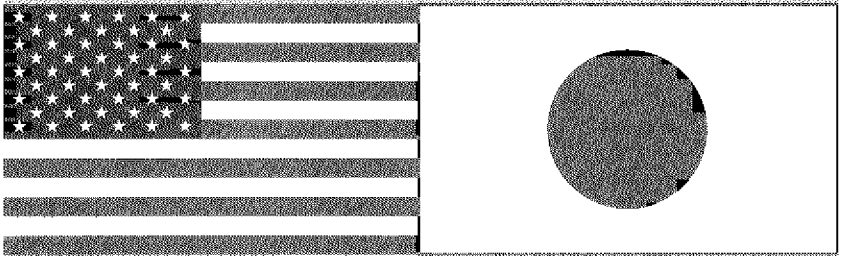
# Interactions Between Cultured Species and Naturally Occurring Species in the Environment



## PROCEEDINGS OF THE TWENTY-SECOND U.S.- JAPAN AQUACULTURE PANEL SYMPOSIUM

Edited by Marcia R. Collie and James P. McVey

UJNR Technical Report No. 22

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Homer, Alaska, August 21-22, 1993

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U.S.-Japan Cooperative Program in Natural Resources
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# Contents

# 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 and academic departments most concerned with aquaculture. Charged with exploring and developing bilateral cooperation, the panels have focused their efforts on exchanging information related to aquaculture that could be of benefit to both countries.

The UJNR was begun 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 in the program include desalination of seawater, toxic microorganisms, air pollution, energy, forage crops, national park management, mycoplasmosis, wind and seismic effects, protein resources, forestry, and several joint panels and committees in marine resource research, development, and utilization.

Accomplishments include: increased communication and cooperation among technical specialists; exchanges of information, data, and research findings; annual meetings of the panel, a policy-coordinating body; administrative staff meetings; exchanges of equipment, materials, and samples; several major technical conferences; and beneficial effects of international relations.

The 22nd U.S.–Japan Aquaculture Panel Symposium was held in Alaska from August 19 to August 28, 1993. The ten-day agenda included plenary sessions in Homer and Seward and field trips in and around Anchorage, Homer, and Seward. The symposium was organized by program chair William R. Heard of the U.S. National Marine Fisheries Service and Brenda Baxter of the Alaska Sea Grant College Program.

Panel Chairmen:
James P. McVey, United States
Kunizo Tanaka, Japan

*Japan and United States Delegations, 22nd UJNR Meeting*
*Homer, Alaska—August, 1993*

# Imprinting Salmon in Saltwater in Southcentral Alaska

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## ABSTRACT

Supplemental production of hatchery-produced chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and pink salmon (*O. gorbuscha*) offers additional opportunities for increasing numbers of anglers who utilize Kenai Peninsula fisheries. Although the Homer Spit was selected for release of smolts because of high accessibility to anglers, the site lacked an adequate freshwater imprinting source. Therefore, we assumed an artificial imprinting cue would be required to imprint salmon smolts and provide a homing stimulus for returning adults. The goal was to attract them to a general offshore area to minimize the potential for a congested fishery.

Since 1984, nearly 1.5 million chinook salmon smolts have been imprinted and released into a small saltwater inlet near Homer, Alaska. Over 18,700 chinook salmon adults have returned since 1985, providing over 43,500 angler-days of effort in this roadside fishery. Returning adult chinook salmon homed back to the inlet where they were released, rather than to the imprinting station anchored offshore. Short-term saltwater rearing and release of later run chinook, pink, and coho salmon have also been conducted to extend sport fishing opportunities on the Homer Spit throughout the summer. The Alaska Department of Fish and Game, in cooperation with the City of Homer and South Peninsula Sportsman's Association, were co-recipients of the Sportfish Management Award of 1990. The award was presented by the American League of Anglers and Boaters for the best enhancement project in the Nation. These positive results demonstrate that biologists may have more options for creating new salmon fisheries in marine locations that lack freshwater for imprinting than previously believed.

## INTRODUCTION

Many of Alaska's sport fishing opportunities exist in remote locations that are accessible to few anglers, while readily accessible fisheries have become overcrowded. Angling opportunities can be created by developing new fish populations for existing access. Large numbers of anglers, comprising approximately 40% of the state total, are concentrated along the limited highway system on the Kenai Peninsula in Southcentral Alaska. In response to this large angling effort, the Alaska Department of Fish and Game (ADF&G), Division of Fisheries Rehabilitation, Enhancement and Development (FRED) Division, and the Sport Fish Division have attempted to create new fisheries for these anglers.

The Homer Spit was selected for sport fisheries enhancement because it is highly accessible to the large numbers of residents and tourists who are already attracted to the area. Unfortunately, no adequate freshwater discharge for salmon imprinting is available on Homer Spit, so this project was originally designed to use the synthetic organic chemical, morpholine,[1] as an imprinting agent during the smolt stage and as a homing stimulus for returning adults. The original goal of this project was to subsequently use a morpholine "drip station" to create an adult chinook salmon return adjacent to Homer Spit, providing a shallow water troll fishery.

This imprinting technique has been used on salmonids in Lake Michigan (Cooper et al. 1976; Cooper and Scholz 1976; Scholz et al. 1975, 1978) and summarized by Hasler and Scholz (1983). Other experiments have been done

[1]Statement of brand names, model numbers, or sources of materials does not represent endorsement of the product by the Alaska Department of Fish and Game or NOAA.

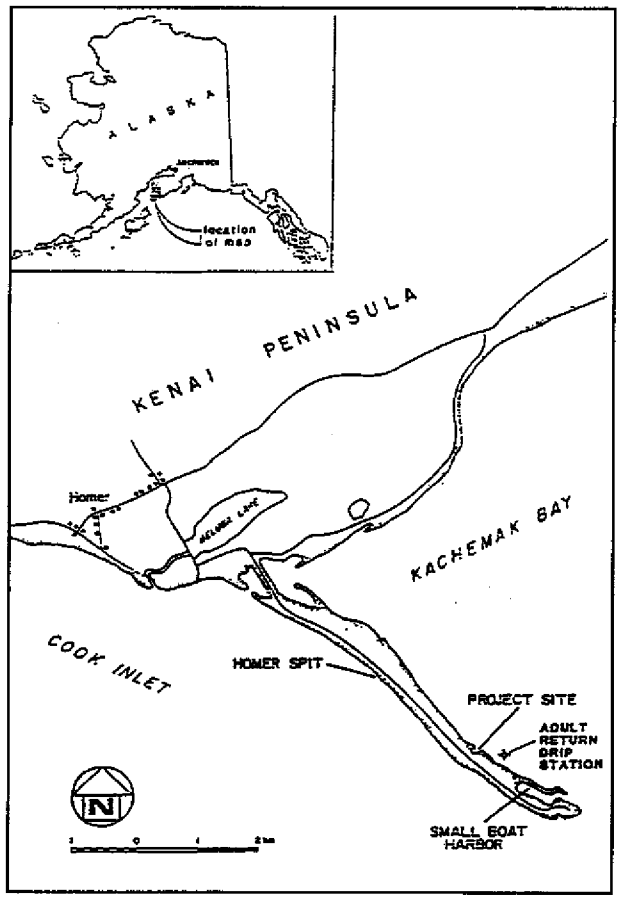


*Figure 1. Homer Spit salmon enhancement site.*

with chinook and coho salmon in California (Hassler and Kucas 1982). These studies have demonstrated success in imprinting salmonids with morpholine in freshwater systems. To our knowledge, however, the Homer Spit experiment may be the first report of using this chemical as an artificial imprinting agent in saltwater for chinook salmon and the first to attempt to decoy returning fish to a more favorable marine sport harvest location. Subsequently, short-term saltwater rearing and release of hatchery-produced pink salmon fry and coho salmon smolts were also conducted without artificial imprinting to extend sport fishing opportunities throughout the summer.

## STUDY AREA

The Homer Spit salmon enhancement site is located in the fishing and tourism community of Homer, on the southern tip of the Kenai Peninsula, in Southcentral Alaska (Fig. 1). The Homer Spit is a naturally occurring 7.2 km long gravel bar or "spit" that extends into Kachemak Bay in lower Cook Inlet. The project site is a small saltwater, intertidal inlet located approximately 5.8 km from the base of the Homer Spit (Fig. 1). This inlet is approximately 100 x 60 m in size, with a maximal depth of approximately 3 m at mean-low tide. There is no freshwater discharge into this inlet except limited surface runoff during rainfall.

## METHODS AND MATERIALS

The chinook salmon spawning operation was conducted at the Crooked Creek Hatchery, and the eggs were transported to the Elmendorf Hatchery in Anchorage where heated water was available to accelerate development in order to produce smolts in less than a year. The smolts in one raceway were exposed to morpholine for 30-38 days each year from 1984 to 1988. Concentration in the raceways was adjusted to 5 x $10^{-5}$ mg/liter of morpholine following the calculation of Scholz et al. (1975).

After imprinting, smolts were transported by tanker truck to the Homer Spit and released into the small saltwater, intertidal inlet. Floating 3.7 x 3.7 x 3.7 m net pens have been anchored in the inlet to hold a portion of the smolts released in 1985 through 1992. The penned smolts are held for 5-7 days and fed 3.5-mm Oregon Moist Pellet[1] frozen fish food.

Coho salmon smolts are handled similarly to the chinook salmon smolts; however, it required an additional year to produce coho smolts at Elmendorf Hatchery. Coho salmon smolts were not imprinted with an artificial agent prior to release. Late run chinook salmon broodstock originated from the Kasilof River, which is also located approximately 96 km north of Homer. Spawning, incubation, and rearing to the smolt stage is conducted at the Crooked Creek Hatchery as a 2-year cycle. Late run chinook salmon also had not been imprinted with an artificial agent prior to release at the Homer Spit.

Pink salmon fry were also released at the Homer Spit site to diversify species return and timing. Fry were transported by skiff-mounted transport tanks from Tutka Lagoon Hatchery, which is located in Tutka Bay approximately 19 km southwest of the Homer Spit. These emergent fry were held for approximately 20-30 days in floating net pens and fed Alaska Dry Pellet[1] fish food by volunteers. The pink salmon fry were not artificially imprinted prior to release.

A floating morpholine "drip station" was anchored just offshore of the Spit (Fig. 1) to provide attractant for returning adult chinook salmon. The concentration of morpholine and the drip rate were gradually increased during the 1985-1988 adult returns. The decoy station was discontinued after 1988.

The number of fish returning to the inlet was estimated periodically by aerial surveys when water conditions allowed. On several occasions, an instantaneous population estimate was made by seining, marking, and recapturing fish in the inlet. The sport harvest was estimated by multiplying the number of anglers by the average catch per angler.

**Table 1. Chinook salmon smolt releases and adult returns, Homer Spit, 1984-1992.**

| Release Year | Smolt Release Date | Treatment | Number Released | size (g) | Estimated Adult Return by Year 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | Total | Estiamted Survival % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1984 | 12 June | None | 80,000 a | 17.8 | 400 | 300 | 580 | 500 | | | | | 1,780 | 2.2 |
| 1985 | 11 June | None | 79,700 | 18.8 | | | | | | | | | | |
| | 15 June | Pen fed | 72,500 | 18.8 | | | | | | | | | | |
| | Subtotal | | 152,200 | | | 1,000 | 790 | 1,880 | 700 | | | | 4,370 | 2.9 |
| 1986 | 10 June | None | 52,300 | 13.8 | | | | | | | | | | |
| | 15 June | Pen fed | 51,600 | 13.8 | | | | | | | | | | |
| | Subtotal | | 103,900 b | | | | 630 | 820 | 1,500 | 600 | | | 3,550 | 3.4 |
| 1987 | 8 June | None | 49,900 | 17.0 | | | | | | | | | | |
| | 13 June | Pen fed | 53,900 | 17.0 | | | | | | | | | | |
| | Subtotal | | 103,800 | | | | | 100 | 500 | 1,000 | 900 | | 2,500 | 2.4 |
| 1988 | 9 June | None | 47,650 | 18.0 | | | | | | | | | | |
| | 12 June | Pen fed | 170,250 | 18.0 | | | | | | | | | | |
| | Subtotal | | 217,900 | | | | | | 300 | 500 | 1,700 | 1,100 | 3,600 | 1.7 |
| 1989 | 8 June | Pen fed | 116,360 | 16.5 | | | | | | | | | | |
| | 14 June | Pen fed | 55,560 | 16.5 | | | | | | | | | | |
| | 14 June | None | 41,380 | 16.5 | | | | | | | | | | |
| | Subtotal | | 213,300 b | | | | | | | 100 | 700 | 1,200 | (2,000) | Preliminary |
| 1990 | 29 May | Pen fed | 107,845 | 13.8 | | | | | | | | | | |
| | 5 June | Pen fed | 102,440 | 15.9 | | | | | | | | | | |
| | Subtotal | | 210,285 | | | | | | | | 200 | 500 | (700) | Preliminary |
| 1991 | 3 June | Pen fed | 96,850 | 18.8 | | | | | | | | | | |
| | 10 June | Pen fed | 94,065 | 20.3 | | | | | | | | | | |
| | Subtotal | | 190,915 | | | | | | | | | 200 | (200) | Preliminary |
| 1992 | 27 May | Pen fed | 115,525 | 17.5 | | | | | | | | | | |
| | 15 June | Pen fed | 110,800 | 19.0 | | | | | | | | | | |
| | Subtotal | | 226,325 | | | | | | | | | | | |
| | TOTALS | | 1,498,625 | | 400 | 1,300 | 2,000 | 3,300 | 3,000 | 2,200 | 3,500 | 3,000 | (18,700) | Avg. 2.5 |

a Estimated number of live smolt released after deducting transport mortality.
b Smolt had unusually high sodium-ion blood plasma levels before release. Mortality after release was estiamted at 20% of the entire release group.

## RESULTS

### Juvenile Releases

Since 1984, over 1,498,600 chinook salmon smolts have been imprinted and released (Table 1). The project began in 1984 with an initial release of 80,000 smolts and has expanded to a release of over 190,000-226,000 smolts in 1988-1992. In 1985, 1986, and 1987, approximately 50% of the smolts were held in net pens for 5-6 days prior to release, and in 1988 and 1989, over 80% of the smolts were held in pens before release (Table 1). Since then, between 80 and 100% of the smolts have been held annually in pens (Table 1). The mortality rate of chinook salmon smolts during the short-term rearing period was less than 1% except in 1989, when the smolts had unusually high sodium-ion blood plasma levels prior to release. Mortality of the 1989 release was estimated to be 20%. The average sizes of the smolts ranged from 16.5 to 20.3 g except in 1986 and 1990 when they averaged 13.8 g and 14.8 g, respectively (Table 1).

Since 1988, over 539,930 coho salmon smolts have been released into the inlet on Homer Spit after a 5-7 day short-term rearing program (Table 2). Over 1,849,000 pink salmon fry were also released from the Homer Spit since 1987 (Table 3). In most years, fry nearly doubled their size, exceeding the 0.45 g size during the 20- to 30-day short-term rearing period.

### Adult Returns

Over 18,700 adult chinook salmon have returned to the Homer Spit since 1985. These have provided more than 43,500 angler-days of effort (Table 4). An estimated 3,300 chinook salmon returned to the Homer Spit in 1988, the first year that all four age classes of chinook salmon returned since the initial release in 1984. The percent composition of the year classes of the 1988 return was 3% for age 0.1, 25% for age 0.2, 57% for age 0.3, and 15% for age 0.4. Similar results were observed through 1992. The highest return was 3,500 chinook in 1991. The mean smolt-to-adult ocean survival for 5 years' data was 2.5%.

The chinook salmon returns have created a very popular sport fishery. Since 1988, sport fishermen have annually expended approximately 7,500 angler-days of effort to

**Table 2. Coho salmon smolt releases (after pen-rearing) and adult returns, Homer Spit, 1988-1992.**

| | Smolt Release | | | | | |
|---|---|---|---|---|---|---|
| Release Year | Date | Number Released | size (g) | Year | Adult Returns Number | Estimated Survival (%) |
| 1988 | 1 June | 62,550 | 21.8 | 1989 | 2,500 | 4.0 |
| 1989 | 26 May | 77,770 | 20.0 | 1990 | 2,300 | 3.0 |
| | 2 June | 76,070 | 21.4 | 1990 | 3,800 | 5.0 |
| | Subtotal | 153,840 | | | 6,100 | 3.9 |
| 1990 | 25 May | 56,635 | 24.8 | 1991 | 4,000 | 7.0 |
| | 28 May | 66,310 | 23.6 | 1991 | 6,000 | 9.0 |
| | Subtotal | 122,945 | | | 10,000 | 8.1 |
| 1991 | 27 May | 59,985 | 21.5 | 1992 | | |
| | 31 May | 40,044 | 23.8 | 1992 | | |
| | Subtotal | 100,029 | | | | |
| 1992 | 3 June | 60,124 | 23.4 | 1993 | | |
| | 8 June | 40,446 | 25.3 | 1993 | | |
| | Subtotal | 100,570 | | | | |
| | TOTALS | 539,934 | | 1989 - 92 | 18,600 | Avg. 5.3 |

harvest an average of 3,000 chinook salmon, with an average catch rate of 0.40 fish per angler-day. Successful angling techniques included light to medium tackle with small artificial lures, flies, salmon egg clusters, herring, or shrimp. Current regulations by "emergency order" allow limited periodic snagging as a legal angling method after June 23. This provides an effective means of harvesting the remaining chinook, pink, and coho salmon when they quit biting during the last third of each species run.

Although the adult return station using morpholine drip was in position and operating during the 1986-1988 chinook salmon returns, there was no conclusive evidence that the chinook salmon were orienting to it. Only twice, during 1987 and 1988, were small schools of fish observed briefly down-current from the drip station. Therefore, the drip station was discontinued in 1989.

An estimated 18,600 adult coho salmon returned in August through September of 1989-1991 from over 339,330 smolts released in 1988-1990, yielding an average ocean survival rate of 5.3% (Table 2). The highest survival rate (8.1%) occurred in the 1991 return from the 1990 release of nearly 123,000 coho smolts (Table 2). This is encouraging data from the initial releases of the coho salmon smolts portion of the project. These smolts returned and homed to the small saltwater inlet where they previously had been reared and released, without exposure to morpholine imprinting.

Since 1988, over 17,600 adult pink salmon have returned to the Homer Spit from releases of 1,849,000 fry. In 1988, over 4,500 adult pink salmon returned, yielding an ocean survival rate of 1.5% (Table 3). In 1989, the survival rate was over 3.3% with an estimated adult pink salmon return of 10,000 fish (Table 3). This was the highest return rate of pink salmon in the history of this project. Similar to most local area pink salmon stocks, recent returns to the Homer Spit have been low at 0.1 to 1.1% survival. The pink salmon adults also homed to the small saltwater inlet where they had been previously reared and released, without artificial imprinting.

## DISCUSSION

The highly visible, roadside fishery created by this experimental salmon smolt and fry release program on the Homer Spit has generated intensive fishing effort, successful results, and very positive public response. To date, over 86,000 angler-days of effort have been expended in this road accessible fishery (Table 4). Local residents, as well as tourists from other parts of Alaska, other states, and

**Table 3. Pink salmon fry releases (after 20-30 days of short-term rearing) and adult returns, Homer Spit, 1987-1992.**

| | Fry Release | | | | | |
|---|---|---|---|---|---|---|
| Release Year | Date | Number Released | Size (g) | Year | Adult Returns Number | Estimated Survival (%) |
| 1987 | 2 June | 295,000 | 0.40 | 1988 | 4,500 | 1.5 |
| 1988 | 1 June | 300,000 | 0.46 | 1989 | 10,000 | 3.3 |
| 1989 | 7 June | 330,000 | 0.45 | 1990 | 600 | < 0.1 |
| 1990 | 13 June | 304,000 | 0.45 | 1991 | 500 | < 0.1 |
| 1991 | 13 June | 320,000 | 0.49 | 1992 | 2,000 | 0.6 |
| 1992 | 10 June | 300,000 | 0.46 | 1993 | | |
| | TOTALS | 1,849,000 | 0.45 | 1988-92 | 17,600 | 1.1 |

many foreign countries, have participated in this fishery. The City of Homer, Homer Harbormaster Office, Port and Harbor Commission, South Peninsula Sportsman's Association, and Cook Inlet Seiners Association have been very cooperative and supportive of this project. Many local merchants have described a significant increase in seasonal business that is directly related to this and the other enhanced fisheries around Kachemak Bay. The sequential returns of chinook, pink, and coho salmon have provided angling opportunities throughout the entire sport fishing season (Table 5) in a location where only minimal angling opportunities previously existed.

The Homer Spit Sportfish Enhancement Project is funded by the Dingell-Johnson/Wallop-Breaux federal funding system and has received national recognition and an award from the American League of Anglers and Boaters. The Alaska Department of Fish and Game, the City of Homer, and the South Peninsula Sportsman's Association were co-recipients of the Sportfish Management Award for 1990 for the best fishery enhancement project in the Nation. As a result of national recognition and because of the economic benefits to the local community, the City of Homer expanded the small lagoon to provide for increased angling opportunities.

Although there is no freshwater available in the small inlet for imprinting, returning adult chinook, pink, and coho salmon homed to the small inlet where they were released, rather than to the morpholine drip station. Most of these fish are harvested either in the small inlet, the intertidal channel, or the adjacent shoreline during flooding tides. Unfortunately, relatively few chinook salmon are taken by trolling in spite of our attempt to imprint them to the drip station in an effort to spread the fishery over a larger area, rather than just to the confined area of the small inlet on the Homer Spit.

We are uncertain if the fish were adequately imprinted to morpholine as smolts. We believe, however, that the adults did not home to the morpholine drip station because the concentration rate was not high enough. The large tidal exchange (+6.6 to -1.5 m) probably dilutes and exports the morpholine so that it cannot be readily detected by the returning salmon. Also, it is likely that unique chemical characteristics associated with the intertidal inlet (e.g., organic matter, metal scraps on the bottom, chemical preservatives from wood in an old barge and pilings, sand and gravel, etc.) impart a stronger influence on imprinting and homing than the exposure to morpholine.

It is most important, however, to note that chinook, coho, and pink salmon fisheries can be created by releasing the juvenile fish in highly saline waters without the influence of a freshwater imprinting source. Another aspect of the imprinting and homing mechanism that we have been particularly impressed with is the apparently brief imprinting period required. All of the chinook salmon smolts released in 1984, and more than half of those released in 1985-1987, were released directly into the inlet. Some were observed migrating out of the inlet within several hours. None of these treatment lots was marked, so there is no estimate of differential survival; however, at another project site, Halibut Cove Lagoon, where treatment lots were differentially marked, the survival of chinook salmon reared in pens for 14 days was approximately 30% greater than those released directly into a

**Table 4. Harvest and angler effort directed toward enhanced king, pink, and coho salmon stocks in the Homer Spit fishery, 1985-1992.**

| | King Salmon | | Pink Salmon | | Coho Salmon | | TOTAL | |
|---|---|---|---|---|---|---|---|---|
| Year | Days Fished | Harvest | Days Fished | Harvest | Days Fished | Harvest | Days Fished | Harvest |
| 1985 | unknown | 400 | | | | | | 400 |
| 1986 | unknown | 1,300 | | | | | | 1,300 |
| 1987 | 6,000 | 2,000 | | | | | 6,000 | 2,000 |
| 1988 | 7,000 | 3,300 | 5,000 | 4,500 | | | 12,000 | 7,800 |
| 1989 | 7,000 | 3,000 | 6,000 | 10,000 | 6,000 | 2,500 | 19,000 | 15,500 |
| 1990 | 6,500 | 2,200 | 3,000 | 600 | 6,000 | 6,100 | 15,500 | 8,900 |
| 1991 | 8,000 | 3,500 | 2,500 | 500 | 10,000 | 10,000 | 21,500 | 14,000 |
| 1992 | 9,000 | 3,000 | 3,000 | 2,000 | (Data will follow season) | | (12,000) | (5,000) |
| TOTALS | 43,500 | 18,700 | 19,500 | 17,600 | (22,000) | (18,600) | (86,000) | (54,900) |

( ) = Preliminary

large lagoon with freshwater discharge (Dudiak et al. 1987). The increased survival advantage may result from better imprinting, better recovery from transport stress, or both.

Although the effectiveness of morpholine imprinting in saltwater appears to be low, the overall success of the Homer Spit Project is evident with the estimated mean survival rate of 2.5% for the chinook salmon smolts released from 1984 to 1988. This is comparable to the 2.4% average survival rate for chinook salmon smolts released and imprinted to freshwater at Halibut Cove Lagoon. As many as 5,000 adult chinook salmon are expected to return in 1993. Survival rates for pink and coho salmon have also been encouraging, and as many as 10,000 adult pink salmon and 10,000 adult coho salmon could also return in 1993.

These results demonstrate that management biologists may have many more options available to create new salmon fisheries in locations previously believed unacceptable because of the lack of freshwater for imprinting. If the chinook salmon had imprinted to morpholine as we had previously thought necessary, we may have been able to decoy them to another harvest location or alter their behavior pattern to create a new troll fishery in the vicinity of Homer Spit that would have been unique in this area. Nevertheless, a fishery that has yielded over 15,500 salmon in 1989 has been developed in a highly accessible location that extends from mid-May to October where none previously existed or was believed possible.

## ACKNOWLEDGMENTS

This project was primarily supported by funding provided by the Dingell-Johnson/Wallop-Breaux Federal Aid in Sport Fish Restoration Program, Contract No. F-27-R, R-5. It was recognized by the American League of Anglers and Boaters as the foremost fisheries management project in the Nation in 1990.

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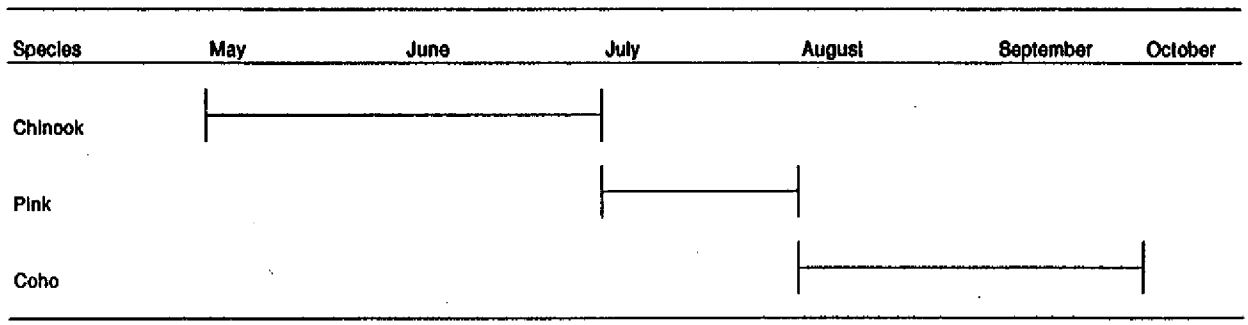
**Table 5. Homer Spit salmon return timing.**

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# Relationships Among Cultured and Naturally Occurring Populations of Freshwater Catfish in the United States

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## ABSTRACT

Commercial production and processing of cultured catfish in the United States was begun in the 1950s in Alabama, and in 1960 the entire industry consisted of only 182 ha of farm ponds and production of 272,727 kg of catfish. In 1992, fish farms, mainly in Mississippi, Alabama, Arkansas, and Louisiana, produced 228,683,500 kg of catfish for processing. Catfish presently accounts for more than half of all U.S. aquaculture yield.

During the period 1960-1992, commercial catch of catfish from natural waters declined from 17,456,363 to 4,931,818 kg. This trend was attributed to consumer concerns about safety of fish products from public waters and increasingly competitive marketing and pricing by the farm-raised catfish industry.

Catfish are mainly produced in ponds; some state and federal agencies stock hatchery-reared fish in public waters. Cultured catfish are sometimes lost during flooding from aquaculture facilities to natural waters, where genetic influences and competitive interactions might impact indigenous populations of catfish. However, these influences and interactions have not been evaluated. More significant influences are those manifested when mature catfish are captured from the wild and added to broodstock populations on farms. Through natural selection and genetic drift, gene frequencies are significantly altered when the wild fish are reproduced and grown in farm ponds under intensive management.

On-farm domestication, with no directed selection, has resulted in performance increases of approximately 5% per generation; directed mass selection has increased body weight by 30% in 3 generations. Crossbreeding between certain strains improved catfish yields by 15% in a single generation; hybridization between species of catfishes improved growth and food conversion by 20% and significantly elevated harvestability by seining and angling.

Genetic engineering efforts through electroporation and microinjection of catfish embryos with genetic material from salmonids have resulted in families of progeny with 40% improvement in growth.

Transgenic fish, projected to be less fit and competitive than individuals in naturally occurring catfish populations, are still secured in U.S. government-approved confinement facilities and will not be released to farms or the wild until several generations of evaluation on inheritance and expression have been completed.

## INTRODUCTION

Commercial production and processing of cultured catfish in the United States was begun in Alabama (Swingle 1959); in 1960 the entire industry consisted of only 182 ha of farm ponds and production of 272,727 kg of catfish (Ivers 1981). In 1992, fish farms, mainly in Mississippi, Alabama, Arkansas and Louisiana, produced 228,683,500 kg of catfish for processing (USDA 1993). Catfish presently accounts for more than half of all U.S. aquaculture yield.

During the period 1960-1992, commercial catch of catfish from natural waters declined from 17,456,363 to 4,931,818 kg (USDC 1993). This trend was attributed to consumer concerns about safety of fish products from public waters and increasingly competitive marketing and pricing by the farm-raised catfish industry.

Catfish are mainly produced in private ponds; some state and federal agencies stock hatchery-reared fish in public waters. Cultured catfish are sometimes lost during flooding from aquaculture facilities to natural waters, where genetic influences and competitive interactions might impact indigenous populations of catfish. However, these influences and interactions have not been evaluated. This paper will review what is known about genetics and performance of domesticated channel catfish, *Ictalurus punctatus*, and discuss possible effects of genetically al-

tered, domesticated catfish on naturally occurring catfish populations.

## ANCESTRY OF DOMESTICATED CHANNEL CATFISH

Catfish have been important commercial and sport fish for many years. The first known spawning of channel catfish in captivity occurred in 1892 (Leary 1908). The Kansas State Fish Hatchery at Pratt began propagating channel catfish as early as 1910. Although channel catfish having ancestry from many river systems are currently propagated (Dunham and Smitherman 1984), the majority of the stock originated near the Denison Dam, Lake Texoma, Oklahoma. These fish were captured in 1949 by the Arkansas Game and Fish Commission in pools formed in the Red River behind Denison Dam after its construction. The fish were spawned in the Arkansas state hatchery system and were the basis of broodstock for some of the earliest catfish farms such as Leon Hill, Edgar Farmer, Anderson-Nelson, and War Eagle Minnow. These fish were also some of the founder stocks in federal hatcheries and research institutions in Alabama, Arkansas, Louisiana, and Mississippi. They were widely distributed in Arkansas and Mississippi via the Hill and Farmer operations. Probably one-half of the Auburn University founder stock and all of the Marion National Fish Hatchery, and Stephens, Inc., founder stock came from Anderson-Nelson or War Eagle Minnow Farm. In turn, Auburn University, Marion National Fish Hatchery, or Stephens, Inc., provided stock for the majority of catfish farms in Alabama. Thus, the ancestry of stocks for the majority of catfish cultured in Alabama, Arkansas, Louisiana, and Mississippi (locations of 95 % of the U.S. pond area devoted to catfish farming) can be traced to a single source of fish: Red River, Denison Dam, Oklahoma.

A number of other stocks have had major impact on the gene pools in Arkansas and Mississippi. Two major fingerling farms in Mississippi, Thompson-Anderson and Transfisheries, have widely distributed fish traced primarily to the Yazoo River and, to a lesser degree, Red River and Kansas. Several farmers have also obtained stock from the Rio Grande River, Texas, or from the Mississippi River, Mississippi. The first catfish farm in Mississippi (V. C. Hammett) used fish captured from the Mississippi River. This influx of "new blood" and the large brood populations used by commercial operations has probably minimized inbreeding in commercial operations.

Another widely distributed stock originated from state and federal fish hatcheries in Kansas, Oklahoma, and Texas. These fish came from many rivers within each state and were exchanged among hatcheries. This stock is common in Kansas, Oklahoma, and Texas and is closely related to Alabama stocks via distribution by Auburn University.

The most widely distributed stock on commercial farms in California is from the Mississippi River, via Osage Fisheries, Missouri. A lesser proportion of stock originated from Kansas.

## DEVELOPMENT OF DOMESTICATED CATFISH

### Strain Evaluation

Acquisition of the best available strains is one of the quickest ways to improve the quality of broodstock. A strain is a breeding population having a similar history and possessing unique characteristics.

