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HERRING FRY PRODUCTION TECHNIQUES

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HERRING FRY PRODUCTION TECHNIQUES

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HERRING FRY PRODUCTION TECHNIQUES

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[Translator's note: page numbers are for the original Japanese text. These numbers are shown in the translation in brackets.]

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INTRODUCTION

The Japan Aquaculture Association Corporation was commissioned by the Fisheries Agency to publish the "Aquaculture Technique Series" for the purpose of disseminating aquaculture techniques. This series systematically arranges the results of aquaculture technique developments and aims at producing practical manuals for people involved in aquaculture (fry production, nursery culture, releases, etc.)

It is known that herring populations visit coastal areas every year during the spawning season to spawn. These visiting adult fish are an important fishery resource in areas of Hokkaido. In the late 1890's, the fish catch peaked at 970,000 tons, but later, there was a massive decline. In the first half of the 1990's, the catch had fallen to the level of 3,000 tons. Of these herring resources, the lake-marsh type herring spawn in the area of river mouths and in brackish lakes. These have a strong regional association and have the characteristic of repeatedly returning to the same spawning grounds. These populations are the ones that have been the subject of aquaculture operations.

From 1982 the Japan Aquaculture Association, Akkeshi Station, received requests from Hokkaido and other areas to culture lake-marsh type herring from the Doutou sea region. As a result there were activities to develop aquaculture techniques. Currently, there is capacity for producing and 1,000,000 fry. Production and release techniques have developed related to Furen Lake and Akkeshi Lake. The fishermen of the region had a major role in the nursery culture and releases, especial at Furen Lake. So far the results of protecting the visiting adult fish and fertilizing eggs has resulted in an increase from a fish catch of about 20 tons to a catch of 600 tons. Along with these results the regional fisheries cooperatives and towns established the Nemuro Jurisdiction Herring Seed Production Management Commission. Fry production facilities were built with national and Hokkaido prefectural assistance. Furthermore, in Hokkaido a seed production facility built on the Japan Sea was used in an initiative to culture herring from the Ishikari Bay race.

This document provides basic information on the herring culture technique development that occurred at the Japan Aquaculture Association, Akkeshi Station. This includes ecology and physiology both for culture of the parent stock and fry production techniques. It is hoped that this document will help advance the establishment of herring aquaculture.

The techniques that are documented here are not always in their final form. In the future there is a lot of room for improvement in technique development and expansion. This information is not just for the Japan Aquaculture Association, it is also for people who are associated with herring aquaculture and who are making efforts to accumulate new information.

In the preparation of this document I received permission to publish basic information and would like to express my sincere thanks to: Tokimasa Kobayashi, Fisheries Agency, Hokkaido Division Fisheries Laboratory (currently at the Tohoku Division Fisheries Laboratory); Takahiro Matsuhara of the same organization; Masaaki Fukuda, Central Fisheries Laboratory, Fisheries Agency; Atsushi Horii, Hokkaido Prefectural Kushiro Fisheries Laboratory; Keizou Ashimura, Hokkaido Prefectural Fisheries Laboratory; and Seiki Kawashita, Hokkaido Aquaculture Promotion Corporation, Haboro Station.

Also, I would like to express my sincere thanks for the guidance and cooperation I received in promoting technique development primarily from the following associated facilities: the Fisheries Agency, Hokkaido Division Fishery Laboratory; Hokkaido Prefectural Kushiro Fisheries Laboratory, the Hokkaido Prefectural Aquaculture Coordination Center, and the Hokkaido Aquaculture Promotion Corporation Haboro Station.

Japan Aquaculture Association Corporation

Board Chairman Kouji Imamura

I. HISTORY OF THE DEVELOPMENT OF TECHNIQUES FOR PRODUCING HERRING FRY AND CULTURE OPERATIONS

Because herring are an important fisheries resource around the world supplying large catches, there is a very long and active history of studies and resource propagation operations. This chapter reviews the past history of herring culture research, herring propagation operations, and techniques for producing eggs, larvae and fry. It introduces the technique development operations and efforts to enhance the resource at Furen Lake that were performed by the Japan Aquaculture Association Corporation, Akkeshi Station.

1. Basic research on herring

(1) Major research projects overseas on herring culture

According to Kurata (1959) there is a long history of experiments on the culture of Pacific herring and the rearing of larvae. The earliest reference to rearing herring was by Meyer (1876). In the reports before the 1930's, it was only possible to culture through the absorption of the yolk. Kotthaus (1939) was the first to rear herring after yolk absorption. Schach (1939) was the first to successfully rear the larvae past metamorphosis. Later, with improvements in culture techniques, Dannevig (1948) obtained survival rates of 20% or more. Also, with Blaxter, et al. (1968), it became easy to assure a supply of eggs for the researches to use in culture experiments.

(2) Basic herring studies and culture operations in Hokkaido

According to Maruyama (1997), herring research in Hokkaido began in 1870 in the form of studies on fishery catches. Hokkaido Fisheries Research Laboratories were established in 1901, and basic herring research was initiated. According to Kobayashi (1993), historically, in Japan basic herring research on herring age, growth, number of eggs, etc. was published in the decade of the 1910's. In the 1920's information was collected on circular migratory movements, spawning, and feeding behaviors. Herring fish catches have wide fluctuations, so it was necessary to make catch predictions on the migrations. Since the 1920's there have been extensive studies related to forecasting the fishery. Since then, in order to determine changing trends in the herring resource, research centered on clarifying the structure of herring populations.

The principal references that analyzed the herring races in the vicinity of Hokkaido and Sakhalin were initially Ikuta (1924), Yamaguchi (1926), Fujita and Okubo (1927). Later references were Kontou (1965), Sanjou, et al. (1968), and Inoe (1980). Kontou & Kitahama (1953) and Kontou & Uchiyama (1958) performed herring tag-and-release experiments that elucidated migratory movements. (Kanno, 1982, 1983a, 1983b) accomplished the major achievement of analyzing the Pacific herring resources and the principal morphological characteristics of the races in the vicinity of Japan. Furthermore, Kobayashi (1979, 1983, 1990, and 1993) studied the isoenzymes of the Pacific herring in detail for all regions of Japan, and used population genetics to differentiate intraspecific characteristics.

Iizuka (1987) summarized the herring propagation projects for Hokkaido that began in 1924 in response to the decline in the Hokkaido-Sakhalin resource. Basic studies on artificial hatching were begun at Hokkaido Fisheries Laboratories. From 1934-1935, the Akkeshi Fisheries Cooperative hatched 20,000,000 – 60,000,000 eggs and released the fry. Large scale projects were performed over a 12-year period from 1941-1952 and involved the hatch and release of 20,000,000,000 – 40,000,000,000 herring. However, in both operations the release results were not effective.

Kurata (1959) clarified the basic culture conditions for rearing herring with experiments on the larval temperature and salinity tolerances, feeding, and phototaxis. When using

artemia as food, there was survival seven weeks after hatching, though at a low rate. Large scale experimental culture projects for useful fish species were contracted by the Japan Fisheries Agency as part of the program called “Research for Developing Techniques for Commercializing Herring Culture.” Kusakari and Mori (1978) reared herring for 55 days after hatching at the Hokkaido Aquaculture Coordination Center in 1974. Kuwatani, et al. (1978) performed research under the same contract at the Hokkaido Fisheries Laboratory to determine culture environmental conditions. However, though the herring were reared with feeding to the fingerling period, survival was extremely poor. Large scale fry production has not been successful.

2. Efforts towards herring nursery production and resource enhancement

(1) Technique development by the Japan Aquaculture Association

Aquaculture techniques were developed in order to enhance the herring resource. Starting in 1982, the Akkeshi Station and the Miyako Station of the Japan Aquaculture Association began nursery production. At the Miyako Station, Mangokuura herring were used and 50,000 nursery fish were reared to a total length of 30 mm. At the Akkeshi Station, Notoroko herring were used and 84,000 nursery fish were reared to a total length of 66 mm. Both production projects were successful (Yamamoto, et al., 1983). Later, at the Akkeshi Station, nursery technique development was performed with Furen Lake herring and Akkeshi herring. Current techniques allow a stable production of 1,000,000 or more herring with a 40% survival rate (Figure I 2-1).

Currently, the two councils of the Furen Lake related fisheries cooperatives and the Akkeshi Fishery Cooperative have established nursery cultures, and there have been tag-and-releases of several hundred thousand to a million fish. Following the releases there were follow-up studies on recovery rates to estimate the migratory dispersion in the eastern part of the seas off Hokkaido. By comparison, at the Miyako Station Matsuzaki Bay (mainly Mangokuura) and Miyako Bay fry production techniques were developed for the herring that visit for spawning. Several hundred thousand to a million were tagged and released. Hachihata, et al. (1991) reported on the growth and migratory behaviors of fish that were released on the Pacific Ocean side of northern Japan.

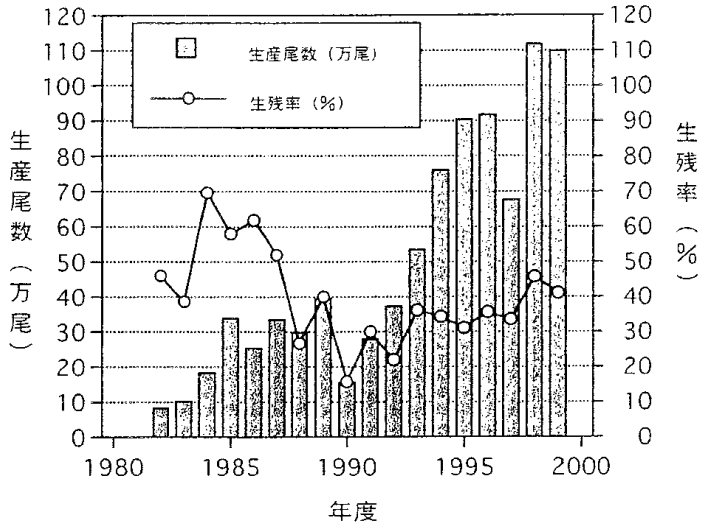

Figure I 2-1 Change over time in the number of herring seed produced and the survival rate at Akkeshi Station.

[y axis, left] Number of seed produced (10,000 fish)
[y axis, right] Survival rate (%)
[x axis] Year
[legend - rectangles] Number of seed produced (10,000 fish)
[legend – open circles on line] Survival rate (%)

(2) Efforts to enhance the Furen Lake herring resource and the current situation

1) Changes over time of Furen Lake herring catches and initiatives to enhance the resource

Furen Lake is in the eastern part of Hokkaido and faces Nemuro Bay. It has a circumference of 96 km and a surface area of 57.5 km^2. It is a typical lagoon, and the effect of fresh water makes the area strongly brackish. This lake is a habitat for lake-marsh type herring, which are the subject of a fishery. Since 1983, Furen Lake herring resource projects have been performed by the Japan Aquaculture Association, Akkeshi Station with the cooperation of the Bekkai Fisheries Cooperative. Eggs were obtained from mature herring which had come to Furen Lake for spawning, and the fry were nursery cultured in Furen Lake. This was followed by tag-and-release studies (Yamamoto and Ohana (2000). Prior to 1988 the scale of the Furen Lake fishery resource was on the order of 20-40 tons per year, but in 1988 and later, it increased to 100's of tons (Figure I 2-2). In 1989, autonomous groups, the fisheries cooperatives and associated experimental facilities in the Furen Lake area started the "Herring Resource Enhancement Council." Fry releases were not the only projects. There were follow-up studies on the spawning grounds, and the catch was studied relative to fishing regulations (no fishing areas, fishing gear, seasons, limiting fish catch). In addition, active resource enhancement activities such as hatching and releasing larval fish were initiated. The results were that there was an increase in the fishery catch every year, reaching 600 tons in 1996. However, then there was a drastic decline in the amount of the fish catch. In 1999. the scale of the fishery was down to the previous levels prior to 1987 (10-40 tons). The reasons are not clear, but the following reasons have been suggested: the recent elevation in summer water temperatures and a decline in winter water temperatures combined with a concurrent decline in the biomass of feed species, a worsening of bottom quality, ruining of the Amamo egg grounds, water quality fluctuates, etc. As it had been confirmed that it was possible to raise the size of the resources through the release of seed, there is a desire, especially among the fishermen, to resume seed releases as occurred previously.

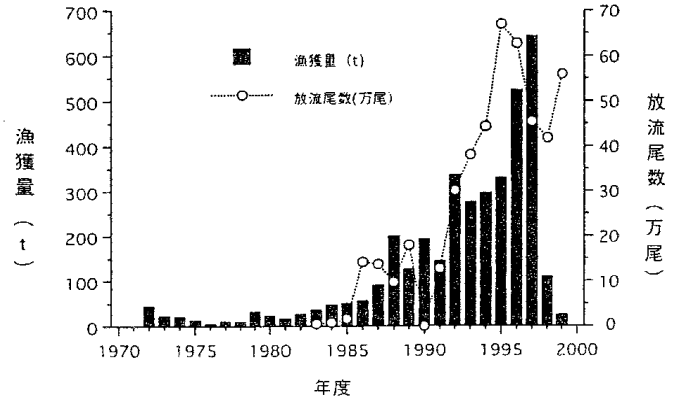

Figure I 2-2 Change over time of Furen Lake herring fish catch and number of fry released.
[y axis, left] Amount of fish catch (t)

[y axis, right] Number of seed released (10,000 fish)
[x axis] Year
[legend – black rectangles] Amount of fish catch (t)
[legend – open circles on line] Number of seed released (10,000 fish)

2) Results of releasing Furen Lake herring

About 30,000 artificial cultured herring fry were released in Furen Lake from 1983-1985. About 200,000 fish were released through 1990 (excluding 1989), and from 1991 there were 300,000-700,000 fish released. Studies performed on herring life history and release results at Furen Lake were supported by the Japan Fishery Agency. From 1995 there was a 5-year program by the Hokkaido Kushiro Fisheries Laboratory (Hokkaido prefectural lab) called the "Operations to Establish Enhancement of New Fishery Species in Designated Marine Areas." From 2000 a number of "Projects for Enhancing Techniques for Resource Development" were performed. The results of these projects clarified estimations of the recovery rate of released fish and the natural distribution of fish fry. Horii (2000) calculated the recovery rate from follow-up studies after the release. The released fish of the study included predominantly mature fish on their spawning migrations. Recovery rate in the 1993-1996 age groups was somewhat variable but the values were 5.7-12.5%, which is very high (Table I 2-1). About 10% of the released fry had matured. This is also a very high ratio when compared to the release results for Shirosake (1.9-5.4%) where mature fish had returned for spawning. There were fluctuations in the natural fishery catch, so these values were fairly stable. In the 1994 and 1995 fish catches, there were very few released fish and the rate was only 0.8%. If there is a release of 10,000,000 fish, and even if few return to the spawning grounds after 2 years, the number would still be at least 100,000 fish, which would make a sizable contribution to the resource after 2-3 years. It could be expected that the released fish would make multiple contributions to the resource by repeated spawnings. Currently, it is believed that the releases caused an increase in the Furen Lake herring resource. However, the natural 1997 year class was extremely small, and at the same time there was a temporary decline in the recovery rate of the released fish to 1.1%. Reasons that have been suggested for this problem are the size of the fish at the time of the release, differences in the quality of the fry, natural resource fluctuations, and predation pressure. However, the reason is not clear, and multifaceted research is required.

Table I 2-1 Number of herring released and recovery rate at Furen Lake and Akkeshi.

Release year	Furen Lake		Akkeshi	
	Number of fry released (10,000 fish)	Recovery rate (%)	Number of fry released (10,000 fish)	Recovery rate (%)

Recovery rate: The proportion of released fish that were caught in the fishery ((Number of cultured fry that were subsequently part of the fish catch/Number of fry that were released) x 100).

表Ⅰ 2-1　風蓮湖および厚岸ニシンの放流尾数と回収率

放流年	風蓮湖		厚岸	
	放流尾数（万尾）	回収率（%）	放流尾数（万尾）	回収率（%）
1993	38.2	6.8	13.0	4.5
1994	44.5	8.9	21.1	7.8
1995	67.1	12.5	18.0	10.2
1996	62.8	5.6	27.4	1.9
1997	45.5	1.1	18.9	6.7

回収率：放流種苗が漁獲された割合（（人工種苗の漁獲尾数/放流尾数）×100）

3) Establishment of the Center for Culturing Herring Fry at Bekkai

In order to enhance the Furen Lake herring resources even further, in 1999 two of the fishery cooperatives at Bekkai town (Bekkai, Nokke) and four fisheries cooperative at Nemuro (Nemuro Bay Central, Nemuro city, Habomai, Ochiishi) became members of the organization “Nemuro Jurisdiction Herring Seed Production Management Commission.” The goal of this organization was to release 1,000,000 herring fry measuring 40 mm every year. Later Shibetsu town and Rausu town fisheries cooperatives also joined. In 2000 the “Bekkai Town Herring Fry Production Center” was put into operation (Photo I 2-1).

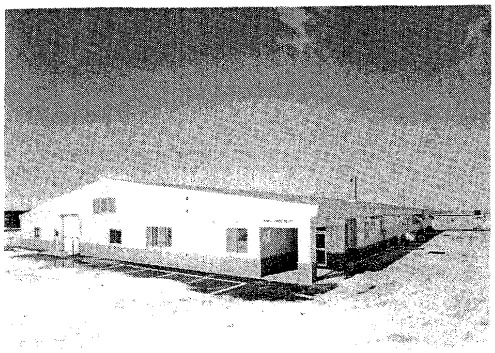

Photo I 2-1 . Outside view of Bekkai Town Herring Fry Production Center (provided by Bekkai Town).

This fry production center has herring rearing tanks (8 tanks, 40 m^3) and feed culture tanks (8 tanks, 20 m^3). This is the first facility in Japan that was established only for culturing herring fry (refer to reference data). The new facility was put into operation in 2000. In cooperation with the Furen Lake Herring Resource Enhancement Council and related facilities, 1,059,000 fry with a body length of 40 mm were produced, and 804,000 were released after offshore nursery culture. The results for the first year of operation of the Bekkai Town Herring Fry Production Center were quite favorable, and it can be expected that in the future the facility will maintain and enhance the resource.

(3) Other technique development facilities

Herring fry production occurs in Miyagi prefecture, Aomori prefecture, and Hokkaido. From 1985 to 2000, the Miyagi Prefectural Aquaculture Center in Miyagi Prefecture produced herring fry using wild herring in their spawning migrations in Ishinomaki Bay and Matsuzaki Bay. Additionally, Otama (1987, 1988) performed detailed studies on the distribution, movements, growth, reproduction, feeding and growth stages of Mangokuura herring. From 1991 to 1995 in Aomori Prefecture the Aomori Prefectural Aquaculture Center produced fry from spawning herring from Noheji Bay and Miyako Bay. In Hokkaido from 1996 the Hokkaido Aquaculture Promotion Corporation, Haboro station was consigned

to produce Ishikari Bay type herring fry using spawning fish from Atsuta and Rumoi. In 1999 a total of 2,260,000 fry were produced. Fry from the Sakhalin-Hokkaido race were produced experimentally in 1997 at the Hokkaido Aquaculture Coordination Center; about 20,000 fry were produced and used in basic culture research. The facilities mentioned above also performed follow-up tag-and-release studies in their respective areas. As will be discussed later, Japan Sea herring resource enhancement projects were started, especially in Hokkaido. Besides the fry and nursery production, there were follow-up studies after the release on spawning, life history, resource management, etc. to comprehensively advance herring resource and ecological studies. Results are expected in the future.

Today with advances in herring seed production techniques, it is possible for the facility to produce 1,000,000 fry or more. In the past, herring fry have been produced at seven facilities in Japan. In 1999 seed production was performed at 4 facilities. In the past the largest total number of seed produced reached a high of 6,212,000 fry (refer to reference data).

(4) Japan Sea Herring Resource Enhancement Project

Starting in 1954 there was a rapid decline in the migrating herring on the Japan Sea side of Hokkaido, and the resource has continued to be depressed. This resource is primarily made up of the Hokkaido-Sakhalin race and the Ishikari Bay race. In 1996 the Japan Sea Herring Resource Enhancement Project initiated projects for resource recovery and enhancements.

The results so far of these projects is that they have established techniques for maintaining a supply of parent fish for fry production and for large scale fry production. They have also provided basic information on the movement of the released fingerlings, dispersion, and feeding, and it was confirmed that some of the released fish spawned repeatedly. Also, it was possible to confirm the herring spawning grounds of the Ishikari race and to clarify the environmental conditions of the seaweed locations of the spawning grounds. In the resource studies it was possible assess ages with the otolith method, and to perform an analysis of the races using the distribution of morphological characteristics and isoenzymes. The migrational routes during spawning migrations were clarified from the fish catches, and changes in environment conditions were identified. In addition, parent fish from Sakhalin were confirmed as being from the Hokkaido-Sakhalin race, their eggs were collected, and fry were produced. The herring fry that were produced were cultured in a tank for 2-3 years, and artificial spawning was possible. The development of the techniques for study items mentioned above were develop by the combined efforts of the project team that included the Hokkaido Prefecture Wakkanai Fisheries Laboratory; Hokkaido Aquaculture Integrated Center; the Hokkaido Aquaculture Promotion Corporation, Haboro Station; Ishikari, Rumoi, and Wakkanai Regional Fisheries Technique Propagation Facilities. These projects have been continuing to 2002 and beyond, and it can be expected that there will be many further developments.

II. BIOLOGICAL CHARACTERISTICS OF HERRING AND THE FISHERY

Herring are widely distributed in the high latitudes of the northern hemisphere and play an important role as a fishery resource. Herring biological characteristics are extremely variable and diverse. Even within the same species there are many races with ecological differences. This document discusses information on fundamental biological characteristics with special emphasis on spawning ecology of the different races, introduces the races in the vicinity of Hokkaido, and details the current condition of the herring resource and fishery.

1. Biological characteristics of herring

(1) Classification

Herring (*Clupea*) are members of the herring family (Clupeidae) and live in the sea at high latitudes. Herring and the Japanese sardine (*Sardinops melanostictus*) make up a large resource. There are two species of herring, the Atlantic herring (*C. harengus*) and Pacific herring (*C. pallasi*). Both species are very closely related and have even been considered as a single species. However, both species are separated regionally, and currently the two races are distinguished by morphological characteristics like the number of spinal bones and differences in ecological characteristics such as spawning ecology. Also, the Baltic Sea herring (*C. harengus membras*) and the Russian White Sea herring *C. pallasi pallasi marisalbi* are considered to be subspecies of the Atlantic Ocean herring and the Pacific Ocean herring, respectively (Watanabe 2000).

(2) Morphological characteristics

The body of the Pacific herring is long, narrow, and oblate. The lower jaw protrudes as it is longer than the upper jaw (Figure II 1-1). Scales are rounded and there are 52 in a row. The lateral line is indistinct. The dorsal fin and pelvic fins are directly opposite each other. The length of the base of the anal fin is nearly identical to that of the base of the dorsal fin. The dorsal fin is positioned midway on the body and has 16 soft rays. The anal fin has 14 soft rays. The body color on the dorsal side is blue black, and the ventral side is silvery white. Herring resemble a related species, the common pilchard sardine, except that the sides of the body are not spotted (Maruyama 1991). The very closely related Atlantic herring can be distinguished because it has no keeled scales (scutes) that protrude anterior to the pelvic fin, and there are fewer kneeled scales posterior to the pelvic fin (Matsuhara 1979). The vertebral count of the Pacific herring is 52-55, which is relatively fewer than the vertebral count of 55-57 of the Atlantic herring (Hinino 1961). The body length of the populations also differs with the largest reaching 35 cm.

Herring order: Clupeiformes
Herring family: Clupeidae

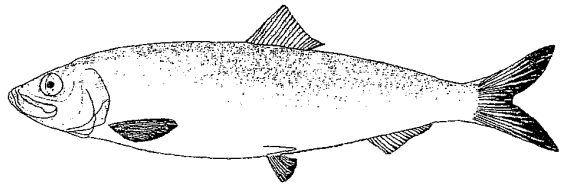

Figure II 1-1 Form of Pacific herring and distinctive features (provided by Keishi Aeda)
Scientific name: *Clupea pallasii* Valenciennes
English name: herring. Pacific herring
Characteristics: Lower jaw protrudes further than upper jaw.
Lateral line is indistinct.
Keeled scales (scutes) do not protrude.
Dorsal fin and pelvic fin are directly opposite each other.

(3) Distribution (Figure II 1-2)

Herring live in the northern and subarctic regions of the Pacific and the Atlantic. They are also seen off river mouths along the coast of Siberia (Iizuka 1987). The distribution of the Pacific herring is in the Pacific Ocean with the northern limit the Bering Sea channel and Arctic Ocean and western limit being the White Sea of Russia on the western side of the Bering Sea. On the American side of the Pacific Ocean, herring are found from the Gulf of

Alaska to San Diego, which is the southern limit. On the Asian side the distribution is from the Bering Sea to the Sea of Okhotsk, the Japan Sea, and the Bok Kai Bay in the northern part of the Yellow Sea. Atlantic herring live in areas influenced by relatively warm North Atlantic Ocean currents. They are widely distributed. In the west the distribution is from the northeastern part of the Americas, to the southern part of Greenland, and to the Svalbard Islands. On the European side the distribution is from the southern limit of the Bay of Biscay of France, to the Baltic Sea. The distribution extends through the Scandinavian Peninsula centered on the Norwegian Sea (Mapti, 1980).

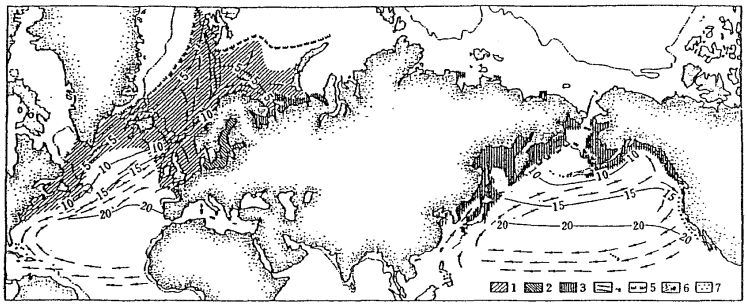

Figure II 1-2 Distribution map of oceanic herring in the north Atlantic Ocean and the Pacific Ocean (Mapti, 1980)
1. *Clupea harengus*
2. *Clupea harengus membras*
3. *Clupea pallasii*
4. Warm currents
5. Edge of currents
6. Surface water isotherm in July and August
7. Deep water upwelling along the California coast.

According to Kobayashi (1993), the southern herring limit on the Japan Sea side was recorded as Toyama prefecture. Annual spawning aggregations and the fishery areas occur from Ishikari Bay and northward. On the Pacific Ocean side, spawning has been recorded at Inubouzaki. However, recently it is believed Hinuma, Ibaragi prefecture, is the southern limit. In the north there is spawning in Mangokuura in Sendai Bay, Obuchi marsh on Shimokita peninsula, Yuutounuma on the eastern part of Hokkaido, Akkeshi Lake, Furen Lake, Notoroko Lake, Saroma, etc. There are small aggregations of the resources living in the vicinity of brackish water and there are very large aggregations distributed widely from the coast along the Sea of Okhotsk in Hokkaido to Sakhalin (Figure II 1-3).

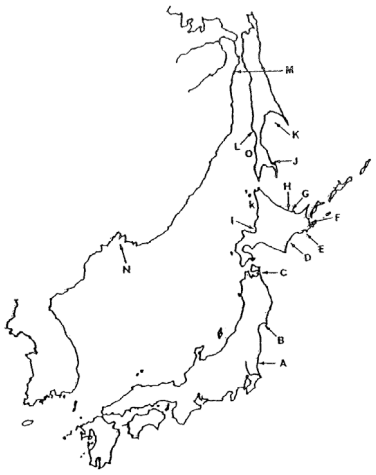

Figure II 1-3 Herring spawning grounds around Japan (Maruyama 1997). A: Hinuma; B: Mangokuura; C: Obuchi marsh; D: Yuutounuma; E: Akkeshi; F: Furen Lake; G: Notoroko; H: Saroma Lake; I: Ishikari Bay; J: Tonnai Lake; K: Terpeniya Bay; L: Ainsuku Lake (Raichin Lake); M: Dekasutori Bay; N: Peter the Great Bay; O: Hokkaido-Sakhalin herring spawning grounds; K: Terpeniya herring spawning grounds.

(4) Life history

From the fry through the adult stage, the herring are in high density schools, and they make circular migratory movements for feeding and spawning. The major population matures at the age of 2-3 years and moves to the coasts during the spawning season. They spawn in schools, and the eggs attach with an adhesive to seaweeds, etc. The larvae and fry live in areas of brackish water or in coastal areas. They feed primarily on calanoid copepods and mysids as they grow. From the immature fish stage to the mature stage period the fish make circular migratory movements from the coast to offshore areas. The food consists principally of mysids, euphausids, large calanoid copepods, and small fish. As they grow the fish aggregations differ by age. The fork length of 1-year old fish is 15 cm (12 -18 cm); 2-year old fish are about 20 cm (15-25), and 3-year olds are about 24 cm (19-29 cm) (Figure II 1-4). The life span is from 5-18 years and differs greatly depending on the population.

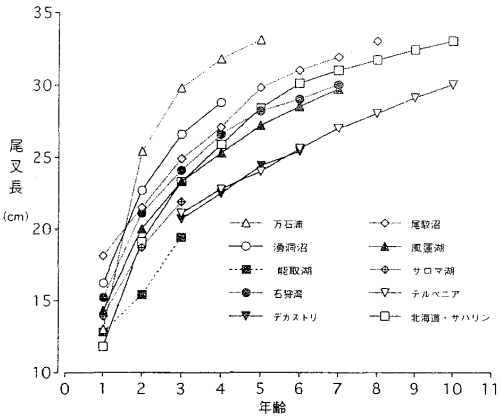

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Figure II 1-4 Growth of Pacific herring in the vicinity of northern Japan and Sakhalin (modified from Obayashi, 1993).

[y axis] Tail fork length (cm)

[x axis] Age in years
[legend, left column, top to bottom, triangle, circle, square, circle, triangle]
Mangokuura
Yuutounuma
Notoroko
Ishikari Bay
Dekasutori
[legend, right column, top to bottom, diamond, triangle, diamond, triangle, square]
Obuchi Marsh
Furen Lake
Saroma Lake
Terupinia
Hokkaido-Sakhalin
[end legend]

Mangokuura (Otama 1978); Obuchi marsh (Rai 1978); Yuutounuma (Kobayashi 1993); Furen Lake (Kobayashi 1993); Notoroko (Kobayashi 1993); Saroma Lake (Kobayashi 1993); Ishikari Bay (Inoe 1980); Terpeniya (Rrolov 1968); Dekasutori (Rrolov 1968); and Hokkaido-Sakhalin (Fujita-Okubo 1927).

(5) Spawning ecology

There are large differences in spawning ecology between Pacific herring and Atlantic herring. Atlantic herring spawn on the sea bottom on sand at comparatively high salinities (close to normal sea water), at high water temperatures, in the depth range of from 10 m to 200 m, and on gravel and rocks. By comparison to the Atlantic Ocean herring, the Pacific Ocean herring spawn in areas with lower salinities and lower water temperatures, in the intertidal or subtidal zones, and in areas of abundant vegetation (eelgrass, *Fucus* (popweed), *kombu* (*Laminaria*, large brown kelps), etc.

(6) Classification based on life history

The numerous biological and ecological differences between populations mean that herring have considerable genetic diversity. It is believed that this diversity in character traits and ecological characteristics developed historically in response to the environment (Kobayashi 1993). It is possible to classify herring according to behavioral diversity between populations, especially as they relate to spawning ecology, the scale of the movements, and circular migrations. Kobayashi (1993) divided the populations into the following 4 categories: lake and marsh region type, oceanic region type, widely dispersed oceanic region type, and intermediate region type (Table II 1-1).

Table II 1-1 Classification of spawning and migratory stages of herring in the vicinity of Japan (modified from Kobayashi, 1993).

	Life history type	Spawning grounds	Spawning marine areas	Salinity of spawning grounds	Migratory limits	Principle schools
I	Vicinity of lakes and marshes	Limited by the population	Brackish water area	Low salinity	Restricted	Furen Lake, Notoro Lake, Yuutounuma, Saroma Lake, Buchi marsh
II	Oceanic areas	Limited by population	Coastal area	High salinity	Wider than restricted	Mangokuura, Ishikari
III	Wide oceanic distribution	Scattered	Coastal area	High salinity	Wide	Hokkaido-Sakalin
IV	Intermediate type	Scattered	Brackish-coastal area	Fairly low salinity	Fairly wide	Terpeniya, Dekasutori

((1)) Lake and marsh region type

The spawning grounds are lakes and marshes with low salinity brackish water. Depending on the population, the spawning grounds are limited. The spawning substrate is aquatic plants such as eelgrass. It is believed that the fry live in marshes and lakes. The immature fish continue to live in the vicinity of the coast, and they do not make large circular migrations. Also, it is believed that they have the trait that with maturation they return to the same area to spawn. However, it is believed that the behavior of spawning at the same location is not as strong as for salmon. Maturation occurs at an age of 2-3 years. Growth differs greatly depending on the population, and it is believed that they have a lifespan of 5-8 years. The resource is small with fish catches only in the range of several hundred tons at the most. The principal populations include Furen Lake, Hinuma, Obuchi marsh, and Yuutounuma.

((2)) Oceanic region type

Spawning occurs along the coast in areas such as Sugamo and Hondawara with high salinities at depths of several meters or less. Spawning grounds are relatively restricted. It is believed that during the fry period they live along the coast at the mouths of rivers. The limits of the circular migrations tends to be wider than the lake and marsh region type but are more narrow than the widely dispersed oceanic region type. The recurring behavior is uncertain, but during the spawning season the populations visit the same marine areas so that it is believed that recurring spawning does occur. Maturation occurs at an age of 2-3 years. Growth differs depending on the population and the lifespan is 5 - 8 years. This resource is not particularly large, and the fish catch is in the range of 100 to 30,000 tons. The principal populations are at Mangokuura and Ishikari Bay. The growth of Mangokuura herring is extremely good; 2-year old fish achieve a fork length of 25 cm, and 3-year olds are nearly 30-cm (Figure II 1-4).

