bay scallops appeared amenable to mariculture.

FUTURE MOLLUSCAN AQUACULTURE IN THE UNITED STATES ATLANTIC AND GULF COASTS

I have briefly described the past and present status of molluscan aquaculture along the Atlantic and Gulf coasts. The next question is where do we go from here? In your country (Japan), we realize that molluscan aquaculture is much further advanced than in the United States. One reason, of course, is your basic protein diet consists of aquatic products while Americans eat basically land-grown products (beef, chicken, etc.). To supply the Japanese people with aquatic products, you utilize your inland waters considerably different than we do in the United States. For example, almost all of your oysters are grown off-bottom in order to produce the maximum numbers per unit of area. You have set priorities on the use of your waters—first, for food production; second, for navigation; and third, for recreation. In the United States the waters are used mainly for navigation and recreation. The use of our waters for food production is on a very low scale. For the United States to develop molluscan aquaculture in the future, we will have to change our philosophy on water usage. This is going to be extremely difficult and maybe impossible.

A second point is that the development of molluscan aquaculture in the United States will only succeed if it is done profitably. Already many companies which entered aquaculture have lost money and have quickly left the business. For this reason the development of aquaculture in the United States must depend initially on animals that have a high market value. These animals must feed at a low trophic level. Even using high valued crops, it is a question whether or not a profit can be made because of high costs of labor, materials, private leases, etc.

The third problem is that legal rights to conduct aquaculture must be defined. Only recently laws were passed in Florida which made mariculture legal (Davis and Shields, 1971). Similarily, in Maryland, until this year, it was illegal to grow oysters off-bottom. These are exceptions—in most states along the Atlantic and Gulf coasts, there are no laws which protect the aquaculture investor or even allows aquaculture to be conducted.

The threat of pollution will hinder the development of molluscan aquaculture in the United States. No one wants to invest a great amount of capital, raise a product to market size, and then find that he cannot sell his product because it comes from polluted waters. One answer to this problem is to avoid the use of waterways and to culture the animals in a closed system similar to methods used to grow chickens. Unfortunately, our technology has not developed far enough to make this possible. Sea Grant Programs, like the one at the University of Delaware, are working towards this goal.

It is the hope of all of us at this Symposium, that aquaculture will develop to the level of agriculture. Your country has made great strides towards this goal. Through our state, university, and govermental agencies, we in the United States are learning more every day about aquaculture techniques. It is hopeful that this knowledge can be applied in the future. It is our goal that someday, through the development of aquaculture techniques, we may produce enough protein to help feed our increasing world population. IT MAY BE OUR ONLY SALVATION!!!

LITERATURE CITED

ANDREWS, J. D., and L. W. MASON.
1969. Exciting new hatchery techniques cultchless seed oysters. Va. Inst. Mar. Sci. 3, 2 p.

AYER, W. C., B. SMITH, and R. D. ACHESON.
1970. An investigation of the possibility of seed oyster production in Great Bay, New Hampshire. N.H. Fish Game Dep., Mar. Survey Rep. 2, Fed. Aid PL 88-309, Proj. 3-32-R. 106 p.

BAILEY, R. S., and F. C. BIGGS.
1968. Let's be oyster farmers. Va. Inst. Mar. Sci., 59 p.

BELDING, D. L.
1910. A report upon the scallop fishery of Massachusetts including the habits, life history of *Pecten irradians*, its rate of growth, and other facts of economic value. Mass. Comm. Fish. Game, 150 p.

CALBO, L. J., A. PERLUMUTTER, D. R. GOODRICH, and R. B. WAINRIGHT.
1968. New engineering approaches for the production of Connecticut oysters. A problem analysis. American Cyanamid Company, Vol. I. 140 p.

CASTAGNA, M. A.
1970. Hard clam culture method developed at VIMS. Va. Inst. Mar. Sci. 4, 4 p.

CASTAGNA, M., and W. DUGGAN.
1971. Rearing the bay scallop, *Aequipecten irradians*. Proc. Natl. Shellfish Assoc. 61:80-85.

DAVIES, C. B., and H. W. SHIELDS.
1971. Mariculture and the law. Proc. 1st Annu. Workshop World Mariculture Soc. 1970:55-59.

ENGLE, J. B.
1966. The molluscan shellfish industry, current status and trends. Proc. Natl. Shellfish. Assoc. 56:13-21.
1970. Oyster and clam management. *In* N. G. Benson (editor), A century of fisheries in North America. Am. Fish. Soc., Spec. Publ. 7:263-276.

FLORIDA DEPARTMENT OF NATURAL RESOURCES.
1970. Current research. Florida Department of Natural Resources, Marine Research Laboratory, St. Petersburg, Fla., 19 p.

GUTSELL, J. S.
1930. Natural history of the bay scallop. U.S. Bur. Fish. 46:569-632.

HIDU, H.
1971. The feasibility of oyster hatcheries in the Delaware-Chesapeake Bay region. *In* K. S. Price, Jr., and D. L. Maurer (editors), Proceedings on the Conference of the Artificial Propagation of Commercially Valuable Shellfish-Oysters-October 22-23, 1969:111-131.

HIDU, H., K. G. DROBECK, E. A. DUNNINGTON, JR., W. H. ROOSENBURG, and R. L. BECKETT.
1969. Oyster hatcheries for the Chesapeake Bay region. Univ. Maryland, Nat. Res. Inst., Contrib. 382, 18 p.

HOFSTETTER, R. P.
1959. The Texas oyster fishery. Tex. Game Fish Comm., Bull. 40:1-38.

INGLE, R. M., and W. K. WHITFIELD, JR.
1962. Oyster culture in Florida. Fla. State Board Conserv., Educ. Ser. 5 (revised), 25 p.

LINTON, T. L.
1968. Feasibility studies of raft-culturing oysters in Georgia. Proceedings of the Oyster Culture Workshop July 11-13, 1967. Ga. Game Fish Comm., Mar. Fish. Div., Contrib. Ser. 6:69-73.

LOOSANOFF, V. L.
1966. Time and intensity of setting of the oyster, *Crassostrea virginica*, in Long Island Sound. Biol. Bull. (Woods Hole) 130:211-227.

LOOSANOFF, V. L., and H. C. DAVIS.
1963. Rearing of bivalve mollusks. *In* F. S. Russell (editor), Advances in marine biology, vol. 1, p. 1-136. Academic Press, London and New York.

LUNZ, G. R.
1956. Cultivation of oysters in ponds at Bears Bluff Laboratories. Proc. Natl. Shellfish. Assoc. 46:83-87.

MAGHAN, B. W.
1967. The Mississippi oyster industry. U.S. Fish Wildl. Serv., Fish. Leafl. 607, 12 p.

MacMILLAN, R. B., and J. H. REDMAN.
1971. Hard clam cleansing in New York. Commer. Fish. Rev. 33(5):25-33.

MARSHALL, H. L.
1969. Development and evaluation of new cultch materials and techniques for three-dimensional oyster culture. N.C. Dep. Conserv. Dev., Div. Commer. Sports Fish., Spec. Sci. Rep. 17, 35 p.

MATTHIESSEN, G. C.
1970a. Seed oyster production in a salt pond. *In* H. W. Youngken, Jr. (editor), Food-Drugs from the Sea Proceedings 1969:87-91.

1970b. A review of oyster culture and the oyster industry in North America. Woods Hole Oceanographic Institution, Contrib. 2528, 52 p.

MATTHIESSEN, G. C., and R. C. TONER.

1966. Possible methods in improving the shellfish industry of Martha's Vineyard Duke's County, Massachusetts. The Marine Research Foundation, Inc., 138 p.

MAY, E. B.

1969. Feasibility of off-bottom oyster culture in Alabama. Ala. Mar. Res. Bull. 3:1-14.

1971. A survey of the oysters and oyster shell resources of Alabama. Ala. Mar. Res. Bull. 4:1-53.

MERRILL, A. S. and H. S. TUBIASH.

1970. Molluscan resources of the Atlantic and Gulf coasts of the United States. Proc. Symp. Mollusca: Part III:925-948.

MILLER, W. S., E. M. WALLACE, C. N. SHUSTER, JR., and R. E. HILLMAN.

1970. Hard clam. . .the gourmet's delight. Atl. States Mar. Fish. Comm., Leafl. 4, 8 p.

MORE, W. R., and L. L. ELAM.

1970. Salt water pond research 1970. Job 4-Oyster research. Tex. Parks Wildl. Dep., Coastal Fish., Austin, Tex., 9 p.

[STATE OF] NEW YORK CONSERVATION COMMISSION.

1927. Report of the experimental shellfish station. *In* State of New York Conservation Commission Sixteenth Annual Report; for the year 1926, p. 113-130. J. B. Lyon, Albany.

OTTO, S. V.

1969. The Manokin River Project. Commercial Fisheries News, Chesapeake Bay Affairs 2(2):4.

ROBINSON, P.

1971. String-growing of Florida oysters has promise of heavy production. Natl. Fisherman, February, p. 4-c.

RYTHER, J. H., and J. E. BARDACH.

1968. The status and potential of aquaculture. Particularly invertebrate and algae culture. Vol. I., Part I. The status and potential of aquaculture. American Institution of Biological Sciences, Washington, D. C., 45 p.

SHAW, W. N.

1962. Raft culture of oysters in Massachusetts. U.S. Fish Wildl. Serv., Fish. Bull. 61:481-495.

1969. The past and present status of off-bottom oyster culture in North America. Trans. Am. Fish Soc. 98:755-761.

1970. Raft production of seed oysters in upper Chesapeake Bay. Proc. Natl. Shellfish. Assoc. 60:11.

1971. Off-bottom growing techniques. American Fish Farmer and World Aquaculture News 2(9):16-21.

ST. AMANT, L. S.

1964. Louisiana leads in oyster production! Louisiana Wildl. Fish. Comm., Wildl. Educ. Bull. 84, 11 p.

TYLER, J.

1970. Raising clams for money. N.C. Tar Heel Coast 6(12):1.

ZAHRADNIK, J. W., and C. A. JOHNSON.

1970. Proposed 50 bushel pilot plant for oyster production. (Abstract.) Proc. Natl. Shellfish. Assoc. 60:12.

FRESHWATER FISH CULTURE IN THE UNITED STATES

HARVEY WILLOUGHBY[1]

INTRODUCTION

Freshwater fish culture in the United States is a popular and fast growing business. Fish are reared for three main purposes: 1) for stocking public and private waters to support commercial and sport fishing or to be used as bait to catch sport and commercial species, 2) for marketing directly to the consumer for food, and 3) for home aquariums or private fish ponds for ornamentation and pleasure.

Rearing fish to augment depleted natural stocks, or to introduce new species into public waters has traditionally represented the greatest expenditure of effort in America. The State of Massachusetts established the first government-owned hatchery in the United States in 1868. It was followed by the States of Connecticut and New York, and in 1871 the federal government established a fish commission to study the decline of native fish stocks and to recommend remedial measures. This commission later became the U.S. Bureau of Fisheries—the predecessor agency of the Bureau of Sport Fisheries and Wildlife, which I represent, and the National Marine Fisheries Service, which employs my colleagues, William N. Shaw, John B. Glude, and Robert D. Wildman. This year then, 1971, marks the centennial year of our federal government's involvement in fish conservation. A series of celebrations and other special events have been held throughout this year to commemorate our centennial year.

The activities of the federal government in the field of fish culture, fishery research, and management have been expanded greatly during the last one hundred years, but they have been outpaced by the individual state governments. As an indication of the relative level of effort by the federal and state governments, it is noted that the federal government operates 95 fish hatcheries and funds another 15 that are operated by states, while hatcheries operated by the state governments number about 500. To get a picture of the total U.S. effort in fish culture, one would add more than 2,000 private fish growers to the above list.

LEVEL OF FISH PRODUCTION

Fish produced at hatcheries operated by federal and state agencies are stocked primarily in public waters to improve or maintain sport and commercial fishing. The Bureau of Sport Fisheries and Wildlife and many state agencies also furnish fish, free of charge, for stocking waters owned or controlled by individuals. Much emphasis is on stocking sport fish since fishing is one of the most popular outdoor sports in the United States. In 1970, over 49 million sport fishermen fished in fresh and salt waters (U.S. Bureau of Sport Fisheries and Wildlife, 1971.)

In addition to federal and state hatcheries, there are well over 2,000 commercial hatcheries in the United States. These are divided into three general classes: bait minnow, catfish, and trout hatcheries.

The estimated production of freshwater fish produced in 1965 by all hatcheries in the United States was as follows:

	Metric Ton
Federal hatcheries	2,565
State hatcheries	12,684
Commercial hatcheries	
Bait minnows	22,650
Catfish and other warmwater fish	13,000
Trout	9,060

Data from federal fish hatcheries show that production costs have been significantly lower in the past 20 yr (Table 1). The total cost of producing a kilogram of trout has decreased about 4% because of better diets, improved feeding practices, and more efficient operations. Feed costs have been

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Table 1.—Production cost of federal fish and hatcheries in 1947, 1956, 1968, and 1970.

	1947	1956	1968	1970
Trout:				
Production, metric ton	157	466	2,172	1,972
Total cost/kg	$ 3.19	$ 2.24	$ 1.83	$ 1.41
Feed cost/kg	$ 0.70	$ 0.57	$ 0.37	$ 0.33
Conversion[1]	4.8	2.8	1.7	1.5
Salmon:				
Production, metric ton	98	58	513	548
Total cost/kg	$ 2.97	$ 2.31	$ 2.60	$ 2.95
Feed cost/kg	$ 0.42	$ 0.48	$ 0.59	$ 0.55
Conversion	2.9	2.3	1.9	1.8
Pondfish:				
Millions of fish	93	96	85	83
Production, metric ton	54	57	109	162
Total cost/kg	$ 7.90	$18.17	$16.24	$ 7.48
Cost/1,000 fish	$ 4.59	$15.41	$26.36	$17.18

[1] Ratio of weight of fish feed used to weight of fish produced.

Trout 1970:

Average production per man-year	10 metric ton
Average production, liters per second	46 kg

Warmwater Fish (1970):

Average production per hectare	170,000 fish
Average production per man-year	725,000 fish

reduced sevenfold since the 19th century, when inflation is considered, and have decreased 25% since the advent of pelleted diets. However, the cost of rearing salmon has remained somewhat stable. Current cost figures were not available for state and commercial hatcheries; however, it is believed that their production costs are somewhat similar to costs listed for federal hatcheries.

TYPES OF FISH CULTURE

It has long been the custom in the United States to classify fish hatcheries into two types—extensive, where large water areas are used to supply both the nutritional and environmental needs, and intensive, where the fish are confined in small ponds or tanks, their nutritional needs met by hand feeding, and their environmental needs met by rapid exchanges of water in the pond. By tradition, extensive culture methods have been used to rear warmwater and cool-water species (temperatures 15°-27°C), while intensive culture has been practiced for the cold-water species (10°-16°C), in the family Salmonidae. This distinction is beginning to disappear however, as improved technology is demonstrating the practicability of rearing such warmwater species as channel catfish, *Ictalurus punctatus*, and striped bass, *Morone saxitilis*, by intensive culture methods.

Extensive Fish Culture

The extensive fish culturist, or pondfish culturist as he is more commonly called, is basically an ecologist. His job is to maintain optimum opportunities for fish to spawn and grow under seminatural conditions. He hopes to improve upon nature by increasing the productivity of the pond. High survival rates are achieved by eliminating competition by other fish and by holding cannibalism to a minimum through the prevention of a size spread of the fish in the pond. In order to maintain uniform size, it is essential that the fish spawn at the same time. This is achieved with channel catfish and striped bass by hormone injection. The spawning time of species such as sunfishes, which are allowed to spawn in the pond, is controlled by separating the sexes and holding them in cold water until seasonal water temperatures have reached the desired level.

Attempts are being made to gain greater control over the spawning and survival of even these species. Limited success in this direction has been achieved by placing nylon fiber mats in the ponds to serve as a place for the fish to deposit their eggs. Experiments conducted at the Fish Culture Development Center at Marion, Ala., during the past several seasons, have indicated a promising preference for the use of the mats by the largemouth bass, *Micropterus salmoides*. After the eggs are deposited, the mats are removed and placed in hatchery tanks where the required care and protection can be given them. This is nothing more than a modern adaptation of the ancient Chinese practice of placing brush mats in known spawning areas to collect carp eggs.

A principal limitation to higher yield of warmwater species in hatcheries has been the problem of providing natural food. To accomplish this, ponds are fertilized. Intensive fertilization can produce enough natural food organisms in static ponds to rear up to 550 kg of fish from a hectare of water in a single season. Supplementary feeding can increase this up to about 2,500 kg. Oxygen limitations in lentic environments prevent higher yields, but aeration devices should prove that higher yields are possible.

Efforts to hand feed largemouth bass have often been discouraging, but work toward this goal continues, and recent reports from the Development Center at Marion, Ala., tell of producing largemouth bass up to 20 cm long by supplemental feeding, with a conversion ratio of 1.4:1.

Cultural techniques of other species reared at our warmwater hatcheries are described as follows:

Walleye *(Stizostedion vitreum vitreum)*

The walleye is one of our most valuable freshwater sport fish. It also ranks high in the commercial harvest. In reclaimed lakes, that is lakes in which the entire fish population has been deliberately poisoned out, this species has had the greatest success when stocked as fingerlings 5 cm long.

It has not proved feasible to rear walleyes to maturity under hatchery conditions. Consequently, adult fish must be trapped from the natural environment during the spring spawning run and hand stripped. The eggs are incubated, usually in a jar battery, and the swim-up fry stocked into fertilized rearing ponds. Under the best conditions, 5-cm fingerlings are harvested in about 4 wk.

Muskellunge *(Esox masquinongy)* and Northern Pike *(E. Lucius)*

The muskellunge and northern pike fit a very special niche as efficient predators in shallow lakes. The muskellunge (or muskies for short) is particularly prized as a trophy fish. Both species are reared in a somewhat similar fashion as adult spawners are trapped in the wild and hand stripped. A certain amount of success has been achieved in speeding maturation of female northern pike by injecting dried carp pituitary interperitoneally at a rate of 5 mg/kg of body weight.

Once the eggs have been fertilized and become turgid, they are incubated in jar batteries until hatching and swim-up. The fry are then stocked into fertilized ponds and 5-cm fingerlings are harvested 3-5 wk later. In the case of muskies, the fingerlings are then stocked back into ponds at a reduced rate and fed forage fish until they reach a length of 25-30 cm. At that size the fish are ready to be stocked back into the natural environment and good survival can be expected.

In recent years, limited success has been achieved in rearing muskies in concrete tanks on a diet of forage fish. Indications are that there will be more tank culture of this species in the future.

Bait Fishes

Bait fishes are raised in farm ponds, natural lakes, and other still waters devoid of predaceous fish. Some of the more common species of bait fish reared in the United States are goldfish, *Carassius auratus;* golden shiners, *Notemigonus crysoleucas;* and fathead minnows, *Pimephales promelas*. Once ponds are prepared, culture in the simplest form may be undertaken by merely introducing adult breeders. The prolific nature of these fish generally results in a rapid increase of the stock by natural reproduction. Annual yields generally range from 1,300 to 4,500 kg/ha.

Channel Catfish, *Ictalurus punctatus*

For the past 10 yr channel catfish cultivation has rapidly increased in the United States. There are now approximately 24,600 hectares of ponds devoted to the growing of catfish. This can be compared to 100 hectares 10 yr ago. The gross annual value to the farmers in 1971 was approximately $31 million from the 40,800 metric tons produced.

To date, most catfish rearing has been done in large impoundments, many of them operated in rotation with rice farming. More recent entrepreneurs into the catfish farming industry are large corporations which employ professional staffs of engineers, biologists, and business managers. These enterprises are beginning to use intensive culture methods to rear catfish. Production levels of 9 kg/m^3 are being realized in circular tanks.

Raceway culture at the Fish Farming Experimental Station which the Bureau of Sport Fisheries and Wildlife operates at Stuttgart, Ark., is producing about 900 kg of catfish per year in 115 m^3 of space with a total flow of 35 liters/sec. Water temperature is 28°C. This is far below the potential for this species in light of experimental data which reveal that 9 kg/m^3 are routinely held in circular tanks with a diameter of 2 m and with a water flow of 0.3 liters/sec.

Striped Bass, *Morone saxatilis*

Striped bass culture, like channel catfish, is showing great promise, although the production of this species is still in the development stage. The geographical range of striped bass extends from the St. Lawrence River, Canada, to the large rivers of South Carolina and Georgia along the Atlantic coast and along the Gulf coast from western Florida to Louisiana (Pearson, 1938).

Recent investigations indicate that the only substantial fishery for this species in Florida is in the Apalachicola River, which empties into the Gulf of Mexico.

On the Pacific coast striped bass ranges from southern California to the Columbia River, Oreg. Introduction of this species to the Pacific coast was accomplished with an initial stocking of 133 yearling fish in San Francisco Bay in 1879 (Mason, 1882). These fish were seined from the Navesink River, N.J., and transported to California by train.

By 1899 the commercial catch of striped bass was 599 metric tons and by 1915 it had risen to 808 metric tons (Raney et al., 1952).

The establishment of landlocked striped bass populations in several inland reservoirs has generated considerable enthusiasm in regard to the future potential of this species. Using striped bass on a put, grow, and take basis could prove to be a desirable management technique for large freshwater impoundments. In addition to its acceptance as a superb game and table fish, the striped bass also exhibits the ability to function as a biological control for gizzard shad, *Dorosoma cepedianum*.

The ability to produce millions of striped bass fry through hormone induced spawning is now a reality (Stevens, 1966). This accomplishment has resulted in major attempts to establish striped bass populations with large-scale fry plantings. A final evaluation of the success of these programs is not available at this time; however, it is the general consensus that predation will prevent the establishment of desirable populations with this type of introduction. The alternative is to introduce fingerlings (6-15 cm) instead of fry. At least six states in the southern United States have embarked on fingerling rearing programs.

Production at federal hatcheries increased from 90,000 fingerlings in 1966 to 1,500,000 in 1970.

Intensive Fish Culture

Some of the more common species of fish reared by intensive culture method are: rainbow trout, *Salmo gairdneri;* brook trout, *Salvelinus fontinalis;* brown trout, *Salmo trutta;* lake trout, *Salvelinus namaycush;* golden trout, *Salmo aguabonita;* cutthroat trout, *S. clarki;* coho salmon, *Oncorhynchus kisutch;* chum salmon, *O. keta;* chinook salmon, *O. tshawytscha;* kokanee or sockeye salmon, *O. nerka;* and Atlantic salmon, *Salmo salar.*

One of the basic advances in trout and salmon rearing is in the area of nutrition. Fish diets are now compounded as carefully and scientifically as diets for domestic animals. The basic nutritional needs of most species of trout and salmon have been defined by such workers as Phillips (1970) and Halver (1970), and diets are formulated to meet these needs. Proximate analysis of typical trout and salmon diets are as follows:

	Starter diets up to 8 weeks old %	*Grower diets 8 weeks to maturity* %
Protein	48.4	42.9
Fat	13.2	9.5
Moisture	4.1	6.0
Ash	10.5	10.4
Fiber	3.9	4.1
NFE[1]	19.8	27.1
Available energy:		
Kcal/kg	3,315	3,315
Cost/kg	$0.31	$0.31

[1] NFE = nitrogen free extract.

Mechanical fish feeders are coming into widespread use and are taking over the role of feeding the precise quantities of feed at prescribed intervals. The more advanced of these devices monitors water temperature, fish size, and adjusts the daily ration accordingly.

Where the pondfish culturist is basically an ecologist, the trout and salmon culturist is a physiologist. He must know the requirements for space, for the physical and chemical components of the water, and for the nutritional requirements of the fish. Through careful control of these factors, each kilogram of trout or salmon produced may require as little as 1.2 kg of feed.

Growth rates can be calculated with utmost accuracy. Haskell (1959) concluded that the increase in length of trout up to 25 cm in size is at a constant rate. He developed a "temperature unit" theory in which he states that the growth rate can be predicted for any temperature between 3.7° and 15.6°C. We have found it practical to restate Haskell's hypothesis to include 0°C as the zero point for growth and consider it to be a straight line relationship when plotted against time up to 15°C. This has proven a useful tool in projecting growth rates and forecasting the time when the fish will reach a given length.

Fish densities in trout and salmon rearing ponds are not as critical as the quality and quantity of the water flowing through the unit. Ample exchanges of water between 0° and 21°C., free of toxic metals such as zinc, copper, and manganese, and from excessive levels of such gases as nitrogen, are essential. Oxygen levels must be maintained above 5 ppm throughout the tank, and ammonia should not exceed 1 ppm for long periods of time. If these water quality criteria are met, most salmonids can be reared at densities exceeding 50 kg/M^3.

The raceway, a linear pond whose length is approximately 10 times its width, has been the most popular type of rearing unit for salmonids in the United States up to this time. Second in popularity has been the circular pond. Many other types of ponds have been tried, but have not been widely adopted. In 1958 Burrows and Combs at Longview, Wash., developed a circulating pond that is being widely copied in the northwestern United States. This pond is rectangular in shape, but employs turning vanes to cause the water to flow in a circular pattern. The merits of this pond are its higher water velocities and thorough circulation which give good distribution of feed and render the pond virtually self cleaning. The increased velocities improve stamina and result in better survival of the fish following stocking. Water supplies, both entering and leaving a fish pond, must be monitored for their chemical content. Sufficient oxygen must be supplied by the incoming water to permit the fish to use the food. The relationship between food eaten and the oxygen required is so constant that many fish culturists calculate the oxygen content of the water entering a pond as a means of determining the carrying capacity. Investigations indicate that 100 g of oxygen are required to metabolize 450 g of trout pellets (1,200 calories) (Willoughby, 1968). This 1.4:5 ratio should hold constant over the temperature range of 4°-16°C.

While oxygen is usually the first limiting factor in the hatchery environment, it is not the only one. As oxygen is used to break down foods for energy and growth, by-products are formed. Prominent among these are carbon dioxide and ammonia. Carbon dioxide poses few problems. Ammonia, however, is another matter, as it is very difficult to remove by mechanical means. Thus, when water is reused from one fishpond to another, it can be aerated to renew its oxygen content but ammonia continues to accumulate and soon reaches toxic levels.

A recent development which has revolutionized fish culture in the United States is the use of bacterial filters, which convert free ammonia to more tolerable nitrates. This development has opened up possibilities for a tenfold increase in the quantity of fish that can be reared in a given water supply. This reconditioning system makes it possible to reduce the quantity of freshwater by as much as 95%.

The Dworshak National Fish Hatchery, Ahsahka, Idaho, utilizes a water reuse system for a part of its ponds. This hatchery began operation in 1968. There are 84 circulating ponds, 25 of which operate on the water reuse system. In this system approximately 10% of the water used in the ponds is added as fresh water after being filtered, disinfected, and either cooled or heated. The water goes through aerators for oxygenation and is supplied at the rate of 27 liters/sec to each pond. When water returns from the ponds, it goes through biological filters where the pH is buffered and ammonia oxidizes to harmless nitrates.

The hatchery was designed and built to replace the spawning and nursery areas for the steelhead trout which will be lost by the construction of the Dworshak Dam. In addition to the rearing of steelhead trout for release into the north fork of the Clearwater River, this station is also participating in the management of the reservoir above the dam. At the present time, the hatchery is rearing catchable size rainbow trout for stocking the reservoir. In addition, there is a limited number of cutthroat trout on hand which will be used for brood stock as a source of eggs for future stocking programs. In addition to these, it is expected that this hatchery will also supply kokanee salmon for the reservoir.