Strains of channel catfish originating from different geographic locations within the United States differ in growth rate, and domesticated strains grow faster than wild strains (Smitherman and Pardue 1974, Chappell 1979, Green et al. 1979, Youngblood 1980, Dunham and Smitherman 1981). The domestication process increases growth rate 2 to 6% per generation (Dunham and Smitherman 1983b). Differences exist in growth rate during winter (Dunham and Smitherman 1981) as well as during summer. Variation of length is more pronounced in some strains than others (Brooks 1977). The fast growth of some strains is caused by a combination of increased feed conversion efficiency (Chappell 1979) and increased feed consumption (Al-Ahmad 1983).

Strains also differ in resistance to viral, bacterial (Plumb et al. 1975, Dunham 1981), and parasitic infections (Shrestha 1977). The oldest domestic strain, Kansas, is one of the fastest growing and most disease resistant strains (Dunham and Smitherman 1984). In contrast, the Rio Grande strain is susceptible to several diseases—channel catfish virus disease (Plumb et al. 1975), *Ichthyopthirius*, and *Flexibacter columnaris* (Dunham and Smitherman 1984). This susceptibility has been observed at more than one geographic location (Broussard 1979, Dunham and Smitherman 1984). Variation in total hemoglobin among strains may be correlated to disease resistance (Taylor et al. 1984). No relationship was apparent between hematocrit and disease resistance among strains.

Dressing percentage varies among strains. Differences in body conformation among strains was correlated to differences in dress-out percentage among strains (Dunham et al. 1983).

Seine escapeability varies among strains (Dunham and Smitherman 1984). Some evidence exists that the practice of retaining progenitors from fish remaining in a pond after most of the population has been removed by hook and line or seining results in populations difficult to capture by seine.

Time of spawning is a dramatic example of strain variation. A Minnesota strain from the St. Louis River, a feeder stream of Lake Superior, spawned 10 to 12 days earlier than most strains. The Rio Grande strain from Texas spawned approximately 2 weeks later than most

strains when both were located at College Station, Texas (Broussard and Stickney 1981). A north-south trend in spawning date was apparent. Smitherman et al. (1984) also found that the strain of female was important in determining spawning date and may impede crossbreeding success. Other reproductive characteristics, such as age of maturation, are distinctive. For example, Rio Grande mature a year earlier, at 2 years of age, than most strains. In contrast, Kansas matures a year later, at 4 years of age, than most strains.

### Crossbreeding

Crossbreeding is a breeding program that can produce immediate improvement through heterosis or hybrid vigor. Crossbreeding has improved body weight in channel catfish, but the tested strains had different combining abilities; 55% of the crosses resulted in positive overdominant growth by the $P_1$ (Dunham and Smitherman 1983a). Domestic x domestic crosses were more likely to give positive heterosis (80%) than domestic x wild crosses (33%). Four domestic crosses resulted in positive heterosis, and one resulted in negative heterosis. Domestic x wild crosses were more likely to result in fish with growth rates intermediate to their parent strains, two exhibiting positive heterosis, three intermediate to their parents, and one exhibiting negative heterosis. Nine of eleven crossbreeds grew better than at least one of their parents (Dunham and Smitherman 1983a).

Reciprocal crossbreeds did not grow at the same rate (Dunham and Smitherman 1983a). Males and females of specific strains had different combining abilities with other strains. Crossbreeds from Auburn female channel catfish grew faster than crossbreeds from Auburn male channel catfish. A maternal effect for combining ability was evident. Bondari (1983) also observed this maternal effect for females utilized for crossbreeding that had been bidirectionally selected for body weight.

Crossbreeding can also affect resistance to disease; increased resistance to bacterial (Dunham and Smitherman 1984), viral (Plumb et al. 1975), and parasitic (Shrestha 1977) diseases has been expressed with channel catfish.

Crossbred and pure-strain channel catfish have been compared for spawning date, spawning rate (percent of replicate pairs that spawned), fecundity, egg size and hatchability, and survival of offspring (Dunham et al. 1983). Crossbred fish usually spawned earlier than pure-strain channel catfish. As 3-year-olds, crossbred fish had higher spawning rates and fecundity than purebred fish, and their fingerling output per kilogram of female parent was greater. Fingerling output/kg female is a good measure of reproductive efficiency and equals spawning percentage x fecundity x hatchability x fry survival. As 4-year-olds, pure-strain fish improved their performance, and crossbreeds lost most of their relative advantages (Dunham et al. 1983). As was the case for rate of growth, heterosis decreased with age. Broodstock derived from crosses of four strains spawned earlier than those from two-strain $F_2$ crosses, but their surviving offspring were no more numerous. The main value of cross-strain breeding is to produce channel catfish that mature earlier in life and spawn earlier in the season than purebreds.

### Hybridization

Hybridization between species is another form of crossbreeding. Different species of catfish have been grown, and they exhibit different culture traits. Channel catfish grow the fastest to harvestable size (Chappell 1979) and are the most disease resistant but are difficult to capture by seining. Blue catfish *Ictalurus furcatus* have superior dressing percentage (Chappell 1979), are very seinable (Chappell 1979), are more uniform in length (Brooks et al. 1982b), but are prone to disease. White catfish *Ictalurus catus* tolerate low dissolved oxygen, have the fastest growth during winter (Dunham and Smitherman 1981), but have slower growth to harvest size and poor dressing percentage (Chappell 1979) caused by a large head (Benchaken 1979). Channel catfish and white catfish become sexually dimorphic in size (males larger) at 6 months (Brooks et al. 1982a), but blue catfish exhibit no sexual dimorphism in size until they are older than 3 years (Dunham 1979).

Attempts have been made to take advantage of these specific characteristics and find crosses exhibiting heterotic growth rates through hybridization. Twenty-eight interspecific hybrids have been produced and evaluated for growth rate (Giudice 1966, Dupree and Green 1969, Yant et al. 1976, Dunham and Smitherman 1984). Only one interspecific hybrid, channel catfish female x blue catfish male, has shown increase in body weight of 20 percent above that of channel catfish (Giudice 1966, Yant et al. 1976, Smitherman et al. 1983). The feed conversion efficiency of channel x blue hybrids was also 11 to 14 percent better than channel catfish. The reciprocal, blue x channel, does not exhibit heterotic rates of growth (Dunham and Smitherman 1987). Dupree and Green (1969) indicated that the channel x white hybrid exhibited superior growth in aquarium studies. Chappell (1979) found that compared to channel catfish and the channel x blue, the channel x white hybrid catfish grew slowly to harvestable size in ponds.

Use of the channel x blue hybrid could reduce losses of cultured catfish due to oxygen depletion. This hybrid exhibits heterosis for resistance to critically low oxygen levels (Dunham et al. 1983). When 90 percent of a channel catfish population succumbed due to low dissolved oxygen, only 50 percent of the hybrids died. When 50 percent of a channel catfish population died from low dissolved oxygen, only 10 percent of the hybrids died.

Fishing success in catfish fee-fishing ponds could be improved by stocking the channel catfish x blue catfish hybrid. Fee-fishing ponds are an important part of the catfish industry in the United States (McCoy and Crawford 1975). Fee-fishing ponds provide both a source of income for the pond owner and a source of recreation and protein for the public. Any management program that could improve fishing success would be beneficial to both parties. Reciprocal channel-blue hybrids are more catchable by hook and line than their parent species (Tave et al. 1981). The channel x blue was the most catchable reciprocal. The parent species did not differ. The channel x blue is also much easier to catch by seining (Dunham and Smitherman 1987), as well as by hook and line, compared to channel catfish.

Yant et al. (1976) found that dress-out percentage was higher in the channel x blue hybrid than in channel catfish. The average dress-out percentage for the hybrid catfish was 64.5 and for the channel catfish was 61.2. Again, blue x channel did not exhibit heterosis and had lower dress-out percentage than its reciprocal (Chappell 1979). The higher dress-out percentage of the channel x blue channel hybrid may be related to its deep body conformation and small head. In contrast, the blue x channel, channel x white, and white x blue hybrids have tremendous fat deposits in the viscera (Chappell 1979), and this appears to cause poor dressing percentage in these hybrids. Abnormal sexual development is also associated with these fat deposits (LeGrande et al. 1984).

### Mass Selection

Dunham and Smitherman (1983b) determined the response to selection and realized heritability for body weight of channel catfish, grown in earthen ponds at 7,500 fish/ha. One generation of mass or individual selection for increased body weight has been successful in all channel catfish populations evaluated (Dunham and Smitherman 1983b). Bondari (1983) also obtained significant response to selection in the Tifton strain in tanks by using a combination of crossbreeding, family selection, and mass selection. The largest 10 percent of each population was selected in these experiments.

Responses to selection of 63, 73, and 54 g (17, 18, and 12% increase in body weight) were obtained (Dunham and Smitherman 1983b) from Rio Grande, Marion, and Kansas strains, respectively, for the fish grown in ponds. Generally, the fish with shorter periods of domestication had greater response. Realized heritability for Marion, $0.50 \pm 0.13$, was higher than that for Rio Grande, $0.24 \pm 0.06$. Kansas, $0.33 \pm 0.10$, did not differ from Rio Grande or Marion. Responses for male and female body weights were the same in Marion, but responses by Kansas males was higher than for Kansas females. There were no significant differences in realized heritabilities for male and female body weights.

Selection for body weight for three generations has further improved growth of channel catfish (Rezk 1993). Three generations of selection resulted in selected lines of Kansas and Marion strains growing 30 and 20 percent faster, respectively, than controls.

Mass selection improved body weight (7 to 10% per generation) in channel catfish more rapidly than the domestication process. Domesticated strains grow faster than wild strains (Smitherman and Green 1973, Burnside et al. 1975, Broussard 1979, Chappell 1979, Green et al. 1979, Dunham and Smitherman 1981). The average increased growth performance of hatchery fish (five strains) over wild fish (six strains) is 3 percent per generation (Smitherman and Green 1973, Smitherman and Pardue 1974, Burnside et al. 1975, Broussard 1979, Chappell 1979, Green et al. 1979). Assuming slow turnover of brood and long generation intervals, 6 percent improvement per generation has occurred. Mass selection for three generations improved growth rate two to three times faster than that which had occurred during 3 to 15 generations of domestication (undirected selection).

### Genetic Engineering

Human and salmonid growth hormone genes have been transferred to channel catfish (Dunham et al. 1987, 1992). One to nine copies of the foreign DNA were inserted in either head-to-tail tandem array at single insertion sites or single copies at multiple insertion sites. All $F_1$ transgenic catfish evaluated produced salmonid growth hormone regardless of the construct. The spawning rate and fertility of these $P_1$ transgenics in artificial spawning conditions was comparable to that of normal channel catfish. In 2 of 3 years, 100 percent spawning and 100 percent hatch were obtained. Percent transgenic progeny observed in the five matings were 20, 52, 7, 47, and 0, which was lower than the 75 percent inheritance expected assuming the $F_1$ broodstock had at least one copy of the foreign gene integrated and were not mosaics in the germ-line. At least 7 of 10 $F_1$ were mosaics, and a minimum of 2 of 10 $F_1$ did not possess the salmonid growth hormone gene in their germ-line. $F_1$ transgenics grew at the same rate as their non-transgenic full-siblings, which was not surprising since the $F_1$ were mosaics. $F_1$ transgenic progeny in two families grew 26 percent faster to 40-50 g than their non-transgenic full-siblings when evaluated communally. $F_1$ progeny groups grew at the same rate as normal full-siblings when grown communally to 25 g. In families where $F_1$ progeny grew faster than controls, the range in body weight and coefficient of variation for the transgenic full-siblings was less than that for controls. In families where $F_1$ progeny grew at the same rate as controls, range in body weight and coefficient of variation were similar for transgenic and normal individuals. The percent deformities observed in $P_1$ transgenics, 13.6 percent, was higher

than in microinjected $P_1$ non-transgenics, 5.1 percent. Percent deformities in transgenic and control $F_1$ channel catfish was not different, 0.5 and 2.8, respectively.

Results obtained for $F_1$ transgenic common carp (Zhang et al. 1990) and channel catfish containing salmonid trout growth hormone gene were similar. The presence or absence of increased growth can vary among families and may be related to family effects, genetic background, epistasis, or dosage effects of the foreign growth gene expression. Apparently, a combination of both family selection as well as gene transfer is needed to optimize increased growth from the insertion of salmonid growth hormone genes.

## COMPARISON OF DOMESTICATED AND WILD POPULATIONS OF CATFISH

Domesticated catfish grow faster than wild catfish when cultured in ponds; production differences can be as great as 250 percent. Domestication has resulted in an average growth increase of 3 to 6 percent per generation. Survival of domestic and wild strains is similar in the aquaculture environment.

A large number of polymorphic enzyme loci have been observed for channel catfish (Hallerman et al. 1986, Hallerman 1984, Dunham and Smitherman 1984). Percentage of loci polymorphic, number of alleles/locus, and mean heterozygosity varied considerably among these domesticated populations but was less than that for the only wild population examined. Carmichael et al. (1992) observed similar results in the only other study of channel catfish isozyme variation; however, their sole wild population was non-variable. This illustrates the need to study the genetics of wild populations and their interactions with domestic populations thoroughly.

## POSSIBLE EFFECTS OF CULTURED CATFISH ON NATURALLY OCCURRING POPULATIONS OF CATFISH

### Effect of Domestication on Genetic Variability

Fish culture in the United States and the world is increasing rapidly. When salmonids are removed from the natural environment and placed in the culture environment, random genetic drift and domestication effects (new and greatly different selective forces act upon fish in the domestic environment compared to the natural environment) alter gene frequencies and reduce genetic variation as measured by isozyme analysis (Allendorf and Phelps 1980, Hallerman et al. 1986, Khana et al. 1975, Koljonen 1989, Ryman and Stahl 1980, Stahl 1983). Then the domesticated populations with reduced genetic variability are propagated in large numbers, sometimes reaching population numbers much greater than that found in natural populations. Purposeful or accidental (such as flooding or escape during harvest) introduction of the domestic fish may then allow mixing of the domestic and natural populations resulting in either greater or less variability depending on the competitiveness, survival, and reproduction of the introduced and natural populations.

### Competition Between Domestic and Wild Fish

Initial studies indicate that wild fish generally outcompete domestic strains of fish in the natural environment. Almost all of these observations were on salmonids (Maclean et al. 1981; Buettner 1962; Flick and Webster 1962; Fraser 1974, 1981; Gordon and Nicola 1970; Flick and Webster 1964, 1976), and coldwater fish and were localized experiments or observations. Larger scale examples with more species, including warmwater species such as channel catfish, are needed to determine the interactions between wild and domestic fish and if wild catfish generally outcompete domestic catfish in the natural environment as seen with salmonids.

### Reproductively Isolated Sympatric Populations

Another possible interaction between domestic and wild populations of fish is the establishment of sympatric, but reproductively isolated, populations. Although strains of fish usually do not have reproductive isolating mechanisms preventing them from interbreeding, occasionally behavioral mating blocks prevent or decrease the rate of inter-strain matings. We have found that Marion channel catfish females preferentially mated with their own strain rather than Kansas males (Smitherman et al. 1984), and Ghana strain of *Oreochromis niloticus* was more likely to mate with its own strain than other strains (Smitherman et al. 1988). The existence of reproductively isolated, sympatric populations of trout (Lerder et al. 1984, Brown et al. 1981, Ryman and Stahl 1981), especially brown trout, *Salmo trutta*, is well-documented. Some strains of domestic and wild rainbow trout are sympatric but reproductively isolated or near to reproductive isolation. This occurs because of behavioral differences, including temporal or spatial differences in spawning (Smitherman et al. 1988).

The relationships studied for domesticated and wild populations of salmonids have not been evaluated for catfish. Survival, growth, behavior, and reproductive success of genetically altered populations must be studied to assess the fitness of cultured catfish in the natural environment.

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# A Genetic Comparison Among Three Groups (Wild Populations, Artificial Seed Populations, and Mixed Populations) of a Sea Urchin *Pseudocentrotus depressus*: A Preliminary Report

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## ABSTRACT

Genetic characteristics of the sea urchin *Pseudocentrotus depressus* were compared by allozyme analysis for six wild populations: three artificial seed populations (artificial populations), and three mixed populations from the sites where artificial seeds were stocked.

Of 25 enzymes analyzed by horizontal starch gel electrophoresis, 9 genetic loci were detected in 7 enzymes (LDH, MDH, IDHP, PGDH, HK, GPI, and PGM). In the 6 wild populations, mean proportion of polymorphic loci and heterozygosity were 0.612 and 0.164, respectively. The divergence points in the dendrogram of Nei's genetic distance ($D$) of 6 populations did not exceed 0.004. The fixation index ($F_{ST}$) was 0.014. These two facts suggest that wild populations were genetically homogeneous.

In the three artificial populations, one showed a remarkable decrease in the proportion of polymorphic loci and heterozygosity. The divergence points in the dendrogram of $D$ of the 3 populations ranged from 0.006 to 0.021. $F_{ST}$ value among them was 0.118. This suggests that artificial populations were genetically different from each other, and that artificial populations and wild populations were genetically heterogeneous.

Two of three mixed populations were genetically similar to wild populations. However, in one of the populations, the proportion of polymorphic loci and heterozygosity decreased, and the divergence point in the dendrogram of $D$ was 0.011, suggesting that this population was genetically affected by released artificial seed.

## INTRODUCTION

*Pseudocentrotus depressus* is an endemic species of sea urchin found in subtropical Far-Eastern waters, southern Japan, and the south coast of Korea, inhabiting the upper infralittoral zone on rocky shores. The species has been an important target of commercial divers. In southern Japan, mostly along the northwest coast of Kyushu, large numbers of artificially produced seed of *P. depressus* were released in the last 10 years in response to demands of fishermen to enhance the wild stocks.

However, there is a concern from the point of view of population genetics. The artificial seeds are genetically distinct from the wild population as a result of genetic drift which occurred because seeds were produced from a limited number of parents. Release of those genetically different seeds to the sea could affect the genetic structure or composition of the wild population. Release of seeds might cause a decline in genetic variability of the wild population. The greater the use of enhancement, the greater the concern that the genetic variability of the wild populations is adversely affected. These efforts may be greater for animals that have limited mobility, such as sea urchins.

## MATERIALS AND METHODS

### Sea Urchin Collection

Twelve samples of *Pseudocentrotus depressus* were collected for the study: 11 from southern Japan and one from Cheju Island, southern Korea. Six are wild populations (W1-W6; Fig. 1 and Table 1) collected by professional divers from the sites where artificial seeds of the species have never been released, except for W3 described below. Three are artificial seeds (A1-A3;

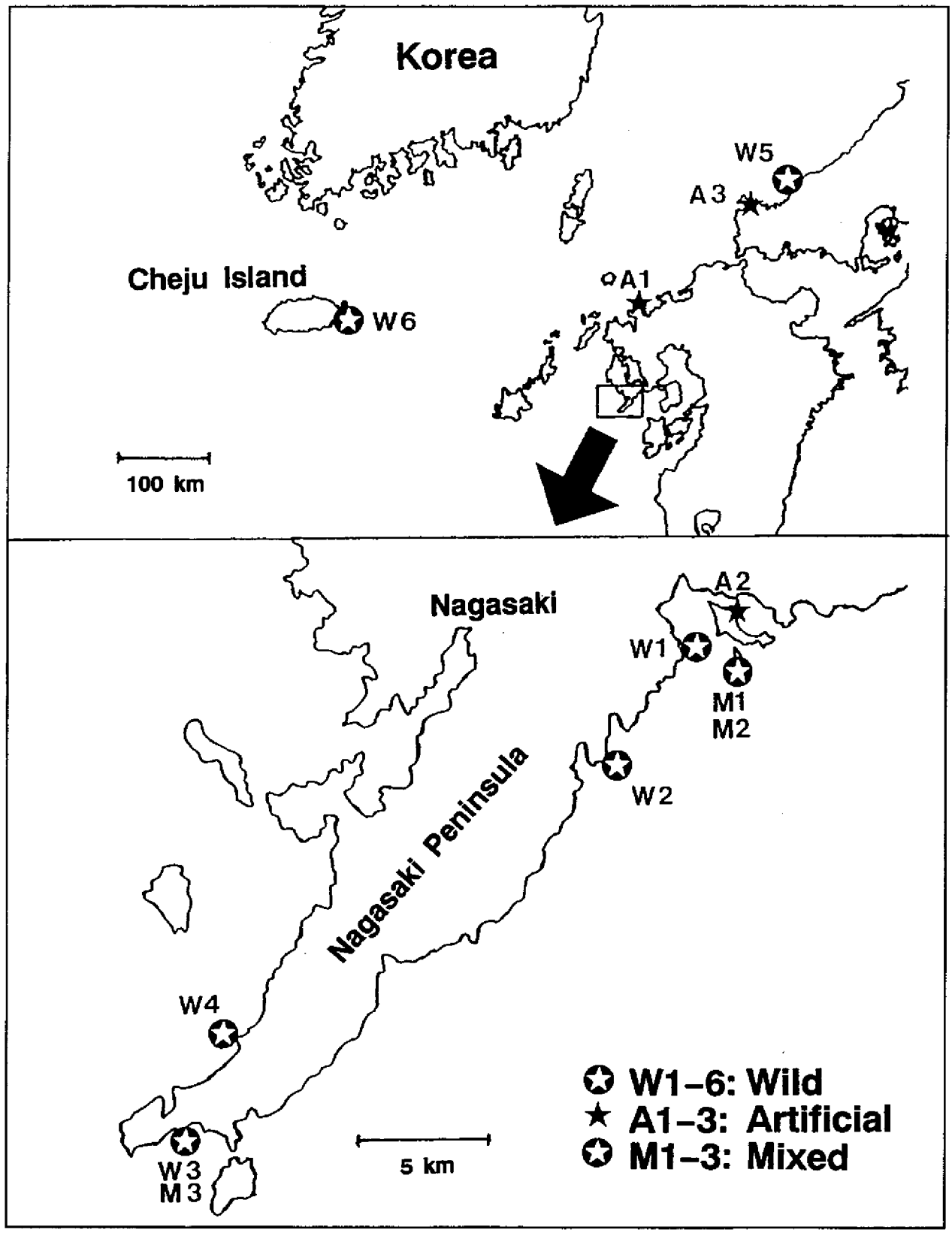


*Figure 1. Maps of localities of collection (or institution where animals were produced) for the sea urchin Pseudocentrotus depressus used in the study. Lower panel shows expanded map of collection sites near Nagasaki. Abbreviations of populations correspond with those in Table 1.*

**Table 1. Collection information and size for the 12 populations of *Pseudocentrotus depressus* used in the study. (Abbreviations of populations correspond with those in Fig. 1.)**

| Population | | Date Sampled | Sample Size | Shell Diameter* (mm) | Locality |
|---|---|---|---|---|---|
| (Wild populations) | | | | | |
| 1. | W1 | Sept. 21–23, '91<br>Nov. 4–6, '91 | 70 | 50 ± 6<br>(41–68) | Aba, Nagasaki City<br>(Nagasaki Pref.) |
| 2. | W2 | Nov. 4–6, '91 | 70 | 51 ± 5<br>(40–67) | Mogi, Nagasaki City<br>(Nagasaki Pref.) |
| 3. | W3 | May 2, '92 | 52 | 51 ± 5<br>(35–60) | Nomo, Nomozaki<br>(Nagasaki Pref.) |
| 4. | W4 | May 3, '92 | 65 | 44 ± 8<br>(22–61) | Takahama, Nomozaki<br>(Nagasaki Pref.) |
| 5. | W5 | June 23, '92 | 121 | 58 ± 7<br>(34–72) | Uta, Abu<br>(Yamaguchi Pref.) |
| 6. | W6 | Aug. 21, '92 | 111 | 59 ± 10<br>(35–85) | Onpyong, Seongsan,<br>Cheju I. (Korea) |
| (Artificial populations) | | | | | |
| 7. | A1 | Aug. 9, '89 | 109 | 47 ± 4<br>(36–58) | Saga Pref. Sea Farming<br>Center, Karatsu |
| 8. | A2 | Oct. 21, '91<br>Oct. 28, '91 | 100 | 22 ± 3<br>(18–30) | Nagasaki City<br>Fisheries Center |
| 9. | A3 | July 5, '92 | 129 | 34 ± 4<br>(22–42) | Yamaguchi Pref.<br>Fish. Exp. Station |
| (Mixture populations) | | | | | |
| 10. | M1 | Sept. 21–23, '91 | 67 | 53 ± 6<br>(40–72) | Toishi, Nagasaki City<br>(Nagasaki Pref.) |
| 11. | M2 | Aug. 3–5, '92 | 66 | 52 ± 6<br>(40–63) | Toishi, Nagasaki City<br>(Nagasaki Pref.) |
| 12. | M3 | May 2, '92 | 68 | 31 ± 4<br>(19–40) | Nomo, Nomozaki<br>(Nagasaki Pref.) |

* Mean ± standard deviation; ranges are in parentheses.

Fig. 1 and Table 1) reared entirely in marine farming institutions until release. The last three are mixed populations of wild ones and non-wild ones originated from the released artificial seeds (M1-M3; Fig. 1 and Table 1) collected by the professional divers from the sites where artificial seeds had been released in recent years.

At the site where the mixed populations M1 and M2 were collected, artificial seeds were frequently released during the last 10 years. At the site where the mixed population M3 was collected, artificial seeds that were spawned in autumn 1990 were released only once in the early summer of 1991. Population M3 contains adults from seeds released in 1991, judging from their size and age. One of the wild population, W3, was collected from the same site where M3 was collected, but it did not contain artificial seeds released in 1991 because they were considerably larger than individuals grown from artificial seeds released in 1991.

Live animals were transported to Nagasaki University in insulated containers containing wet seaweed or newspapers with ice cubes or freeze packs. All the sea urchins were dissected within several days after arrival at the laboratory, while they were still alive. Dissected gonad and oesophagus were stored at -40 or -85°C until further analysis. The shell top of all the specimens, including the genital plates, were dried and preserved for age determination.

Enzyme nomenclature and enzyme commission numbers assigned followed the recommendations of the International Union of Biochemistry (1984). Abbreviations of enzyme and locus and allele symbols followed Shaklee et al. (1990).

### Electrophoretic Procedures

Electrophoresis was carried out using standard horizontal starch gel system (Hoelzel 1992). Thawed drips of the two tissues, gonad and oesophagus, were used as crude extracts of enzymes (Numachi 1971). Filter paper wicks saturated with the extracts were inserted in the cut portion of the gel. Eight buffer systems (pH 6.0-9.2) were used. Two of those 8 buffer systems, C-A pH 7.0 (modified from Clayton and Tretiak 1972) and T-C pH 8.0 (modified from Siciliano and Shaw 1976), were used through the study.

Twenty-five enzymes were examined in extracts of gonad and intestine. Enzyme staining procedures followed those of Siciliano and Shaw (1976) for ADH (EC: 1.1.1.1), G3PDH (1.1.1.8), LDH (1.1.1.27), GLYDH (1.1.1.29), MDH (1.1.1.37), MEP (1.1.1.40), IDHP (1.1.1.42), PGDH (1.1.1.44), G6PD (1.1.1.49), SOD (1.15.1.1), AK (2.7.4.3), ACP (3.1.3.2), TPI (5.3.1.1), MPI (5.3.1.8), GPI (5.3.1.9), PGM (5.1.2.2); those of Shaw and Prasad (1970) for IDDH (1.1.1.14), XDH (1.2.1.37), CAT (1.11.1.6), HK (2.7.1.1), EST (3.1.1.*), ALP (3.1.3.1); those of Ayala et al. (1972) for ODH (1.1.1.73); those of Christfferson et al. (1978) for AAT (2.6.1.1); and those of Kayano (1978) for LAP (3.4.11.1).

### Statistical Analysis

Significance of departure from Hardy-Weinberg proportions was tested using the AIC (Akaike Information Criterion, Akaike 1973) value of observed and expected allelic frequency at each locus in each population sample.

Proportions of polymorphic loci ($P_{0.95}$; frequency of the most common allele <0.95), number of alleles per locus ($A$), and mean heterozygosity; both the observed ($H_O$) and the expected ($H_E$) were calculated for each population.

The amount of genetic divergence among populations was calculated by the genetic variance statistics $F_{ST}$ (Wright 1965) at each locus for the three groups: wild, artificial, and mixed populations. In addition, a mean $F_{ST}$ for all loci was obtained for each group.

Nei's genetic distance ($D$) was calculated between all pairs of 12 populations (Nei 1972). A dendrogram based on the genetic distance was constructed using the unweighted pair-group arithmetic average (UPGMA) clustering (Sneath and Sokal 1973).

## RESULTS

### Enzyme Activity and Zymogram Interpretation

Ten enzymes (G3PDH, IDDH, GLYDH, MEP, XDH, AAT, AK, ALP, ACP, and TPI) did not show any activity in any of the eight buffer systems. Eight enzymes (ADH, G6PD, ODH, CAT, SOD, EST, LAP, and MPI) showed some activity, but resolution of zymograms was not improved by any buffer systems or activities were not stable and could not be resolved for all individuals. Seven enzymes (LDH, MDH, IDHP, PGDH, HK, GPI, and PGM) showed both stable activity and good resolution of zymograms.

Polymerization structure, detected locus, and number of alleles at each locus were interpreted as follows: LDH: monomorphic, one locus *LDH**; MDH: polymorphic, dimer, two loci *MDH-1** and *MDH-2**, each two alleles; IDHP: polymorphic, dimer, one locus *IDHP**, three alleles; PGDH: polymorphic, dimer, one locus *PGDH**, three alleles; HK: polymorphic, monomer, one locus *HK**, three alleles; GPI: polymorphic, dimer, one locus *GPI**, five alleles; PGM: polymorphic, monomer, two loci *PGM-1** and *PGM-2**, each three alleles.

### Genetic Variability

Allelic frequencies and genetic variability ($P_{0.95}$, $A$, $H_O$, and $H_E$) for 12 populations of *Pseudocentrotus depressus* are shown in Table 2.