((3)) Oceanic widely dispersed region type

For this type there is dispersed spawning in coastal areas with high salinity (32-34‰). The spawning areas are not restricted. Large scale migrations are characteristic from the time the fish are immature through maturity (Figure II 1-5). The age of maturation at 3-5 years is relatively high, and the life span is long. It is believed that they may live several decades. There is a possibility of extremely large biomasses, and there are past records of fish catches that exceeded 1,000,000 tons. The populations are primarily the Hokkaido-Sakhalin race, Gizhiga race, and the Okhotsk race (Figure II 1-6).

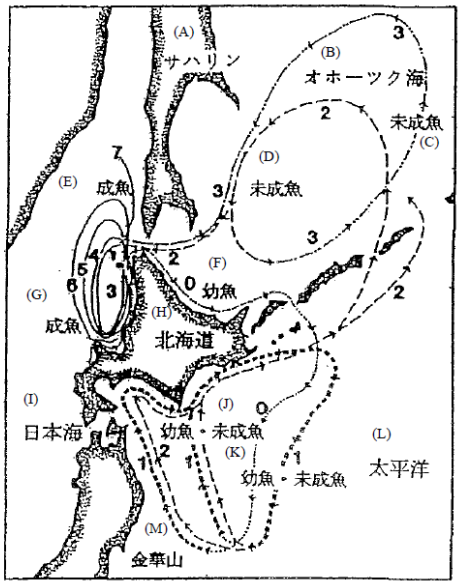


Figure II 1-5 Presumed circular migration movements of Hokkaido-Sakhalin race herring (oceanic widely dispersed region type) (modified from Yamaguchi, 1926). □

*The numbers in the figure show age.

(A) Sakhalin
(B) Okhotsk Sea
(C) Immature fish
(D) Immature fish
(E) Mature fish
(F) Fry
(G) Mature fish
(H) Hokkaido
(I) Japan Sea
(J) Fry and immature fish
(K) Fry and immature fish
(L) Pacific Ocean
(M) Kanehana
[end figure]

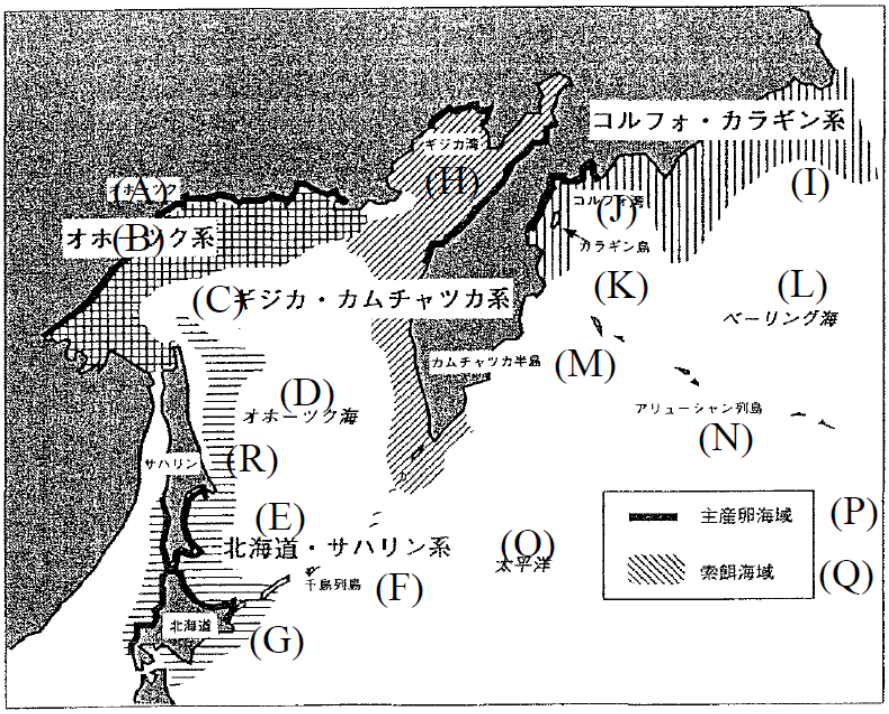


Figure II 1-6 Pacific herring in the far eastern area. Oceanic widely dispersed region type. Distribution of principle races
(A) Okhotsk
(B) Okhotsk race
(C) Gizhiga-Kamchatka race
(D) Okhotsk
(E) Hokkaido-Sakhalin
(F) Kurile Islands
(G) Hokkaido
(H) Gizhiga Bay
(I) Korfo-Karaginsk
(J) Korfo Bay
(K) Karaginsk Island
(L) Bering Sea
(M) Kamchatka Peninsula
(N) Aleutian Islands
(O) Pacific Ocean
(P) Principle spawning areas
(Q) Feeding areas
(R) Sakhalin
[end figure]

((4)) Intermediate type

This race has traits that are intermediate between the lake and marsh type and the oceanic type. Spawning takes place in areas with comparatively low salinities. In the eastern part of Hokkaido, there is a tendency for this type to spawn after the type lake and marsh area type, and the migratory range is somewhat large. Age, life span, and growth have intermediate characteristics. Records indicate fish catches ranging from several thousand tons to 10's of thousands of tons. The prominent populations consist of the Terpeniya race and Dekasutori race (Figure II 1-3).

(7) Herring races that live in the sea around Hokkaido

Herring races that live in Hokkaido have respective spawning races in Ishikari Bay, Yuutounuma, Furen Lake, Notoroko Lake, Saroma Lake, and Akkeshi Lake. According to Kobayashi (1993), Furen Lake has an endemic population that has a different spawning period. It has been suggested that the Terubenia race visits for spawning. Also, Kaai (1934) and Satou (1944) have suggested that there are two different populations that spawn at Akkeshi, principally Akkeshi Lake. The population that spawns in early April is an endemic population (marsh herring), and the other population spawns mainly in May (cherry blossom herring). The former has a different body form including a taller body height. Except for the spawning season, this race is known to migrate for feeding migrations over relatively large areas.

Using tag-and-release, Yamamoto and Ohana (2000) clarified that the limits of the movements of Furen Lake herring gradually became broader over time; and the circular feeding migrations were in the eastern region off of Hokkaido. The same type of results for Akkeshi herring were also found by Kontou & Kitahama (1953) and Kontou & Uchiyama (1958) using exterior tag-and-release, and by Susuki (1999) used labeled otoliths. There was some mixing of the populations but not during the spawning season.

In addition, Hotta (1996) studied morphological characteristics and analyzed isoenzymes for herring in the area off the east of Hokkaido. The results indicated that there were no genetic differences in the herring in the same area of the sea. It was believed that the Furen Lake herring and the Akkeshi herring were different Yuutounuma populations based on morphological differences. However, it was pointed out from an analysis of morphological characteristics and isozymes that there were not any fundamental differences between the Furen Lake herring and the Akkeshi herring. The reason is that there are frequent crosses between the both populations or it can be assumed that historically there has been relatively little genetic change. However, according to follow-up tag-and-release studies on widely dispersed populations on circular feeding patterns, in it was indicated that in April and May each race returns to the vicinity of their own respective spawning grounds (Yamamoto & Ohana 2000, Susuki 1999). Hereafter, it would be desirable to perform a comprehensive study that clarifies the imprinting period for recurring behaviors.

2. The herring resource and fishery

(1) The herring resource and fishery worldwide

According to Watanabe (2000) the herring catch worldwide tended to increase during the 1990's. In 1997, about 3,000,000 tons were caught principally by Norway and Russia. A large amount of the catch was from the race of Atlantic herring that spawns on the Norwegian coast in the summer. These are caught in large migrating aggregations in the Norwegian Sea, the Arctic Ocean, and Barents Sea. In modern times the highest fish catch occurred during the 1960’s and was 1,500,000 tons, but this had declined to only several tens of thousands of tons in the 1970's. The reason for this was the rapid increase in fishing pressure and the effect on changes to colder water conditions. In the 1980’s, presumably because of strict fishing regulations and warming temperatures, the scale of the resource had increased to 1,000,000 tons. Also, in 1947 the fall spawning race of the North Sea was nearly 5,000,000 tons. Thereafter there was a rapid decline to only about 50,000 tons. In the 1980’s the spawning resource exceeded 1,000,000 tons, and in the 1990’s the variation was between 500,000-1,000,000 tons.

By comparison, the Hokkaido-Sakhalin race was a prominent race of Pacific herring in the 1950’s and before with catches of several tens of thousands of tons. However, from 1955 the catch had declined to 100,000 tons or less, and currently the level is extremely low. On the

eastern coast of Russia the Okhotsk race and the Gizhiga-Kamchatka race had catches of about 50 tons in the last half of the 1990's. Currently, there are no large-scale herring fisheries on the American side.

(2) The Japanese herring resource and fishery

According to Maruyama (1997) the principal fishing grounds of Japanese herring are in the Hokkaido area. In the past the largest fish catches were the Hokkaido-Sakhalin race of the widely dispersed oceanic type which had been a major race. The Hokkaido-Sakhalin race is referred to as summer herring. In the 1800's, the ban on fixed nets was lifted and there was a rapid expansion of fishing with large catches centered in the Japan Sea side of Hokkaido. It is estimated that from the 1830's through the 1850's the catches were 100,000 to 150,000 tons. From fish catch statistics that were recorded from 1870 through the 1950's, the fishery catches on the Japan Sea side of Hokkaido were generally several tens of thousands of tons (Figure II 2-1). The largest fish catch occurred in 1897 with 975,000 tons. From 1955 there has been a drastic decline in the fishery catch and there have been almost no visiting fish. In 1958 there were landings of 15,000 tons and in 1967 about 20,000 tons. However, thereafter, there was rapid decline in the resource and in 1971 and afterwards, the catch was only several tons.

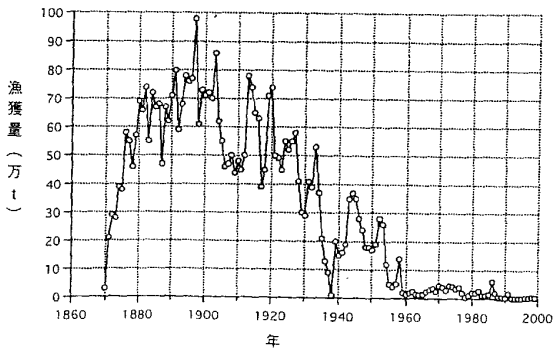


Figure II 2-1 Change over time (years) of herring catches in the Hokkaido area.
[y axis] Fish catch (10,000 tons)
[x axis] Years

In the 1960's and afterwards the principal fishing grounds have been on the Okhotsk coast of Hokkaido. The fish catch has been several thousand tons to several tens of thousands of tons and has focused on the Terpeniya race. At the same time the type of fishing has changed from coastal fixed nets and gill nets to bottom trawling nets.

According to Iizuka (1987) the local herring (lake and marsh region type and oceanic region type) make up a relatively small part of the fishery. The fishery catches from the individual races is on the order of several tons to several hundred tons. The Notoroko race is representative; because of construction operations at the mouth of the lake, it was impossible for the herring to enter the lake during the spawning season. Also, there have been changes in water quality within the lake, which have contributed to the problem of resource depletion. The lake and marsh herring have temporarily disappeared. This situation is extremely serious because recovery is not possible.

Similar to the situation described above, the Japanese herring catch peaked from the 1890's to the 1900's with catches of 800,000-900,000 tons after which time there was a decline. In recent years the level has been extremely low, and had declined to 100,000 tons by the 1950's. From 1978 until now the level has declined to several thousand tons (with the

exception of 1987 when there was about 60,000 tons). Because of this, according to Hanyuu (1997) beginning in 1980 there were large scale imports from foreign countries (especially Russia and Norway). Currently 60,000-70,000 tons are imported (Figure II 2-2).

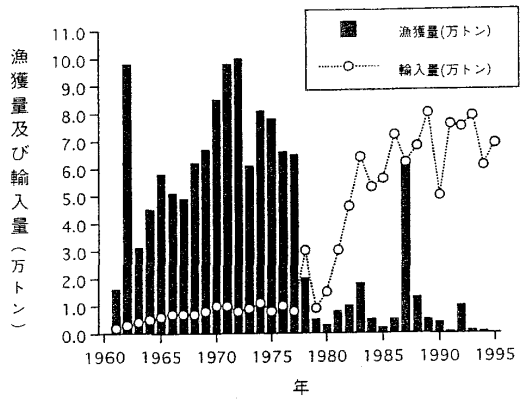


Figure II 2-2 Change over time of Japanese herring catch tonnage and imported tonnage (modified from Hanyuu, 1997).
[y axis] Amount of fish catches and imports (10,000 tons)
[x axis] Year
[legend, black rectangles] Weight of fish catches (10,000 tons)
[legend, open circles] Weight of imports (10,000 tons)

III. MATURATION OF PARENT FISH AND MAINTAINING THE SUPPLY

When producing herring young, it is extremely important to secure a supply of ripe parent fish. For this reason it is necessary to obtain information on such factors as natural maturation and the state of the fishery. This chapter summarizes details on herring maturation and provides basic information on herring maturation in the area east of Hokkaido. It describes the age classes of the adult fish.

1. Summary of herring maturation

(1) Morphological changes of herring gonads and eggs and sperm

The general structure and maturation process of herring gonads was presented by Bowers and Holliday (1961). The structure of the gonad is pleated when the eggs are completely matured. Eggs are then released from the follicles and ovulated. The structure of the ovary is such that it allows ovulation of all the eggs in a short time period. After ovulation the outer surfaces of the egg membranes become adhesive. Following spawning, the adhesive glues the eggs to the substrate. The ovary is covered with a bag like ovarian membrane which connects the ovary to the genital opening through which the eggs are spawned. The upper part of the structure of the testis is a spermaduct through which the sperm are moved posteriorly. Matsuhara (1997) systematically described oogenesis and the structure of the ovary and testis (Figure III 1-1, 1-2).

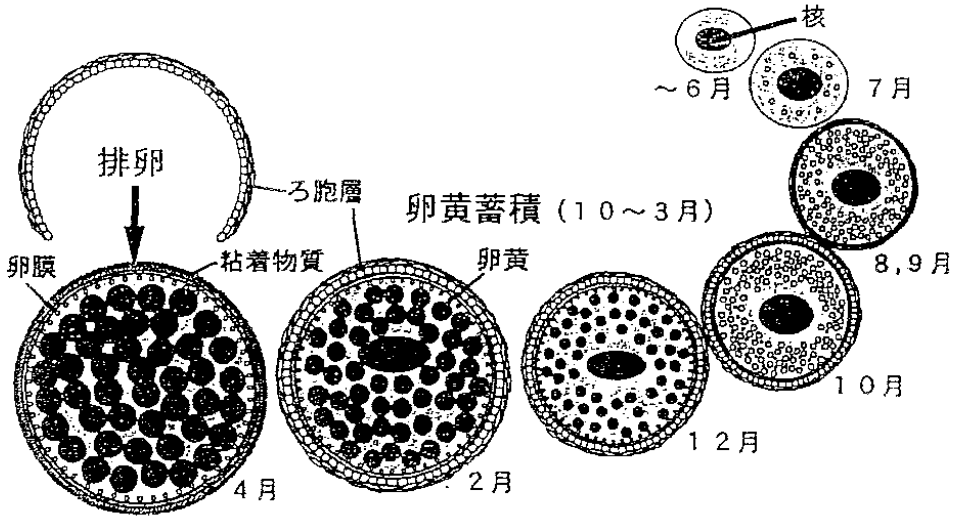


Figure III 1-1 Schematic drawing of herring egg development (Matsuhara, 1997).
[Eight egg drawings are described below from smallest egg to largest]
[Drawing 1, smallest]
Nucleus
About June
[Drawing 2]
July
[Drawing 3]
August, September
[Drawing 4]
October
[Drawing 5]
December
[Drawing 6]
[arrow on left]
Acinus
[arrow on right]
Egg yolk
[bottom right]
February
[Drawing 7]
[arrow on left]
Egg yolk
[arrow on right]
Adhesive substance]
[below, right]
April
[Inside drawing 8]
Ovulation
[arrow on right]
Acinus
[end figure]

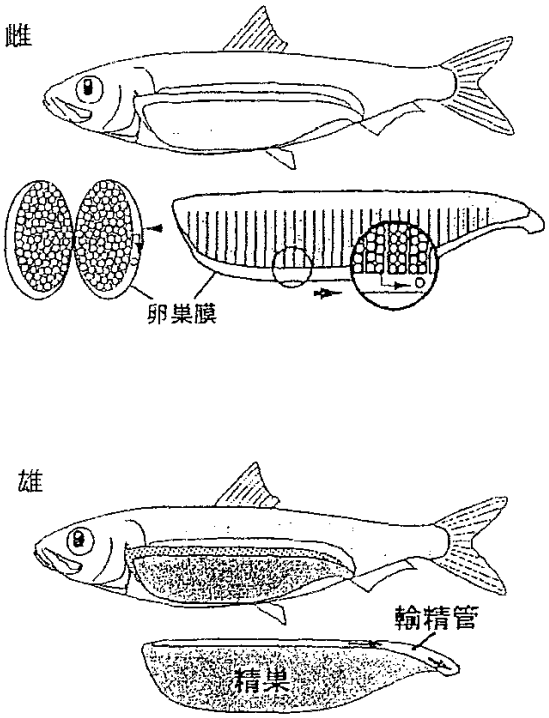


Figure III 1-2 Structure of ovary and testis of ripe herring (Matsuhara, 1997).
[There are 4 drawings from top to bottom]
[Top drawing]
Female
[Second drawing]
Gonad membrane
[Third drawing]
Male
[Fourth drawing]
[word inside drawing]
Testis
[word top right with indicator line]
Sperm gonoduct

(2) Seasonal maturation and spawning

Maturation in most herring populations occurs at 2-3 years, and the herring spawn for several years. Spawning occurs once a year, and the spawning season differs depending on the population and the area. In Atlantic herring there are 3 groups forming a summer spawning group, a fall spawning group, and a winter spawning group, and these are structured with multiple races (Kawasaki 1982). In the Pacific herring there is only a spring spawning season.

In Japan the herring in the Mangokuura group spawns in February, the Ishikari Bay group in February and March, the Hokkaido-Sakhalin Group and each of the groups on the east side of Hokkaido groups in April and May. The Terubenia group spawns in May-June (Kobayashi 1993). Pacific herring characteristically spawn close to the shore in shallow water where there is luxuriant growth of plants and algae (Kobayashi 1993).

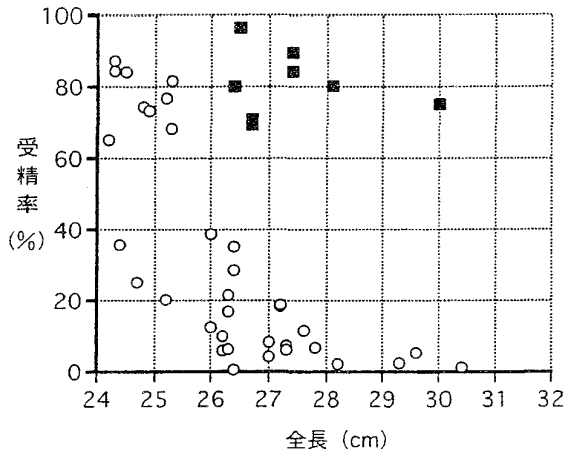
Koya, et al. (submitted manuscript) studied the first seasonal maturation of artificially cultured adult herring at Akkeshi Station. The results established that during the initial maturation of the herring, the yolk formation of the oocytes began in April-July. There was

active yolk accumulation over the period from August to March. A high proportion of the oocytes were in the rounded yolk stage. Egg yolk formation was completed in the period from late March through April. The oocytes reached the final stage of maturation and ovulation occurred. The two herring egg development stages in the ovary could be clearly distinguished, and the development of the eggs was synchronized (Kouno 1989).

Hay (1986) reported that at a temperature of 5 - 6ºC the fertilization rate remained high for a month following ovulation. Ohana, et al. (1997) studied natural spawning of 3-year old cultured adult fish and found that 19 days or more after ovulation fertilization rates were 64.1-75.4%. Also, Yamamoto, et al. (1994) studied maturation in cultured adult fish in 1990-1992. Maturation progressed very rapidly from late March and during an 8-15 day period, 60% or more of the individuals were in the final stages of maturation and had ovulated. Thus, it is characteristic of herring eggs that they can be fertilized 19-30 days after final maturation and ovulation, which is relatively long for most species of fish.

(3) Post mature

Maruyama (1991) studied the effect of maturation on the fertilization rate of cultured adult herring from Akkeshi. There was a 100% fertilization rate for mature eggs, but the rate for post mature eggs dropped to 0-50%. Also, Yamamoto (2000) studied the fertilization rate of wild caught Akkeshi herring after the spawning season in May of 1997 and 1998. Compared to the herring that were caught in April, numerous cavities in the ovary contained fluid; the eggs were light in color, and it is presumed that the eggs were in post spawning conditions. This pattern was particularly pronounced in large herring. The fertilization rate of post mature eggs was extremely low (Figure III 1-3).



図Ⅲ 1-3　1997年と1998年の４月と５月に漁獲された成熟ニシンの全長と人工授精した卵の受精率の関係
■ ４月採卵　○ ５月採卵

Figure III 1-3 Relationship between the fertilization rate of eggs that had been artificially fertilized and the total length of ripe wild-caught herring that were caught in April and May of 1997 and 1998.
■ Eggs collected in April
○ Eggs collected in May
[y axis] Fertilization rate (%)
[x axis] Total length (cm)

From the above it can be understood that it is common for mature fish to retain eggs that have been ovulated but not spawned whether or not the mature fish were artificially cultured or were wild. In addition, after the spawning season there is a high ratio of fish in this condition. When mature artificially cultured fish are in a culture tank that does not have spawning substrates, the fish are not able to spawn. When this condition is continued, it is common that ovulated eggs become overripe. However, it is not understood why wild herring off the east coast of Hokkaido also contain overripe eggs during the last half of the spawning season. There appears to be a number of questions remaining.

(4) Maturation criteria from visual observations

The Japanese national criteria for Pacific herring maturation are based on revised criteria originally from Hjort (1910). The classification is as follows.

Stage 1: The gonads are very small with a width of 2-3 mm. The ovary is dark red colored and lobular shaped. The testis is white with small ash colored zones and is small and blade shaped.

Stage 2: The shape of the gonad indicates that maturation is beginning. It is still small with width of 5-6 mm, and the eggs of the ovary cannot be observed macroscopically.

Stage 3: The gonads have swollen and thickened to a width of 1-2 cm. The ovary is tinged yellow and the eggs can be seen macroscopically. The testis is tinged gray.

Stage 4: The gonad is nearly the length of the peritoneal cavity and is orange yellow or light yellow. The eggs are large but not round, and they are opaque. The testis is tinged with white.

Stage 5: The gonad fills the peritoneal cavity. The ovary has a yellow tinge and the eggs are spherical and fairly transparent. The testis is milky white.

Stage 6: Completely matured. When the abdomen is pressed lightly, eggs flow out of the genital opening, and the testis fluid is milky.

Stage 7: After eggs are spawned or sperm has been released, the gonads become soft. The ovary is dark red, and the testis is grey-red.

Stage 8. Recovery period following spawning (eggs and sperm). The gonad is somewhat firm, is about 1 cm in width, and the color is dark red.

Also, in order to distinguish eggs that were suitable for fry production, Oukouchi (2001) divided stage 6 into the following 2 categories.

・Ripe eggs: The ripe eggs and ovary are soft and the eggs are yellow or orange and transparent.

・Overripe eggs: Ovaries contain a lot of moisture; there is patchy egg debris; and eggs are milky.

The ripeness stages can be determined by visual observations (Table III 1-1). These standards can be used to determine ripeness which is necessary for the careful selection of good quality gonads. It is especially important that there be careful discrimination of over ripe eggs.

Table III 1-1 Criteria for maturation level of female herring.

Stage	Classification	Characteristics
1	Immature ovaries	Gonads are very small with a width of 2-3 mm. The ovary is dark red and lobular shaped. The testis is white with small ash colored zones, and is small and blade shaped.
2	Formation of egg yolk	The shape of the gonad indicates that maturation is beginning. The gonad is still small with width of 5-6 mm, and the eggs of the ovary cannot be observed macroscopically.
3	Period prior to when egg yolk has been accumulated	The ovary is firm and has begun to swell to a width of 1-2 cm. The ovary is opaque and tinged yellow. Eggs can be seen macroscopically.
4	Period after yolk has been accumulated	The ovary is firm and is nearly the length of the peritoneal cavity. It is orange yellow or light yellow. The eggs are large but not round, and they are opaque.
5	Period after yolk has been accumulated (immediately before ovulation)	The ovary is somewhat firm and fills the peritoneal cavity. It has a yellow tinge. Eggs are spherical and fairly transparent. When the area near the genital orifice is pressed, few transparent eggs are expressed through the orifice.
6	Mature (immediately after ovulation)	Ovary is soft and resilient. When the area near the genital orifice is pressed, many transparent eggs are expressed through the orifice.
7	Postmature (when there has been a long period after ovulation)	The ovary is soft but not resilient, and is a light yellow color. It contains a lot of water. When the area near the genital orifice is pressed, the eggs that are expressed through the orifice are milky.
8	Immediately after spawning	Immediately after spawning, the gonad is small and soft. The gonad is dark red.
9	Recovery	There is a recovery period after spawning. The gonad has a firm shape, has a width of about 1cm, and is dark red in coloration

2. Maturation and securing parent herring from the area offshore of eastern Hokkaido.

(1) Maturation period

Herring with ripe gonads migrate back to the center of Furen Lake in the last half of March to early May, so egg collection is limited to this period. In 1983, eggs for producing fry were collected in the period from March 22 to May 14. In recent years it has been most common for early April to be the optimal period for obtaining ripe eggs.

Horii studied the 1994 and 1995 year classes of herring produced in Furen Lake (sex, age, and gonad index). The gonad index (hereafter referred to as GSI) is GSI=weight of gonad/body weight x 100 (Figure III 2-1). In a study for the period from November 1997 to April 1998, the GSI of 3- and 4-year old female herring had increased from 10 to 30 in the period from November to March. In March there was a rapid increase, and the GSI peaked on March 20 at a GSI of 35-40.

There was then a rapid decline from late March through late April. In the 2-year old fish, the peak of ripeness occurred in early April, which was later than for the 3-4 year old fish. This phenomenon is common in other species of fish; the first year that the gonads mature, there is a tendency for spawning to occur later than for older fish. In the males the GSI stayed level at about 20 for the period from November to March 10. In the period from March 10 to 20, the GSI value increased by 5. Then, in a period of 1-2 days, there was a sudden drop in the GSI value to 10-15. This was followed by a gradual drop

to below 10. From this pattern, it is believed that there was a simultaneous spawning around March 20, and that spawning then continued on a smaller scale.

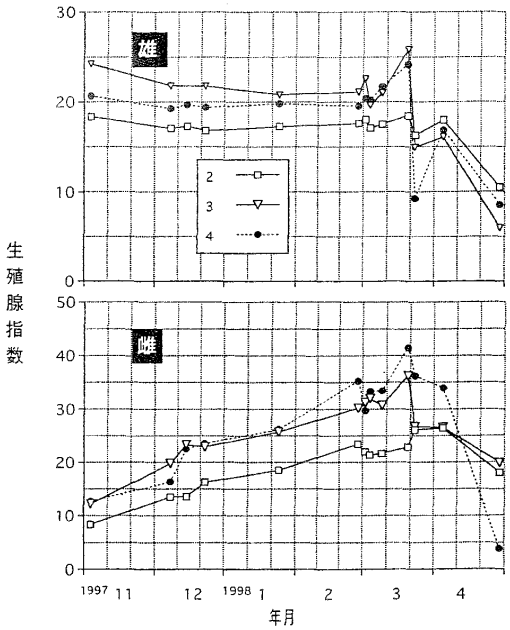
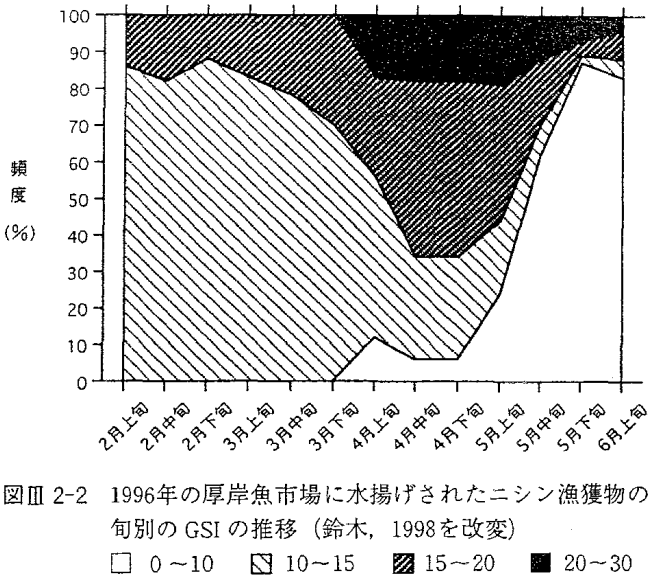


Figure III 2-1 Change over time of reproductive index relative to age of herring at Furen Lake in 1997-1998 (provided by Horii).
*Gonad index = (gonad weight/body weight of cleaned fish) x 100.
[y axis] Gonad index
[x axis] Month and year
[Top chart] Males
[Bottom chart] Females



図Ⅲ 2-2　1996年の厚岸魚市場に水揚げされたニシン漁獲物の旬別の GSI の推移（鈴木，1998を改変）
□ 0～10　▨ 10～15　▨ 15～20　■ 20～30

Figure III 2-2 Changes in the gonad index about every 10 days in wild caught herring at the Akkeshi fish market in 1996 (modified from Suzuki,1998).

□ [crosshatching with backward leaning lines (\)] 10-15
□ [crosshatching with forward leaning lines (/)] 15-20
■ 20-30
[y axis]
Frequency (%)
[x axis, left to right]
Early February
Mid February
Late February
Early March
Mid March
Late March
Early April
Mid April
Late April
Early May
Mid May
Late May
Early June
[end x axis]

Susuki (1998) showed the maturation period for another location in the Doutou marine area. In 1997-1998 (late march to mid May), the GSI was studied for males and females together in the fish catch at the Akkeshi market. The trends were about the same as for Furen Lake (Figure III 2-2).

(2) Age and size of parent fish

Yamamoto & Ohana (2000) studied the body-length distribution of each year class in wild caught Furen Lake herring during the spawning season (March to April). The catch consisted of fish in the 1-5 year classes, with the principal population being the 2-3 year classes (Table III 2-1). The peak mode for each year class was 19 cm for 1-year-old herring, 23 cm for 2-year olds, 27 cm for 3-year olds, and 29 cm for 4-year olds (Figure III 2-3). Currently, the wild fish that are used for obtaining eggs are generally 2-3 years old. The parent fish used from 1997-1999 had an average total length of 27.3 cm (23.4-34.9 cm) and an average body weight of 186.4 g (104.3-460.9 g). The general total body lengths were 25-30 cm, and the general body weights were 130-250 g (Figure III 2-4).

For reference, the relationship between total length and fork length is shown (Figure III 2-5).

Table III 2-1 Body length distribution of each year group in wild caught Furen Lake herring during the spawning season.