The first year's operation of the Dworshak hatchery started with the collection of eggs from trout transported to the hatchery from the trap at the dam site during the period of October 1968-May 1969. The fish reared in the untreated water for 2 yr from the 1969 brood year were released in the spring of 1971. At the same time, the 1970 brood year fish reared in the controlled environment of the reuse system were also released. The controlled environment of the reuse system made it possible to rear fish to migrating size (17 cm) in 1 yr instead of the 2-yr growing period that is required when the untreated water is used.

DISEASE CONTROL

In 1968, the federal government of the United States imposed regulations requiring that salmonid fish and eggs imported into the country be free of whirling disease, caused by the protozoan *Myxosoma cerebralis*, and viral hemmorrhagic septicemia. The regulation is intended to protect the nation's fishery resources from further introduction of these two fish diseases. It may also serve as a model for adoption by other countries similarly concerned about protecting their own resources. This regulation is included in Title 50, Code of Federal Regulations.

Increased traffic in fish and eggs has spread the virus disease, infectious pancreatic necrosis, in 10 yr from the northeastern section of the country into the trout and salmon producing areas of the West.

The detection of this virus cannot be accomplished by border inspections; consequently, control had to be effected at the originating hatchery. Several states now require that eggs or fish entering the state be accompanied by a certificate of health. But separate actions by the states can only be partially successful, and to effect a coordinated nation-wide program, federal legislation has been introduced in the Congress. If passed, the bill will regulate the interstate and foreign commerce of fish for purposes of disease control.

FISH TRANSPORTATION

Fish hatcheries in the United States utilize many diversified types of distribution equipment from 40-liter cans to elaborate tanks equipped with aeration devices and oxygen equipment. However, most hatcheries today generally use truck mounted distribution tanks. Hauling capacity is governed by volume of water in the tanks, design of tank, auxiliary equipment used, and size and species of fish being hauled. Various materials such as wood, plywood, fiber glass, steel, and aluminum are used for construction of tanks. Fiber glass-plywood tanks are becoming very popular because of such advantages as lightweight, low cost, good insulation, and strength. Insulated units, having recirculating water systems and an oxygen supply, can be used to haul loads in ratios (unit weights of fish to equal unit weight of water) of 1.1:5 for trout and 1.2:4 for channel catfish, Maloy (1966).

There are reports of varying degrees of success in increasing hauling ratios by use of sedative drugs and buffer agents. Phillips and Brockway (1954) found that starvation of fish before shipment and the maintaining of low water temperatures were more effective than the addition of chemicals.

Maxwell and Thoesen (1965) reported on the successful hauling of large quantities of rainbow trout and largemouth bass fingerlings by airplanes equipped with water tanks. Sealed plastic containers, 2 mil and thicker—packed in insulated outer cartons, partially filled with water, and inflated with oxygen—are used successfully by many hatcheries for surface and air transportation of fish. A typical shipment is 50,000 bass fry in 3.8 liters of water for a period of 48 hr.

A recent development in the field of fish transportation is the "fish pump." The fish pump is a modified fruit pump which was initially used to transfer vegetables, fruit, dead fish, and seafood. The pump is especially designed to eliminate sharp edges in the pump body and to allow unobstructed passage of water and produce. The water serves as a cushioning agent.

The pump comes in two diameters, 12 and 15 cm. The 12-cm size is used for fish up to 15 cm in length and the 15-cm size handles fish up to 47 cm in length. The California Department of Fish and Game tested this pump and found that 900 kg of trout could be loaded into a tank truck in 6 min with slight loss of time due to crowding racks. Other tests indicate that

200 kg of trout per minute can be loaded onto trucks from concrete raceways.

In addition to loading distribution trucks and transferring fish between ponds, the pump can be attached to a grading device. With this device about 200 kg of fish per minute can be sorted by size.

TRAINING SCHOOLS

The federal government operates three in-service training schools for training fish culturists. These schools are located in Spearfish, S.Dak.; Marion, Ala.; and Leetown, W. Va. They were established to provide essential technical training in the field of fish hatchery management. Operation of the schools is oriented to the activities of the Bureau of Sport Fisheries and Wildlife and includes such topics as nutrition, pathology and disease control, fish-cultural development, and general fish hatchery management. In addition, strong emphasis is placed on the use of hatchery fish in managing open waters.

Although the primary goal is to provide trained fish culturists for the National Fish Hatchery System, there has been increased interest in recent years from state and foreign agencies in sending trainees to the schools. The trainees may already have a broad academic background in biology, but the art of application must be learned through practice. The training schools serve as a link between the academic world and the actual hatchery operation. In fact, T. Sana, a native of Japan, completed our fish disease course at the Leetown National Fish Hatchery last year.

TEHAMA-COLUSA SALMON SPAWNING CHANNEL

A totally different approach to intensive fish culture is the Tehama-Colusa multipurpose water diversion project and spawning channel in California. Built to divert water for irrigation purposes from the Sacramento River, the upper 5.5 km of this canal will function as a spawning channel for 60,000 chinook salmon.

Access to the spawning channel will be controlled to allow optimum numbers to lay their eggs at one time. The eggs will incubate in the canal, and the resulting young fish will live and be fed there until they are ready to migrate to sea.

When the spawning channel reaches full capacity, up to 60 million chinook salmon will begin life in this man-made habitat. They will migrate to the ocean to live and grow. Three to seven years later they will return to the Sacramento River as vigorous fighting game fish and also valuable, nutritious food. Some individuals may weigh 30 kg, and where 1 kg of fish migrated to sea from the spawning channel, 50 kg will return. Most of the returning fish will be captured by either sport or commercial fishermen before they reach Tehama-Colusa, but sufficient numbers will reach the canal to assure perpetuation of the run.

Operation of the spawning channel is both an engineering and a fish cultural challenge. The engineering challenge will be in operating the mammoth traveling bridge which will service the canal. The bridge will span the canal, and travel its length via motorized carriages running on rails along the sides of the canal. It will serve as a working platform from which biologists and engineers can manipulate both the fish and their environment for optimum production. An underwater viewing chamber will be suspended from the bridge to permit the observation of the movements and behavior of the fish. Elaborate gravel cleaning devices will flush deposited silt from the channel after each spawning season. Young fish will be sorted, counted, and representative numbers marked as a means of evaluating the contribution to the Pacific salmon fishery.

These and other changes that have taken place during the last few years in fish hatcheries, reflect an emerging scientific approach to the ancient art of fish culture.

REFERENCES

BOWEN, J. T.
1970. A history of fish culture as related to the development of fishery programs. *In* N. G. Bensen (editor), A century of fisheries in North America, p. 71-93. Am. Fish. Soc., Spec. Publ. 7.

BURROWS, R. E., and H. H. CHENOWETH.
1970. The rectangular circulating rearing pond. Prog. Fish-Cult. 32:67-80.

BURROWS, R. E., and B. D. COMBS.
1968. Controlled environments for salmon propagation. Prog. Fish-Cult. 30:123-136.

DAVIS, H. S.
1953. Culture and diseases of game fishes. University of California Press, Berkeley. 323 p.

HAGEN, W., and J. P. O'CONNOR.
1959. Public fish culture in the United States, 1958. A statistical summary. U.S. Fish. Wildl. Serv., Circ. 58. 44 p.

HALVER, J. E.
1970. Nutrition in marine agriculture. Mar. Agric. p. 75-102.

HASKELL, D. C.
1959. Trout growth in hatcheries. N.Y. Fish Game J. 6:204-237.

MALOY, D. R.
1963. Hauling channel catfish fingerlings. Prog. Fish-Cult. 25:211-212.
1966. Status of fish culture in the North American region. Proceedings of the FAO World Symposium on Warm-Water Pond Fish Culture, p. 125-132.

MASON, H. W.
1882. Report of operations on the Navesink River, New Jersey, in 1879, in collecting living striped bass for transportation to California. U.S. Comm. Fish and Fish., Part 7, Rep. Comm. 1879:663-666.

MAXWELL, J. M., and R. W. THOESEN.
1965. Lake Powell stocking story. Prog. Fish-Cult. 27:115-120.

PEARSON, J. C.
1938. The life history of the striped bass, or rockfish, *Roccus saxatilis* (Walbaum). Bull [U.S.] Bur. Fish. 28:825-851.

PHILLIPS, A. M., JR.
1970. Trout feeds and feeding. *In* Manual of fish culture, Part 3.B5, 49 p. U.S. Bureau of Sport Fisheries and Wildlife.

PHILLIPS, A. M., JR., and D. R. BROCKWAY.
1954. Effect of starvation, water temperature, and sodium amytal on the metabolic rate of brook trout. Prog. Fish-Cult. 16:65-68.

RANEY, E. C., E. F. TRESSELT, E. H. HOLLIS, V. D. VLADYKOV, and D. H. WALLACE.
1952. The striped bass, *Roccus saxatilis*. Bull. Bingham Oceanogr. Collect., Yale Univ. 14(1):1-55.

SPEECE, R. E.
1973. Trout metabolism characteristics and the rational design of nitrification facilities for water reuse in hatcheries. Trans. Am. Fish. Soc. 102:323-334.

STEVENS, R. E.
1966. A report on the operation of Moncks Corner Striped Bass Hatchery, 1961-1965. South Carolina Wildlife Research Department, 25 p. [Mimeograph.]

TUNISON, A. V.
1951. Comparison of fish food costs in federal hatcheries in 1945 and 1949. Prog. Fish-Cult. 13:121-128.

WHITE, J. T. (editor).
1971. Live fish transfer pump reduces harvesting costs. Am. Fish Farmer and World Aquacult. News 2(2):12-14.

WILLOUGHBY, H.
1968. A method for calculating carrying capacities of hatchery troughs and ponds. Prog. Fish-Cult. 30:173-174.
1971. A new look at hatcheries. Sport Fishing USA. p. 359-369.

GENETICS OF THE AMERICAN OYSTER, *CRASSOSTREA VIRGINICA* GMELIN

A. CROSBY LONGWELL[1]

INTRODUCTION

The development of refined culture techniques for the commercial East Coast American oyster, *Crassostrea virginica*, at the U.S. government's Milford Laboratory (Loosanoff and Davis, 1963), along with the opening of experimental and commercial shellfish hatcheries in the United States, have led to an interest and modest support of genetic research on the oyster (Longwell, 1969; Longwell and Stiles, 1970). Our growers of *C. virginica*, whether dealing with a wild oyster set in the field or with their own hatchery products, are faced with the dilemma of cultivating an organism which does either exceedingly well producing a superabundance or does very poorly, both for reasons seldom known. Part of the hoped for process of bringing this oyster under some greater measure of control by the cultivator necessitates some information on its genetic and breeding system. This is particularly so for profitable hatchery production and for the best pond culture. Knowledge of oyster genetics would also be of value for the special stocking of decimated beds or for the introduction of stock to previously uncultivated beds in the wild.

CHROMOSOME BASIS OF *C. VIRGINICA'S* BREEDING SYSTEM

An examination of the male gametogenesis and of the spawned and fertilized eggs of *C. virginica* revealed that its meiotic system, fertilization, and cleavage are of the typical type found in most higher plants and animals (Longwell and Stiles, 1968a). The oyster is not characterized by any anomalous chromosome behavior as, for example, is the honey bee, which would frustrate breeding plans based on successes in higher organisms. Interestingly, the fate of the fertilizing sperm can be followed from the time of its entry into the egg until the fusion of its chromosomes with the chromosomes of the female gamete on the first cleavage spindle (Fig. 1). It should be noted that any cytogenetic examination of the eggs of at least this species of oyster must be preceded by treatment of the eggs with methyl alcohol and chloroform in a micro-Soxhlet apparatus to remove interfering yolk granules (Longwell and Stiles, 1968b).

There are 10 pairs of chromosomes at metaphase I of meiosis in the mature spawned eggs of *C. virginica* (Longwell, Stiles, and Smith, 1967). Genes are linked together then in 10 different groups. At least in the female the chromosomes indicate that there is a small amount of recombination or crossing-over of the genes making for genetic variability without which there can be no improvement by selective breeding. There is no evidence for any sex chromosomes. This is in keeping with the protandric nature of this oyster. See Figure 2.

The chromosomes of *C. virginica* are all short, about the same length, and hardly any of them readily distinguishable from the others on any basis. This makes for difficulty in their detailed study (Fig. 3, 4).

Also studied were the chromosomes of the Japanese oyster, *C. gigas;* the Puerto Rican oyster, *C. rhizophorae;* the European flat oyster, *Ostrea edulis;* the U.S. West Coast small Olympia oyster, *O. lurida;* and the horse oyster, *O. equestris*. All of these species of both the viviparous *Crassostrea* genus and of the larviparous *Ostrea* species have the same number of chromosomes as *C. virginica*. Also, insofar as can be discerned, the chromosomes of all these species are metrically and morphologically like those of *C. virginica* (Longwell et al., 1967). Menzel (1968b) in Florida has examined several other species of these two oyster genera. He further found no variation in chromosome number and morphology. At least at the chromosome level then there

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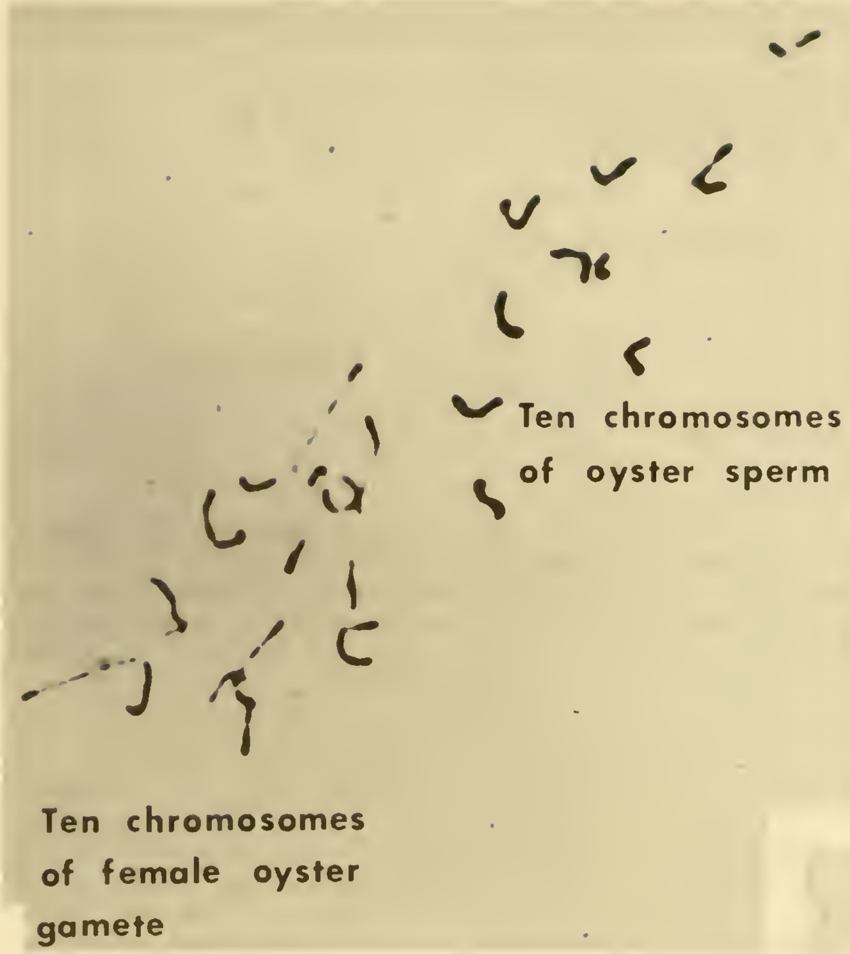

Figure 1.—The coming together on the first cleavage spindle of the 10 chromosomes of the male and 10 chromosomes of the female gamete of the American oyster, *Crassostrea virginica*.

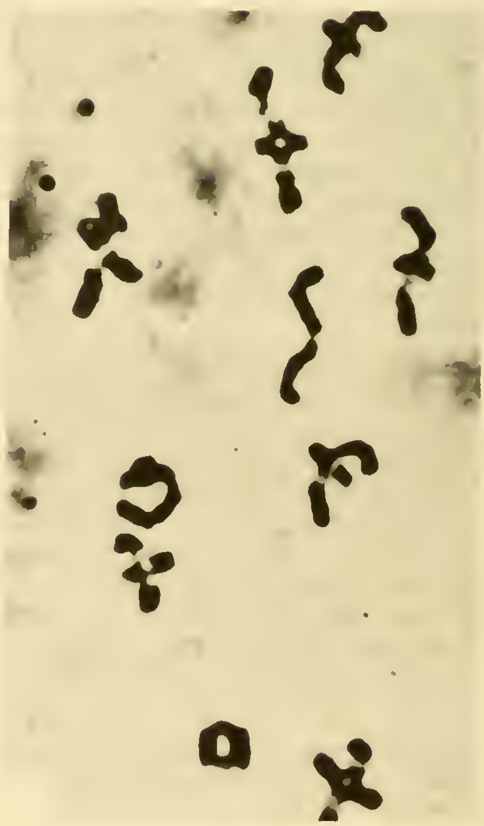

Figure 2.—The 10 pairs of chromosomes of the mature, spawned egg of the American oyster, *Crassostrea virginica*.

Figure 3.—The 20 chromosomes of an early cleavage in the American oyster, *Crassostrea virginica* (after colchicine treatment).

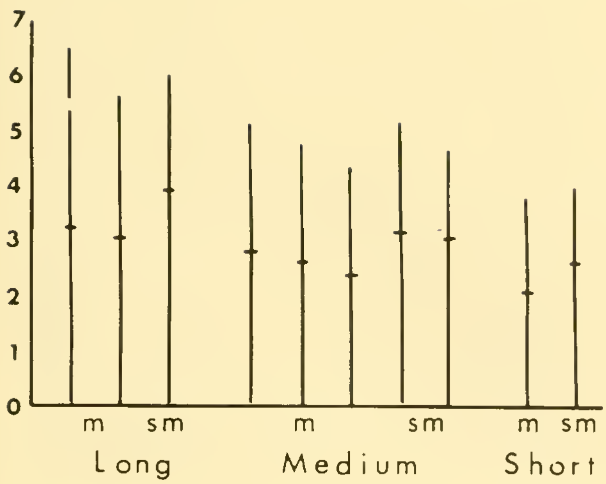

Figure 4.—Diagrammatic representation of the American oyster, *Crassostrea virginica*, chromosomes based on their lengths and position of their spindle attachment regions.

should be no barrier to the making of fertile hybrids between the species within these two genera or even between these two genera of oysters. No species of the third oyster genus, *Pycnodonte*, has yet been examined chromosomally probably because of the difficulties of obtaining these noncommercial forms which occur as singles in deep water.

To date, there have been no indications for any chromosome polymorphism in any of the populations of *C. virginica* in Long Island Sound nor in any other population thus far examined from as far north as Prince Edward Island, Canada, to as far south as the State of Virginia. Ahmed and Sparks (1970) may have uncovered a chromosome polymorphism in marine mussels; Staiger (1957) found extensive polymorphism of chromosome numbers in a marine gastropod mollusk; and Battaglia (1970) has reported extensively on genetic polymorphisms in marine copepods. Chromosome polymorphisms aid the population in making rapid adjustments to fluctuations in the local environment.

In contrast to the population, species, and generic constancy of the chromosomes of the oyster, early developmental stages of *C. virginica* are marked by a high frequency of variation in chromosome number (Stiles and Longwell, unpublished data). Fertilized and cleaving eggs from a series of about 15 mass-spawned groups, with a total of 835 spawning oysters, had an average of about 26% postfertilization genetic abnormalities. Abnormalities of chromosome number were present in 12% of the eggs. It appears that the sensitivity of this oyster egg to all kinds of environmental distresses results in acute effects at the chromosome level. This should make the oyster an excellent assay species for detecting genetically damaging and zygote-destructive pollutants (Stiles and Longwell, in press).

INBREEDING *C. VIRGINICA*, ITS EFFECTS AND THE SPECIES MATING SYSTEM

Inbreeding to some extent will accompany mass selection in commercial hatcheries. More extreme forms will eventually be used to develop lines for subsequent hybridization in hopes of so obtaining hybrid vigor.

Full-sib crosses of *C. virginica* made over a period of a year gave consistently poor development to the straight-hinge larval stage. An investigation into this revealed that marked fertilization and early developmental failures were occurring in these crosses (Longwell and Stiles, 1973). In 5 of 9 cultures thus far studied carefully, an average of 63% of the sib-crossed eggs remained unfertilized. Only 13% of the eggs of the contemporary between-line crosses or outcrosses to unrelated wild oysters remained unfertilized. Only 3% of cleavages in the sib-crossed eggs were normal. In the controls 70% of the cleavages were normal. Parthenogenesis averaged 10% in the inbreeding crosses and 0.5% in the controls. See Table 1. Some of the inbreeding crosses were characterized by polyspermy. In others there was a degeneration of the one or more sperm that had penetrated the egg.

A second, more extensive series of sib crosses with their contemporary control interline crosses showed essentially the same crossing difficulties. The incidence of ineffective fertilization was higher than in the first series. Only 46% of the fertilizations actually achieved with sibling sperm activated the eggs to normal development, contrasted to 98% when the sperm of nonrelated oysters of other lines was used. Parthenogenesis was also higher; only 7% in the controls but 29% in the sib crosses.

Prolonged fertilization attempts increased the number of eggs fertilized in sib crosses by 20%. It, however, also led to more polyspermy, and there was more degeneration of sperm in the cytoplasm of the eggs. Such late fertilizations seldom seem to be effective.

These crossing barriers are interpreted as meaning that a strong outbreeding system in *C. virginica* must, at least in some individuals in some populations, be reinforced by a system of gamete cross incompatibility with a basis in genetic factors. This system must operate to prevent the crossing of gametes of closely related oysters with similar genes. Inbreeding is thereby discouraged, and outbreeding promoted. Incompatibility genes are known to be highly mutable. An increased crossability of *C. virginica* full- and half-sibs originating from irradiated gametes so supports this interpretation.

Genetic systems of cross incompatibility preventing inbreeding exist in an estimated 3,000 higher plants (Brewbaker, 1964; Williams, 1964). The only carefully studied case in animals though has been in a marine organism—the hermaphroditic ascidians (Morgan, 1924, 1942a, 1942b). Some of these are self-fertile, others self-sterile, with some variability between geographic races. Other groups having inbreeding incompatibility often show interspecies crossing barriers as well. From the pioneering work of Imai in Japan (Imai and Sakai, 1961) and the later

Table 1.—Fertilization failures, cleavage failures, and parthenogenesis in full-sib crosses of *Crassostrea virginica* and in contemporary control outcrosses and between-line crosses.

Type of cross	% of 100 ripe eggs with normal bivalents remaining unfertilized	% of 100 eggs with normal cleavages with 2 polar bodies	% of 100 eggs parthenogenetic
Contemporary control	0	99	0
outcrosses and	0	92	0
between-line	27	62	0
crosses	25	25	2
Full-sib	56	5	6
crosses	77	0	9
	35	6	20
	47	0	12
	39	0	21
	81	1	7
	68	1	3
	93	4	11
	68	6	3

work of Menzel (1968a) we know that such crossing barriers do exist between oyster species.

Some of the difficulties of inbreeding *C. virginica* in the face of gamete cross incompatibility might somehow be compensated for by making practical use of the parthenogenesis induced in the incompatible matings. A variety of physical and chemical agents and other means can be used to overcome these crossing barriers, as done in other organisms.

As for the less intensive, lower level of inbreeding which will accompany mass selective breeding, incompatibility will tend to keep the level of inbreeding lower than would otherwise occur. This will sometimes work in the breeder's favor, other times against him. When too much inbreeding is practiced too fast, fertilization failures should occur.

In a third group of sib-inbred and between-line crosses of *C. virginica*, food and water levels were adjusted every other day to number of surviving larvae (Longwell and Stiles, 1973). For the period 12 to 17 days, survival of the outbreds was 6 times greater than for the inbreds. In a highly fecund outbreeding species as the oyster a large number of defective recessive genes can be expected to be harbored. On becoming homozygous with inbreeding these will increase total mortality. [Battaglia (1970) has found marine copepods to be extremely sensitive to protracted inbreeding, as are perhaps most highly fecund outbreeding marine species.]

Measurements were made on a total of 1,562 larvae of this series and a least squares analysis of variance done. Looking to the means and standard errors which were quite small—0.7 to 3.0%—differences in larval lengths between the inbreds and outbreds became apparent by day 6 with differences becoming more pronounced as time progressed (Fig. 5).[2]

These measured differences between inbreds and outbreds point to considerable genetic variation in these oyster stocks. Judging from these results alone there is a good basis for expecting improvements in hatchery-produced *C. virginica* by selective breeding.

Considering the high degree of inbreeding depression and the high mortality of inbred larvae thus far encountered, it can be anticipated that commercial breeders of *C. virginica* will probably find it necessary to hybridize highly selected lines for marketing. Certainly they will have to hybridize intensely inbred lines. No spat have yet been obtained from any of the full-sib crosses made at the Milford Laboratory with the exception of some from the irradiated lines. While some portion of this failure to obtain

[2] Statistical analysis was done by Ruel Wilson of the Biometrical Services, Livestock Research Staff, Agricultural Research Center, ARS, U.S. Department of Agriculture, Beltsville, MD 20705.

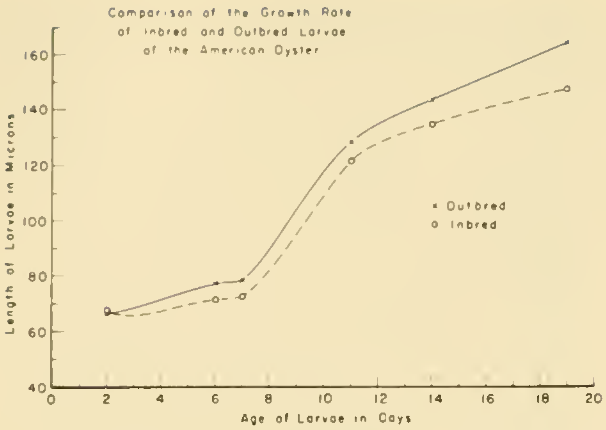

Figure 5.—Comparison of the growth rate/of inbred and outbred larvae of the American oyster. *Crassostrea virginica.*

inbred oysters is undoubtedly attributable to the sporadically and unpredictable poor water quality at the Milford Laboratory, much of it represents the severity of the effect of enforced inbreeding of this oyster. This is particularly significant in that the inbreeding cultures were initiated with unusually large numbers of eggs, as compared to the far smaller population numbers available for studies with species of higher organisms.

Imai and Sakai (1961) detected and made some measurements of inbreeding depression in *C. gigas*. Lines of *C. gigas* were lost in the third generation of full-sib crosses.

SELECTIVE BREEDING OF *C. VIRGINICA*

Quantitative, commercially important traits are controlled predominantly by exceedingly large numbers of either of two types of genes. The effect of one type is additive; the effect of the other is non-additive. It is the additive type that responds to molding and change by selective breeding. The heritability of a trait is a measure of this additive genetic variance as separated from the other type and from the total phenotypic variance. Heritability estimates can be used to predict progress by selection (see formulae in Fig. 6).

Theoretical heritability estimates should be readily obtainable in the oyster in one generation for any number of commercial traits by crossing the divided lots of eggs of several females by several different males. Contemporaneous cultures of such crosses should provide enough full-sib, and maternal- and paternal-half-sib families for an analysis of variance. From the results of this analysis heritability estimates can be derived directly.