**Table 2. Allelic frequencies, proportion of polymorphic loci ($P_{0.95}$), number of alleles per locus (A) and heterozygosity; observed ($H_O$) and expected ($H_E$) for 12 sample populations of *Pseudocentrotus depressus*. Number of individuals scored in parentheses. (Abbreviations of population correspond with those in Table 1 and Fig. 1.)**

| | | Wild Populations | | | | | | Artificial Populations | | | Mixed Populations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Locus | Allele | W1 (70) | W2 (70) | W3 (52) | W4 (65) | W5 (121) | W6 (111) | A1 (109) | A2 (100) | A3 (129) | M1 (67) | M2 (66) | M3 (68) |
| *LDH** | *a | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| *MDH-1** | *a | .735 | .795 | .819 | .783 | .767 | .724 | .940 | .447 | .855 | .813 | .770 | .742 |
| | *b | .265 | .205 | .181 | .217 | .233 | .276 | .060 | .553 | .145 | .187 | .230 | .258 |
| *MDH-2** | *a | .993 | 1 | .981 | 1 | .979 | .990 | 1 | 1 | .984 | 1 | .977 | 1 |
| | *b | .007 | 0 | .019 | 0 | .021 | .010 | 0 | 0 | .016 | 0 | .023 | 0 |
| *IDHP** | *a | .074 | .094 | .098 | .095 | .229 | .134 | .018 | .150 | .191 | .075 | .073 | .238 |
| | *b | .926 | .891 | .902 | .905 | .771 | .866 | .982 | .840 | .809 | .925 | .919 | .762 |
| | *c | 0 | .015 | 0 | 0 | 0 | 0 | 0 | .010 | 0 | 0 | .008 | 0 |
| *PGDH** | *a | .120 | .172 | .202 | .082 | .131 | .129 | 0 | .041 | .280 | .142 | .105 | 0 |
| | *b | .873 | .820 | .798 | .918 | .869 | .871 | 1 | .938 | .720 | .858 | .895 | 1 |
| | *c | .007 | .008 | 0 | 0 | 0 | 0 | 0 | .021 | 0 | 0 | 0 | 0 |
| *HK** | *a | 0 | .060 | 0 | 0 | .004 | .005 | .023 | .006 | .031 | .008 | 0 | 0 |
| | *b | .993 | .940 | 1 | 1 | .996 | .995 | .977 | .994 | .969 | .992 | 1 | 1 |
| | *c | .007 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *GPI** | *a | .015 | 0 | .020 | .008 | .013 | .015 | 0 | 0 | .018 | .015 | .025 | 0 |
| | *b | .119 | .149 | .216 | .158 | .178 | .204 | .010 | .111 | .100 | .164 | .221 | .008 |
| | *c | .858 | .843 | .755 | .817 | .797 | .771 | .990 | .889 | .837 | .806 | .738 | .992 |
| | *d | 0 | 0 | 0 | .017 | .004 | .005 | 0 | 0 | .009 | 0 | .016 | 0 |
| | *e | .008 | .008 | .009 | 0 | .008 | .005 | 0 | 0 | .036 | .015 | 0 | 0 |
| *PGM-1** | *a | 0 | .055 | 0 | 0 | .009 | .042 | 0 | .105 | 0 | .023 | .010 | 0 |
| | *b | .908 | .852 | .913 | .877 | .903 | .875 | .986 | .883 | .888 | .901 | .912 | .856 |
| | *c | .092 | .093 | .087 | .123 | .088 | .083 | .014 | .012 | .112 | .076 | .078 | .144 |
| *PGM-2** | *a | .046 | .116 | .011 | .008 | 0 | .027 | .108 | .021 | .010 | .037 | .022 | 0 |
| | *b | .886 | .830 | .978 | .984 | .991 | .957 | .892 | .963 | .975 | .940 | .924 | 1 |
| | *c | .068 | .054 | .011 | .008 | .009 | .016 | 0 | .016 | .015 | .023 | .054 | 0 |
| $P_{0.95}$ | | .667 | .778 | .556 | .556 | .556 | .556 | .222 | .556 | .556 | .667 | .667 | .333 |
| $A$ | | 2.33 | 2.33 | 2.11 | 2.00 | 2.33 | 2.33 | 1.66 | 2.22 | 2.33 | 2.22 | 2.33 | 1.44 |
| $H_O$ | | .168 | .206 | .147 | .138 | .159 | .169 | .047 | .153 | .158 | .141 | .156 | .135 |
| $H_E$ | | .156 | .191 | .157 | .139 | .163 | .173 | .048 | .152 | .170 | .148 | .159 | .110 |
| $H_O/H_E$ | | 1.08 | 1.08 | .941 | .997 | .971 | .974 | .990 | 1.01 | .928 | .953 | .979 | 1.22 |

$P_{0.95}$: Proportion of polymorphic loci ($P$<0.95)
$A$: Number of alleles per locus
$H_O$: Mean heterozygosities per locus (observed)
$H_E$: Mean heterozygosities per locus (expected)

**Table 3. Fixation index ($F_{ST}$) for eight polymorphic loci in three groups of *Pseudocentrotus depressus*.**

| Locus | Wild (6 popu.) | Artificial (3 popu.) | Mixed (3 popu.) |
|---|---|---|---|
| *MDH-1** | 0.0062 | 0.2450** | 0.0049 |
| *MDH-2** | 0.0070 | 0.0107 | 0.0152 |
| *IDHP** | 0.0243 | 0.0512* | 0.0512* |
| *PGDH** | 0.0124 | 0.1461* | 0.0478 |
| *HK** | 0.0368 | 0.0057 | 0.0055 |
| *GPI** | 0.0079 | 0.0380 | 0.0744* |
| *PGM-1** | 0.0056 | 0.0452 | 0.0085 |
| *PGM-2** | 0.0475 | 0.0308 | 0.0206 |
| Mean | 0.0139 | 0.1178* | 0.0339 |

* $0.15 < F_{ST}$ 0.25: ≤ intensive genetic differentiation

** $0.15 < F_{ST}$ 0.15: ≤ moderate genetic differentiation

Artificial population 1 (A1) and mixed population 3 (M3) had discernibly less genetic variation; and $P_{0.95}$ was 0.222 and 0.333, respectively. In contrast, values of the other 10 populations were 0.5-0.7. In addition, the number of alleles per locus of these two populations was less than 2 for both populations.

In all populations except W2 and A1, observed heterozygosities ($H_O$) were similar and were from 0.135 to 0.169. In the remaining two, W2 and A1, $H_O$ was 0.047 and 0.206, respectively. Mean $H_O$ of the 12 populations was 0.1480 (SD, 0.0340). The mean value of $H_O/H_E$ was 1.0105 (SD, 0.0815).

$F_{ST}$ for the three groups, wild (six populations, W1-W6), artificial (three populations, A1-A3), and mixed (three, M1-M3) are shown in Table 3. In 6 wild populations, the $F_{ST}$ of each locus ranged from 0.0056 to 0.0475 and the mean was 0.0139. Those in artificial group were 0.1178 (mean), 0.0107 (min.), and 0.2450 (max.). In the mixed group, they were 0.0339 (mean), 0.0049 (min.) and 0.0744 (max.). The means were largest in the artificial and smallest in the wild populations.

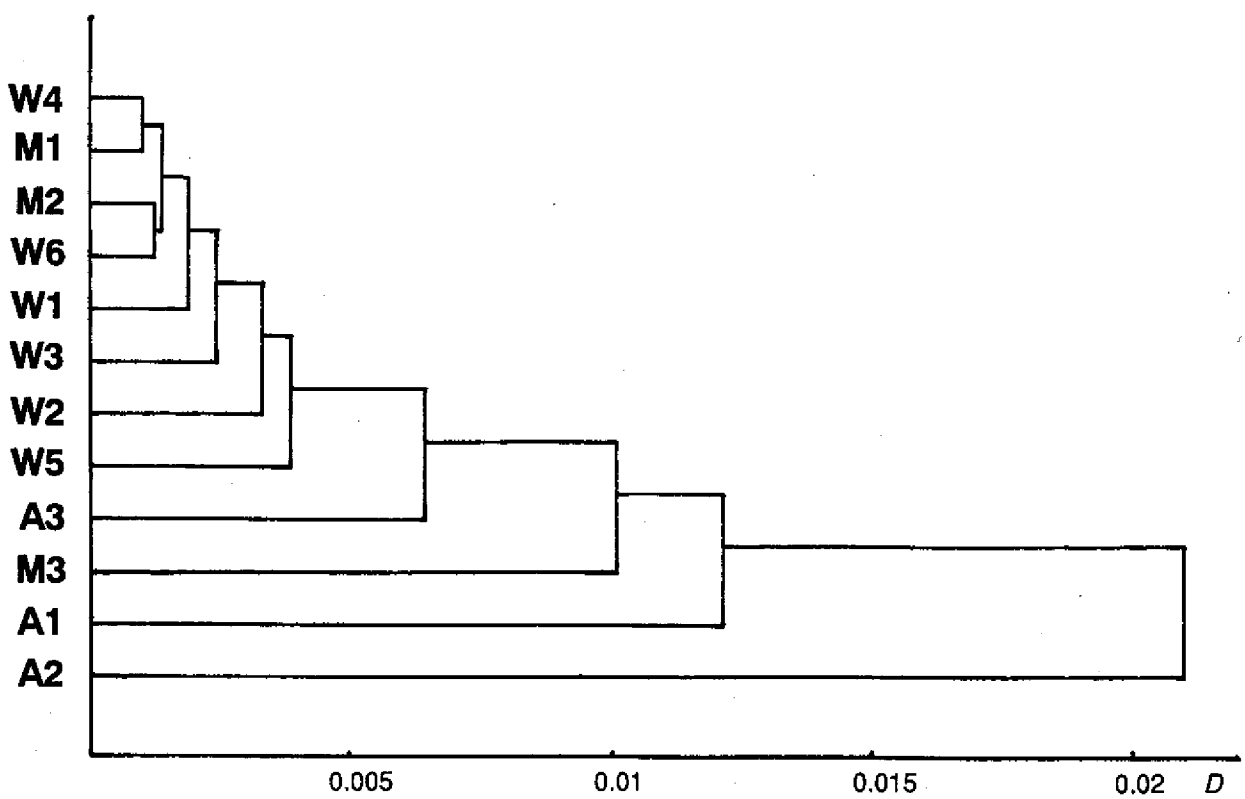


*Figure 2. UPGMA dendrogram derived from genetic distance (Nei 1972) among 12 populations of Pseudocentrotus depressus. Abbreviations of population correspond with those in Tables 1, 2, and 4, and Fig. 1.*

**Table 4. Genetic distance (D; Nei 1972) between pairs of 12 populations of *Pseudocentroutus depressus*. (Abbreviations of population correspond with those in Tables 1 and 2, and Fig. 1.)**

| | Wild | | | | | | Artificial | | | Mixed | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | W1 | W2 | W3 | W4 | W5 | W6 | A1 | A2 | A3 | M1 | M2 |
| W2 | .002219 | | | | | | | | | | |
| W3 | .004053 | .004146 | | | | | | | | | |
| W4 | .001827 | .003914 | .002679 | | | | | | | | |
| W5 | .004950 | .006321 | .003550 | .002769 | | | | | | | |
| W6 | .002182 | .003872 | .002374 | .001299 | .001816 | | | | | | |
| A1 | .008939 | .008965 | .013863 | .009332 | .015640 | .014593 | | | | | |
| A2 | .014407 | .021878 | .025086 | .017454 | .017258 | .013196 | .035120 | | | | |
| A3 | .008082 | .006054 | .003684 | .007322 | .004986 | .007279 | .016436 | .031459 | | | |
| M1 | .001561 | .001928 | .001139 | .001070 | .003742 | .001742 | .008220 | .021118 | .005153 | | |
| M2 | .002088 | .003963 | .002031 | .001375 | .004042 | .001243 | .011756 | .018654 | .009095 | .001155 | |
| M3 | .008721 | .012339 | .015225 | .007072 | .006568 | .009262 | .013592 | .015638 | .014132 | .012842 | .011096 |

### Genetic Distance and Dendrogram

Nei's genetic distance ($D$), calculated between all pairs of 12 populations, are shown in Table 4. A dendrogram based on genetic distance using the unweighted pair-group method of analysis (UPGMA, Sneath and Sokal 1973) is shown in Figure 2.

None of the values of diverging points for the six wild populations, W1 to W6, exceeded 0.004. Judging from Figure 2, two of the three mixed population (M1 and M2) were genetically similar to the wild ones. However, the diverging point of M3 population was fairly large. In contrast, those values for the three artificial populations, A1 to A3, were all large. Among the three, A2 is remarkably different from the others. Genetic distance of the diverging point between A2 and the other 11 populations all exceeded 0.02 (Fig. 2).

## DISCUSSION

Mean $H$ for the 6 wild populations used in this study were fairly high: 0.165 for $H_O$ (range: 0.138-0.206; SD: 0.024) and 0.163 for $H_E$ (0.139-0.191; 0.018) in comparison to reported values for other species of the class Echinoidea. A range of mean values of 0-0.05 (mean: 0.02) has been reported for the four species, *Toxopneustes pileolus*, *Tripneustes gratilla*, *Pseudoboletia maculata*, and *Pseudocentrotus depressus* (Matsuoka 1985); 0-0.055 (mean: 0.033) for the two species, *Echinostrephus aciculatus* and *E. molaris* (Matsuoka and Suzuki 1987); 0.031-0.043 (mean: 0.035) for *Diadema setosum* (Matsuoka 1989); 0.035 for *Diadema savignyi* (Matsuoka 1989); 0.027-0.056 (mean: 0.0415) for *Echinothrix calamaris* (Matsuoka 1989); 0.035 for *Echinothrix diadema* (Matsuoka 1989); 0.028-0.088 (mean: 0.0632) for *Anthocidaris crassispina* (Matsuoka and Suzuki 1989); 0.072 for *Glyptocidaris crenularis* (Matsuoka and Nakamura 1990); 0.0126-0.0127 (Watts et al. 1990) and 0.055-0.07 (mean: 0.0653) for *Echinometra mathaei* (Matsuoka and Hatanaka 1991); 0.032-0.038 (mean: 0.035) for *Stomopneustes variolaris* (Matsuoka and Nakamura 1991). This difference might be caused by an insufficient number of loci evaluated in the present study. More than 15 loci were used in the reported studies.

As shown by the low $F_{ST}$ value (0.0139) for the 6 wild populations and their dendrogram (Fig. 2), the gene pool of wild populations of *Pseudocentrotus depressus* is geographically homogeneous, in spite of their benthic behavior and poor mobility after settlement. However, this homogeneity may be attributable to the fairly long planktonic larval stages that occur before settlement. Therefore, it was not unexpected that the $F_{ST}$ value was highest in the artificial and lowest in the wild population.

The dendrogram resulting from this study (Fig. 2) suggests certain relationships among the three mixture populations. Unexpectedly, two of the three mixed populations, M1 and M2, were genetically similar to the wild ones, while the diverging point of the M3 was

fairly large and isolated from populations M1, M2, and W1-W6. The populations W3 and M3 were collected from the same site but differ from each other in size as shown in Table 1. According to the age determination as derived from the annual ring appeared in the genital plates (Chung and Natsukari, unpublished), all individuals of M3 were 2 years old or less, and all of W3 were more than 3 years old. A year prior to the collection of M3, 1-year-old seeds that were fertilized in 1990 and whose origin was the same as artificial population A2 were released at the site. No other seed release was made except this release in 1991. Thus, W3 does not include released artificial seed, and all collected were wild individuals. The population M3 should be a mixture of wild and artifically reared urchins. Considering the above facts, M3 was probably influenced genetically by the released seed that had the same origin as artificial seed A2.

Contrary to our expectations, the two mixed populations M1 and M2 were not genetically different from the six wild populations. Artificial seeds were frequently released extending over a 10-year period at the site where the two were collected. The failure of M1 and M2 populations to be distinct from wild populations is attributable to the cumulataive effects of multiple seed releases.

## ACKNOWLEDGMENTS

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# Shellfish Aquaculture in Alaska and the Potential of Interaction with Wild Species

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## ABSTRACT

In 1989, Alaska Senate Bill 514 revitalized the shellfish culture industry. As a result of the legislation, regulation changes were made that streamlined permit processing and added more security for use of state tidelands for aquaculture. The stabilizing effect of the new regulations has increased the number of aquatic farms from a handful in the mid-1980s to 72 at the end of 1992.

The majority of Alaska aquatic farmers culture Pacific oysters *Crassostrea gigas* because spat are available, and the oysters grow very well on the abundant high quality phytoplankton. Cold, clean water retards sexual maturation which results in high quality half-shell oysters being marketable during the summer when oysters from other United States farms are in reproductive condition and unsuitable for consumption. Small quantities of blue mussels and scallops are cultured because spat are available from natural reproducing populations. Littleneck clams, urchins, and abalone are potential candidates for farming, but spat are not available and growth of these species is slow at northerly latitudes. Giant kelp, *Macrocystis integrifolia*, culture was investigated, but further research and development are needed. Young sporophytes are not available to stock the farms.

Alaska has strict shellfish transportation regulations to control interaction between cultured and wild species of shellfish and to prevent spread of diseases. As an example, import restrictions allow only spat of the Pacific oyster into the state. Oyster spat must also be less than 20 mm shell height to prevent importation of the parasite *Mytilicola orientalis*. Alaska's shellfish culture industry is severely hampered by the absence of a shellfish hatchery in the state. In addition to import restrictions, detailed review of shellfish transport and aquatic farm permit applications are major components of Alaska's shellfish transportation regulations. These strict regulations are a source of controversy between the shellfish culture industry and the Alaska Department of Fish and Game. Due in part to the conflict, the Alaska Department of Fish and Game is currently modifying the existing regulations. A shellfish transport policy based on larval drift patterns is proposed.

## INTRODUCTION

Alaska's shellfish aquaculture industry has a relatively long history beginning in 1910 with introduction of the Pacific oyster *Crassostrea gigas*. The oysters were planted on beaches from Ketchikan to Homer, Alaska, but they grew best in southeastern Alaska where meat production reached a peak of 550 gallons in 1943 (Yancey 1966). The industry ended production in 1961.

Shellfish culture started again in the late 1970s with the reintroduction of Pacific oyster spat into southeast Alaska. This time the renewed industry cultured oysters for raw consumption in the half-shell market. Restrained primarily by lack of capital and restrictive tidelands permit regulations, the industry was confined to a few farms in southeastern Alaska near the community of Wrangell.

In 1989, passage of Alaska Senate Bill 514 revitalized the shellfish culture industry. New regulations streamlined permit processing, agency coordination vastly improved, and changes in tidelands permit regulations added more stability to the industry. Improvements in permit processing increased the number of applications. By the end of 1992, 72 aquatic farms using 196 acres of tidelands were permitted to culture seaweed, clam, scallop, blue mussel, abalone, and sea urchin (Table 1).

The new industry is now more dispersed with aquatic farms located in five primary areas: Kodiak Island, Kenai Peninsula, Prince William Sound, Yakutat, and south-

**Table 1. Number of aquatic farming permits by species for 69 farms permitted at the end of 1992.**

| Permit type | Numbers of permits |
|---|---|
| Pacific oyster | 49 |
| Blue mussel | 33 |
| Scallop | 9 |
| Clam | 11 |
| Seaweed | 21 |
| Urchin | 2 |
| Abalone | 1 |

eastern Alaska (Fig. 1). As a result of increased participation in shellfish aquaculture, sales of shellfish have increased substantially since 1989 (Fig. 2).

Shellfish aquaculture in Alaska is a challenging enterprise. To begin with, the state of Alaska does not have a shellfish hatchery and does not allow importation of any fish or shellfish into the state other than Pacific oyster spat that are less than 20 mm in length. Oyster spat are purchased from shellfish hatcheries in Oregon, Washington, and California that are approved by the Alaska Department of Fish and Game. These import restrictions require shellfish farms, culturing species other than Pacific oysters, to use only species native to Alaska. Seed stock for the farms culturing native species must currently be captured from wild populations.

High operation cost is another major problem faced by Alaska shellfish farmers. The expense of shipping equipment to the farms and product to market is a major problem. For instance, paralytic shellfish poison (PSP) toxin affects all bivalve shellfish cultured in Alaska, and all shellfish cultured in Alaska must pass the PSP test before the shellfish can be shipped to market. The PSP problem has not seriously harmed shellfish aquaculture, and over 10 years of extensive PSP monitoring of shellfish farms throughout Alaska have resulted in very few failed tests. However, PCP testing adds to the expense of getting the product to market and adds uncertainty to marketing. If toxicity is detected, the shellfish cannot be delivered to market.

The constraints under which shellfish aquaculture in Alaska operates are unique to the nation. Finding ways of dealing with the constraints and taking advantage of the promises are what will ultimately determine the success or failure of each shellfish aquaculture venture.

## PACIFIC OYSTER CULTURE

Pacific oysters do not reproduce in the cold waters of Alaska. As a result, Alaskan oyster farmers must buy oyster spat from a shellfish hatchery. Unfortunately, Alaska does not have a shellfish hatchery; thus, farmers must buy spat from an out-of-state hatchery. This problem places the farmers in a precarious position because spat are not always available, shipments can be delayed, and spat may not arrive at the farm at the optimum time to take advantage of abundant feed from natural plankton blooms. An example of the spat availability problem occurred in 1993 when only one oyster hatchery was certified to ship oyster spat to Alaska, and several shipments were delayed.

Nearly all oyster farming in Alaska employs suspended culture techniques. Oyster are cultured off the bottom in lantern net cages and suspended from some form of flotation, buoy, or raft. Suspended culture is labor intensive and is a costly form of culture.

Alaska is an outstanding place for Pacific oyster culture. The Pacific oyster, although native to warmer waters, is an attractive species for aquaculture in Alaska because it grows very well in cold water providing there is abundant, high quality plankton as a source of feed. Many estuaries in Alaska produce an amazing quantity of high quality plankton during bloom periods. This enables some farms to match growth achieved in the warmer waters of the Pacific Northwest (Fig. 3). Cold, clean water also reduces bacterial contamination, enables extended shelf-life, assures safety for the consumer, and retards sexual maturation making the Alaska oyster marketable during the summer when the supply of half shell oysters is low.

## PACIFIC BLUE MUSSEL CULTURE

Native populations of Pacific blue mussels (*Mytilus trossulus*) live on many beaches in Alaska. Mussel farmers cannot buy spat from a shellfish hatchery but must capture spat from the wild population.

Mussel larvae generally set during the summer. Spat are ready for transfer to culture gear during the fall or spring following the set. The farmer removes spat from the gear and packs them into a net mesh tube called a mussel sock. The spat filled mussel sock is hung from a raft or buoy until the mussels reach market size. In Alaska, blue mussels grow from spat to a market size of 2 to 3 inches in about 1 year (Fig. 4).

A major constraint for culturing mussels is the labor required to culture, harvest, and process mussels for market. Mussel culture has promise because cultured mussels are fast growing and the meat high quality. Attaining an adequate production level to allow mechanization of some of the laborious tasks, providing a stable flow of product to the market, and developing a marketing strategy are some of the challenges facing mussel farmers.

## SCALLOP CULTURE

The muscle from large scallops is in great demand and commands a high price. For these reasons, scallop culture

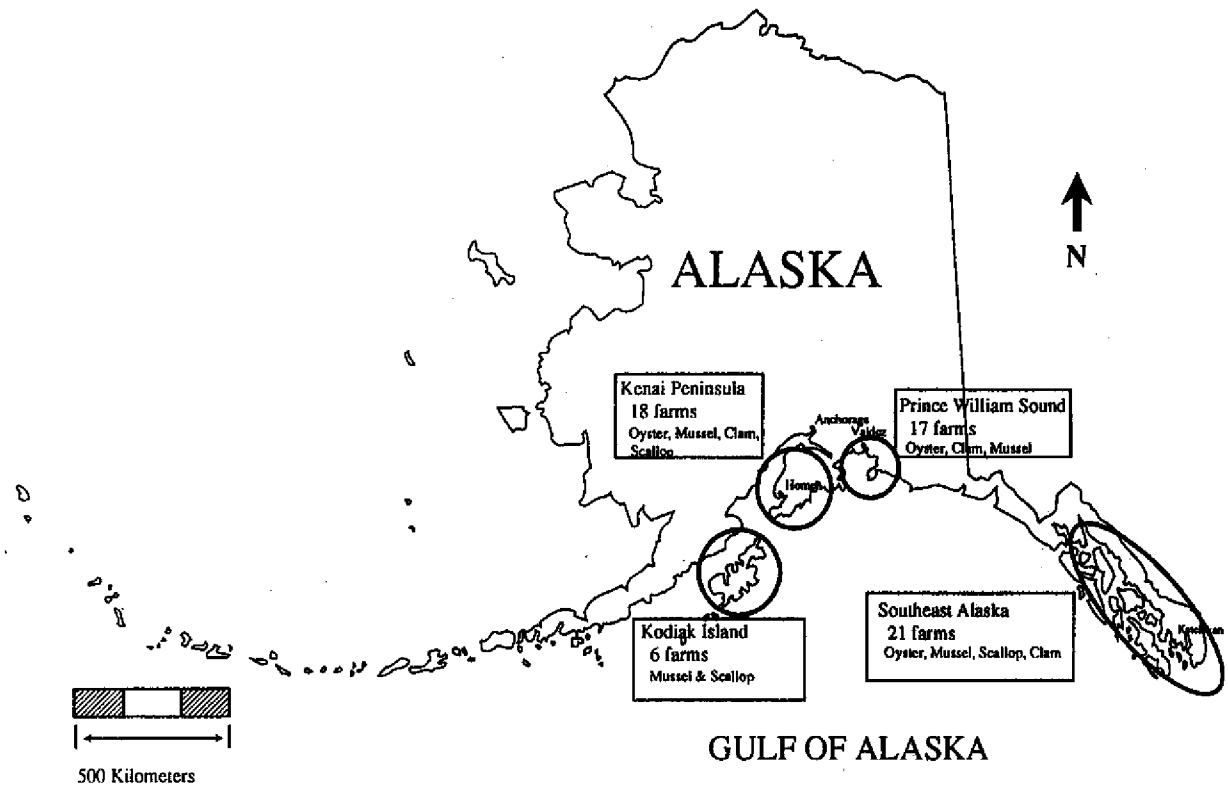


*Figure 1. Distribution of aquatic farm permits in Alaska in 1993.*

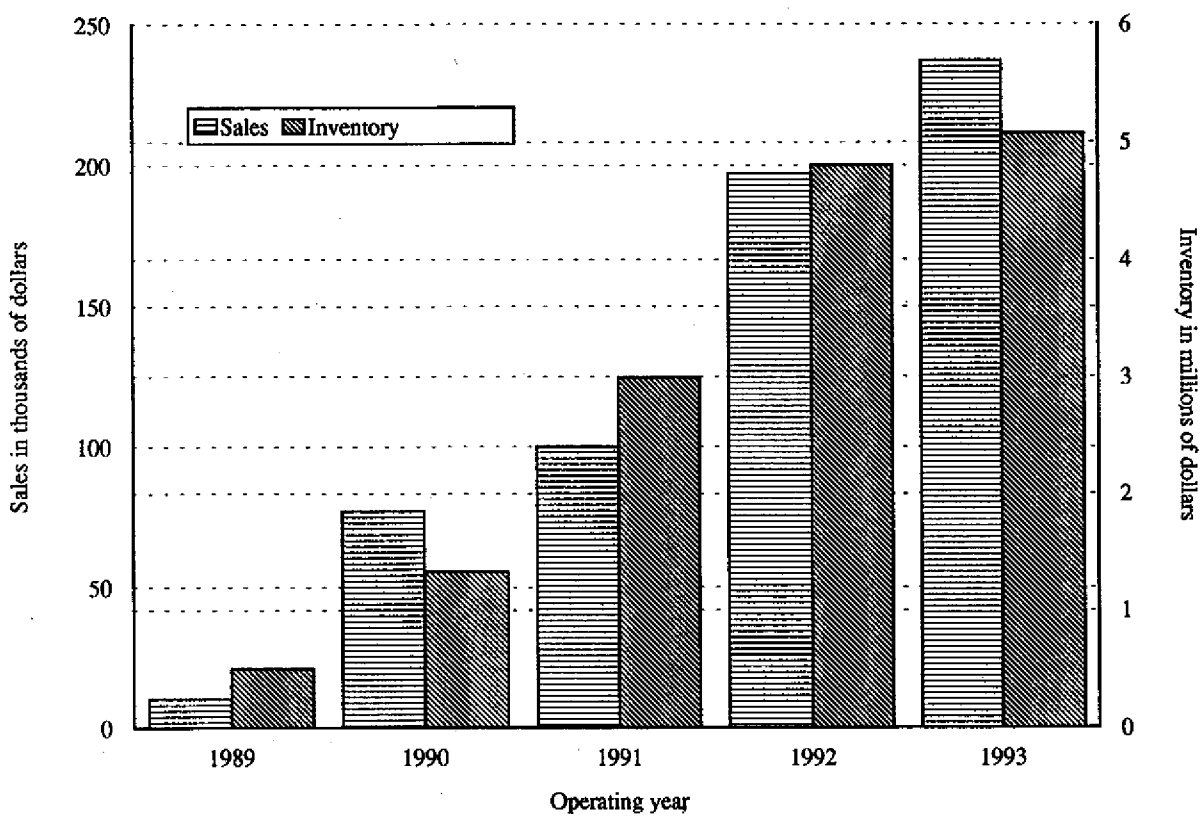


*Figure 2. Alaska aquatic farm sales and inventory.*

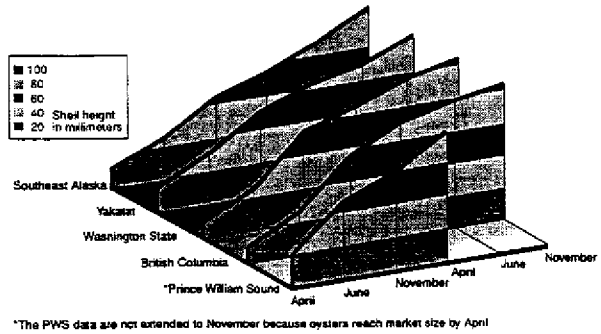


*Figure 3. Comparative growth of Pacific oysters between locations in Alaska, British Columbia, and Washington.*

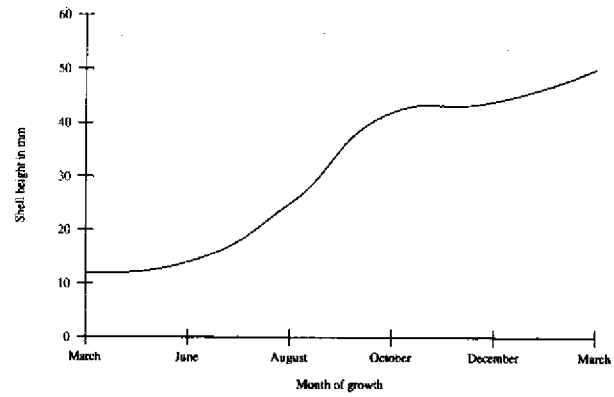


*Figure 4. Growth of Pacific blue mussel in Kachemak Bay, Alaska (Hemming and Hemming 1984).*

is very attractive. Four scallop species have aquaculture potential. Of these species, weathervane scallop *Patinopecten caurinus* attracts the most attention since it has a large, marketable size adductor muscle. Unfortunately, weathervane scallop spat are not available because shellfish hatchery technology is not able to produce spat efficiently.

Wild spat collection, applied with great success to capture spat of the Japanese scallop, *Patinopecten yessoensis*, has not proven successful for capturing spat of weathervane scallop. The growth rate for wild weathervane scallop is slow. Although the growth rate of farmed shellfish often exceeds that of their wild counterparts, the question of potential growth for cultured weathervane scallop needs study.

Culture of purple hinge rock scallop *Crassadoma gigantea* has promise because this species also has a large marketable size muscle. Spat can be hatchery produced, but since Alaska has no shellfish hatchery, this species is not currently feasible to culture. Collecting spat from wild populations has not been successful. Traditional shellfish culture gear cannot be employed to culture purple hinge rock scallops, since 1-inch-size scallops have the uncontrollable tendency to attach to a hard surface. The only way to remove scallop from the culture gear at harvest time is to cut them out and, in the process, destroy the gear.

Collecting scallop spat from wild populations has not been a total failure, because incidental captures of pink scallop *Chlamys rubida* and spiny scallop *C. hastata* spat have been very successful. Unfortunately, pink and spiny scallop do not grow large enough to produce a marketable size muscle (Fig. 5). Farms currently culturing these species hope to develop a whole scallop market. Although of very good quality and easy to culture, whole scallop can retain more PSP toxin than is accumulated in the scallop muscle alone. Whole scallops must also be kept alive for market but have a short shelf life out of water.

## LITTLENECK CLAM

In Alaska, littleneck clam, *Protothaca staminea*, will be cultured on the bottom and mixed with the existing wild population of clams. Farming clams will cause the greatest potential for interaction with wild species, since the clam spat will be planted among the wild population. Culture of littleneck clams in Alaska has not started since spat are not available. Growth of littleneck clams is slow in the northern latitudes, requiring up to 6 years for a crop to reach market size of 35 to 50 mm in length (Fig. 6).

## OTHER SPECIES

Abalone is a seafood commanding a very high price, but culture of the Alaska pinto abalone *Haliotis kamtschatkana* is not currently feasible because no spat are available. Abalone grow slowly and are expensive to feed. A serious potential abalone farmer should consider including seaweed culture as part of the farm operation to assure a constant food supply. Sea urchin *Strongylocentrotus* sp. culture has generated some interest in recent years because the wild fishery is plagued by the inconsistency of gonad quality. This causes wide fluctuations in market price. Culturing urchins may help to eliminate this problem but has not been explored in Alaska to date.

## INTERACTION OF CULTURED SHELLFISH WITH WILD SPECIES

Even though shellfish production of the current industry is small and has a negligible effect on the wild shellfish populations, the number of farms and production is expected to increase. Shellfish farmers and the Alaska Department of Fish and Game are currently developing a comprehensive shellfish transportation policy. Conflicts concerning transportation issues are increasing. Alaska is also a special place because our marine systems are often in pristine condition and highly productive in their natural state. For shellfish aquaculture to be compatible with the current and future uses of state marine ecosystems, the

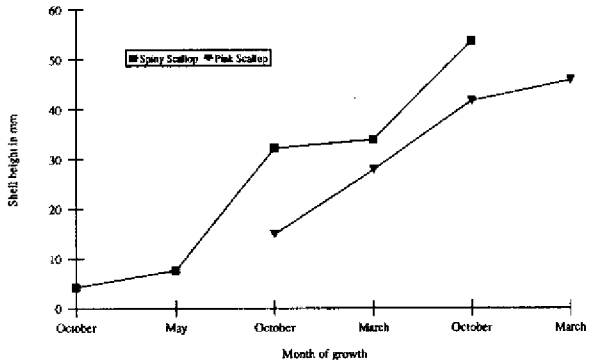


*Figure 5. Comparison of growth between pink scallop cultured in the Kodiak region with spiny scallop cultured in Sitka Sound, Alaska.*

potential problem of wild and cultured species interaction must be addressed.

Shellfish farmers are very apprehensive about the potential implications of the developing shellfish transport policy. The farmers feel that to some degree they must have the ability to move shellfish between selected locations. The question is how far and where should shellfish be allowed to be transported within the state of Alaska.