Total length (cm)	Number of test animals	Age 1		Age 2		Age 3		Age 4		Age 5	
		Number of fish	Composition (%)	Number of fish	Composition (%)	Number of fish	Composition (%)	Number of fish	Composition (%)	Number of fish	Composition (%)

全長（cm）	供試尾数	1歳		2歳		3歳		4歳		5歳	
		尾数（尾）	組成（%）	尾数（尾）	組成（%）	尾数（尾）	組成（%）	尾数（尾）	組成（%）	尾数（尾）	組成（%）
15～	1	1	0.3								
16～	1	1	0.3								
17～	33	32	9.1	1	0.0						
18～	117	110	31.3	7	0.3						
19～	153	135	38.5	18	0.7						
20～	85	62	17.7	23	0.9						
21～	154	8	2.3	146	5.7						
22～	328	2	0.6	323	12.5	3	0.3				
23～	843			840	32.6	3	0.3				
24～	773			758	29.4	15	1.3				
25～	402			351	13.6	51	4.3				
26～	335			102	4.0	233	19.5				
27～	437			6	0.2	422	35.3	9	11.3		
28～	341			5	0.2	312	26.1	24	30.0		
29～	162					135	11.3	26	32.5	1	20.0
30～	38					19	1.6	18	22.5	1	20.0
31～	6					1	0.1	3	3.8	2	40.0
32～	0										
33～	0										
34～	0										
35～	1									1	20.0

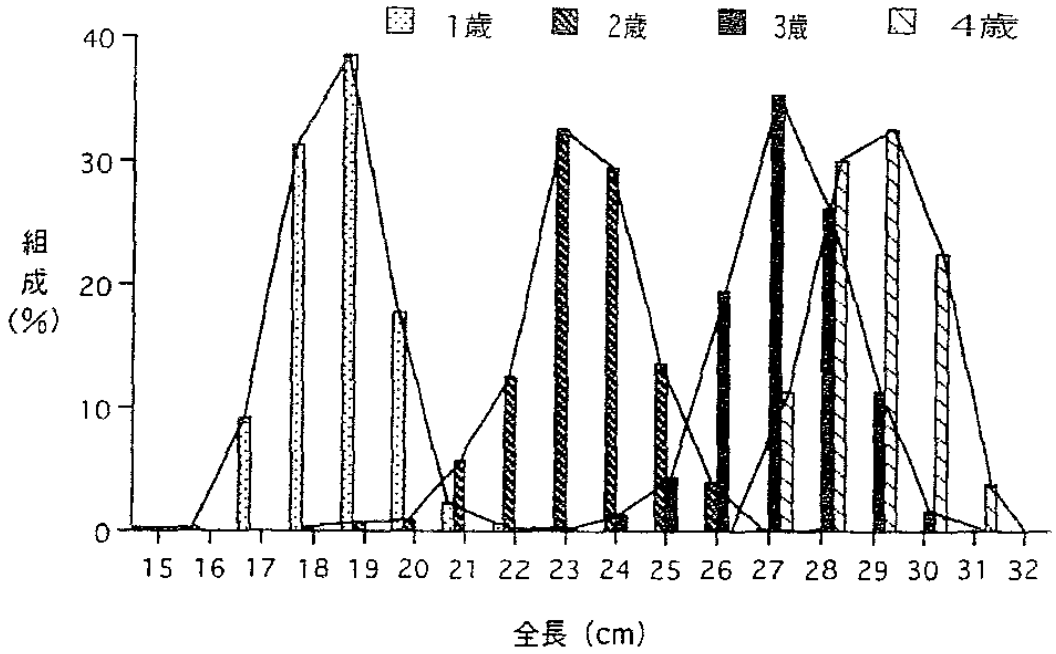


Figure III 2-3 Body length composition and age of Furen Lake herring during the spawning season (modified from Yamamoto & Ohana, 2000)
*Sample collected: March through April of 1989-1990.
[y axis] Composition (%)
[x axis] Body length (cm)
[rectangles with dots] Age 1 year
[rectangles with narrow crosshatching] Age 2 years
[black rectangles] Age 3 years
[rectangles with wide crosshatching] Age 4 years

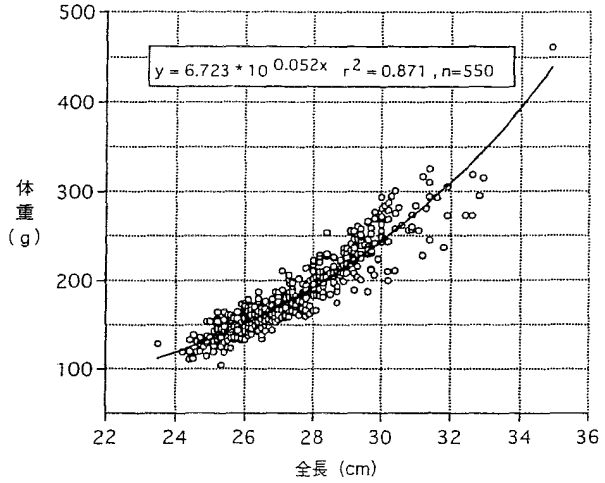


Figure III 2-4 Relationship between total length and body weight of ripe females that were used for obtaining eggs in the years 1997-1999.
[y axis] Body weight (g)
[x axis] Body length (cm)

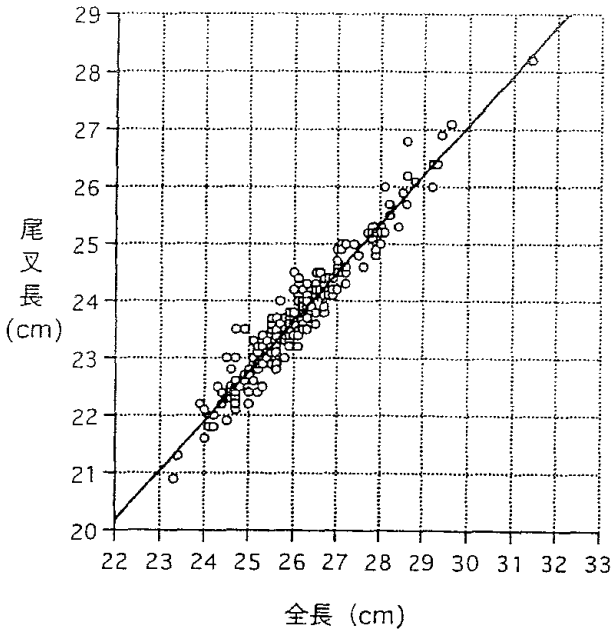


Figure III 2-5 Correlation between total length of adult herring and fork length ($y=0.866x+1.113$ $r^2 = 0.932$ ($n = 193$)).
[y axis] Fork length (cm)
[x axis] Total body length (cm)

(3) Weight of ovaries of parent fish and GSI

From 1997-1999 fry were produced using adult fish that were in the final stage of maturation. The correlation formula for the relationship between total length and ovary weight was $Y=0.37310^{0.073x}$ $r^2=0.630$ (Y: weight of ovaries; x=total length) (Figure III 2-6). The average GSI value for fish with a total length of 25 cm was about 20, for a length of 28 cm the GSI averaged 23, and for 30 cm it averaged 25. There was tendency for larger fish to have higher GSI values (Figure III 2-7).

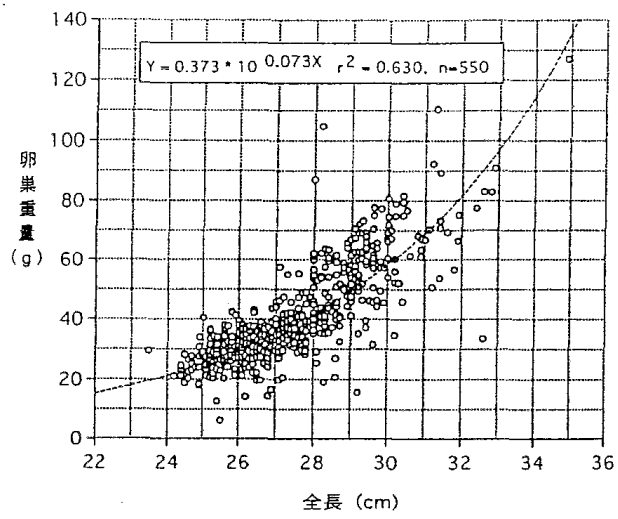


Figure III 2-6 Correlation between total herring length of ripe females used for egg collection at Akkeshi Station and ovary weight (1997-1999).
[y axis] Ovary weight (g)
[x axis] Total length (cm)

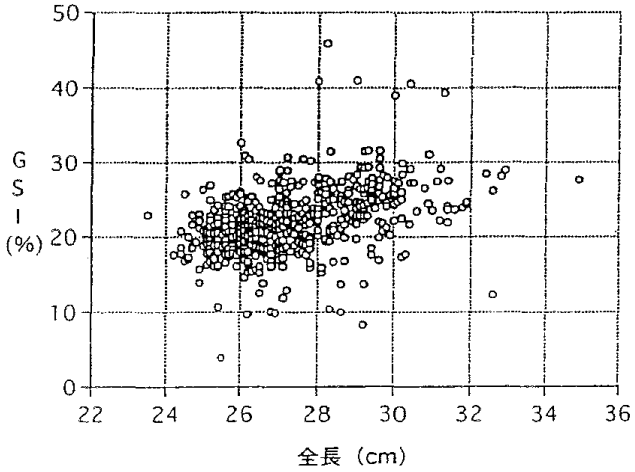


Figure III 2-7 Correlation between total length of ripe females and GSI of herring at Akkeshi Station in 1997-1999. [y axis] GSI (%) [x axis] Total length (cm)

(4) Classification of grades relative to age and size (Table III 2-2)

In March of 1989, Yamamoto & Ohana (2000) studied the grading of herring at Bekkai fish market. Average body lengths and average body weights for each grade were 26.7 cm (181 g) for "large," 24.3 cm (127 g) for "medium," and 22.8 cm (96 g) for "small." In a 20-kg fish box, there was an average of 110 fish in the "large" grade, 160 fish in a box of "medium," and 210 in "small." The ages for the fish in the "large" grade were 2-5 years, and 71.7% were 3 years old. The fish that had been graded as "medium" were 2-3 years old, and the "small" graded fish were 1-3 years old. In the smaller sizes, nearly all were 2 years old (92.7% and 97.7%, respectively). The average total length of 2-year old fish graded as "medium" was 24.1 cm and the length for "small" was 22.8 cm. The average price for each size class in 1993 was 1710 yen/kg for "large," 745 yen for "medium," and 269 yen/kg for "small." The larger the fish, the higher the price.

The state of maturation was determined from the fish catch. Maturation occurred earlier in 3-year old fish than fish that were spawning for the first time. The 3-year old fish (large grade) matured in early April. In mid to late April it was possible to obtain herring with mature gonads by purchasing the "medium" grade (as this grade contains 2-year old fish).

Table III 2-2 Composition of herring grades from Furen Lake during the spawning season (modified from Yamamoto & Ohana, 2000).

Grade classification	Age (years)	Number sampled		Total length (cm)			Body weight (g)			Number of fish per box* (fish/box)	**Average unit price (Yen/kg)
		Fish	%	Average	Smallest	Largest	Average	Smallest	Largest		
Large	,										
	Total										
Medium											
	Total										
Small											
	Total										

* Calculations are for 20-kg fish boxes

** Average unit price values calculated for 1993

銘柄	年齢	供試個体		全長 (cm)		体重 (g)		魚箱の尾数	**平均単価
	(歳)	(尾)	(%)	平均	(最小 ～ 最大)	平均	(最小 ～ 最大)	* (尾/箱)	(円/kg)
大	2	95	25.1	24.9	21.0 ～ 28.0	152	85 ～ 203		
	3	271	71.7	27.2	24.0 ～ 31.0	188	89 ～ 299		
	4	11	2.9	28.8	27.4 ～ 31.0	233	184 ～ 308		
	5	1	0.3	31.4	31.4 ～ 31.4	319	319 ～ 319		
	計	378		26.7	(21.0 ～ 31.4)	181	(85 ～ 319)	110	1,710
中小	2	872	92.7	24.1	20.6 ～ 27.4	125	75 ～ 196		
	3	69	7.3	26.2	23.0 ～ 28.4	154	18 ～ 232		
	計	941		24.3	(20.6 ～ 28.4)	127	(75 ～ 232)	160	745
小	1	1	0.1	21.4	21.4 ～ 21.4	72	72 ～ 72		
	2	692	97.7	22.8	20.0 ～ 28.4	95	61 ～ 214		
	3	15	2.1	25.0	22.0 ～ 27.0	131	85 ～ 179		
	計	708		22.8	(20.0 ～ 28.4)	96	(61 ～ 214)	210	269

* 魚箱は20kgで換算

** 平均単価は1993年度の数値

IV. EGG COLLECTION

Herring eggs have an adhesive egg membrane. In nature the eggs are attached to marine vegetation by the spawning herring. This chapter presents the essential points related to techniques for collecting eggs, fertilization methods, and the handling operations of the fertilized eggs.

1. Selection of parent fish

The supply of adult fish used in the production of herring fry commonly comes from herring that have been landed in the commercial catch and have been bought in the marketplace. The following five standards are considered when selecting parent fish (Photos IV 1-1, 1-2, 1-3).

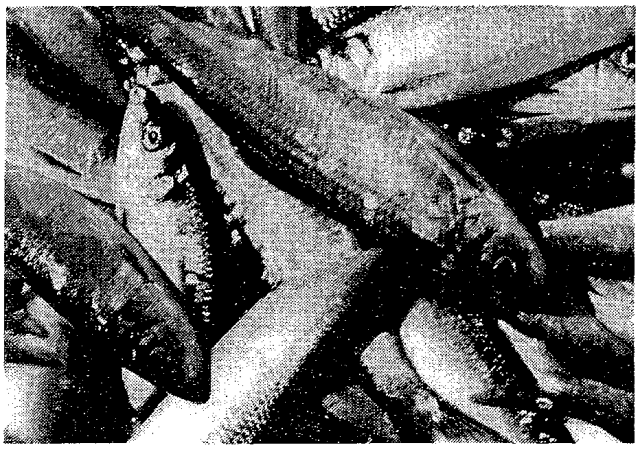


Photo IV 1-1 Landed herring in the marketplace.

Photo IV 1-2 Location where egg collection operations were performed.

Photo IV 1-3 Selection operations of ripe adult fish.

((1)) Freshness is desirable. Fish caught with gill nets should be avoided as much as possible as fish caught in set nets are fresher.
((2)) The body of the fish should show little trama.
((3)) The ventral part of the body should be inflated and appear full of eggs.
((4)) When the ventral area near the genital opening is gently pressed, mature eggs or sperm are expressed.
((5)) When there are eggs, the herring should be avoided if there is a lot of fluid and the eggs are postmature.

The reason for avoiding herring that are caught in gill nets is that the nets are set the day before the fish are landed. For this reason it is not possible to determine how many hours the fish were in the nets, so the degree of freshness is uneven. Thus these fish cannot be efficiently used.

At the Miyako Station the fishermen are requested to keep the fish in the set nets alive. After the wild parent fish are caught, landed, and selected, they are transported under refrigeration. Even after 6-7 hours of transport, it is possible to obtain high fertilization rates of 90% or more.

In the case of males, as long as the testes are kept refrigerated, sperm activity is not lost even after several days. In the case of females the eggs die is a comparatively short period of time and cannot be fertilized. Kakahashi, et al. (1984) showed that when the parent fish were maintained at a temperature of 5-10ºC, the fertilization rate was 80% or higher up to 5 hours after death. The fertilization rate declined rapidly after 6 hours, and

dropped to 50% or less at 7 hours, 30% after 12 hours, and to 10% or less after 24 hours (Figure IV 1-1). It is believed that maintaining the temperature has a large effect on freshness, but additional study is necessary to quantify the effect.

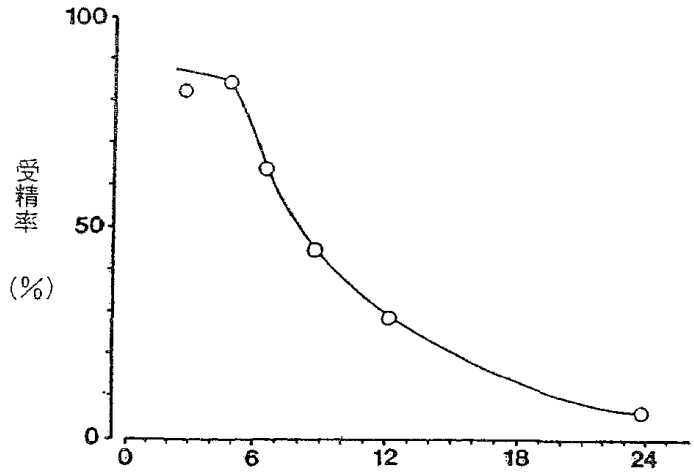


Figure IV 1-1 Relationship between fertilization rate and the length of time that the parent herring fish have been dead (modified from Kakahashi, et al. 1984) [y axis] Fertilization rate (%) [x axis] Length of time elapsed after death (hours)

2. Measuring parent fish and extracting the gonads

The ventral part of the parent fish is cut open with a scissors and the gonads are extracted (Photo IV 2-1). The extracted ovaries and testes are piled up separately on trays. Measurements are taken on fish length and body weight. The weight of the fish after the gonad has been removed is also measured, so that later the weight of the gonad can be calculated. During the selection process, fish confirmed to be immature, etc. are excluded.

Photo IV 2-1 Removing ovaries from the parent fish and making measurements.

The number of collected eggs is estimated from the weight of the eggs. As the eggs are adhesive, a lump of eggs (about 1 g) is added to a sample bottle filled about 2/3 full with 99% ethyl alcohol. The bottle is strongly shaken until the adhesion disappears. Then the number of eggs is counted and the number of eggs per unit weight is calculated. Using the correlation relationship between the average total body length (X) of herring produced at Furen Lake and the number of eggs per 1 g (Y), the correlation equation obtained was $Y=98847.9\ X^{-1.376}$ $r^2=0.81$ (Figure IV 2-1). In the case of herring produced at Furen Lake, the average number of eggs per gram for 26-cm herring was 1,100; the number for 28-cm herring was 1,000, and for 30-cm herring it was 900.

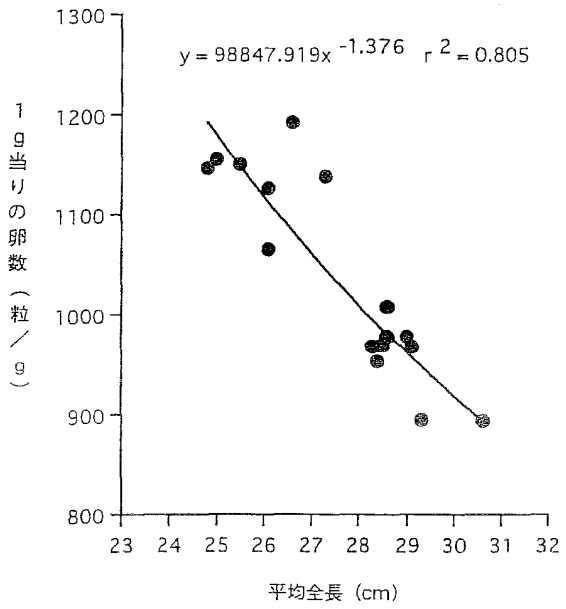


Figure IV 2-1 Relationship between the number of eggs per gram and the total length of Furen Lake produced herring parent fish.
[y axis] Number of eggs per gram
[x axis] Average total length (cm)

An egg collection study was performed from 1997 -1999 to determine the number of ovaries that could be relied on to provide eggs. It was shown that the percentage was 82.1% (74.5-87.1%) (Table IV 2-1).

Table IV 2-1 Summary of egg collection from ripe female herring produced at Akkeshi.

Day eggs collected	Collection of parent fish (average values) Total length (cm)	Body weight (g)	Weight of ovary (g)	GSI (%)	Number of test fish	Total weight of ovaries collected (g)	Weight of eggs collected (g)	*Effectiveness of egg collection (%)	Comments
April 28, 1997									Gill net
April 28, 1997									Gill net
April 14, 1998									Gill net, set net
April 19, 1999									Gill net, set net
April 20, 1999									Gill net, set net
Total									
(Average)									

*Effectiveness of egg collection (%): (Total weight of eggs collected/total weight of ovaries) x 100

採卵日	採卵親魚（平均値）				供試	卵巣重量合計	採卵重量	*採卵効率	備考
	全長(cm)	体重(g)	卵巣重量 (g)	GSI (%)	尾数	(g)	(g)	(%)	
1997年4月28日	27.4	179.1	35.0	24.2	30	1,050	908	86.5	刺網
1997年4月28日	27.9	193.5	42.2	27.2	10	422	367	87.1	刺網
1998年4月14日	27.1	198.4	43.7	21.7	98	4,285	3,580	83.5	刺網、定置網
1999年4月19日	26.6	153.5	29.8	19.3	137	4,531	3,701	81.7	刺網、定置網
1999年4月20日	27.3	169.6	34.7	20.3	44	1,451	1,081	74.5	刺網、定置網
合計(平均)	(27.0)	(173.2)	(35.6)	(20.9)	319	11,738	9,637	(82.1)	

*採卵効率（%）：総採卵重量/総卵重量×100

3. Artificial fertilization methods (Figure IV 3-1)

(1) Obtaining eggs and sperm

A rubber spatula is used to remove the eggs from the ovaries. The surface is first smeared with Vaseline (Photo IV 3-1). The ovarian membrane is cut with a scissors so eggs are easy to remove. The collected eggs are placed in a small bowl (about 1 liter), and the total weight is measured. At this time it must be remembered to remove a sample (about 1 g) to calculate the number of eggs. The testis from several individuals are cut along their sides and the pieces are placed in a 70-mesh bag and are mashed with the fingers to squeeze out sperm. The squeezed out sperm solution is accumulated in a bowl and is then well mixed. To maintain genetic diversity, it is desirable to use about the same number of males as females.

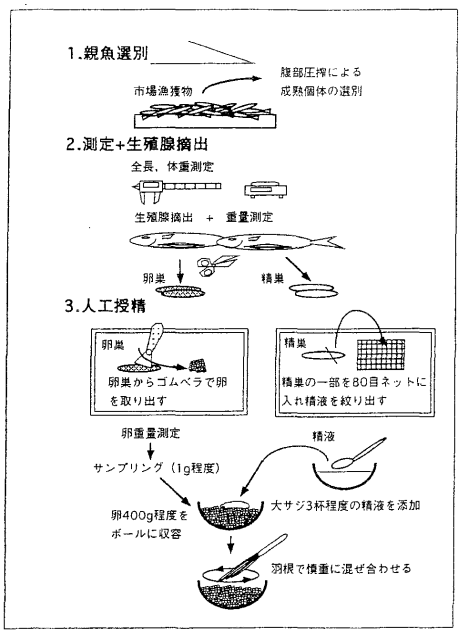


Figure IV 3-1 Schematic diagram of the process of fertilizing collected herring eggs (gonad extraction + artificial fertilization)
[Top to bottom]
1. Selection of parent fish
[above drawing]
Commercial fish catch
[right of drawing]

Pressure is applied to the abdomen to select ripe individuals.
2. Measurement + extraction of gonad
[above callipers and scale]
Measurement of total length and body weight
[above drawing of two herring]
Gonad extraction + gonad weight measurement
[above gonad drawings, left arrow]
Ovary
[above gonad drawings, right arrow]
Testis
3. Artificial fertilization
[inside left box]
Ovary: Eggs are removed from ovary with a rubber spatula
[inside right box]
Testis: Seminal fluid from a piece of the testis is pressed through 80-mesh netting.
[under left box]
Measurement of weight of ovary
[under left arrow]
Sample (about 1 g)
[left of bowl]
About 400 g of eggs is placed in a bowl
[under right box]
Sperm solution
[right of bowl]
Add about 3 large spoonfuls of sperm solution
[bottom drawing, right of bowl]
Mix together gently with a feather
[end of drawing]

Photo IV 3-1 Operation of removing eggs with a rubber spatula.

(2) Artificial fertilization

Artificial fertilization is performed using the dry method. Sperm solution is added to the bowl with the accumulation of eggs (Photo IV 3-2). About 3 tablespoons (about 50 ml) of sperm solution is added to a bowl holding 600-800 g of eggs. Sperm and eggs are then adequately mixed with a feather (Photo IV 3-3). One of the advantages of mixing with a feather is that it is easy to mix the bottom of a rounded bowl. It is important that the eggs be somewhat loose and that only small amounts of sperm are added. Care must be taken that the eggs are lumpy.

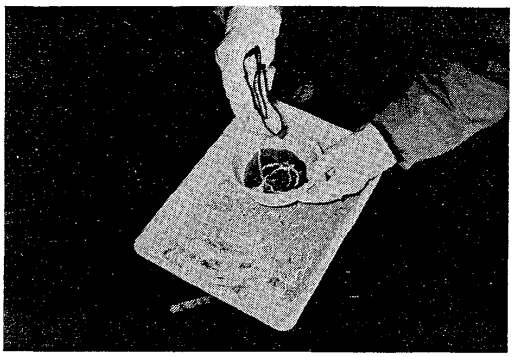


Photo IV 3-2 Artificial fertilization (eggs are covered with squeezed seminal fluid).

Photo IV 3-3 Dry method (mixed with a feather).

4. Attachment of fertilized eggs

Iiwasaki, et al. (1980) pointed out that when the adhesive eggs of carp get piled up, this lowers the hatch rate. This is the same for herring. For this reason, it is important that the eggs be attached in as uniform manner as possible. Kakahashi, et al. (1984) studied the amount of eggs that could be attached to hatching plates at Miyako Station. The eggs were collected from Mangokuura herring. It was reported that a desirable amount of eggs on a hatching screen (38 x 25 cm) was 30 g or less.

(1) Attachment to the hatching screen (Figure IV 4-1).

The hatching screens measured 38 x 25 cm and were wooden frames with mesh attached (Russell tetronic T-280, 40 mesh nylon netting, etc.) (Figure IV 4-2). The hatching screen is floated in a 60-liter container filled with filtered seawater. About 30 g of eggs, a full tablespoon) is spread uniformly over the hatching screen with a feather brush or by the fingertips in thin gloves (Photo IV 4-1). Then the excess sperm solution, etc. is washed away with filtered sea water, and the sperm is diluted by the filtered sea water in the tank.

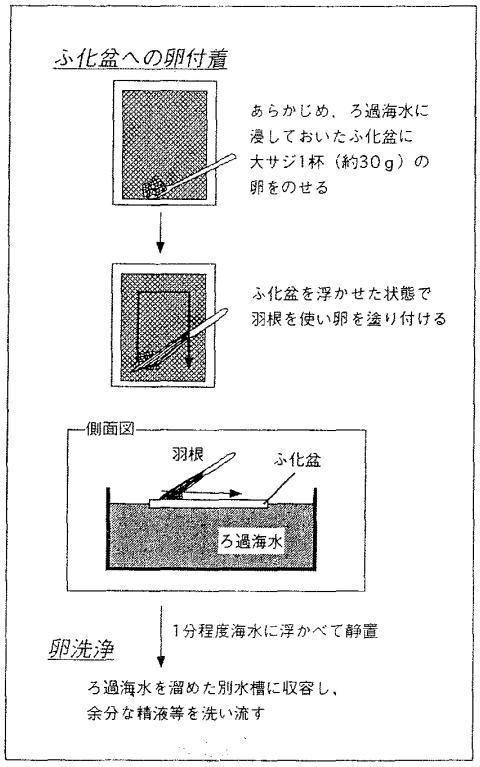


Figure IV 4-1 Procedure for collecting herring eggs (hatching screen technique)
[There are three drawings, top to bottom]
[above top drawing]
Attachment of eggs to hatching tray
[right of top drawing]
First, a screen is soaked in filtered seawater and is covered with a large spoonful (about 30 g) of eggs.
[right of middle drawing]
With the hatching tray floating, the eggs are spread with a feather.
[bottom drawing]
[top of drawing, left to right]
Side view drawing
Feather
Hatching screen
[inside drawing]
Filtered seawater
[Below bottom drawing]

The tray is allowed to float on the seawater without disturbance for about a minute.

Washing eggs

Excess sperm solution, etc. is washed off in a separate tank filled with filtered sea water.

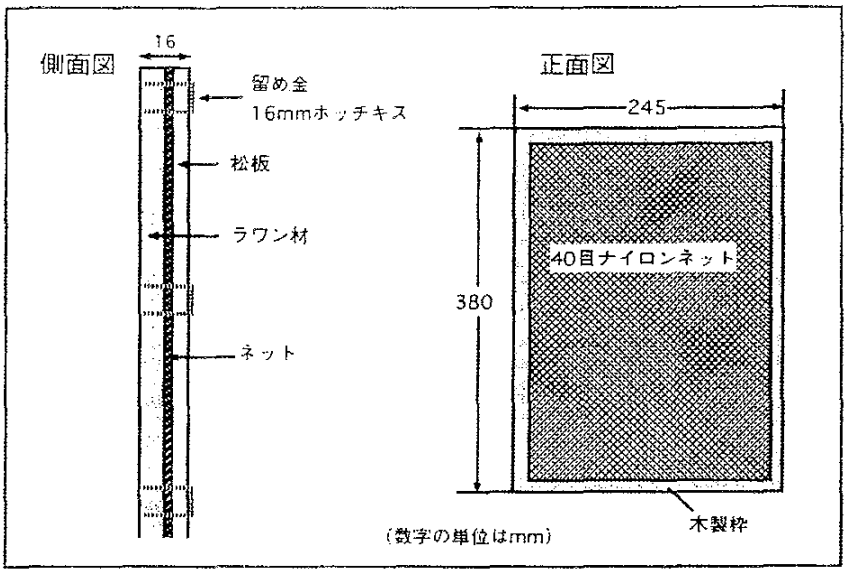


Figure IV 4-2 Construction of hatching plate used for handling herring eggs.
[left side of left figure]
Side view
[right side of left figure, top to bottom]
Metal fastener 16 mm staples
Pine board
Lauan tropical plywood
Netting
[right figure, top to bottom]
Front view
40-mesh nylon netting
Wood frame
Numerical units are in mm
[end figure]

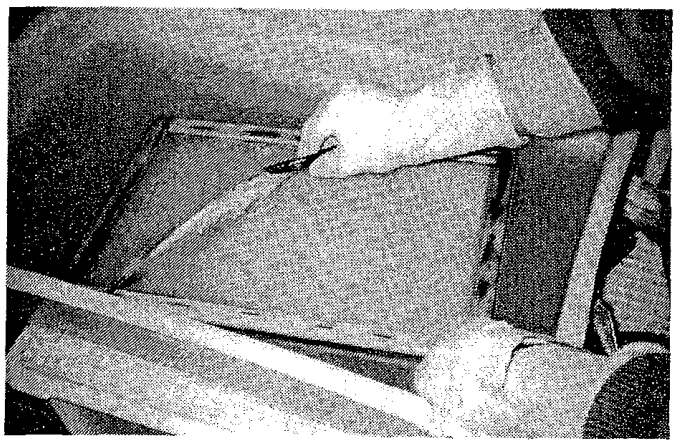


Photo IV 4-1 Operation to attach eggs to hatching screen using a feather brush.

Advantages of hatching screens are that they are compact, and it is easy to count and observe the attached eggs. Dead eggs and the remaining egg membranes after hatching can be easily removed, and if the screens are not damaged they can be reused. The disadvantages are that the egg attachment operation is troublesome and time consuming. Also, it is easy for the eggs to drop off during the attachment operation, resulting in a lot of loss. There can be an additional drop-off of eggs during culture when the eyes develop.

(2) Attachment to hemp palm brushes (Figure IV 4-3)

Mabushi brushes are made by using natural hemp palm fibers. The fibers are wrapped into a brush like shape with copper wire. Mabushi brushes are used to collect ayu eggs (sweetfish, a freshwater trout). This method is the standard method that is performed at the Hiroshima Aquaculture Association for ayu.) The brush portion is about 60 cm in length, and the column is about 15 cm wide. The transfer operation to the Mabushi brush is performed using a dry transfer method; 50-100 g of eggs is transferred from a small bowl to a bucket with 5 liters of filtered sea water. The eggs are dispersed into the water with a feather brush and the water is promptly hand mixed. A brush is placed in the water and turned over 4-5 times causing the eggs to rapidly attach to the hemp palm fibers. In a separate tank containing sea water, the excess sperm solution, etc. is washed off. The eggs are then placed in a tank with filtered sea water for culture.

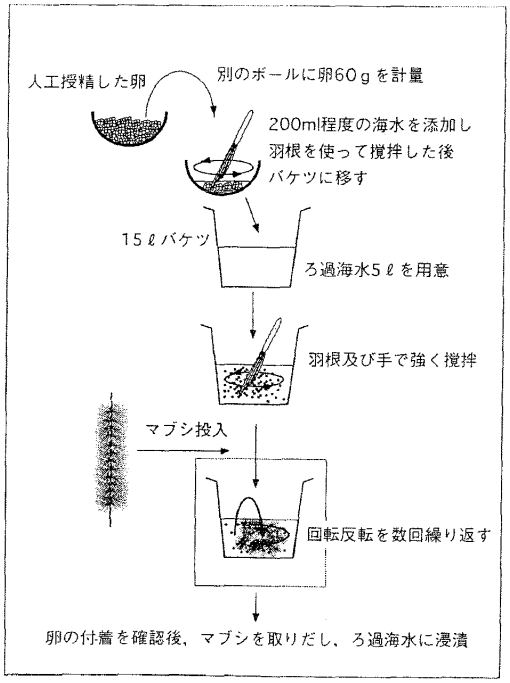


Figure IV 4-3 Technique for collecting herring eggs (Mabushi hemp palm brush technique).
[There is a series of 6 drawings, top to bottom]
[top drawing, left of bowl]
Artificially fertilized eggs
[top drawing, right of bowl]
A total of 60 g of eggs are placed in a separate bowl
[right of second drawing]
About 200 ml of seawater is added. After mixing with a feather, the eggs are

transferred to a bucket
[left of third drawing]
15ℓ buckets
[right of third drawing]
Prepared by adding 5ℓ of filtered seawater
[right of fourth drawing]
Strong agitation using a feather or the hands
[right of fifth drawing]
Put Mabushi hemp palm brush into bucket
[right of sixth drawing]
Rotate and repeat
[under bottom figure]
After attachment of eggs, the hemp palm brushes are removed and soaked in filtered sea water.

The advantages of this method are that the attachment operation is simple and the operation can be performed by a large number of people at the same time. Compared to the hatching screen operations, this can reduce the time required for attaching eggs. Also, the loss of eggs is very small, only 0.5 to 1.1%. During the handling process there is very little loss in eggs. If the brushes have been newly purchased, it is important that they be soaked in fresh tap-water for about a week to remove contaminants. In one case where this soaking treatment was not performed, the development rate was about 20% lower (Figure IV 4-4). The disadvantages of using the brushes are that observations are obscured, and if the adhesion operations are delayed, eggs have a tendency to be only partially attached. Also, it is a characteristic of the fibers that it is difficult for the eggs to drop off. For this reason it is difficult to remove egg membranes after hatching. Strongly washing the brushes to remove the egg membranes makes the fibers fall out. Consequently it is difficult to reuse the brushes.

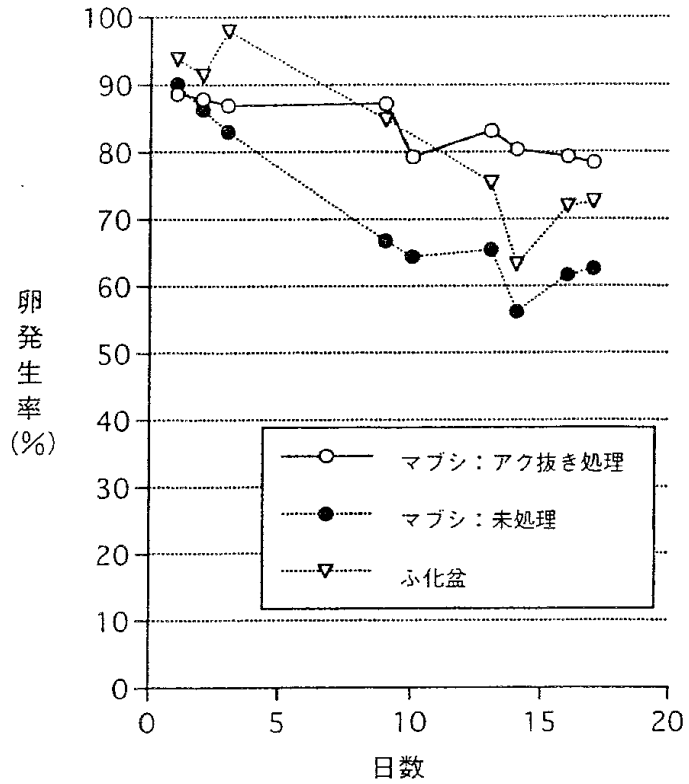


Figure IV 4-4 Changes in egg development rate with type of egg attachment substrate and differences in egg handling (1999 Hokkaido Public Corporation for the Promotion of

Aquaculture, Haboro Station Data).
[y axis]
Egg development rate
[x axis]
Number of days
[legend, top to bottom]
-o- Mabushi brush: detoxification treatment
-●- Mabushi brush: No treatment
-∇- Hatching screen

(3) Operation to separate eggs with tannic acid

Adhesive eggs can be separated using tannic acid. This makes it possible to handle the eggs without the use of an attachment substrate.