This was attempted several times to estimate heritability of growth rate for laboratory-reared *C. virginica* larvae and spat. Unfortunately, in spite of its merits, this method did not prove successful at the Milford Laboratory. This is because these very high larval mortalities experienced at the laboratory so much of the time seldom leave enough contemporary culture families for statistical comparisons. However, in a commercial-scale pilot hatchery at the University of Oregon operating under better environmental conditions heritability estimates for several different characteristics of *C. gigas* were obtained recently (Lannon, 1972). It is also probable that *C. gigas* is more vigorous and easier to handle in artificial culture than *C. virginica*.

In one series of these diallel crosses of *C. virginica* at Milford enough larval families did survive long enough in sufficient numbers to obtain a rough estimate of heritability of larval growth to the larval age of 2 wk. This estimate, 24%, is in the medium-to-low range.

Realized heritability estimates, as opposed to such theoretical heritability estimates, can be obtained from selection experiments. Selection experiments can also tell something about the duration of the response to selection, and about the limits of selection response for different coefficients of inbreeding, and selection differentials. Such experiments would fare better under the variable culture conditions at Milford than the diallel crosses of the theoretical estimates.

BASIC FORMULA FOR SELECTIVE BREEDING

Annual Progress for Trait Being Selectively Bred For =

$$\frac{\text{Heritability} \times \text{Selection Differential}}{\text{Generation Interval}}$$

Heritability =

$$\frac{\text{Variation Due to Additive Genetic Variance}}{\text{Total Phenotypic Variance}}$$

Selection Differential =
Difference Between Selected Oysters and Average of All Oysters From Which Selected

Generation Interval =
Average Age of Oysters at Time of Reproduction

Figure 6.—Basic formula for selective breeding of oyster.

A large selection experiment is currently underway for spat and juvenile growth rate of *C. virginica*. It is intended to keep this breeding experiment going at Milford for an indefinite number of selection generations to estimate the duration and extent of response for a particular inbreeding coefficient and selection differential to upward and downward selection for growth rate. It is hoped to keep the experiment going on a scale large enough to provide seed oysters of known genetic background for other projects

A carefully chosen collection of about 6,000 wild *C. virginica* was set up for mass spawning. Some nonlocal *C. virginica* were included in this group with the hope of increasing the base of genetic variability (Fig. 7). Of the approximate 6,000, 835 oysters spawned. Of these spawners, 85% were from Long Island Sound and the rest from areas extending from Prince Edward Island, Canada, to Virginia.

Several million eggs from 835 spawners were cultured, and the resulting larvae reared to metamorphosis. About 8,000 juvenile oysters were obtained.

At the age of 1 yr a portion of the surviving juveniles was selected on the basis of their size. The population was divided into a large-selected group, a small-selected group, and a nonselected population. The selection differential for the large juveniles was 18%; for the small juveniles, 8%. The first generation has been obtained from mass spawnings of the two selected populations, and from the random-breeding, unselected F_1 control population. This first generation from selected parents is currently

Figure 7.—Mass spawning of a group of American oysters, *Crassostrea virginica*, from different geographic areas.

being selected itself and spawned for the second selected generation of spat.

Larval data collected in the course of rearing these progeny of the first generation to be selected are showing, as did the larvae from a prior spawning of the same animals which failed to give set, a correlation between selection for juvenile oyster size and larval growth rate. This correlation could be a nongenetic one or a significant genetic one.

First realized heritability estimates are being made on measurements of the spat from the first selected generation of parents at 33 days postsetting. Data are not yet fully analyzed. Nonetheless, preliminary calculations indicate the heritability for fast growth to this age to be high, 93%.

Considering these estimates, and the possibility in the oyster of very high selection differentials, hatchery breeders should be able to improve growth rate of their oysters. This could be done by mass selection without recourse, for some cycles of selection, to family performance records or progeny testing which are time consuming and costly. Problems will probably arise from inbreeding. Commercial shellfish hatcheries seem prone to start selection programs with too few oysters. Because the spawn of a single, excellent cross might fill even a good-sized commercial hatchery, the problem is accentuated.

Selection progress is being made for resistance to the microsporidian MSX disease of *C. virginica* in the U.S. mid-Atlantic states by both natural selection on the wild beds and in a small artificially selected experimental stock (discussion at 63rd Joint Annual Convention between Shellfish Institute of North America, Pacific Oyster Growers Association, and National Shellfisheries Association, June 1971, Seattle, Wash.). Over a period of years the *C. virginica* oysters of Malpeque Bay, Prince Edward Island, Canada, slowly but certainly made themselves resistant to the Malpeque disease through the agency of natural selection (Needler and Logie, 1947).

HYBRIDIZATION OF *C. VIRGINICA*

Plants and animals are artificially crossbred or hybridized in order to combine in the offspring some of the desirable characteristics displayed by either set of parents. Another purpose of crossbreeding or hybridizing is to utilize the effects of hybrid vigor. In different species, in addition to the general effects of hybrid vigor, there can be an increase in size sometimes accompanied by partial or complete sterility; increased reproductive capacity sometimes accompanied by a reduction in another character; increased environmental range, or ability to live in a range in which either parent is unable to live; greater uniformity among individuals. Often hybrid vigor is concentrated in a critical stage of early life. Unfortunately, there is no way of predicting for any species just how to obtain hybrid vigor. Inbreeding lines might be test-crossed with one another each generation so that selection can be practiced in terms of the potential of the separate lines for producing heterosis on crossing (see Fig. 8).

Hybridization for the sake of combining the desirable genes of two different types sometimes takes the form of upgrading practiced when the overall performance of the import is better than the local, but when the local is superior in some particularly important traits related to local environmental conditions. The initial hybridization is followed by backcrosses to the import with either natural or artificial selection. Another way of combining the characteristics of two types is the introgression of special desirable foreign genes into the local stocks. This is accomplished by backcrossing the hybrid to the local type again with either natural or artificial selection.

Hybridization of *C. virginica* might supply a less sensitive, more vigorous larval form better able to hold up to the vicissitudes of the hatchery. Hybrids could furnish a diversification of the U.S. East Coast oyster crop. It is a fact that the close cultivation of any species facilitates the spread of disease. Diversification can break the wildfire spread of a disease by the interdispersal of resistant types. It can assure some marketable crop when the disease toll of the susceptible type is greatest. Were more known about the genetics of different geographic populations of *C. virginica*, some of the fear might be diminished of experimental transplantation of oyster set to commercial beds badly in need of seed from areas where it occurs in great abundance and goes to waste.

C. virginica occurs extensively over an unusually wide range of temperature, from cold to subtropical, along the Atlantic coast from the Gulf of St. Lawrence to the Gulf of Mexico and farther south to Panama, and around the West Indies. There is evidence for a number of physiological spawning races within the species. Accumulated experience of growers of *C. virginica* indicates that these oysters transferred from one region to another often fail to thrive in the new environment. No doubt, as in *C. gigas* (Imai and Sakai, 1961), there are real genetic

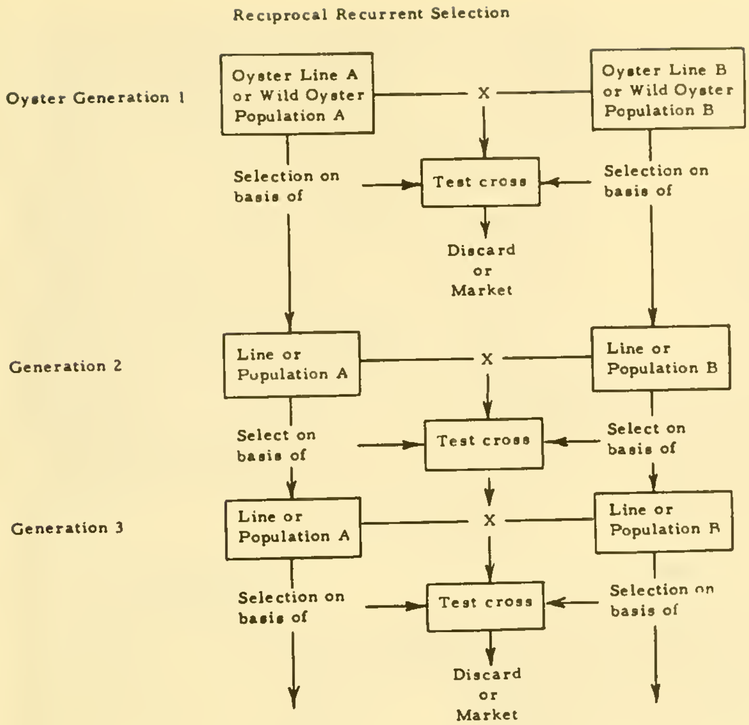

Figure 8.—Reciprocal recurrent selection of oyster.

adaptations to local conditions, as well as subtle genetically based morphological and biochemical differences in the different populations (Stauber, 1947, 1950; Loosanoff and Nomejko, 1951; Hillman, 1964; Numachi, 1962; Loosanoff, 1969).

Old, well-established subspecies usually have gene combinations so well adapted to the environments they occupy that any new gene combinations created by hybridization will nearly always be less favorable. If, however, hybridization takes place in an unstable environment, some of the vast array of segregates appearing in later generations will very likely be better adapted to the new field environment than any individual of the parental group. They could also be better adapted to the artificial environment of a commercial hatchery or experimental shellfish laboratory.

Inclusion of nonlocal *C. virginica* in several of the individual mass-spawned groups that made up the foundation stock of the selection experiment already referred to had no measurable adverse effects in respect to percentage fertilization and percentage development of the eggs to the straight-hinge larval stage. Numbers of dead larvae and abnormal larvae at this stage were not increased—just as many larvae reached setting. There was an increase in the incidence of polyspermy, but this seemed to have no adverse effects.

Wild *C. virginica* sampled from approximately 25 different sites—from areas farmed commercially and from nonfarmed areas, from Prince Edward Island, Canada, to Greenwich, Conn.—are being test-hybridized.

To date, individual hybrid crosses along with appropriate local and nonlocal control crosses have been made between Long Island Sound oysters and oysters from:

Prince Edward Island	Martha's Vineyard, Mass.
Maine	Niantic, Conn.
New Hampshire	Greenwich, Conn.

Some spat have been obtained from all these crosses. F_2 segregates have been obtained from Niantic and Prince Edward Island hybrids. At least these hybrids are fully fertile.

Fertilization records, larval culture histories, and spat records of all these hybrids and control crosses are being studied. Data accumulated up to the present time appear to show to following:

1. Lack of any crossing barriers between Long Island Sound oysters and the populations thus far crossed with the exception of some oysters from Maine which may be developing an incipient crossing barrier.
2. Good performance of all the hybrids as larvae.

3. But outstanding performance of Maine hybrids as larvae and early postsetting spat.

4. A hybrid growth rate of the spat in the first year slower than that of the local controls, but better than that of the nonlocal controls.

5. Extremely poor growth of the older spat of Maine hybrids and of the Maine × Maine controls with total mortality before the second year. Maine hybrids did better though than the Maine × Maine control.

Full fertility was found in some geographic hybrids of *C. gigas*, along with fertility of their F_1 (Imai and Sakai, 1961). Generally speaking, the crossbreds had a higher degree of hardiness, as compared to the inbred strains, and a greater adaptation to environmental conditions. Morphological characteristics fell between those of the strains crossed as did growth, weight, index of meat weight, and glycogen content.

Some years ago H. C. Davis of the Milford Laboratory crossed *C. virginica* with *C. gigas* (Davis, 1950). Fertilization took place readily, cell division was normal, and early veliger larvae were obtained. However, they all died before reaching the umbo stage. Imai and Sakai (1961) obtained the same result. They further found both crossing barriers and hybrid inviability in crosses of *C. gigas* with *C. rivularis* and *C. echinata*. More recently, Menzel (1968a) reported obtaining a few spat from the hybrid cross of *C. virginica* with *C. gigas*, and some spat from crosses of other species with *C. virginica*. Interspecies crosses, at least those involving *C. virginica*, in general, though appear difficult to obtain and difficult to culture successfully (Menzel, 1967, 1971). Recently, a cross of *C. virginica* with *C. angulata*, the Portuguese oyster, resulted in 20% of the eggs developing to the straight-hinge larval stage (Stiles, 1973). All of the larvae, most of which were abnormal, died shortly after this. Cytogenetic examination of this interspecies fertilization revealed 35% of the eggs to be unfertilized. Another 10% had a very delayed fertilization. Polyspermy occurred in 35% of the eggs. Sperm nuclei were abnormally large and irregular in 25% of the eggs. Cleavage was irregular in 5%. Nuclei of the early larval tissues were abnormally vacuolated and highly irregular in shape. Adult oysters were reared from the hybrid *C. gigas* × *C. angulata* made by Imai and Sakai (1961).

Difficulties in obtaining species hybrids of oysters should not be viewed altogether pessimistically. Some of the methods used in plants and other animals to break down gamete cross incompatibility barriers, as in inbreeding, would, no doubt, be useful in accomplishing interspecific fertilization in the oyster. The problem of hybrid inviability might be overcome by crossing large enough numbers of individuals, carrying larger than usual cultures, by crossing different races of the species involved, or with mutagenic agents. If direct hybrids between the desired species are not possible even then or are sterile, the use of a third "bridging" species can sometimes circumvent the barrier.

Currently the only reliable way to achieve pure hybridization in the oyster without any contaminating nonhybrids is to make single crosses of individual oysters spawned separately, a tedious process not commercially practical. This is so since the oyster cannot be sexed until spawning and because the oyster once sexed can reverse its sex. One male spawning in a group of intended female hybrid parents would fertilize all the eggs before the desired hybrid cross could be achieved. This problem could possibly be solved through the use of some sperm inhibiting agents in the mass-spawning population intended for use as the pool of female parents in the mass hybridization.

EFFECTS OF IONIZING IRRADIATION ON *C. VIRGINICA*

Mutation breeding has been scarcely attempted in economically useful farm animals. This is because of the high cost of culling out the large numbers of individuals carrying the great numbers of lethal or subvital mutations due to the low reproductive rate of mammals. Because of the oyster's tremendously high reproductive rate and the insignificant worth of a single oyster, there would be no such limitations on mutation studies, or breeding with mutations in the oyster.

Some irradiation-mutation studies were initiated in *C. virginica* for the basic information that could be derived, and to determine the radiosensitivity of this mollusk, a member of a group about which there is relatively little such information (Fig. 9) (Longwell, 1969; Longwell and Stiles, 1970; Longwell and Stiles, unpublished data).[3] There is, of course, the probability of practical application of such information in the future. For example, irradiation might

[3] Irradiation was carried out at the Brookhaven National Laboratory with the assistance and advice of A. H. Sparrow.

Figure 9.—Adult American oyster, *Crassostrea virginica*, set up for gamma-irradiation at the Brookhaven National Atomic Energy Commission Laboratory.

have use in sterilizing highly selected strains of a commercial hatchery to increase somatic growth and to prevent competitor companies from breeding the strain. Irradiation might be used commercially to induce parthenogenesis in obtaining instant, one-generation pure homozygous individuals. A mutant larval form with a larger mouth could increase the types of algae an oyster larva would find acceptable as a food since the larva would then be able to ingest larger sized algal cells.

Gamma rays from a Cs^{137} source extending from 65 to 10,000 R administered to large, old wild adults in 1 hr, and from 220 to 20,000 R administered in 1 and 2 hr to wild spat about 9 mo old were not sufficient to establish an LD_{50} for *C. virginica*. The lethal dose must be affected by the season of the year the oysters are irradiated, as well as by size of the oyster and shell thickness. These oysters and spat were irradiated in the spring of the year as they were coming out of their winter dormancy. Germ-line primordia were beginning active mitoses.

Gross cytological study of the gonads of the gamma-irradiated adults revealed that even the maximum dose of 10,000 R did not adversely affect the production of gonadal material. Instead, the treated group as a whole had roughly about 20% more gonadal bulk than did the control group; also, there were fewer sexually undifferentiated oysters in the treated group.

Spawning performance of the irradiated adults was better than that of the controls. Some adult oysters receiving the maximum 10,000 R spawned. However, none of the juveniles receiving more than 8,000 R spawned.

Cytogenetic study of spawned eggs X-irradiated at a rate of 164 R/15 sec and then crossed with untreated sperm showed chromosome damage to begin at 500 R. By 2,000 R such damage was pronounced. The highest dose used on the eggs was 4,000 R.

In terms of the number of set produced and surviving for 1 yr from cultures of 500,000 fertilized eggs, even the lowest dose of 125 R of X-rays administered at a rate of 199 R/10 sec to pooled sperm crossed with untreated eggs had a slight effect. By 2,000 R the number of these spat was reduced appreciably. At 3,000 R there was hardly any, and none at all at doses above this. From 4,000 R on there was a clear, strong drop in percent development of the eggs to some cleavage stage and percent development to the straight-hinge larval stage. There was an increased percent of abnormal straight-hinge or 2-day-old larvae. The highest dose used on the sperm was 10,000 R. See Table 2.

The overall performance of the larval and spat cultures from the F_1 of the gamma-irradiated oysters and from the F_2 of the irradiated sperm lines has been characterized by an increased incidence of abnormal larvae at the straight-hinge stage, increased mortality at all the early larval stages, heterosis of the surviving larvae, and possibly some heterosis also in the young spat. This extra vigor must be due to the increased genetic heterozygosity resulting from the irradiation. Irradiation lines are also characterized by a greater crossability of sibs, as mentioned earlier, and also by a greater success of the inbreds. Improved crossability of sibs can likewise be attributed to the increased heterozygosity that results from induced mutations and to mutations of the cross-compatibility genes themselves as well. There has been very little morphological change in either the larvae or spat as a result of the irradiation.

Fertilization and early cleavage stages of these crosses have increased polyspermy, more spindle disturbances, more abnormalities of chromosome number, more chromosome rearrangements, abnormal coiling of the chromosomes, and abnormal nuclei. These are all classic signs of irradiation damage to the genetic material.

LITERATURE CITED

AHMED, M., and A. K. SPARKS.
1970. Chromosome number, structure and autosomal polymorphism in the marine mussels *Mytilus edulis* and *Mytilus californianus*. Biol. Bull. (Woods Hole) 138:1-13.

BATTAGLIA, B.
1970. Cultivation of marine copepods for genetic and evolutionary research. Helgoläender wiss. Meeresunters. 20:385-392.

Table 2.—Summary of the culture history of crosses of 1 wild adult × pooled irradiated sperm of 5 wild adult *Crassostrea virginica*.

Dose of X-irradiation	% development to some cleavage stage	% development to straight-hinge larvae	% 2-day culture abnormal	Numbers of spat surviving 1 yr
125 R	26	25	12	1057
250 R	23	20	27	126 (most lost)[1]
500 R	19	16	46	1022
1,000 R	28	25	24	790
2,000 R	19	16	45	468
3,000 R	20	15	53	7
4,000 R	25	15	69	0
5,000 R	6	2	95	0
7,500 R	1	0.5	80	0
10,000 R	0.3	0.2	100	0
Control 1	30	27	25	1167
Control 2	20	16	53	168 (most lost)[1]
Control 3	33	30	23	1151

[1] Accidental loss of larvae in culture process.

BREWBAKER, J. L.
1964. Agricultural genetics. Prentice-Hall, Englewood Cliffs, N.J., 156 p.

DAVIS, H. C.
1950. On interspecific hybridization in *Ostrea*. Science 111:522.

HILLMAN, R. E.
1964. Chromatographic evidence of intraspecific genetic differences in the Eastern oyster, *Crassostrea virginica*. Syst. Zool. 13:12-18.

IMAI, T., and S. SAKAI.
1961. Study of breeding of Japanese oyster, *Crassostrea gigas*. J. Agric. Res. 12:125-171.

LANNON, J. E.
1972. Estimating heritability and predicting response to selection for the Pacific oyster *Crassostrea gigas*. (Abstract.) Proc. Natl. Shellfish. Assoc.

LONGWELL, A. C.
1969. Oyster genetics: Research and commercial applications. Conference on Shellfish Culture, April 1968, at Suffolk Community College, Selden, Long Island, N.Y.

LONGWELL, A. C., and S. S. STILES.
1968a. Fertilization and completion of meiosis in spawned eggs of the American oyster, *Crassostrea virginica* Gmelin. Caryologia 21:65-73.
1968b. Removal of yolk from oyster eggs by Soxhlet extraction for clear chromosome preparations. Stain Technol. 43:63-68.
1970. The genetic system and breeding potential of the commercial American oyster. Endeavour 29:94-99.
1973. Gamete cross incompatibility and inbreeding in the commercial American oyster, *Crassostrea virginica* Gmelin. Cytologia 38:521-533.

LONGWELL, A. C., S. S. STILES, and D. G. SMITH.
1967. Chromosome complement of the American oyster *Crassostrea virginica*, as seen in meiotic and cleaving eggs. Can. J. Genet. Cytol. 9:845-856.

LOOSANOFF, V. L.
1969. Maturation of gonads of oysters, *Crassostrea virginica*, of different geographical areas subjected to relatively low temperatures. Veliger 11:153-163.

LOOSANOFF, V. L., and H. C. DAVIS.
1963. Rearing of bivalve mollusks. *In* F. S. Russell (editor), Advances in marine biology, vol. 1, p. 1-136. Academic Press, London and New York.

LOOSANOFF, V. L., and C. A. NOMEJKO.
1951. Existence of physiologically-different races of oysters, Crassostrea virginica. Biol. Bull. (Woods Hole) 101:151-156.

MENZEL, R. W.
1967. Hybridization in species of *Crassostrea*. (Abstract.) Proc. Natl. Shellfish. Assoc. 58:6.
1968a. Cytotaxonomy of species of clams *(Mercenaria)* and oysters *(Crassostrea)*. Proc. Symp. on Mollusca, Part 1, p. 75-84.
1968b. Chromosome number in nine families of marine pelecypod mollusks. Nautilus 82:45-60.
1971. The role of genetics in molluscan mariculture. Am. Malacol. Union Bull., p. 13-15.

MORGAN, T. H.
1924. Self-fertility in Ciona in relation to cross-fertility. J. Exper. Zool. 40:301-305.
1942a. Cross- and self-fertilization in the ascidian Styela. Biol. Bull. (Woods Hole) 82:161-171.
1942b. Cross- and self-fertilization in the ascidian Molgula manhattensis. Biol. Bull. (Woods Hole) 82:172-177.

NEEDLER, A. W. H., and R. R. LOGIE.
1947. Serious mortalities in Prince Edward Island oysters caused by a contagious disease. Trans. R. Soc. Can., Ser. 3, 41(5):73-89.

NUMACHI, K.
1962. Serological studies of species and races in oysters. Am. Nat. 96:211-217.

STAIGER, H.
1957. Genetical and morphological variation in *Purpura lapillus* with respect to local and regional differentiation of population groups. Ann. Biol. 33:251-258.

STAUBER, L. A.
1947. On possible physiological species in the oyster *Ostrea virginica*. (Abstract.) Anat. Rec. 99:614.
1950. The problem of physiological species with special references to oysters and oyster drills. Ecology 31:109-118.

STILES, S. S.
1973. Cytogenetic analysis of an attempted inter-species hybridization of the oyster. Incompatibility Newsletter, No. 3, p. 41-45. Association EURATOM-ITAL., P.O. Box 48, Wageningen, The Netherlands.

STILES, S. S., and A. C. LONGWELL.
In press. Fertilization, meiosis and cleavage in eggs from large mass spawnings of *Crassostrea virginica* Gmelin, the commercial American oyster. Caryologia.

WILLIAMS, W.
1964. Genetical principles and plant breeding. Blackwell Scientific Publications, Oxford, 504 p.

RECENT DEVELOPMENTS IN SHELLFISH CULTURE ON THE U.S. PACIFIC COAST

JOHN B. GLUDE[1]

OYSTERS

Two species of oysters are produced in the States of Washington, Oregon, and California in the bays shown in Figure 1. The small native oyster, *Ostrea lurida* Carpenter, 1863, is found in all three states, but is raised commercially only in the southern part of Puget Sound, Wash. Production is low, but prices are extremely high since this oyster is served as a specialty in seafood restaurants.

The major species produced on the West Coast of the United States is the "Pacific" oyster, *Crassostrea gigas* Thunberg, 1793, which was first introduced from Japan about 40 yr ago. Except for the period 1941-46 seed oysters have been imported from Japan each year. Periodically local reproduction occurs and U.S. growers are able to augment their seed supply by collecting spat locally.

Major oyster producing areas are Willapa Bay, Grays Harbor, and Puget Sound in Washington; Tillamook, Yaquina, and Coos Bays in Oregon; Humboldt Bay, Tomales Bay, Morro Bay, and Drakes Estero in California.

The major part of U.S. West Coast production comes from Washington, as shown in Figure 2. Peak production of over 10 million pounds of shucked meats was reached in 1954 to 1956. Since that time production has decreased to a mean of 6.4 million pounds for the period 1966-70.

Oyster production in California increased rapidly from 1954 to 1957, exceeded 1 million pounds of meats from that time until 1965, and decreased somewhat in the following years, but again exceeded 1 million pounds in 1970.

Oyster production in Oregon reached nearly 1 million pounds per year in 1950 to 1952 and then

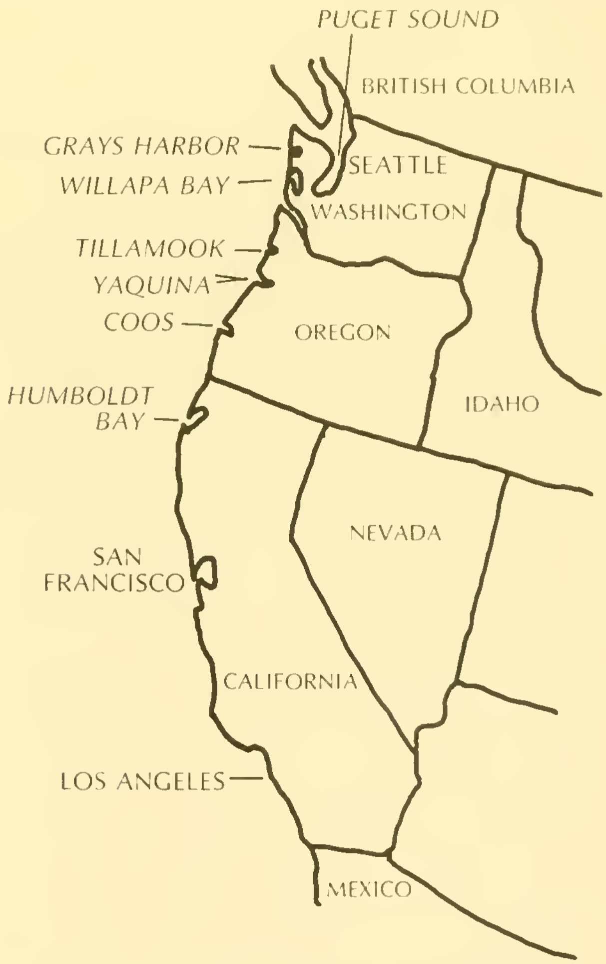

Figure 1.—United States Pacific coast.

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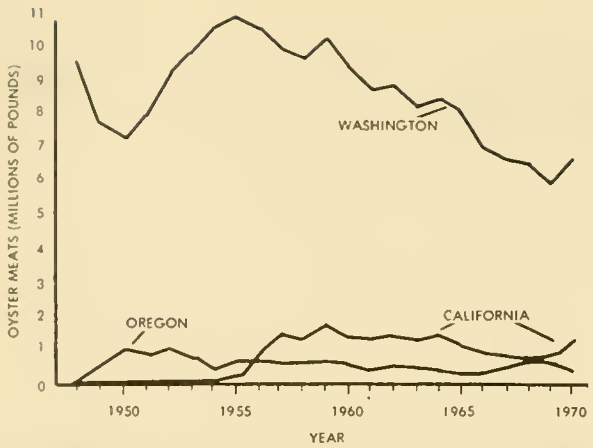

Figure 2.—Production of Pacific oysters, *Crassosstrea gigas*, on the U.S. Pacific coast.