The state of Alaska has several regulatory controls that can effectively limit the impact cultured species have on wild shellfish populations. These controls are in the form of an import ban on exotic species that also applies to native species that are located outside the state. Essentially, the regulation prohibits any aquaculture species to be transported across the state boundary into Alaska with the exception of Pacific oysters. Before importation into the state, the oyster spat must come from a certified disease free source, and spat must be less than 20 mm in shell size to prevent importation of the parasite *Mytilicola orientalis*. The aquatic farm permit application process also screens applications to determine the impact cultured species will have on the local marine ecology and existing uses of the uplands and marine resources. The aquatic farm permit review process is extensive and may require more than a year to complete (Fig. 7). The third controlling mechanism is the shellfish transport permit. This permit provides the Alaska Department of Fish and Game with the most potent tool to control shellfish transportation by enabling department-wide scrutiny to identify and respond to the potential effects of shellfish transport on wild shellfish populations. A shellfish transport permit is required for any individual to transport or hold shellfish. The permit application must be approved by the Alaska Department of Fish and Game pathology section, district and regional fisheries managers, mariculture coordinator, the genetics section, and director of the department. All permit applications must be signed by the commissioner of Fish and Game (Fig. 8). This review process takes approximately 45 days and can be a very complex and controversial process.

The shellfish transport permit review done by the Alaska Department of Fish and Game must assure authorities that the shellfish are disease free, not genetically harmful to the existing wild populations of the same species, and that the intensity of culture will not significantly effect biodiversity of the marine life in the area. Currently, permit review is done on a case-by-case basis. Shellfish farmers view this as too arbitrary and restrictive.

A major part of the current problem with shellfish transport regulations is that a comprehensive shellfish transport policy has not been developed and decisions concerning shellfish transportation are made cautiously. Adequate information about the genetic impacts of aquaculture on wild species is not available to formulate a policy, and the industry is very concerned about the potential for a very restrictive policy being developed. In addition, the state legislature has passed funding to construct a shellfish hatchery. Operation of this facility will require developing broodstock. With no clear policy about shellfish transport or how many regional broodstocks must be developed, future operation of the new shellfish hatchery is not clear. If transportation of shellfish is very restrictive, how realistic will it be for a shellfish hatchery to manage numerous broodstocks, one to supply each region of the state.

Current thinking about shellfish transport within the industry and the Alaska Department of Fish and Game is directed toward developing an initial policy based on shellfish larval drift patterns. Shellfish transportation then can occur within the normal drift pattern of the shellfish of concern.

A policy based on drift patterns of larva requires information about ocean currents, estimates of shellfish reproduction location and timing, measurements of shellfish larva development time, and an understanding of metamorphosis and spat setting. Unfortunately, ocean current data is incomplete and complex, and larva development data is estimated only from laboratory research. Even with these limitations, however, a rough larval drift pattern can be developed.

## SEA SURFACE CURRENT INFORMATION

The northeastern Pacific is dominated by the Alaska current that flows northward along the coast of southeastern Alaska, then turns in a counterclockwise direction west along the south-central region passing Kodiak Island, then along the Aleutian chain (Fig. 9). The velocity of the Alaska current varies between 8.6 and 12.9 km/day with the higher velocities occurring on the outside of the current and closer to the Alaska shoreline. Current velocities along the Alaska stream, which flows from the Kenai Peninsula southwest past Kodiak Island and into the Aleutians, run between 21.6 and 43.2 km/day (Favorite 1970).

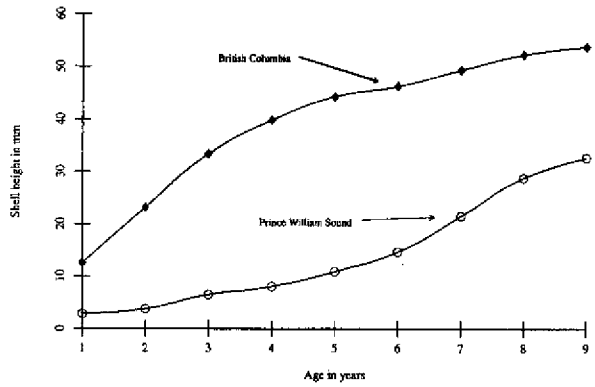


*Figure 6. Comparison of littleneck clam growth between Prince Willian Sound and British Columbia (data from Paul et al. 1976, Quayle and Brown 1972).*

In southeastern Alaska, the average surface current velocity along the western shore is approximately 15.12 km/day (Ingraham et al. 1976). Sea surface current direction and velocity through the islands of southeastern Alaska, commonly called the inside waters, is more complex, caused by the irregularity of the shoreline, influence of tidal currents, and forces added from freshwater runoff. Studies by Martin (1969), Washburne (1989), and Crean (1967) show a complex surface current flow picture for the inside waters south of Sumner Strait (Fig. 10). The surface current in this vicinity flows north and east during ebb tide and south and west during flood tides. The general trend of surface current is directed southeast, out of Clarence Strait, then flowing north along the west coast of Prince of Wales Island. North of Sumner Straits, the currents are dominated by a northerly flow pattern. Currents flow both east and west across the southern tip of Kuiu Island, but the westerly flow dominates. Chatham Strait has both a north and south current, but the north current dominates. For channels nearest the mainland, the surface current is predominantly directed north. Velocities in the inside water vary from 0 to 8.1 km/hr. The average current velocity is approximately 2.8 km/hr.

Sea surface currents within Prince William Sound flow west as demonstrated by deposition of oil from the *Exxon Valdez* oil spill which fouled the beaches of the Kenai Peninsula, Cook Inlet, and Kodiak Island (Fig. 11). The average velocity of the surface current in this vicinity is estimated to be over 12 km/day. The surface currents that enter into Cook Inlet flow into the inlet along the northern shore of the Kenai Peninsula, change direction at the northern extreme of the inlet, and then flow southwest reaching Kodiak Island and the Aleutian chain (Fig. 12). Current velocities within Cook Inlet range from 1.8 to 5.6 kms/hr (Rosenburg et al. 1967). Around Kodiak Island, the prevailing surface current flows southeast toward the Aleutian chain (Fig. 13).

## SHELLFISH LARVAL DEVELOPMENT

Shellfish larval development is most dependent on water temperature (Strathmann 1987). In Alaska, bivalve larvae begin to appear in significant numbers during May and June (Coyle and Paul 1990, Overseas Fisheries Cooperation Foundation of Japan et al. 1989). Of the Alaska bivalve species, the Pacific blue mussel and spiny scallop are most widely dispersed, and larval development data is available to estimate the length of their drifting planktonic phase.

Sea surface temperature data from June through September indicates a warming trend during the summer and sudden cooling in September. The surface water temperature for the inside waters of southeastern Alaska are found in Table 2, while Fig. 14 and Table 3 show the locations and surface temperatures for the Alaska current. This data was used to estimate larval growth for inside waters in southeastern Alaska and the Alaska current.

Pacific blue mussel development was estimated using growth rate data reported by Widdows (1991) (Table 4). Within the ocean surface temperature ranges found in Alaska, the rate of larval growth was assumed to have a linear relationship with temperature causing settling to occur within 24 to 56 days. Hodgson and Bourne (1988) estimated spiny scallop larva setting times based on temperature. From their conclusions, estimates of larva development were calculated assuming a linear relationship between larval growth and temperature (Table 5). Settling occurs between 31 and 50 days after spawning.

A point of caution is due at this point. The larval development data obtained from most research is done under laboratory conditions where temperatures and nutrition of the larva are controlled. The growth rates calculated from laboratory studies can only be an estimate of natural growth rates. Bivalve larva also have the ability to extend their larval life if environmental conditions at the setting site are not suitable or if food deficiency slows the growth rate. Spiny scallop larvae, for example, can extend their larval life phase by 95 days before evidence of deterioration occurs (Hodgson and Bourne 1988). Widdows (1991) reported that blue mussel larva can extend their larval life by up to 3 months. One factor common to both studies, however, is that mortality of larvae is increased substantially during an extended larval growth period.

Combining the effect of sea surface temperature on development, the length of larval life of blue mussels and spiny scallop, and the direction and velocity of surface currents, a pattern of larval drift was estimated. These estimated larval drift patterns and setting location will be discussed by region.

## LARVAL DRIFT IN SOUTHEASTERN ALASKA

In southeastern Alaska, the effect of water temperature indicates that Pacific blue mussel larva can drift, during

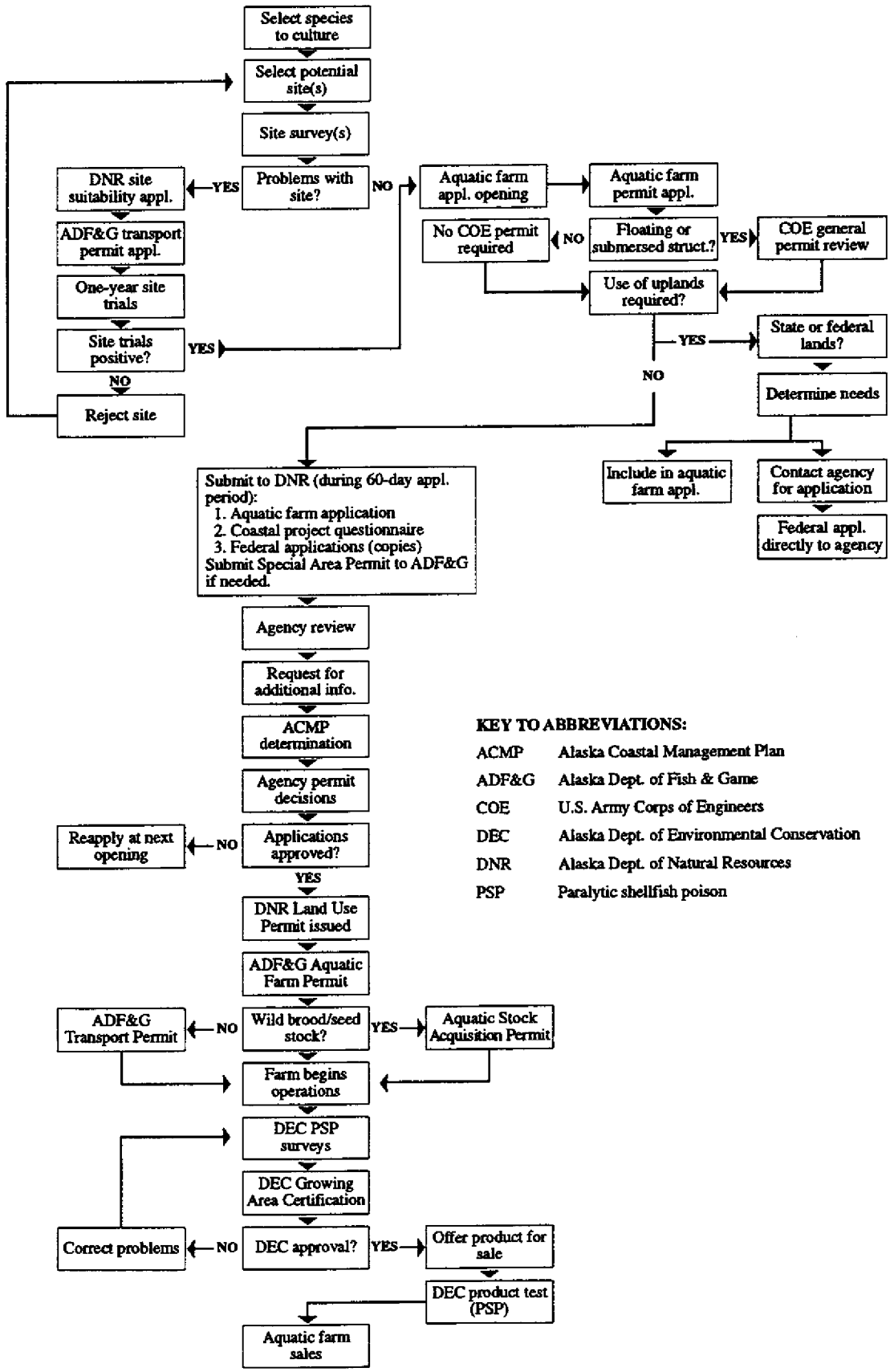


*Figure 7. Aquatic farm permit processing flow chart (from Alaska Department of Fish and Game).*

**Shellfish Transport Permit Review Process**

1. Regional Supervisor
2. Fish Health Services Pathologist
3. Principal Geneticist
4. Mariculture Coordinator
5. Director - Division of Commercial Fisheries Management and Development
6. Director of Fish and Game
7. Commissioner of Fish and Game

*Figure 8. Shellfish transportation permit review procedure for the Alaska Department of Fish and Game.*

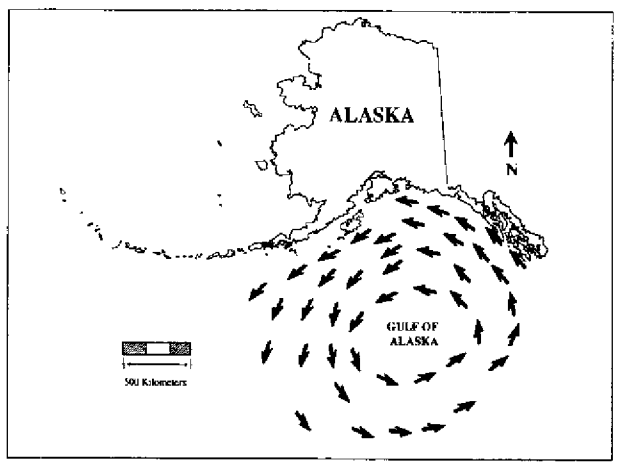


*Figure 9. Sea surface current pattern in the Gulf of Alaska (from Schumacker and Reed 1987).*

their normal development period, 30 days during the month of June (Table 6). Estimated current velocities during the larval development period can disperse bivalve larva throughout much of southeast Alaska and, in the Alaska current, larvae can drift the entire distance from Dixon Entrance to Cape Spencer. For the inside waters, however, tidal influences can cause bivalve larvae to drift back and forth for extended periods. This is particularly true for the region south of Sumner Strait (Table 7). The

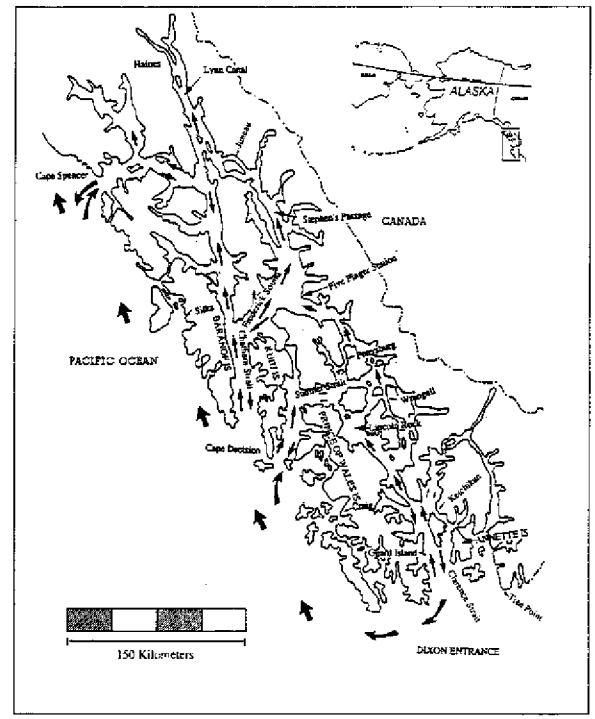


*Figure 10. Surface current flow pattern for the inside waters of southeastern Alaska (compiled from Martin 1969 and Washburne 1989).*

southeastern Alaska region appears to be separated from Prince William Sound since mussel larva, even when starting a northerly drift at Cape Spencer, must have an extended larval period to reach Cordova in Prince William Sound.

Larvae dispersal and setting is similar for spiny scallop larvae. Scallop larva drifting for 31 days in a northerly direction along the coast of southeastern Alaska have ample time to be widely dispersed. Setting will occur between 31 and 50 days at summer water temperatures which means that scallop larvae starting their drift at Dixon Entrance can set throughout much of southeastern Alaska. Larvae starting their drift at Cape Spencer, like blue mussel, will reach settle size before arriving at Prince William Sound (Table 8).

## LARVAL DRIFT IN SOUTH-CENTRAL ALASKA

Blue mussel and spiny scallop larvae drifting out of Prince William Sound can reach much of the Kenai Peninsula, Kachemak Bay, Kodiak Island, and portions of the Aleutian chain within normal larval development times (Table 9). Table 10 presents a summary of settling sites for the blue mussel and spiny scallop larva and indicates several important features.

Bivalve larvae in the outside waters of southeastern Alaska will most often drift north, and the long section of

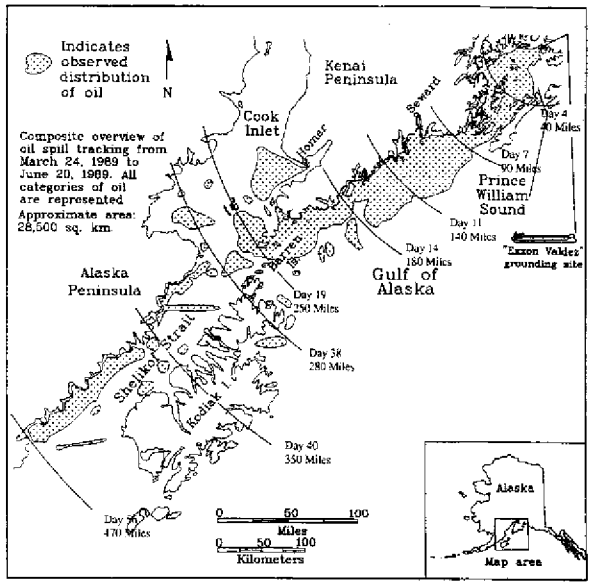


*Figure 11. Flow pattern of oil from the Exxon Valdez oil spill (Alaska Department of Environmental Conservation data).*

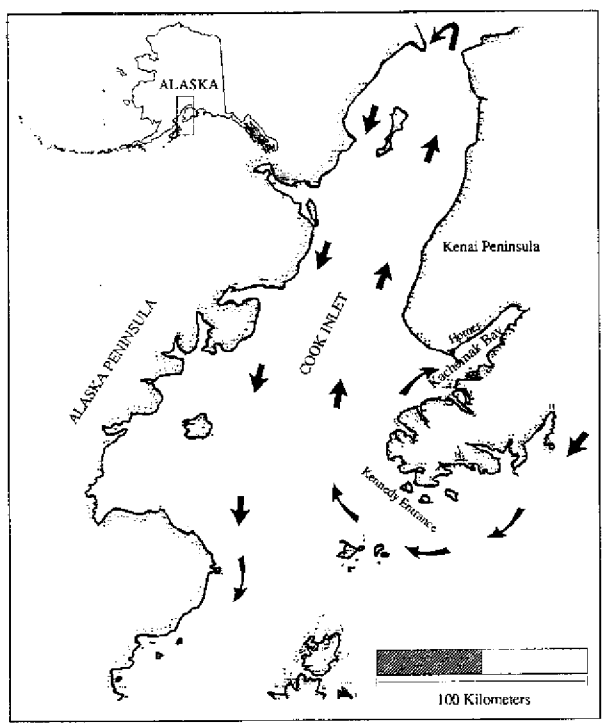


*Figure 12. Sea surface currents around Cook Inlet, Alaska (modified from Burbank 1977).*

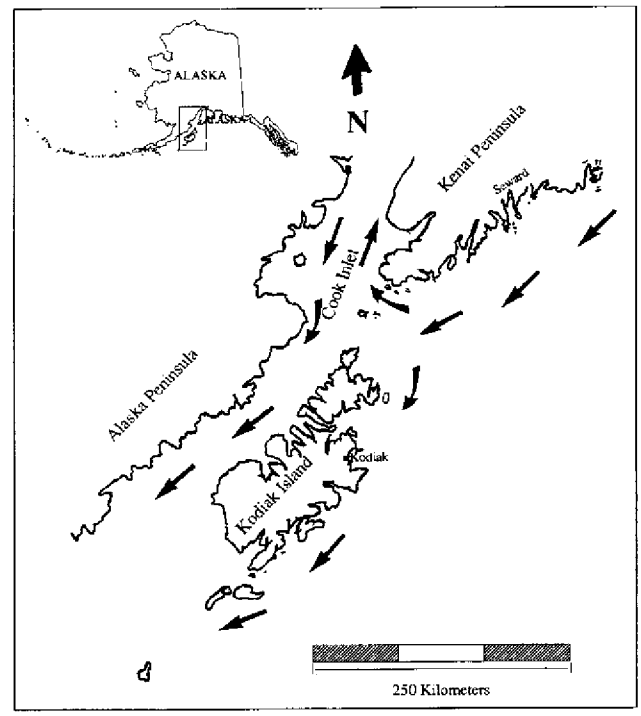


*Figure 13. Sea surface currents around Kodiak Island (Galt 1979).*

coastline between Cape Spencer and Prince William Sound effectively separates southeastern larvae from south-central larvae when their development time is normal and the setting environment is suitable. For south-central Alaska, with the predominant currents flowing west, the eastern stock of bivalves impacts more on the western stocks and the influence may extend from Prince William Sound to the Aleutian chain. Western stocks of bivalves do not influence more eastern stocks, except for possible short distance transport influenced by tides and freshwater runoff. For reproducing bivalve species, a shellfish transport policy based on larval drift appears to have some merit.

## OTHER SHELLFISH TRANSPORT ISSUES

While considering shellfish transportation, the potential for spread of disease also must be considered. This issue is not addressed in this paper. Obviously, shellfish farmers and the Alaska Department of Fish and Game want to prevent importation or spread of disease. This issue needs to be addressed independently of larval drift arguments.

It is important to keep in mind what else affects the survival of bivalve larva to adult age, other than larval drift. Blue mussel populations have been found to be genetically similar for broad regions, particularly the younger age classes (McDonald and Koehn 1988 and McDonald et al. 1991), but selective pressure caused by environmental conditions can significantly change the genetic characteristic of the adult population from that of

**Table 2. Surface water temperature data for the inside waters of southeastern Alaska (compiled from Jones 1978).**

| Location | Degrees centigrade | | | | |
|---|---|---|---|---|---|
| | June | July | August | September | October |
| Guard Island | 13.60 | 14.40 | 14.80 | 13.10 | 10.40 |
| Lincoln Rock | 12.50 | 13.30 | 14.30 | 12.00 | 9.70 |
| Five Fingers | 5.80 | 8.90 | 10.30 | 8.70 | 7.90 |
| Point Retreat | 10.80 | 12.80 | 12.40 | 9.80 | 7.20 |
| Eldred Rock | 13.10 | 13.30 | 12.20 | 8.90 | 5.80 |

Note: Refer to Figure 10 for locations.

**Table 3. Surface water temperature data for the northeastern Pacific (compiled from Brower et al. 1989).**

| Region | Degrees centigrade | | | | |
|---|---|---|---|---|---|
| | June | July | August | September | October |
| A | 10.00 | 12.00 | 13.00 | 12.50 | 11.00 |
| B | 9.50 | 12.50 | 14.00 | 13.00 | 9.50 |
| C | 8.00 | 11.50 | 12.50 | 11.50 | 9.00 |
| D | 7.00 | 10.00 | 11.50 | 10.00 | 8.50 |

Note: Refer to Figure 14 for location of regions.

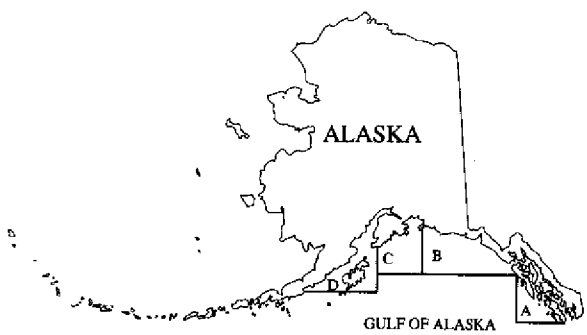


*Figure 14. Sea surface temperature zones designated in Table 3.*

**Table 4. Rate of blue mussel development with temperature (Widdows 1991).**

| Temperatures C | Developmental rate microns/day | Days required to settle |
|---|---|---|
| 7 | 3.96 | 56 |
| 8 | 4.53 | 49 |
| 9 | 5.10 | 43 |
| 10 | 6.75 | 33 |
| 11 | 7.42 | 30 |
| 12 | 8.10 | 27 |
| 13 | 8.78 | 25 |
| 14 | 9.45 | 23 |
| 15 | 10.13 | 21 |

**Table 5. Number of days to setting for spiny scallop larva based on water temperature (estimates based on data from Hodgson and Bourne 1988).**

| Temperature | Days to set |
|---|---|
| 7 | 50 |
| 8 | 48 |
| 9 | 46 |
| 10 | 44 |
| 11 | 42 |
| 12 | 39 |
| 13 | 37 |
| 14 | 35 |
| 15 | 33 |
| 16 | 31 |

the origin spat set (McDonald and Siebenallar 1989). Generalizing the assumption that selective pressure will sort out shellfish transportation mistakes can also be dangerous since scallop, for example, have been shown to have less selective pressure and a number of subpopulation genotypes can coexist in the same area (Beaumont 1982, Kijima et al. 1984, Krase 1989).

## RESEARCH NEEDS

A comprehensive shellfish transportation policy needs further research to establish regulations using sound information. Genetic studies need to be conducted on several important bivalve species including the Pacific blue mussel, littleneck clam, and scallop. Studies that can determine the extent of selective pressures will be useful to refine guidelines for reviewing shellfish transport permit applications and to estimate the prospects for success of culturing or transplanting a bivalve species from one location to another. Reciprocal transplants and studies comparing spat and adult population genetic characteristics should be conducted to estimate the effects of natural selection. In southeastern Alaska, research needs to be conducted to determine if there are populations of bivalveS isolated by counter surface current flows. Other laboratory techniques used to define shellfish transportation policy are only estimates of natural phenomena and should be treated as such.

## CONCLUSIONS

1. The use of larval drift for evaluation of shellfish transport permit application appears to have merit.
2. Drift of larva from a single location can spread over a wide area, and in the Gulf of Alaska the drift is predominantly north for southeastern and west for south-central Alaska.

**Table 6. Summary of larval development and setting times of blue mussel larvae for the inside waters of southeastern Alaska.**

| Current drift section | Month | Kilometers | Temperatures C | Developmental rate microns/day | Days to drift through section* | Days to settle |
|---|---|---|---|---|---|---|
| Ketchikan to Wrangell | June | 143.20 | 13.61 | 9.19 | 8.29 | 23.95 |
| Ketchikan to Wrangell | July | 143.20 | 14.44 | 9.75 | 8.29 | 22.57 |
| Ketchikan to Wrangell | August | 143.20 | 14.83 | 10.01 | 8.29 | 21.98 |
| Ketchikan to Wrangell | September | 143.20 | 13.00 | 8.78 | 8.29 | 25.07 |
| Ketchikan to Wrangell | October | 143.20 | 10.44 | 7.05 | 8.29 | 31.22 |
| Wrangell to Petersburg | June | 64.36 | 12.50 | 8.44 | 3.72 | 26.07 |
| Wrangell to Petersburg | July | 64.36 | 13.33 | 9.00 | 3.72 | 24.45 |
| Wrangell to Petersburg | August | 64.36 | 14.28 | 9.64 | 3.72 | 22.82 |
| Wrangell to Petersburg | September | 64.36 | 11.94 | 8.06 | 3.72 | 27.30 |
| Wrangell to Petersburg | October | 64.36 | 9.72 | 6.56 | 3.72 | 33.53 |
| Petersburg to Juneau | June | 173.77 | 10.83 | 7.31 | 10.05 | 30.09 |
| Petersburg to Juneau | July | 173.77 | 12.78 | 8.63 | 10.05 | 25.50 |
| Petersburg to Juneau | August | 173.77 | 12.39 | 8.36 | 10.05 | 26.31 |
| Petersburg to Juneau | September | 173.77 | 9.83 | 6.64 | 10.05 | 33.16 |
| Petersburg to Juneau | October | 173.77 | 7.17 | 4.06 | 10.05 | 54.15 |
| Juneau to Haines | June | 160.9 | 13.06 | 8.82 | 9.30 | 24.96 |
| Juneau to Haines | July | 160.9 | 13.33 | 9.00 | 9.30 | 24.45 |
| Juneau to Haines | August | 160.9 | 12.22 | 8.25 | 9.30 | 26.67 |
| Juneau to Haines | September | 160.9 | 8.89 | 5.04 | 9.30 | 43.67 |
| Juneau to Haines | October | 160.9 | 5.83 | 3.30 | 9.30 | 66.59 |

* Assumes maximum drift velocity of 20 cm/sec (17.28 Kms/day).

**Table 7. Summary of development and setting times for blue mussel larvae drifting in the Alaska current.**

| Current drift section | Kilometers | Drift days through section at 15cms/sec | Larva growth in June | Cumulative growth | Proportion of growth at setting at 220 microns | Cumulative proportion of development toward setting at 220 microns * |
|---|---|---|---|---|---|---|
| Dixon Entrance to Craig | 142.60 | 9.75 | 65.70 | 65.70 | 0.30 | 0.30 |
| Craig to Port Alexander | 135.20 | 9.23 | 62.21 | 127.91 | 0.28 | 0.58 |
| Port Alexander to Sitka | 151.86 | 10.37 | 69.89 | 197.80 | 0.32 | 0.90 |
| Sitka to Cape Spencer | 157.42 | 10.75 | 72.45 | 270.25 | 0.33 | 1.23 |
| Cape Spencer to Cordova | 775.99 | 55.00 | 357.75 | 357.35 | 1.16 | 1.69* |
| Cordova to Seward | 270.39 | 11.35 | 51.47 | 51.47 | 0.23 | 0.23 |
| Cordova to Homer | 500.04 | 28.00 | 126.99 | 126.99 | 0.58 | 0.58 |
| Cordova to Kodiak Island | 518.56 | 38.00 | 172.14 | 172.14 | 0.78 | 0.78 |

* A proportion equal to 1 indicates that the larva has reached setting size. If the proportion is significantly greater than 1, the larva does not reach the destination within normal development time.

3. A larval drift policy must also account for localized shift in currents as occurs in southeastern Alaska which may cause mixing of populations of shellfish in more than one direction of current flow.
4. The south-central region, with current flow from east to west, causes extensive dispersion of eastern population of bivalve toward the western region ranging from Prince William Sound to the Aleutian chain.
5. Transporting shellfish over a long distance with significant environmental differences can result in high mortalities and is not an effective way to manage an aquaculture operation.
6. Environmental similarities, particularly temperature and salinity, are important to consider when transporting shellfish if the transplant is to be successful.
7. Extensive research is necessary for eventual development of a comprehensive shellfish transport policy.

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**Table 8. Summary of larval development and drift timing for spiny scallop in southeastern Alaska.**

| Current drift section | Month | Kilometers in length | Temperature C | Days to drift through section* | Normal days to settlement |
|---|---|---|---|---|---|
| Ketchikan to Wrangell | June | 143.20 | 13.61 | 8.29 | 38.00 |
| Ketchikan to Wrangell | July | 143.20 | 14.44 | 8.29 | 38.00 |
| Ketchikan to Wrangell | August | 143.20 | 14.83 | 8.29 | 36.00 |
| Ketchikan to Wrangell | September | 143.20 | 13.00 | 8.29 | 40.00 |
| Ketchikan to Wrangell | October | 143.20 | 10.44 | 8.29 | 46.00 |
| Wrangell to Petersburg | June | 64.36 | 12.50 | 3.72 | 40.00 |
| Wrangell to Petersburg | July | 64.36 | 13.33 | 3.72 | 40.00 |
| Wrangell to Petersburg | August | 64.36 | 14.28 | 3.72 | 38.00 |
| Wrangell to Petersburg | September | 64.36 | 11.94 | 3.72 | 12.00 |
| Wrangell to Petersburg | October | 64.36 | 9.72 | 3.72 | 46.00 |
| Petersburg to Juneau | June | 173.77 | 10.83 | 10.05 | 44.00 |
| Petersburg to Juneau | July | 173.77 | 12.78 | 10.05 | 40.00 |
| Petersburg to Juneau | August | 173.77 | 12.39 | 10.05 | 42.00 |
| Petersburg to Juneau | September | 173.77 | 9.83 | 10.05 | 46.00 |
| Petersburg to Juneau | October | 173.77 | 7.17 | 10.05 | 52.00 |
| Juneau to Haines | June | 160.90 | 13.06 | 9.30 | 40.00 |
| Juneau to Haines | July | 160.90 | 13.33 | 9.30 | 40.00 |
| Juneau to Haines | August | 160.90 | 12.22 | 9.30 | 42.00 |
| Juneau to Haines | September | 160.90 | 8.89 | 9.30 | 48.00 |
| Juneau to Haines | October | 160.90 | 5.83 | 9.30 | 54.00 |

*Assumes a drift velocity of 20 cm/sec.