In experiments on Hokkaido-Sakhalin herring, it was possible to weaken the adhesive with a 5-minute soaking treatment with 0.1-0.15% tannic acid. Takabatake, et al. (1999) reported that it was possible to handle and hatch separated eggs. With the separated eggs it was possible to obtain relatively high hatch rates of 57-61%. An advantage of this method is that it requires less space for handling the eggs. The disadvantage is that specialized hatching containers are required for egg culture, and it is difficult to separate dead eggs.

The Japan Aquaculture Association Akkeshi Station presented reference data on past operations of the results from egg collection.

Of the three egg collection methods mentioned above, hatching plates were used from 1982 to 1998 at the Akkeshi Station. Starting in 1999 the use of hemp palm brushes was adopted.

V. MATURATION OF ARTIFICIALLY CULTURED FISH AND EGG COLLECTION

This chapter introduces the efforts that were made at the Akkeshi Station over a 2-3 year period starting in 1983 to develop techniques for culturing broodstock in land-based tanks. It discusses the results of using eggs from cultured adult fish that had been artificially fertilized, and also the preparation of spawning substrates to induce natural spawning. It describes the results of egg collection from broodstock that had been artificially reared from the egg.

1. Sequence of events

From 1970, the Akkeshi herring resource has been very small so artificial culture techniques of the broodstock have been developed. As it was difficult to secure broodstock during the spawning season, starting in 1983, wild 1-2 year old herring were collected from Akkeshi Lake and cultured in land tanks. A year later experiments were performed on obtaining eggs from the cultured herring. Furthermore, from 1984, eggs and fry produced from Akkeshi wild broodstock were cultured for 2 years or more so they could be used to collect eggs.

2. Culturing broodstock and maturation

(1) Culture methods

About 5000 eggs and fry were obtained by artificial spawning of cultured adults. The eggs and fry were from broodstock that had been reared for periods of 2-3 years (Photo V

2-1). The culture tanks used were 40-50m^3 RC tanks. The water replacement rate was 3-4 times per day, and the water was rotated using aeration. Feed consisted of frozen mysid crustaceans, minced fish, and moist pellets. Commercial formula feed was supplied at a rate of 5-7% of body weight/day (Obana, et al. 1997). In order to regulate illumination at the surface of the tank, a sun shield was put in place. The bottom of the tank was cleaned 2-3 times per week. As the bottom and sides of the tank became dirty after long culture periods, the tanks were changed after about 6 months.

(2) Culture water temperature

Controlling the water temperature is an important factor in culturing herring broodstock. At Akkeshi Station the culture water temperature from May to November was the natural water temperature (6-16ºC). During the months of December through April, when the water temperature was less than 5ºC, the herring almost stopped feeding. For this reason the water temperature was maintained at 5ºC. For comparison, Oogauchi (2001) studied the effects on survival rates of and limits of high water temperatures for the culture of broodstock from Miyakowan Bay. The results indicated that a temperature of 20ºC or less was desirable.

Koya (in the submission process) found that the maturation of herring in the marshes in the eastern part of Hokkaido required conditions of short days and lowered water temperatures. Takabatake (2000) performed experiments on culturing broodstock at the Hokkaido Aquaculture Coordination Center in 1999. The maturation of Hokkaido-Sakhalin herring that had been cultured from the egg and fry stage was studied at different fixed water temperatures. The results were that maturation occurred even when the water temperature was constant, and it was clarified that it was possible to obtain fertilized eggs. In 2000 at the same center, culture experiments of broodstock were performed at fixed water temperatures (8º, 10º, and 15ºC) by Isao (unpublished). At the respective temperatures, it was possible to maintain fertilization rates of 90% or more. Even with this information it is believed that further research is still necessary to determine the optimal culture rearing temperature for maturation.

(3) Growth

Larval herring that were cultured in 1993 had an average total length a year later in April of 19.2 cm and an average body weight of 59.5 g. After 2 years the females had an average total length of 25.1 cm and an average body weight of 152 g. For males these growth values were 24.7 cm and 143 g, respectively. This size is sufficient for maturation. Growth was essentially identical to the growth of wild fish.

(4) Maturation

The initial maturation of broodstock that had been cultured from the egg began in October with active yolk accumulation that continued through March. The GSI increased until late March and then ovulation was observed. (Refer to Chapter III, section 1(2)). Depending on the culture method, the season of maturation differed. It was confirmed that there was a long maturation season from late March to late May before the last of the fish matured.

3. Obtaining eggs from artificially cultured broodstock

(1) Artificial fertilization of the collected eggs

Wild fish were cultured from 1983 and eggs were obtained in 1984. Altogether, 20,000 eggs were obtained from two females. Also, in 1984, there were experiments to obtain eggs from broodstock that had been reared from the egg from 1984. These fish were cultured over a period of 2-3 years and were sampled periodically to estimate the maturation period. Based on these results, egg collection from broodstock was performed

during the period from late March to mid May, 1987. Eggs were obtained from wild broodstock in the same way. Fish that were gravid were removed from the culture tank, and the eggs were artificially fertilized. The results were that in the period from 1987 to 1992, the number of egg obtained from 2- to 4-year old broodstock was 490,000 to 1,800,000 eggs (Table V 3-1). Artificially cultured herring were raised in land based tanks to adulthood for use as broodstock. It was possible to obtain eggs using an artificial fertilization method (Yamamoto 1987-1992).

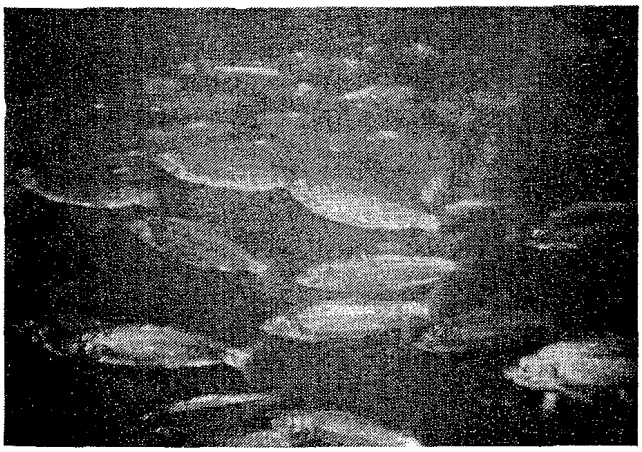


Photo V 2-1 Schooling of artificially cultured adult herring.

Table V 3-1 Egg collection results of artificial fertilization of eggs from cultured broodstock from Akkeshi.

Year	Wild mature herring			Artificially cultured wild herring			
	Number of broodstock		Eggs collected	Number of broodstock		Eggs collected	History of broodstock
	Female	Male	(10,000 eggs)	Female	Male	(10,000 eggs)	
							Fry cultured in 1984, 3 year old
							Fry cultured in 1984, 4 year old
							Fry cultured in 1987, 2 year old
							Fry cultured in 1987, 3year old
							Fry cultured in 1987, 4 year old
							Fry cultured in 1990, 2 year old

年	天然魚養成			人工種苗養成			
	親魚尾数		採卵数	親魚尾数		採卵数	親魚履歴
	雌	雄	(万粒)	雌	雄	(万粒)	
1984	2	6	2.0				
1985							
1986							
1987	7	18	2.0	21	15	49	1984年種苗3歳
1988				29	17	104	1984年種苗4歳
1989				123	44	130	1987年種苗2歳
1990				37	5	93	1987年種苗3歳
1991				40	30	162	1987年種苗4歳
1992				73	30	180	1990年種苗2歳

There were no problems during the initial maturation season. However, in the second and later maturation seasons, abnormalities were observed in the gonads of broodstock that had not been able to spawn in the previous year. It is apparent that this was due to poor conditions following spawning (Yamamoto 1994). The ovaries of the broodstock that could not spawn remained at the same size from October through May. As the eggs in the ovaries could not be adequately absorbed, at the next spawning season the eggs were those that had remained from the previous year. It was confirmed that there was some type of inhibition to the proper development of the ovaries. Also, it was observed that the testis showed the same pattern to a lesser degree. According to these findings, in order to continue to use the same fish, reliable conditions to allow spawning must be determined.

In the case of artificial culture, the time period for when ovulated eggs become post mature is 10 to 15 days shorter than for wild fish. It is easy to miss the maturation peak with the artificial fertilization method. For this reason it would be desirable to use broodstock in a natural way where this was not a problem and where the broodstock could be used repeatedly.

(2) Collecting naturally spawned eggs

Tests on obtaining naturally spawned eggs from cultured fish were begun in 1987 (Yamamoto 1989). On May 10, kinran brocade mats were supplied as an artificial substrate, and starting the following day, small amounts of eggs were deposited. On April 15, 1992, hemp palm brushes were used successfully as spawning substrate (Yamamoto, et al., unpublished). Many eggs were observed to be attached to the hemp palm brushes (Mabushi).

In 1995 and 1996 Ohana, et al. (1997) performed natural spawning experiments using hemp palm brushes that were in place for a 3-day period. Approximately a thousand 2-year old fish and 564 3-year old fish were used. The investigation confirmed that obtaining fertilized natural spawning was a possibility. The tests were performed twice, once on April 11 and again on April 18. The resulting fertilization rates were high (90.0% and 96.0%, respectively) and 10,350,000 eggs were obtained (Photo V 3-1). Also, in 3 tests performed on April 15, 18, and 19, the fertilization rates were 64.1% to 75.5%, and a total of 12,830,000 eggs were obtained. Because of this, it was confirmed that it was possible to obtain an adequate degree of fertilization of spawned eggs using natural fertilization methods with artificially cultured fish (Table V 3-2). Also, the eggs were not spawned on the hemp palm brushes in clumps. It was observed that the eggs were attached to the palm fibers in a uniform manner.

Photo V 3-1 Eggs spawned naturally on artificial spawning substrate (hemp palm brushes).

Table V 3-2 Results of obtaining eggs from natural spawning of cultured broodstock.

Year	Month/Day	Water temperature (ºC)	Spawning substrate positioning method	Number of substrates	Amount spawned (10,000 eggs)	Amount of fertilized eggs (10,000 eggs)	Fertilization rate
1995	April 10						
	April 11						
	April 28						
	April 20						
Subtotal							
	April 15						
	April 15						
	April 18						
	April 18						
	April 19						
Subtotal							

*Spawning substrates were hemp palm brushes (trade name: Mabushi).

年	月日	水温 (℃)	*産卵基質 設置方法	基質本数 (本)	産卵量 (万粒)	受精卵量 (万粒)	受精率 (%)
	4月10日	5.9	垂下式	30	0	0	-
1995年	4月11日	5.5	垂下式	30	461	415	90.0
	4月18日	5.5	垂下式	30	574	551	96.0
	4月20日	5.7	垂下式	30	0	0	-
小計				120	1,035	966	93.3
	4月15日	5.6	垂下式	25	121	92	76.0
	4月15日	5.6	沈下式	25	608	459	75.5
1996年	4月18日	5.1	垂下式	25	20	13	65.0
	4月18日	5.1	沈下式	25	473	303	64.1
	4月19日	5.4	底層垂下式	20	61	46	75.4
小計				120	1,283	913	71.2

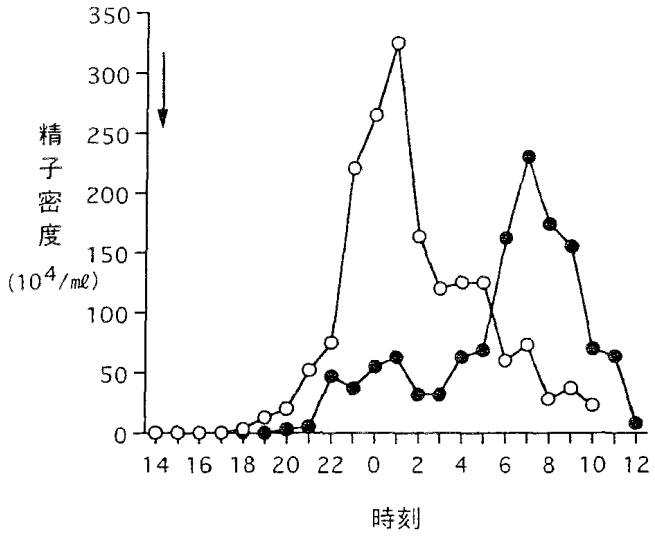
*産卵基質はシュロブラシ（商品名：マブシ）を使用

Yamamoto (2001) performed fry production experiments using naturally spawned eggs. It was confirmed that hatching occurred from eggs that had a fertilization rate of 63.9% (the hatch rate was 21.8%). The young were reared in a 0.5m^3 tank for 34 days. The fry measured 22 mm in length and had a 27.7% survival rate. It was confirmed that it was possible to use naturally spawned and fertilized eggs for culture of fry.

4. Technique for inducing spawning in mature artificially cultured fish

(1) Induction of spawning

Yamamoto (1994) performed egg spawning induction experiments. In the experiments mentioned above, sperm solutions from males were used for induction. On April 15, 1992, a suspension of sperm fluid in seawater was added to a culture tank to see if it could successfully induce spawning, and it was confirmed that spawning was induced. The sperm fluid had been separated by centrifuging and the supernatant was used as the inducer in the tests. The concentration of sperm in the spawning tank was measured to estimate the peak spawning period. Peak spawning occurred 9-11 hours after the addition of the sperm solution. When the sperm solution was not added, the earliest that peak spawning occurred was after 17 hours. Thus, it is assumed that the addition of sperm solution induced natural spawning (Figure V 4-1).



図Ⅴ 4-1　産卵水槽への精漿添加と産卵床設置に伴う水槽内の精子密度の推移（松原提供）
＊図中の矢印は精漿添加と産卵床の設置を示す
—○— 精漿添加＋産卵床　　—●— 産卵床

Figure V 4-1 Change in sperm concentration in water tank accompanying the addition of sperm solution and placement of spawn collectors in spawning tanks (provided by Matsuhara).
*The arrow in the figure indicates when the sperm solution was added and the spawn collectors were put in place (Matsuhara, unpublished).
[y axis] Sperm concentration (10^4/ml)
[x axis] Time of day
[open circles] Addition of sperm solution + spawn collectors
[closed circles] Spawn collectors

(2) Spawning behavior

To test natural spawning in 2- to 3-year old cultured herring, in 1995 and 1996 the cultured herring were put in a land-based tank with spawning substrates (Ohana, et al., 1997). The results were that for several hours after placement of the spawning substrates, spawning behavior could be observed. Spawning behavior consisted of a swimming pattern where the fish swam close to the substrates in a pattern from the bottom to the top, and then spawned on the substrate (Figure V 4-2). The spawning behavior that is observed was graded as follows: 1) Rapid movements in and around the spawning substrates; 2) Approaching the substrate and touching with the abdomen but prior to spawning; and 3) Females laying eggs and males releasing sperm. The females layed several dozen eggs on the substrate during each spawning pass. It was observed that by the completion of egg laying, this behavior had been repeated multiple times. When spawning began, the seawater in the tank became so milky with the sperm solution from the males that it was not possible to observe the adult fish. Also, foam was observed.

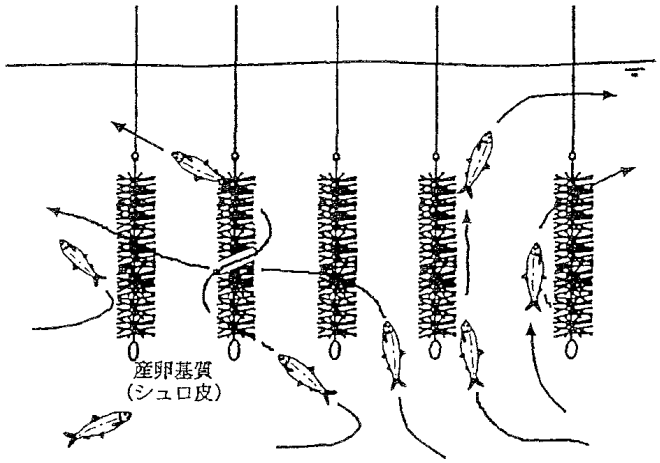


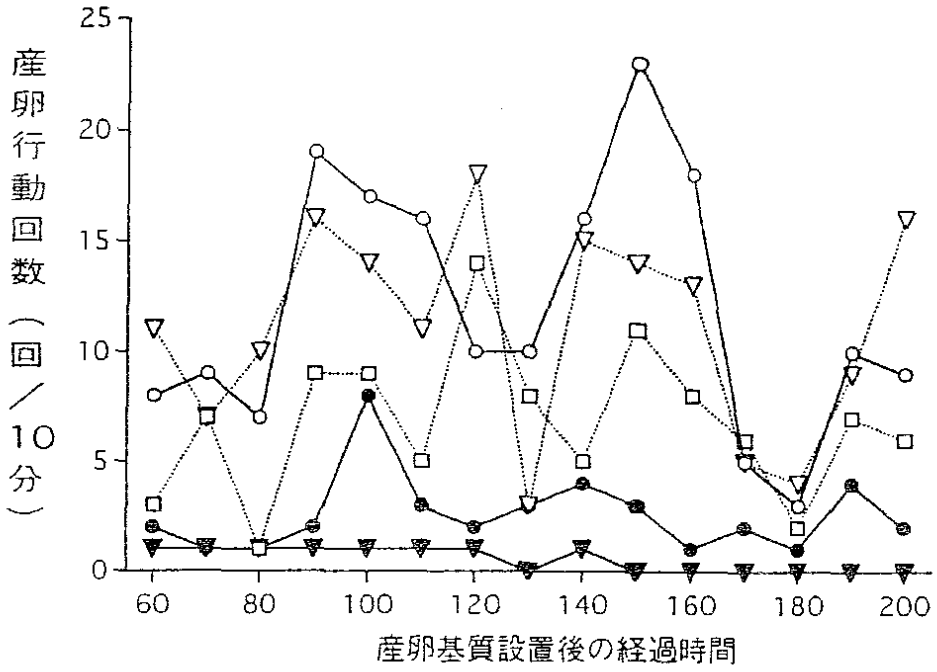
Figure V 4-2 Diagrammatic drawing of herring spawning behavior.
[left bottom of figure]
Spawning substrate (hemp palm brushes)

(3) Egg substrate selection

Ohana, et al. (1997) studied the results of egg substrate selection with artificial substrates: hemp palm brushes, kinran brocade mats, and hatching screens. No spawning was observed on hatching screens. There was small amount of spawning on the kinran brocade mats, and a large amount of spawning on the hemp palm brushes. This indicated that of the artificial materials tested, the hemp palm brushes were superior.

Yamamoto (2000) studied spawning substrate selection of natural substrates (eelgrass, surf grass, and sargassum) as well as artificial substrates (hemp palm brushes and kinran brocade mats). Observations were made on both the frequency of spawning behaviors and the condition of the attached eggs. Spawning behavior was observed for 44 minutes after the placement of the substrates. Spawning behavior was frequent on the eelgrass, surf grass, and sargassum. Spawning behaviors were relatively infrequent on the artificial substrates (Figure V 4-3, Photo V 4-1). Two days later the condition of the spawn was studied, and large amounts of eggs were also observed on the artificial substrates. The hemp palm brushes, in particular, had a lot of spawned eggs. Also, spawning was even observed on the vinyl tubes that were used for the frames of the spawning substrate.

According to these findings, there was substrate selection when spawning began, and spawning occured more commonly on natural substrates such as marine plants. However, when the females had been stimulated by the sperm solution, it can be presumed from the morphology of the egg masses that they were less selective about substrates, and layed their eggs indiscriminately. This phenomenon has the result that in nature, when the herring have schooled together, spawning is observed even on the mesh of set nets and on downed floating trees.



図Ⅴ 4-3　ニシン人工養成親魚の各産卵基質に対する産卵行動の経時変化
（産卵行動は基質設置後44分後に確認）
天然基質　—○— アマモ　…□… スガモ　…▽… ホンダワラ
人工基質　—●— マブシ　—▼— キンラン

Figure V4-3 Spawning behavior over time of artificially cultured adult herring with different spawning substrates.
(Observations were made of spawning behavior 44 minutes after the substrates were placed).
Natural substrates: -○- eelgrass; -□- surf grass *(Phyllospadix)*; -▽- Sargassum (*Sargassum fulvellum*)
Artificial substrates: -●- hemp palm brushes, -▼- kinran brocade mats
[y axis] Frequency of spawning behaviors (number of times in 10 minutes)
[x axis] Change over time after placement of spawning substrates

Photo V 4-1 Natural spawning tests in water tank.

VI. HANDLING THE EGGS

There are reports on methods of handling herring eggs from fertilization to hatching and estimating the number of days for hatching. This information is indispensible for culturing feed and producing fry. Information in this chapter describes the characteristics of the egg and the basics of egg development. It discusses the accumulated water temperature from spawning to hatching, environmental tolerances, and egg handling.

1. Egg characteristics

Following is a description of the characteristics of herring eggs from Uchida, et al. (1958). Herring eggs are heavier than water and are adhesive. The eggs have a diameter of 1.3 to 1.6 mm. The yolk has a diameter of 0.8-1.0 mm. The egg chorionic membrane is nearly colorless and transparent and is thick and stiff. On the surface is an extremely thin amorphous layer of adhesive. The yolk contains fine transient structures, and has a very light yellow color. The shape is spherical. When the spawned eggs glue to each other and to other surfaces, they form somewhat irregular clumps. As hatching approaches, the egg chorionic membrane thins. The hatching opening in the chorionic egg membrane has an irregular shape, which is commonly triangular.

2. Egg development

Egg development stages were described in detail by Kuwatani, et al. (1978) (Figure VI 2-1). At a water temperature of 10ºC, the day after fertilization the eggs were at stage 4, the blastula.

On the second day they were at stage 7, embryonic shield formation.

On the third day, stage 8, the embryonic body formed.

On the fourth day, stage 10, Kufpper's vesicles formed.

On the sixth day, stage 12, heart pulsations could be observed.

On the eighth day, stage 14, the eye appeared.

Hatching began on the eleventh day.

Figure VI 2-2 shows the stage of egg development when the eggs were cultured at average water temperatures of 3.6ºC and 9.8ºC.

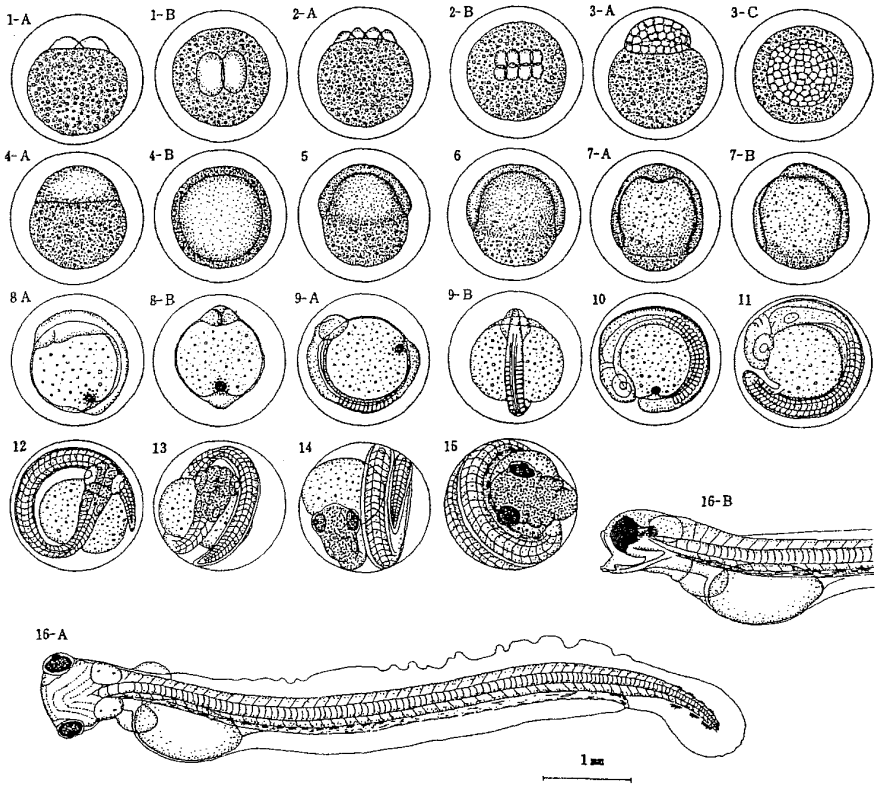


Figure VI 2-1 Herring egg development (modified from Kuwatani, et al., 1978).
1A: 2-cell stage (side view).
1B: The same (top view).
2A: 8-cell stage (side view).
2B: The same (top view).
3A: Morula stage (side view).
3B: The same (top view).
4A: Blastula stage (side view).
4B: The same (side view [sic. top view]).
5: Gastrula stage (1/2 covered, side view).
6: The same (2/3 covered, side view).
7A: Embryonic shield has expanded (side view).
7B: The region of the embryonic body can be seen to thicken.
8A: Optic bud formation can be observed. Kufpper's vesicle formation process (side view).
8B: The same (back view).
9A: Ten myomeres can be seen in the center of the larval body. Contours of optic buds and Kufpper's vesicles can be clearly seen (side view).
9B: The same (back view).
10: Twenty myomeres can be counted. A lens has formed in the eye bud. Kufpper's vesicles are clear.
11: The myomeres cover 2/3 of the total body length. The ear vesicle can be seen. On the interior, the two black spots and the Kufpper's vesicle disappear. There is a separation at tail. The length of the body makes about one curl encircling the yolk sac (side view).
12: Myomeres can be seen on the whole body. The heart pulsations can be seen. The embryonic body makes about 1.2 curls (dorsal side view).
13: Optic vesicles are light brown. The hatching gland on the anterior dorsal surface is dispersed. Total body length is 1.5 curls (dorsal side view).

14: Optic vesicle and lens both become brown. Length of body is about 2 curls.
15: Optic vesicle and lens darkens and both become black. There are scattered black spots of pigment on the peritoneum and ventral fin positions. This is just before hatching.
16A: Fry after hatching (dorsal side view).
16B The same (side view of head)

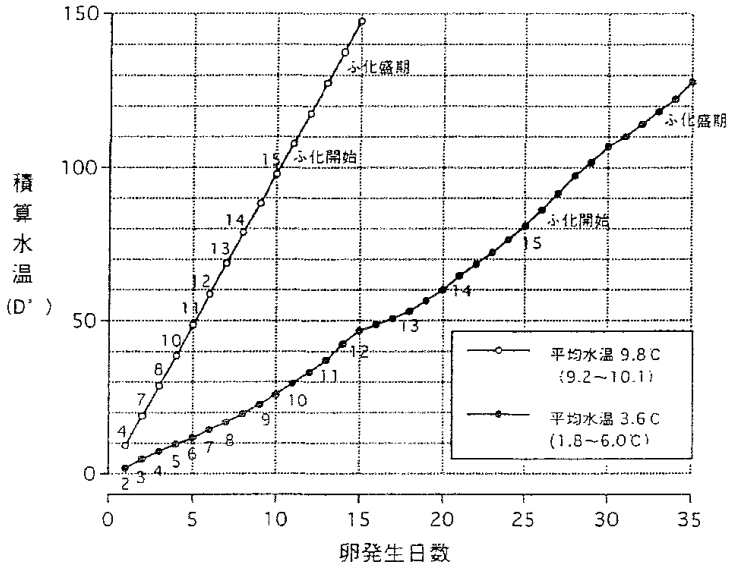
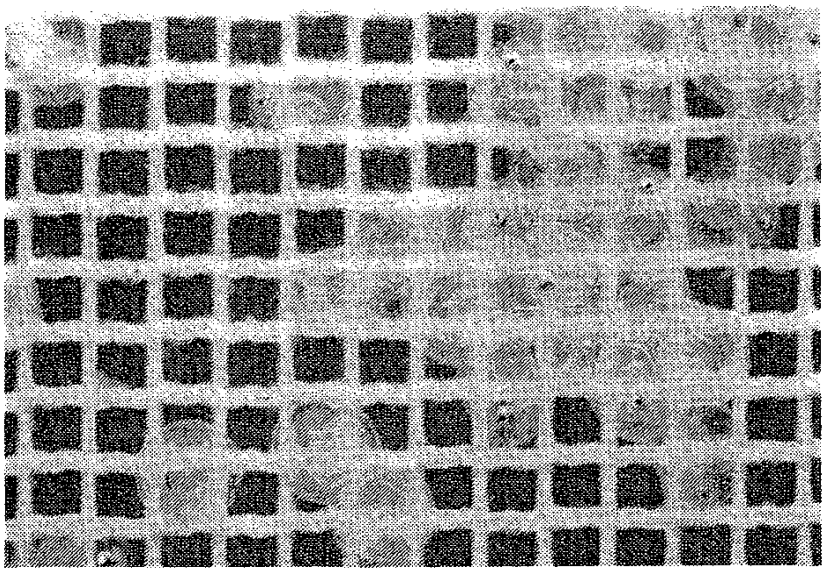


Figure VI 2-2 A comparison of the relationship between differences in egg development with respect to water temperature: stage of egg development and accumulated water temperature. (The numbers in the drawing refer to the egg development stages given by Kuwatani, et al. 1978.)

[y axis] Accumulated water temperature (Dº)
[x axis] Number of days of egg development
[legend, open circles] Average water temperature 9.8ºC (9.2-10.1ºC)
[legend, closed circles] Average water temperature 3.6ºC (1.8-6.0ºC)
[word close to “15” on both curves] Hatching begins
[word close to top of each curve] Eye development on hatching screen



Photograph VI 2-1 Hatching screen with herring eggs at the eyed stage.

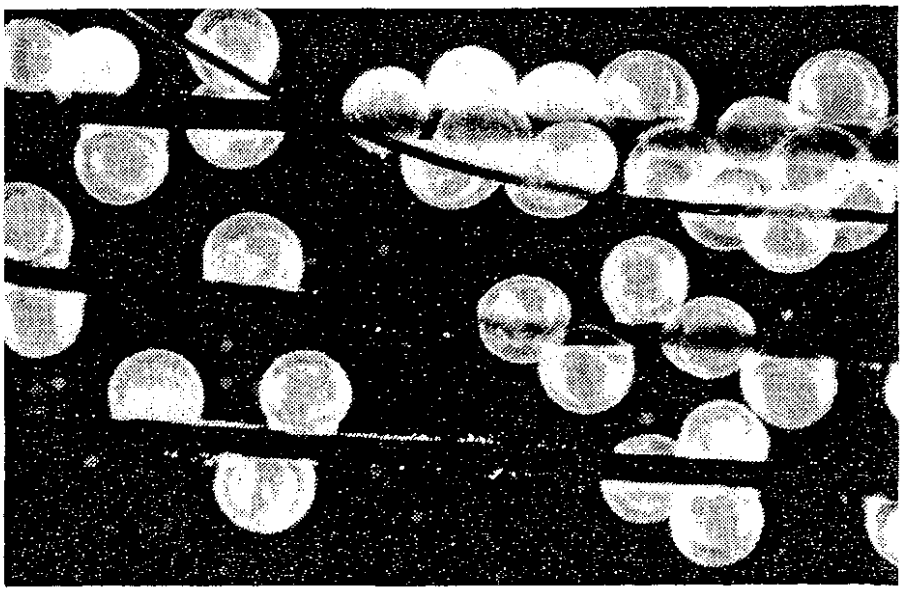


Photo VI 2-2 Attachment of eggs to hemp palm brush

Daily observations were made of the development stages. Observations were made of randomly selected hatching screens (photo VI 2-1) and hemp palm brushes. Egg development rates were determined every third day. 1) Each lot was observed with a wide-field dissecting microscope and had 100 or more eggs. 2) Several hatching screens were used, 3) Observations on development conditions were made at 4 or 5 positions on each hatching screen, and the number of dead eggs was counted. In the case of the hemp palm brushes, a portion that had eggs attached was cut off. Eggs were pealed off with tweezers and observed (photo VI 2-2).

3. Environmental tolerance of eggs

(1) Water temperature

At Akkeshi Station, the temperature of the egg treatment water was 10ºC. Water temperature was measured twice each day, and the accumulated water temperature was calculated. Hatching was observed when the accumulated water temperature exceeded 100 Dº. As the fry take about two days to hatch, they are exposed to an accumulated water temperature of 120 Dº. The majority hatch in the range of 130-140 Dº, and all have hatched by 150 Dº. At a temperature of 10ºC, it took 14-15 days for all herring to hatch.

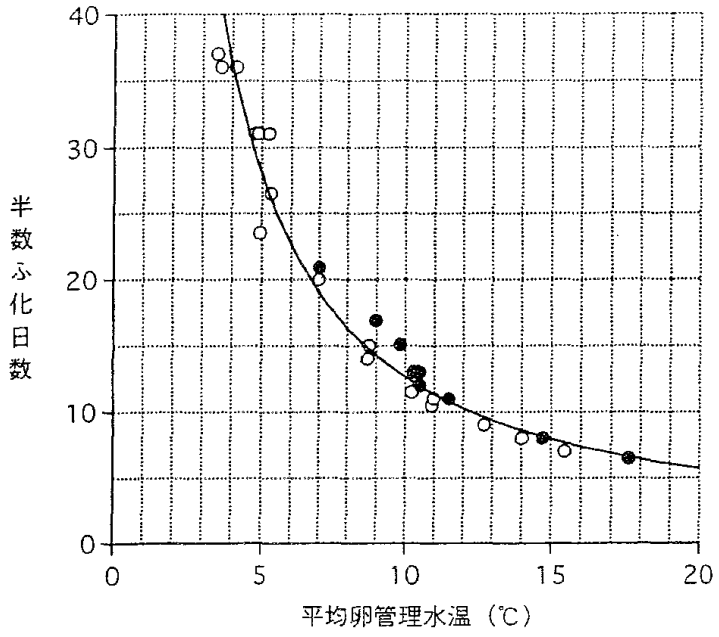
1) Suitable water temperatures for egg development

The water temperature for egg development was studied by Alderdice, et al. (1971) and Kuwatani, et al. (1978) for Pacific herring. According to these references, suitable temperatures for herring development are in the range of 3.5-10ºC, with the optimal water temperature presumed to be in the range of 5.7-7.8ºC. There is an indication that the optimal temperature differs depending on the stage of development. Takahashi, et al. (1984) tested herring from Mangokuura at different temperatures. At temperatures of 10ºC, 15ºC, and 20ºC there were no differences though the eye development stage. However, at 20ºC, there was a decrease in the hatching rate and the activity level was worse. At 15ºC the hatch rate was the same as for 10ºC. According to the above report, this indicates that normal hatching is possible in higher water temperature zones. According to Shibuya (1978), at the low water-temperature limits (0ºC or less) development proceeded and reached the Kufpper's vesicle stage on the 38th day. Of these, 14% reached the eyed egg stage, but then all died. Therefore, it is assumed that at 0ºC or less, egg development does not result in hatching. For the high temperature limits, it can

be surmised from the data of Takahashi, et al. (1984) that development can take place at temperatures of 20ºC or less. Kuwatani, et al. (1978) found that in the test groups reared at 20ºC or higher, there was almost no hatching. The highest temperature for which there was at least a 75% hatch rate of normal herring was 17.5 ºC. The conclusion is that the high water temperature limit is close to 17.5ºC.