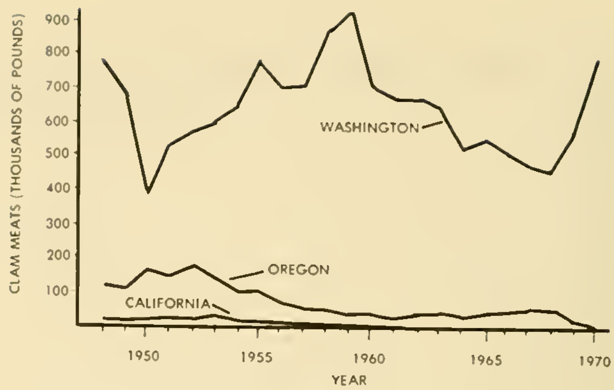

Figure 3.—Production of clams on the U.S. Pacific coast.

dropped to about one-half million per year, and continues at about that level.

CLAMS

Several species of clams are harvested commercially on the U.S. Pacific coast. The razor clam, *Siliqua patula* (Dixon, 1788), and the Pismo clam, *Tivela stultorum* (Mawe, 1823), occur on the open wave-swept ocean beaches. Although both of these species were originally harvested commercially, the growing trend toward recreational fisheries has resulted in a disappearing commercial fishery. Only a few areas remain on the Washington coast where commercial harvesting of razor clams is still permitted; but each weekend during the open season up to 25,000 recreational diggers attack the beaches hoping to obtain their limit of 18 clams each.

Other species grouped in the category of "hard" clams found in protected bays and inlets provide a significant commercial fishery. Species include the native littleneck or rock clam, *Protothaca staminea* (Conrad, 1837); the butter clam, *Saxidomus nuttali* Conrad, 1837; and the introduced Japanese littleneck or "Manila" clam, *Tapes semidecussata* (Reeve, 1864).

The commercial demand for hard-shell clams is very good and prices are high in comparison to oysters. Production does not meet the demand and significant quantities of hard-shell clams are imported from British Columbia, Canada. There is very little "farming" of these clams and production is based on harvesting natural populations, principally upon privately-owned or privately-leased intertidal lands.

Clam production on the U.S. Pacific coast is centered in Washington with production ranging from 400,000 to nearly 1 million pounds of meats per year, as shown in Figure 3. Although production has varied during the past 20 yr, no clear production trend is evident from these records which include all species of clams. Decreases in commercial production of razor clams are largely offset by increased harvests of hard clams.

The few protected bays and inlets along the Oregon coast produced between 100,000 and 200,000 pounds of clam meats per year for the period 1948-55 and have since dropped to a relatively low level.

Commercial clam production in California was never great and has been negligible in recent years.

In both Oregon and California the tourist demand for hard-shell clams, as well as razor and Pismo clams, has utilized an increasing proportion of the available supply.

ANALYSIS OF TRENDS IN OYSTER PRODUCTION

There are several factors which help to explain the decrease in production of Pacific oysters during the past decade, as shown on Figure 4. A major factor is the limited U.S. market for oysters. The United States per capita consumption of fishery products generally has remained nearly static for a number of years at about 11 pounds, and per capita consumption of oysters during this period has actually decreased. There has been little or no market promotion by the oyster industry which is poorly organized and made up of many small companies.

Although the quality of oysters produced and marketed as a refrigerated, raw, shucked product is generally good at the time the oysters leave the plant, the delay in the distribution, especially to more distant areas, results in a significant decrease in quality.

Distribution to the Rocky Mountain and Mid-West states from the Pacific coast is more difficult now because Railway Express, which utilized rapid passenger trains, has become less available as trains are being discontinued because of the general trend toward air travel. Transportation of oysters by air to many of these locations is not economical because of the small volume to be shipped. All of this has resulted in curtailment of oyster markets in a large portion of the United States.

Another factor is the competition for the fresh-oyster market from East Coast or Gulf of Mexico, the American oysters, *Crassostrea virginica* Gmelin. Much of the production in these areas is from public beds which results in a low price when oysters are abundant, and a high price when oysters are scarce.

Oyster production on the Atlantic coast was generally low for several years following the major mass mortalities of oysters caused by the Haplosporidian *Minchinnia nelsoni* which began in Delaware Bay in 1957 and spread to Chesapeake Bay during the following 2 or 3 yr. During this period the demand for Pacific oysters expanded and prices increased during the years 1960-61 and again between 1966 and 1967. More recently, production of low-priced oysters on the East Coast has increased, causing a reduction in market demand for Pacific oysters. Market price of oysters on the Pacific coast has remained static for the past 4 yr even though costs generally

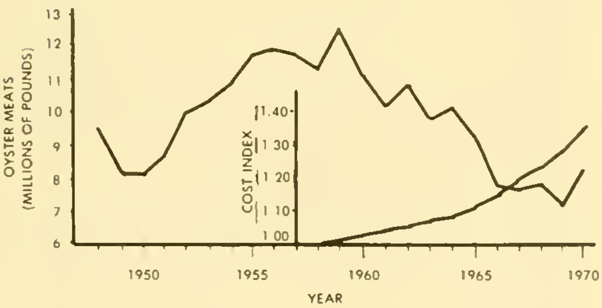

Figure 4.—Pacific oyster, *Crassostrea gigas*, production and cost index.

Table 1.—Wholesale price of shucked Pacific oysters, *Crassostrea gigas*, in Seattle, Wash., cost index and oyster price adjusted to 1958 base.

Year	Oyster price	Cost index	Oyster price adjusted to 1958 base
	Dollars/gal	*Implicit price deflator*	*Dollars/gal*
1958	4.10	99.97	4.10
1959	4.00	101.66	3.93
1960	4.10	103.29	3.97
1961	4.80	104.62	4.59
1962	4.75	105.78	4.49
1963	4.50	107.17	4.20
1964	4.50	108.85	4.13
1965	4.55	110.86	4.10
1966	5.75	113.95	5.05
1967	6.75	117.59	5.70
1968	6.75	122.31	5.52
1969	6.75	128.11	5.27
1970	6.75	134.86	5.00

have increased during this period, as indicated by Table 1 and Figure 4.

The price per gallon of oysters shown in Table 1 is somewhat misleading since this is the price paid by wholesalers for shucked oysters delivered to Seattle, Wash., for the fresh-oyster trade. During recent years when supplies have exceeded the market demand for fresh oysters, it has been necessary to divert a part of the production into canned oysters, smoked oysters, or oyster stew. The price of oysters for a processed product must necessarily be lower than the price for fresh oysters. Therefore, the average price received by many growers was significantly less than that indicated on Table 1.

Efficient growers have reduced production during this period and now use only their best land. This reduces their costs by increasing the yield per unit area and by reducing the time required for a crop to reach marketable size.

Another factor which has increased costs has been the lack of local setting during the past 3 yr. Locally produced seed is generally less costly than imported seed, especially for those growers who are able to collect their own seed from natural reproduction. Also, the price of imported seed has increased recently and many growers hesitate to invest in seed because of the squeeze between increasing costs of production and limited demand at static prices.

In summary, production of Pacific oysters has decreased to fit the present market. Marginal producers have dropped out, and efficient producers have curtailed production. Prices have remained generally static, whereas costs have increased producing a generally unfavorable profit picture for the Pacific coast oyster industry. Given increased demand at profitable price levels, production could be greatly increased.

NEW DEVELOPMENTS IN OYSTER PRODUCTION

Specialty Products

Hidden in the statistics, because of low volume, is a newly developed market for "specialty" oysters. These are partially grown Pacific oysters, usually marketed under the trade name "yearling" oysters. These oysters are about 3 inches in length, similar to the size marketed in Japan, and are suitable for the raw half-shell trade, oyster cocktails, stews, sauteed oysters, etc. This product has a much better market acceptance than large Pacific oysters which must be blanched and cut into pieces before cooking.

The market for yearling oysters is rather limited, production costs are high and volume is low, but these oysters sell for two to three time the price of standard-sized oysters. Turnover is rapid because of the short time required to grow marketable-sized oysters. All factors considered, several small companies have been able to improve their profit picture by producing this specialty product.

Another development is a patented process which reportedly produces superior frozen oysters. This process consists of hand-shucking, partial cooking, breading, and rapid freezing. This product retains the flavor well and resists oxidation during frozen storage. Although relatively expensive to produce because of the costs of hand-shucking, this product is finding good market acceptance. Frozen oysters can be shipped by surface transportation which is cheaper than the air shipment required to deliver fresh shucked oysters to distant markets.

Increasing Use of Off-bottom Culture

Although off-bottom culture of Pacific oysters has been used in Japan for many years, this method has only recently gained acceptance on the Pacific coast of the United States. This is mainly because extensive intertidal areas have been available for oyster culture and production of oysters on bottom is less costly than production off-bottom.

Within the past 3 yr, however, several oyster growers have begun oyster culture using rafts or racks, and those who have been able to market a specialty product at a higher price have been quite successful. One company has constructed simple rafts using styrofoam for flotation and suspends seed oysters on wires below the rafts in a protected part of Puget Sound, Wash. After 15-18 mo those oysters which have reached commercial size are marketed, and the rest are placed on-bottom for another growing season. These small oysters are well accepted in the Seattle market at higher than average prices, and it appears that this production method will be economical.

Several Oregon growers in Yaquina Bay near Newport, Oreg., suspend Fiberglas[2] trays of oysters below rafts and market these oysters at a small size in restaurants in Portland, Oreg. These growers have found that tray culture is somewhat more expensive than "string" culture, and they may discontinue the use of trays.

One company at Eureka, Calif., has an extensive system of racks placed along the banks of channels in Humboldt Bay. Oysters raised on these racks grow faster than those on bottom and are generally in better condition.

It has also been observed that mortality of oysters suspended from racks is lower than that of oysters placed directly on the tide flats. Oyster mortality on the beds in Humboldt Bay in 1971 was recorded as 40% by pathologists of the California Department of Fish and Game, whereas mortality of oysters suspended from racks was 10%.

Although rack culture generally is more costly than "on-bottom" culture and requires special locations, there is a belief that Pacific oysters raised off-bottom have a milder flavor than those raised on-bottom. An organoleptic test to compare the flavor of oysters reared under various conditions will be conducted by the Washington State Department of Fisheries and the National Marine Fisheries Service in Seattle during November 1971.

Raft culture has many of the advantages of rack culture and also provides more latitude in selection of locations since rafts can be anchored in waters of

[2] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

various depths. The principal requirements for raft culture are 1) shelter from storms, 2) sufficient depth, and 3) permits from local zoning authorities and Corps of Engineers for anchoring rafts.

An anticipated development is a system of growing oysters on submerged rafts or racks. This system will probably be necessary in areas where recreational use of the water surface for fishing, boating, etc. would make it difficult to obtain permission for raft culture. Engineering designs for structures needed for this type of culture have not yet been completed, but might be patterned after the submerged racks which are used in French Polynesia for pearl oyster culture to avoid storm damage and fouling.

Use of "Unattached" or "Cultchless" Seed

Pacific Mariculture, Inc. near San Francisco, Calif., has patented a process of producing individual seed oysters which have several advantages. This seed is readily available at any time of the year and can be shipped economically by air freight. Survival during shipment and after planting has been excellent and the individual oysters develop a uniform shape which makes a very attractive product.

Disadvantages of "unattached" seed are that it requires special handling in screen trays, and this requires a large amount of hand labor. Growth is generally poor in trays unless there is adequate circulation of water which contains adequate food supplies. These individual oysters must be quite large before they will stay in place on oyster beds which are exposed to waves, currents, or storms. This limits the use of this seed for traditional oyster farming and requires development of new aquacultural systems. It appears that "unattached" seed will become an important factor during the next few years, provided specialty markets can be developed for the product.

During March 1971, I made experimental plantings of "unattached" *Crassostrea gigas* seed from the Pacific Mariculture hatchery at several locations in the Fiji Islands. Survival of this seed was excellent and growth was satisfactory after the spat were cemented to fiberboard (Masonite or asbestos board) squares strung on wire or rope and suspended below rafts. It appears that this method will be applicable any place where hydrographic conditions permit the use of rafts or racks and where labor costs are low.

Air Shipment of Anesthetized Oyster Larvae

Pacific Mariculture, Inc. has recently patented a method for temporarily suspending activity of mature oyster larvae. With this method it is possible to air ship large quantities of mature oyster larvae in small containers from California to oyster culture areas. At these locations larvae are placed in tanks of warm water with suitable cultch materials. Attachment is completed within 2 hr. This method avoids the cost of shipping heavy "mother" shells or other cultch materials since one-half million larvae can be shipped in a ½-liter bottle. Oyster growers can then "set" the larvae on desired cultch materials and plant them on their oyster beds. This method needs further development to improve its reliability, but it appears probable that this will be accomplished in the near future and that this method will find application in many places.

Investigation of Causes of Oyster Mortality on the Pacific Coast

Mortalities of 10-70% during the second or third summer after planting Pacific oyster seed has been observed at several locations along the Pacific coast. The most severe mortalities have occurred in southern Puget Sound and part of Willapa Bay in Washington, and Humboldt Bay in northern California. Negligible mortality levels have been observed in British Columbia, northern Puget Sound and Hood Canal in Washington, Oregon bays, and elsewhere in California.

Generally, heavy mortalities occur near the heads of bays which are warm and muddy with high nutrient levels, abundant phytoplankton, where oysters grow rapidly and fatten well. Mortalities generally occur during a few weeks in midsummer when the oysters are in spawning condition. It has been observed that mortalities have been more severe during warmer years.

Investigations during the past 5 yr by state fisheries agencies of Washington, Oregon, and California and by the laboratory of the National Marine Fisheries Service in Oxford, Md., have failed to detect a specific cause for this mortality. Tests for *Labyrinthomyxa marina* which causes extensive losses of oysters in the Gulf of Mexico and *Minchinnia nelsoni* which kills oysters in Chesapeake and Delaware Bays have proved negative. Although numerous microorganisms have been observed in the thousands of oysters examined from the Pacific coast, none have occurred consistently enough to indicate that they are associated with the observed mortalities.

In a new project, a graduate student at the University of Washington College of Fisheries in Seattle is investigating the relationship between the bacterium *Vibrio anquillarum* or *V. parahaemolyticus* and oyster mortalities. He has observed that *Vibrio* can kill oysters at elevated temperatures in laboratory experiments, but field tests have not yet been made.

Efforts of Washington State Department of Fisheries have recently been reoriented to develop new oyster culture techniques which will circumvent or offset mortalities. For example, transplanting partially grown oysters to low mortality areas before the second summer when heavy mortalities begin seems to be a practical solution. Also, improvement of handling methods for seed to reduce losses would help to offset mortality which might occur during the second summer.

In summary, mass mortalities significantly reduce production and profits in specific locations, but other areas remain unaffected. Research to determine causative factors is still in progress.

NEW DEVELOPMENTS IN CLAM PRODUCTION

Ocean beaches on the Pacific coast are owned by the states and held for public use. This prevents the private commercial development of farming for species such as the razor clam or Pismo clam which occur only in this habitat.

The intertidal zone in bays or estuaries is also owned by the states, but much of this land, especially in the State of Washington, has been sold to individuals who are usually the owners of the adjacent upland. Large areas of intertidal zone have also been leased by the states to individuals or companies for special purposes, such as oyster and clam culture. Subtidal bottoms also can be leased to individuals or companies for aquaculture.

Farming of clams has not reached the stage of development attained by oyster culture. The few commercial clam farms on the U.S. Pacific coast still depend upon natural setting to restock their beds. Clam farming is still only selective harvesting of a natural crop to obtain the greatest yield.

Until recently there has been no source of "seed" clams which might be used for planting on private lands and this has been a major deterrent to clam farming. Now a commercial hatchery in California has successfully produced large quantities of young Manila clams and has offered these for sale. Test plantings have been made in Willapa Bay, Wash., and in some other locations, but it is too soon to evaluate the success of these ventures.

I had the opportunity in March 1971 to obtain a small quantity of these seed clams from California and to plant them in trays in the Fiji Islands. Survival of clams was excellent, but growth was not outstanding. This experiment is still in progress, but it is already apparent that the first step in the development of commercial farming for clams, availability of seed, has been accomplished. With the large demand for clams and the limited supply, it is likely that a new clam farming industry will develop in Washington State within the next few years.

Three new developments in the utilization of natural stocks of mollusks occurred in Washington. Exploratory diving and population assessment by scientists of the Washington State Department of Fisheries have shown that less than 5% of the geoduck clam, *Panope generosa* Gould, 1850, are exposed at extreme low tide. Before this discovery it was thought that the geoduck was a scarce species which needed stringent regulation to prevent overharvesting. No commercial digging had been permitted and the recreational or personal use limit was set at three clams per day.

Now Washington has surveyed subtidal beds and established a system for leasing areas for commercial harvest by scuba divers using suction pumps. The product is now achieving market acceptance and a new industry has been established.

Another species of clams, *Mya arenaria* Linnaeus, 1758, known as the soft-shell clam in New England and Chesapeake Bay, is present in Washington but has not been utilized commercially. This clam has a somewhat less attractive appearance than the local littleneck and butter clams, and traditionally it has not been marketed in the Pacific Northwest. Heavy concentrations of soft-shell clams are found in muddy or sandy beaches, usually at the mouths of rivers, but areas suitable for these species are rather limited.

Recently several individuals or companies have begun harvesting soft-shell clams using two types of hydraulic dredges to minimize labor costs. One type similar to that used in Chesapeake Bay is operated from a boat and consists of a digging head which is forced through the bottom and a conveyor to bring the clams to the surface. The second type is hand-operated at low tide, but uses water pressure to wash the clams out of the bottom.

The quality of the soft clams in Washington is comparable to those from Chesapeake Bay or New England. If harvesting and shipping costs are not prohibitive, it is likely that a new industry for soft-shell clams will become established in the Pacific Northwest.

Large populations of the blue mussel, *Mytilus edulis* Linnaeus, 1758, occur in Puget Sound, Wash., but this species also traditionally has not been fully utilized in the United States. Puget Sound mussels are comparable to the European mussels in quality and the paralytic shellfish poisoning caused by their feeding on the dinoflagellate Gonyaulax, which sometimes limits mussel harvesting along the ocean coast, is not a problem in the inshore waters of Puget Sound.

Recently, through efforts of the marketing specialists of the National Marine Fisheries Service, local restaurants have begun to serve mussels and the product seems to be gaining acceptance in the Pacific Northwest. There are substantial natural stocks of mussels which could be harvested if a market develops. Also, it would be possible to supplement natural production by applying mussel farming techniques used in Holland, Spain, and elsewhere as the market expands.

COASTAL ZONING

People in the United States are becoming increasingly aware of the need to protect the environment from industrial or residential development. This need is especially apparent along the shoreline where several classes of users compete for space. Shellfish farmers are finding difficulty in obtaining approval from local "zoning boards" to anchor rafts for oyster culture in areas where shoreline residents want to use the water surface for boating, fishing, water skiing, etc. Even the installation of pilings or stakes marking boundaries of shellfish beds or wharfs for unloading the product are being questioned.

At the same time there is a major effort to maintain or improve water quality in the bays and estuaries and to eliminate sources of industrial and domestic pollution. These public efforts will help to assure continuation and expansion of aquaculture which is a "clean" industry. Furthermore, aquaculture provides a good economic justification for maintaining high water quality in inshore areas.

Federal and state legislation has been passed or is being considered to establish authorities and procedures for zoning the shoreline for special purposes. If fish and shellfish farmers can present a convincing argument, it is likely that certain areas will be reserved for aquaculture with assurance that water quality will be maintained at acceptable levels.

CONCLUSION

In conclusion, oyster production on the Pacific coast is limited by demand, but the potential exists for greatly increased harvests through application of modern methods of aquaculture.

Clam production is limited by natural supply. Clam farming has not been developed but, now that seed of at least one species is available, it is likely that commercial clam culture will develop rapidly in the Pacific Northwest.

Water quality will not be a limiting factor if the present awareness of the importance of the environment is translated into action to control pollution. Coastal zoning is a threat to aquaculture in some areas but could protect those areas which are most important for production of fish and shellfish.

SEAWEED CULTURE IN JAPAN

ROBERT WILDMAN[1]

The culture of marine algae, primarily for human consumption, is a large and expanding industry in Japan. At the present time, the growing and harvesting of *Porphyra*, "nori," is considered to be one of the most profitable fisheries in Japan. In contrast, seaweed culture is still in a research phase in the United States. Our demand for marine algae is much more limited in terms of both total volume and number of species. This is mainly due to the fact that few Americans eat the plants as such. Our use of seaweed is almost entirely in the form of phycolloids extracted from the plants, and to a very limited degree, as fertilizers and food. These uses of several species of marine algae and the recognition that the U.S. possesses a limited supply of the three or four most used species has led to seaweed culture on an experimental basis in this country. However, we have not and, in the foreseeable future, will not place the amount of our coastal waters under "cultivation" as has Japan. Another important difference between the United States and Japan is that the seaweed beds can be harvested only by fishermen's cooperative associations in Japan whereas in this country the harvesting is done by industrial firms either directly or through contractors. The cooperatives are responsible for the management and protection of these resources while in the United States such efforts are rarely required by the government but are usually voluntary.

PORPHYRA (NORI)

Culture Techniques

The most extensively cultivated seaweed in Japan, nori, has been grown since about 1600 (Tamura, 1966). The early culture techniques consisted of setting bundles of twigs in estuaries on which the spores settled and grew, and the mature plants were harvested. The nori harvest grew gradually until the end of World War II and is now six times that of the prewar level. Much of this increase was made possible by dramatic improvements in culture techniques. Two other factors were the establishment of cooperative unions which increased the profit to the grower and increasing coastal eutrophication which resulted in more fertile waters in many new areas, while the latter is the less important factor.

At first bamboo twigs replaced the tree twigs, then these were replaced in many areas by nets which were still placed in the water to collect the spores. This use of net collectors is thought to be responsible for a doubling of production, but the discovery by K. M. Drew of the Conchocelis stage in the life history of *Porphyra* enabled the Japanese to make the increases in production to the current level. The fisherman or cooperatives are now able to artificially "seed" their nets through the controlled culture of the Conchocelis stage, which in turn releases the spores to attach onto the nets in tanks or in the sea. (See Suto's paper in this report for a complete description of this process.) When the nets are "innoculated" in tanks, the nets are rotated slowly in the tanks containing the Conchocelis and then transported to the growing area where they are attached to the bamboo poles. This procedure allowed the nori grower to control the seeding of his collectors and thus, be more confident of his crop in areas with a good natural population. It also provided a means of growing nori in regions which had experienced a shortage in natural spores, especially in western Japan.

With the advent of the use of the Conchocelis—spore culture technique, the predominant species used changed from *Porphyra tenera* to *P. yezoensis* which could withstand higher salinities. In many areas *P. tenera* and *P. yezoensis* are grown in the inner parts of bays and estuaries with *P. pseudolinearis* being grown in the deeper waters. In

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the former situation, the nets (18.2 m × 1.3 m) are stretched between bamboo poles stuck to the bottom, with the nets being tied at the mean water level. The nets with *P. pseudolinearis* growing on them float on the water surface, anchored to maintain their position, and kept on the surface by glass or plastic floats.

Recent work by Imada and co-workers has yielded results that could increase the production of nori. This research indicated that amino acids are effective growth promoting substances for *Porphyra* and that the exposure of the fronds to air by tidal fluctuations is a significant factor in disease control (Imada, Saito, and Teramoto, 1971). Crossing experiments by Suto between different species of cultivated *Porphyra* succeeded, the cross developing to the Conchocelis phase. Other attempts at crossing monoecious and dioecious species, and between species with different chromosome numbers were not as successful (Suto, 1971).

Production and Use

The demand for nori in Japan and the increasing production capability have resulted in a very significant industry. In 1970, about 60,000 hectares (150,000 acres) of coastal waters in Japan were being used for nori cultivation. This acreage produced nearly 6 billion sheets of the dried product worth 70-80 billion yen per year (approximately $230 million). Each paper-thin sheet is 20 cm (8 inches square and weighs about 3 g. In addition, 200 million sheets are imported from Korea, a number now limited by an import restriction and one which could be increased to 1 billion sheets in the future (see Suto).

Approximately 60,000 fishermen are now cultivating nori, setting about 10 million nets each year and realizing the 50% (Furukawa, 1971) to 70% (see Suto) net income for their efforts. This level of production is required to meet the needs of the average Japanese who consumes 50-60 sheets of nori per year. The price of nori, up to $15 per kilogram dry weight (nearly $7 per pound), is a major factor in making this the most profitable of all fisheries in Japan.

Problems and Needed Advances

In spite of the high level of productivity, the Japanese recognize the need to increase their production and improve the profit potential of this fishery. Briefly summarized, these problems and activities are as follows. (Again, see Suto's paper in this report for a more complete description of them.)

1. Development of new nori grounds or improvement of old ones, using the new net collector techniques, the floating net cultures and coastal engineering works (pilings to protect growing areas, deepening such areas to increase water exchange, etc.). This would bring new areas into production to replace old ones lost because of pollution and increase the productivity of existing areas.
2. Prevention of large-scale fluctuations (heavy losses) yearly production primarily through disease control. This is done partially now by preventing overcrowding of the nets in the growing areas and by refrigerating the "buds" (juvenile plants, 5-50 mm in length) at −20°C. This refrigerating procedure is applied to a large part of the newly hatched fronds essentially for the procurement of frond stocks. These stocks are used to replace poorer quality fronds in the growing areas. By refrigerating these buds, the "weeds" (such as *Enteromorpha*) and diatoms are killed, and the development of a parasitic fungus is prevented. By 1970, one-half of all culture nets used were refrigerated using this technique (Okazaki, 1971). Most of the diseases or diseaselike problems are not well understood, or, in many instances, not even identified. Frequently, the plants appear to be infected by a fungus, but this could be caused by environmental or physiological conditions (temperature, salinity, malnutrition, etc.). Most of these conditions are called various kinds and colors of "spot disease" or "rots," but the exact causitive agent is not identified.

   Work reported recently by Ishio and his co-workers identified pollution from chemical plants as a cause of one type of algal disease. A "cancerous" disease observed in *Porphyra* in shallow coastal waters polluted by industrial wastes was shown to be related to contact between the fronds and the contaminated bottom mud. The mud was extracted and it was found that the carcinogenic fraction contained a mixture of organic compounds discharged by a dye factory which uses tar distillates as raw materials (Ishio, Yano, and Nakagawa, 1972).
3. Mechanization of nori cultivation and processing. With the current labor shortage in Japan and other

industries drawing workers away from the fisheries, with the resultant rising labor costs, as much of the growing, harvesting, and processing of the nori must be mechanized as possible. Even so, the nori fishery is not suffering nearly as severe a problem as that facing the oyster fishery.