**Table 9. Summary of development and setting times for spiny scallop larvae drifting in the Alaska current.**

| Current drift section | Kilometers | Drift days* through section | Temperature | Development days to set | Cumulative days of development |
|---|---|---|---|---|---|
| Dixon Entrance to Craig | 142.60 | 9.75 | 10.00 | 44.00 | 9.75 |
| Craig to Port Alexander | 135.20 | 9.23 | 10.00 | 44.00 | 18.98 |
| Port Alexander to Sitka | 151.86 | 10.37 | 10.00 | 44.00 | 29.35 |
| Sitka to Cape Spencer | 157.42 | 10.75 | 10.00 | 44.00 | 40.10 |
| Cape Spencer to Cordova | 775.99 | 55.00 | 10.00 | 44.00 | 95.10 |
| Cordova to Seward | 270.39 | 11.35 | 8.00 | 48.00 | 11.35 |
| Cordova to Homer | 500.04 | 28.00 | 8.00 | 48.00 | 28.00 |
| Cordova to Kodiak Island | 518.56 | 38.00 | 8.00 | 48.00 | 38.00 |

*Assumes a drift velocity of 15 cm/sec.

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**Table 10. Summary of probable setting locations for blue mussel and spiny scallop spat for the Alaska coast.**

| | Region of possible setting | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Location of origin | Craig | Port Alexander | Sitka | Cape Spencer | Cordova | Seward | Homer | Kodiak |
| Craig | + | + | + | + | - | - | - | - |
| Port Alexander | - | + | + | + | - | - | - | - |
| Sitka | - | - | + | + | - | - | - | - |
| Cape Spencer | - | - | - | + | - | - | - | - |
| Cordova | - | - | - | - | + | + | + | + |

+ Indicates successful setting during normal larval development time.
- Indicates that setting is not possible or extended development time is necessary.

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# Use of Propagated Fishes in Fish and Wildlife Service Programs

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## ABSTRACT

Authority and responsibility for stewardship and management of fish and fishery resources in the United States is shared by state agencies and several federal agencies. The Fish and Wildlife Service (FWS) has responsibilities for: 1) restoring populations of fishes with national importance, 2) mitigating the impacts of federal water development projects on fish populations, 3) protecting and restoring populations of threatened and endangered fishes, 4) providing fisheries management assistance to tribal governments and other federal agencies, 5) managing fisheries on certain federal lands, and 6) providing federal leadership for the stewardship of inland fish resources. The FWS also cooperates with the National Marine Fisheries Service (NMFS) in many programs, especially those pertaining to anadromous, estuarine, or coastal migratory fishes.

Propagated fishes produced at 78 National Fish Hatcheries are used extensively in the Service's fisheries activities. The federal government has operated fish hatcheries since 1871. Only two states, Delaware and Hawaii, have never had a federal fish hatchery. During most of the history of federal fish propagation, the desirability of producing and stocking such fish was not questioned by resource managers, or their constituents. Propagated fishes compensated for habitat destruction, pollution, dam construction, and overfishing. Propagated fishes could be used to enhance fisheries by supplementing existing populations, filling "uninhabited niches," and/or adding additional desirable fishes to the fishery. However, the assumption that all of these purposes were desirable and consistent with sound environmental principles has been challenged. Consequently, the FWS has initiated a comprehensive review of its fish propagation activities to ensure that the various uses of propagated fishes are consistent with management goals, other Service policies, and statutory laws.

## INTRODUCTION

The individual states within the United States have primary responsibility and authority for fishery resource management under the Constitution of the United States. However, the federal fisheries agencies, the National Marine Fisheries Service (NMFS) and the Fish and Wildlife Service (FWS), have active fisheries programs that carry responsibilities for specific functions, species, or geographic areas. The NMFS has responsibility for all species and activities in the Exclusive Economic Zone (EEZ), outside the state territorial seas and inside the "200 mile limit." NMFS also has major, shared responsibilities for anadromous species and coastal or estuarine ecosystems. The FWS provides federal leadership for aquatic resource management and preservation activities in inland (fresh) water ecosystems and cooperates in the management of anadromous species, as well as some estuarine or coastal species. The FWS has lead authority for the protection and recovery of endangered species in the fresh waters of the United States. The FWS is responsible for also leading and coordinating activities designed to restorepopulations of freshwater fish stocks depleted through overharvest, pollution, habitat degradation, or other factors. Responsibility for mitigating the effects of federal water development projects such as building dams, irrigation programs, or channelization for shipping have also been given to the FWS. Mitigation activities often involve the production and use of fishes propagated in one or more of the 78 fish hatcheries operated by the FWS to replace stocks or species lost through development activities. Similarly, restoration, recovery, and management programs have often used propagated fishes to maintain stocks where the entire life cycle of particular species cannot be completed naturally or to supplement natural production that is inadequate to maintain the fish stocks at desired levels. The use of propagated fishes for such purposes has been an activity of the federal government for over 120 years. Propagation of fishes for food purposes has never been a primary activity of the National Fish Hatchery system; however, commercial fisheries for some spe-

cies of salmon have been partially supported by public aquaculture.

## HISTORICAL PERSPECTIVES

The first federal fish hatchery was established at Bucksport, Maine, in 1871, followed shortly in 1872 by another on the McCloud River in California. Both hatcheries were intended to supplement and maintain populations of salmonid fishes that were in serious decline due to habitat degradation and relatively unrestricted harvest. Since that time, over 200 federal fish hatcheries have been constructed and operated in 48 states. Only Delaware and Hawaii have never had a federal fish hatchery. The National Fish Hatcheries have propagated more than 60 species of fishes, primarily for stocking into inland waters and in support of recreational fisheries. Seventy-eight National Fish Hatcheries remain in operation in 1993. Most of the 120+ facilities no longer in the federal system remain in production, but they are operated by state fishery resource agencies.

The missions assigned to each facility depended on the circumstances associated with its authorization and construction, but generally goals were related to restoring or maintaining a particular stock or to enhancing or diversifying fishing opportunities for recreational anglers. Early fisheries managers often assumed that hatcheries could compensate for watershed/habitat destruction, dams, pollution, and over-fishing. In addition, introduction of "desirable" sport fishes to new waters, or extending their range to new areas, or supplementing natural production in the hope of having larger harvests were considered as beneficial. Politicians could rely on voter approval to obtain authorization and appropriations to build fish hatcheries in their districts.

Fish propagation during the first 80 years of operation of the National Fish Hatchery system was often more art than science. Hatchery managers were often recruited from nearby farms and had only practical backgrounds in farm animal husbandry to guide them in their fish production activities. Survival and growth within the hatchery, resistance to disease, and hardiness during handling were the most important characteristics of "hatchery fish." Survival after stocking, development to maturity, and contribution to the long-term stability of the stock often were assumed without supporting evidence. Concern for genetic integrity or the evolutionary potential of the receiving ecosystem were simply not considered. Many fisheries were maintained where natural processes could not have sustained them and yet the general public continued to support the operation and expansion of the system. This may be taken as an indication that the goals of maintaining and diversifying recreational fisheries were met satisfactorily by fish propagated in the public aquaculture systems, insofar as the public was concerned.

Prior to 1950, state and federal hatcheries were the primary sources of fish for both private and public waters. Development of farm ponds, starting in the 1930s, created additional demands for fish from federal hatcheries to stock these new waters. The concept that public hatcheries may compete with private fish farmers did not exist at that time. Commercial aquaculture did not develop on a large scale until formulated feeds (dry diets) were developed; therefore, public hatcheries were developed and operated to supply farm ponds, as well as public waters.

The focus on supplying desired species for stocking, combined with the assumption that stocking guaranteed better fishing, led to practices that are now being questioned. For example, eggs for propagation were taken from whatever source was available. Although concern for pathogen transmission through egg shipments developed quite early, little thought was given to practices that would ensure maintenance of genetic diversity or genetic integrity. Eggs were shipped to wherever they were needed for rearing and stocking. Selection for growth and survival under hatchery conditions, whether deliberate or inadvertent, did not consider other genetic factors. Genetic conservation practices varied from hatchery to hatchery and between agencies.

Nevertheless, National Fish Hatchery system development must be evaluated within the context of the time, values, and practices of the period during which it developed. The National Fish Hatcheries and propagated fishes provided resource managers with a product and practices through which they were able to maintain fisheries that otherwise might have disappeared. Generations of anglers, and others concerned with aquatic ecosystems, had continuing reasons to observe and value the ecosystems that received the product of these pioneer facilities.

## PRESENT OPERATIONS AND SITUATION

National Fish Hatcheries are now concentrated in the Northwest (Washington, Oregon, Idaho, and northern California) and the Southeast regions of the United States. The Northwest hatcheries produce fish to support the goal of restoring and/or maintaining populations of Pacific salmon and steelhead in rivers throughout the area. Construction of dams, forestry and agriculture practices, pollution, overharvest, and climatic variations have seriously reduced many populations to the point where they seem dependent on propagated fish. Hatcheries in the Southeast region serve as mitigation for habitat and fisheries that were lost because of dam construction. In particular, trout fisheries have been established in the cold tailwaters below dams, thereby replacing the recreational fishing opportunities that were based on native fishes.

Several hatcheries focus on restoration and/or maintenance of lake trout or Atlantic salmon. Restoration of lake trout in the Great Lakes, following decimation by overfish-

**Table 1. Summary of primary species of fishes produced at National Fish Hatcheries in 1992, by total weight andnumber.**

| | Pounds | Millions |
|---|---|---|
| Chinook salmon | 1 million | 53.0 |
| Coho salmon | 300,000 | 6.5 |
| Chum salmon | 6,000 | 3.2 |
| Atlantic salmon | 275,000 | 4.5 |
| Lake trout | 380,000 | 6.7 |
| Rainbow trout | 2.5 million | 13.6 |
| Steelhead | 800,000 | 5.4 |
| Cutthroat | 240,000 | 2.0 |
| Brown trout | 120,000 | 2.0 |
| Walleye | 7,300 | 34.0 |
| Northern pike | 5,600 | 19.0 |
| Striped bass | 51,600 | 9.2 |
| Channel catfish | 183,000 | 6.1 |
| Bluegill | 6,200 | 4.3 |
| Largemouth bass | 6,400 | 3.7 |

ing and the sea lamprey that invaded after the construction of the Welland Canal, is the primary goal of National Fish Hatcheries in Wisconsin and Michigan. National Fish Hatcheries in New England have focused on reestablishing self-sustaining populations of Atlantic salmon. Hatcheries in other regions supply fish for a variety of purposes, but nearly all production supports goals of restoration of nationally important stocks, recovery of endangered species, or mitigation for water development.

Production data from 1992 indicates that the emphasis of the National Fish Hatchery system is on salmonid fishes (Table 1). Production for 1992 shows that chinook salmon (for restoration) and rainbow trout (for mitigation) were the primary species produced by the federal hatcheries. Large numbers of walleye, northern pike, and striped bass were produced, but the weight was much less than that for the salmonids due to the small size at which these fish were stocked.

Salmonids are produced throughout the country except for the lower Mississippi River Valley and the Gulf Coast regions. Walleye and northern pike are produced primarily in the Great Lakes and northern Great Plains areas, while striped bass, channel catfish, largemouth bass, and bluegill are produced in southern and southeastern locations. Facilities specializing in the production of largemouth bass, channel catfish, and bluegill in support of farm pond stocking programs were either transferred to state operation and/or ownership in the early 1980s or converted to the production of other species. Paddlefish, four species of sturgeon, and 26 other species are reared at warmwater facilities, primarily in southern areas. Although one facility, the Dexter (NM) National Fish Hatchery and Technology Center, specializes in the propagation of endangered species, several facilities maintain populations of endangered fishes.

## THE CHALLENGES AND THE FUTURE

Many stocks and populations of fishes are at all-time low levels. The number of populations and species listed as endangered or threatened has risen rapidly. Evidence of habitat degradation, pollution, and overharvest of fish stocks has accumulated rapidly as the impacts of human population growth and industrialization become better recognized. Although these and other factors not related to propagation have been determined to be responsible for many of the declines in fish stocks, hatchery practices have been suggested as contributing factors by some critics.

Concern for animals at the individual organism level, rather than at the population level, has grown in concert with awareness of species that are rare, threatened, or endangered. The Endangered Species Act requires protecting endangered or threatened species from all activities that might further reduce their populations. Practices that once were evaluated only in terms of the benefits they produced for humans are now subject to criticism that they create risk to protected species, or even entire ecosystems. Stocking hatchery propagated fishes that might prey on or compete with endangered species must be reconsidered to be certain that such activities do not further jeopardize species at risk. Some geneticists and evolutionary scientists have also challenged stocking and hatchery operational practices based on the belief that all native species and strains, whether at risk or not, are critical to evolutionary potential, long-term ecosystem stability, and productivity of each system. The role and benefits of fish hatcheries and management of fisheries based on stocking activities have been challenged by these individuals, and support for their position has grown in the absence of substantial and adequate studies to the contrary. In response, proponents of hatcheries and stocking programs contend that hatcheries have been the primary force acting to save many stocks from extirpation because of pollution, habitat degradation, overharvest, and other human influences.

As the controversy continues, the list of "charges" against the use of propagated fishes in restoration, recovery, mitigation, and public resource management programs becomes longer and opponents to practices that have been considered acceptable speak with louder and louder voices. Hatchery programs and hatchery produced fishes are alleged to cause a variety of problems. Some of the allegations are:

1. Permanent dependence on stocking programs is created;

2. Populations decline despite stocking programs; therefore, hatcheries and stocking are not the solution;

3. Reliance on hatcheries has led to failure to prevent habitat destruction, pollution, and dams, thereby permitting continued habitat loss;

4. Hatchery construction and operation are expensive, thereby siphoning off funds needed for habitat restoration;

5. Stocking propagated fishes modifies ("pollutes") the genetic integrity of "wild" fishes, diminishing the fitness of wild stocks;

6. Propagation and stocking allow increased harvest of wild populations that are already stressed by overharvest;

7. Fish produced in hatcheries may carry higher pathogen loads than "wild" fish, thereby spreading pathogens;

8. Use of natural spawning fish for hatchery broodstocks has the effect of "stealing" spawners from wild populations, thus reducing both the numbers and the genetic diversity of natural spawners;

9. Hatcheries are expensive and unreliable, as evidenced by the decline of many stocks that have been supplemented with propagated fishes;

10. "Hatchery fish" are inferior because of learning that took place in the hatchery environment and because of selection for characteristics that are not valuable under natural conditions;

11. Stocking large numbers of "hatchery fish" may "swamp" native populations and change a genetic constitution that has been developed specifically in response to long-term evolutionary pressures.

Regardless of whether such claims are valid, public agencies must consider them if they are held by substantial numbers of their constituents. Practices that have been assumed to be beneficial and that have not been observed to be harmful must be evaluated more critically. Even if substantial changes are not made, greater resources must be devoted to evaluating the results of natural resource propagation and stocking programs.

As the Fish and Wildlife Service looks to the future and attempts to define the appropriate uses of propagated fishes in its programs, changes will be made. Even though we believe that many of the allegations and criticisms of stocking and propagation programs are misdirected, or even invalid, they reflect real concerns of substantial numbers of people. Valuable programs cannot be eliminated simply because highly motivated individuals or groups call for such action, but neither can their criticisms be ignored. We recognize that the "political climate" and the value systems of younger generations favor "greener" strategies than traditional conservation has provided. The Aquatic Nuisance Species Act, the Endangered Species Act, and the National Environmental Protection Act provide legal bases to challenge "business as usual" if the FWS does not respond or develop unimpeachable rebuttals to the challenges it has heard and will continue to hear. How then, will the FWS evaluate its existing activities and programs? What uses of propagated fishes will be made in the future programs of the Fish and Wildlife Service?

As a first step, the Fish and Wildlife Service is initiating a comprehensive review of its entire fish hatchery program. Change should be expected, but no one expects a recommendation to eliminate propagation and stocking from the fisheries management "tool chest." The recommendations of the review will establish fundamental policies but cannot answer all of the many pertinent questions that can be answered only through careful scientific investigations.

Reliable information and data are needed and will be obtained to answer the following questions: What, if anything, is the impact of changes in allele (gene) frequency of fish populations that include large numbers of propagated fishes? Are propagated fishes neutral, inferior, or superior to native populations in altered environments? What impacts do introduced or propagated fishes have on populations of native fishes? Is there a difference between the distribution and impacts of pathogens in hatcheries and in natural habitats? How should harvest be managed in mixed stocks of propagated and wild fishes? Is a "hatchery gene pool" better than "no gene pool," or does alteration of the genetic integrity of a population seriously diminish its evolutionary potential?

Some changes and conditions that can be expected include: a) greater attention to "genetic matching," along with increased emphasis on "ecosystem management"; b) management plans, based on the condition and potential of each ecosystem, will guide propagation activities in the future—one policy *will not* fit all situations; c) private sector aquaculture will continue to expand and will become the primary source of human seafood and aquarium fishes and will provide major sources of supply for recreational fishing where specific species and genetic strains are not required; d) public hatcheries will be tailored to specific functions such as "production hatcheries" to maintain commercial fisheries; "experimental hatcheries," for research and maintenance of threatened and endangered fishes, and "temporary hatcheries," to provide short-term production while temporary problems are corrected; and e) greater participation by constituents in the process of determining the appropriate use of propagated fishes in the programs of the Fish and Wildlife Service.

# Predators of Artificial Seedlings of Abalones: An Unknown Example in Hermit Crabs

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## ABSTRACT

Predation of juvenile abalones by decapod crustaceans has been poorly known, especially in anomuran crabs. We examined predation of artificially bred juvenile abalones (*Nordotis*) by Japanese hermit crabs in three diogenid (*Aniculus aniculus, Dardanus crassimanus, D. pedunculatus*) and two pagurid (*Pagurus similis, P. japonicus*) species under laboratory conditions. Diogenid crabs preyed on abalones whereas pagurid crabs did not. The predation rate of *Dardanus* differed for two abalone species at 15°C.

## INTRODUCTION

Abalone is one of the most important commercial species with a high economic value in the coastal fisheries of Japan. Recently, artificial seedlings have been released to enhance the abalone fisheries. There are 30 prefectural facilities for abalone seedling production, and approximately 30 million seedlings of 15-30 mm in shell length (SL) were produced artificially in 1988 (Uki 1989). The survival rate of juvenile abalone, however, is remarkably low after release. It has been pointed out that predation is chiefly responsible for the high mortality of juvenile abalone. Decapod crustaceans have been listed as one of the predators (Cox 1962, Shibui 1971, Momma 1972, Shepherd 1973, Kojima 1981, Hayashi 1988). Tegner and Butler (1985) reported that from one-third to one-half of the total mortality of young abalone was attributable to predation by crabs. However, few previous studies on seedling mortality in abalones focused on hermit crabs, while many brachyuran predators have been known as cited in Table 1.

This study gives a preliminary description of predation of juvenile abalones by hermit crabs in two major taxonomic groups, families Diogenidae and Paguridae, under laboratory conditions.

## MATERIALS AND METHODS

We examined predatory behavior of hermit crabs in five Japanese species: three diogenid (*Aniculus aniculus, Dardanus crassimanus, D. pedunculatus*) and two pagurid (*Pagurus similis, P. japonicus*) species. For comparison, two brachyuran crabs, *Thalamita prymna* and *Plagusia dentipes*, were also examined. These crabs are commonly found in the abalone fishing ground at Taso, Mie Prefecture. The animals were collected by crab pots at Taso. Two species of artificially bred juvenile abalones, *Nordotis discus discus* (= *Haliotis discus discus*) and *Nordotis gigantea* (= *Haliotis sieboldii*), were used for the prey. Twenty seedlings of the abalone, 20-30 mm, were placed in a tank filled with 20 liters of seawater with a rectangular shelter 3 days before the test. Two hermit crabs were put into each tank; before the experiment, these crabs had been starved for a week. A test tank without crabs was used as a control. Each experiment lasted for 10 days; three tanks were maintained at three water temperatures: 15°C, 20°C, and 25°C. The condition of the animals was checked every day, and the behavior of the hermit crabs was also monitored using a VTR system with optical intensifier. Damage to the shell of the consumed abalone was classified into three types: 1) no damage, 2) chipped margin, and 3) broken into pieces.

## RESULTS

In general, brachyuran crabs tend to break or crush the shell of the abalone they attack. We can see in Figure 1 that abalone shells of *N. discus discus* preyed by the brachyuran crab *Thalamita prymna* were broken into pieces, but most of those eaten by hermit crabs of *Dardanus* usually suffered no damage. In addition, *Aniculus aniculus* also broke the shells. Three diogenid species preyed on juvenile abalones, whereas the pagurid crabs did not (Table 2). Figures 2a and 2b show daily consumption of seedlings by *A. aniculus* and *D. crassimanus* at different temperatures. Predation by the hermit crab decreased below 20°C for all species examined. In the case of *D. crassipes*, the predation rate is higher in *N. discus discus* than in *N. gigantea* at 15°C. A similar result was obtained for *D. pedunculatus*, while no difference was recorded for *A. aniculus*.

**Table 1. A list of main decapod predators for abalones.**

| Decapod Predator | Prey Species | References |
|---|---|---|
| Infraordre Panuliroidea | | |
| *Panulirus interruptus* | *Haliotis* | Zimmer-Faust & Case 1983 |
| *Jasus novaehollandiae* | *Haliotis scalaris* | Shepherd 1973 |
| Infraorder Anomura | | |
| *Paguristes frontalis* | *Haliotis roei* | Shepherd 1973 |
| | *Haliotis ruber* | |
| | *Haliotis scalaris* | Mower & Shepherd 1988 |
| Infraorder Brachyura | | |
| *Pugettia quadridens* | *Nordotis discus hannai* | Shibui 1971, Momma 1972 |
| *Cancer antennarius* | *Haliotis* spp. | Cox 1962 |
| *C. amphioetus* | *Nordotis discus hannai* | Shibui 1971 |
| *Nectocarcinus tuberculosus* | *Haliotis roei* | Shepherd 1973 |
| | *Haliotis ruber* | |
| *Charybdis japonica* | *Nordotis discus discus* | Kojima 1981 |
| | *Nordotis discus hannai* | Shibui 1971 |
| *Thalamita prymna* | *Nordotis discus discus* | Hayashi 1988 |
| *Ozius truncatus* | *Haliotis roei* | Shepherd 1973 |
| | *Haliotis ruber* | |
| *Etisus electra* | *Nordotis discus discus* | Hayashi 1988 |
| *Megametope carinatus* | *Haliotis scalaris* | Mower & Shepherd 1988 |
| *Gaetice depressus* | *Nordotis discus discus* | Kojima 1981 |
| *Plagusia chabrus* | *Haliotis roei* | Shepherd 1973 |
| | *Haliotis ruber* | |
| | *Haliotis scalaris* | |

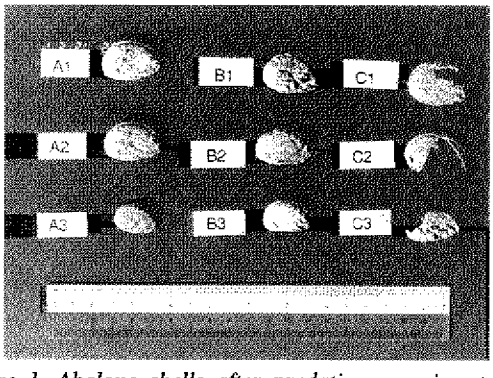


*Figure 1. Abalone shells after predation experiment. A1-3: control (natural death), B1-3: shells consumed by hermit crab (Dardanus crassimanus), C1-3: shells consumed by portunid crab (Thalamita prymna). Neither the control nor the Dardanus-consumed shells is damaged.*

## DISCUSSION

Kojima (1981) stated that predatory brachyuran crabs broke the abalone shells into pieces when they attacked. In the present result, predation occurred in a similar manner for two brachyurans and*A. aniculus*. In contrast, diogenids cause no damage to the shells. Shepherd (1973) listed six decapod crustaceans including an anomuran *Paguristes frontalis* as predator of Australian abalones. His study showed that diogenid crabs did not break but only slightly chipped the margin of abalone shells. Hayashi (1988) reviewed predators of artificially reared juveniles of *Nordotis discus discus* and included hermit crabs as predatory animals. Thus, in the field, it is difficult to distinguish abalone that have been killed by hermit crabs from those that died naturally.

Predator hermit crabs fed above 20°C during this study. The predation rate seems to be related to temperature. Furthermore, in *D. crassimanus* the predation rate of *N. discus discus* is higher than that of *N. gigantea*. It is

**Table 2. Summary of the result of predation experiment between abalone seedlings and decapod crabs at 20°C.**

| Species | Size of predator (mm) | *Nordotis discus discus* | | | | *Nordotis gigantea* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | TC(%) | Damage inflicted(%) | | | TC(%) | Damage inflicted(%) | | |
| | | | Br. | Ch. | NO. | | Br. | Ch. | NO. |
| Infraorder Brachyura (crabs) | | | | | | | | | |
| Fam. Portunidae | | | | | | | | | |
| *Thalamita prymna* | 56-63(CW) | 95 | 85 | 15 | 0 | 65 | 90 | 10 | 0 |
| Fam. Grapsidae | | | | | | | | | |
| *Plagusia dentipes* | 43-50(CW) | 87 | 32 | 45 | 23 | 55 | 35 | 43 | 22 |
| Infraorder Anomura (hermit crabs) | | | | | | | | | |
| Fam. Diogenidae | | | | | | | | | |
| *Aniculus aniculus* | 15-18(SHL) | 83 | 94 | 6 | 0 | 60 | 25 | 58 | 17 |
| *Dardanus crassimanus* | 11-17(SHL) | 100 | 5 | 35 | 60 | 95 | 16 | 45 | 39 |
| *Dardanus pedanculatus* | 15-20(SHL) | 90 | 20 | 36 | 44 | 75 | 10 | 47 | 43 |
| Fam. Paguridae | | | | | | | | | |
| *Pagurus similis* | 11-15(SHL) | 0 | – | – | – | 0 | – | – | – |
| *Pagurus japonicus* | 12-17(SHL) | 0 | – | – | – | 0 | – | – | – |

Br.: broken, Ch.: chipped, CW: carapace width, NO.: no damage, SHL: shield length, TC: total consumed seedlings

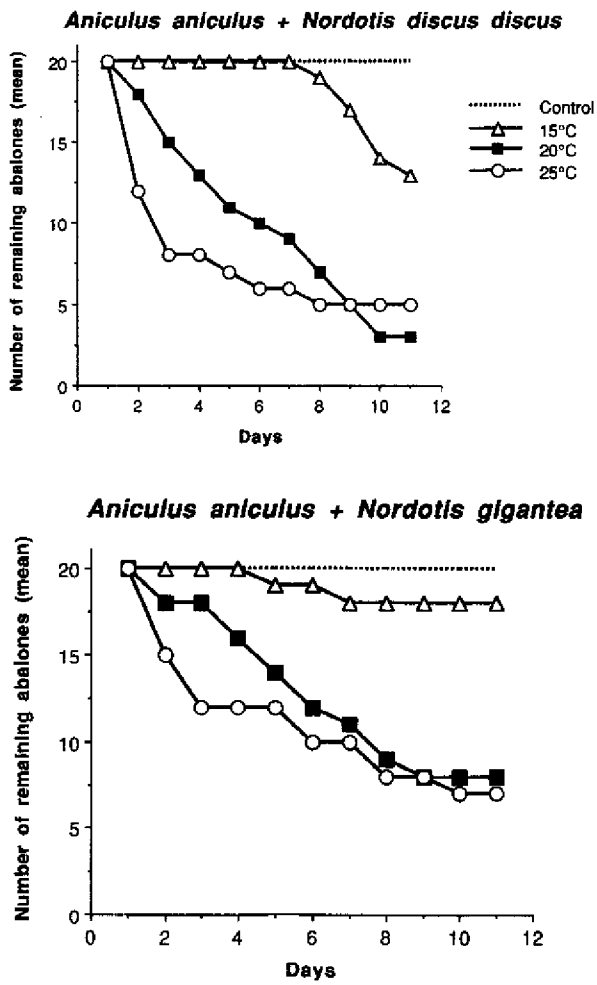


*Figure 2a. Daily consumption of abalone seedlings by Aniculus aniculus at different temperatures.*

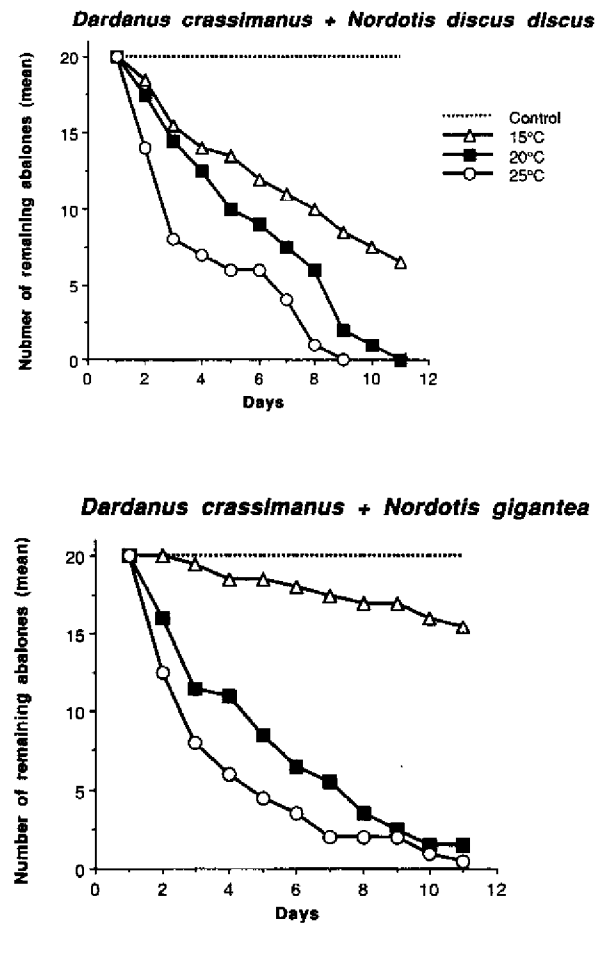


*Figure 2b. Daily consumption of abalone seedlings by Dardanus crassimanus at different temperatures.*

suggested that differences in escape behavior of abalones affect their predation mortality: *N. discus discus* usually lift the shell and move quickly from the site whereas *N. gigantea* adhered firmly to the substrata when attacked by predators.

The hermit crabs are classified into two major groups: the Coenobitoidea including the family Diogenidae with a large left cheliped, and the Paguroidea including the family Paguridae with a large right cheliped. Although the two families are similar in morphology, their phylogenetic relationship is different, as has been evidenced by the process of larval development (McDonald et al. 1957) and by comparison of mitochondrial DNA (Cunningham et al. 1992). It is interesting that the predation behavior of hermit crabs on abalones is clearly different between these left-handed and right-handed families.

Mechanisms of predation behavior of hermit crabs are still unknown, although they have been studied in detail in spiny lobsters (e.g. Zimmer-Faust and Case 1983). To improve survival of released abalone seedlings, more information is needed on the predator-prey relationship.

## ACKNOWLEDGMENTS

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# Prince William Sound Salmon Enhancement Programs and Considerations Relative to Wild Stocks

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## ABSTRACT

Prince William Sound has always been an important salmon production area of Alaska. Wide fluctuations in the annual wild stock production levels have been a characteristic of the Sound. Supplemental production of hatchery-produced pink *Oncorhynchus gorbuscha*, sockeye *O. nerka*, coho *O. kisutch*, chum *O. keta*, and chinook salmon *O. tshawytscha* offer additional opportunities for commercial, sport, personal use, and subsistence fishermen in Prince William Sound. The salmon enhancement program in the Sound is the largest and one of the most successful in Alaska. The Prince William Sound Aquaculture Corporation operates five hatcheries, and another is operated by the Valdez Fisheries Development Association. Hatchery stock return rates have fluctuated from year to year.

To allow hatchery produced fish in the fisheries to be identified, large numbers of juvenile salmon are tagged each spring prior to their release. Tags are recovered in the fisheries, and estimates of hatchery contribution are tabulated. In years when wild stock production was weak, protection was offered by restricting the fisheries on these stocks. A regional planning team coordinates the hatchery program direction. State law requires a detailed review and approval process for all fish transports; this includes a review by State fisheries management, genetics, and pathology staff. Annual hatchery production and evaluation plans are developed jointly by the operators and fishery managers to determine program needs and direction. Proposed hatchery production increases require a permit alteration request that is reviewed by both the Alaska Department of Fish and Game and the regional planning team.

## BACKGROUND

Prince William Sound is an important salmon producing region for Alaska. The Sound is a semi-protected body of saltwater with openings to the Gulf of Alaska. It is rimmed by glacial fjords and largely undisturbed upland habitat. The communities of Cordova, Tatitlek, Valdez, Whittier, and Chenega are located around the Sound. There are more than 1,100 coastal streams and a number of lakes that are used by salmon for spawning and rearing habitat. The Copper River, a large glacial system flowing from Alaska's interior, empties into the Pacific Ocean near Cordova.

Six species of salmon inhabit the rivers, streams, lakes, and coastal waters of Prince William Sound. Pink salmon is most abundant. The Copper River is known for its sockeye and chinook salmon. Chum salmon occur in a number of areas, and coho are scattered throughout the Sound. Rainbow trout/steelhead (*Onchorhynchus mykiss*) also inhabit the area but are not abundant.