2) Relationship of water temperature and number of days for egg development

To determine the relationship of water temperature and number of days for egg development data from Kuwatani, et al. (1978) and Takahashi, et al. (1984) was combined. The formula for the relationship between the average egg development water temperature (T: ºC) and the number of days for half of the eggs to hatch (D: days) was $D=177.46T^{-1.147}$ ($r^2=0.972$) (Figure VI 3-1). The number of days required for half of the eggs to hatch was as follows: 32 days at 4ºC, 21 days at 6ºC, 16 days at 8ºC, 14 days at 10ºC, 11.5 days at 12ºC, and 10 days at 14ºC.



図Ⅵ 3-1　ニシン卵発生時の平均水温と半数ふ化日数の関係
● (高橋ら, 1984)　○ (桑谷ら, 1978)

Figure VI 3-1 Relationship between the average water temperature during culture and the number of days for hatching of half of the eggs.
[y axis] Number of days for half of the eggs to hatch
[x axis] Average water temperature during egg culture (ºC)
● Takahashi, et al. (1984)
○ Kuwatani, et al. (1978)
$y=177.460x^{-1.147}$ ($r^2=0.972$)
y: Number of days for half of the eggs to hatch; x: average water temperature during egg culture

According to Takahashi, et al. (1984), the accumulated water temperature for the herring eyed stage was 70-80 Dº, and this did not depend on water temperature. However, it was suggested that depending on the water temperature zone, there are differences in the period from the eyed stage through hatching. At Akkeshi Station the water temperature of the egg

culture tank and the number of days until hatching was about 130 ºD when the water temperature was below about 10ºC. At higher temperatures the value was about 140 ºD. Herring in other areas show the same type of trend. In the Hokkaido-Sakkalin race, the accumulated water temperature for hatching was comparatively low. Takabatake (2000) reported that at temperatures lower than about 10ºC the value was about 90-110 ºD, and for higher temperatures it was 110-132 ºD.

(2) Salinity

Herring eggs develop normally at a wide range of salinities, and can also tolerate very rapid changes (Kurata 1959). Excluding the extremes, the salinity does not have an effect on the number of days for hatching (Isahaya, 1932; Ford, 1929). Depending on the race, there are differences in suitable salinities. Isahaya (1932) reported a range of 14.1-27.2‰ and Dushkina (1973) reported 10-36‰. Alderdice (1971) reported the hatching of normal herring at rates of 80% or more when the salinity was in the range of 6-25‰, and Kuwatani, et al. (1978) reported the hatching of normal herring at rates of 60% or more at 13.4-33.2‰. In the reports, there were high hatch rates over a broad range of salinities. The lower end of the salinity range has been tested. Yamaguchi (1932) reported that there was hatching even in fresh water but all of the herring died. Kuwatani (1978) reported that there was no hatching at salinities below 1.8‰. In addition, for areas with high salinity, it was reported by Isahaya (1932) that there was a small number that hatched even at a salinity of 43.9%.

In the Furen Lake vicinity the salinity range within the lake is 7-20‰ (Nakagawa 1999). As there is generally normal hatching within this range, it is believed that in Furen Lake the effect of salinity is minor.

4. Egg culture tank

A small specialized egg culture water tank was used for culturing the eggs and there was also a large production scale spawning tank. The former was used hatching screens and separated eggs. The latter was used for hatching screens and hemp palm brushes.

Photo VI 4-1 Egg treatment tank (eggs on hatching screens).

Stainless steel frames that could accommodate 15 hatching screens were used to culture the eggs. The water was filtered sea water that was exchanged at a rate of once every 24 hours. Aeration was provided through ϕ13 vinyl tubes. Aeration was sufficiently strong to provide good water circulation.

2) Separated eggs

Specialized hatching jars were used. There was flowing water exchange throughout the day, but no aeration.

(2) When using the large water tank for culture

1) Using hatching screens

As the frames for the hatching screens were made of wood, there was sufficient natural floatation. A sinker was attached to one end of each screen so that each floated up from the bottom of the tank. Screens were positioned randomly. Water was exchanged once a day. Water was circulated with air tubes that were located in each corner of the tank (Figure VI 4-1).

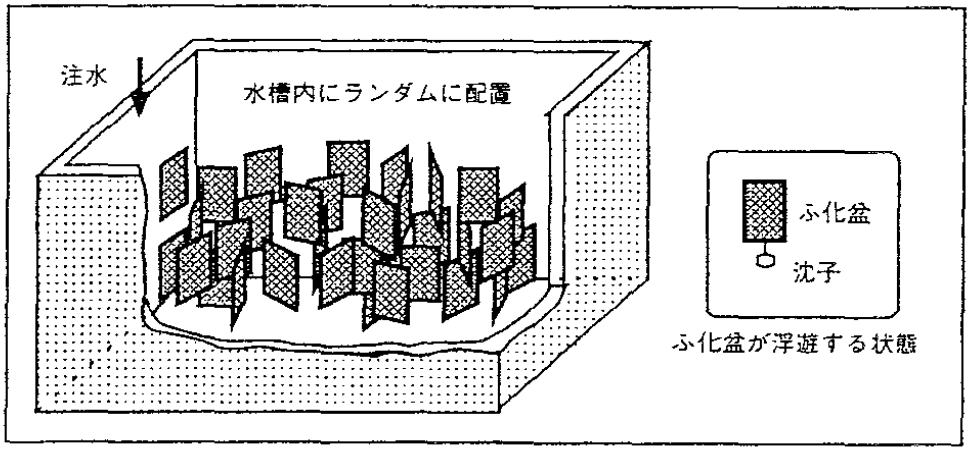


Figure VI 4-1 Herring egg culture method in a large water tank using hatching screens.
[top left] Water added
[top center] Random positioning in water tank
[right side of figure, top to bottom]
Hatching screen
Sinker
Positioning of screen when floating

2) Using hemp palm brushes (Photo VI 4-2)

The floats were about 1 m long. These were 3-cm square wood supports that were used for the vertical attachment of 6 hemp palm brushes. Each of the brushes had a sinker attached and was positioned so that the brushes did not touch the bottom. Water exchange and aeration was the same as for the hatching screens (Figure VI 4-2).

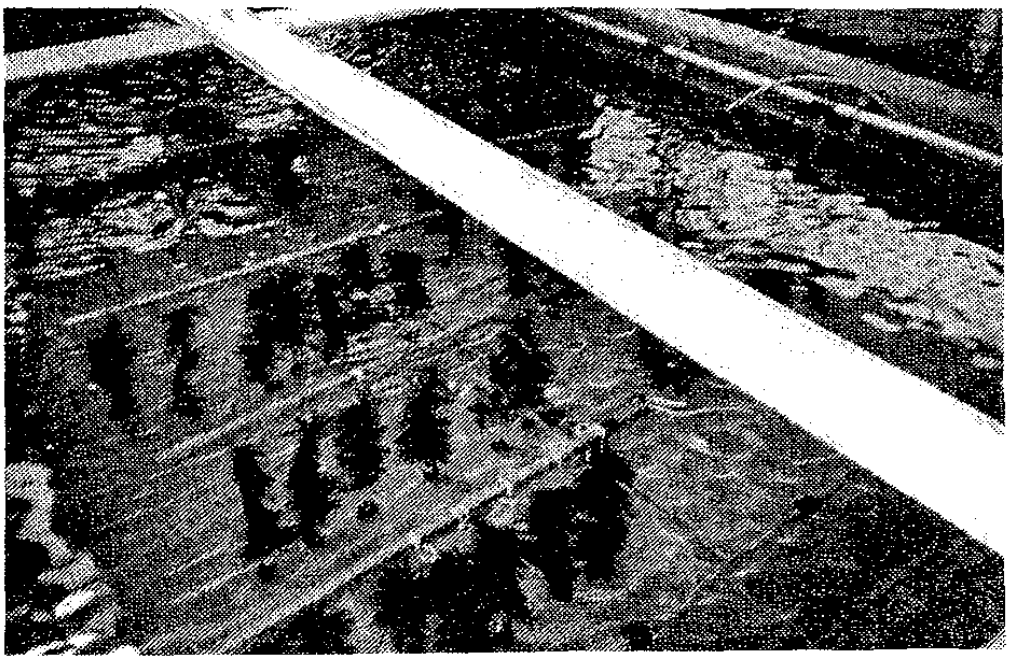


Photo VI 4-2 Egg culture tank (eggs on hemp palm brushes)

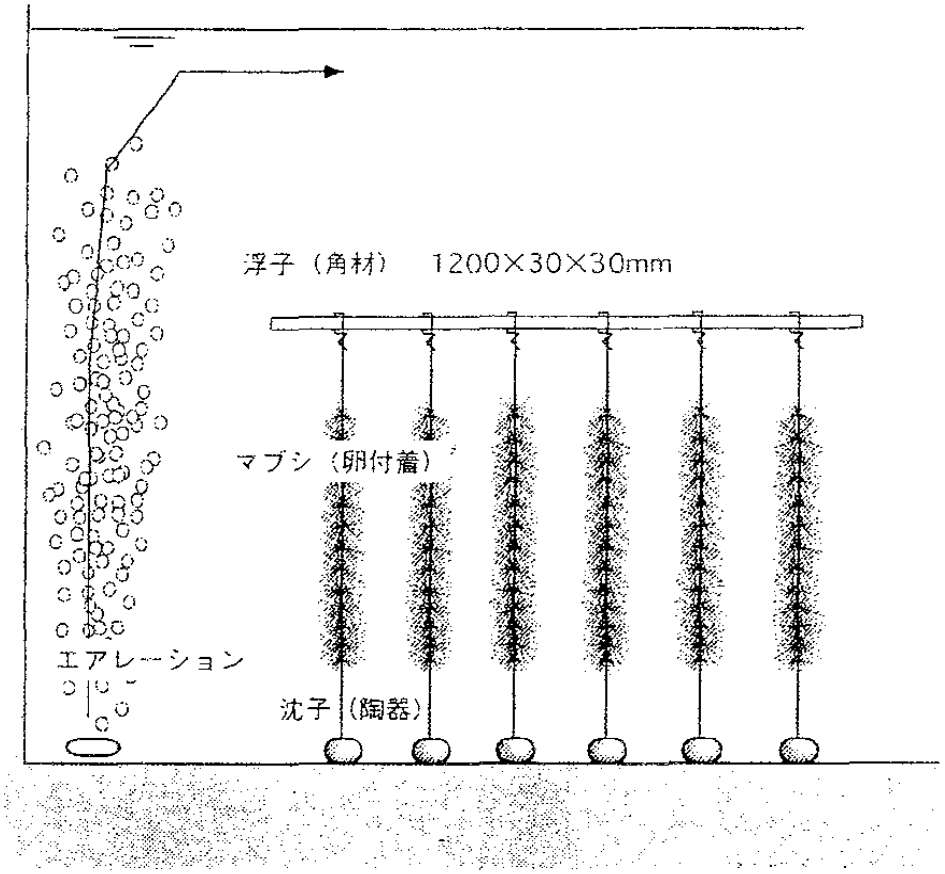


Figure VI 4-2 Egg culture method using hemp palm brushes in a herring culture tank.
[Japanese comments from top to bottom]
Floating hanging rack 1200 x 30 x 30 mm
Hemp palm brushes (eggs are attached to brushes)
Aeration
Weight sinker

5. Disinfection of eggs

The eggs were disinfected 3-4 days after they were collected and again in the eyed egg stage. They were immersed for a period of 15 minutes in a 50 ppm solution of Isojin Disinfectant (isodine, an iodine disinfectant). A 60ℓ box-shaped container made of poly [polyethylene?] was used for disinfection. The method allowed the use of a hatching frame holding 15 hatching screens. The solution was changed after every use. The eggs collected on hemp palm brushes were not disinfected.

VII. DEVELOPMENT OF LARVAE AND FRY

Basic information on the herring developmental process is extremely important for the production of herring fry. In this chapter there are descriptions of the developmental process of the principle exterior morphological features, the skeleton, fins, gastrointestinal tract, muscles, otoliths, etc. It includes systematic observations of how the body parts change relative to length during the developmental process. It also describes the morphology of each of the developmental steps, physiology, and life history characteristics.

1. Developmental process and basic observations

Table VII 1-1 organizes information on herring development and the seed production process through the larval and fry periods. If refers to the development stages of herring larvae and fry by Uchida, et al. (1958). The table includes the average results from Akkeshi Station. Figures were published by Kuwatani, et al. (1978).

Uchida, et al. (1958) published the morphology of the egg before and after hatching and during the fry and larval stages (Figure VII 1-1). This chapter (Chapter VII, sections 2-5) introduces details of the development of herring during the larval and fry stages. The principal reference is Fukuda (1986). A portion of the material is from items that have been arranged from research at Akkeshi Station.

TableVII l-l Development stages of herring and embryological features

Number of days		Development stage	Degree days (D°)	Total length (mm)	Figure	Developmental characteristics	Feeding/ nutrition	Rearing conditions, etc.
Eggs	After hatching							
0		Fertilized egg				Fertilization, polar body extruded	Internal nutrition from egg yolk	Artificially fertilized (dry method). Attached to spawning substrate. Eggs cultured with flowing water and a water temperature of 10ºC
		2-cell stage				Cell division begins		
		8-cell stage						
		Morula stage						
1		Blastula stage						
2		"				Expansion of embryonic shield. Thickening of gastrula body.		
3		Gastrula stage				Optic vesicle outline appears. Formation of Kufpper's vesicle		
		"				Ten myomeres in the center of the larval body. Clear outlines of optic vesicles and Kufpper's vesicles		
4		"				20 myomeres, lens, formation of eye vesicles and Kufpper's vesicles		
5		"				Ear vesicle. Disappearance of Kufpper's vesicles. Separation at tail. Embryonic body makes about 1 curl.		
6		"				Myomeres on all of body. Heart pulsations. Embryonic body makes about 1.2 curls.		
7		"				Hatching gland on dorsal surface of head. Embryonic body makes about 1.5 curls.		
9		"				Optic lens and optic vesicle are brown. Embryonic body makes 2 curls.		
11		Just before hatching				Optic lens and optic vesicle are black. Black spots of pigments on peritoneum and base of pelvic fins.		Transfer to culture tanks. Larvae are counted (cylinder type). Culture temperature 13-15ºC. Fed rotifers. Begin exchanging water.
14	0	Hatched larvae				Egg yolk diameter 1.0 x 0.6 mm. Air bladder rudiment appears.		
	1	Early larval stage				Head is parallel to body axis. Lower jaw protrudes. Stomach rudiment appears.	Nutrition from the exterior Rotifers	
	2					Mouth opens. There is an arrangement of black pigment cells in the vicinity of the terminal notochord of the tail.		
	3					Egg yolk is absorbed		
	4	Late stage larvae 1				Development of lower jaw. Protrusion from proboscis. Rudiments of dorsal fin, anal fin and tail appear.		
	5					Intestinal mucosal epithelium develops.		
	10					Notochord terminal and caudal fin ray rudiments appear.		Begin bottom cleaning. Artemia feed. Increase in mortalities.
	15					Outlines of dorsal and pelvic fins. Rudiments of pelvic fin appear.	Artemia	
	30	Late larval stage 2				Intestinal mucosal epithelium develops.		
	34					Rays of dorsal and anal fins are completed. Nares in the process of differentiation. Gastrointestinal tract has rotated.		
	36					The stomach portion of the gastrointestinal tract has started to differentiate. A short pyloric cecum has appeared. Bubbles appear in the swim bladder.		
	42					Body height somewhat higher. Lateral myomeres cover sides of digestive system. There is still a strong similarity with the young of sardines (shirasu stage, white fry)		Increase water exchange
	45	Fry Stage				Nares completed with 2 openings (before and back). Dorsal fin and anal fin are advancing. Morphology is becoming fixed.		Landed and counted
	50					Body height becomes higher. Head is also sloped. Final body shape is in place. Short protruding scales appear in the ventral fin area. Gastrointestinal tract is completed.		Offshore nursery culture
	55					Weak keeled scales appear on the ventral edge from the pelvic fin forward. Black pigment cells appear dorsally		
	70					Scales cover most of body		
	72					Keeled scales appear on the ventral surface between the base of pelvic fins and the anus. Scales on upper sides of body are outlined with a black membrane.		
	78					Relative positions of fins, anus, etc. are the same as for adults. Fixed number of keeled scales on the ventral surface.		
	85							
	100	Fingerling stage				Exterior appearance has nearly the same aspect as the adult. Fish has the same classification attributes,	Comp. food	Release

日数 卵	日数 ふ化後	発育過程	積算水温 (D)	全長 (mm)	図	発生学的特徴	餌料・栄養	育成条件等
0		受精卵				受精，極体放出		人工授精(乾導法)
		2細胞期			VI 2-1，1	卵割開始		産卵基質へ付着
		8細胞期	2		VI 2-1，2			卵管理
		桑実期	5		VI 2-1，3			流水，水温10℃
1		胞胚期	7		VI 2-1，4			
		嚢胚期	9－10		VI 2-1，5,6			
2		〃	15－20		VI 2-1，7	胚楯拡大，胚体域の膨出		
3		胚体	20－28		VI 2-1，8	眼胞の輪郭出現，クッパー氏胞形成		
		〃	28－32		VI 2-1，9	胚体中央に10数個の筋節，眼胞とクッペル氏胞の輪郭明瞭	内部栄養	
4		〃	32－38		VI 2-1，10	20数個の筋節，レンズ形成，眼胞とクッペル氏胞の形成	卵黄	
5		〃	38－48		VI 2-1，11	耳胞，クッペル氏胞の消失，尾部の遊離，胚体長約1巻き		
6		〃	48－55		VI 2-1，12	筋節全体に出現，心臓の搏動，胚体長1.2巻き		
7		〃	55－75		VI 2-1，13	頭部背面にふ化腺，胚体長1.5巻き		
9		〃	75－100		VI 2-1，14	眼胞・レンズとも褐色，胚体長2巻き		
11		ふ出直前	100－140		VI 2-1，15	眼胞・レンズとも黒色，胚体腹膜鰭基部に黒色色素叢点在		飼育水槽に移送
14	0	ふ化仔魚	120－140	7－8	VII 1-1，3	卵黄径1.0×0.6mm，鰾の原基出現		仔魚計数（柱状）
	1	仔魚前期		8.5	VII 1-1，4	頭部が体軸と平行，下顎が出現，胃の原基出現		飼育水温13－15
	2			9	VII 1-1，5	開口，尾部脊索末端中線上付近に数個の黒色胞縦列		ワムシ給餌
	3			9－10.5	VII 1-1，6	卵黄吸収		換水開始
	4	仔魚後期1		10.4	VII 1-1，7	下顎の発達し吻端より突出，背鰭基底と臀鰭基底と尾下骨原基出現	外部栄養	
	5			11		腸の粘膜上皮にしわ形成	ワムシ	底掃除開始
	10			14.3	VII 1-1，8	脊索端上屈，尾下鰭条原基出現		アルテミア給餌
	15			16.8	VII 1-1，9	背鰭，腹鰭の輪廓はほぼ整う，腹鰭原基出現		斃死増加
	30	仔魚後期2		22		胃の粘膜上皮にしわ形成		配合飼料給餌
	34			24	VII 1-1，10	背鰭，臀鰭とも鰭条は完成，鼻孔前後に分化途上，消化管の回転	Ar	
	36			25－26		消化管に胃部の分化開始，短い幽門垂出現，鰾に気泡が出現		
	42			30	VII 1-1，11	やや体高が高くなり，体側筋肉節下縁は消化管側面を覆う，シラス期の様相がまだ強い		換水増加
	45	稚魚期		32.5	VII 1-1，12	鼻孔完成（前後2孔）背鰭と肛門は前進		
	50			36		体高は高くなり，頭部も側扁し，体形が整う，腹鰭腋部に短い突起状鱗片出現,消化管ほぼ完成		
	55			42	VII 1-1，13	腹鰭より前方の腹縁に弱い稜鱗が出現，背部に黒色胞が発達	配合飼料	取り揚げ，計数
	70			50		鱗がほとんど体全体を覆う		沖出し，中間育成
	72			52		腹鰭基底と肛門の間の稜鱗が出現，体側背部の鱗の輪郭は黒色胞により明瞭化		
	78			58		各鰭・肛門等の相対的位置はほとんど成魚に等しく，腹面の稜鱗も定数に達する		
	85			70				放流
	100	幼魚期		90		外形がほとんど整い，成魚の分類学的特徴も良く現れる		

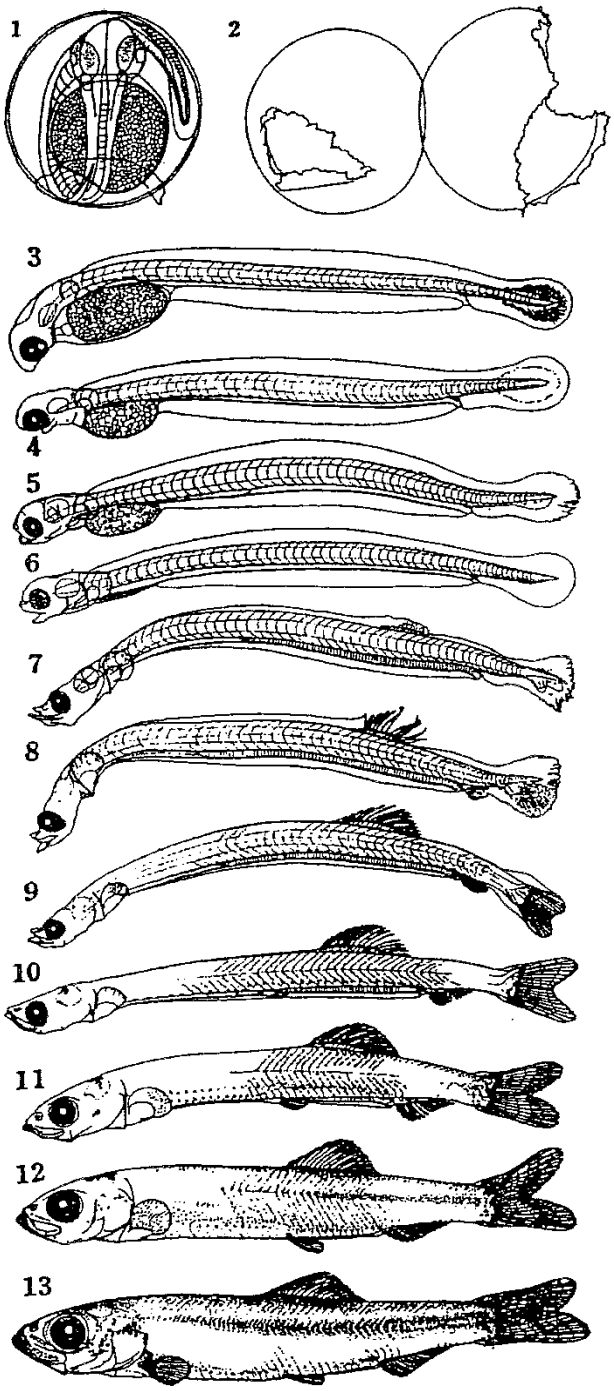


Figure VII 1-1 Exterior morphological changes during the herring larval and fry periods (modified from Uchida, et al., 1958).

Egg:

1. Egg immediately before hatching.
2. Hole in egg membrane immediately after the hatching of the larval fish.

Larval period:

Early stage larval period:

3. Hatched larval fish. Total length 3.8-7.6 mm.
4. One day after hatching.
5. [Note: this number is missing from list]
6: Seven days after hatching. Total length 9-10.5 mm.

Late larval period:

7. Total length 10.4 mm.
8. Total length 14.3 mm.
9. Total length 16.8 mm.
10. Total length 24.0 mm.
11. Total length 30.0

Fry period:

12. Total length 32.5 mm.
13. Total length 42.0 mm.

2.Changes in exterior morphology

(1) Changes in relative growth morphology (Figure VII 2-1, 2-2)

Herring have growth stages where they resemble the young of sardines (what is called the shirasu stage or white fry stage) (Photo VII 2-1). During this period there are large changes in the form of the body. Fukuda (1986) studied the growth of the total body length relative to the following body parts: length of body anterior to the anus, head length, trunk length, eye diameter, and body height. The results show that the flexion points for each of the body part ratios are centered around 18 mm and 30-33 mm. Changes in the allometric growth flexion points match the flexion points for ossification, gender differentiation, and sexual maturation (Kubata 1961; Amaoka, 1964). It is assumed that at a body length of about 18 mm, there is some functional change. The larval stages have been divided into the following categories: early stage larval period from hatching to a body length of 10 mm, late stage larval stage I from 10 to 18 mm; and late stage larval period II from a body length of 18-30 mm (Figure VII 2-3). Reference data shows correlations between total lengths, fork lengths, body lengths, and body heights starting at the late larval stage.

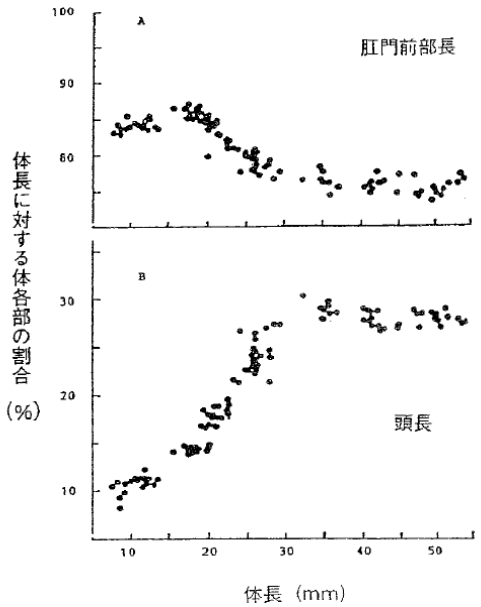


Figure VII 2-1 Changes in relative allometric growth of herring larvae and fry (Fukuda, 1986)
A: Body trunk length.
B: Head length.
[y axis] Ratio of each body part relative to body length (%|)
[x axis] Body length (mm)
[upper figure] Length of body before the anus
[lower figure] Head length

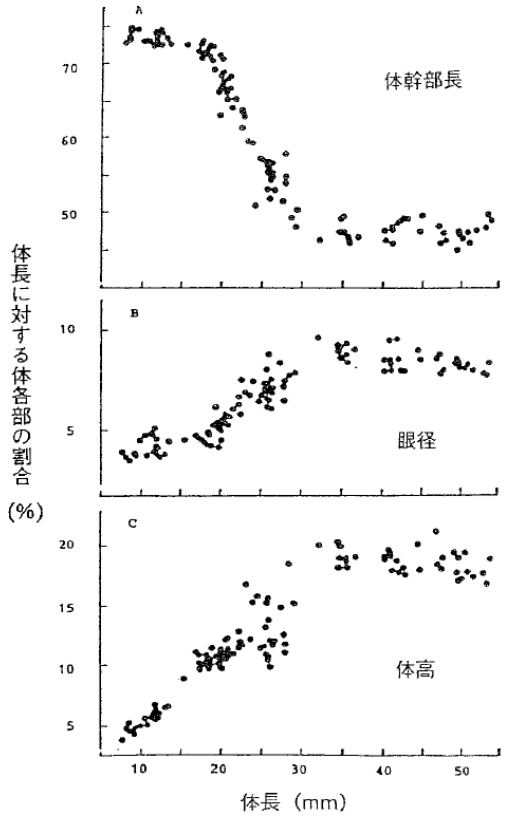


Figure VII 2-2 Changes in the form of the herring body through relative growth (Fukuda, 1986)
[y axis] Ratio of each body part relative to body length (%|)
[x axis] Body length
[upper figure] Length of body before the anus
[middle figure] Eye diameter
[lower figure] Body height

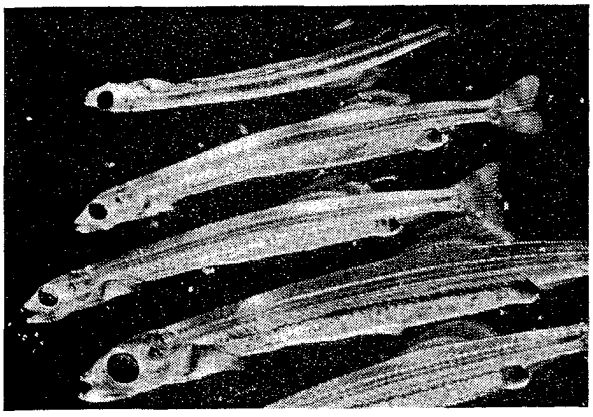


Photo VII 2-1 Larval stage of herring (shirasu stage, white fry stage)

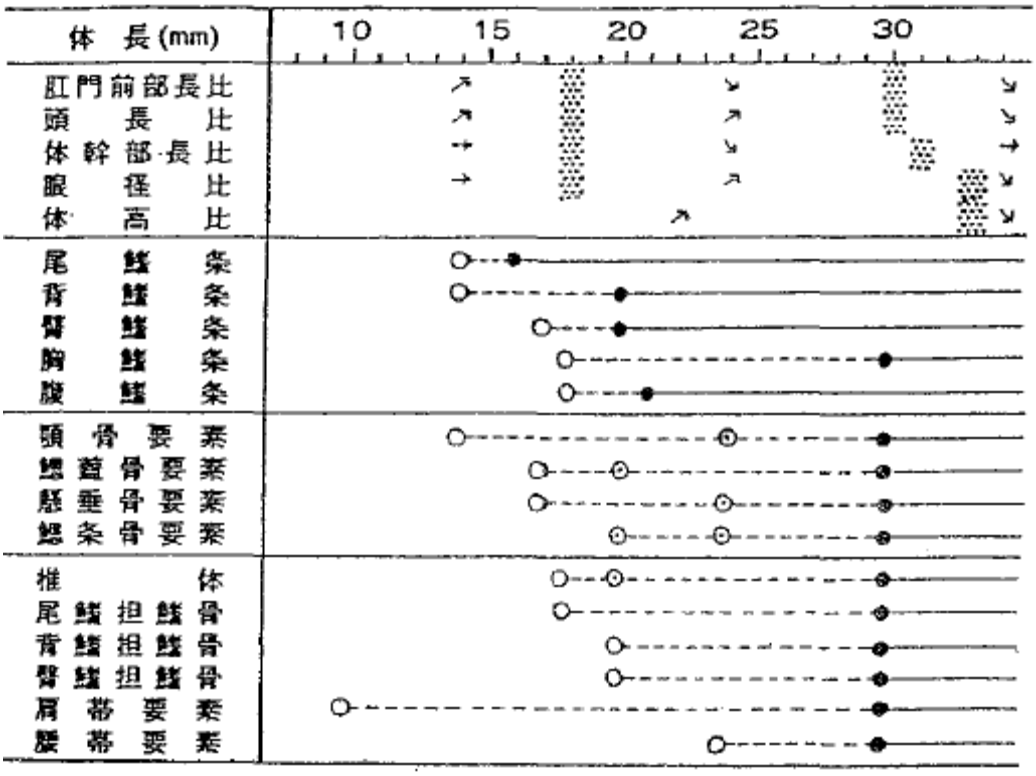
Body length (mm)	
Ratio of length that is anterior to the anus	
Ratio of head length	
Ratio of trunk length	
Ratio of eye diameter	
Ratio of body height	
Caudal fin rays	
Dorsal fin rays	
Anal fin rays	
Pectoral fins rays	
Pelvic fin	
Mandible bone components	
Opercular bone components	
Suspensorium bone components	
Components of fish fins rays	
Vertebral body	
Pterygiophore bones for the caudal fin	
Pterygiophore bones for the dorsal fin	
Pterygiophore bones for the anal fin	
Pectoral area components	
Pelvic area components	

Figure VII 2-3 Diagrammatic figure of the relative developmental progression of skeletal components during the growth of herring larvae and fry (Fukuda 1986). Arrows indicate increases and decreases in relative growth. The stippling indicates the flexion points of the relative growth.

○ Indicates the initiation of ossification.

[circle with dot in center] Indicates that all elements have appeared but ossification is not sufficiently developed。

● Indicates adequate ossification.



(2) Skeleton formation

The development of the skeleton was studied by Fukuda (1986). The central axis with the attached bones and coccygeal bones provides body support and swimming functions. The ossification of the central axis begins at a body length of about 18 mm at the 11th to the 23rd vertebra. Then ossification of the vertebra proceeds rapidly and is completed by a length of 21 mm. In the pelvic zone there is ossification of the pelvic fin area at a body length of 23.5 mm. Also, supporting pterygiophores fin bones of the dorsal fin and pelvic fins appear at a body length of 21 mm, and the respective bones have completely ossified by a body length of 30 mm (Figures 2-4, 2-5).

The facial bones related to the capability of catching food develop at a body length of 14 mm, and ossification of the maxillary bone and the dental bone begins. At a body length of 17 mm ossification of the quadrate bone and opercular bone begins. At a body length of 20 mm, the facial bones are largely ossified, and at 23 mm the maxillary bone is completely ossified. At a body length 31.5 mm there is an expansion of the ossified surfaces of each of the facial bones which then join, and become connected with increasing strength. A portion of the bone is not ossified, but they are nearly completed. All of the facial bones are ossified at a body length of 40 mm (Figure VII 2-6).