4. Eutrophication in the coastal areas around Japan. This, in fact, is going on, and it may provide nutrients to the nori cultivating areas to some extent, but most of the causative elements of coastal eutrophication such as industrial discharge, domestic sewage, and agricultural run-off contain undersirable constituents. Industrial pollution, particularly that which contains cadmium, mercury, and other highly toxic elements poses a much greater threat to nori cultivation. Pollution of all kinds is now a very serious problem for Japan, but their heavy dependence on seafood, much of which comes from their coastal waters, makes marine pollution a very real health and economic threat.
5. Potential for oversupply with its resultant economic effects. With the high prices, the growers are obviously attempting to increase their total production. The success of efforts to expand the nori growing areas, solve the disease problems, eliminate pollution problems, and mechanize the industry will all lead to increased production. Further, the growing tendency of separating the producers and processors into separate operations will cause the producers to grow more algae to maintain their income level. Another possibility is that with the increasing mechanization and increasing size of cultivation operations, fewer workers and separate operators will be needed. Thus, many nori fishermen will be moved into other types of employment.

UNDARIA (WAKAME)

Introduction

In comparison to nori, cultivation of the brown alga, *Undaria*, is of relatively recent origin. The amount of wakame grown is still significantly less than nori, but is increasing rapidly from almost zero production in 1963 to over 60,000 tons in 1970. This exceeds the amount being harvested in Japan from natural beds. This alga, one of the Laminariales, is not native to American waters.

Culture Techniques

In the spring when the mature plants release the zoospores, "collector strings" are hung in the water on which the spores attach and the sporophytes grow. As with nori, this seeding now takes place in tanks although in the past it was done in the sea near natural beds. Also, past efforts to expand the beds have included creating new substrate surface by dropping rocks onto the bottom and exploding existing rocks with dynamite in areas with natural populations of *Undaria*. A wide variety of other techniques have been experimented on over the past 55 yr with some success (Tamura, 1966).

However, currently the collector string method is used in which the mature sporophylls are partially dried, placed into the tanks of fresh seawater and the released zoospores settle on a 100-m long string, previously wound around a vinyl plastic frame. The frame is removed after 1-2 hr and transferred to a 1-m deep culture tank for the summer season. When the young plants reach about 1 mm in length (in the fall), the strings are transferred to rafts in the sea. The plants are harvested when they reach about 1 m in length.

Attempts to produce hybrids of three species of *Undaria* have met with some success, indicating that at least closely related species can be crossed (Saito, 1971).

Problems

If the strings are placed on the rafts before the water temperatures have dropped to 15°C, serious fouling can occur. Also, if the rafts are located in a rough water area and left floating on the surface, the young plants can be seriously damaged. In these areas the rafts can be anchored to a depth of 1 m to avoid this problem. Other problems which are not so easily remedied include some bacterial diseases and grazing of the young plants by isopods and gastropods. One last potential problem is the indication that production is increasing to the point of equalling, if not exceeding, the demand for wakame in Japan.

LAMINARIA (KOMBU)

Introduction

Many species of this genus are used by the Japanese as food; several of them being cultivated at the present time. While important as a food and as a source of alginic acid, kombu is still not in as great a demand as are nori and wakame.

Culture Techniques

The cultivation, dating back 250 yr, is quite different than that for nori and wakame. Kombu production is increased primarily through the improvement of available substrate and control of harmful "weeds" such as *Phyllospadix*, a marine spermatophyte. The latter is accomplished by dynamiting to clear the *Phyllospadix* from areas suitable for growth of *Laminaria*. The former involves the placing of additional large rocks on the seabed on which the plants may grow or, in some instances, using artificial substrate such as various shapes of concrete. In addition, some cultivation has been done using a hanging culture system (line and float).

Problems

Laminaria is one of the many valuable marine algae which have been plagued by the phenomenon called "iso-yake" by the Japanese which prevents the plant from adhering to the bottom. Apparently, the cause of this problem still has not been identified, but it usually occurs in areas where the bottom is covered with coralline algae. Some investigators have advanced the theory that this results in a "desert" condition with very little in the way of edible seaweeds available to shellfish in the area. Thus, if juvenile plants of *Laminaria* and other such algae begin to grow, they are grazed off rapidly.

In this same vein, the Japanese have determined, as we have in California, that abalone are found only where their primary source of food (brown algae-kelps) is available (R. Burge, pers. comm.). In many areas, the brown algae are completely lacking and, thus, coastal waters in which abalone could grow, are not usable for cultivation. A very large-scale experiment is planned to begin in 1972 which will involve the establishment of a large kelp bed in a bay. If this is successful, 10 million abalone seed per year for 3 yr will be introduced into the kelp bed. This could lead to a new technique for expanding the capability of the Japanese for producing both *Laminaria* and abalone (Hisashi Kan-no, pers. comm.).

Other possibilities being researched include the development of techniques for cutting the normal 2-yr growth period to harvest down to 1 yr (Hasegawa, 1972). This has been accomplished and should lead to significant production increases.

GELIDIUM AND OTHER AGAROPHYTES (TENGUSA)

Introduction

Perhaps the most familiar algal extract to Americans because of its wide use as a component of bacterial growth media in both educational and medical facilities, agar is used for similar purposes in Japan. It is harvested for both domestic and export purposes, including sales in the United States. However, to meet the demand of the processors, Japan must now import about 5,500 tons of the 12,000 tons dry weight used in agar production.

Many red algae belonging to the families Gelidaceae and Gracilariaceae serve as the source of agar, but *Gelidium* is the most important genus in both Japan and the United States.

Culture Techniques

While much of the raw material for agar production is harvested from natural beds, some artificial propagation is practiced and has been for about 300 yr. In the past, this has consisted largely of increasing the available substrate by throwing large rocks into the coastal waters in areas near existing beds where spores will be sufficiently abundant to seed the rocks. Other efforts to increase the supply of agarophytes have included mechanical cleaning of the rock surfaces, eliminating weeds *(Ecklonia* and *Eisenia)* from *Gelidium* beds, growing young plants to harvestable size attached to ropes hanging from floating lines, and, more recently, fertilizing the coastal water in which the algae are growing (Yamada, 1972). In this last effort, a lump of fertilizer (in the form of urea, ammonium sulfate, or a "nitrogen/phosphate mixture") is placed on the seafloor in the *Gelidium* bed and allowed to dissolve slowly. While this has succeeded on a commercial scale, the economic feasibility of this practice has not been fully demonstrated as yet.

Problems

Gelidium and its relatives are among the harvested seaweeds known to suffer from the iso-yake phenomenon. To date it has not been possible to control the release of spores from *Gelidium* as has been done with many other algae. Ability to do this would make the establishment of new populations much more certain. Another potential problem is Korea's growing production and export of agar which could create an excess and result in a profit loss for Japan.

ANALYSIS OF SEAWEED CULTURE IN JAPAN

Although the Japanese are still encountering many problems in optimizing the culture of the several species of marine algae, they are able to produce nearly as much as they need. Their real problems of the future appear to lie in the fields of 1) undesirable pollution, 2) oversupply with its resultant lowering of price, and 3) idealizing the labor situation (improved working conditions, keeping wages and profits in line with other industries in Japan, keeping sufficient workers in the industry and finding acceptable employment for any excess over that which is needed, etc.).

Many of the techniques developed in Japan could be used by U.S. industry, but we face many problems which the Japanese do not. Our labor costs are already so high that nearly all seaweed farming in the United States would have to be essentially totally mechanized. Since the principal uses of seaweed in America are for nonfood purposes, the price paid for raw material will remain quite low. It is very doubtful that the public will allow the surface of our coastal water to be covered with a bambo-net type system used for *Porphyra* except in some very remote areas, such as in southeastern Alaska or on U.S. controlled islands.

BIBLIOGRAPHY

FURUKAWA, A.
1971. Outline of the marine aquaculture in Japan. Jap. Fish. Res. Conserv. Assoc.

HASEGAWA, Y.
1972. Forced cultivation of *Laminaria*. *In* Proc. Seventh Internatl. Seaweed Symp., Sapporo, Japan, Aug. 8-12, 1971, p. 391-393. Univ. Tokyo Press.

IMADA, O., Y. SAITO, and K. TERAMOTO.
1972. Artificial culture of laver. *In* Proc. Seventh Internatl. Seaweed Symp., Sapporo, Japan, Aug. 8-12, 1971, p. 358-363. Univ. Tokyo Press.

ISHIO, S., T. YANO, and H. NAKAGAWA.
1972. Cancerous disease of *Porphyra tenera* and its causes. *In* Proc. Seventh Internatl. Seaweed Symp., Sapporo, Japan, Aug. 8-12, 1971, p. 373-376. Univ. Tokyo Press.

OKAZAKI, A.
1971. Seaweeds and their uses in Japan. Tokai Univ. Press, 165 p.

SAITO, Y.
1971. On the effects of environmental factors on morphological characteristics of *Undaria pinnatifida* and the breeding of hybrids among the genus Undaria. Seminar on the Contributions of Culture, Laboratory, Field and Life History Studies to the Systematics of Benthic Marine Algae of the Pacific Abstracts, Jap.-U.S. Comm. on Sci. Coop., p. 18-19.

SUTO, S.
1971. Variation in species characters of *Porphyra* under culture condition. Seminar on the Contributions of Culture, Laboratory, Field and Life History Studies to the Systematics of Benthic Marine Algae of the Pacific Abstracts, Jap.-U.S. Comm. on Sci. Coop., p. 28-29.

TAMURA, T.
1966. Marine aquaculture. 2nd ed. (Translated from the Japanese by M. I. Watanabe, p. C-1—A2-30; available U.S. Dep. Commer., Natl. Tech Inf. Serv., Springfield, VA, as PB194051T.)

YAMADA, N.
1972. Manuring for Gelidium. *In* Proc. Seventh Internatl. Seaweed Symp., Sapporo, Japan, Aug. 8-12, 1971, p. 385-390. Univ. Tokyo Press.

FRESHWATER FISH CULTURE IN JAPAN

HARVEY WILLOUGHBY[1]

INTRODUCTION

The following observations on Japanese Fish Culture were made during field travel in Japan in the period October 20-27, 1971.

SALTWATER TROUT CULTURE

My only observation of trout culture in seawater was at Ogatsu Bay in Miyagi Prefecture. John Glude and I travelled to Ogatsu Bay in the afternoon of October 20, with Akimitsu Koganezawa, Chief of Shellfish and Fish Research for the Migayi Prefectural Station.

The principal trout culture installation was a new commercial hatchery just getting into production at Karakuwa. This is a commercial venture operated by a Fishermen's Cooperative Association. The station consists of a small hatchery building and six large circular rearing ponds. Each pond has a supply line for fresh water and one for seawater.

Each pond also is equipped with its own built-in recirculating system and filter. Since the rearing facilities were completed too late to rear fish for the current year's stocking of the rearing pens in Ogatsu Bay, the fish were to be shipped in from another location and acclimated to seawater at Karakuwa before being transferred to the seawater rearing pens. Koganezawa explained the procedure to be used as follows:

The trout are hatched in fresh water and reared in the conventional manner until they are approximately 150 g each. At this time they are separated as to sex and the females are acclimated to seawater.

The acclimatization process requires from 12-20 days. Seawater is mixed with the fresh water at a rate that increases the salinity level in the rearing pond by approximately 10% per day. At a couple of points during the acclimatization period, salinities are held static for one or more days to let the fish become adjusted to the change. Average survival is 70%. Growth in seawater is very rapid. Average size at harvest after 10-12 mo in seawater is 1.5-2.0 kg. This is approximately double the growth rate in fresh water, and the price is approximately double that of freshwater-reared fish. Sea-reared trout were commanding 600-800 yen/kg compared with the market price of 300 yen/kg for farm raised rainbow trout.

SALMON CULTURE

From October 21 to 23, I visited the Island of Hokkaido to view salmon management operations.

The organization of the Hokkaido salmon program is impressive. Overall program direction and principal research activities are conducted from the central headquarters in Sapporo. Regional field supervisors at six locations direct the field work carried on at 41 hatcheries and a number of fish collection stations.

On October 22, I visited several chum salmon *(Oncorhynchus keta)* hatcheries on the Tokachi River in the vicinity of Obihiro. The annual spawning run of chum salmon was in progress, and I was able to observe the seining of these fish at an irrigation dam which blocked their upstream movement. Approximately 100 million eggs were being incubated in the three hatcheries visited.

The following day, October 23, I visited the headquarters of the Hokkaido Salmon Hatchery Fisheries Agency in Sapporo where I met the Director, Ayahiko Hemmi. Later in the day, Toshinobu Tokui and I travelled to Lake Shikotsu and visited the kokanee salmon hatchery.

Kokanee salmon *(O. nerka kennerlii)* are native to only two lakes in Japan, both on the island of Hokkaido. They have, however, been widely trans-

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planted and now occur in about 20 lakes. Lake Shikotsu, a large natural lake on Hokkaido, contains a population of kokanee salmon and is the site of a hatchery devoted to the propagation of the species. Because of the low mineral content and consequent low productivity, it is difficult to maintain a satisfactory commercial harvest of kokanee salmon in Lake Shikotsu without depleting the spawning population. Officials of the Hokkaido Salmon Hatchery are searching for sources of kokanee salmon eggs with which to supplement their own supply. They have requested eggs from the State of Montana, but to date have not been able to get any.

I concluded my visit to Hokkaido by touring the Chitose Hatchery where an extensive expansion project is underway. I believe this is the oldest hatchery in Hokkaido. It rears chum salmon and rainbow trout *(Salmo gairdneri)*. The capacity of the expanded hatchery will be about 13 million eggs.

In summary, I was impressed by the sheer volume of salmon released from the hatcheries in Hokkaido. These hatcheries incubate over 500 million eggs per year. The breakdown by species is approximately 85% chum, 10% pink *(Oncorhynchus gorbuscha)*, and about 5% masu *(O. masou)*. The chum salmon are fed for 70-90 days and released in early spring. The return after 2 or 3 yr at sea is consistently between 1 and 2%, an excellent return figure by standards achieved at Pacific salmon hatcheries in America.

On Sunday afternoon of October 24, I visited the Tansui Fish Research Laboratory in Tokyo. Yamakawa and his staff showed me the laboratory and explained their research projects.

This is a national laboratory devoted to the problems of freshwater fish culture. Their principal work is on the diseases and nutritional problems of eels, ayu, carp, and trout. The principal investigators present during my visit were: Takeshi Nose who was working on the nutritional requirements of eels, Hiroshi Kawatsu on disease and microbiology of freshwater fishes, Shimadju on ayu culture, and Inui on hepatic diseases of eels.

I visited the Nikko Branch of the Freshwater Fish Research Laboratory, which is located on Lake Chūzenji in Nikko National Park. The Chief of this laboratory was Yoshikazu Shiraishi, who passed away during his official travel to South America in 1972.

Lake Chūzenji is one of the few publicly owned bodies of fresh water in Japan where public sport fishing is permitted. This cold-water lake contains populations of the native Japanese salmon, *Oncorhynchus masou*, or cherry salmon, and various exotic salmonids such as rainbow and brook trout. Scientists at the Nikko Branch of the Freshwater Fish Research Laboratory, are investigating the population dynamics, the fish movements within the lake, the characteristics of various species of salmonids, including hybrids, and the management of trout in populations in streams. The interests of Yoshikazu Shiraishi and his staff parallel those of management biologists everywhere who are charged with maximizing sport fishing yield in fresh waters.

COMMERCIAL TROUT FARMS

Accompanied by Soichiro Shirahata, biologist with the Nikko Branch of the Freshwater Fisheries Research Laboratory, I visited trout farms and fish processing plants in and around Fujinoyama City, Shizuoka Prefecture, on October 25.

The Shizuoka Prefectural hatchery and laboratory produces 30 million rainbow trout eggs annually. They make extensive use of light to control time of spawning. This management technique makes it possible to provide eggs for their customers over a period of several months. The manager, Matsuura, reported that in one instance they were able to get three spawns in 2 yr from a pond of fish by regulating the photoperiods.

Matsuura and his staff are faced with a formidable labor problem of removing dead and infertile eggs by manual means. They were quite interested in slides I showed them of a mechanical egg picker in use at the Dworshak National Fish Hatchery in Idaho.

A thriving sport fishing business is operated by the Shizuoka Prefectural Hatchery. Some 10,000 fishermen per year participate in fee fishing in a stream running through the hatchery grounds. As I understand it, the provision of sport fishing facilities is a condition of granting a commercial hatchery license in some, if not all, prefectures in Japan.

Trout farms in Shizuoka Prefecture, and I assume they are typical of Japanese trout farms in general, are as modern and efficient as any I have seen. The fish are reared in raceway-type ponds with a high rate of water exchange. The food is pelleted dry food, commercially manufactured. The chemical analysis is very close to that used in the United States and a 1.4 conversion ratio of food into fish flesh also approximates that achieved at successful hatcheries in the United States.

The Fuji Rainbow Trout Breeders Association operates a processing plant in Fujinomiya City. The association president, Watanabe, and the plant manager, S. Aoki, conducted me on a tour of the modern facility that processes 1,000 tons of rainbow trout for export each year. During my visit, trout were being packed in 5-lb packages for export to the United States.

My impression of the Japanese trout farming business is that it operates on a very low margin of profit and is successful only by virtue of its operating efficiency at all levels. For example, the retail price for farm raised trout is approximately 300 yen/kg. This can be compared to the price of salmon which ranges from 550 yen/kg upward and tuna which sells at 600 yen/kg and upward.

Watanabe and his associates are quite concerned over the restrictions of our salmonid import regulations. These require certification that all salmonid fishes entering the United States from foreign countries are free of the virus causing viral hemorrhagic septicemia and *Myxosoma cerebralis*, the causative organism of whirling disease. I discussed these regulations with Watanabe, S. Aoki, and T. Sano, virologist at the Tokyo University of Fisheries, who serves as advisor to the Cooperative on Fish Diseases. These gentlemen feel that since neither of the two diseases in question have ever been found in Japan, our regulations requiring that certification as to disease status be based upon specified sampling and analytical procedures, places an unnecessary hardship on exporters. After reviewing their problem and discussing it with our own experts in the United States, it appears that Sano and the disease technicians at the prefectural laboratory had misinterpreted our instructions and were indeed performing more laborious inspections than required. I have attempted to clarify these points by letter since my return to the United States.

EEL CULTURE

Eels, *Anguilla japonica*, are an important species in Japanese freshwater fish culture. They command premium prices at all times. For example, in 1969, when the production in Shizuoka Prefecture was 15,000 tons, the price ranged from 774-1,400 yen/kg. In 1970, a year of low production, the price range was 1,037-1,718 yen/kg.

The culture of eels in Japan goes back 150 yr, and despite great effort by scientists, culture methods have not changed much. Since the eel is catadromous, spawning occurs at sea and the young migrate to fresh water where they grow to adulthood. The Japanese eel culture industry is based on the capture of young eel as they migrate to fresh water during the months of December to March. Size at time of capture is about 3 inches in length. Introduced into ponds, and fed a diet of either chopped fish or chopped fish and pelleted feeds, they reach a market size of 18-24 inches in 12-18 mo.

The principal restriction on the volume of eel culture in Japan is availability of fry. Scientists are attempting to overcome this problem by breeding eels in captivity, but so far little or no success has been achieved.

The Tokyo University of Fisheries operates an eel culture research station on Lake Hamana in Shizuoka Prefecture near the City of Hamamatsu. This well-equipped and well-staffed laboratory is conducting basic research on the problems associated with the culture of eels, mullet, carp, and various other species, including largemouth bass.

The shortage of native eels for culturing purposes is compounded by other problems connected with culture of the species. Principal among these is disease. In 1970, disease took an unusually heavy toll of eels in Shizuoka Prefecture. That year the industry was hit by an epidemic of a new disease, named branchionephritis by S. Egusa, Tokyo University of Fisheries. This epidemic took 2,600 tons of fingerling and yearling eels during the first half of the year.

Supplemental stocks of *A. japonica* are purchased from Taiwan and New Zealand, but these and other foreign sources cannot fulfill the need, and the Japanese are turning more and more to Europe for the Atlantic eel, *A. anguilla*. In 1971, 34,000 kg of glass eels from Europe were imported. So far, the results with *A. anguilla* have been less than satisfactory, because of disease and nutritional problems.

I concluded my trip to Lake Hamana by dining on smoked eel at the Prefectural hotel and dormitory. I was so impressed by this product that I purchased cans of smoked eel to take home with me.

SHELLFISH CULTURE IN JAPAN

WILLIAM N. SHAW[1]

INTRODUCTION

Japan has long been recognized as a leader in the aquaculture of molluscs. In 1969, approximately 560,000 tons (with shell) of shellfish were harvested (Japanese Fisheries Association, 1971). Principal species under cultivation include Pacific oysters, *Crassostrea gigas*, scallops, *Patinopecten yessoensis*, and the abalone, *Haliotis discus*. Several species of clams and snails also play an important role in the total production figures, but these are mostly caught from wild populations and are not farmed to any extent.

During my short tour of aquaculture sites in Japan related to the UJNR (United States-Japan Natural Resources) Aquaculture Panel, I concentrated my effort on surveying the areas where oysters, abalone, and scallops are being farmed. An overview based on these visits is listed below.

OYSTERS

Oyster production in Japan has shown a steady increase in recent years. From 1958 to 1968, landings rose from 151,894 tons (with shells) to 265,881 tons (Furukawa, 1971). Production declined slightly in 1969 when 245,000 tons were harvested (Japanese Fisheries Association, 1971).

A major reason for the increase in production is the expansion of the hanging method of oyster culture, raft, longline, and rack. By using the third dimension, the yield per acre is greatly increased over the bottom or sowing method. Furukawa (1971) estimates that the oyster yield from raft culture in the Hiroshima Prefecture is 20 tons of oyster meats per acre per year. These figures compare favorably with Ryther and Bardach's (1968) estimate of 23.3 tons per acre per year.

The entire industry is dependent on the natural production of seed oysters. Both scallop shells (northern and southern variety) and oyster shells are used for cultch. Shells are strung on wires (½-inch bamboo spacers are used to separate scallop shells) and draped over racks. Following setting, the seed caught on scallop shells is used domestically while a considerable portion on oyster shells is exported to the United States and France.

Two major areas of oyster production were visited during the tour—Miyagi and Hiroshima Prefectures. In addition, we visited Lake Hamana, the only saltwater lake in Japan, where shallowwater rack culture is being carried out.

According to Furukawa (1971), Miyagi Prefecture produced 3,814 tons of oyster meats in 1968, or about 9.3% of the total Japanese production. Matsushima Bay has been one of the most important culture areas in Miyagi Prefecture. In 1959, 1,456 tons of shelled oysters were harvested. However, beginning in 1961 mass mortalities occurred in Matsushima Bay. Total annual losses from 1961 to 1964 were 62.5, 41.6, 42.3, and 51.9%, respectively (Kan-no et al., 1965).

From our on-site visit of Matsushima Bay, it was apparent that the Japanese had solved their oyster mortality problems by converting the Bay's use from oyster culture to seaweed culture. Very little oyster culture in the Bay proper was observed.

Yet, total oyster production for Miyagi Prefecture has declined only slightly. The Japanese have expanded raft and longline culture in areas outside Matsushima Bay.

One big industry in the Miyagi Prefecture is the exportation of seed oysters. On our tour, we had the opportunity to visit this operation at Watanoha as they were preparing seed for air shipment to France. Oyster seed, which is hardened on racks for 3 mo, is brought ashore in small boats. The seed (all caught on oyster shells) is removed from the galvanized wire strings, placed in baskets, and thoroughly washed. It is then culled into single pieces and examined for predators; all shells with six or less spat are discarded. The good shells

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are placed in freshwater for 1 hr to kill flatworms, *Pseudostylochus* sp. After a quick saltwater dip (5 to 10 sec), 750 spat-laden shells are placed in shipping cases. Before wrapping, a random sample of 50 shells are taken out of the case and the number of seeds counted. Within 48 hr after crating, the seeds reach France.

The French's interest in Japanese seed has come about only in recent years. Heavy mortalities have occurred among the Portuguese oyster, *Crassostrea angulata*, in France, and the government has banned the importation of Portuguese oyster seed in their country. In its place, they are now importing seed from Japan.

The new competition for Japanese seed could have two implications in the U.S. Pacific coast oyster industry: 1) the cost of Japanese seed to the United States could increase, and 2) because the French have entered the market, there could develop a possible shortage of Japanese seed for importation to the United States. In 1972, heavy sets of Pacific oysters occurred on the west coast, so the need for Japanese seed, at least in that year, was considerably less.

About 77% of the total oyster production in Japan comes from Hiroshima Prefecture (31,188 tons of meat out of a 1968 total of 40,928 tons). Furukawa (1971) states that a total of 10,962 rafts (9.1 × 18.2 m average size) are utilized in the Prefecture.

During our tour of the area, seed oysters were being strung on galvanized wire and suspended from bamboo rafts. Initially, 1,600 strings (wrens) are suspended. As the oysters grow, the number per raft is reduced to 800. On each string, about 15 m long, spat bearing scallop shells are separated by a 9-inch bamboo spacer.

Each raft is constructed out of bamboo logs. A typical raft, 20 × 9 m, is supported by 25 styrofoam floats, each the size of a 50-gal oil drum. Fifteen floats are located down the center of the raft while two series of five floats are located along the outer edge. An iron cable runs down the center of the raft and is the connecting link between each series of four or five rafts. The rafts are held in place by six (5 tons each) concrete anchors. A typical raft, including labor, costs about $350 and takes a crew of four 1 day to build.

As in Miyagi Prefecture, the entire industry is dependent on natural setting. No attempt is being made to supplement natural sets with hatchery-reared stocks. The seed is caught in the intertidal zone on scallop shells draped over racks.

Several problems are facing the oyster industry of Japan. Of considerable concern is the increased threat of both domestic and industrial pollution. Industries are located in areas adjacent to oyster growing and setting areas. Further expansion of such industries could seriously affect the oyster industry.

Because the bulk of oysters in Japan are grown off-bottom, a considerable amount of labor is involved. In recent years, there has developed a serious labor shortage in the oyster industry. Young people do not wish to follow their parents in this line of work. Thus, simplification of techniques and development of mechanization in the oyster industry is urgently needed (Fujiya, 1970).

ABALONE

Abalone production in Japan has increased from 4,600 metric tons in 1964 to 6,500 metric tons in 1970. One possible reason for this increase is the effect of a large seed planting program. According to Sanders (1971), there are 16 laboratories in Japan artificially producing 2 to 3 million seed abalone annually.

A typical laboratory is the Kanagawa Prefectural Fisheries Experimental Station located on the island of Jōga Shima near the City of Miura. Their quota, which is set by the government, is to produce about 300,000 seed abalone annually.

At the Station, mature abalone are induced to spawn by first air-drying and then placing them in shallow, standing water tanks which are exposed to sunlight. Apparently as the sunlight heats the water, the abalone spawn.

The fertile eggs are transferred to setting tanks located inside an adjacent building. These tanks are covered with black plastic sheeting to eliminate light. The larvae, which require no supplementary feeding, set in about 1 week on special plastic plates. These plates have been previously exposed to running seawater in order to obtain a film of diatoms, the food of young abalone. Since the larvae swim near the surface, the water is slowly raised in the setting tanks so that the setting abalone are distributed as evenly as possible on the plates. Once setting is over, the plates are transferred to outdoor tanks where the abalone continue to feed on the diatom film until they reach 5 to 10 mm in size. They are then removed from the plates and placed on either tiles, oyster shells, stones, or cross-shaped plastic configurations. At this stage, they are fed macroscopic algae such as *Ulva* and *Laminaria*. When the abalone are approximately 2.5 cm in size (about 8 mo to 1 yr old), they are sold to the fishermen for 10 yen each. The growth rates in the area of the Kanagawa Station are as follows:

Age in yr	*Size in cm*	
1	2.5	
2	6.0	
3	11.0	
4	14.0	(market size)

The hatchery-reared abalone acquire a green shell coloration which natural populations do not have. This green "tag" helps to evaluate the government's success in this seed planting program since the color persists throughout the abalone's life. It has been estimated, on preliminary results, that there is a 10% recovery on planted seed (Ryther, 1968).