Commercial salmon fishing for pink, sockeye, chum, coho, and chinook salmon has long been a mainstay of the Prince William Sound economy. Fish are harvested by both seine and gillnet gear. Salmon sport fisheries are important in accessible areas near Cordova, Valdez, and Whittier. Subsistence and personal use fisheries are important to local residents as a source of food and particularly important to the Native Alaskan villages of Tatitlek and Chenega in the Sound as well as communities along the Copper River drainage.

Salmon are critical in the Prince William Sound ecosystem, as they represent a primary food source at their various life stages for a wide variety of birds, fish, and mammals. Similarly, the salmon depend on the productivity of the Sound for food during their migrations as juveniles and adults. The 1989 *Exxon Valdez* oil spill was a landmark event in Prince William Sound that impacted the ecosystem, the communities, and the fisheries.

## HATCHERIES AND WILD STOCKS

The Prince William Sound Aquaculture Corporation (PWSAC) operates five hatcheries in this area. The Armin

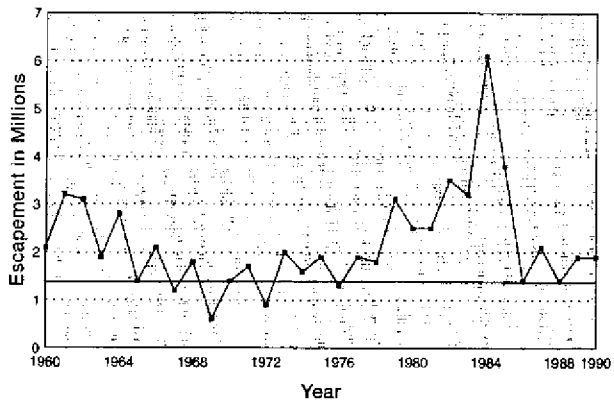


*Figure 1. Prince William Sound wild pink salmon escapement. Based on numbers presented by Eggers et al. (1991).*

F. Koernig Hatchery began production in 1976 and produces pink salmon. The Cannery Creek Hatchery also produces pink salmon and has been operating since 1978. The W.F. Noerenberg Hatchery began production in 1986 and produces pink, chum, coho, and chinook salmon. The Main Bay Hatchery began production in 1983 and currently produces sockeye salmon. The Gulkana facility, located in the upper Copper River basin, began sockeye salmon fry releases in 1974. The Valdez Fisheries Development Association (VDFA) operates the Solomon Gulch Hatchery near Valdez which produces pink, chum, and coho salmon. The program at this facility began in 1979 (Kron and Suzumoto 1989). In 1992, these facilities collected a combined total of 677.5 million pink salmon eggs, 132.2 million chum salmon eggs, 29.1 million sockeye salmon eggs, 4.7 million coho salmon eggs, and 1.3 million chinook salmon eggs. This represents more than half of the statewide egg take by hatcheries in Alaska. The adults returned to Prince William Sound hatcheries in 1992 totalled 8.6 million pink salmon, 0.7 million sockeye salmon, 0.4 million chum salmon, 0.2 million coho salmon, and 2,500 chinook salmon (McNair and Holland 1993).

In Alaska, wild stocks of salmon provide the foundation for the salmon industry. Wild stock conservation receives a priority in fishery management decisions. Alaska has strict fish genetics and pathology regulations and policies to protect wild stocks as well as the hatchery program. Decisions regarding permits for hatchery programs have included fishery managers, technical staff, and the public from its inception. Comprehensive regional planning has provided the direction for the hatchery production program; this is a cooperative effort involving the Alaska Department of Fish and Game (ADF&G), PWSAC, VFDA, the U.S. Forest Service, other agencies and interest groups, and the general public. Each year fishery managers and hatchery operators coauthor and sign off on a detailed plan for hatchery operations, egg takes, releases, evaluation, and adult return management. This program control document is the primary mechanism for conflict resolution. Even with all the planning, co-development of control documents, and joint discussions, hatchery-wild stock considerations continue to be a focal point for discussion and debate.

ADF&G monitors wild pink salmon stocks in approximately 200 index streams using aerial surveys when adults are spawning and, in addition, conducts foot surveys (personal communication, T.M. Willette, ADF&G, P.O. Box 669, Cordova, Alaska, 1993). Weirs are operated on a number of systems to enumerate adult and juvenile salmon migrations. Salmon spawning streams are sampled in late winter to evaluate the over-wintering survival rate of eggs to fry in the gravel. Other cooperative research programs with the University of Alaska and the hatchery operators include estuarine plankton monitoring and juvenile salmon migration studies.

Fishery management decisions have become an increasingly complex process. For example, when there is a lack of understanding of temporal and spatial distribution of different stocks, management errors can result. If hatchery stocks are overharvested, the economics of the hatchery are seriously affected. Alternately if managers mistake hatchery production for wild stock production, wild stock may be overharvested.

Tagging programs have been in place in Prince William Sound since 1984 and have become a useful tool for estimating hatchery pink salmon contributions in the fisheries (Geiger and Sharr 1990, Peltz and Geiger 1990, Peltz and Miller 1990). In recent years, more than 1 million juvenile salmon have been adipose clipped and wire tagged annually in the Sound to assess hatchery contributions to the total adult return (personal communication, T.M. Willette, 1993). This allows fishery managers to determine the mix of hatchery and wild stocks taken in the fishery. Along with other inseason indicators, results from tagging studies are used to direct the harvest while providing for wild stock escapement, hatchery cost recovery, and broodstock needs. Wild stock escapement is a top priority by state law. There is interest in mass marking (i.e., thermal marking of otoliths) to better evaluate hatchery contributions.

ADF&G has a mixed record in meeting wild stock pink salmon escapement goals. The longstanding wild stock pink salmon escapement goal for Prince William Sound is 1.35 million fish (personal communication, H.J. Geiger, ADF&G, P.O. Box 25526, Juneau, AK 1993). In a 17-year period (1960-76) prior to the hatchery program, estimates of the wild stock pink salmon escapement averaged 1.8 million fish annually (range 0.6-3.2 million) (Eggers et al. 1991). The escapement was less than the 1.35 million goal in 4 of the 17 years (Fig. 1). Since the initiation of the

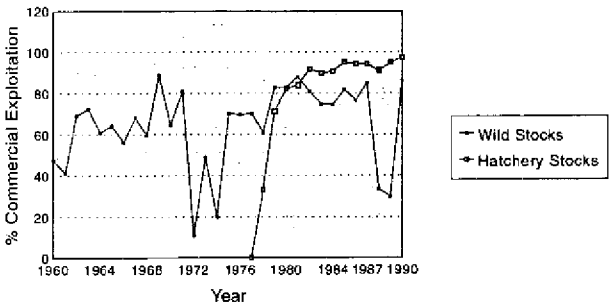


*Figure 2. Estimated exploitation rate for Prince William Sound pink salmon. Based on numbers presented by Eggers et al. (1991).*

hatchery program, the wild stock escapement goal was achieved every year through 1992, and the escapement has averaged 2.6 million fish (range 1.4-6.1) (Fig. 1). It should be noted, however, that all indications are that the escapement will not be achieved with the run failure this season. We expect to come in at 70-80% of the wild stock escapement goal (personal communication, T.M. Willette, 1993). Quality of escapement is another issue of concern; while the overall numerical escapement goal may be achieved in a given year, escapements may be inadequate in some districts of the Sound. There are also concerns about hatchery fish straying to nearby streams and the potential impact this may have on wild stocks (Eggers et al. 1991).

Achievement of wild stock escapement goals is an ongoing challenge that ADF&G faces. The success of the hatchery program in Prince William Sound is dependent on the maintenance of healthy wild stocks of salmon. It appears that the run strength of pink salmon is impacted by estuarine water temperatures in spring with warmer years contributing to higher marine survival (Willette and Cooney 1991, Willette 1991). Returns of both wild and hatchery fish fluctuate greatly from year to year. In situations where wild stocks are weak and hatchery stocks are strong, fishing has been restricted to terminal areas immediately in front of the hatcheries thereby reducing the harvest rate on wild stocks (Fig. 2) (Eggers et al. 1991). While this is an effective tool from a wild stock resource conservation perspective, it is not popular with fishermen and processors.

Pink salmon wild stock escapement estimates for Prince William Sound as a whole have been based on aerial surveys of index streams and estimates of stream life of spawners. Recently, more detailed district evaluations of stream life have yielded a more complete assessment of this characteristic than was available previously. Based on this new data, it is apparent that we may have been underestimating wild stock escapement and overestimating the exploitation rates for pink salmon wild stocks (personal communication, T.M. Willette, 1993). This being the case, wild stock harvest rate

**Table 1. Commercial catch of pink salmon in Prince William Sound prior to and during hatchery operation, in millions.**

| Time Period | X | Range |
|---|---|---|
| A. Prehatchery (1960-76) | 3.3 | 0.1 - 7.3 |
| B. With Hatchery Production (1977-92) | | |
| 1. Estimated wild stock contribution | 9.4 | 0.7 - 18.0 |
| 2. Estimated Hatchery Contribution | 10.3 | 0.0 - 43.4 |
| 3. Total | 19.7 | 2.9 - 50.8 |

Based on numbers presented by Eggers et al. (1991) for 1960-90 and Geiger (personal communication) for 1991 and 1992.

determined from Eggers et al. (1991) shown in Figure 2 would be reduced further.

During the period 1960-76 when the pink salmon fishery was supported wholly by wild stocks, the average pink salmon catch in Prince William Sound was 3.3 million fish (Eggers et al. 1991). The catch fluctuated from 0.1 to 7.3 million fish (Table 1). Since hatchery releases were begun, the average pink salmon catch has been 19.7 million fish and has ranged from 2.9 to 50.8 million (Table 1). It should be noted that the increase is not only due to hatchery production but also to an increase in wild stock productivity. It appears that environmental conditions were favorable for pink salmon survival during the late 1970s and early and mid 1980s. Between 1977 and 1992, the survival rate from fry to adult return for hatchery produced pink salmon has ranged from 11.2 to 1.3% and has averaged 5.3% (Fig. 3) (Eggers et al. 1991; personal communication, H.J. Geiger 1993). In recent years, wild stock salmon production levels have dropped down to levels found during the 1960s and early 1970s. There are concerns that the Prince William Sound ecosystem has been out of balance since the 1989 oil spill. This year's pink salmon return has been a disaster with a failure of wild and hatchery runs alike. The wide fluctuations in the pink salmon run that occurred prior to hatchery construction and are present now as well.

## SUMMARY

ADF&G has a responsibility to achieve satisfactory wild stock escapements for all stocks and species. This, however, is very difficult given the fluctuations in the size of the runs, the nature of the fishery, and the mixture of the stocks taken. While tagging has been implemented since the inception of the Prince William Sound hatchery

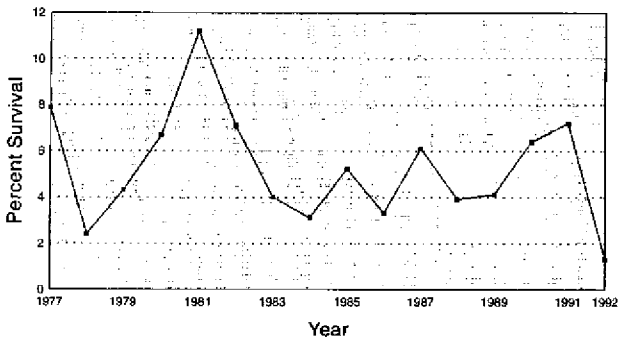


*Figure 3. Average survival rates by return year for Prince William Sound Hatchery produced pink salmon. Based on Eggers et al. (1991) for 1960-90 and Geiger (personal communication) in 1991 and 1992.*

program, a renewed commitment to a joint tagging-recovery effort this year represents progress in state-private cooperation to collect basic information for the management of the salmon fishery. New information for other species is also critical. Tagging projects for wild and hatchery produced sockeye salmon stocks are providing greater insight into their distribution and vulnerability to various fisheries. These insights will allow ADF&G to improve protection of wild salmon stocks in the future and help assure that escapement goals are met for the future of salmon fisheries in the Sound.

It is clear that healthy wild stocks are a prerequisite to a successful hatchery program and a healthy economy in Prince William Sound.

## ACKNOWLEDGMENTS

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# Successful Enhancement of the Texas Red Drum (*Sciaenops ocellatus*) Population

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## ABSTRACT

Red drum (*Sciaenops ocellatus*) is an estuarine-dependent sciaenid that inhabits estuaries, bays, and coastal regions from New York to Mexico. In Texas, the red drum population began a dramatic decline in the 1970s, prompting the Texas Parks and Wildlife Department (TPWD) to set up a three-pronged recovery plan. Management approaches were: 1) Initiate an independent monitoring program to assess relative abundance; 2) Implement restrictive regulations to reduce fishing pressure, including license restrictions, size, bag, and possession limits, a commercial quota, restrictions on netting, and a ban on commercial sale of red drum; and 3) Develop and start a marine enhancement program based on the release of hatchery-reared fingerlings and assessment of subsequent survival.

Recently, the red drum population in Texas coastal water rebounded because of several factors that had a positive effect on the recovery. TPWD's long-term management plan utilizing hatcheries and stocking to supplement natural spawning played a role in reversing the decline of the red drum population. The strategy used by the TPWD can serve as a blueprint for other marine enhancement programs.

## INTRODUCTION

The objective of this paper is to provide a synopsis of Texas' 20-year red drum enhancement program. The red drum population consists of two distinct groups: adults in the inner shelf habitat, and young less than 6 years old in estuaries and nearshore habitats (Pearson 1929, Matlock 1984). Red drum spawn in late summer and fall in the nearshore habitat; larvae migrate through passes into estuarine nursery grounds (Pearson 1929). Historically, red drum supported recreational and commercial fisheries throughout its range.

Texas' recreational fishery, with about 1.6 million fishermen, is worth $2.3 billion (U.S. dollars); red drum is a major targeted species. In the 1970s, the red drum population in Texas began a dramatic decline because of growth (Matlock 1984) and possibly recruitment overfishing. In response to this decline, Texas Parks and Wildlife Department (TPWD) fishery managers formulated the following recovery plan in 1975:

1) Establish a long-term monitoring program to assess red drum relative abundance. Experimental gill nets are used to assess estuarine sub-adult relative abundance; bag seines are used to assess juvenile recruitment to the estuary population (Dailey et al. 1992).

2) Implement increasingly more strict regulations on both sport and commercial fishermen. Ultimately, no nets were allowed in Texas waters, the sale of red drum was banned, and sport anglers were restricted to three fish per day, 51-71 cm long.

3) Set up a stock enhancement program using hatcheries. For the purpose of the present paper, the focus will be on stock enhancement.

Red drum is an excellent candidate for enhancement through stocking because larval recruitment into estuaries from nearshore spawning areas is probably a limiting factor of year class abundance. Matlock (1987) presented results showing that in 1967, recruitment of red drum in upper Laguna Madre (Fig. 1) was higher than in any of the previous 8 years. This was a result of three passes created by a hurricane storm surge, thus providing excellent conditions for ingress of larvae into the bay. If managers could bypass mortality associated with larval recruitment from the nearshore spawning areas into the bays, then stocking "enough" red drum directly into estuaries could possibly supplement the natural stock. Capture of tagged stocked red drum up to 284 days following release in Matagorda Bay (Fig. 1) in 1976 documented that stocked red drum can survive in the wild (Matlock et al. 1984).

Matlock's limited recruitment theory and possible use of hatchery-produced fish for enhancement were tested in St. Charles Bay from 1979 through 1981 (Matlock et al. 1986). This 566 ha bay was stocked with two million fingerling red drum (25-30 mm total length) in summer 1979, fall 1980, and spring 1981. Since red drum spawn

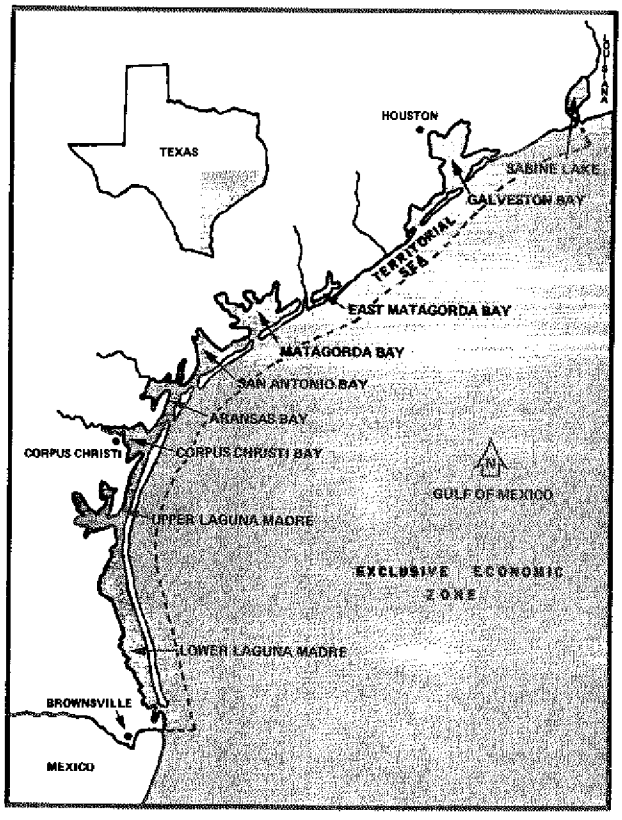


*Figure 1. Texas bay systems.*

in late summer and fall, the 1 million fish stocked in spring and early summer were smaller than all natural fish spawned during the previous falls. These out-of-phase fish were tracked by length frequency up to 9 months after stocking in both bag seine and gill net samples. Some fish were micro-tagged before stocking, a few of which were later recaptured. Therefore, double confirmation of survival of stocked fish was documented. Based on the success of this study (Matlock et al. 1986), the TPWD, in partnership with the Gulf Coast Conservation Association and the Central Power and Light Company, constructed its first production-scale marine fish hatchery in 1982.

## THE RED DRUM HATCHERY SYSTEM

The present hatchery system consists of spawning/incubation facilities with 30 ha of production ponds. Red drum broodfish are maintained in 13,000-L circular tanks in environmentally controlled rooms. Each spawning tank contains five to six broodfish (three females) ranging from 8-18 kg; they are fed shrimp (Penaeidae), squid (Loliginidae), and mackerel (Scombridae). Twenty-five percent of the broodfish are exchanged annually with wild fish to maintain genetic diversity. Broodfish are subjected to a 150-day photoperiod-temperature maturation cycle (McCarty 1990). Spawning occurs at a water temperature of 24° to 26° C, salinity of 30-38 ppt with 11 hours of light. Buoyant fertilized eggs float to the top of the circular tanks where they are skimmed off the surface, flow into an egg collector, then are collected by dip-net. Eggs are volumetrically measured and counted. On average, two million eggs are collected each night from March through November. Eggs are transferred to 945-L incubators where they hatch within 24 hours. Within 36 to 40 hours post hatch, larvae have developed mouthparts, distinct eye pigmentation, and a complete digestive tract. These first-feeding larvae average 2.7 mm total length.

Rearing ponds, filled five to 10 days earlier with filtered water and fertilized, are stocked with larvae when zooplankton densities reach 250 organisms/L. A combination of inorganic and organic fertilizers applied to rearing ponds produce a rapid phytoplankton bloom that stimulates a copepod population, a primary food for larval red drum. Dissolved oxygen, salinity, temperature, zooplankton densities, and fish growth rates are routinely monitored. Larvae remain in the ponds for 30 days or until they reach a target size of 30 mm total length. Once they reach target size, ponds are drained, fish are harvested, and they are transferred to distribution tanks for stocking into coastal waters. Between 1983 and 1989, 5 to 10 million fingerlings were stocked each year. In 1990 the primary facility was enlarged, and additional grow-out ponds went into production. Each year between 1990 and 1992, 15 to 20 million fingerlings were stocked. Through 1992, more than 115 million fingerlings were stocked into Texas coastal waters.

## ASSESSING THE RESULTS OF STOCK ENHANCEMENT

The key question is: Does stocking work? Evaluations of the success of enhancing the red drum population using hatchery-reared fingerlings have been ongoing since 1983. Three different methods are used in assessment: 1) bag seines chronicle year class strength of young-of-the-year red drum (Dailey et al. 1992); 2) gill nets estimate relative abundance of sub-adults (Dailey et al. 1992); and 3) sport anglers' catches are measured by surveying harvest and fishing success (Weixelman et al. 1992). Length distribution of wild fish each month is relatively tight; all naturally spawned fish follow this normal seasonal pattern (Figs. 2, 3). Fish stocked in upper Laguna Madre during late spring and early summer in 1991 and 1992 were caught in bag seines up to 8 months following stocking (TPWD unpublished data), after which they were not vulnerable to bag seine collection. These "out-of-phase" fish were collected during routine TPWD sampling. Each month, 18.3-m bag seines (19 mm stretched mesh in wings; 13 mm stretched mesh in bag) are pulled along the bay shoreline at 20 randomly selected sites. [For a detailed description of bag seine sampling methodology, see Dailey et al. (1992).] At least 20% of all red drum caught in upper Laguna Madre

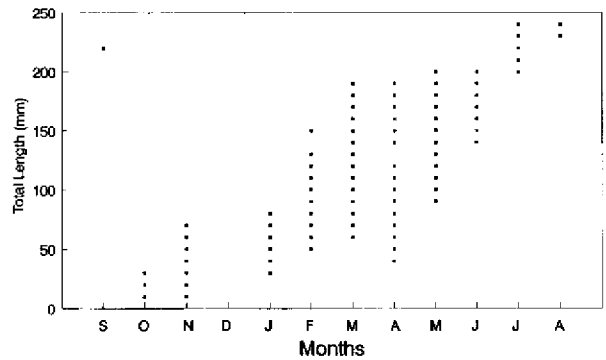


*Figure 2. Combined monthly (September-August) length frequencies of Texas red drum collected in bag seines during 1926-27 (from Pearson 1929). Squares = size classes, not individual fish.*

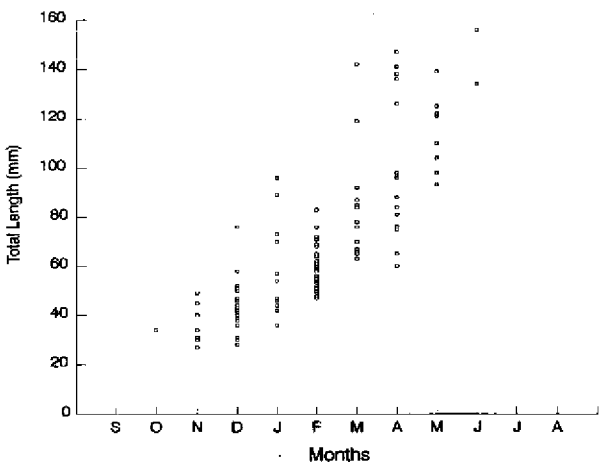


*Figure 3. Combined monthly (September-August) length frequencies of red drum collected in upper Laguna Madre during non-stocking years (1978-1990). Squares = size classes, not individual fish.*

bag seine samples in both 1991 and 1992 were positively identified as stocked fish (TPWD unpublished data).

During 1983 to 1985, TPWD gill net catches in a stocked (Corpus Christi Bay) and unstocked (upper Laguna Madre) bay were compared (Matlock 1990). Gill nets used were 182.9 m long, 1.2 m deep, with 45.7 m sections of 7.6-cm, 10.2-cm, 12.7-cm, and 15.2-cm stretched monofilament mesh tied end to end with smallest mesh on shore. [For a detailed description of gill net sampling methodology, see Dailey et al. (1992).] Fish were stocked in 1983 in Corpus Christi Bay. Matlock (1990) reported that these fish began to be caught in fall 1984 in the 7.6 cm mesh; increased catches 1 year after stocking were primarily in this mesh. This pattern was not apparent in the unstocked bay. Stocked fish were also caught 6 months later in the 10.2 cm mesh and 1 year later in the 12.7 cm mesh. Again, this trend was not observed in the unstocked

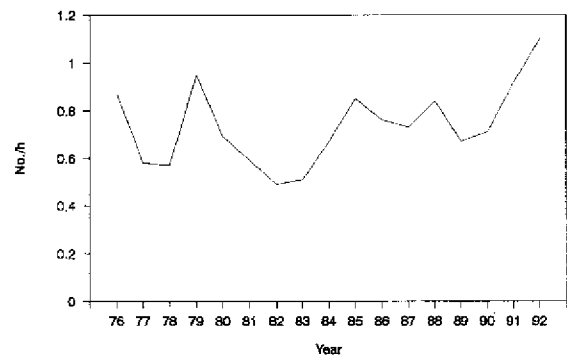


*Figure 4. Coastwide gill net relative index of abundance (No./hr) during fall 1976-1992.*

bay. Also, in fall 1985 the 7.6 cm mesh began to catch fish from the second stocking. These fish were caught in the 10.2 cm mesh 6 months later, thus following the same pattern observed after the first stocking.

In these same two bays, sport-boat fishermen catches were estimated. The TPWD has conducted a continuous survey of sport-boat fishermen since 1975 (Weixelman et al. 1992). The number of red drum landed annually and catch-per-unit-effort (No./hour) were estimated before stocking and after stocked fish reached the minimum size limit. Matlock (1990) reported that the number of red drum harvested from the stocked bay increased 100% over the historic mean (1979-1984). There was a 27% increase in the number of fish landed in the unstocked bay but sport fishermen fished 45% more man-hours than in the stocked bay. This pattern is also reflected in the catch rate, which is a measure of success. In the stocked bay, the catch rate increased 150% over the historic mean, whereas in the unstocked bay the catch rate only increased 50% over the historic mean.

Gill nets, described previously, have been used since fall 1975 to estimate sub-adult relative abundance (Dailey et al. 1992). Fall catch rates were highly variable through 1984 (Dailey et al. 1992; Fig. 4). In 1983, Texas' hatchery went on-line and large-scale stocking began. Regulations implemented in the mid- to late-1980s were also starting to affect the red drum population. Since 1985 the coastwide gill net relative abundance index has stabilized and increased (Fig. 4). Stocking probably stabilized recruitment from the typical marine scenario of high recruitment in a few years and low recruitment in most years by supplementing the natural spawn. Improved regulations allowed more fish to survive and, as a result, stocked fish helped enhance the population.

Four studies are currently underway to further assess the success of enhancement through stocking. First, selectively bred fingerlings will be stocked in East Matagorda Bay. TPWD geneticists found a gene marker (King et al. 1993) that can be used in estimating the magnitude of

enhancement. For the first time, researchers can follow stocked fish throughout their 4- to 6-year life in the bay. Second, the Optical Pattern Recognition System (Biosonics 1987) is being used to distinguish differences in scale annuli patterns between hatchery and wild fish caught in TPWD samples. Third, oxytetracycline (OTC) marked fish will be stocked to distinguish stocked fish from wild fish during fall and winter. OTC lays down a mark on otoliths and other calcified structures that will fluoresce under UV illumination (Thomas 1993). Fourth, TPWD fishery managers are in the initial stage of conducting a detailed multivariate analysis partitioning biological, environmental, sampling, and stocking components, so the parameters affecting success of stocking can be identified. All four of these studies should allow a more precise, quantifiable assessment of the role hatcheries played in the increase in red drum abundance.

## CONCLUSIONS

TPWD fishery managers have used several different techniques to address the success of hatcheries in enhancing populations. This was planned at the very beginning of the program because multiple approaches increase the chance of detecting and quantifying the influence of hatchery production. The answer to the question of hatchery success is very complex with many components to address.

It has taken the TPWD 20 years to reach the present stage in development of its stocking and recovery program. To date, over 115 million fingerlings have been stocked. Fishery managers in Texas have taken the often controversial technique of hatcheries and used it to benefit the red drum resource and fishery. The innovative use of stocking, combined with traditional management practices, has proven to be a powerful combination in managing Texas natural resources wisely. We encourage fishery managers in other overexploited fisheries to assess the feasibility of using hatcheries to supplement marine populations. All evidence in Texas at this stage weighs heavily in favor of the fact that stocking hatchery fish has enhanced Texas red drum. This enhancement program serves as a model for managers developing future recovery programs.

## ACKNOWLEDGMENTS

Thanks go to Kyle Spiller for creating the figures depicting red drum bag seine and gill net catch rates.

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# Interactions Between Released and Wild Japanese Flounder (*Paralichthys olivaceus*) on a Nursery Ground

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## ABSTRACT

The Japanese flounder, *Paralichthys olivaceus*, is one of the most important fishes in the coastal fisheries of Japan. But recently, overfishing has caused a reduction of the stock size. To enhance the stock, artificial seeds of Japanese flounder have been released. Interactions between released and wild flounder were examined to determine the success of the stocking program.

We performed experimental releases of artificial seeds in the shallow waters off Igarashi-Hama on the northwestern coast of Japan, from 1990 to 1992. The growth rate of wild flounder varied annually depending on the abundance of mysids that are the most important food for the flounder on the nursery ground. When mysids were less abundant, released flounder dispersed rapidly from the release site, ingested small amounts of food, and grew slowly compared with other years.

The feeding habits of released flounder differed from those of wild flounder when mysids were less abundant. Flounder released then ingested less food and also consumed gammarids which the wild flounder never ate. It was assumed that an abundance of mysids was more critical for released than for wild flounder. Further investigations on the carrying capacity of the nursery ground and improvement of the quality of artificial seeds are needed to enhance the stock size of Japanese flounder efficiently.

## INTRODUCTION

The Japanese flounder, *Paralichthys olivaceus*, is a large flatfish with maximum total length of 1 m and weight of more than 10 kg. The fishery production of the flounder is about 7,000 metric tons a year; however, there have been increased fishing efforts suggesting that the stock of the flounder has been decreasing. Recently, artificial seeds of Japanese flounder have been released to enhance the stock size, and the number of released seeds has been increasing. In 1991, about 15 million artificial seeds were released in Japan (Fisheries Agency and Japan Sea-Farming Association 1993).

The life cycle of Japanese flounder is shown in Figure 1. In Niigata, mature Japanese flounder inhabit offshore areas where the water depth is about 100 m. They spawn in shallower water of less than 50 m from April to June (Kobayashi 1974, Nashida 1984). Eggs and larvae undergo a planktonic life for 1 or 2 months (Minami 1984). Metamorphosing larvae are transported to near-shore by currents (Imabayashi 1980a, Minami 1985, Fujii et al. 1989, Goto et al. 1989) and settle on sandy nursery grounds of less than 10 m in depth (Koshiishi et al. 1985). They spend about 2 months in their nursery ground and then migrate offshore. This migration is associated with the shift of feeding habits from mysids to pisces in August when they reach 100 mm in body length. On the nursery ground, the most important food for Japanese flounder is mysid crustaceans (Imabayashi 1980b, Yasunaga and Koshiishi 1981, Koshiishi et al. 1985, Kato 1987).

The size of most artificial seed is less than 100 mm in body length when they are released. Seed are released into the natural nursery ground where the density of the flounder is normally the highest. In this stage, releasing

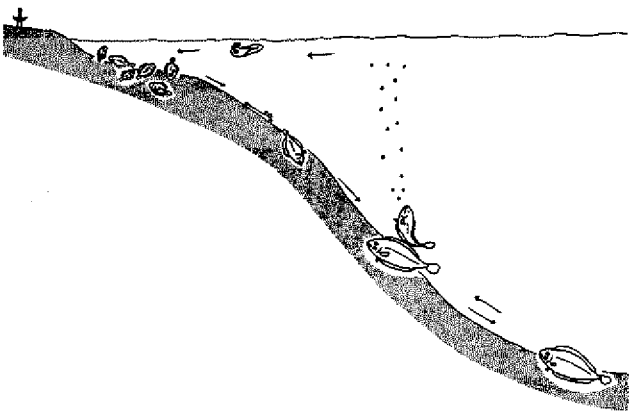

*Figure 1. The life cycle of Japanese flounder.*

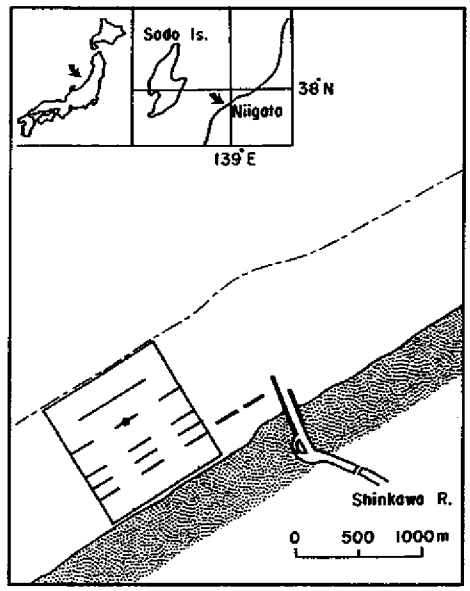


*Figure 2. The research area in the shallow waters off Igarashi-Hama. Artificially produced flounder were released along the line with a dot, and collected along the lines in the research area and around the area. Each side of the research area is 1 km. The dotted line indicates a 10 m contour.*

**Table 1. The date of the release, number, mean body length, and standard deviation of released flounder.**

| Date of release | Number of released flounder | Mean bodylength of released flounder(mm) | Standard deviation |
|---|---|---|---|
| 1990.6.28 | 120,000 | 43.4 | 7.53 |
| 1991.7. 2 | 80,000 | 52.5 | 9.99 |
| 1992.6.30 | 58,000 | 43.9 | 4.89 |

artificial seeds may cause severe interactions between released and wild fish, such as competition for habitat or food; the latter results in cannibalism or starvation.