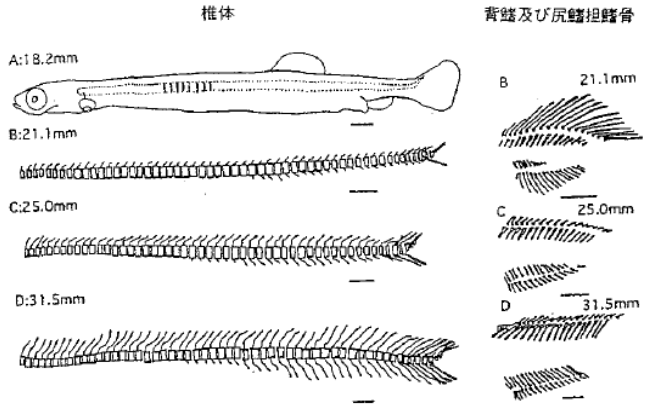
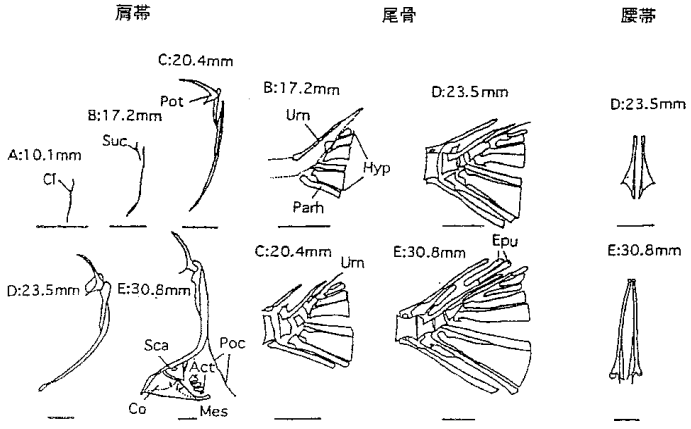


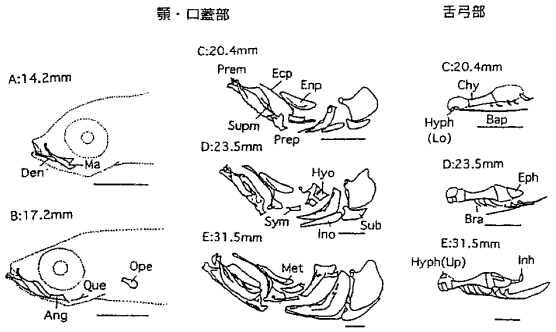
Figure VII 2-4 The ossification process of vertebral bodies and pterygiophores during the herring larval and fry stages (Fukuda, 1986) (Scale in figure 1 mm.)
[top of drawing - left]
Vertebra
[top of drawing - right]
Dorsal fin and caudal fin pterygiophore bones



図Ⅶ 2-5　ニシン仔稚魚期の尾骨，肩帯，腰帯の骨化過程
（福田，1986）
Act：射出骨，Co：烏口骨，Cl：擬鎖骨，Epu：上尾骨，Hyp：下尾骨，Mes：中烏口骨，Parh：準下尾骨，Poc：後擬鎖骨，Pot：後側頭骨，Sca：肩甲骨，Suc：上擬鎖骨，Urn：尾神経骨（図中スケール：0.5mm）

Figure VII 2-5 The ossification process of coccygeal bones, pectoral (girdle) bones, and pelvic bones in herring larvae and fry (Fukuda, 1986).
[top of figure, left] Pectoral girdle
[top of figure, middle] Caudal bones
[top of figure, right] Pelvic girdle
Act (actinost bone), Co (corocoid bone), Cl (cleithrum, Epu (upper coccygeal bone), Hyp (lower coccygeal bone), Mes (middle corocoid bone), Parh (under quasi-coccygeal bone), Poc (post cleithrum), Pot (post-temporal bone); Sca (scapula); Suc (supracleithrum); Urn (caudal nerve canal). (Scale in figure: 0.5 mm.)

Ossification begins in bones that make feeding possible, especially the maxillary bone and dental bone. In the late larval stage (which begins at 18 mm ossification) ossification can be observed in most bones. From the larval stage to the fry stage at 30 mm, bone formation is nearly completed (Figure VII 2-3).



図Ⅶ 2-6　ニシン仔稚魚期の顔面骨の骨化過程（福田，1986）
Ang：角骨，Bap：基翼状骨，Bra：鰓状骨，Chy：角舌骨，Den：歯骨，Ecp：外翼状骨，Enp：内翼状骨，Eph：上舌骨，Hyo：舌顎骨，Hyph：下舌骨，Inh：間舌骨，Ino：間鰓蓋骨，Ma：主上顎骨，Met：後翼状骨，Prem：前上顎骨，Prep：前鰓蓋骨，Que：方骨，Sub：下鰓蓋骨，Supm：上主顎骨，Sym：接続骨（図中スケール：1 mm）

FigureVII 2-6 The ossification process of facial bones during the larval and fry stages (Fukuda, 1986). [top of figure, left] Jaw, mouth, and opercular parts [top of figure, right] Hyoid arch
Ang (Anglar bone), Bap (basal pterygoid), Bra (gill type bone), Chy (ceratohyal bone), Den (dentary bone), Ecp (ecto pterygoid bone), Enp (endo pterygoid bone), Eph (epihya), Hyo (hyomandibular), Hyph (hypohyal), Inh (interhyal bone), Ino (interopercular bone), Ma (mandibular bone), Met (post pterygoid bone, Prem (premaxillary bone), Prep (preopercular bones), Que (quadrate bone), Sub (Sub opercular bone), Supm (super mandibular bone), and Sym (connecting bone). (Scale: 1 mm).

(3) Fin ray formation (Figure VII 2-3)
According to the results of a study by Fukuda (1986) on changes in the number of fin rays of each fin and the progression of ossification, the fins rays with the most rapid ossification were the caudal fin rays and the dorsal fin rays. Ossification began at a body length of 14 mm. The number of caudal fin rays became fixed at 16 mm, and the number of fin rays in the dorsal fin becomes fixed at 20 mm. The anal fin rays began to ossify at 18 mm, and at 20 mm the number of fins rays became fixed. Ossification began in the fin rays of the pelvic fins and pectoral fins at 20 mm. The pelvic fins were completed at 21 mm and the pectoral fins at 30 mm or later, which is somewhat slower. There is a relationship between the development of swimming behavior and the progressive development of the fin rays of the fins. In water tanks, schooling behaviors began at 21 mm, and the completion of the fin rays was related to this swimming behavior.

(4) Formation of scales

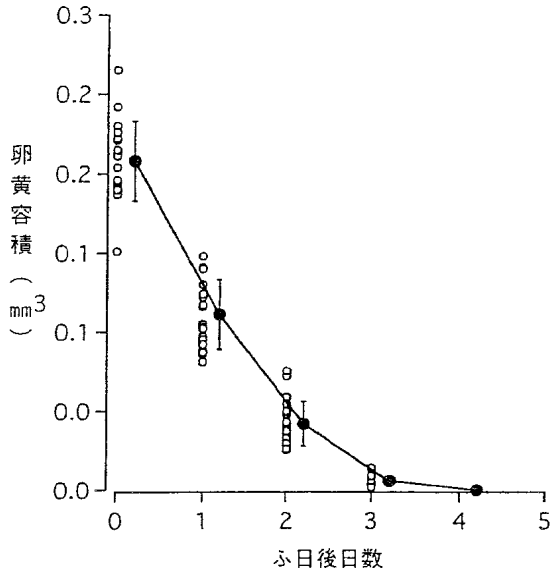
According to Uchida, et al. (1958) at a total length of 36 mm, short protruding scales appeared in the support areas of the pelvic fins. Then scales gradually spread widely to support areas of the whole body. At a total length of 42 mm, weak keeled scales appeared along the ventral edge in the area anterior to the pelvic fins. The entire body was covered with scales during the period when the body length is 50 mm. At a total length of 52 mm, keeled scales appeared between the base of the pelvic fin and the anus. Black colored sheaths could be seen outlining the scales on the dorsal area and sides of the body. At a body length of 58 mm, the keeled scales in the ventral part of the body reached a fixed number, and the formation of the scales was nearly completed.

3. Development of internal organs

(1) Yolk

The yolk of the larval herring was present below the 10^{th} myomere. The yolk diameter was commonly 1.0 x 0.6 mm Uchida, et al., 1958). At Akkeshi Station, larval fish at a total length of 8.4 mm were fed on a diet of rotifers, and the progression of yolk absorption was studied. Immediately after hatching, the diameter of the yolk was 1.08 x 0.48 mm, and the volume of the yolk was 0.21 mm^3. This was followed by a sudden decrease in the yolk, and a day after hatching the volume had decreased by half. Three days after hatching the yolk diameter was 0.60 x 0.02 mm, and the yolk volume was 0.006 mm^3; the yolk had nearly disappeared. On the fourth day it could not be observed under a light microscope (Figure VII 3-l). When the egg yolk disappeared (three days after hatching), the total length of the larval fish was 9.8 mm. According to Kurata (1959), the accumulated water temperature for the disappearance of the yolk in low water temperature (4.9-7.7ºC) culture was about 45-60Dº. At Miyako Station (1983) a similar result of 60Dº was also obtained. Uchida, et al. (1958) reported that there were pronounced individual differences in the size of the body and the development stage at the point that the egg yolk was absorbed.

Also, Iizuka et al., (1962) reported that there were large annual variations in the size of the egg yolk at hatching. In years when the yolk was small, the yolk was quickly absorbed, and when it disappeared the body length was also small. In years when the yolk was larger, there was a longer period before the yolk disappeared, and it is presumed that this was followed by better survival. Blaxter and Hempel (1963) and Hempel and Blaxter (1967) made a detailed study of egg size and larvae in17 groups of Atlantic herring from a variety of areas and in each of the spring, fall, and winter spawning groups. Egg size and the speed that the yolk was absorbed correlated with different seasons and regions.



図Ⅶ 3-1　ふ化後のニシン仔魚の卵黄容積の推移
（飼育水温15℃の場合）
—●— 平均　○ 個体別

Figure VII 3-1 Change over time in egg yolk in herring larva and fry (when the culture water temperature is 15ºC).
[y axis] Volume of egg yolk (mm^3)
[x axis] Number of days after hatching
-●- Average
-○- Separate individuals

In the early larval fish stage there is a change from internal to external nutrition. The accumulated water temperature from hatching until feeding was 20-30Dº (Miyako Station, 1983). Thus, to remain alive in the sea, it is necessary that the herring have at least an adequate food collecting ability when there is no further internal nutrition. When fry are cultured at a water temperature of 15ºC, their mouths open 1-2 days after hatching. This is why it is necessary to supply an adequate amount of feed (rotifers at a rate of 10 per ml).

(2) Gastrointestinal tract formation (Figure VII 3-2)

The gastrointestinal tract during the herring larval period is a simple tube (Iizuka et al., 1962). A constriction forms in about the middle of the gastrointestinal tract which differentiates into the pyloric cecum (Sanjou, et al. 1961). Uchida, et al. (1958) reported that a short pyloric cecum appeared at a total body length of 25-26 mm. Sanjou, et al. (1961) stated that at a length of 27.0-29.0 mm, the cecum had the same Y-type shape that occurs in mature fish. Except for the gastrointestinal tract, the other organs appeared along the dorsal edge of the yolk. From here the pancreas, liver and other organs provided backup functions for the digestive tract until the constriction of the gastrointestinal tract (Kusakari and Mori, 1978). At a body length of 10.4 mm, the terminal part of the liver could be clearly seen in a side view at the 18^{th} to 19^{th} myomere (Uchida, et al. 1958). Also, Kusakari and Mori (1978) divided the development of the gastrointestinal tract of the early to late stage larvae into the following 5 stages: 1) Rod-shaped gastrointestinal tract, 0-1 day after hatching; 2) Basic formation of the stomach, total length 8.6mm; 3) Formation of the intestinal mucosal epithelium, total length 11 mm; 4) gastrointestinal tract rotation (pyloric cecum development), body length 20.0 mm; and 5) Formation of the mucosal epithelium in the stomach, total length 22.0mm.

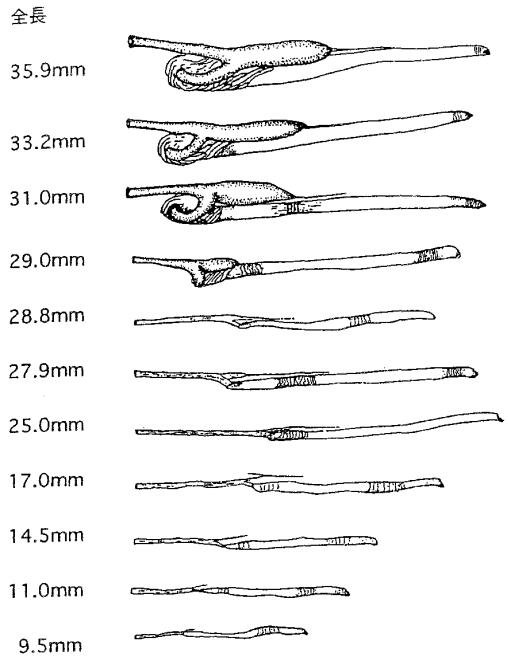


Figure VII 3-2 Development of the gastrointestinal tract during the herring larval and fry periods (modified from Sanjou, et al., 1961).
[top of left column] Total length

(3) Swim bladder formation

Immediately after the larvae hatch, an air bladder appears on the dorsal side of the central area of the gastrointestinal tract. The air duct is connected to the gastrointestinal tract (Kusakari & Mori, 1978). However, the air bladder is not filled with gas. At a total length of 26-32 mm, gas is introduced and the bladder is opened (Figure VII 3-3). Allen, et al. (1976) made observations on the differentiation of the air bladder in Atlantic herring at a body length of 18-20 mm.

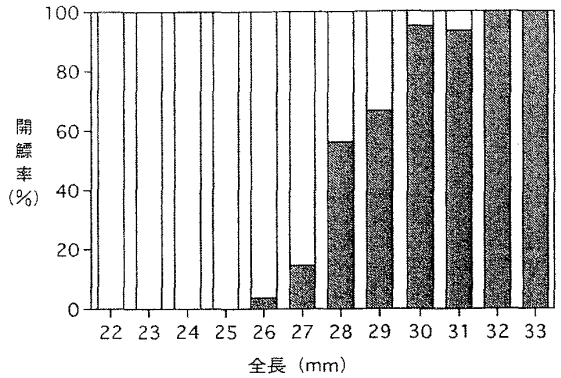


Figure VII 3-3 Change with growth in the rate of cultured herring fry with open air bladders.
[y axis] Ratio of open air bladders (%)
[x axis] Total length (mm)
■Individuals with open air bladders
□ Individuals with unopened air bladders

(4) Muscle development and swimming behavior

Swimming behavior became possible when 40-60% of the body lateral muscles were in place (Bone 1978). There was a change in swimming ability with the development of the body lateral muscles and related factors (Betty, 1984; Matsuoka 1984).

Fukuda (1986) made observations on tissue cross-sections during the development of the herring lateral muscles and clarified the thickness and number of muscle fibers. There was a careful examination of the relationship between the swimming speed from measurements of actual swimming speeds and body lateral muscle. According to these results, from the time that the yolk was absorbed and the herring lateral muscles began to develop there were white colored muscles. Then two types of muscles fibers appeared. There was an enlargement of large type muscles fibers and an addition of new small type muscle fibers. The progression of the development of the body lateral muscles in the larva and fry was as follows. Until a body length of about 17 mm, the main development was an increase in the diameter of muscle fibers, and there was a small increase in the number of muscle fibers. By comparison, at a body length of from 20 mm to 28 mm, there was only a small increase in the diameter of the large type muscle fibers. With the appearance of the small type muscle fibers, there was a rapid increase in the number of muscle fibers. At a body length of 28 mm and larger, a variety of thick muscle fibers could be observed, and there was less of a trend towards an increase in the number of muscle fibers. Thus, it can be seen that the development of the body lateral muscle (like the other morphological changes) had distinct changes that took place at body lengths of about 18 mm and 30 mm.

Fukuda (1990) Blaxter and Dickson (1959) measured the fastest swimming speeds of herring larvae and fry. The results were that there was an increase from 6.9 cm/sec (at a body length 11 mm) to 47.6 cm/sec (at a body length 46 mm). At a body length of about 27-28 mm, there was a very rapid increase in swimming speed (Figure VII 3-4). This resembles the results reported by Blaxter (1969) and Webb (1975) for Atlantic herring. As in the previous case, when the herring entered the fry period, the full development of the herring muscle fibers was reflected in an increase in the swimming speed. It is believed that the developed muscle provides the herring the capability of swimming in dense schools. They also allow active feeding and escape behaviors.

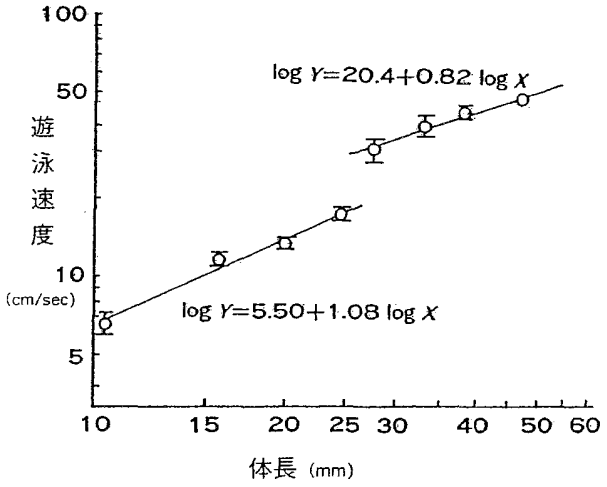


Figure VII 3-4 Correlation between body length and swimming speed of herring larvae and fry (modified from Fukuda, 1990).
[y axis] Swimming speed (cm/sec)
[x axis] Body length (mm)

(5) Otolith development

Herring otoliths could be observed during egg development. At hatching the average diameter of the otoliths was 22.5μm (Photo 3-1). The size of the otoliths increased rapidly. Ten days after hatching the diameter was 42.3μ. On the 20th day it was 90.4 μm, on the 30th day it was 162.4 μm, and on the 40th day it was 268.3 μm. After a length of 60 mm, one side of the otolith became constricted. When they became adults, the shape resembled a stone arrow head (Photo 3-2). Until about 60 days after spawning, it was possible to recognize daily rings using a light microscope (Photo VII 3-3). Table VII 3-1 and Figure VII 3-5 show the relationship between the daily rings in herring fry cultured in 1999, body length, and otolith diameter.

The rings of the otolith were caused by transparent and opaque zones. Takanayagi & Tanaka (2000) observed the edges of otoliths of herring from the Ishikari Bay group. They found that the edges of the otoliths were transparent except for the summer season. They presumed that the opaque zones were formed during the summer, and that this fact allowed the use of otoliths to determine the age of the herring.

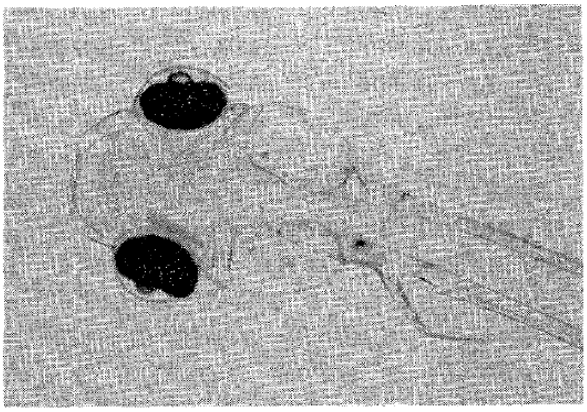


Photo VII 3-1 Head area of larval fish 3 days after hatching (the otolith is visible).

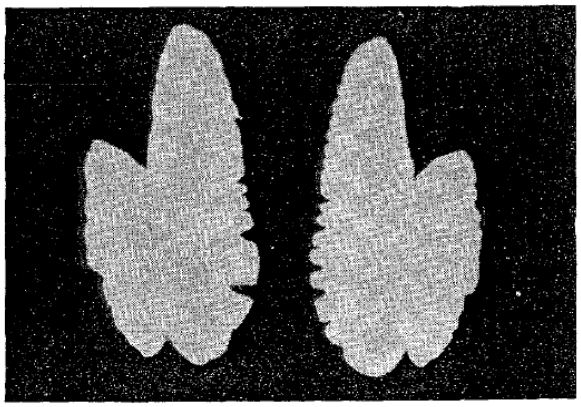


Photo VII 3-2 Otolith of adult fish.

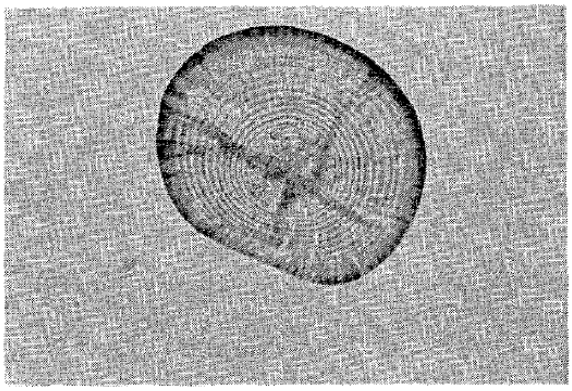
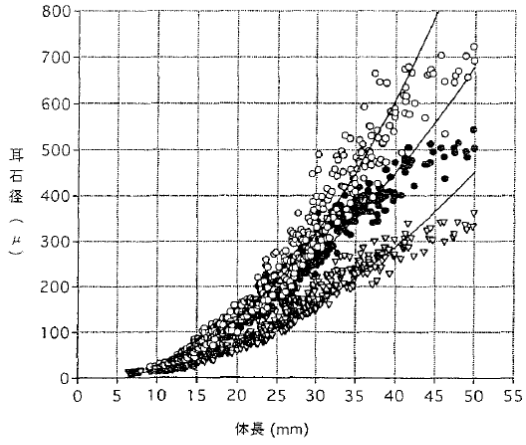


Photo VII 3-3 Daily rings of a larval herring after 25 days.

Table VII 3-1 Relationship between the age in days and length of otolith in cultured herring fry.

Average body length (mm)	Length of otolith			
	Average length (μm)	Standard deviation	Maximum (μm)	Minimum (μm)

日令 (日)	平均体長 (mm)	耳石長径 平均長径 (μm)	標準偏差	最大 (μm)	最小 (μm)
0	7.3	22.5	1.2	25.0	19.4
5	10.6	28.0	3.0	33.0	24.1
10	13.0	42.3	4.8	51.0	33.0
15	14.4	60.3	7.8	73.9	43.8
20	16.6	90.4	11.8	107.5	60.0
25	19.9	132.1	17.3	159.4	93.6
30	22.0	162.4	31.6	220.8	102.2
35	23.9	199.1	33.0	263.2	116.4
40	27.9	268.3	43.5	351.5	172.0
45	29.8	325.8	53.9	466.5	243.8
50	32.7	394.9	100.8	580.0	220.3
55	35.3	476.1	84.6	660.3	246.0
60	39.8	589.0	83.4	723.0	447.5



図Ⅶ 3-5 ニシン人工種苗の体長と耳石径の関係
○ 長径 $y=0.155x^{2.243}$ $r^2=0.973$
● 短径 $y=0.153x^{2.043}$ $r^2=0.971$
▽ 最大半径 $y=0.485x^{1.852}$ $r^2=0.946$

Figure VII 3-5 Relationship between body length and otolith diameter in cultured herring fry. [y axis] Otolith diameter (μ), [x axis] Body length (mm), ○ Length $y=0.155x^{2.243}$ $r^2=0.973$, ● Width $y=0.153x^{2.043}$ $r^2=0.971$, ∇ Maximum radius $y=0.485x^{1.852}$ $r^2=0.946$

4. Changes in body composition

Fukuda (1986, 1988 &1993) analyzed the body composition of the early developmental stages, and gave the following analysis for the developmental progression. Table VII 4-1 shows the body composition indicators and the suggested significance for each item.

Table VII 4-1 Items of body composition that are indicators and the significance.

Item	Index and significance of body composition items
DAN [sic. DNA] value	Number of cells
Protein/DAN [sic. DNA] ratio	Cell size
RNA/DNA ratio	Protein synthesis
Triglyceride	Neutral lipid, energy storage
Glycogen	Sugar, energy storage
Proteins	Principal structural component of cells
Phospholipid	Principal structural component of cell membrane: used in membranes

During the initial stage of development there was an increase in the absolute amount of protein, nucleic acids, fats, and glycogen. However, the relative amounts (the percentage of body weight) showed changing patterns for the amount of each of the components. These timing of these changes were centered at body lengths of 18-19 mm and about 30 mm. As stated previously, the changes in morphology showed the same pattern.

Until a body length of 18 mm, the triglycerides and phospholipids increased little. Generally, the indicator for larger cells is a rapid increase in the protein/DNA ratio (Figure VII 4-1). This suggests that during this period the size of the cells was expanding. Metamorphosis occurred in the period from 18 mm to 30 mm. The protein/DNA ratio decreased and at about 22 mm the RNA/DNA ratio high for a short time. This suggests that growth was accomplished by active cell divisions so that growth was accompanied by an increase in the number of cells. This reflects the fact that this was the period when body organs formed. Also, during this period the protein/body-weight ratio began to decrease (Figure VII 4-2). The phospholipid/body-weight ratio specific was constant. Neutral lipids are believed to be indicators of energy storage. The triglyceride/body-weight ratio increased until a body length of 22 mm. Afterwards the ratio decreased until a body length of 30 mm (Figure VII 4-3). It is assumed that the fats were consumed during the metamorphosis period. This suggests that during the period of peak morphological changes the triglycerides are used as a source of energy. For fry that are 30 mm in body length or more, it characteristic that there are rapid increases in storage of triglyceride and glycogen (Figure VII 4-3, 4-4). This suggests that the digestive system had the ability to accumulate energy. Also, in this period there was an increase in the protein composition type indicators (the RNA/DNA ratios and the protein /DNA ratios). It is assumed from the growth pattern that from the time that the DNA/body-weight ratio decreases the active protein synthesis is causing the cell size to increase (Figure VII 4-5, 4-1).

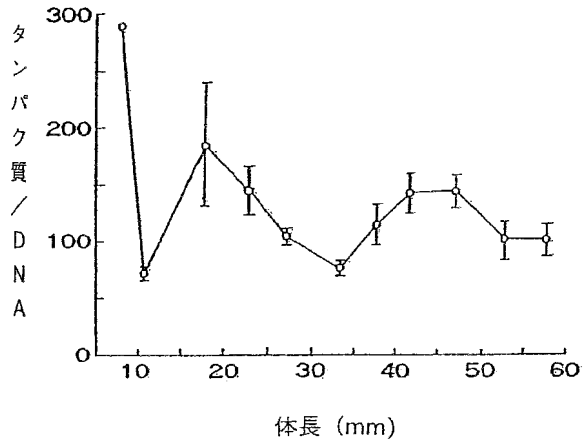


Figure VII 4-1 Figure VII 4-1 Change in the protein/DNA ratio with the growth of herring larvae and fry (modified from Fukuda, 1988).

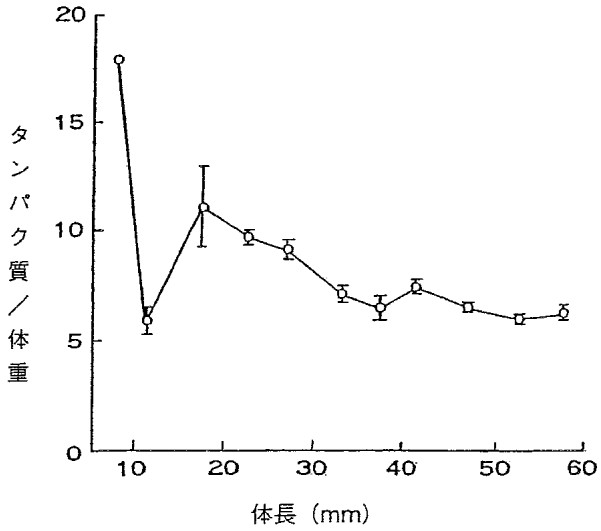


Figure VII 4-2 Change in the protein/body weight ratio with the growth of herring larvae and fry (modified from Fukuda, 1988).

[y axis] Protein/body weight

[x axis] Body length (mm)

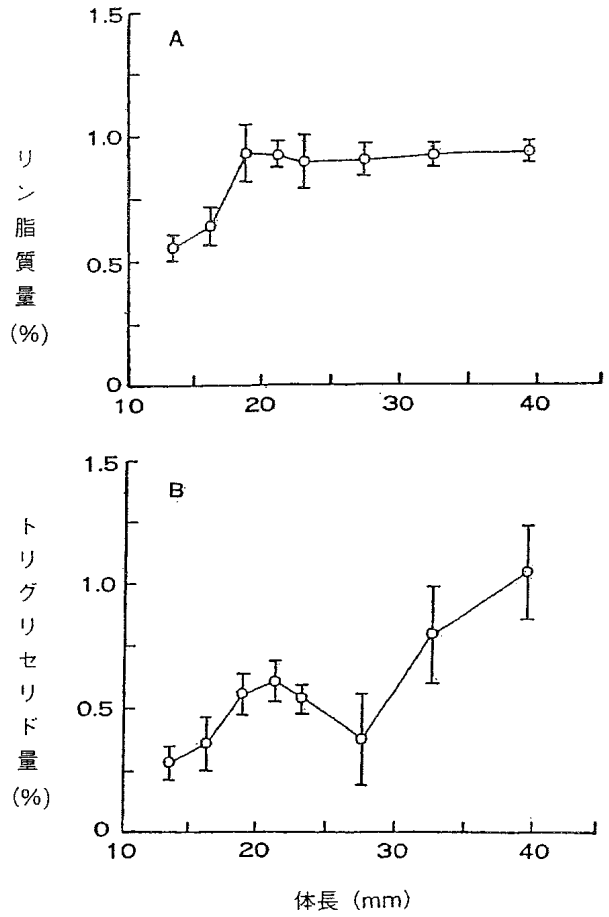


Figure VII 4-3 Change in the amounts of phospholipids (A) and triglycerides (B) with the growth of herring larvae and fry (modified from Fukuda, 1988).
[y axis, top graph] Amount of phospholipids (%)
[y axis, bottom graph] Amount of triglycerides
[x axis] Body length (mm)

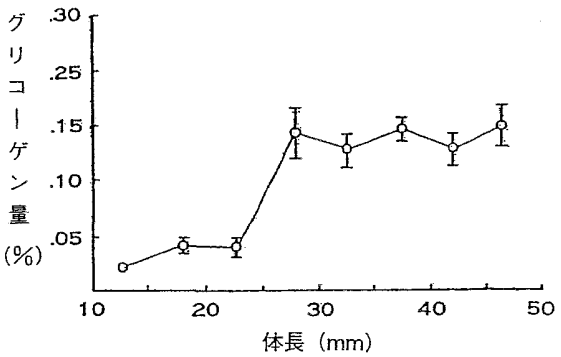


Figure VII 4-4 Change in the amount of glycogen with growth of herring larvae and fry (modified from Fukuda, 1988).
[y axis] Amount of glycogen (%)
[x axis] Body length (mm)

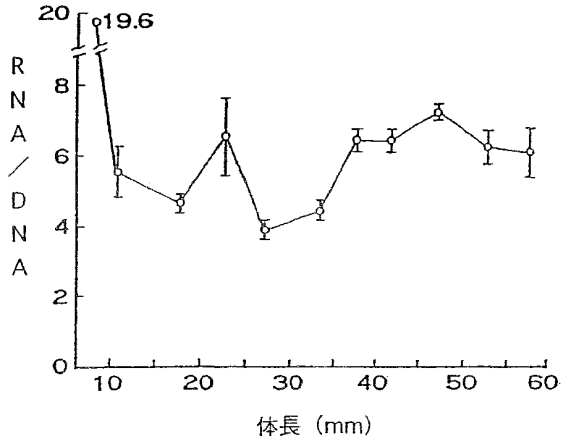


Figure VII 4-5 Change in RNA/DNA ratio with growth of herring larvae and fry (modified from Fukuda 1988).
[y axis] RNA/DNA ratio
[x axis] Body length (mm)

Thus, the change in body composition corresponds to the period when the morphology changes. It is also clear that there is also a progression of physiological changes.

5. Developmental stages

Reports on basic herring development have been mentioned above. In addition there are reports on changes in feeding and nutrition, behavioral patterns, and development of the sense organs to increase the functionality of the movements. Information of developmental stages is arranged here separately.

(1) Early larval stage (hatching to 10 mm)

During the period from hatching (total length 8.5 mm) until the absorption of the egg, the body length reaches a body length of 10 mm. During this period food begins to be taken through the open mouth, and there is a change from internal nutrition to exterior nutrition. The fundamental structures forming the organs are already in place, but there are still numerous character traits that have not yet been expressed. Immediately after hatching, the larval fish lie recumbent on the sea bottom. They swim occasionally and then sink to the bottom (Uchida, et al. 1958). Later they demonstrate especially strong phototaxis during the daytime (Yamaguchi, 1925; Kurata, 1959). They swim into the surface layers when the surface is calm. It has been reported that they respond very rapidly to shaking of the water surface, and sink to the bottom if there is even just water dripping at the surface (Kurata, 1959). In observations in a culture tank, there was no nocturnal swimming, and the herring drifted on the bottom with the currents.

During this period there are few behaviors besides phototaxis and the initial feeding behaviors. They are completely controlled by the physical environment when they are in the stage where they are converting from internal nutrition to external nutrition. To remain alive in the sea, they must enter the stage where they have at least adequate feed by the time that the yolk is gone (Fukuda 1986).

(2) Late stage larval period I (body length 10-18 mm)

This is the stage when the yolk has been absorbed and the body length is from 10 mm to 18 mm. There are no major changes in the basic structure of the external morphology and skeleton. During this period there is a characteristic increase in protein, and the growth of the body is principally in length (Fukuda, 1986). Also the gastrointestinal tract is rudimentary and of simple construction. It has the minimal organ differentiation necessary for feeding.