In addition to the Prefecture laboratories which are producing seed abalone, there are Regional laboratories (equivalent to Federal laboratories in the United States) which are studying the biology of abalone. One such laboratory is the Tohoku Regional Fisheries Research Laboratory located in Shiogama, about 10 miles northeast of Sendai. Several studies on the growth of abalone are now underway. These include studies on the growth of juveniles using different varieties of diatoms and the growth of older forms on different varieties of seaweeds.

Shogo Kikuchi, biologists at the Tohoku Laboratory, is initiating a large-scale study where he will establish an artificial kelp bed in one of the Japanese bays. It is planned to plant the area with 10 million seed abalone.There are many areas in Japan where abalone set but do not grow or survive due to the lack of macroscopic algae. The development of artificial kelp beds may help to solve this problem. Kikuchi plans also to keep a close watch on invading predators and develop control methods if such invasion does take place.

The only commercial company producing seed abalone in Japan is the Oyster Research Institute. The Institute is located on Mohne Bay near the City of Kesenuma. Under the initial leadership of Takeo Imai, the Institute has become famous throughout the world for some of the basic studies in molluscan aquaculture. Since the untimely death of Takeo Imai in 1971, Hisashi Kan-no of the Tohoku Laboratory has been Acting Director.

The tank farm at the Institute has been described in a number of papers (Imai, 1967; Ryther, 1968; Costlow, 1969). At the time of my visit, 80% of the tanks (there are 180 in all) were devoted to abalone culture. The remainder contained oyster and scallop seeds.

At the Institute, abalone are spawned in early September and the larvae are caught on plastic plates (coated with *Platymonas* and *Navicula*) similar to those used at the Kanagawa Station. As the juveniles grow, they are removed from the plates, placed in plastic containers wrapped in netting, and resuspended from the floating tank farm. Twice a week the abalone are fed seaweed such as *Ulva* and *Laminaria*. When they are 20 mm or larger, the Institute sells them to the fishermen for 1 yen/mm.

The Institute has a cooperative program with the Sendai Thermal Power Station located near Shiogama on Matsushima Bay. Young abalone (1 to 2 mm in size) are transferred in the fall from the Institute's installation at Mohne Bay to tanks at the Power Station. Using the heated water from the Power Station, the young abalone grow four to five times faster than in the natural environment. When the abalone are 1 cm in size, they are transferred back to the tank farm at Mohne Bay. Lack of seaweed around the Power Station and costs for collecting or buying seaweed are the main reasons for moving them back to Mohne Bay at the 1-cm size.

Because the preliminary results were so promising, the Power Station had built five new canvas-lined, steel-frame tanks. Each tank, 20 × 1 × ½ m deep, can hold 60,000 seed abalone. Plans are to build up to 50 of these tanks in the next few years with a goal of producing 10 million seed abalone annually. All the equipment, including installation, is being paid for by the power company.

SCALLOPS

The sea scallop fishery reached its peak of production in 1934 when 80,000 metric tons (in shell weight) were harvested. Since then, production has declined and only 6,000 metric tons were produced in 1968 (Sanders, 1971). With the increased expansion of off-bottom culture, scallop production has been increasing in the past few years. The Japanese estimate that 40,000 metric tons would be produced in 1972 and possibly 100,000 tons in 1974.

In Mutsu Bay, the longline method of culturing scallops has been expanding in recent years. Here longlines are used not only for collecting seed but also for growing the scallops to market size. A scallop longline differs from those used in oyster culture in that there is a second buoyed line 3 to 8 m below the surface. It is from this lower line that seed collectors and cages for growing scallops are attached.

Scallop spawning in Mutsu Bay begins in March, peaks in early April, and is over by mid-April. The larvae life is about 35 days (temperature during this period ranges from 7° to 12°C). The fishermen put out their seed collectors in early May.

Initially, seed scallops were caught on suspended cyprus branches, but now over 50% of the collectors consist of plastic web bags filled with used gill nets. Eventually, most collectors will be of this type. In 1971, 2.3 million bag collectors were used and 40 billion seeds were collected in Mutsu Bay.

Before the young scallops lose their byssal threads, they are removed from the bags and placed in pearl nets. As the scallops grow, they are transferred to new pearl nets with larger mesh size. At about 4 cm, the scallops are either planted on the bottom or placed in circular or book nets and resuspended from the longline. The suspended scallops reach commercial size, 10.5 to 11.0 cm, in about 2 yr. It costs the fisherman approximately 14 yen/scallop to raise it to market size using the longline method. In turn, he can sell the scallop for 30 to 60 yen apiece.

Unlike the sea scallop fishery of the United States, the Japanese save all the scallop shells. These are bagged and shipped to the Inland Sea where they are used as cultch for catching seed oysters.

One of the principal laboratories involved in sea scallop research is the Aquaculture Center located on Mutsu Bay near the City of Asamushi at the northern end of Japan's main island of Honshu. The Center is a new installation that opened in April 1968. One of its largest programs is related to the propagation of sea scallops. Their goal is to produce 1 million seed scallops annually using hatchery techniques.

The Oyster Research Institute is also culturing sea scallops at their tank farm.

Scallops are induced to spawn using both natural and conditioned stocks. Over 200,000 seed scallops are cultured annually. They are suspended from the tank farm in book nets, circular nets, and pearl nets until a size of 2 to 3 cm is obtained. The scallops are then sold to local fishermen who grow them suspended from rafts. When the scallops are approximately 5 cm in size, the fisherman drills a hole in the ear (wing) of the scallop, threads a nylon line through the hole, and ties it to ropes suspended from rafts. They reach market size (12 cm) in about 2 yr (Costlow, 1969).

LITERATURE CITED

AUSTRALIAN FISHERIES.
1971. Australian studies Japanese fish culture techniques. Aust. Fish. 30(10):3-7, 9.

COSTLOW, J. D., JR. (editor).
1969. Marine biology, Vol. V. Proceedings of the Fifth Interdisciplinary Conference on Marine Biology. Gordon and Breach, New York, 606 p.

FUJIYA, M.
1970. Oyster farming in Japan. Helgolaender wiss. Meeresunters. 20:464-479.

FURUKAWA, A.
1971. Outline of the Japanese marine aquiculture. Jap. Fish. Resour. Conserv. Assoc., Tokyo, 39 p.

IMAI, T.
1967. Mass production of molluscs by means of rearing the larvae in tanks. Venus 25:159-167.

JAPANESE FISHERIES ASSOCIATION.
1971. Fisheries of Japan - 1971. Jap. Fish. Assoc., Tokyo, 45 p.

KAN-NO, H., M. SASAKI, Y. SAKURAI, T. WATANABE, and K. SUSUKI.
1965. Studies on the mass mortality of the oyster in Matsushima Bay. 1. General aspects of the mass mortality of the oyster in Matsushima Bay and its environmental conditions. [In Japanese, English abstr.] Bull. Tohoku Reg. Fish. Res. Lab. 25:1-26.

RYTHER, J. H.
1968. Invertebrate and algae culture. *In* The status and potential of aquaculture, particularly invertebrate and algae cultures, Vol. 1, Part II, p. 1-261. Am Inst. Biol. Sci., Washington, D.C. (Distrib. by: Clgh. Fed. Sci. Tech. Inf., Springfield, Va., as PB 177 767.)

RYTHER, J. H., and J. E. BARDACH.
1968. The status and potential of aquaculture. *In* The status and potential of aquaculture, particularly invertebrate and algae culture, Vol. 1, Part 1, p. 1-45. Am. Inst. Biol. Sci., Washington, D.C. (Distrib. by: Clgh. Fed. Sci. Tech. Inf., Springfield, Va., as PB 177 767.)

CRUSTACEAN CULTURE[1]

CORNELIUS R. MOCK[2]

SHRIMP, *PENAEUS JAPONICUS*

One of the most valuable marine species in Japan is the "kuruma-ebi," *Penaeus japonicus*, shrimp fishery, which commands a price of 7-30 U.S. dollars per kilogram, at the Tokyo Central Fish Market. Although this price is high compared to U.S. prices, it is due to the fact that the Japanese people demand live shrimp for the preparation of a delicacy known as tempura.

Over the years much time has been spent developing methods of holding this species in ponds and rearing it to market size. Even though the Japanese have successfully reared shrimp through several generations, they explained that it was not economical to rear shrimp to sexual maturity because it was time consuming and because the fecundity of the females was reduced. Therefore, gravid females are purchased directly from the commercial fishing fleets and then spawned.

Once the eggs have hatched, the water is fertilized to stimulate the growth of diatoms. Predetermined amounts of fertilizer and seawater are added each day to the tank until the larval shrimp have reached the last mysis stage. Brine shrimp nauplii (*Artemia* spp.) are fed from the last mysis stage through the fourth postlarval stage. The shrimp are then fed fresh meats of clams *(Venerupis philippinarum)* and mussels *(Mytilus edulis)*, which are crushed and distributed throughout the ponds. Because it is too costly and time consuming to separate the crushed shell from the meats, the shell eventually covers the pond bottom, resulting in a substrate that hampers the burrowing of the shrimps. Thus, ponds must be drained or dredged periodically to remove the shell debris.

Although larval rearing techniques are primarily the same today as they were 10 yr ago, research in shrimp culture has been expanded due to three important factors: 1) the rising demand and costs for fresh food items to be fed to the shrimp; 2) the rising wages of employees; and 3) disease problems encountered.

Of particular interest is the use of a by-product of soy sauce production, a cake which is ground into powder to fertilize the water. Not only does it stimulate the growth of diatoms, but the larval shrimp also eat it. As the shrimp grow in size, this powder is either extruded or pressed into a size suitable for eating. At the Kagoshima Prefecture Fisheries Experimental Station, the Director, K. Shigeno, remarked that although the shrimp ate this artificial food and grew to market size, the consumer was not satisfied with the quality or color of the prawns. He felt that the problem was primarily a vitamin deficiency. Artificial foods with a variety of additives are being tested at Shigeno's laboratory.

Research is also being directed toward rearing prawns to market size in a closed system. A 1,000-m^3 cement tank (23 m in diameter and 3 m deep) has been built at the Tarumizu Kagoshima Prefecture Fish Experimental Station. The water temperature can be controlled, and a false bottom with airlift pipes has been installed as an in-bottom filter. Twenty-day-old postlarval shrimp have been stocked in this tank and reared to market size with good results. However, during two recent experiments a number of problems occurred, resulting in poor production.

Circulation of the water mass within a rearing system was emphasized for either fish or shrimp culture. At Tarumizu Kagoshima Prefecture Fish Experimental Station the flow was maintained with water jets, while a large mechanical stirrer was being tested at Setonaikai Saibai Gyogyo Center, Tamano Jigyojo.

At the Nansei Regional Fisheries Research Laboratory, H. Kurata spoke about the natural waves of *P. japonicus* postlarvae that enter the estuaries. Monitoring of these waves now indicates

[1] Contribution No. 343 from the National Marine Fisheries Service, Biological Laboratory, Galveston, Texas.

[2] Gulf Coastal Fisheries Center, National Marine Fisheries Service, NOAA, Fort Crockett, Galveston, TX 77550.

that recruitment is presently less than in previous years. The total tonnage landed by the commercial shrimp fleet is also down. Therefore, the concept of seeding the system with (1.2×10^8) 20-day-old post-larval shrimp is being tested to see if the system is still a suitable environment, if production of shrimp can be stimulated and if new areas can be used. Some shrimp are released directly into the nursery grounds, while others are placed in a pen ($30 \times 10 \times 10$ m) for 2 to 4 wk to acclimate them to estuarine waters.

M. Fujiya, also of the Nansei Laboratory, began physiological studies to measure the "quality" of shrimp larvae reared in different ways, by observing their reaction to anesthetics. His approach is to insert electrodes into the brain of the shrimp and record their brain waves on an oscelloscope.

H. Hirata, at Kagoshima University, has begun work on the production of single-species mass cultures of diatoms and their preservation. At present, diatoms are concentrated and later frozen at 0°C. They can be held successfully for periods of 30 days or less. Various other techniques are now being tested.

Table 1 is part of a statistical report, translated by Jiro Tanaka. Of particular interest is the number of tons of *P. japonicus* cultured. Since 1967, annual production has been about 300 tons. Although some live shrimp are imported, the tonnage is far below the market demand. The importation of frozen shrimp has no direct bearing on the live shrimp market.

CRABS, *PORTUNUS TRIBERCULATUS*

Crabs, primarily *Portunus triberculatus*, have been reared successfully to the 5th generation at the Yamaguchi Fisheries Experimental Station. *P. triberculatus* is similar to the American blue crab, *Callinectes sapidus*. Larval crabs in the zoea I-III stages are fed rotifers, *Brachionus plicatilis*, which are maintained on freshwater cultures of *Chlorella*. Older stages are fed *Artemia*, chopped fish, and crushed clams. Since crabs are active and difficult to maintain in a barren enclosure, a series of vertical netlike structures were placed in the rearing pond. The growth of natural filamentous algae upon these structures serves as a hiding place for the crabs.

Unfortunately, fighting over territories and food results in a high rate of mortality in the pond. Harvesting is accomplished by draining the pond and raking the crabs, a process which is time consuming. Although the price of these live crabs in United States is $1.10 each, their culture is not yet economically profitable in Japan.

A number of prefectural laboratories rear crabs to the megalops stage and release them into estuaries.

FRESHWATER SHRIMP, *MACROBRACHIUM* SP.

At the Tokyo University of Fisheries, Ogasawara and T. Sano discussed the culture of freshwater shrimp of the species *Macrobrachium*. Eleven different species were being studied. To rear the larval stages, they indicated that a medium of 50% fresh water and 50% seawater was necessary. A diet of *Artemia*, reared on a freshwater culture of *Chlorella*, is fed during the larval stages along with ground clam (*Tapes* sp.) meat. When the shrimp are older, pieces of chicken egg shells are added to supplement the calcium in their diets.

Juveniles of *Macrobrachium rosenbergi* have been reared on commercial trout pellets to market size in 6 mo at the Izu Branch Laboratory. Although results have been satisfactory, production costs were not made available.

SPINY LOBSTER, *PANULIRUS JAPONICUS*

At Kanagawa Prefectural Laboratory, research on the spiny lobster, *Panulirus japonicus*, is being conducted. Of particular interest is the work of Inoue who has found that the phyllosoma larvae will

Table 1.—Annual production (in metric tons) of cultured, naturally caught, and imported *Penaeus japonicus*, 1965-69.

Source	1964	1965	1966	1967	1968	1969
	Metric tons					
Cultured	154	95	211	307	311	295
Natural catch	3,184	3,010	2,479	2,338	1,884	1,585
Imported[1]	17,087	21,011	36,156	44,466	32,204	48,886

[1] Prawns in general.

feed on the arrow worm, *Sagitta*, which is collected from the natural habitat. After a number of days, the larvae are then fed *Artemia* nauplii. Although phyllosoma larvae have been reared in 180 days, their size is smaller than those found in nature. They have not yet reared the larvae to the benthic stage.

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Through the efforts and guidance of M. Miyamura, Vice-President of Technical Operations, Marifarms Incorporated, Panama City, Fla., my trip was quite fruitful. Not only did he provide me with a list of places to see and letters of introduction, but helped arrange for Jiro Tanaka to accompany me while in Japan. Jiro Tanaka's assistance was invaluable.

Their pleasant attitude, cordial response, and voluntary gesture of discussing their research clearly signified the willingness of the Japanese to cooperate on this joint venture of mariculture.

MARINE FISH CULTURE IN JAPAN

JOHN B. GLUDE[1]

INTRODUCTION

The concept of rearing fishes in floating net cages in sheltered bays or in fish ponds supplied with seawater has been applied in Japan to several coastal species of high value, and commercial ventures are well established. In 1967 the production of cultivated marine fishes in Japan amounted to 27,103 tons in gross weight worth over $24 million and consisted of 98.6% yellowtails, 0.25% puffers or globefish, and 1.2% other marine fishes (Harada, 1970). Production of yellowtail has increased remarkably in recent years, as shown by the following table:

Yield of yellowtail culture (Furukawa, 1970)

Year	*Tons*
1961	2,579
1962	4,758
1963	5,083
1964	9,493
1965	18,083
1966	19,629
1967	26,712
1968	30,774

Production of puffers or globefish by aquaculture has decreased year by year because of the shortage of seed fish, and by 1968 was only 43 tons (Furukawa, 1970).

A number of species of marine or anadromous fish are being cultivated in seawater in Japan on an experimental or commercial basis, as listed in the following table:

Species of fish cultivated in seawater in Japan

Seriola quinqueradiata	yellowtail
Seriola purpurescens	amberjack
Longirostrum delicatissimus	striped jack
Fugu rubripes rubripes	puffer (globefish)
Chrysophrys (Pagrus) major	red sea bream (red porgy)
Acanthopagrus schleglii[1]	black sea bream (black porgy)
Sparus sarba	silver sea bream
Oplegnathus fasciatus	Japanese parrotfish
Oplegnathus punctatus	spotted parrotfish
Paralichthys olivaceus	bastard halibut
Sebasticus marmoratus	scorpionfish
Oncorhynchus keta	chum salmon
Salmo gairdneri irrideus	rainbow trout
Salvelinus pluvius	steelhead

[1] Also listed as *Mylio macrocephalus*.

The short time available for the present survey in Japan prevented a complete survey of the status of aquaculture of each of the species listed above, and the following summary is based on brief visits to select locations and several published articles listed below.

YELLOWTAIL CULTURE

Culture of the yellowtail, *Seriola quinqueradiata*, is the most successful marine fish farming venture in Japan, and production from farming now exceeds landings from fishing of wild stocks. Yellowtail culture is conducted by individuals, companies, or fishermen's associations in floating net cages and in fish ponds which are made by partitioning sheltered places from the sea with nets or earthen dams. The great expansion during recent years is because of the increase in the number of floating net cages, since the number of locations suitable for ponds is limited.

Although spawning, fertilization, hatching, and raising to seedling size have been achieved experimentally for yellowtail, methods have not been developed to the stage that seedlings can be produced in commercial quantities for the industry (Harada, 1970). Instead, young fish 5-15 cm in length are caught 5-15 miles offshore during April and May. Young yellowtail collect under floating patches of seaweed, and the fishermen simply encircle a mass of seaweed and catch the small fish which are placed in small floating net enclosures. To conserve the natural resources, the Japanese Government has limited the number of young yellowtail which may be

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supplied to all farms in the country from 28,363,000 to 30,780,000 per year (Harada, 1970).

The young yellowtail are reared in small net enclosures for 1-2 mo until they reach a length of 25-40 mm. These seedlings are then placed in larger floating net cages approximately 6 × 6 × 2 m in which 1,500-2,500 fish can be kept. By December the yellowtail reach a size of 1.0-1.5 kg and are shipped to market.

In southern Japan where the minimum temperature exceeds 11°C, it is possible to hold yellowtail through the winter and sell them in April when they reach a weight of 2-3 kg, but winter temperatures farther north are too low for yellowtail. According to Fujiya (1969), about 95% of the yellowtail are shipped to market by December. Detailed descriptions of yellowtail farming procedures are included in papers by Harada (1970), Furukawa (1970), and Fujiya (1969).

Problems of the industry include 1) a stable supply of seedlings, 2) disease control, and 3) adequate food supply or development of suitable artificial diets.

1) *Stable supply of seedlings.* Production from yellowtail farming is limited to approximately the present level because of government restriction on the number of young fish which can be taken from coastal waters. According to Harada (1965), it is highly desirable to produce seedling yellowtail by artificial fertilization in a hatchery. This has been accomplished recently on an experimental basis, but has not been perfected for commercial application. In the meantime, Harada recommends collecting the seed (larval or juvenile fish) at as early a stage as possible and keeping them under careful management to reduce mortalities.

Although production could be increased by improving growth rate, reducing mortality, or by extending the rearing time in places where winter water temperatures are not too low, ultimate development of the industry will require maintenance of a spawning stock, collection and hatching of eggs, and rearing of larval stages to assure a dependable supply of seedlings.

2) *Disease control.* The monogenetic trematode, *Benedenia seriolae*, infects the skin of the yellowtail causing an unsightly appearance, loss of appetite, weakening or death of the fish. This parasite is considerably less resistant to low specific gravity than the host fish and consequently is easily controlled by dipping the infected fish in fresh water for a few minutes and then returning it to seawater. The time of dipping must be shorter in the summer (3 min at 26°C) than in the autumn (5 min at 16°C) to prevent damage to the fish. Since this parasite grows very fast and becomes adult within 2 or 3 wk, the freshwater treatment must be repeated frequently during periods of infection.

Another monogenetic trematode, *Axine (Heteraxine) heterocerca*, infects the gills of yellowtail causing anemia which may kill the fish. Treatments, according to Fujiya (1969), include 4-min bath in water containing 4% salt, 2) dipping in a 1% solution of "Tremaclean" for 30 sec, and 3) oral treatment by including "Bitin" (4,5-dichlorophenol) in the food.

The bacteria *Vibrio* can cause extensive infections in yellowtail populations. Treatments include incorporation of sulfa drugs or antibiotics in the food.

Virus diseases are suspected, but no information is available concerning these.

The feeding of oxidized, unsaturated fatty acids contained in fish used as food causes nutritional diseases of yellowtail. This can be prevented by feeding white-meated fish instead of anchovy, mackerel, and sand lance.

3) *Adequate food supply or development of artificial diet.* Farming of yellowtail in Japan depends on availability of large quantities of cheap fish suitable for use as food. These include mackerel, horse mackerel, anchovy, sand lance, and saury. With conversion rates of 6:1 to 8:1 the food must be obtained at very low price in order to make yellowtail farming economical. Expansion of the industry or perhaps even continuation at the present level will require development of artificial diets which will provide better nutrition for the fish and reduce dietary disease problems. Furthermore, the artificial diet must be available at a price which will permit economic fish farming.

PUFFER CULTURE

Puffers, also known as globefish or blow fish of the genus *Fugu*, are in high demand as a luxury food in Japan even though certain species are extremely toxic. About 10 species of edible puffers occur in Japan, but one species, *Fugu rubripes rubripes*, is used principally for farming ventures. The toxicity of puffers changes seasonally, becoming the greatest in the spawning season from May through June. The toxic substance "Tetradotoxin" occurs mostly in the ovary, liver, intestines and skin, and rarely in the muscle. When prepared carefully by licensed cooks in Japan, puffers are completely safe to eat.

Production of puffers in fish farms has decreased during recent years because of a shortage of seedlings, as indicated in the following table:

Year	*Production in tons*
1964	86
1965	91
1966	82
1967	53
1968	43

The farming of puffers is generally carried out in the warmer part of Japan since the puffers require water temperatures between 10° and 29°C. Of the 14 management units in Japan, 8 are located in the Seto Inland Sea, 4 in the west Japan Sea area, 1 in the east China Sea, and 1 in the north Japan Sea area.

Traditionally, puffer farming depended on the capture of partially grown fish in the spring, rearing these fish to market size in net enclosures, and marketing them in the winter when demand and price were high. Larger fish, 40-60 cm in length, weighing 1.5 to 2.5 kg, can be fed in enclosures from spring to early winter and then shipped to market. Younger fish, about 200 g when captured, require another year before reaching market size.

Methods for artificial propagation of puffers were developed in Japan in 1960 and are now used commercially. Seedling fish of about 3 g are transferred from the hatchery to the growing net cages in July and should average 550 g by August of the following year. At the end of 1½ yr, the puffers should reach 800 g, the minimum market size, and after one additional year should weigh 1.5-2.0 kg.

The procedures for rearing puffers are similar to those used in the culture of yellowtail. Since both of these fish are carnivorous, fresh or frozen fish, such as horsemackerel, mackerel, anchovy, sand eel, and saury are used for food. Minced flesh is recommended for fish less than 100 mm in length, but larger fish can be fed chopped flesh.

The fish are fed 4 times a day during midsummer, 3 times a day from September to November, and less frequently during the winter and early spring. Puffers stop feeding in winter when the water temperature falls below 14°C, and this causes a weight loss of about 10% during the winter.

Expansion of puffer farming will require greater production of seedlings through artificial propagation. Detailed description of procedures used in the farming of puffers is given by Fujiya in his 1969 paper, "Farming Fisheries in Japan."

BLACK PORGY CULTURE

The Japanese black porgy, or sea bream, *Mylio macrocephalus* (also listed as *Acanthopagrus schlegelii*), is a nonmigratory species found in shallow water along the coasts of Japan, Korea, Taiwan, and China. The annual catch of this species in Japan is 3,600-3,900 tons, about 65% of which is landed in the Seto Inland Sea (Fujiya, 1969). Black porgy can be raised in floating net cages or seawater ponds; and, since this species is more resistant to lower temperatures than some other species which are used in aquaculture, the geographical range suitable for farming is greater. Black porgy are reported to stop feeding at water temperatures below 10°C but can survive temperatures several degrees colder.

The species is omnivorous, feedling on mollusks, crabs, polychaete worms, and seaweeds, so a variety of waste fishes and unutilized mollusks can be used as food. With the conversion rate of 3 or 4:1 in experimental scale farming reported by Fujiya (1969) for fresh fish diets, commercial culture should be economical. Market size fish reportedly can be produced within 16 to 20 mo.

Black porgy farming using "natural seedlings" is of two types, depending on the size fish which can be obtained. Small seedlings, 1 to 4 cm in length, are caught along the coast by seines from late May to late July. These small fish are put in fine-mesh floating cages for 1-2 mo and then transferred into larger mesh net cages. Market size fish, about 150 g, can be expected within 15-18 mo.

The second type of farming depends on capture of seedlings, 10-15 cm in length (30-50 g in weight), in set nets or by angling from May to July. Fish of this size will reach market size after about 6 mo of feeding in floating net cages.

The limiting factor in farming of black porgy is the supply of seedlings from natural reproduction.

Methods for artificial propagation of black porgy have been developed in Japan and with a suitable increase in production of seedlings, porgy farming can be greatly expanded. Further details concerning the farming of black porgy are given by Fujiya (1969).

RED PORGY CULTURE

The red porgy or sea bream, *Chrysophrys (Pagrus) major*, known in Japan as the "tai" or "madai" is in great demand since it is the traditional fish served at celebrations. The commercial catch of sea breams in Japan was nearly constant from 1965 to 1967, but during 1968 and 1969 decreased slightly to a level of about 30,000 tons (Japan Fisheries Association. 1971).

Research on the farming and artificial propagation of red porgy began in Japan over 70 yr ago but was generally unsuccessful until recent years. In 1958 research on artificial propagation was intensified with more modern facilities are equipment and successful results were obtained on an experimental scale in 1962. By 1965 an experiment in the propagation of red porgy using artificially produced seedlings succeeded at the Propagation Center in the Seto Inland Sea. It now appears that a basis has been established for expansion of red porgy farming, but this knowledge has not yet been commercially applied (Fujiya, 1969).

The Association of Marine Stock Farm of the Seto Inland Sea was incorporated in 1963 to increase the fisheries resources of the Inland Sea of Japan by releasing young marine fishes. In 1958, this Association produced 166,686 red porgy in a hatchery and released them into the Inland Sea. The effectiveness of these plantings in supplementing natural stocks is now being investigated. The success of this hatchery also portends the expansion of commercial farming of the red porgy.