In this report, we focus on the ecological interactions between released and wild flounder.

## MATERIALS AND METHODS

This study was carried out from 1989 through 1992 in the shallow waters off Igarashi-Hama on the northwestern coast of Japan (Fig. 2). Igarashi-Hama is part of a 60 km sandy beach.

Field surveys of wild flounder and food organisms were carried out from 1989 through 1992. Experimental releases of artificial seeds were carried out on June 28, 1990, July 2, 1991, and June 30, 1992, which is the suitable season for the release of Japanese flounder (Koshiishi et al. 1986, 1988, 1991). The artificial seeds were released in 6-m-deep water (release site located along line with a dot; see Fig. 2). Hence, this line will be called "the release line."

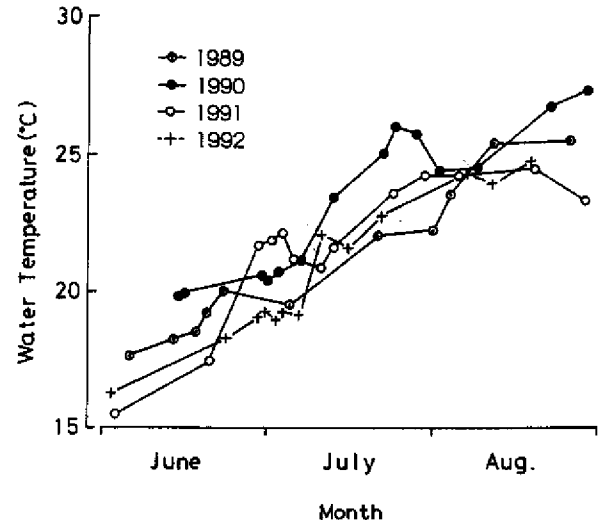


*Figure 3. The water temperature at a depth of 4 m from June through August.*

The number of released flounder was 120,000 in 1990, 80,000 in 1991, and 58,000 in 1992. The mean body length was 43.4 mm in 1990, 52.5 mm in 1991, and 43.9 mm in 1992 (Table 1).

The flounder and food organisms were collected periodically along the lines in Figure 2 and around the research area. To collect the flounder, a small beam trawl of 2 m width and 0.4 m height was used. The net aperture was 2.1 mm in early season and 3.6 mm in later season. To collect food organisms, a sledge net of 0.6 m width, 0.4 m height, and 0.76 mm mesh aperture was used. The towing speed of both gears was about 1.5 knots. Some flounder collected by the small beam trawl were preserved in a 10% seawater formalin solution, and others were frozen on the research boat and stored at -80°C for otolith microstructure or RNA/DNA analysis. The organisms collected by the sledge net were preserved in 5% seawater formalin.

The artificially produced flounder have melanism on the blind side and wild flounder don't. Released seed were distinguished from wild flounder easily by the melanism. The stomach contents of 979 wild flounder and 695 released flounder were examined to determine the feeding habits. The otolith microstructure was analyzed by Goto's method (Goto unpublished data) to estimate the growth rate of wild flounder. The modified Schmidt-Thaunhauser-Schneider (STS) method (Nakano 1988) was used to quantify RNA and DNA in the nucleic acids to evaluate the nutritional condition of released flounder.

## RESULTS AND DISCUSSIONS

### Population Size and Growth of the Wild Flounder in Relation to the Abundance of Food

The water temperature at 4 m depth from June through August is shown in Figure 3. In mid-June, when Japanese

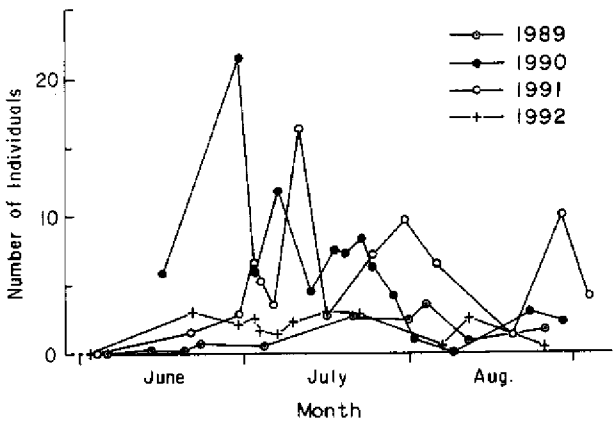


*Figure 4. The mean number of collected wild Japanese flounder per 500 m tow of the small beam trawl from June to early September in the research area. The gear was towed at the depth of 2, 4, 6, and 8 m on every sampling date.*

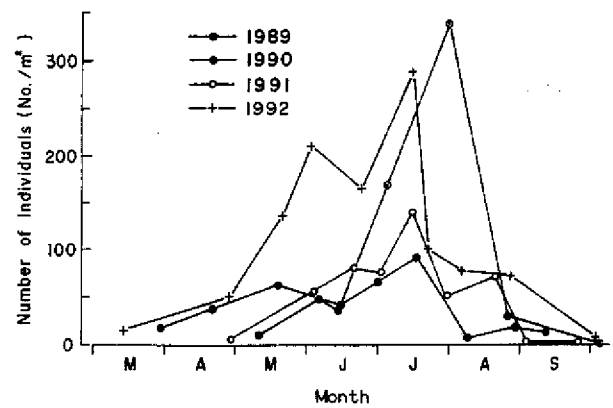


*Figure 5. The mean number of collected mysids per 1 m² by the sledge net from May to early October in the research area. The gear was towed at the depth of 2, 4, 6, and 8 m on every sampling date.*

flounder began settling, the temperature was between 18°C and 21°C. The highest temperature reached 26°C in late August. The mean water temperature in July and August was 23.0°C in 1989, 24.4°C in 1990, 23.1°C in 1991, and 23.0°C in 1992. The density of wild Japanese flounder in the research area increased in June and July, during the settling season, and decreased in August, during the offshore emigrating season (Fig. 4). The mean density of the wild flounder in the research area between mid-July, after the end of settling, and mid-August, before the beginning of the emigrating, was used as the population size index of that year. The population size index of the flounder was 2.4 in 1989, 5.4 in 1990, 7.2 in 1991, and 2.0 in 1992. The density of mysids, including about 20 species of which *Acanthomysis robusta* is dominant (Hirota et al. 1986), changes seasonally in the research area. It began to increase in May and June, peaked in July, and decreased rapidly in August (Fig. 5). The maximum abundance was found to be 339 individuals/m² in July 1989. The mean density of mysids in July and August, when Japanese flounder stay in the nursery, was used as the population size index of mysids of that year. The population size index of mysids also fluctuated annually and was 121 in 1989, 44 in 1990, 77 in 1991, and 114 in 1992.

During the nursery residence, Japanese flounder grow lineally in terms of the body length (Koshiishi et al. 1988). The daily growth rate of the wild flounder estimated from the microstructure of otolith was 1.9 mm in 1989, between 0.8 mm and 1.3 mm in 1990, depending on whether settling occurred late or early in the settling season, respectively, between 1.6 mm (late settlers) and 1.8 mm (early settlers) in 1991, and 1.8 mm in 1992 (Fig. 6). Rearing experiments show that high temperatures between 17 and 26°C result in high growth rates for all body lengths (Fig. 7; Fujii unpublished data). However, field data showed an inverse relationship between water temperature and the growth rate (Fig. 8). The relationship between population size of mysids and daily growth rate of wild flounder is shown in Figure 9. The growth rate depended on the population size of mysids. Rearing experiments showed that maximum daily growth rate is about 2 mm (Fujii unpublished data). The observed daily growth rate of 1.8 to 1.9 mm is higher than any other nursery ground in Japan (Imabayashi 1980a, Goto unpublished data). The growth rate was not limited by food in 1989 and 1992. In 1990, when mysids were less abundant, a decrease in the growth rate was observed. In 1991, the decrease in growth rate was observed only among the late settlers. Therefore, growth rate in 1990 and 1991 is considered limited by food.

It has been reported that the growth rate of plaice *Pleuronectes platessa* in the western Wadden Sea, the Netherlands, is not limited by food (Van Der Veer 1986). However, it has also been suggested that growth is limited by both water temperature and availability of food in some species of flatfish such as plaice (Berghahn 1987, Van Beek et al. 1989 Karakiri et al. 1989), winter flounder *Pseudopleuronectes americanus* (Sogard and Able 1992), and sole *Solea solea* (Marchand 1991). It appears that the abundance of food is more effective in influencing annual growth rate of Japanese flounder than the water temperature for the research area. If the supply of the food is sufficient, then the water temperature might determine the growth rate.

**Dispersion, Feeding, and Growth of Released Flounder**

An example of dispersion is shown in Figure 10 for 1992. Released flounder dispersed gradually both offshore and parallel to the coast. Offshore movements were limited to water depth less than 8 m. During the nursery residence,

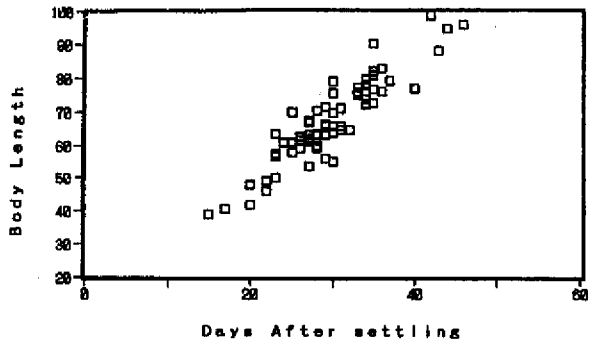


Figure 6-1

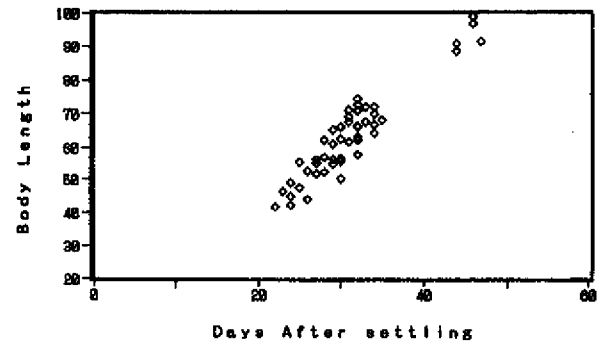


Figure 6-3

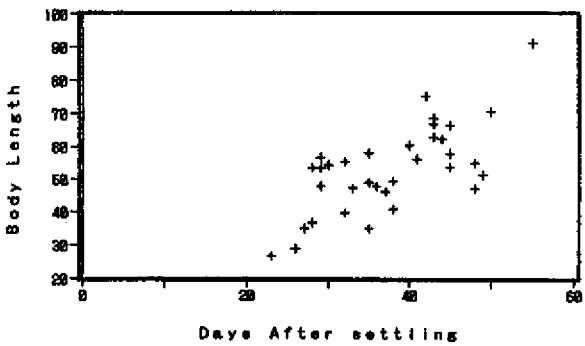


Figure 6-2

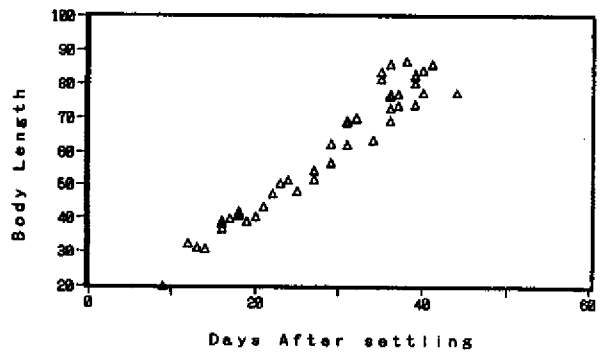


Figure 6-4

*Figure 6. The relationship between the days after settling estimated from otolith microstructure and body length of wild flounder; 6-1, 1989; 6-2, 1990; 6-3, 1991; 6-4, 1992.*

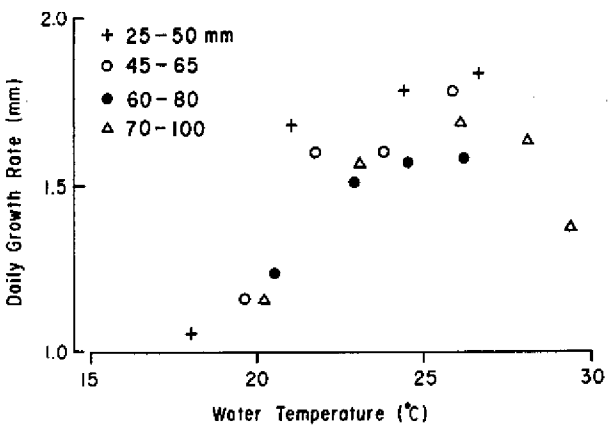


*Figure 7. The relationship between water temperature and the daily growth rate of reared Japanese flounder for different sizes of body length.*

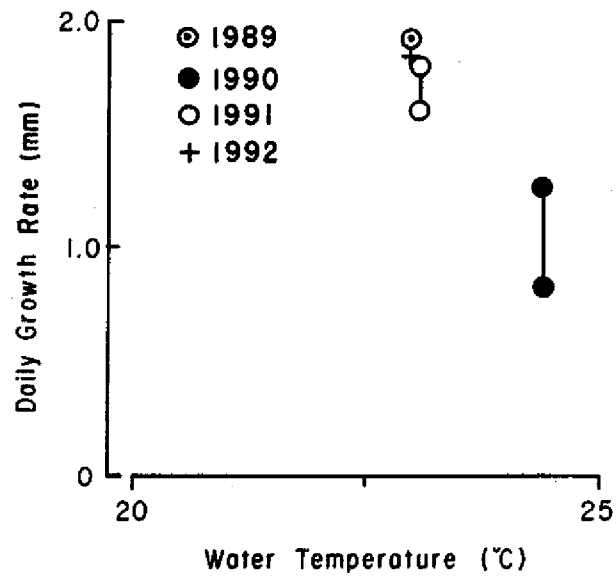


*Figure 8. The relationship between mean water temperature in July and August and the daily growth rate of wild Japanese flounder collected in the research area.*

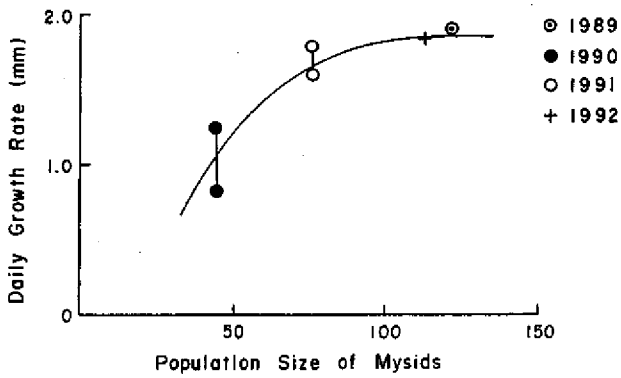


*Figure 9. The relationship between the population size of mysids and daily growth speed of wild Japanese flounder collected in the research area.*

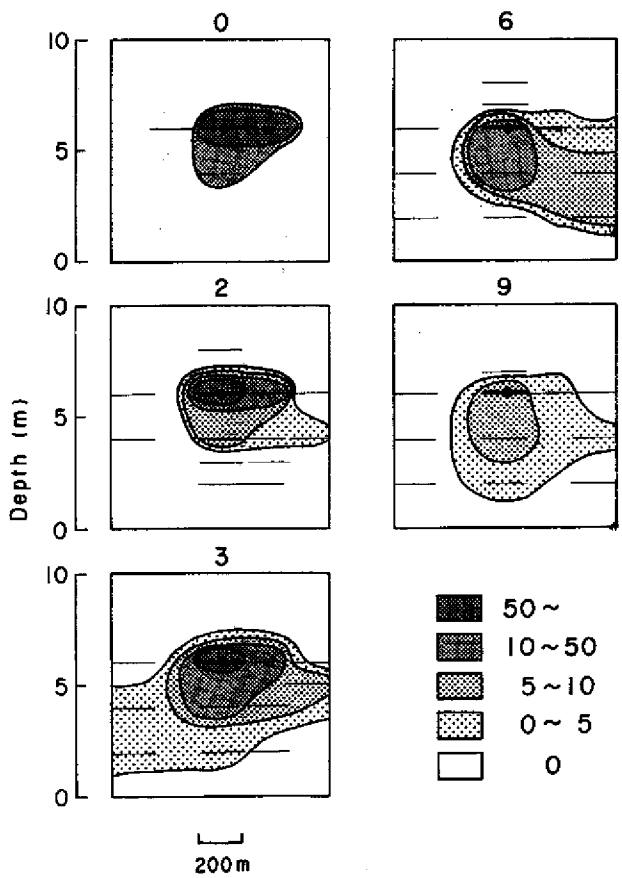


*Figure 10. The process of the dispersion of released flounder in 1992. The squares show the research area. The numbers beside the squares show the days after release. The density of dots indicate the number of recaptured flounder per 200 m tow of the small beam trawl.*

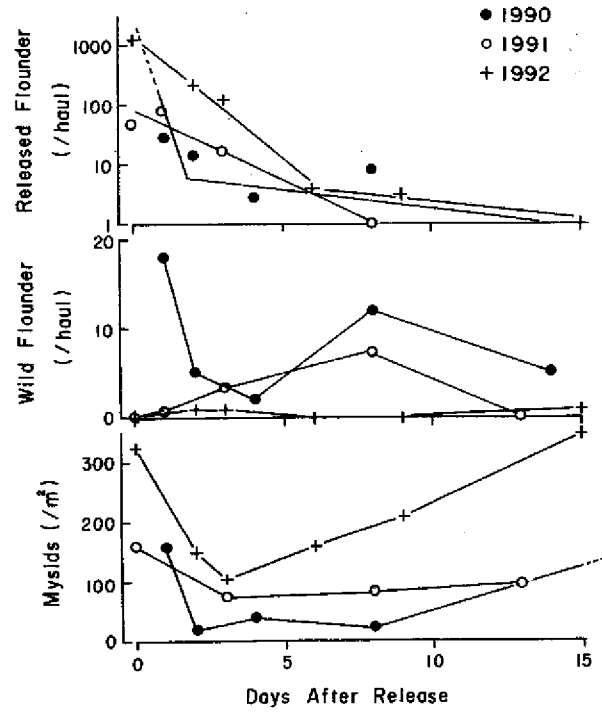


*Figure 11. The density of released flounder (per 200 m tow), wild flounder (per 200 m tow), and mysids (per m²) caught along the release line at intervals after release.*

the farthest distance where released flounder were recaptured was 2.5 km from the release site, and most released flounder were recaptured less than 1 km from the release site. The number of flounder recaptured in the first 5 days after the release along the "release line" was greater in 1992 than in 1990 and 1991 (Fig. 11, upper column) although the number of released flounder was the smallest in 1992 (Table 1). The density of mysids along the release line decreased rapidly just after the release but began to recover 10 days later. The minimum density of mysids along the release line was 20 individuals/m² in 1990, 73 in 1991, and 108 in 1992. In 1992, the minimum density of mysids was five times as much as 1990, and it recovered more rapidly than in 1990 and 1991 (Fig. 11, lower column). Perhaps a shortage of food hastened the dispersion of flounder in 1990.

The incidence of feeding (percentage of fish found with food in their stomach) and feeding rate (stomach content weight of all fish/body weight of all fish) of released flounder recaptured in the research area is shown in Figure 12. The incidence of feeding of released flounder was greater in 1991 and 1992, and feeding rate was also high except for a few sampling data. It appears that in 1990, when the growth of wild flounder was limited by food, the food shortage caused both the reduction of the feeding incidence and feeding rate of released flounder. The RNA/DNA ratio, an indicator of nutritional condition of the

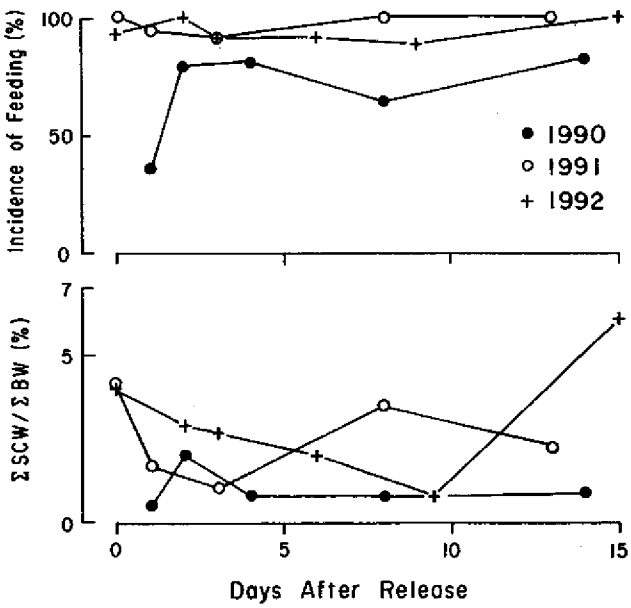


*Figure 12. The incidence of feeding (percentage of fish found with food in their stomach) and feeding rate (stomach content weight of all fish/body weight of all fish, ΣSCW/ΣBW) of released flounder at intervals after release.*

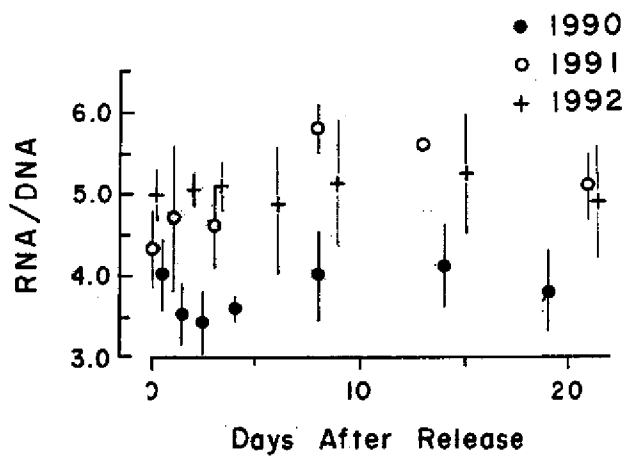


*Figure 13. The ratio of RNA/DNA as an indicator of the nutritional condition of released flounder at various intervals after release.*

flounder (Fujii 1990), decreased for 3 days after the release in 1990, while it didn't in 1991 and 1992 and, in fact, was maintained at a higher level than in 1990 (Fig. 13). It is suggested that the nutritional condition of released flounder in 1990 was poor compared with other years.

Released flounder did not grow for 4 or 5 days after release. This phenomenon has also been observed in the rearing experiments (Fujii unpublished data). Since feeding of the artificial seed is stopped 2 or 3 days before the release to prepare for the transportation, it is likely that

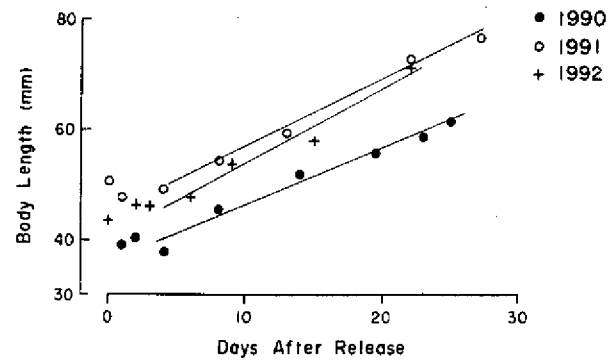


*Figure 14. Mean body length of the released flounder at intervals after release.*

it takes 4 or 5 days for released flounder to recover physiologically prior to the beginning of growth. After that, they grew lineally and the daily growth rate was 1.0 mm in 1990, 1.2 mm in 1991, and 1.4 mm in 1992 (Fig. 14). The mean water temperature during the first month after release was 23.6°C in 1990, 22.1°C in 1991, and 21.6°C in 1992. Rearing experiments show that higher temperatures in this range led to higher growth rate (Fig. 7; Fujii unpublished data). It is suggested that the abundance of mysids resulted in the highest growth rate in 1992 in spite of the low water temperature.

### Comparisons of Distribution, Feeding Habit, and Growth Between Released and Wild Flounder

The number of captured wild flounder along the release line was low or decreased rapidly after the release and increased as the the density of released flounder decreased except for 1992, when the population size of wild flounder was relatively small (Fig. 11, middle column). At other stations in the research area, population movements of wild and released flounder appeared to be more independent.

The comparison of incidence of feeding, feeding rate, and stomach contents of wild and released flounder in 1990, when wild flounder were abundant and mysids were less abundant, is shown in Figure 15. Released flounder were inferior to wild ones in both incidence of feeding and feeding rate. Food composition was slightly different between released and wild flounder. Released flounder recaptured on days 1, 2, and 4 had ingested gammarids, which the wild flounder had not. In 1992, when mysids were abundant, more than 85% of the released flounder ingested food on every sampling date. There is no significant difference in the feeding rate between wild and released flounder (Fig. 16). Released flounder did not ingest gammarids. It is suggested that when the density of mysids is low, released flounder do not ingest food efficiently compared with wild flounder.

The Japanese flounder is cannibalistic (Minami 1986).

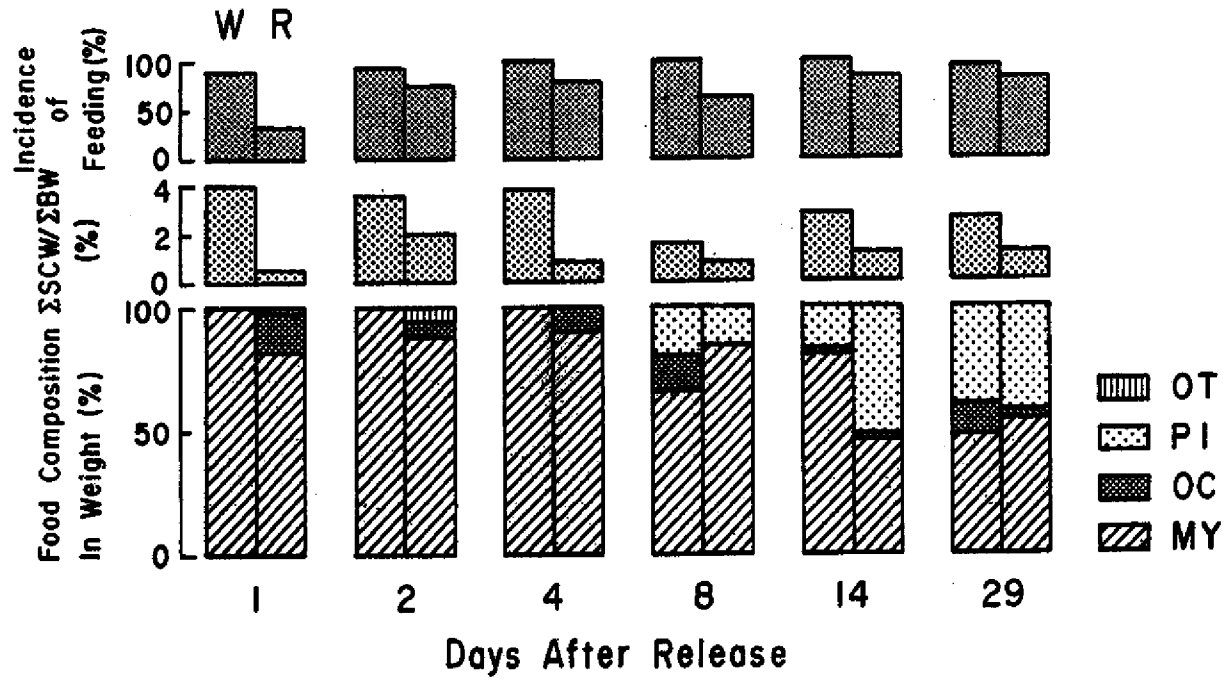


*Figure 15. Comparison of incidence of feeding (percentage of fish found with food in their stomach, upper section), feeding rate (stomach content weight of all fish/body weight of all fish, ΣSCW/ ΣBW, middle section) and food composition in weight between wild (left side) and released flounder (right side) at each sampling date in 1990, when the food was less abundant. Numbers under the lower column show the days after release (MY=Mysidacea, OC=other crustaceans, PI=Pisces, OT=others).*

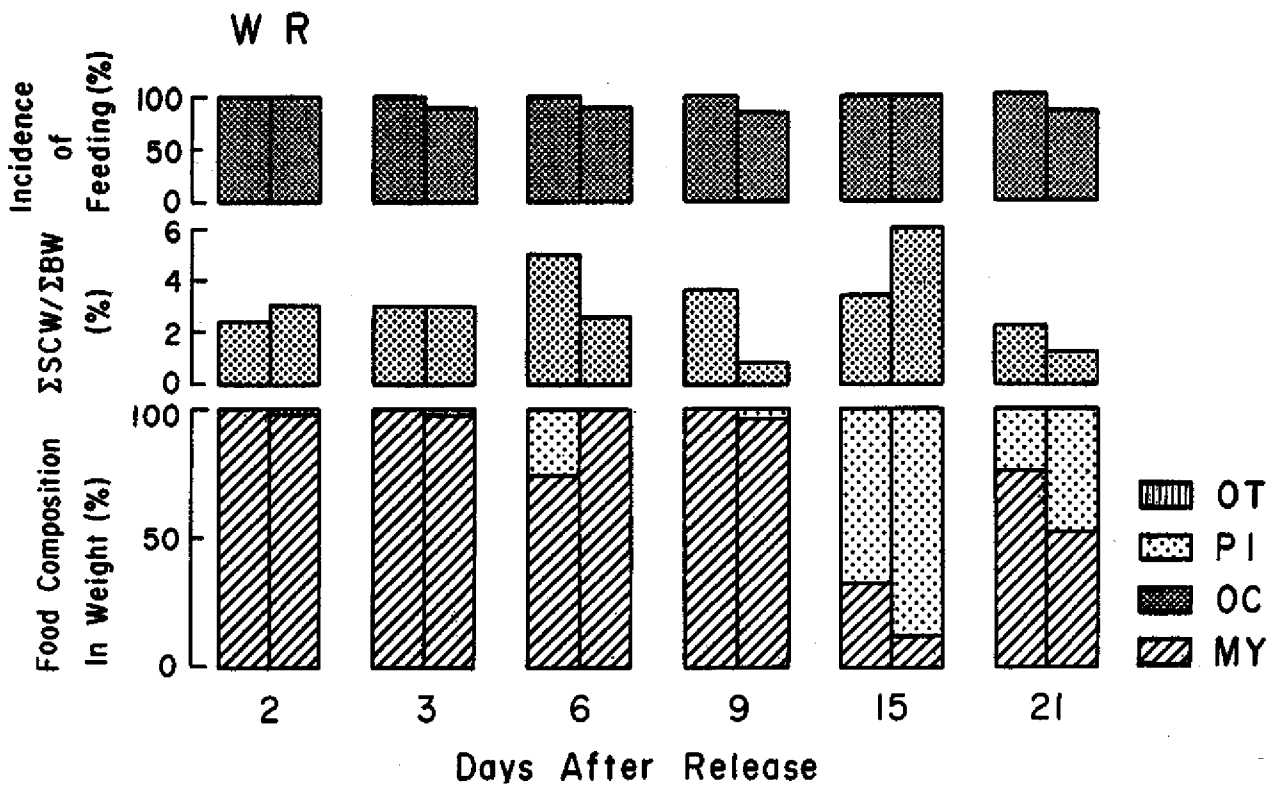


*Figure 16. Comparison of incidence of feeding (percentage of fish found with food in their stomach, upper section), feeding rate (stomach content weight of all fish/body weight of all fish, ΣSCW/ ΣBW, middle section) and food composition in weight between wild (left side) and released flounder (right side) at each sampling date in 1991, when the food was abundant. Numbers under the lower column show the days after release (MY=Mysidacea, OC=other crustaceans-PI=Pisces, OT=others).*

**Table 2. Body length of 1-year-old Japanese flounder that ingested released flounder, number of released flounder found in the stomach, and their body length.**

| Date | Body Length of Predator(mm) | Number of Released flounder in stomach | Body Length of Prey(mm) |
|---|---|---|---|
| 1991.7. 3 | 174.5 | 2 | * - 53.0 |
| | 159.5 | 1 | 53.1 |
| | 160.0 | 1 | 43.0 |
| 1992.7. 2 | 184.0 | 8 | 41.2 - 49.6 |
| 7. 3 | 173.5 | 1 | 49.9 |
| | 187.5 | 3 | * |
| 7. 6 | 190.0 | 1 | 42.9 |

*unable to determine length

It has been reported that if the difference in body length is more than three times, then cannibalism can occur (Tanaka et al. 1989). From 1990 through 1992, the difference in body length between released flounder and the "late settlers" was enough to cause cannibalism. However, none was found among 0-year-old Japanese flounder. Some of the 1-year-old Japanese flounder collected in the research area ingested released flounder (Table 2). Released flounder may be inferior to wild flounder in their ability to escape from predators.