The principle foods during this stage are the eggs of calanoid copepods or nauplius larvae (Iizuka, 1966; Rudakova, 1971). It is believed that the uptake of protein by the intestinal epithelium cells is by pinocytotic absorption (Watanabe, 1982). At the same time, there is little energy accumulation, and there is a long period of hunger. Vertical movements in the natural environment are affected by hydraulic factors. At a body length of 13 mm and longer the herring move in the mid and bottom layers (Iizuka, 1966). Daily diurnal movements become pronounced (Selierstov, 1974). During this period they are passive relative to the physical environment, and they have low metabolic capacity. There is an improved ability to feed and make diurnal movements, etc. (Fukuda, 1986).

(3) Late stage larval period II (body length 18-30 mm)

The period when the body length is from18 mm to 30 mm is a time when there is a change in the intrinsic metabolism and a metamorphosis. It is believed that this is accomplished with rapid changes in each of the morphological factors. This is also the period when there is also active differentiation in organ weights and tissues organization (Fukuda, 1986).

When this period over, the skeleton, fins, and gastrointestinal, etc., were nearly completed. The muscle fibers had also differentiated. These structures supported the formation of other organs. An increase in the nucleic acid ratio was a characteristic feature, especially at a body length of 22 mm; so active cell differentiation was presumed. In this period of dramatic morphological changes, the energy source made use of triglycerides. It was a period when there were high energy demands (Fukuda, 1986). It has been determined that energy source depletion had a strong effect on the formation of the organs, so it was necessary that there be an adequate supply of nutrients (Fukuda, 1986). At the same time, there was a high level of support for the development of the sense organs including the air bladder, inner ear, lateral line, and the lamella of the gills. It was possible for active schooling behaviors to begin.

They are not collected in samples of the surface layers of the sea (Uchida, et al. 1958). It is assumed that they have moved to the mid and deep water layers (Iizuka 1966). However, during this period little is known about their mode of life, and there are many questions remaining.

During this period there are high internal metabolic demands that require an improvement in feeding and other behaviors. The herring are impacted by sea currents and other physical environmental factors until they can actively choose their own regional distribution (Fukuda, 1986).

(4) Fingerling period (body length 30~90mm)

In the growth period around 30 mm length and larger, there is a change from differentiation of the organ tissues to an increase in the size of the cells. It is characteristic that energy components are being stored (Fukuda, 1986). Each of the organs is nearly in its final form. There is continuing development of the sense organs of the visual system and lateral line (Blaxter and Jones, 1976; Allen, et al., 1976). Also, the gills surfaces expand, and there is specialization, etc. of the blood cells and other respiratory organs. The development of the circulatory organ system and other structures are essentially completely. At a body length of 40 mm and larger, black pigment cells enlarge and scale formation begins. Also, even at the completion of this period there is an external camouflage pattern. When the herring reach a body length of 60 mm, they have the characteristic appearance of the adult fish, and at a total length of 90 mm the exterior appearance is the same as that of mature fish. They have completed the essential development of the characteristics of their group (Uchida, et al. 1958).

During the fry period, there is a characteristic increase in power capacity. Muscle fibers for basic movements during the fry period are substantially completed, and there is an accumulation of energy and an improvement in the glucose metabolism system and enzymatic activity. With an increase in feeding opportunities and a completion of the functionality of the digestive system, it is possible to consume a variety of food items. There is an increase in the level of glucose metabolism enzymes which are representative of the metabolic system. There is energy accumulation through triglyceride and glycogen metabolism, which strengthens their resistance to starvation (Fukuda, 1986).

In this period they swim in schools in the sea, and active feeding is observed. They seek larger sized feed species and move offshore. It is presumed that the limits of the migrational range become gradually wider.

III. NURSERY PRODUCTION

The annual schedule for producing herring fry at Akkeshi Station starts in mid March when the culture of rotifers (the initial food) is begun. The herring eggs are collected in early April, and fry production beings when the larvae hatch in early May. In mid July the fry reach a total length of 40 mm. They are collected and counted. At a length of 50 mm they are put into offshore nursery culture. This Chapter describes fry production methods, primarily those used at Akkeshi Station. It describes actual methods including the items that require care during culture. (The Reference Data shows a herring fry production schedule.) Also, this Chapter provides sequential information from the day of hatching (day 0). Section 4.(1) gives an example of the average growth relative to the number of days after hatching.

1. Hatching and stocking

(1) Hatching mechanism and condition

The hatching mechanism for herring eggs is similar to other fish species. Just prior to when the larvae hatch, proteolytic enzymes are released from a close formation of hatching glands on the head. The enzymes dissolve some of the egg membrane and the larvae then hatch. Before hatching the larvae in the egg are actively turning which promotes hatching. Just before hatching, the egg membrane is elastic and has thinned. After hatching there is an opening in the egg membrane with irregular edges that commonly has a triangular shape. Generally, the larvae hatch out of the egg head first, but rarely there are cases when hatching occurs tail first. The amount of time for hatching after the head protrudes is generally short, typically several seconds to several dozen seconds. If hatching does not occur within a threshold period, the herring die during hatching. Immediately after hatching the larvae begin to swim. They sink somewhat but are suspended in the water column. Periodically, they repeat swimming.

(2) Egg stocking and hatching

Before stocking, the temperature of the culture water is increased until it is the same temperature as the water in the egg culture tank. (Currently, the temperature is set at 10ºC.) The water is adequately aerated. This can be of special concern if the gas pressure of the seawater is supersaturated, in which case it is desirable to measure the gas pressure of the seawater before it is used. Before stocking, weak aeration is used to establish a weak current.

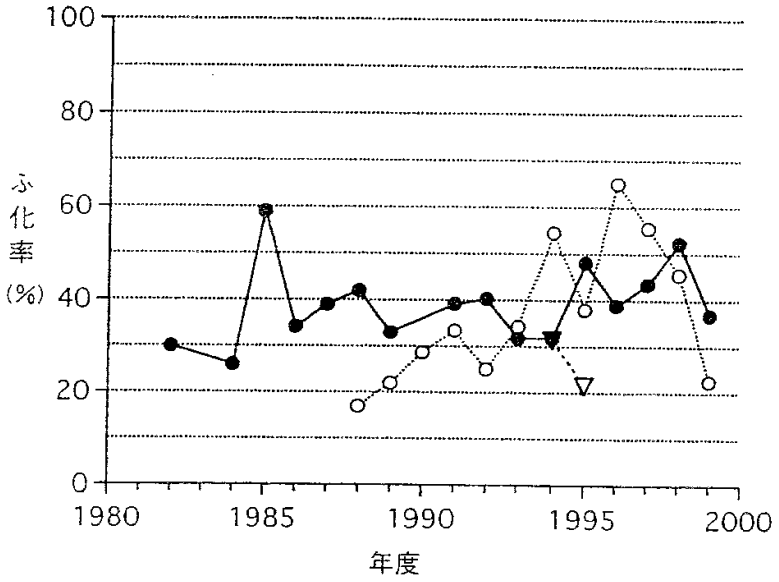
Herring eggs are stocked in the fry production tank prior to hatching. The day for stocking is checked after the accumulated water temperature of the eggs reaches 70 Dº. Netting is placed over the discharge water of the egg culture tank, and the netting is examined for the presence of hatched larvae. The fish are counted using a volumetric method. This information is used to determine the day for stocking the eggs in the culture tank. Generally, when the water temperature of the egg culture is 10ºC, the eggs are cultured in the egg culture tank until the accumulated water temperature is 120 Dº.

The transfer operation of moving the eggs from the egg culture tank to the fry culture tank is performed rapidly to avoid temperature changes. When the transfer takes place outdoors, a sunscreen is used during transport. The hatching screens or Mabushi brushes are placed in the tank in a suitable configuration. They are not placed close to heating pipes or aeration hoses. After stocking, hatching occurs under still water conditions.

Hatching commonly takes place at night. In the morning the eggs attached to the substrate are observed with a microscope. When hatching is completed, the attachment substrates are removed from the culture tanks. The general criterion is that hatching has completed at an accumulated water temperature of 150 Dº. Then substrates are removed. Following removal of the attachment substrates, hatching conditions are studied.

(3) Hatch rate

The hatch rate in production tests at Akkeshi Station averaged 39.1% (26.0-59.0%) for Furen Lake production and 36.8% (17.0-65.1%) for Akkeshi (Figure VIII 1-1). The hatch rates at other facilities are comparatively higher at 60-90%. In Akkeshi there have also been experiments where eggs obtained from carefully selected broodstock had hatching rates of 60-80%. The main reason for the low rates is that the herring broodstock from Akkeshi are mixed and contain fish that are caught in the fishery many hours before they are used. From separate experiments, it is believed that the low hatch rate is due to the lack of freshness of the herring broodstock.



図Ⅷ 1-1　厚岸事業場におけるニシン卵のふ化率の推移
—●— 風蓮湖　…○… 厚岸　---▽--- 野村湾

Figure VIII 1-1 Change over time of herring hatch rate at Akkeshi Station.
[y axis] Hatch rate (%)
[x axis] Year
-●- Furen Lake
-○- Akkeshi
-∇- Nomura
[end figure]

(4) Counting the number of hatched larvae

In order to estimate the number of hatched larvae in the culture tank, a night sample is taken of a column of water. The reason for doing this at night is that during the day the distribution of the herring larvae is uneven so accurate estimates are not possible (Figure VIII 1-2). Sampling begins 2 hours after sunset. The method used is that 20 minutes before sampling, the tank is strongly aerated so that the water is well mixed. A polyvinyl chloride tube with a diameter of 50 mm is used to take a sample of the water column. Assistants collect the samples in buckets. Each tank is sampled at 30 different locations. The volumetric method of making an estimate involves measuring the water in the buckets and counting the number of larvae. A day after hatching has completed, the larval fish have a tendency to sink to the bottom of the tank. For this reason, when performing night water-column sampling, there is a tendency for the estimates to be too low. For this reason it is desirable to perform the counts 2-3 days after hatching has been completed. Also, 5 days after hatching and later, the fry are actively swimming causing large measurement errors which makes it impossible to make estimates.

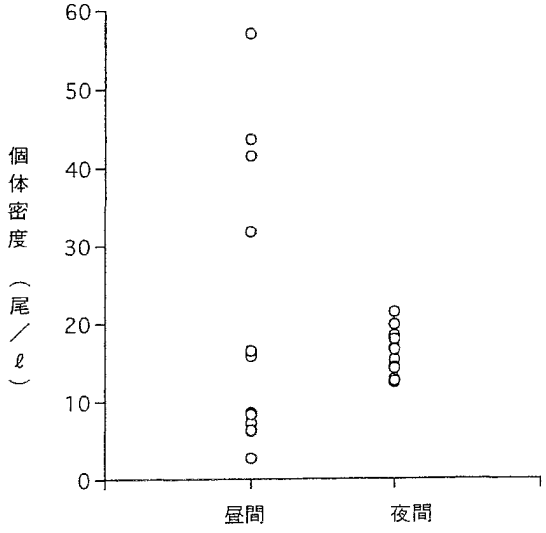
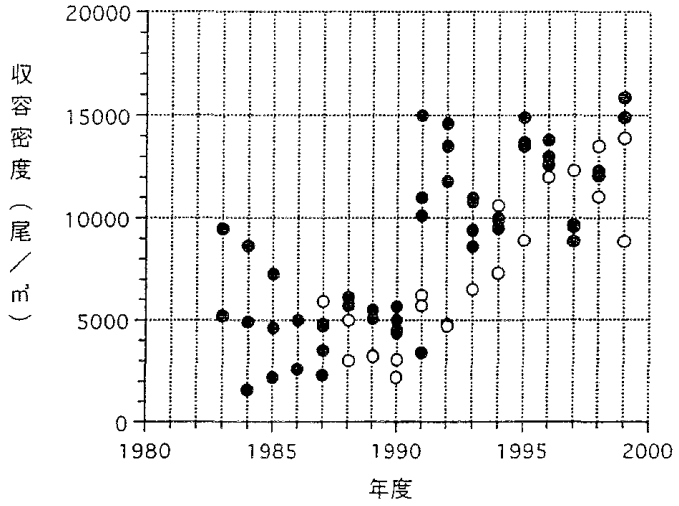


Figure VIII 1-2 Comparison of the density of the larvae in water-column samples between day and night.
[y axis] Density of fish (fish/ℓ)
[x axis, left to right]
Day time
Night time
[end of figure]

(5) Stocking number

The standard stocking density of the hatched larvae is 10,000-15,000 larvae/m^3 (Figure VIII 1-3). Miyako Station experimented with using high stocking densities, and currently has not had problem during culture even when stocking at 20,000 larvae per m^3 or more. Also, from past experience it has been determined that the survival rate does not improve at lower stocking densities. However, when the stocking densities are higher, culture densities must be matched with higher water exchange rates, which can interfere with culture. The reason that the set culture density at Akkeshi Station is not higher is that they have problems with water intake, and cannot assure an adequate exchange rate. The maximum water exchange rate is 400% per day. Just before uptake, the dissolved oxygen saturation rate may be 70% or lower.



図Ⅷ 1-3　厚岸事業場のニシン種苗生産における収容密度の推移
● 風蓮湖産　　○ 厚岸産

Figure VIII 1-3 Change over time of the culture density during the production of herring fry at Akkeshi Station.
[y-axis] Culture density (fish/m^3)
[x-axis] Year
● Produced from Furen Lake
○ Produced from Akkeshi

(6) Hatched larvae

At Akkeshi the total length and standard deviation of the larvae at hatching is 8.5 ± 0.3 mm, and the variation coefficient is 2.9%.

The larvae generally swim actively as their ability improves. In 1997, a portion of the larvae produced at Furen Lake had inferior activity levels. Individuals were observed with white-cloudy symptoms and with the central part of the body bent. It is presumed that this occured when there was a lot of adhesive material included in the collected eggs. The larvae are then damaged when they hatch out of the egg membrane. However, this type of case was not observed later.

2. Rearing facilities and rearing environment

(1) Culture tank

The culture tanks at Akkeshi Station are rectangular and are made of RC. They have a 50m^3 capacity (7.8 x 4.8 x 1.4 m). The sides of the tank are treated with epoxy resin. The color is a dark green (Photo VIII 2-1). Water temperature is controlled with a boiler in the side of the tank. There is a heat exchanger using heating tubes made of titanium.

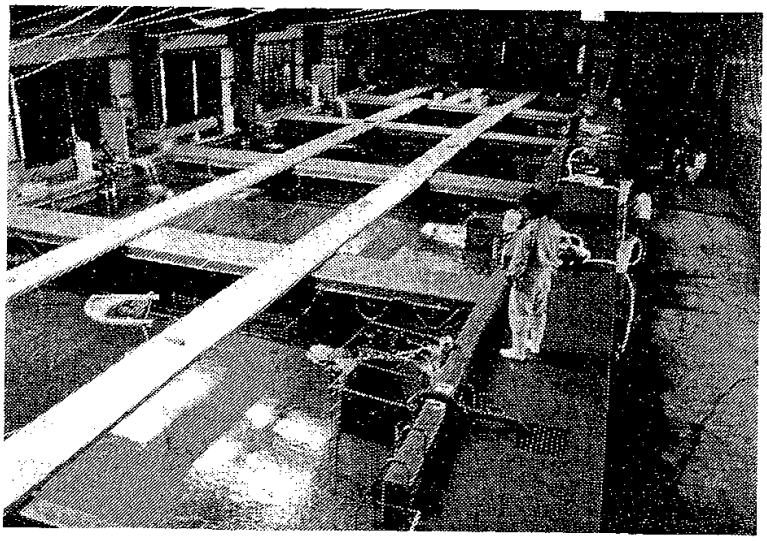


Photo VIII 2-1 General view of the herring fry production tanks.

(2) Culture water temperature

Previously, the standard for water temperature was 15ºC. Every day after hatching the temperature was raised by 1ºC until reaching this set level. Currently, the set level is 13ºC. There were six cases when the culture water had been dropped to 13ºC, and growth and survival was still nearly the same as for the cultures at 15ºC. The lower temperature has the advantage of being more energy efficient.

The production period is May through July. However, Akkeshi Station is on the eastern coast of Hokkaido where ambient water temperatures are low. For example, in 1997, the ambient water temperature was in the temperature range of 4.3-12.5ºC; the average was 8.0ºC. Thus, the water temperature needed to be raised an average of 5.0ºC (0.5ºC-8.7ºC). Also, the water that is exchanged normally required heating.

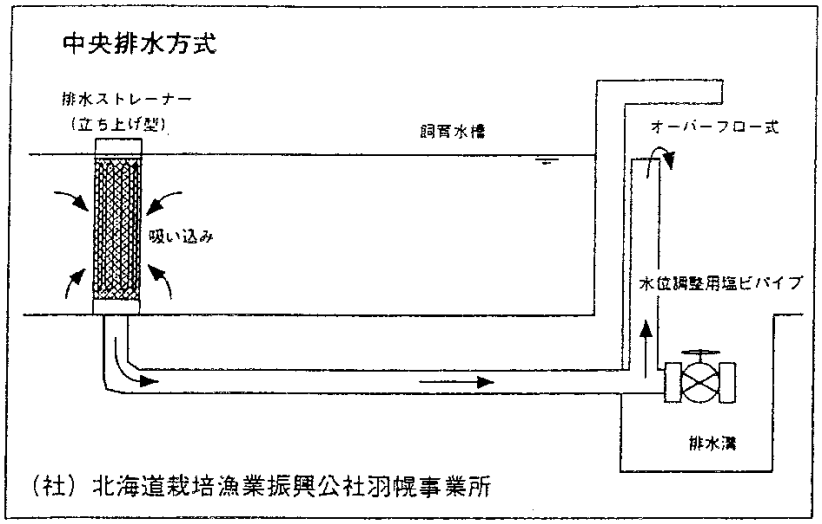
(3) Water exchange

1) Adding water

Filtered sea water is used for culture. In order to actively decrease gas supersaturation of the sea water, the water is first pumped into a separate tank for regulating the temperature and for aeration. A water pump is used to transfer the filtered water into the tanks.

2) Water discharge

At Akkeshi Station the method for water discharge is to siphon the water through a strainer and a 50-mm hose (Figure VIII 2-1). The mesh sizes used for the discharge strainers are #70 (day 0 to day 10), #40 (day 10 to day 20), #30 (day 20 to day 30), #24 (day 30 to day 40), #18 (day 40 to day 50). The diameter of the mesh from day 50 and afterwards is 260. The screens are changed with the growth of the larvae and fry (Table VIII 2-1



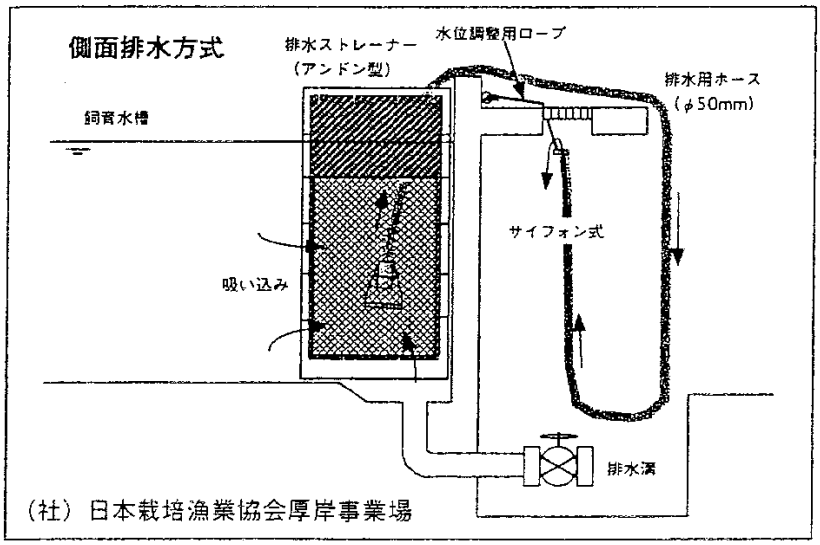


Figure VIII 2-1 Diagrammatic drawing of discharge water method for herring culture.
[There are two drawings, top to bottom]
[top drawing]
[left side of drawing, top to bottom]
DIAGRAM OF CENTRALLY LOCATED DRAIN
Strainer for drain
Standing type
Water is sucked in

Hokkaido Aquaculture Promotion Public Corporation Haboro Station
[center of drawing above water line]
Culture tank
[right side of drawing, top to bottom]
Overflow
Standing vinyl water pipe regulates water position
Pit for drained water
[bottom drawing]
[left side, top to bottom]
DRAWING SHOWING SIDE VIEW OF WATER DRAINAGE METHOD
Culture tank
Japan Aquaculture Association Corporation, Akkeshi Station
[above screen]
Discharge strainer (shaped like a Japanese paper lantern)
[Left side of drainage screen]
Water sucked in
[right of drainage screen, top to bottom]
Water position regulated with a rope
Siphon type
Water drainage pit
[top, extreme right]
Drainage hose (ϕ 50 mm)
[end figure]

Table VIII 2-1 Exchange rate and mesh size of strainer for herring larvae and fry culture for fish of different ages (in days).

Age (days)	Mesh size	Opening (μm)	Total length (mm)	Water exchange rate (%)
	70 mesh			
	40 mesh			
	30 mesh			
	24 mesh			
	18 mesh			
	Diameter 260			

日齢 (日)	網目	オープニング (μm)	全長 (mm)	換水率 (%)
0～10	70目	286	9～14	25～100
10～20	40目	508	14～18	100～200
20～30	30目	691	18～22	200～250
30～40	24目	925	22～28	250～300
40～50	18目	1,241	28～36	300～350
50～70	260経	1,800	36～50	350～400

It is most efficient to place the discharge positions centrally to take advantage of dirt removal and the currents in the culture tank. The Hokkaido Aquaculture Promotion Corporation Haboro Station uses this type of discharge method (Figure III 2-1).

The discharge strainers are washed once a day to keep them from plugging. When the strainer is moved in the tank, it is important to move it slowly. Until the larvae reach a total length of 20 mm, they are weak swimmers, and it is necessary to prevent mortalities caused by stress. As will be explained later, at a total length of about 20 mm and more, it is necessary to prevent the startled larvae and fry from colliding with the sides of the tanks to avoid spinal abnormalities.

3) Water exchange rate

Water exchanges begin 5 days after hatching. The standard daily exchange rate on the fifth day is 0.5 exchanges; on the tenth day 1.0 exchanges; on the 20th day 2.0 exchanges; on the 25th day 2.5 exchanges; on the 40th day, 3 exchanges; and on the 50th day, 4 exchanges (Table VIII 2-1). These exchange rates are adequate, but exchange rates twice as high as mentioned above can be expected to stabilize water quality.

4) Countermeasures for gas supersaturation of sea water

At Akkeshi Station, when the water tank is filled with fresh sea water with the intake pump, the water is cold. When this water is mixed in, gas supersaturation can reach 120% (Figure VIII 2-2). Fish can suffer from gas disease when the supersaturation limits exceed 115%. Until 1997, the supersaturated seawater was added directly to the culture tank. Because of the warming of the water in the culture tank (a difference of water temperatures of 5-10ºC), it is presumed that there was elevated supersaturation.

As stated above, the dissolved gases during supersaturation can cause the appearance of gas disease in herring larvae (Photo VII 2-2). This can result in a decline in activity and the occurrence of mass mortalities. Methods for preventing gas disease include: 1) Treating the water in the filtered water tank by strong aeration from a diaphragm blower, thus lowering the dissolved gas supersaturation as much as possible. 2) Removing the gas in the culture water in an accessory tank with strong aeration while regulating the temperature. 3) Using a submersible pump to move the treated sea water to the culture tank. With these treatments the total dissolved gas saturation can be reduced to 110% or less, which is below the limit that causes gas disease (Figure VIII 2-3).

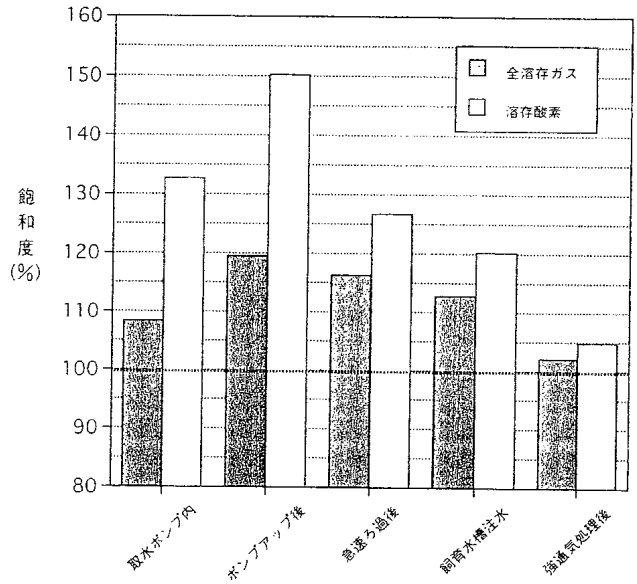


Figure VIII 2-2 Comparison of dissolved gas supersaturation relative to water intake at Akkeshi Station (measurement results on June 21, 1999; water temperature 9.0-10.8ºC).

[y-axis] Saturation (%)
[x-axis] Location of test
[left to right]
In intake pump
After pump up
After rapid filtering
Inlet water in culture tank
After strong aeration treatment
[legend, dark rectangles]
Total dissolved gas
[legend, light rectangles]
Dissolved oxygen
[end figure]

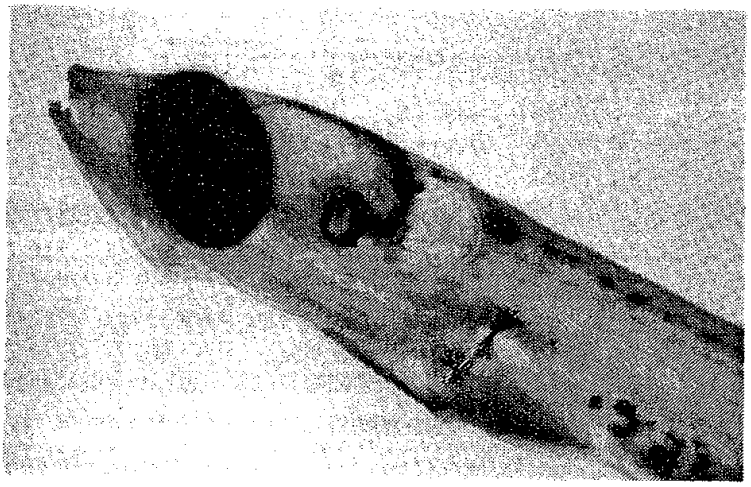


Photo VIII 2-2 Gas disease (retention of gas in the head area).

(4) Aeration

Aeration is provided with two air stones in the central part of the tank. Air tubes are installed in the four corners of the tank for microbubbles (Figure VIII 2-3). The figure shows how four air tubes are installed to cause circulating currents. The speed of the current is controlled by the amount of aeration. Aeration is increased as the herring grow.

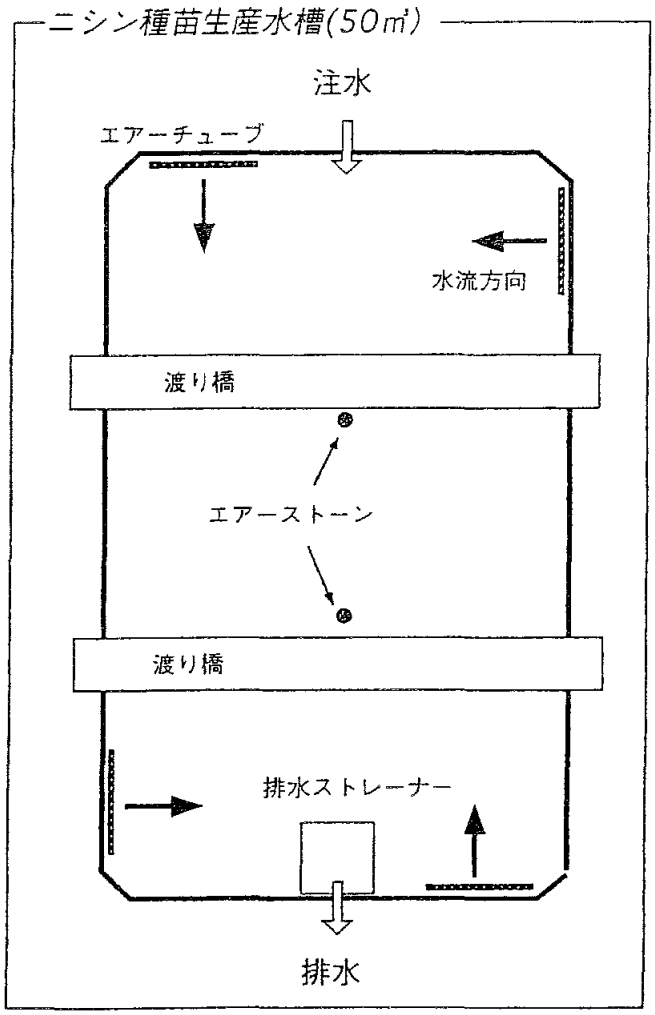


Figure VIII 2-3 Locations in herring nursery tank where water flows and the drainage. It also shows aeration and direction of current (example at Akkeshi Station).

[Top to bottom]
HERRING NURSERY TANK (50m^3)
Water inlet
Air tube
Water current direction
Bridge over tank
Air stones
Bridge over tank
Drainage strainer
Drainage water
[end figure]

(5) Regulating illumination

Herring larvae exhibit phototaxis and school together when there is light (Kurata, 1961). Light increases the phytoplankton in the culture water, and for this reason, methods are used to disperse the light. Previously, light regulation was used to culture the algae *Nannochloropsis*. However, in order to reduce labor during culture, currently a commercial concentrate of a freshwater species of *Chlorella* is used. The use rate is 1.0 ℓ per tank per day.

The method for adding freshwater *Chlorella* is to first dilute it with seawater in a 30ℓ polycarbonate tank. For the 50 days after hatching, light is regulated every day for the added freshwater *Chlorella*. At Akkeshi Station part of the roof over the culture tanks is made with transparent acrylic. Cheesecloth (2 layers) is placed 2-3 m above the tanks to provide a 99% shade cover. This lowers the illumination at the water surface below 2-450 lux. Controlling the illumination provides calming conditions for the larvae and fry, and this reduces excessive alarm reactions.

(6) Bottom cleaning and removing dirt from the water surface

Bottom cleaning begins 5 days after hatching and is performed once daily until the fry are harvested. An automatic bottom cleaning device is used for bottom cleaning at Akkeshi Station. When formula feed is increased during the last half of culture, the cleaning operations of the automatic cleaning device are supplemented with hand operations.

When the formula feed is increased, there is an accumulation of feed and feces on the bottom. If the bottom cleaner is the type that runs on tires, this material can make the tires spin. When this happens the spinning can be prevented by placing a 5-kg weight on the automatic cleaner. Table VIII 2-2 shows the points of concern when cleaning the bottom with the automatic cleaning device and with hand operations. The most important factor when cleaning the bottom is that it be performed carefully so the larvae and fry are not startled, even if this requires more time. Also, immediately after feeding with *Artemia*, there is a tendency for the *Artemia* to sink to the bottom. Thus, it is easy for the larval fish to also school on the bottom. Bottom cleaning is not desirable immediately after feeding with *Artemia* because the larval fish are pursuing the *Artemia* to suck them in.

During cleaning, the dead fish in the drainage are retrieved with a net, and the number of dead fish is estimated using a volumetric method or a weight method.

Figure VIII 2-4 shows the relationship between the number of fish mortalities/g and age (in days).

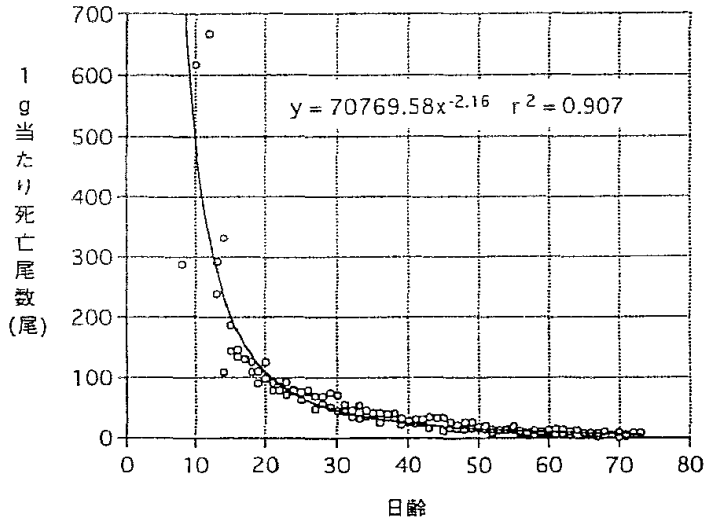


Figure VIII 2-4 The relationship between the number of dead fish per gram in the drain and age (in days) when using an automatic bottom cleaning device.
[x axis] Number of dead fish per gram (number of fry)
[y axis] Age in days

A polyvinyl chloride tube is adapted as a specialty tool for retrieving debris from the surface of the water (Photo VIII 2-3). The construction and concept for the device is to form a polyvinyl chloride tube (diameter 50 mm) into a "U" shape. It is floated on the water surface, and the open part of the "U" shape is kept open with simple vinyl tube (diameter 13 mm). Holes (0.5 mm) are made at 4-cm intervals on the upper part. It is placed so air is slanted towards the surface. Debris is removed twice a day.

Table 2-2 Operational procedures using automatic cleaning equipment in herring nursery culture.