According to Fujiya (1969), larvae of the red porgy, 2 to 3 cm in length, are usable as seedlings. They have been grown successfully in floating net cages using fresh fish meat or pellets as food and reach market size in 12 to 18 mo.

CULTURE OF OTHER MARINE FISHES

Several other species of marine fishes are being cultured in Japan on an experimental or limited commercial basis. These include amberjack, *Seriola purpurescens*, and the striped jack, *Longirostrum delicatissimus*. Both of these species can be cultured by using the methods which are so successful with the yellowtail. Teruo Harada of Kinki University is conducting large-scale experiments in the culture of these species at the University facility at Shirahama in Wakayama Prefecture. Commercial culture of these species is especially attractive because there is a demand at prices considerably higher than those for yellowtail.

At the same research facility Harada is studying the artificial culture of many other species of fish including the Japanese parrotfish, *Oplegnathus fasciatus*, and the spotted parrotfish, *O. punctatus*, and the flatfish, *Paralichthys olivaceus*. *Paralichthys* is in high demand at a price 4 times as great as for yellowtail, so artificial propagation of this species should be profitable. Harada et al. (1966) described growth and rearing methods for the fry of the flounder, *Paralichthys olivaceus*, obtained by artificial fertilization.

The silver sea bream, *Spurus sarba*, is also being studied at the Shirahama field station of Kinki University.

Another marine fish *Sebasticus marmoratus*, known as the scorpionfish is artificially produced in the hatchery of the Association of Marine Stock Farm of the Seto Inland Sea, and 125,536 juveniles were released into the Inland Sea in 1968. Similar releases of sea breams are being made by the Nansei Regional Fisheries Laboratory, many of which are tagged to evaluate the success of these plantings.

TROUT CULTURE

Trout have been raised in Japan in fresh water for domestic and export markets for many years and standard rearing methods have been developed.

Recently, methods have been developed for culture of rainbow trout, *Salmo gairdneri irrideus*, in the marine environment. Three Fishermen's Cooperative Associations in Japan are now rearing trout commercially in the protected waters of coastal bays and estuaries; the most recent a new venture at Ogatsu Bay in Miyagi Prefecture.

Procedures for marine culture of rainbow trout described by Akimitsu Koganezawa, Chief of Shellfish and Fish Research for the Miyagi Prefectural Station, are as follows:

Rainbow trout spawn in December in this part of Japan and are raised in fresh water until the following September or October. At that time they are acclimated to salt water over a period of 12-20 days by gradually increasing the salinity to that of the marine environment which is about 34‰. Koganezawa has determined that mortality during acclimation can be minimized by increasing the salinity 10% each day except at the levels of 40% and 80% of the salinity of seawater which appear to be more critical. The fish are therefore held at least one extra day at these salinities.

At the time of transfer to the sea the trout weigh 100-150 g and are about 18-23 cm in length. The trout are harvested the following August at 1.5-2.0 kg, but some may reach a size of 3.4 kg.

Maximum survival during the marine phase of this aquaculture system is 90%; minimum survival is 60%; mean survival is about 70%. Bacteria of the genus *Vibrio* are the major cause of mortality, but infections can be controlled to a certain extent by the use of nitrofuran, sulfa drugs, and terramycin. In the United States, nitrofuran probably could not be used for this purpose since it has not been cleared for use in treating food products by the Food and Drug Administration.

A new commercial trout farming project was observed at Karakuwa at the head of Ogatsu Bay during October 1971. This project, which is operated by Fishermen's Cooperative Association with the guidance of Koganezawa, included shore-based facilities for rearing trout and acclimating them to seawater and a series of net enclosures for culture of the trout in the marine environment.

Shore facilities included six circular concrete tanks, 12 m in diameter and 2.5 m deep, with four more to be built. The fish will be reared for approximately 1 yr in these tanks before they are acclimated to seawater and transferred to the floating net enclosures. This year, since the project was just beginning, the fish were raised at another location and were brought to Karakuwa for acclimation to salt water and transfer to growing pens. A system of large plastic pipes makes it possible to drain each of the large round tanks to transfer the 14,000 trout which will be acclimated in each tank into a long drainage channel which takes them to the shore where they can be transferred through pipes into the floating pens.

The floating pens are anchored in Ogatsu Bay which is well protected from storms by steep hills. The water in this area is 10-30 m deep and varies in temperature from above 8°C during the winter to a maximum temperature of 23-25°C during the summer.

The fish are fed ground raw fish and meal, making a product similar to Oregon moist pellets which is used in U.S salmon hatcheries. This food has been found to be better than dry pellets.

Only female trout are used in this type of culture as they are more disease resistant and are easier to acclimate to seawater than males. Also, females can mature in the sea in 2 yr producing healthy viable eggs, whereas males require fresh water to become mature. The sorting of male trout from female trout at a size of 18 cm is a time consuming operation.

The price of marketable trout 1.5-2.0 kg in weight is 450-550 yen ($1.46 to $1.79) per kilogram in the Tokyo fish market. This is about the same price as yellowtail *Seriola*, whereas smaller rainbow trout which weigh 150-200 g each sell for 250-300 yen ($0.81 to $0.97) per kilogram. In comparison, salmon from natural production sell for 600-800 yen ($1.95 to $2.60) per kilogram.

One of the problems of raising rainbow trout in net enclosures is that they have tender skin and may lose some scales rubbing against the netting which may permit the entrance of the bacteria *Vibrio*. Japanese scientists have found that adding 10 μg of testosterone per gram of food will increase the mucous production in skin which will protect the scales from erosion. It is unlikely that testosterone could be used in the United States for this purpose because it is considered to be a carcinogen.

Another trout, *Salvelinus pluvius*, known as the steelhead, is being reared experimentally in seawater at the Miyagi Prefectural Field Station at Ogatsu Bay. According to Koganezawa, *S. pluvius* spawns in the headwaters of streams, is very resistant to changes in temperature, and can be successfully acclimated to seawater. Therefore, this is considered a good species for aquaculture, although it is not reared commercially at the present time.

SALMON CULTURE

The first Japanese pilot-scale experiments in culture of salmon in floating net pens in the marine environment are being conducted at Yamada Bay in Iwate Prefecture. Yamada Bay is completely enclosed except for a narrow entrance where the water is reported to be 90 m deep. Hills protect the inner bay from storms making it an ideal location for aquaculture. The Bay is about 60 m deep in the center, but 15-25 m deep in the area where the salmon culture rafts were anchored.

The objective of these experiments at Yamada Bay which was visited in October 1971 is to perfect methods which could be used commercially to rear salmon to marketable size in the sea.

The first experiments were with the chum or dog salmon, *Oncorhynchus keta*, which had been hatched at Fishermen's Cooperative Association hatchery at Miyako Bay just north of Yamada. This hatchery which is located on the Tsugaruishi River has a capacity of 50 million eggs and is one of the many hatcheries operated by local Fishermen's Cooperative Associations. These hatcheries take eggs from chum salmon in November, December, and January when the fish enter the streams, or occasionally from those salmon which are caught in trap nets in the bays. After the eggs hatch, the fry are reared until April in an effort to reduce the mortality of fry which they estimate as 50% in the streams plus a significant mortality during the month which the fry spend in shallow bays before going to the sea.

The eggs used in the experiment at Yamada were hatched on 22 February 1971 and began feeding on 8 April. They were held at the hatchery at Miyako Bay until 10 May because the holding tanks at Yamada had not been completed. After transfer, the salmon were held in fresh water at Yamada until 28 May when the seawater system was completed. Transfer to salt water was accomplished in about 24 hr with no significant mortality.

Because of the delay in completing the floating net enclosures the small salmon were held in seawater in tanks ashore until August when the temperature in the tanks reached 25.8°C. They were then transferred to the sea, but even there temperatures reached 24.4°C. These temperatures were too high and the mean survival was only 42%, although individual lots had survivals as high as 90%.

According to Chikara Iioka, who is in charge of this Iwate Prefectural Experiment Station, they will normally rear the salmon in fresh water until June or July and transfer them into floating net pens before midsummer. Even so, it appears likely there will be significant mortalities from diseases such as *Vibrio* since surface water temperatures usually reach a maximum of 22°C according to Iioka. Furthermore, the thermocline is deep in this area, according to Iioka's measurements, and the maximum temperature difference between the surface and a depth of 60 m is less than 4°C. In midsummer there appears to be only 1°C difference between the surface and bottom at a depth of 15-25 m where the salmon culture pens are anchored.

National Marine Fisheries Service experiments with salmon culture in Puget Sound, Wash., have indicated increased mortalities due to *Vibrio* when seawater temperatures exceed 15°C. On this basis it appears likely that the high summer temperatures at Yamada Bay will be a limiting factor to salmon culture unless methods can be developed for preventing or reducing *Vibrio* infections.

Three kinds of net enclosures were being tested by Iioka and his associates. One type was a floating net pen similar to those used for the culture of trout or yellowtail, but with some refinements in the design. These enclosures were about 6 or 8 meters square and about 3 m deep with nearly 1 m of the sides above the surface of the water. The tops were covered with a coarse mesh to exclude birds and the sides and bottoms were made of about 8 mm square mesh. These enclosures contained 4,000 young salmon which by October had reached a length of 20-25 cm. Another similar pen contained 300 2-yr old salmon which appeared to be about 40-50 cm in length. Iioka reported that these floating surface pens were satisfactory except that the nets had to be changed every month because of heavy fouling by seaweeds.

The second type of enclosure was a middepth pen which was located at a depth of 10 m to the top of the net. The enclosure was 10 meters square and 7 m with a top and bottom. Even at this depth the heavy growth of seaweed required changing the net about every 3 mo.

The third type of enclosure was a large octagonal net 55 m in diameter which extended from the surface to the bottom and was anchored in position. The net was supported by a series of floats at the surface and held in contact with the bottom by a lead line.

A horizontal section of fine mesh at the surface extended inward about 3 m from the vertical walls and the inner border was supported by net floats placed about 4 inches apart. Iioka had found that the fish made no attempt to jump over the inner row of floats and indeed found refuge and shade under the floating section of the net which rapidly became fouled with seaweeds.

Feeding was accomplished by rowing a boat over the top of the net into the center of the pen where the food was thrown into the water.

Predation by diving water fowl was prevented by stretching twisted bright-colored plastic tape, 1½ to 2 cm wide, across the enclosure at intervals by tying it to vertical supports so that it was about 1 m above the surface of the water. The apparent movement of this tape caused by the wind seemed to scare the birds away. The same system is used to keep birds away from the rice fields.

The young salmon were fed a dry pellet food that had been developed for feeding rainbow trout in the sea, and this was found to be fairly satisfactory. The fish were fed 3 times a day, and the pellets were mixed with water before feeding. The Japanese scientists stated it is important to mix the food with fresh water so that the fish have a source of fresh water to replace that which they would normally receive by eating other fish.

The objective of the Yamada Experimental Station is to develop methods for commercial salmon culture so a number of experiments are in progress or planned. Experiments by Koganezawa et al., reported in 1968, indicated that chum salmon grow more rapidly in brackish water than in fresh water or salt water. These experiments are being repeated at Yamada to develop procedures for increasing growth rate during the time that the fish are held in tanks on shore.

Also, next year Iioka and his associates plan to transfer chum salmon fry to salt water at various ages from 9 to 90 days in order to determine the optimum time. They also would like to test other species, such as the pink salmon, *O. gorbusha*, and the king or chinook salmon, *O. tshawytscha*, from Hokkaido, and possibly the coho salmon, *O. kisutch*, from the United States.

In summary, the Iwate Prefectural salmon culture station at Yamada is located at a delightful place for experimental aquaculture. The only limiting factor appears to be the high temperature of the water during the summer and the adverse effects of this may be overcome by selection of species or races of salmon, use of hybrids, or treatment to prevent or alleviate the effects of *Vibrio* and other diseases which are accelerated by high temperatures. Both domestic and export demands are excellent and it appears probable that commercial salmon culture in the marine environment will be economical.

BIBLIOGRAPHY

FUJIYA, M.

1969. Farming fisheries in Japan. Long Island Univ., Grad. Dep. Mar. Sci. [Processed.]

FURUKAWA, A.

1971. Outline of the Japanese marine aquiculture. Jap. Fish. Res. Conserv. Assoc., Tokyo, 39 p.

HARADA, T.

1965. Studies on propagation of yellowtail (*Seriola quinqueradiata* T. & S.)—with special reference to relationship between feeding and growth of fish reared in floating net crawl. [In Japanese, English abstr.] Kinki Univ., Mem. Fac. Agric., Vol. 3, 291 p.

1970. The present status of marine fish cultivation research in Japan. Helgoländer wiss. Meeresunters. 20:594-601

HARADA, T., H. KUMAI, K. MIZUNO, O. MURATA, M. NAKAMURA, S. MIYASHITA, and H. HURUTANI.

1971. On the rearing of young bluefin tuna. [In Japanese, English abstr.] Kinki Univ., Mem. Fac. Agric. 4:153-156.

HARADA, T., K. MIZUNO, O. MURATA, S. MIYASHITA, and H. HURUTANI.

1971. On the artificial fertilization and rearing of larvae in yellowfin tuna. [In Japanese, English abstr.] Kinki Univ., Mem. Fac. Agric. 4:145-151.

HARADA, T., S. UMEDA, O. MURATA, H. KUMAI, and K. MIZUNO.

1966. On the growth and rearing methods of the fry of hirame *(Paralichthys olivaceus)* obtained by artificial fertilization. [In Japanese, English title.] Kinki Daigaku Suisan Kenkyusho Hokoku (Kinki Univ., Fish. Res. Lab. Rep.) 1:289-303.

INOUE, M.

1970. Possibility of tuna cultivation and propagation. [In Japanese, English abstr.] Tokai Univ. Collect. Repr., Coll. Mar. Sci., Technol. 4:195-210.

JAPAN FISHERIES ASSOCIATION.

1971. Fisheries of Japan. Jap. Fish. Assoc., 45 p.

KOGANEZAWA, A.

(No date but after 1966.) Surface culture of salmon and trout and some problems thereof. [In Japanese.] J. Fish. Oceanogr. Res. Soc. 17:95-101.

KOGANEZAWA, A., N. ISHIDA, and K. GOTO.

1968. Studies on several diseases of fingerling dog salmon *(Oncorhynchus keta)*. [In Japanese, English title.] Bull. Miyagi Prefect. Fish. Exper. Stn. 4:1-7.

KOGANEZAWA, A., N. ISHIDA, K. SUZUKI, K. GOTO, and H. ABE.

1968. Studies on the growth of fingerling dog salmon *(Oncorhynchus keta)* in relation to salinity. [In Japanese, English title.] Bull. Miyagi Prefect. Fish. Exper. Stn. 4:1-6.

(No date.) Comparative study of surface and mid-depth live pens for rearing chum salmon and rainbow trout. Fish. Cov. Eng. 3(2):37-40.

OKIYAMA, M.

1967. Study on the early life history of a flounder, *Paralichthys olivaceus* (TEMMINCK et SCHLEGEL). I. Descriptions of postlarvae. [In Japanese, English abstr.] Bull. Jap. Sea Reg. Fish. Lab. 17:1-12.

1970. Studies on the early life history of the rainbow runner, *Elagatis bipinnulatus* (Quoy & Gaimard) in the Indo-Pacific Oceans. [In English, Japanese abstr.] Bull. Far Seas Fish. Res. Lab. 3:167-186.

UDA, M.

1970. Recent advances in fisheries oceanography of Japan from 1967 to 1969. Jap. Soc. Fish. Oceanogr., Advan. Fish Oceanogr. 3:171-185.

SOME IMPRESSIONS REGARDING GENETICS AND THE FISHERIES OF JAPAN

A. CROSBY LONGWELL[1]

INTRODUCTION

This report is based on a tour of Japanese laboratories concerned with aquaculture or subjects pertinent to it, 8-13 October 1972; and on attendance at the Second International Ocean Development Conference, Tokyo, Japan, 5-7 October 1972.

Tour included: Oyster Research Institute at Kesen-numa on Mohne Bay; Pearl Research Laboratory of the Fisheries Agency at Kashikojima, Mie-ken (Director, T. Hayashi); Ocean Research Institute of the University of Tokyo; Nikko Branch of Freshwater Fisheries Research Laboratory at Nikko on Lake Chūzenji (Director, K. Onodera); Tohoku University School of Fisheries; Tohoku Regional Fisheries Research Laboratory.

BACKGROUND INFORMATION ON GENETICS IN JAPANESE FISHERIES

There has been, in the past, no overall, concerted effort at applying genetics to the aquaculture endeavors of Japan which are without dispute the most extensive in the world. Now, however, in conjunction with a national research program on aquaculture it appears that some special committee on the application of genetics to aquaculture is being organized.

Since the advent of genetics at the turn of the century, Japan has had a number of highly trained geneticists, many of world renown, invariably prominent at International Congresses of Genetics. Breeding sciences and genetics are regarded important enough for school children to memorize the names of famous Japanese (Kihara) and American (Sears) wheat geneticists. Genetic applications to breeding have, however, been with few exceptions in agriculture not in fisheries, the same situation as in the United States.

Japan has had nothing at least in recent years equivalent to the symposium the Russians held in 1968, "Genetics, selection, and hybridization of fish," published in 1969 (Cherfas, 1969), and translated in 1972 through the auspices of the National Oceanic and Atmospheric Administration. (Nor has the United States.) It is relatively in recent years that there has been a reinstatement of Mendelian, "Western" genetics in Russia after years of propaganda—serving Lysenkoism (which proposed that most of "heredity" was due to environment). Perhaps the Russians, with all vested interests in traditional fields of genetics disbursed, are now more free to address the reestablished discipline of genetics to the new research challenges of the time of which aquaculture is certainly one.

In any comparison of the application of genetics to agriculture and to fisheries, irrespective of what nation's research programs are being discussed, it should be noted that even prehistoric man was working on the cultivation of land crops and domesticating animals. Modern man, on the other hand, is still for the most part content, correctly or incorrectly, with leaving marine organisms wild. University schools of fisheries are dedicated to the advancement of the science and art of fishing wild fish in the wild. No doubt, this is partly the result of man's lack of day-to-day familiarity with aquatic organisms, one measure of his failure to control the seas as he does land. Also, the advance of civilization necessitated the promotion and ultimate success of agriculture as wild crops and animals disappeared in its wake. In the same way pollution of the seas may assure the promotion of aquaculture over the span of the next few decades.

Whatever the background reasons only presently is genetics beginning to be applied to the fisheries in Japan, which rank among the most important industries of this island nation. By contrast triploid seedless watermelons are bred in Japan from sterile crosses made between special lines, and giant,

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highly polyploid apples are sold at railroad station food stands.

Until now there has been no pressing economic necessity in Japan to employ genetics to produce an organism better able to perform in an intensive aquaculture system. Aquaculture could be inefficient, depend on capture of young wild animals or gravid females for a kind of semifarming, be labor intensive, and still be worthwhile as a means of producing food and obtaining an income. This is no longer the case, and the change may be attributable, in part, to rising labor costs and to increasing demands for high quality seafood by a population with a higher living standard.

EXPANSION OF INTENSIVE AQUACULTURE, A PREREQUISITE FOR GENETIC APPLICATION

Certainly, the genetic study of wild fish populations has some profound implications for fishery management. Genetic knowledge of wild populations, in addition, makes for more judicious selection from such wild populations of the founding populations used to breed hatchery stocks with particular characteristics. The hatchery breeding of special, though still undomesticated, stocks for release to the wild represents still another area of genetics little considered in the fisheries. Such methods have been employed in forestry and grassland management, at least, in the United States. However, the deliberate severe alteration of the genotype of the wild organism, which aquaculturists need to transform the wild fish or invertebrate into a domesticated or cultivated form, requires, to begin with, intensive and fairly successful aquaculture of the organism. For that reason, it is important to note here the current status of aquaculture programs in Japan.

At the opening of the Oceanology Conference in Tokyo (Second International Ocean Development Conference, 1972), it was indicated in a special talk that one of five major projects recommended by a special Council for Ocean Development created in July 1969, as an advisory organ to the Prime Minister, was the development of fish culture with undersea experimental farms. This is, it was explained, because Japan's coastal fishing has declined owing to pollution and overfishing, because of the exclusion of Japan from some fisheries in their part of the world by neighboring nations, and because of an intensification of the world "fishing race." New fishing grounds will be developed and underutilized species exploited. Still of great importance, the Council believes, will be the switchover in the fish industry to farming-type endeavors. The necessity of breed improvement for maximum success in such intensive culture under artificial conditions seems to be well understood.

At the same conference Akio Honma from the Fishery Agency, Ministry of Agriculture and Forestry, gave a presentation on "Fish farming in Japan." Honma said that in the fishing field, farming, along with concomitant management and breeding, has been applied in the past only to a few freshwater species and to a few species of seaweeds and crustaceans. Over the years 1962-1966 the government's Fishery Agency established five Fish Farming Centers to encourage coastal fishing in the Seto Inland Sea. The entire Seto Inland Sea is being considered as one huge pond. Several important marine species are to be preserved and multiplied. Fry are bred at the centers and released to the prefectures for raising and releasing. In this program for the Seto Inland Sea a certain period of growth will be left to nature eliminating the necessity of using cheaper fish for the farming of more expensive fish.

Catching and releasing fry, as a source of seed, proved entirely inadequate. Seed breeding from artificially spawned animals is now the work of the project. It was found that, on the whole, breeding techniques were inadequate for the scope of the undertakings. (Here, genetic improvement in reproductive performance under artificial conditions could lead to better breeding techniques in the hatcheries as an intermediate step in the total program. Nothing was said of this.) The main work of the center is now accordingly the development of mass production schemes. As the need arises, fishing experiment station and university personnel work together at the center.

It has become the policy of the government to subsidize research work for seed production to some nongovernment public corporation where they believe management is better. Seed production is the area to which most money is now being directed.

Efforts are now being made to rear artificially produced fish to maturity in larger tanks so that they can subsequently be used to breed another generation. When this is accomplished, of course, genetically controlled breeding will be possible.

Systematic work in the release and control of seed has been limited since so much of the project had to be aimed at developing seed and better seed-producing techniques. It was found that, if young prawns are protected for a certain period and released after adapting them to natural water, 5 to 10% of the released numbers can be harvested.

As a result of this program, prawn has been produced on a commercial scale. Also red sea bream, octopuses, globefish, scorpionfish, sea-eel, blue crab, and abalone. The prawn project is emerging from its experimental to a semibusiness stage.

The prawn commonly cultured in Japan is *Penaeus japonicus*. It is one of the most expensive of seafoods in Japan. Artificial culture techniques for this species have been developed over the last 10 yr by fisheries biologists and professional aquaculturists. Despite a number of technical and socioeconomic difficulties in the commercial production of prawn in Japan, it is evident to the Japanese that an increasing demand for prawn and shrimp will stimulate the development of its culture as an industry wherever in the world it is at all feasible. Culture should be particularly promoted in the untouched, widely ranging swamplands in the tropical zones. However, presently in Japan, poor culture techniques, defects in the present system of intensive culture, laborious rearing operations, rising land costs, and unfavorable rearing conditions owing to pollution make for unstable and costly production on prawn farms. A decrease in artificial production is anticipated. Culturists wonder whether prawn farms can even be maintained in Japan in competition with more productive enterprises. Yet, an overwhelming demand continues to exceed production even though at the Tokyo Central Fish Market a kilogram of live prawn has been sold for as much as 8 to 30 U.S. dollars (Second International Ocean Development Conference, 1972).

The prawn fishery, just as the shrimp fishery in the United States, might well be the fishery that would benefit monetarily most quickly from a well-integrated, sensibly supported genetics program.

Experimental studies on the hybridization of the freshwater shrimp are being carried on at the Tokyo Fisheries University (Uno and Fujita, 1972). Crosses of *Macrobrachium nipponense* ♀ × *M. formosense* ♂ and reciprocal crosses were reared from the larval stage to sexual maturity. Morphological comparisons of hybrids to each parent were made. These interspecies crosses were achieved by exposing the excised spermatophores to 50% seawater for 15 to 30 min, and then attaching them to the ventral thoracic part of the female of the other species just before she spawned. Such hybrids could have advantages over nonhybrids for intensive aquaculture under artificial conditions, or for "colonization" of a new area in the wild.

POLLUTION AND INTENSIVE AQUACULTURE WITH "SEMIDOMESTICATED" STRAINS

Possibly, even before breed improvement, with concomitant genetic adaptation to the cultivated state, aquaculture of some "semidomesticated" forms will become a success with the disappearance of their wild progenitors from Japan's coastal waters, or when these wild forms accumulate enough contaminants to become unfit for human consumption. Oyster seed production has been eliminated from around the City of Hiroshima with implications for the entire fishery. Yet, while pollution of wild stocks and their demise by marine contaminants may make some aspects of commercial hatchery production more attractive, too widespread pollution would render even artificial production in natural seawater virtually impractical. The Japanese regard the future success of artificial culture to be intimately tied to a resolution of pollution problems.

APPLIED AND BASIC GENETIC RESEARCH TO SUPPORT FISH BREEDING

For many years Japan has emphasized applied research in the fishing fields. A system of extension services for the fisheries is well established. In the United States the Sea Grant Program stresses applied research and extension services, but Japan is looking in the opposite direction. Unlike the Americans, the Japanese have made near maximum and efficient use of applied research. Now, Japanese scientists actually carrying out the work and their research administrators alike are of the opinion that, to increase further the productivity of their fisheries, more basic research is required. In the past, such research has been largely confined to universities where it has not been well funded and to special national institutes. Basic research, they believe, is necessary to develop reliable means of carrying regularly large numbers of fish from egg through sexual maturity, and this in the face of serious pollution. Such work should be deliberately associated with breed improvement programs, and the Japanese recognize this. Even if they did not, some useful genetic selection would occur inadvertently.

Food and disease appear to be presently regarded as more important constraints on aquaculture generally than lack of special breeds. However, the

Japanese regard water quality—pollution—as the current most serious point to consider in establishing aqua-farms. In considering this ordering of pollution, nutrition, then disease, then genetics, in terms of priority, it should be noted that:

1) Genetics will not succeed in accomplishing much of anything if the animal, to begin with, is not reasonably easy to culture;

2) but that genetics can in an early stage of aquaculture contribute to the development of types better able to utilize artificial foods, resist disease, be more vigorous, and develop good gametes;

3) so nutrition, disease, and genetics should not be regarded, either in the United States or Japan, as three separate research entities—they overlap.

STORAGE OF STOCKS AND COLLECTIONS FOR BREEDING PURPOSES

A directory prepared for distribution at the Twelfth International Congress of Genetics, Tokyo, 1968, lists important genetic stocks of plants and animals and microorganisms being maintained in national universities (Oshima, 1968). Tohoku University, Faculty of Agriculture, is named as holding oyster stocks, but no other fish stocks are listed. There are plans for establishing future "storage" centers to maintain genetic stocks. Fish are not mentioned in these proposals for storage of genetic stocks prepared by classic geneticists. "Stocks would be managed by an expert geneticist so that uncontrolled, random breeding" of the closed stocks would not result in genetic changes in the stocks making them unrepresentative of the genotypes of the wild populations or cultured lines from which they were sampled for preservation.

JAPANESE GENETICISTS

In this same directory, names of 944 Japanese geneticists are registered. Only four are cited as involved in research on fish: one was listed at the Nippon Institute of Scientific Research on Pearls, two as working on the genetics of sexuality in fish, and one on the genetics of invertebrate sex-determination. An exhibit, "Genetics in Asian countries," at this Twelfth International Congress of Genetics," featured research on the origin, differentiation, distribution, and breeding of a number of plants and animals especially associated with the life of Asian peoples: nothing was included on fish.