The growth rate of released flounder was always less than wild flounder. For example, reduced feeding ability of artificial seed (Furuta 1988) may cause a reduction in the growth rate.

## CONCLUSION

An abundance of mysids is needed for the success of artificial seeds on their nursery grounds. In the absence of food, release of artificial seeds will not be successful. Further investigations on the carrying capacity and improvement of the quality of the artificial seeds are needed to enhance the stock size of Japanese flounder efficiently.

## ACKNOWLEDGMENTS

We would like to thank the fishermen of Igarashi-Hama; without their support and cooperation, our research could not have been accomplished. We are also grateful to N. Naganuma and K. Kubota for their helpful assistance.

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# Use of Triploids for Gene Conservation of Salmonids

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## EXTENDED ABSTRACT

The use of triploid fish has been promoted for many management applications (Ihssen et al. 1990, Thorgaard 1992). Stocking of triploid salmonids instead of diploids may promote long-term conservation of biodiversity. Stocking diploids can result in unwanted hybridization, predation, or competition with native species (Taggart and Ferguson 1986, Garcia de Leániz et al. 1989, Mork 1991). Triploids are reproductively sterile, thereby eliminating the potential for hybridization (Allen et al. 1986). In many salmonids, sterility also means that fish will live longer, resulting in some trophy individuals (Lincoln and Scott 1984, Donaldson et al. 1993). If competition or predation problems arise between stocked triploids and native species, then halting stocking would eliminate these interactions within one life cycle.

Interestingly, proposed uses in aquaculture include gene conservation as well as enhanced meat production (Seeb et al. 1993). Several nations have considered requiring that farmed salmonids be sterilized in order to protect wild stocks from introgression due to large-scale escapes (Gausen and Moen 1991, Lura and Saegrov 1991). Triploidy has also been suggested by some workers as a prerequisite to the use of transgenic fish (Kapuscinski and Hallerman 1990, Seeb and Miller 1990).

Problems with triploid production and performance occasionally have been reported, but these problems are not consistent and depend on the species examined and on the production environment. For example, achieving 100% triploids in production lots can be an elusive goal with some species, limiting conservation applications. Additionally, triploids have exhibited growth superior to (Scheerer et al. 1987), equal to (Habicht et al. 1994), or inferior to (Solar et al. 1984) the corresponding diploid controls depending on the species tested and rearing environment. Finally, there is a risk that triploid males may try to spawn with diploid females in wild-stock areas, disrupting wild-stock production (Masaru et al. 1993).

These factors make it difficult to form generalizations concerning usage of triploids. Successful applications will depend on project goals, and managers must balance the needs of gene conservation against the possibility of reduced performance of triploids. Thought must be given to standardizing certification of triploid salmonids for stocking and to the consequences of false spawning of triploid males.

Finally, managers must be aware that the risks of stocking diploids are seldom evaluated as thoroughly as are the risks of stocking triploids. Clearly, in some cases, use of diploids will have more dire consequences than the use of triploids. We believe that, given the information available now, use of triploids should be required for some types of stocking programs and most net-pen farming.

## ACKNOWLEDGMENTS

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# The Economic View of Artificial Propagation of Masu Salmon (*Oncorhynchus masou*)

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## ABSTRACT

The propagation of masu salmon (*Oncorhynchus masou*) to increase fishery production in an economically efficient manner faces major challenges. There are three methods of seed production and release. The economic advantages and disadvantages with regard to each method are analyzed and discussed.

Costs are higher for propagation of masu salmon than for chum and pink salmon. An important comparison is the combined production and release costs in relation to the smoltification ratio that is strongly influenced by the character of seed.

It should be mentioned, however, that production and release costs are only one part of the overall economic aspect of propagation of masu salmon. Recapture ratios and market prices also play vital roles. Moreover, natural conditions such as fresh water, climate, and water temperature are also important factors. Methods of seed production and release should reflect whatever natural conditions prevail at the propagation and release sites. These factors may point to the conclusion that the propagation of masu salmon has little potential as an economical profitable project in comparison to the propagation of chum salmon.

There are some other problems and challenges of an ecological and social nature with respect to the propagation of masu salmon. Mixture of stocks from different rivers is a big problem. Masu salmon, especially landlocked, is one of the most popular game fishes in Japan. Consideration from this viewpoint should be stressed. The most important challenge from both an ecological and social perspective is preserving natural reproduction. There are few natural stocks remaining in Japan. The propagation of masu salmon should not be undertaken if naturally reproducing stocks are lost.

## INTRODUCTION

Masu salmon (*Oncorhynchus masou*) inhabits the Asian side of the northern Pacific Ocean. Population size is not well known. The catch along the Japanese coastal area is about 2,000 or 3,000 metric tons and only 1 or 2% of the total catch of salmonid fish in Japan. Populations are thought to be decreasing to low levels.

In contrast, artificial propagation of chum salmon is a strong success in Japan. The catch of chum salmon in the Japanese coastal area has increased in recent years. However, there are some problems. Along the northern coast of the Japan Sea, the rate of return is still low. Also, the quality of chum salmon caught in the coastal area is poor. The total supply of all salmonid fish is too large, because of the increase of imported and cultured fish. Price has dropped to a very low level.

The quality and flavor of meat of masu salmon is very good, and its price on the market is much higher than that of chum salmon. Locally, it is sometimes more than ¥8,000 per kilogram. The geographical distribution of the catch for 1984 is shown in Table 1. Most of the masu salmon is caught along the Japan seacoast rather than the Pacific Ocean coast. The Japan Sea coastal fisheries have strongly requested that masu salmon resources be increased. Masu salmon is an endangered species, but it is also expected to be a fishery resource.

Masu salmon usually spend 1 year in fresh water prior to seaward migration as a smolt. They then stay in the coastal sea for 1 or 2 years until beginning a spawning up its parent river. Recent environmental degradation in these spawning rivers has resulted in serious decreases in masu salmon resources. We cannot expect masu salmon to increase only by natural reproduction in their native rivers. Artificial propagation technology should be established, based on the many studies and investigations that have been done. However, this practice point should be checked from an economic and social viewpoint. This is important in order for the fisheries to be successful.

**Table 1. Estimated landings of masu salmon in Japan during 1984 (in metric tons).**

| | Japan Sea | | Pacific Ocean | | Nemuro straits | Okhotsk Sea | Total | |
|---|---|---|---|---|---|---|---|---|
| | Hokkaido | Honshu | Hokkaido | Honshu | | | Hokkaido | Honshu |
| Off shore | 187.6 | 744.1 | 418.3 | — | — | — | 605.9 | 744.1 |
| Coastal | 562.4 | 1162.4 | 224.0 | 143.4 | 2.1 | 43.5 | 832.0 | 1305.8 |
| Total | 750.0 | 1906.5 | 642.5 | 143.4 | 2.1 | 43.5 | 1437.9 | 2049.9 |
| Each area | 2656.5 | | 785.7 | | 2.1 | 43.5 | 3487.9 | |
| (%) | 76.17 | | 22.53 | | 0.06 | 1.25 | 100.0 | |

**Table 2. Seed production cost of masu salmon per fish (in yen).**

| | fry-release in the first spring | fingerling-release in the late autumn | yearling-smolt release |
|---|---|---|---|
| Final weight | 20g | 25g | 20g |
| Egg price / berry | 2.0 | 2.0 | 2.0 |
| Survival ratio | 50% | 40% | 60% |
| 1. Egg | 4.0 | 5.0 | 3.3 |
| 2. Feed (conversion ratio is 1.5) | 7.5 | 9.4 | 7.5 |
| 3. Water source type 1 | 14.9 | 28.0 | 14.9 |
| type 2 | 1.2 | 2.0 | 1.2 |
| 4. Consumable items | 5.5 | 9.9 | 4.1 |
| 5. Labour | 6.6 | 8.0 | 5.3 |
| 6. Transportation | 2.0 | 2.5 | 2.0 |
| Total cost per fish type 1 | 40.5 | 62.8 | 37.1 |
| type 2 | 26.8 | 36.8 | 23.4 |

Water source type 1; well as source of water
type 2; water withdrawn from river

**Table 3. Seed production cost in relation to the smoltification ratio for masu salmon (in yen).**

| | smolt ratio | fry-release in the first spring | fingerling-release in the late autumn | yearling-smolt release |
|---|---|---|---|---|
| water source type 1 | 100 | 40.5 | 62.8 | 37.1 |
| | 80 | 50.6 | 78.5 | 46.4 |
| | 50 | 81.0 | 125.6 | 74.2 |
| water source type 2 | 100 | 26.8 | 36.8 | 23.4 |
| | 80 | 33.5 | 46.0 | 29.3 |
| | 50 | 53.6 | 73.6 | 46.8 |

Water source type 1; well as source of water
type 2; water withdrawn from river

## VALUE OF MASU SALMON

The value of masu salmon is not only to the commercial and sport fisheries; it is of social value to these people who want to preserve the salmon as an important part of the ecology of the river environment and as an important genetic resource. Thus, it is necessary to understand that the future of masu salmon cannot be determined only by its profitability in the fishery.

## PROFITABILITY AND COST OF ARTIFICIAL PROPAGATION OF MASU SALMON

In Japan, there are three methods of masu salmon seed production and release: fry-release in the first spring; fingerling-release in the late autumn prior to the overwintering period; and yearling-smolt-release at the time that wild smolts normally migrate to the sea. Each of these methods has its own advantages and disadvantages. Each method is suitable depending on geographic conditions.

Economic advantages and disadvantages and other problems associated with each method were analyzed and discussed for 5 prefectures with different geographic conditions—Iwate, Hokkaido, Aomori, Niigata, and Toyama. Differences in costs were determined among the three methods. The approximate seed production costs expected using each of the three methods are shown in Table 2. These costs are increased by initial or start-up costs. In many cases, however, initial costs are assumed by the government and can then be omitted.

The most important consideration, however, is the combined production and release costs per fish in relation to the smoltification ratio (Table 3). Actually, in many cases yearling-smolt release is chosen because of its cost advantage. These costs are much higher than in the case of chum salmon. Production and release cost of chum salmon is about 4 per fish. Production and release costs are only one part of the overall economic aspects of masu salmon artificial propagation. The recapture ratio also plays vital role.

**Table 4. Profit rate of chum salmon in Japan.**

〈1983〉

- number of released fry; 2,170,000,000
- total cost for production and release; ¥9,107,000,000

〈1987〉

- number of return; 46,753,000 ( rate of return; 2.12% )
- average weight; 3.5 kg/fish
- average price; ¥635/kg

〈Profit rate〉

- cost per caught fish; ¥9,107,000,000 / 46,753,000 = ¥194.8/fish
- receipt per caught fish; ¥635/kg * 3.5kg/fish = ¥2,222.5/fish
- profit = receipt - cost
  ¥2,222.5 - ¥194.8 = ¥2027.7
- profit rate = profit / receipt
  ¥2,027.7 / ¥2,222.5 = 0.91 ( 91% )

## CONDITIONS NECESSARY FOR MASU SALMON FISHERIES SUCCESS

We expect to be able to achieve a high profit rate in this project similar to that for chum salmon. A rough estimate of profit rate for chum salmon is shown in Table 4. The profit rate is more than 90%, which is a very high level.

The average price of masu salmon is about ¥1,500 per kilogram, higher than that of chum salmon. The average catch weight of fish is about 1.5 kilograms, and thus the price per fish is ¥2,250. If the expected profit rate is over 90%, the cost per caught fish should be under ¥225. Then, the rate of return necessary to achieve 90% profit rate can be estimated. Table 5 shows the rate of return necessary to achieve a profit rate similar to that for chum salmon. Yearling-smolt-release is the most profitable.

Yearling-smolt-release is also preferred for other reasons. In the case of fry-release, fry remain for a year in the river where the survival rate is estimated to be vary low and a high rate of return is then not expected. Fingerling-release is not preferred for the same reason. Moreover, hatcheries for these life stages need much water and there are very few places available. An additional reason exists. In the case of yearling-smolt-release, parent fish should be bred in ponds because the eggs must be taken in summer by artificial methods. These parents are selected from stocks that achieve a high smoltification ratio.

The rates of return shown on Table 5 may be achieved only in special cases and not under the technical level of production and release existing today. Normally, the rates of return reported are under 1%. Therefore, masu salmon fisheries cannot achieve an acceptable profit rate as long as the rate of return remains low. These rates on Table 5 thus become the targets for Japanese scientists and technicians to achieve.

**Table 5. Rate of return (in %) necessary to achieve the target profit rate of 90%.**

| | smolt ratio | fry-release in the first spring | fingerling-release in the late autumn | yearling-smolt release |
|---|---|---|---|---|
| water source type 1 | 100 | 18.0 | 27.9 | 16.5 |
| | 80 | 22.5 | 34.9 | 20.6 |
| | 50 | 36.0 | 55.8 | 33.0 |
| water source type 2 | 100 | 11.9 | 16.4 | 10.4 |
| | 80 | 14.9 | 20.4 | 13.0 |
| | 50 | 23.8 | 32.7 | 20.8 |

water source type 1: well as source of water
type 2: water withdrawn from river

## ESTIMATION OF OTHER VALUES

It is also important to understand values other than commercial and recreational harvest. The degradation of rivers is occurring everywhere, and the environment suitable for masu salmon reproduction is being destroyed. We should not exterminate the masu salmon species in its natural habitat. Conserving the natural environment in rivers and preserving natural stocks of masu salmon has great ecological value. From the standpoint of preservation of genetic resources, preservation of natural stocks of masu salmon is also of great value. At present, however, there is little societal support in Japan for the preservation of natural stocks of masu salmon.

Outside of the harvest fisheries, only sport fishing can exert social pressure that may influence the future existence of masu salmon. Masu salmon is considered the finest sport fish in the river systems of Japan in size, style, and fighting ability. The fish caught in the sport fishery are wild fish that return to the river for spawning. Because there are so few, many regulations exist for fishing. Since artificial propagation began in many districts, masu salmon fishing in rivers has been prohibited because the spawning fish in the river are used for propagation only. However, there are strong demands by the sport fishing community for masu salmon. Sport fishermen are gaining strong power in the Japanese society in response to the demand for leisure time. The masu salmon sport fishery depends on the existence of natural stocks. This is an important point to note.

## PHASES OF EXISTENCE OF MASU SALMON IN JAPAN

There are three phases of masu salmon existence in Japan. Figure 1 shows phase one when the life cycle of masu salmon is still natural and unaltered. Masu salmon can utilize the productivity of both the river and the sea. Figure 2 shows the second phase when development of rivers has

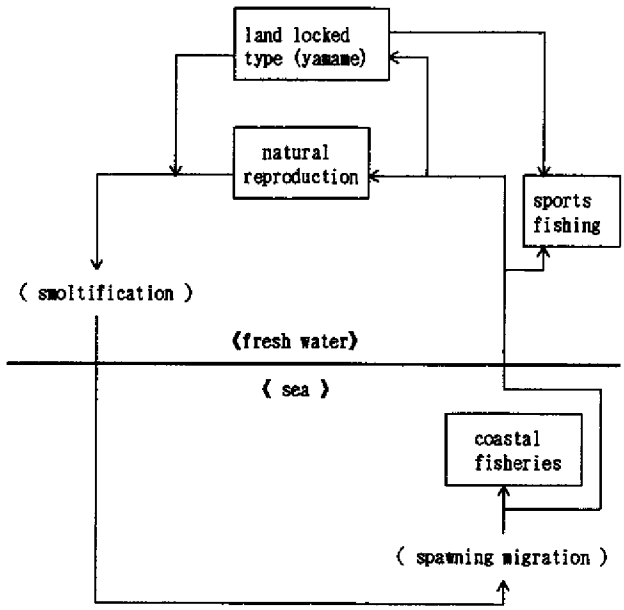


*Figure 1. Life cycle of masu salmon, first stage.*

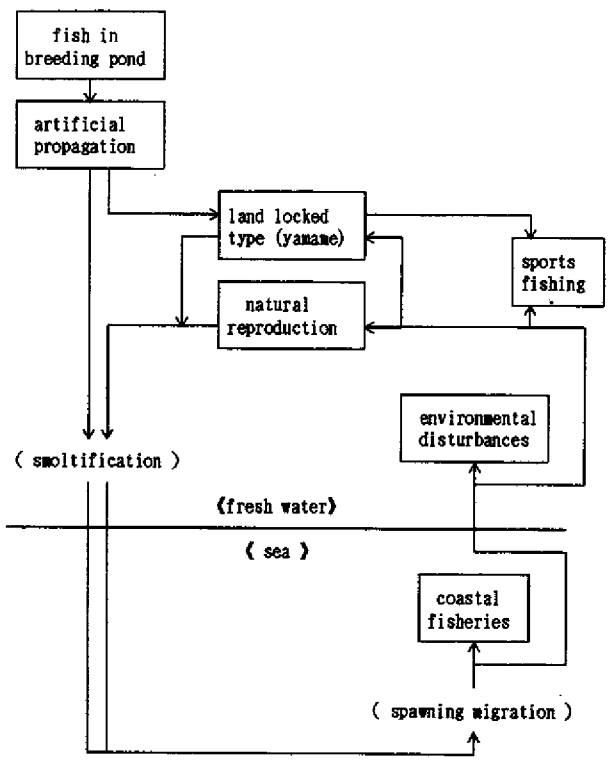


*Figure 2. Life cycle of masu salmon, second stage.*

begun, and environmental disturbances in the rivers have resulted in decreases in masu salmon resources. Artificial propagation begins in this phase. The natural process is still the most important component of the phase, and artificial propagation is expected only to replace losses. Sport fishing is still allowed. Figure 3 shows the final

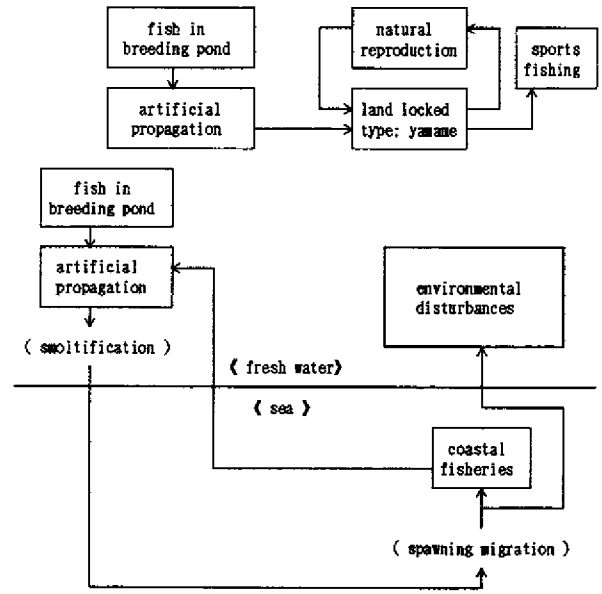


*Figure 3. Life cycle of masu salmon, third stage.*

phase where development of rivers has progressed to the point that natural stocks of masu salmon nearly disappear. In this phase, only artificial propagation can preserve masu salmon resources. Natural processes have been replaced by artificial processes such as the case of chum salmon. Reproduction is controlled artificially, and the cost is shared by the government and beneficiaries similar to the set-net fisheries. All of the spawning fish are caught, and there is no escapement for natural reproduction or the sport fishery.

It is an important question as to what phase our society should support for masu salmon resources. Actually, there is no choice. The development of rivers for flood control or water supply to big industries is continuing. Japan is presently in the second phase in Hokkaido and the final phase in Honshu Island. The ability to propagate artificially has been one of the conditions for which permission has been granted to develop rivers. The development of rivers has been one of the reasons that artificial propagation was needed. It is a vicious circle. Throughout this process, replacement has been continuing. It has become difficult to preserve the natural stocks.

There are many problems in the final phase for masu salmon resources. One of the biggest problems is that the reproduction of masu salmon is influenced by the profitability of fisheries. If the profitability of a project is not sufficient or if there are losses, then the project can no longer continue. The previous discussion on profitability shows this risk. If natural stocks are replaced completely by artificially propagated fish, then masu salmon will disappear. Of course, if the project is operated by the government, then any losses will be absorbed by them.

However, such costs cannot continue if this project is to be on a profit-making basis. Thus, projects should be done with two purposes: 1) to make a profit, and 2) to preserve masu salmon resources.

In the second phase, masu salmon resources are common property based on natural reproduction, and artificial propagation only replaces the losses. We catch and use masu salmon as a natural resource. However, in the final phase, masu salmon is no longer a natural resource. It is a kind of domesticated livestock or fish and may belong to anyone who pays for the cost of propagation. In Japan, because of the social and geographical background, the final phase tends to be prevalent. There are large changes in Japanese rivers. Because much of the population live in the low plains, flood control is necessary. Large manufacturing industries and cities demand a lot of water. To promote industry and to supply water to the people in the cities, the government constructed many dams on numerous rivers where masu salmon migrated for spawning.

However, society needs to consider all facets of these problems, including the value of natural stocks and how to preserve them. Artificial propagation is necessary for the commercial fisheries and for the preservation of masu salmon. It will be a difficult challenge to stay in phase 2.

The sport fishing community is only one component of society that has considerable power to insist on the continued existence of natural stocks of masu salmon. However, there is no resource management system that includes sport fishing. Only commercial fisheries can manage the resource.

In my opinion, we should create a resource management system that will include both commercial fisheries and sport fishing. Then, the sport fishing constituency can help pay for the propagation. This system should be operated on a non-profit basis and supported by the public. Through this arrangement, artificial propagation could be promoted as well as the preservation of natural stocks through negotiation with industries.

## TODAY'S CHALLENGES IN STUDYING MASU SALMON ARTIFICIAL PROPAGATION

In the United States, resources of salmonid fish are maintained primarily by natural reproduction. Natural environments suitable for their reproduction are scientifically studied and investigated. Research on the fresh water environment and ecological system have been done for a long time. Sport fishing plays a vital role in resource management.

In contrast, in Japan research is focused on the technology of artificial propagation. There has been little study of the environment or the ecology of freshwater systems. Also, minimal attention has focused on developing a resource management system for salmon. In Japan, the condition of the rivers is very different from the United States. Research on the freshwater environment and ecological system should be urged. Based on these studies, a resource management system for masu salmon should be established. This system should include sport fishing, in order to preserve the natural stocks and provide for commercial fishery resources. This is a difficult but important challenge for today's Japanese researchers.

# Induced Masu Salmon Spawning of Diploid Females by Triploid Males

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## ABSTRACT

Sexual behavior of triploid males of masu salmon (the Amago strain, *Oncorhynchus masou rhodurus*) was observed to determine whether they showed quivering, a typical courtship behavior of salmonids, and if this behavior could induce spawning behavior and oviposition of diploid females. The triploid males showed external secondary sexual characteristics without sperm, while the diploids were spermiating. A triploid or diploid male was placed in an aquarium with an ovulated diploid female, and the behavior of male fish was observed. Triploid males showed typical quivering toward ovulated diploid females as did diploid males. In the first experiment, the mean frequencies of quivering in the triploids and diploids were 83.6/h and 40.7/h, respectively. However, females failed to spawn with both diploid and triploid males. In the second experiment with slight modification of the aquarium conditions, the frequencies of quivering in triploid and diploid males were 89.0/h and 75.8/h, respectively. All the females tested spawned accompanied by spawning behavior of males, irrespective of the male ploidy. These results indicate that triploid male masu salmon without sperm show typical courtship behavior and have the ability to induce spawning of ovulated females, suggesting that a female could spawn with a triploid male even in a natural environment.

## INTRODUCTION

Technical development of chromosome set manipulation has promoted not only experimental but also practical uses of triploid fish whose performances are expected to be better than those of diploids, due to their lower investment in gonad genesis (Lincoln and Bye 1984). In general, although triploid females have poorly developed ovaries, triploid males in some salmonids have been known to have partially developed testes with normal levels of reproductive hormones (Benfey and Sutterlin 1984, Lincoln and Scott 1984, Johnson et al. 1986, Kobayashi 1992, Kobayashi et al. 1993). Also, triploid females of masu salmon are sterile, and the testes of triploid males are less developed than diploid males and have no spermatozoa even in the breeding season (Nakamura et al. 1987). However, the males show external secondary sexual characteristics with similar levels of steroid hormones and gonadotrophic hormone (GTH) as diploid males. These facts lead us to assume that triploid males, even without sperm, show typical sexual behavior toward diploid females. The sexual behavioral pattern of triploid fish has not been fully investigated. Prior to actual use of triploid fish for fish farming, their reproductive potentialities should be fully investigated, and the risk of their escape into a natural environment should be assessed. In this study, sexual behavior of triploid males of masu salmon was observed to determine whether males show quivering, a typical courtship behavior of salmonids, and if this behavior would induce spawning behavior and oviposition of diploid females. Part of this paper has been presented earlier in a preliminary form (Kitamura et al. 1991).

## MATERIALS AND METHODS

The test animals used in this study were masu salmon of the Amago strain, *Oncorhynchus masou rhodurus*. Fish were raised on a commercial trout diet in an indoor glass tank (30 x 60 x 30 cm in size; water temp., 13-16°C), and in an outdoor pond (1 x 4 x 1 m in size; water temp., 13-16°C). Triploidy was induced by hydrostatic pressure at 650 atm for a duration of 6 minutes, 15-30 minutes after fertilization (Onozato 1983). Triploids were identified just prior to the experiments by comparing major axes of red blood cells (RBC) with those of diploid controls, using an image analyzer (Ibas 2000, Zeiss Co. Ltd.). The following two experiments were conducted in 1989 and 1990.

In the first experiment, triploid males were 2 years old and diploids were yearlings. The mean values of RBC major axes of triploids and diploids were 18.5-20.0 mm and 14.8-15.8 mm, respectively. The body lengths of

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**Table 1. Frequencies of quivering displayed by the triploids and the diploids of male masu salmon toward ovulated females, and number of pairs in which spawning act was observed.**

| Combination | 1989 | | 1990 | |
|---|---|---|---|---|
| | 2n-M x 2n-F | 3n-M x 2n-F | 2n-M x 2n-F | 3n-M x 2n-F |
| Number of pairs | 10 | 5 | 5 | 3 |
| Quivering/hr | 40.7 | 83.6* | 75.8 | 89.0 |
| Number of spawned pairs | 0 | 0 | 5 | 3 |

Frequencies of quivering displayed by male were counted for 1 hour from the time when the first quiver was observed. M, male; F, female.
* $p<0.05$ (Mann-Whitney U-test).

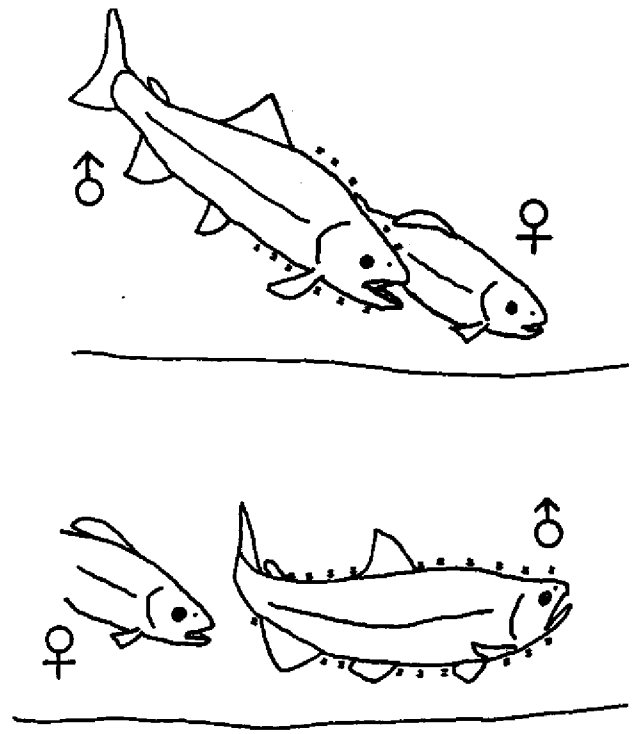

*Figure 1. Two different patterns of quivering by male masu salmon. A: male approaches the female from downstream and vibrates his body on one side of the female; B: male arches and strongly vibrates his body upstream or on one side of the female. Total frequencies of both types of quivering were counted.*

triploids and diploids ranged from 25.0 to 28.5 cm and from 19.0 to 24.5 cm, respectively. The test tank was 45 x 90 x 45 cm in size, with a sufficient depth of gravel to allow for nest building. Precooled well water (15°C) was provided at a velocity of about 3cm/s through the tank during the experiments. A triploid or diploid male was placed in the tank with a diploid-ovulated female (2 years old, body length 22.8-28.8 cm), and then male behavior was observed and recorded using a video camera recorder for a constant time. Frequencies of quivering displayed by males were counted for 1 hour from the time of the first quiver, and subsequently, whether or not spawning occurred, was observed for 24 hours. Ten different pairs of diploid male-diploid female and five pairs of triploid male-diploid female were used. In the first experiment, we failed to induce female spawning, and then conducted the following experiment. Both triploid and diploid males were yearlings. Body lengths of the triploids and the diploids were 12.5-18.9 cm and 17.0-18.3 cm, and the average major RBC axes were 18.3 mm and 16.9 mm, respectively. Diploid-ovulated females paired with the males were 2 years old and 23.0-28.5 cm in body length.

In the second experiment, we modified aquarium conditions by changing tank size and water velocity to promote induction of oviposition. The tank size was changed to 45 x 120 x 45 cm, and the velocity was increased to 12 cm/s. Five pairs of diploid male-diploid female and three pairs of triploid male-diploid female were used. Other procedures were the same as those above. Differences in the frequencies of quivering between the triploids and the diploids was statistically evaluated by the Mann-Whitney U-test ($p<0.05$).

## RESULTS AND DISCUSSION

Although the triploid males used in this study showed external secondary sexual characteristics, their testes appeared to have almost no sperm. By contrast, the diploids were spermiated and sperm was easily expelled by slight pressure to the abdomen. Based on histological examinations (photographs not shown), almost no sperm was found in the seminal lobules of the triploid testes which is known to be involved in the production of steroid hormones, while seminal lobules in the diploid testes were filled with sperm. Although we did not determine steroid hormone levels in the present study, Nakamura et al. (1987) reported that steroid hormone and GTH levels in triploid male masu salmon are not significantly different from those in diploid male, as is the case of other salmonids (Benfey and Sutterlin 1984, Lincoln and Scott 1984, Johnson et al. 1986, Kobayashi et al. 1993).

Triploid males showed typical quivering behavior toward ovulated-diploid females as did diploid males. As reported previously (Kitamura et al. 1991), male masu salmon showed two different patterns of quivering (Fig. 1). The total numbers of the two types of quivering are shown in Table 1. The triploid and diploid males both began their quiverings 10 to 30 minutes after being placed in the tank. In the first experiment, the mean frequencies of quivering in the triploids and the diploids were 83.6/hr (range, 54-122/hr) and 40.7/hr (range, 9-79/hr), respectively. The former number was significantly higher than the latter. A possible reason that triploid males quivered

more than twice as much as diploids might be attributable to differences in the age between the triploids and diploids rather than in ploidy differences. In the first experiment, female spawning failed to be induced, although nest digging behavior by ovulated females was often observed. In the second experiment where the aquarium conditions were slightly modified, the triploids displayed a frequency of quivering similar to the diploids (Table 1). The frequencies of quivering in triploid and diploid males were 89.0/hr (range, 39-141/hr) and 75.8/hr (range, 34-109/hr), respectively, without significant differences. All the females tested spawned within 12 hours after the beginning of the experiments, irrespective of the male ploidy. However, at the moment of spawning, the triploids showed spawning acts without sperm release, while sperm release was observed in the diploids. Normal display of sexual behavior by triploid male masu salmon in these experiments can probably be ascribed to the natural activity of steroid hormone productions within the fish (Nakamura et al. 1987).

Thus, in this study, we confirmed that triploid male masu salmon without sperm show typical courtship behavior and have the ability to induce spawning of ovulated females. Similarly, Inada and Taniguchi (1991) observed that induced triploid males of ayu (*Plecoglossus altivelis*) with poorly developed testes chased female diploids and were involved in spawning activity. These investigations suggest that a diploid female could spawn with triploid males even in a natural environment. However, mating by normal females and triploid males, even if they have sperm that have the ability to fertilize, would result in abnormal development of the zygote. Escape or release of a large number of induced triploid males into a natural environment could affect the productivity of the natural resources.

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