Japan was represented by one of six members of the FAO ad hoc Working Party on Genetic Selection and the Conservation of Genetic Resources of Fish, which met in Rome in 1971 (Food and Agriculture Organization, 1972). Their representative was K. Suzuki, Chief Fish Culture Section, Ueda Branch of Freshwater Fisheries Research Laboratory, Nagano Prefecture. The report published by this panel is an excellent statement. It is mostly, however, oriented towards freshwater fish. In this report the case for widespread utilization of genetics in the fisheries is put more strongly than presented here where emphasis is on genetics in the total perspective.

JAPAN'S NATIONAL INSTITUTE OF GENETICS

Japan has an excellent National Genetics Institute, which consists of 10 departments and was established in 1949 as the governmental institute for fundamental studies of genetics. One of its first directors was the now retired H. Kihara, world renowned wheat geneticist. In the November 1972 edition of Nature devoted to "Science in Japan" there is an article by Kihara, "Activities of the National Institute of Genetics."

One of the most active groups is the Department of Developmental Population Genetics. The work of this group is currently all theoretical and not at all concerned with fish. Training of this staff though could be well utilized in fishery research.

The silkworm is a much used organism for genetic research at this Institute. Genetic mutations interfering with the feeding patterns of the silkworm larvae are being studied. Such mutations no doubt also present themselves in larvae of marine invertebrates, as the oyster, which have delicate larval stages often difficult to culture. Studies on radiation and chemical mutagenesis are being actively pursued using the silkworm. Emphasis is on dose-rate effects. (This is a very important area. There is a necessity internationally to clarify effects or lack of effects at very low doses of radiation, something most difficult to carry out experimentally.) With embryonic death as a criterion, radio-sensitive and radio-resistant strains of silkworms have been isolated, differences being 6- to 9-fold. Using *Drosophila*, induced mutations affecting viability rather than simply inducing lethality have been found to occur 40 times as often as lethal mutations. This work in the field of mutagenesis might be directed toward establishing control standards for marine contaminants as they affect the lethal gene load and reproductive cells of breeding fish populations. Recently, workers at this National Institute of Genetics have developed a very sensitive test system for the detection of chemical mutagens in polluted environments.

The Department of Cytogenetics is studying chromosome polymorphism in populations of the black rat around the world. With emphasis on the Japanese population, the aetiology of Down's syndrome in humans is being studied. Expertise is certainly available then for breeding-related cytogenetic work.

Microbial genetics is also being pursued. Training in such a field could be the basis for studying disease organisms of aquatic plants and animals.

In the Department of Applied Genetics, rice is most extensively investigated - aquatic, marine organisms not at all. A worldwide collection of rice species is maintained; there is a complete collection of wheat and its relative species.

OYSTERS OF JAPAN, SPECIFIC USE OF HYBRIDS AND HYBRID VIGOR

There is a very real separation of *Crassostrea gigas*, commonly called the Japanese oyster, into several distinct races (Imai and Sakai, 1961).

There may even be a variation in the chromosome number in some Japanese populations of *C. gigas*. This is at variance with all the recent reports of American workers (review, Longwell and Stiles, in press). However, all the *C. gigas* sampled in the United States for chromosome analysis derive from seed imported from Japan to the U.S. West Coast, and most of the spat exported from Japan has been taken from one particular region.

C. gigas is collected widely in Japan in the shallow waters on the coast from Hokkaido to Kyushu. Seed were, until recently, collected most actively in Hiroshima, where oyster culture is said to have begun 400 yr ago. The Miyagi district is next in production to Hiroshima. Main seed-producing beds in Japan are Hiroshima, Miyagi, Mie, and Kumamoto Prefectures. The Miyagi Prefecture is famous for their export of oyster seed. This is most likely where most seed imported to the U.S. West Coast has been originating. Hiroshima culturists seldom bought oyster seed and seldom exported their seed to other prefectures or countries.

There are 20 different species of oysters in Japan, all edible. Only three of these are of direct economic importance, *C. gigas*, *C. rivularis*, and *Ostrea nippona*.

It is believed that *C. laperousi* and *C. ariakensis*, native Japanese oysters, reported some years ago by Kobayashi (1954) to have four more chromosomes than *C. gigas*, are really *C. rivularis*. The species *C. rivularis* is not cross-compatible with *C. gigas* (Imai and Sakai, 1961). Confusing here is the fact that American malacologists regard *C. laperousi* and *C. ariakensis* as merely forms of the variable *C. gigas*.

C. rivularis, imported with seed of *C. gigas*, has been planted in Puget Sound and, according to Galtsoff (1964), has established itself there.

Some of this taxonomic confusion in classifying oysters may stem from the existence already of several hybrid-type populations in the wild. Nothing was learned in Japan regarding the opinion of some U.S. workers that *C. angulata*, the Portuguese oyster, and *C. gigas* are the same species.

Lest an understanding of the nature of these species be regarded as esoteric, it should be pointed out that such much publicized benefits of genetics, as miracle rice, resulted from a combination of two species or varieties. The characteristics of each of these types of rice were clearly known and understood by the breeders who test-hybridized them initially along with many others which were not "miracles" at all.

Part of the vigor of *C. gigas* relative to the more sensitive commercial East Coast American oyster, *C. virginica*, may derive from a slow though steady rate of introgressive hybridization. That is, by the addition of other species genes to *C. gigas* on a small scale over a long period. It could also derive from larger scale hybridization in various oyster populations in the more distant past. Both of these probabilities can be checked experimentally. This is basic research, of course, but it would provide some information on how important hybridization programs are in developing vigorous hatchery stocks. Such would remove some of the present unavoidable guesswork as to the usefulness of wide species crosses.

Spat of *C. gigas* are now being shipped to France from Japan for planting on oyster beds once populated by *C. angulata*. There is a chance of natural hybridization on the wild beds in France between imported *C. gigas* and the remains of the once plentiful *C. angulata* populations. These two species readily hybridize in the laboratory, the hybrids survive and are fertile (Imai and Sakai, 1961).

It would be hard to overemphasize the importance hybrid vigor will have in developing hatchery lines of oysters, lobsters, scallops, fish and other marine food animals, and algae. Hybrid vigor is so important because, unless artificial seawater is used, water pollution will always be a threat to the commercial success of a hatchery. Because a hatchery must carry its product through its most sensitive larval stages, in smaller numbers than in the wild, and in one spot as opposed to many in the wild, water pollution can have a more disastrous effect in a hatchery than in the field.

Widespread use of artificial seawater would necessitate the breeding of lines commercially productive in such a media. Drastic changes in the genotype would most probably be necessary. This is not a genetic improbability by any means, but aquaculturists do not give the idea much thought.

LABORATORY VISITS

Even though there has been no general, broad program of fish or aquacultural genetics in Japan, some fine genetic research has gone on in various fishery laboratories. This work has not yet had a great deal of impact on the general fisheries. It is related here along with comments and discussions regarding aquaculture-related genetics. The research cited is a sampling of the sort of work that will most likely be conducted in the future on a larger scale.

Oyster Research Institute at Kesen-numa on Mohne Bay—Oyster, Scallop, and Abalone

The Oyster Research Institute at Kesen-numa (chief researchers now H. Kan-no and T. Seki) developed, under the leadership of T. Imai, methods for the artificial rearing of the Japanese oyster, *C. gigas*. This Japanese work paralleled the prior work of Loosanoff and Davis (1963) of the Milford Biological Laboratory, now part of the National Marine Fisheries Service. From the Kesen-numa Laboratory also came a breeding study on *C. gigas*, which included the effects of inbreeding, hybridization between members of different geographic races, and interspecies crosses using the Japanese oyster as one of the species parents (Imai and Sakai, 1961). Additional aquaculture and breeding information is contained in a recent book edited by Imai et al., 1971, "Through culture in shallow seas (progress in shallow seas culture)." This book is now being translated from the Japanese through the auspices of the National Oceanic and Atmospheric Administration. At least for some considerable period of time adult, fertile hybrids of the cross *C. gigas* × *C. angulata* were maintained at the Kesen-numa Laboratory.

This Institute is now rearing the European oyster, *Ostrea edulis*, which does well in Japan as a hatchery species. These oysters are sold as spat to growers and marketed. *C. angulata* is also being reared. No genetic studies are now being conducted on the oyster.

The sea scallop, *Patinopecten*, is also being raised. The scallop fishery still depends on the capture of juveniles, not on hatchery rearing. However, at least in Mutsu Bay annual catches of *P. yessoensis* fluctuate widely. This is attributed to a natural instability of the reproduction of this species. Natural reproductive instability would make this scallop an excellent candidate for reproduction in the hatchery. Some of the scallops are known to be functional hermaphrodites. Use could so be made, for both experimental and commercial breeding work, of their rapid inbreeding potential by self-crossing.

Research at the Kesen-numa Laboratory is now concentrating on the abalone. The market for this marine gastropod is excellent, and there is an urgent need to mass produce the young. Unlike the situation for the oyster and scallop, mass collection of wild abalone is fairly difficult. Young abalone escape from the collectors, and in their natural habitat, they shelter themselves under boulders or rocks. To increase production it is, therefore, essential to produce the young artificially.

In Japan 10 species of abalone are found. Only four of these species constitute the staple food products—*Haliotis haliotis discus hannoi*, *H. discus*, *H. sieboldii*, and *H. gigantea*. Of the total catch *H. discus hannoi* supplies 58%.

At present, no genetic studies on abalone are being conducted at Kesen-numa. However, there is interest in possible genetic causes of the less than desired percent survival of the young larvae, in the chromosomes of the abalone, and in genetic resistance to disease. Disease is anticipated as a potential serious problem in the very intensive system under which the abalone will be reared. The intensive system includes a period of growth in the heated waters of a nearby power plant at Shiogama. An aboveground running water tank system contains the abalone at this time, and a hatchery with experimental facilities has been built at the power plant near the tank farm.

At the Iwate Prefectural Roes and Fries Distribution Center the gametogenesis of adult abalone was observed, as well as the normal development from fertilized egg to creeping stage larvae (Shibui, 1972).

Once the artificial production of abalone in Japan progressed to the commercial scale, interest developed in the potential of interspecies crosses. At Chikura Branch of Chiba Prefectural Fisheries such hybrids were made and studied. These were between *H. discus* and *H. gigantea;* between *H. discus* and *H. sieboldii;* and between *H. gigantea* and *H. sieboldii* (Oba, Toyama, and Kaneko, 1972). All were reared through metamorphosis in the laboratory. Hatching, fertilization abnormalities, and shell form and structure were compared to the parental characteristics. Such hybrids could have advantages over nonhybrids for intensive aquaculture under artificial conditions, or for colonization of a new area in nature.

Some hybridization work was also conducted at the Kesen-numa Institute (J. W. McBeth).[2]

Pearl Research Laboratory of the Fisheries Agency at Kashiko-jima, Mie-ken

Research is confined exclusively to study of those mollusks used to culture pearls. Work is ultimately directed at improving the quality of the cultured pearl. All the research appears to be basic. It seems that, because the science and art of pearl culture are well worked out, these researchers have more freedom to pursue fundamental work. There is a persistent near 40% mortality of the pearl oyster, *Pinctada fucata*, in the trays and racks used to hold them in the pearl farming. Mortality appears to be accepted as part of the business. The demand for pearls has dropped and there is now a government restriction on the amount of pearl farming to be conducted. There are no projects aimed at breeding disease resistant organisms, as those for the commercial *Crassostrea virginica* in the U.S. mid-Atlantic states.

Research is being carried out on the artificial culture of this pearl oyster's mantle (A. Machii, pers. comm.). Mitosis and cell proliferation have been obtained in vitro. American, European, and Japanese workers can all generally attest to the fact that success in invertebrate tissue culture has been most elusive. A persistent measure of culture success would find application in numerous fields of fishery research. It would apply to work on this epidemic MSX disease of the American oyster, which just about devastated the oyster industry of the U.S. mid-Atlantic states a few years ago (Sindermann and Rosenfield, 1967).

Some inbreeding and some hybridization studies are being conducted on the pearl oyster (K. Wada).[3] Also, some studies have been conducted on its chromosomes in spite of technical problems caused by the presence of so much yolky material in the eggs (K. Wada, see footnote 3). This latter work will probably be published soon. It seems that some research effort will be directed in the future towards study of biochemical polymorphisms in the wild stock.

Ocean Research Institute, University of Tokyo—Genetic Polymorphisms of Wild Populations

In the division, Biology of Fisheries Resources, studies are being conducted on enzyme variation in fish populations (Numachi, 1972a).

Shortage of genetic markers has been a handicap in the study of fish genetics. Now variation in different enzymes can be used as genetic markers by employing gel electrophoresis followed by histochemical staining methods. This method makes possible an examination of the structure of a population of fish in genetic terms. Identification of self-sustaining subpopulations of fish is a most basic problem in fisheries management.

Enzyme polymorphisms reflect a mutation in the structural gene of the enzyme concerned. A few years ago variants of enzymes were regarded as rare events. It is now known that such variants are very common in most enzymes in various organisms. An increasing number of electrophoretically distinguishable variants has been discovered in fish, as well as in other organisms. Marine mammals, such as whales, dolphins, and seals, all contain five lactate dehydrogenase forms. Their enzyme "patterns" are similar to those of terrestrial mammals, including man.

Numachi (1971, 1972b, c) has specifically reported in the literature on interspecific and intraspecific variation of enzymes in fish species and on analysis of the genetic control of such enzymes in fish—on

[2] Communication through Japanese staff member acting as Director at the time.

[3] Personal communication from a fellow staff member. K. Wada was away at a fisheries meeting at the time the laboratory was visited, so more precise information on this work was not obtained.

electrophoretic variants of catalase in black rockfish, *Sebastes inermis;* genetic polymorphisms of tetrazolium oxidase in black rockfish; genetic control and subunit composition of lactate dehydrogenase in *Pseudorasbora parva* (a cyprinoid fish); duplicate genetic loci and variant forms of malate dehydrogenase in chum salmon, *Oncorhynchus keta,* and rainbow trout, *Salmo gairdneri.*

Evidence has importantly been provided for the tetraploid condition of salmon. This means that salmon, like many higher plants, basically have four of each chromosome instead of the usual two each found in normal diploid organisms. Diploidy is the common state in the animal kingdom. Further examination of the evolutionary process of salmonids remains to be done. Already though recognition of the tetraploidy of salmonids should be of intrinsic importance in genetic studies. Because of the tetraploid nature of salmon, big salmon obtained by selection are not a good general example of what might be expected by similar programs of breeding using truly diploid species. Tetraploidy lends itself particularly well to gigantism.

Study of enzyme variation in species transplanted and farmed in the not-so-distant future will be an important means of stock identification, and of determining whether desired or unwanted hybridization has occurred in the wild between the local and transplant type. This will be no small job since the present most effective utilization of different genetic characters of various populations is still by transplantation of populations and species suitable for the environmental conditions of the areas intended for farming (Numachi, 1972a).

Another application of enzyme variants to genetic improvement of aquatic organisms may be as markers linked with economic characters. Economic characters are usually polygenic and so are impossible to study by simple Mendelian genetics as are distinct, qualitative, morphological characters.

Nikko Branch of Freshwater Fisheries Research Laboratory on Lake Chūzenji

Breed improvement is now regarded as one of the main problems in the freshwater fish culture in Japan. Some selective breeding is underway at the Nikko Branch of Freshwater Fisheries Research Laboratory (for preliminary work on *Salmo gairdneri* see Kato and Sakamoto, 1969; Kato, 1970). Extensive hybridization studies have been carried out and reported in the literature (Suzuki and Kato, 1966; Kato, 1967; Suzuki and Fukada, 1971, 1972). Most likely, such programs will be stepped up as breed improvement is stressed in the future.

It is believed that no fish populated Lake Chūzenji until 1873 when some local people volunteered to stock the lake with such fishes as the char and carp. Since that time, many species of salmonid fishes have been stocked frequently in the lake. The eggs of *Salvelinus fontinalis,* the brook trout, were imported in 1901 from the United States and fry released in the lake.

It is well known that distinct species and genera of fishes hybridize frequently in nature. A considerable number of natural hybrids has been reported, especially in the freshwater families—Cyprinidae and Castostomidae; also, in Percidae, Centrarchidae, Poeciliidae, etc; and importantly in Salmonidae. Natural hybrids seem to occur much less frequently in marine fishes. Information about natural crosses is most useful in determining the relationship of groups of fishes.

Natural hybrids between *S. pluvius,* the Japanese char, and *S. fontinalis* were collected from a brook flowing into Lake Chūzenji. They are estimated to constitute about 12% of the population at the area of the headspring.

Growth and survival rates of artificially produced hybrids between *S. pluvius* and *S. fontinalis* were studied from 6 mo after fertilization until they were 2 yr old and compared to the nonhybrid parents. This was to determine their relative suitabilities for pond culture. Best growth was in *S. fontinalis* followed by the hybrid, then by *S. pluvius.* Survival rate was highest in the hybrids. All the hybrids and *S. fontinalis* came to maturity during this time, but a third of *S. pluvius* was still immature. Hybrids were fertile and, in fact, produced a significantly larger number of eggs than did the nonhybrid parents.

With the hope of directly utilizing the information obtained to increase annual trout harvests, hybridization experiments with 62 combinations of Salmonidae have been going on since 1965. The purpose of this work was to find F_1 hybrids suitable for pond culture and for stocking lakes or rivers. Until a few years ago the freshwater fishes of Japan were abundant in nature. They were used mostly by rural people as a main protein source. Due to a reduction in their natural habitats, such fish are now less plentiful. At the same time the demand for them has gone up, making them a luxury food. Presumably it was believed that genetic and breeding work would have some bearing on this situation. It was further hoped that some of these hybrid crosses would be sterile. Sterile hybrids might, because of their sterility, have a faster rate of growth or greater ultimate size than fertile nonhybrids.

Hybrid development did occur in all combinations. There were, however, wide differences in survival rates. Hybrids between 32 combinations survived until they reached the free-swimming stage. Nine of these showed survival rates similar or better than those of parental species. Those combinations that did survive are currently being studied at later growth stages.

Among hybrid characteristics already ascertained is a heterosis against disease. This is an important feature since prevention of epidemic disease is a serious problem in trout culture.

Even some intergeneric hybridization was achieved. These hybrids though presented special difficulties in culturing and rearing.

Tohoku University School of Fisheries and Tohoku Regional Fisheries Research Laboratory—Radiation Effects on Oyster; Seaweeds

The effects of ionizing radiation on *Crassostrea gigas* are being studied at Tohoku University (L. Maeda, pers. comm.). This work may be similar in nature to some done on *C. virginica* (Longwell and Stiles, 1972).

Recent advances in cultural techniques for the seaweeds, like *Porphyra* and *Undaria*, have brought substantial benefit to a considerable portion of fishermen engaged in seaweed production in Japan. (At the same time once important nori grounds about Tokyo have been irretrievably lost to pollution, and nori products have come to contain mercury and cadmium.) Little attention though has been given to the possibility of artificially crossing seaweed types to give a more productive, profitable strain. Since 1958, S. Suto has been making interspecies hybrids always using a local commercial species as one parent. This work has been done with a view of obtaining a new seaweed with good characteristics for culture (Suto, 1963; also see Suto, 1972). Fortunately, self-fertilization rates are low, facilitating artificial fertilization. However, much preliminary work had to be done before artificial fertilization could be achieved with certainty. Also, the relationship between *Porphyra* species had to be clarified.

Artificial crosses were attempted between five species of the *Porphyra* genus, including four local forms. Crosses occurred easily between any two species tested. Descendants from crosses of two dioecious parents and from two monoecious parents grew normally. Those from dioecious-monoecious combinations died in mass at a young stage, but left a few survivors. The three dioecious species studied appear to be very closely related. At least in hybrids of the dioecious species, there is normal reproduction with typical genetic segregation.

Recently, some lines started from an interspecies hybrid have yielded two and three succeeding generations. Some of the lines grow more vigorously than did their native parents.

This work demonstrates that new lavers, more suitable for commercial production than the present wild lavers, can be bred. Probably the F_1 interspecies hybrids will first have to be subjected to a program of artificial selection in the laboratory, or one of natural selection in the wild before being used commercially.

Introduction to Japan of foreign species of *Porphyra*, which may be disease resistant, for field trials and for use in hybrids with Japanese species, is regarded important. High quality species already being utilized are, unfortunately, not the most productive, and disease is a factor in lowering productivity.

There is a likelihood of some natural hybridization occurring on the wild beds between closely related species. The genetic and other implications of this are recognized.

Some cytogenetic studies on *P. yezoensis* have been done elsewhere at Nagasaki University Faculty of Fisheries (Migita, 1967). There are three chromosomes in vegetative and spermatogonial cells in the leaf thalli, and six chromosomes in fertilized carpogonia. The haploid chromosome number of this alga is then three. Meiosis takes place in the cell division of the conchospore at the time of spore formation. Such information is pertinent to the making of artificial crosses. Also for the artificial somatic replication of a single plant for multiplication prior to larger scale commercial production.

Aside from the great commercial value of seaweeds in Japan (their most important fishery), the Japanese probably have here one of the most interesting areas of the future field of marine genetics with most promise of great commercial application. This is because plants, in general, lend themselves so well to genetic study with subsequent genetic manipulation and because so many genetic and breeding techniques are so well worked out for plants.

LITERATURE CITED

CHERFAS, B. I., (editor).

1969. Genetika selektisya i gibridizatsiya ryb (Genetics, selection, and hybridization of fish). Moscow, Izd. Akad. Nauk. (Translated by Israel Program Sci. Transl., 1972, 269 p.; available U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, Va., as TT-50112.)

FOOD AND AGRICULTURE ORGANIZATION.

1972. Report of the first meeting of the FAO *ad hoc* working party on genetic selection and the conservation of genetic resources of fish. FAO (Food Agric. Organ. U.N.) Fish. Rep. 119, 9 p.

GALTSOFF, P. S.

1964. The American oyster *Crassostrea virginica* Gmelin. U.S. Fish Wildl. Serv., Fish. Bull. vol. 64, 480 p.

IMAI, T. (editor).

1971. Through culture in shallow seas (progress in shallow seas culture). [In Japanese.] Koseisha Koseikaka Publishers, Tokyo, 454 p. (English transl. by U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv.)

IMAI, T., and S. SAKAI.

1961. Study of breeding of Japanese oyster. *Crassostrea gigas*. J. Agric. Res. 12:125-171.

INTERNATIONAL CONGRESS OF GENETICS, TWELFTH.

1968. Genetics in Asian countries. XII International Congress of Genetics. Organizing Committee (D. Moriwaki, Chairman). 19-28 Aug. 1968. Tokyo. [Brochure accompanying exhibit.]

INTERNATIONAL OCEAN DEVELOPMENT CONFERENCE, SECOND.

1972. Special lectures and reprints, vol. 2. Secretariat, International Ocean Development Conference and Exhibition, Japan Management Association, Tokyo.

KATO, T.

1967. Studies on the techniques of salmon - and trout - culturing. 3. Growth and survival rate of *Salvelinus pluvius*, *Salvelinus fontinalis fontinalis* and the hybrid, *Salvelinus pluvius* ♀ and *Salvelinus fontinalis fontinalis* ♂. [In Japanese. English summary.] Minato-Ku Suisan Kenkuysho. Kenkyu Koku 16:59-64.

1970. Studies on the variation of growth in rainbow trout *Salmo gairdnerii*-II Regression line of satiation amount on the body weight as an indication of food amount. [In Japanese. English summary.] Bull. Freshwater Fish. Res. Lab. 20:101-107.

KATO, T., and Y. SAKAMOTO.

1969. Studies on the variation of growth in rainbow trout, *Salmo gairdnerii* -I. The effect of grading of body size on the course of growth. [In Japanese. English summary.] Bull. Freshwater Fish. Res. Lab. 19:9-16.

KIHARA, H.

1972. Activities of the National Institute of Genetics. Nature (Lond.) 240:219-220.

KOBAYASHI, H.

1954. Über die chromosomenzahl der zwei arten von japanischen austern. Cytologia 19:371-376.

LONGWELL, A. CROSBY, and S. S. STILES.

1972. Breeding response of the commercial American oyster to ionizing radiation. Radiat. Res. 51:1-545 (He-5).

In press. Oyster genetics and the probable future role of genetics in aquaculture. Malacol. Rev.

LOOSANOFF, V. L., and H. C. DAVIS.

1963. Rearing of bivalve mollusks. *In* F. S. Russell (editor), Advances in marine biology, vol. 1, p. 1-136. Academic Press, London and New York.

MIGITA, S.

1967. Cytological studies on *Porphyra yezoensis* Ueda. Bull. Fac. Fish., Nagasaki Univ. 24:55-64.

NUMACHI, K.

1971. Electrophoretic variants of catalase in the black rockfish, *Sebastes inermis*. Bull. Jap. Soc. Sci. Fish. 37:1177-1181.

1972a. Genetic polymorphism in enzymes and its research application in fisheries biology. *In* Second International Ocean Development Conference 2:1813-1821. Secretariat, International Ocean Development Conference and Exhibition, Japan Management Association, Tokyo.

1972b. Genetic polymorphism of tetrazolium oxidase in black rockfish. Bull. Jap. Soc. Sci. Fish. 37:1-789.

1972c. Genetic control and subunit compositions of lactate dehydrogenase in *Pseudorasbora parva*. Jap. J. Genet. 47:193-201.

OBA, T., T. TOYAMA, and S. KANEKO.

1972. Studies on the experimental hybridization of *Haliotis*. *In* Second International Ocean Development Conference 2:1725. Secretariat, International Ocean Development Conference and Exhibition, Japan Management Association, Tokyo.

OSHIMA, C. (editor).

1968. Recent activities of Japanese geneticists. Idengaku Fukyukai, National Institute of Genetics, Misima, Shizuoka-Ken, Japan.

SHIBUI, T.

1972. Biological studies concerning the mass production of young abalone *Haliotis discus hannoi* ino. *In* Second International Ocean Development Conference 2:1715-1724. Secretariat, International Ocean Development Conference and Exhibition, Japan Management Association, Tokyo.

SINDERMANN, C. J., and A. ROSENFIELD.

1967. Principal diseases of commercially important marine bivalve Mollusca and Crustacea. U.S. Fish Wildl. Serv., Fish. Bull. 66:335-385.

SUTO, S.

1963. Intergeneric and interspecific crossings of the lavers (*Porphyra*). Bull. Jap. Soc. Sci. Fish. 29:739-748.

1972. Variation in species characters of *Porphyra* under culture conditions. *In* J. A. Abbott and M. Kurogi (editors). Contributions to the systematics of benthic marine algae of the North Pacific. Japanese Society of Phycology, Tokyo.

SUZUKI, R., and Y. FUKADA

1971a. Survival potential of F_1 hybrids among salmonid fishes. Bull. Freshwater Fish. Res. Lab. 21:69-83.

1971b. Growth and survival of F_1 hybrids among salmonid fishes. Bull. Freshwater Fish. Res. Lab. 21:117-138.

SUZUKI, R., and T. KATO.

1966. Hybridization in nature between salmonid fishes *Salvelinus pluvius* × *Salvelinus fontinalis*. Bull. Freshwater Fish. Res. Lab. 16:83-90.

UNO, Y., and M. FUJITA.

1972. Studies on the experimental hybridization of freshwater shrimps, *Macrobrachium nipponense* and *M. formosense*. *In* Second International Ocean Development Conference 2:1762. Secretariat, International Ocean Development Conference and Exhibition, Japan Management Association, Tokyo.

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