Location	Detail of operations
Device for clearing debris	Clears debris from water surface.
On drainage pit	Confirm that the hose is set in the net that is used to collect dead fish.
Water tank	Set up the 2 central air stones.
Water tank	Remove strainer that is used for drainage.
Automatic bottom cleaning device	Slowly place the automatic bottom cleaning device in the tank.
Automatic bottom cleaning device	Connect with a line. The position of the rope portion faces the drainage hose position.
Control panel	Confirm that the switch of the operation panel is set to “Automatic.” and that the remote control switch is set to “Advance.”
Control panel	When the main electric switch is "ON,” bottom cleaning begins
Water tank	Pull in the hose of the automatic bottom cleaning device from inside the tank.
Pump	Confirm that water is flowing in the discharge hose. If it is not flowing, pull in the drainage hose an appropriate amount.
Water tank	Confirm that the discharge hose does not interfere with temperature regulation, etc.
Water tank	Check occasionally that the automatic bottom cleaning device has not stopped or been derailed.
Water tank	Bottom cleaning is completed after one pass on the line.
Operation panel	Set the main power switch to OFF.
Water tank	Remove the automatic bottom cleaning device.
Water tank apron	Pull in and cleanly wind up the drainage hose.
On drainage pit	Clean the bottom of the automatic cleaning device with tap water.
On drainage pit	Clean the net use for dead fish with tap water. Store the dead fish in a cup that is used exclusively for this purpose.
Laboratory	Count number of dead fish using weight method
Garbage storage location	Dead fish are soaked in chlorine and are disposed of

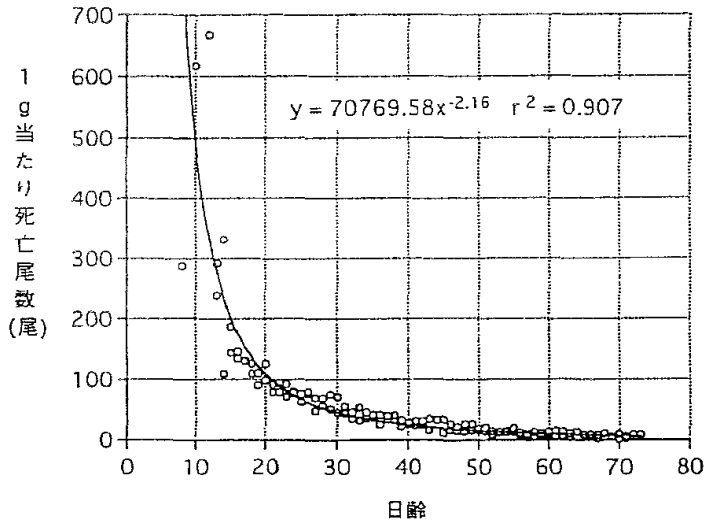


Figure VIII 2-4 The relationship between the number of dead fish per gram in the drain and age (in days) when using an automatic bottom cleaning device.
[x axis] Number of dead fish per gram (number of fry)
[y axis] Age in days

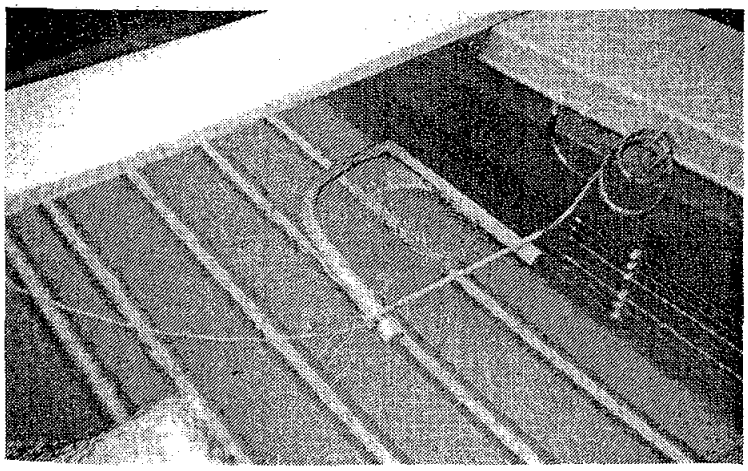


Photo VIII 2-3 Apparatus for collecting debris on the water surface.

3. Feed

(1) Feeding sequence and feeding schedule

The standard feeding sequence is rotifers, *Artemia*, and formula feed. After hatching, rotifers are fed from day 1 to day 15; *Artemia* are fed from day 10 to 45; and formula feed from day 20 until landing (Figure VIII 3-1).

Experiments were performed to determine an appropriate feeding schedule for rotifers. In the test groups that were fed rotifers for 7 days or 12 days, the survival rate was only 22%, whereas the test groups that were fed 16 days or 22 days had a survival rate of about 37%. It is presumed that the shortest period for feeding with rotifers is 15 days (Figure VIII 3-2).

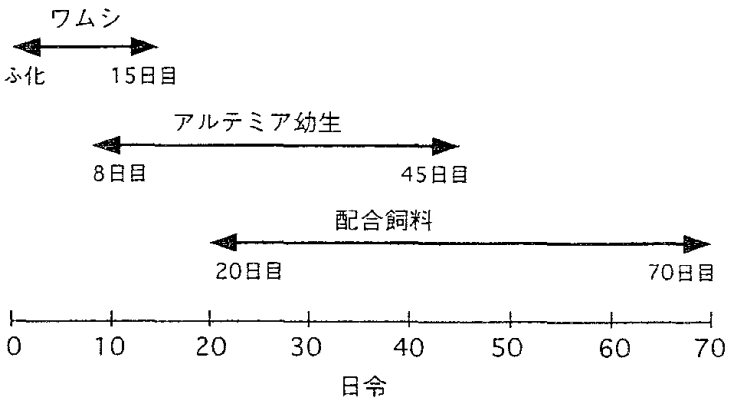


Figure VIII 3-1 Feeding sequence for producing herring fry.
[x axis] Age in days
[three arrows, top to bottom]
[Above top arrow]
Rotifer
[below top arrow, left to right]
Hatching
Fifteenth day
[Above middle arrow]
Artemia larvae
[below middle arrow, left to right]
8th day
45th day
[Above bottom arrow]
Composition feed
[below arrow, left to right
20th day
70th day

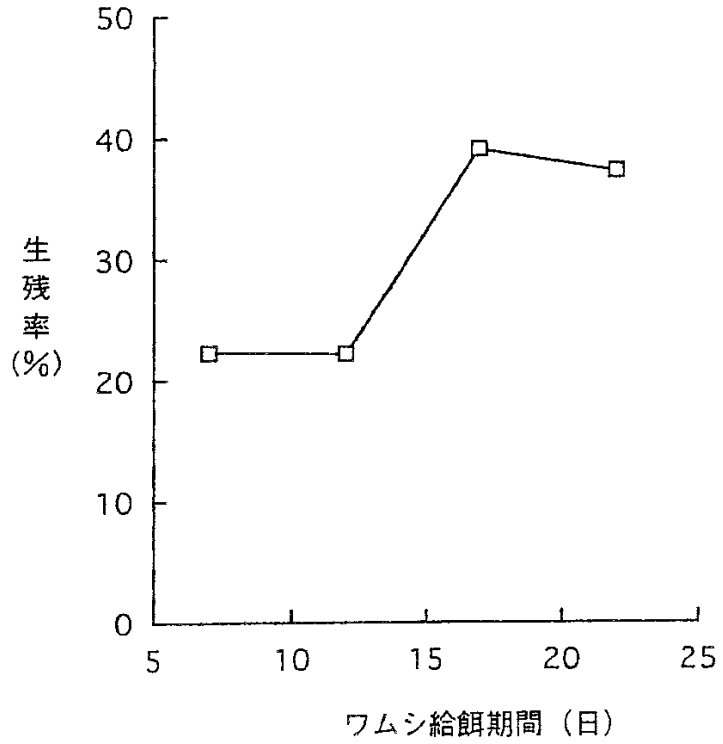


Figure VIII 3-2 Relationship between the length of the rotifer feeding period and survival rates. [y axis] Survival rate (%) [x axis] Period in which rotifers were used as food (days)

(2) Live animal feeds

1) Rotifers

At Akkeshi Station the rotifers are cultured with bread yeast and commercial concentrated freshwater *Chlorella*. The rotifers are used when they reach the L stage. Rotifers are cultured continuously in a constant temperature tank for 40 days prior to starting fry culture. The cultures are fundamentally batch cultures. The culture tanks are stocked at a density of 100 rotifers/mℓ. After 14 days this increases to more than 500 rotifers/mℓ. These are used for several days up until day 20, when they are transplanted. There are a number of tanks at different stages of this cycle which makes it possible to supply food every day. Currently, with average cultures of 10,000,000,000 rotifers, it is possible to supply 2,000,000,000 per day. Figure VIII 3-3 shows average culture and an excellent culture case.

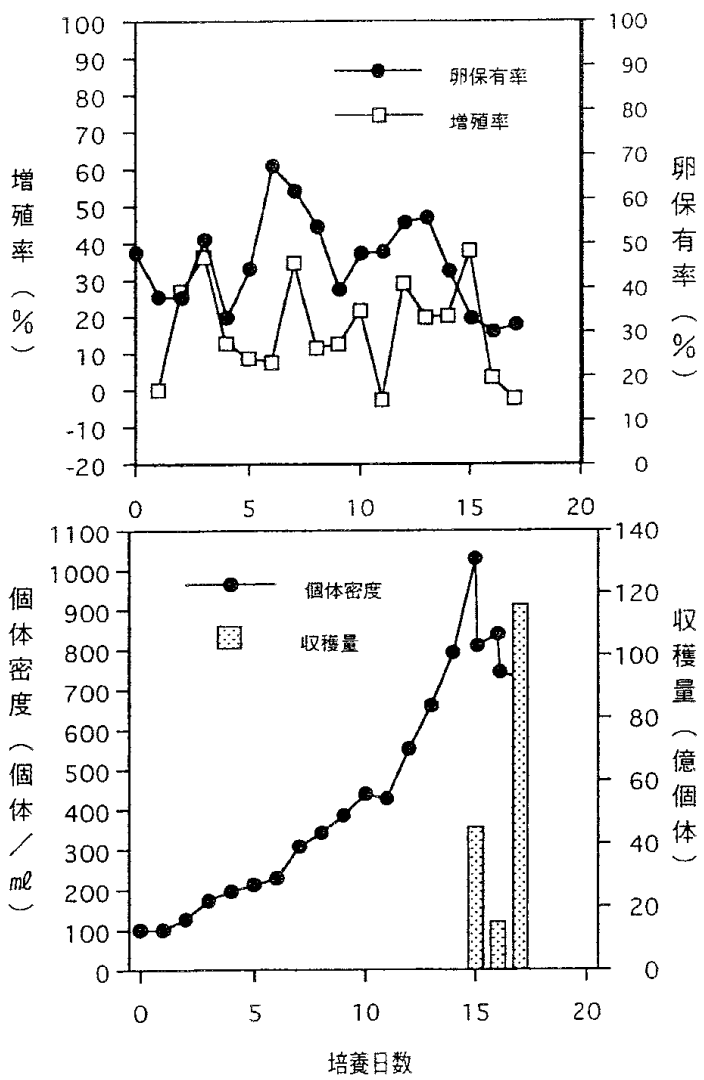


Figure VIII 3-3 A case where rotifers were cultured with excellent results.
[upper figure]
[y axis left] Propagation rate (%)
[y axis right] Egg maintenance rate (%)
[legend]
-●- Egg maintenance rate
-○- Propagation rate

[lower figure]
[y axis left] Individual concentration (individuals/ml)
[y axis right] Amount cultured (100,000,000 individuals)
[x axis] Number of days of propagation
[legend]
-●- Concentration of individuals
[stippled rectangles]
Amount harvested
[end figure]

Harvesting of the rotifers is done either with a pump or siphon. In order to avoid sucking in debris on the bottom, the intake is at least 20 cm above the bottom. They are collected in a specially made cylindrical plankton net made with a 63-micron mesh size.

2) *Artemia*

The *Artemia* that were used had been produced in North America, and had been hatched at a water temperature of 22°C for 48. Table VIII 3-1 shows the procedures for stocking *Artemia* eggs and extracting larvae. A multipurpose circular harvesting net made of nylon netting with a 200 mesh size is used exclusively for this purpose.

The following indicates the points of concern during the *Artemia* harvesting operations. (1) The upper limit for stocking is 1,100g of eggs per $1m^3$. (2) Following harvesting, the *Artemia* are promptly counted and supplied as food. (3) When they are concentrated, the activity level declines because of oxygen deficiency. Besides normal aeration, care must be taken that the operations are performed rapidly. (This is also the case for rotifers.) (4) Care must be taken so that the heaters do not overheat.

Table VIII 3-1 Tank for culturing *Artemia* culture and operational procedures for recovering hatched larvae.

Egg culture procedures
(1) Add 1000ℓ of seawater to a temperature controlled culture tank that is used for culturing the eggs.
(2) Set up central column, air, heater, temperature sensor, and float switch.
(3) Add *Artemia* eggs. Add 1000 ml of chlorine*.
(4) After 5 minutes, add an equal amount of hypo** (1000 ml). Wait 1 minute.
(5) Use a white cap to determine if there is residual chlorine***.
(6) Finally, check the heater switch.

*Chlorine: Sodium hypochlorous acid, 12% solution, food grade

*Hypo: Sodium thiosulfate 5-hydrate; 8 kg is dissolved in 20ℓ of tap-water.

***Chlorine residual test: a 20% solution of potassium iodide is employed. If the light brown color does not appear, the chlorine has been neutralized.

Procedure for recovering hatched larvae
(1) On the day for recovery, turn off the switch to the heater for the *Artemia* hatching tank.
(2) Remove air stone and central column.
(3) Put 400ℓ of sea water in a tank used for counting.
(4) About 15 minutes after the larvae and egg shells are separated while aerating, they are recovered through a valve that is half open.
(5) After the tank has 350ℓ, move larvae to counting tank and resume.
(6) Recovery is completed when there is 150ℓ left in the tank
(7) The recovered *Artemia* are stocked in the container used for counting
(8) All egg shells are recovered, and the feces are well separated from the water. These are disposed of in the trash.
(9) The hatching tank is washed well with a brush.
(10) After being placed in the 500ℓ counting tank, the *Artemia* larvae are counted.
(11) During the second recovery, *Artemia* are wash-filtered with temperature controlled, filtered sea water for 1 minute or more and are then transferred to a nutritional enhancement tank.

3) Improving the nutritional content

Procedures are performed with the purpose of increasing polyunsaturated fatty acids such as DHA and EPA. Standard nutrition enhancement compounds are used to enhance nutritional value. At Akkeshi Station the nutritional enhancement compound that is used for both rotifers and *Artemia* is Aquaran (manufactured by BASF Japan). The standard water temperature during nutritional enhancement and the concentration of the nutritional enhancement drug is 15°C and 200g/m^3 for rotifers, and 18°C and 150 g/m^3 for *Artemia*. The standard treatment period for rotifers is 22 hours and for *Artemia* 22-30 hours. The maximum concentration of rotifers during nutritional enhancement is 2,000,000,000/m^3 and for *Artemia* it is 300,000,000/m^3. During nutritional enhancement, the activity level of rotifers and *Artemia* is decreased and there can be mortalities. If this occurs during stocking, the enhancement concentration of the feed organism is decreased and the treatment is adjusted with strong aeration. Table VIII 3-2 shows the nutritional enhancement practices at each facility.

Table VIII 3-2 Summary of procedures for nutritional enhancement of rotifers and *Artemia* that are used in the production of herring fry (1999 data).

Facility	Rotifer			Artemia		
	Nutritional enhancement drug	Enhancement concentration g or ml/m^3	Enhancement period (h)	Nutritional enhancement drug	Enhancement concentration g or ml/m^3	Enhancement period (h)
Japan Aquaculture Association, Akkeshi Station (Corporation)	Aquaran			Aquaran		
Hokkaido Aquaculture Promotion Corporation, Haboro Station	Aquaran + freshwater Chlorella			Super Capsule A-1		
Japan Aquaculture Association, Miyako Station (Corporation)	Aquaran			Aquaran + *Phaeodactylum*		
Miyagi Prefecture Aquaculture Center	Aquaran			Super Capsule A-1		
Hokkaido Aquaculture Integrated Center	Aquaran			Powersh-A A + Hydro Bit		
Aomori Prefecture Aquaculture Center	Aquaran			Powersh-A		

機関	ワムシ			アルテミア		
	栄養強化剤	強化濃度 (gまたはml/ml)	強化時間 (h)	栄養強化剤	強化濃度 (gまたはml/ml)	強化時間 (h)
(社) 日本栽培漁業協会厚岸事業場	アクアラン	200	20	アクアラン	150	20
(社) 北海道栽培漁業振興公社羽幌事業所	アクアラン+淡水クロレラ	200+500	4～17	スーパーカプセルA-1	200	15～24
(社) 日本栽培漁業協会宮古事業場	アクアラン	200	16	アクアラン+フェオダクチラム	150	16
宮城県栽培漁業センター	アクアラン	100	4～18	スーパーカプセルA-1	100	6～24
北海道栽培漁業総合センター	アクアラン	200	16～24	パワシュA+ハイドロビット	80+25	16～24
青森県水産増殖センター	アクアラン	100	6～24	パワッシュA	20	18～24

4) Washing treatment before feeding

After nutritional enhancement, the rotifers and *Artemia* are caught in nets specialized for each species. The rotifers are filtered before the following washing operation in order remove debris.

Washing operations are performed in the net under concentrated conditions. Washing is performed in filtered sea water that is maintained at a temperature of 15°C. Washing continues until the seawater is clear.

The nutritional enhancement drug and the feces of the live feed should be removed. In addition, the number of cells on the surface of the live feed should be reduced. Also, In order to determine the condition of the live feed, the following should be checked: number of individuals, activity, condition when fed, mortalities, and debris. When the condition is poor, it is important to dispose of the live feed.

5 Larval feeding

(1) Time period for digestion and evacuation of live feed

The gastrointestinal tract of larval herring is of simple construction. As the gastrointestinal tract is transparent, it is easy to observe from the exterior. Kurata (1959) used this characteristic to estimate the period required for digesting *Artemia*.

According to these results, at a temperature of 8.6ºC-9.6ºC a larval fish on day 12 after hatching takes 7-8 hours to digest *Artemia*. It takes an additional 5-7 hours for total evacuation.

Akkeshi Station performed a study on digestion and evacuation of feeding larval fish at a temperature of 13°C. Ten days after hatching, the evacuation period of rotifers was 3-4 hours, and 20 days after hatching the evaluation time was 5-6 hours. These digestion and evacuation periods were faster than those reported previously by Kurata, but temperatures were higher than the experiments by Kurata. It is believed that the higher rates occurred because temperature has a large influence on feeding and digestion (Hathaway, 1927).

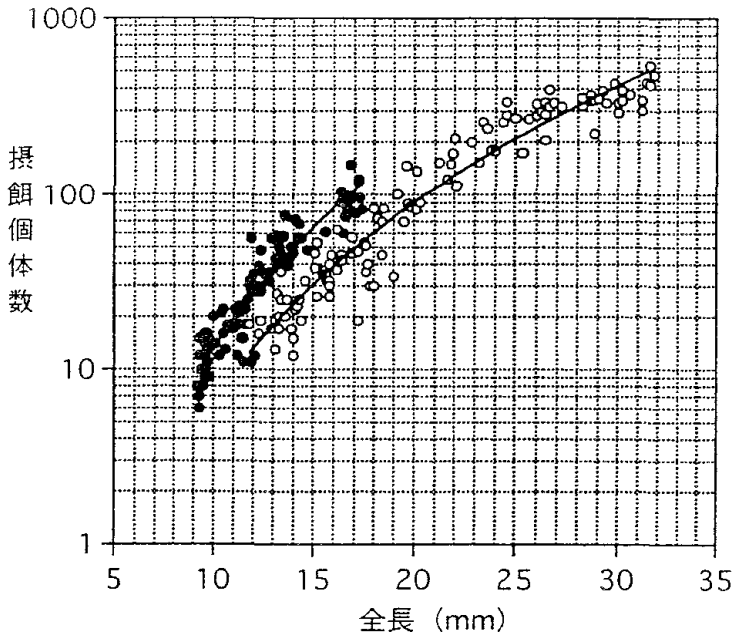
(2) Number of live feed organisms consumed

The amount of rotifers and *Artemia* consumed during a feeding (to satiation) was studied for herring larvae and fry (total lengths 9 to 32 mm). The results were that when the larvae were 10 mm in length, they consumed about 10 rotifers. At a length of 15 mm they consumed 60 to 70 rotifers or about 30 *Artemia*. At a length of 20 mm the larvae consumed 80 to 100 *Artemia*. Then at a total length of 25 mm, they consumed 110-130 *Artemia*; at a length of 30 mm consumption was 130-150. At this size the gastrointestinal tract was completed and the speed of digestion also jumped upward. It is believed that the turnover from feeding to evacuation was faster, so they could consume a lot more food.

[Page 48]

On the basis of these results, a correlation relationship can be obtained for the number of rotifers or *Artemia* (Y) that can be consumed at one time relative to total length (X).

The formula for rotifers is $Y=0.00150X^{3.940}$ ($r^2=0.880$), and for *Artemia* it is $Y=0.00113X^{3.768}$ ($r^2=0.933$) (Figure VIII 3-4). When feeding,it is important to make good observations at the same time on feeding condition. Feeding must be set so that there is no excess or deficiency and feeding must match feeding ecology.



図Ⅷ 3-4　ニシン人工種苗が摂餌したワムシとアルテミアの個体数と全長の関係

● ワムシ　　$y=0.00150x^{3.940}$　$r^2=0.880$

○ アルテミア　　$y=0.00113x^{3.768}$　$r^2=0.933$

Figure VIII 3-4 Correlation between growth and the number of rotifers and *Artemia* consumed by cultured herring larvae and fry.
[y axis] Number of organisms consumed
[x axis] Total length (mm)
● Rotifers　$y=0.00150x^{3.940}$ $r^2=0.880$
○ *Artemia*　$y=0.00113x^{3.768}$ $r^2=0.933$

(3) Formula feed

Feeding with formula feed begins 20 days after hatching (total length 18 mm). To cause the fish to begin feeding on the formula feed, it is provided at sunrise immediately after feeding with live food. During the early period an automatic feeding device is used which provides feed about 10 times. Using this method, it is possible to have the fish eating formula feed within 5 to 7 days after beginning the feeding change. After the feeding change, the feeding method uses an automatic feeding device, which supplies about 2/3 of the daily ration uniformly through the day. In order to observe the feeding behavior, 1/3 of the ration is dispersed by hand. Table VIII 3-3 shows the 1999 feeding schedule. The schedule shows the amount of formula feed for a single $50m^3$ tank producing 250,000 fry.

(4) Amount fed

Observations have been made on herring feeding characteristics, on conditions of digestion and evacuation, the structure of the simple digestive tract, etc. It has been suggested that it is possible to consume an excessive amount of *Artemia*. For this reason feeding tests with cutbacks in the feed were performed at Akkeshi Station in 1998. In order to observe the feeding behavior, a count was made of the number of live prey items in the gut. In order to make a relevant test, 1995 was used as a control. Using 66% of the food, it was possible to obtain the same survival rate. Thus it is possible to reduce the amount of *Artemia* fed by 30%. However, as there was large variation in growth, in 1999 the ratio of feed during the early culture period was modified, so that the variation in growth also declined. It was possible to set efficient feeding standards (Table VIII 3-3).

Table VIII 3-3 Amount of live food and formula feed during herring fry production (50 m^3 water tank with 12,000 fry per m^3, with a survival rate of 40%).

Age in days	**Rotifers**	**Artemia**	**Formula feed (kg)**			
			A	**B**	**C**	**D**
Total						

Particle size of formula feed (µm)	

日令	ワムシ	アルテミア	配合飼料（kg）			
（日）	（億個体）	（億個体）	A	B	C	D
0	2					
1	2					
2	2					
3	2					
4	3					
5	4					
6	5					
7	5					
8	5	0.15				
9	5	0.20				
10	5	0.35				
11	5	0.55				
12	5	0.75				
13	5	0.75				
14	5	0.75				
15	5	0.75				
16		0.75				
17		0.75				
18		0.95				
19		0.95				
20		0.95	0.1			
21		1.20	0.1			
22		1.20	0.1			
23		1.20	0.1			
24		1.50	0.2			
25		1.50	0.2			
26		1.50	0.2			
27		1.80	0.2			
28		1.80	0.2			
29		1.80	0.2	0.1		
30		1.80	0.2	0.1		
31		1.80	0.2	0.2		
32		1.80	0.2	0.2		
33		1.80	0.2	0.2		
34		1.50	0.2	0.2		
35		1.50	0.2	0.3		
36		1.50	0.2	0.3		
37		1.50	0.2	0.4		
38		1.50	0.2	0.4		
39		1.50	0.2	0.6		
40		1.50	0.2	0.6		
41		1.50	0.2	0.8		
42		1.50	0.2	0.9		
43		1.50	0.2	1.2		
44		1.13	0.2	1.3		
45		0.95	0.2	1.4		
46				1.4	0.4	
47				0.8	1.4	
48					2.8	
49					2.8	
50					2.8	
51					2.8	
52					3.3	
53					3.3	
54					3.3	
55					3.3	
56					3.3	
57					3.3	
58					3.3	
59					3.3	
60					4.3	
61					4.3	
62					4.3	
63					4.3	
64					4.3	
65					4.6	
66					4.6	
67					4.6	
68					2.6	2.0
69					2.6	2.0
70						5.0
71						5.0
72						5.0
73						5.0
74						5.0
75						5.0
合計	65.0	46.4	4.7	11.4	79.9	34.0

配合飼料	A:	250-400
粒径（μm）	B:	360-620
	C:	620-920
	D:	920-1410

When comparing the amount of feed at each facility, Mayako Station has the highest feeding amounts for both rotifers and *Artemia*. They have a low dependence on formula feed, and feeding is centered on live feed. Also, dependence on rotifers is extremely low at Hokkaido Aquaculture Promotion Corporation Haboro Station, and the amount of *Artemia* fee is high (Figure VIII 3-5).

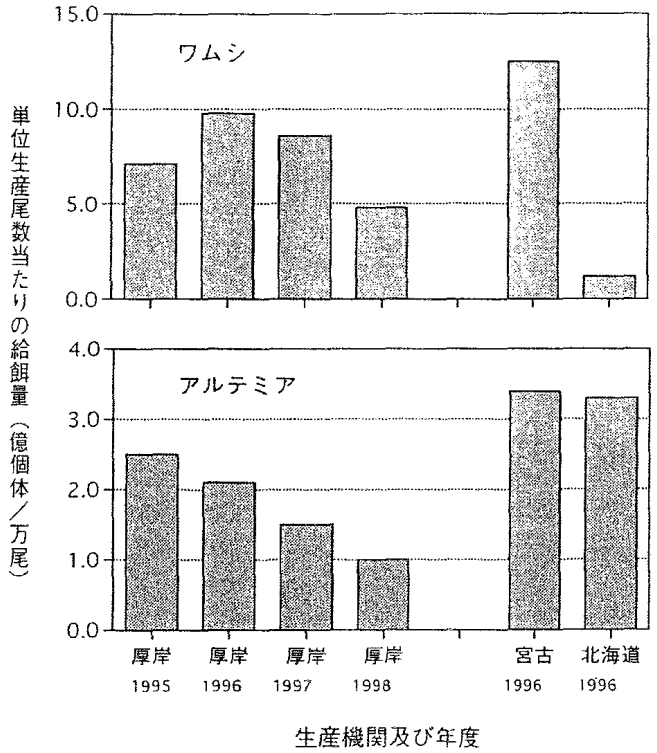


Figure VIII 3-5 Comparison at different facilities of rotifer and *Artemia* feeding units for herring fry production.
[inside top figure] Rotifers
[inside bottom figure] *Artemia*
[y axis] Feeding units. The number of food items per cultured fish (100,000,000 invertebrate food items/10,000 fish)
[x axis] Production facility and year
Akkeshi: Japan Aquaculture Association, Akkeshi Station
Miyako: Japan Aquaculture Association, Miyako Station
Hokkaido: (Hokkaido Aquaculture Promotion Corporation, Haboro Station

Thus, the ratio of each food differs depending on the facility. To reduce costs it is desirable to reduce the use of live feeds as much as possible. However, it is important to investigate the effect of reducing live feeds.

4. Growth

(1) Examples of average growth

Fry and larvae were sampled and measured at intervals of 5 to 10 days to monitor growth. The samples contained 20 or more fish, and the fish were anesthetized with FA-100 (eugenol). Also, as growth was variable, growth is represented by a variation coefficient (variation coefficient =standard deviation/mean value). The average growth at Akkeshi Station is as follows: at hatching the larvae have a total length 8.5 mm; at 10 days after hatching the length is 14 mm; at 20 days the length is 18 mm; at 30 days 22 mm; at 40 days 28 mm; at 50 days 35 mm; at 60 days 45mm; and at 70 days 50 mm (Figure VIII 4-l). The relationship between a total length (Y) and the number of days after hatching (X), for the first 70 days is represented by the correlation coefficient $Y=10.725 \times 10^{0.10102x}$ ($r^2=0.986$). In 1982, Miyako Station obtained a correlation equation between accumulated water temperature (D) and the total length (L) for Mangokuura fry production, which was D=0.838L (r=0.989). Also, the Reference Data shows the relationship between body length and body weight.

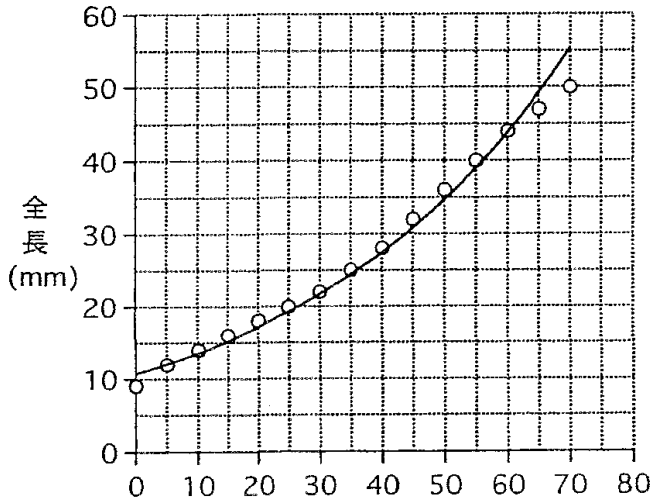


Figure VIII 4-1 Change over time in the average growth rate of cultured herring fry after hatching.
[y axis] Total length (mm)
[x axis] Number of days after hatching $y=10.7253 \times 10^{0.0102x}$ $r^2=0.9858$

An example of growth rates is a culture that was performed in 2000 at a temperature of 13ºC. Growth rates were determined every 5 days. For 30 days after hatching the daily growth rate varied between 0.4-0.6 mm. Then, there was an increasing trend and at 55 days and later the rate was 0.8-0.9 mm/day (Figure VIII 4-2).

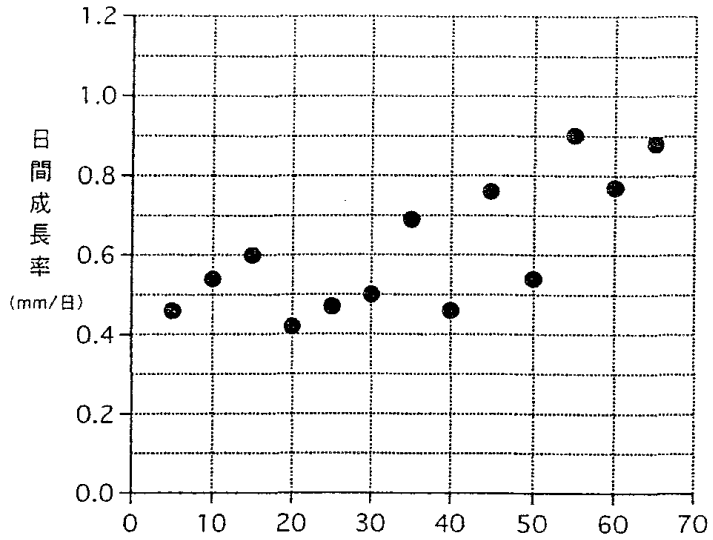


Figure VIII 4-2 Change over time in the daily growth rate of Akkeshi herring fry production.
[y axis] Daily growth rate (mm/day)
[x axis] Days after hatching

There was variation in the total length. The variation coefficient of total length changed over time, and there was a rapid increase between the day 20 and day 40 after hatching. The development of the growth dispersion is shown in Figure VIII 4-3. This is the period when there is a conversion from live food to formula feed. It is believed that this is a reflection of individual differences in feeding.

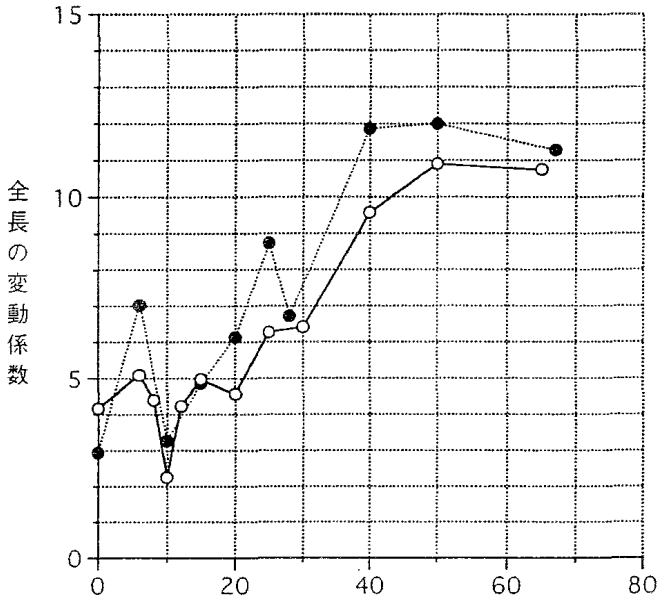


Figure VIII 4-3 Change over time of the total length coefficient for herring fry produced at Akkeshi. [y axis] Change in total length growth coefficient. [x axis] Number of days after hatching. ○ Produced at Furen Lake ● Produced at Akkeshi

(2) Culture water temperature and growth

1) Temperature of the culture water and daily growth rate

In 1986 growth tests were performed at set water temperatures of 10ºC and 15ºC. The results were that the growth rate at a water temperature of 10ºC was 0.37-0.39 mm/day, and at a temperature of 15ºC the growth rate was 0.69-0.70 mm/day. The growth rate was clearly much higher at 15°C. Because of these results, the relationship between daily growth rates and average water temperatures in 1983-1986 were studied for those cultures where feeding had been the equivalent. The results indicated that in the temperature range of 10°C to 13.5°C, the growth rate was faster at higher temperatures, and there was a direct linear relationship. However, in the temperature range of 13.5°C to 14.5°C, it was clear that the growth rate was almost the same, or even tended to decline somewhat (Figure VIII 4-4). Because of this, a temperature of 13°C was considered to be the best with respect to culture.

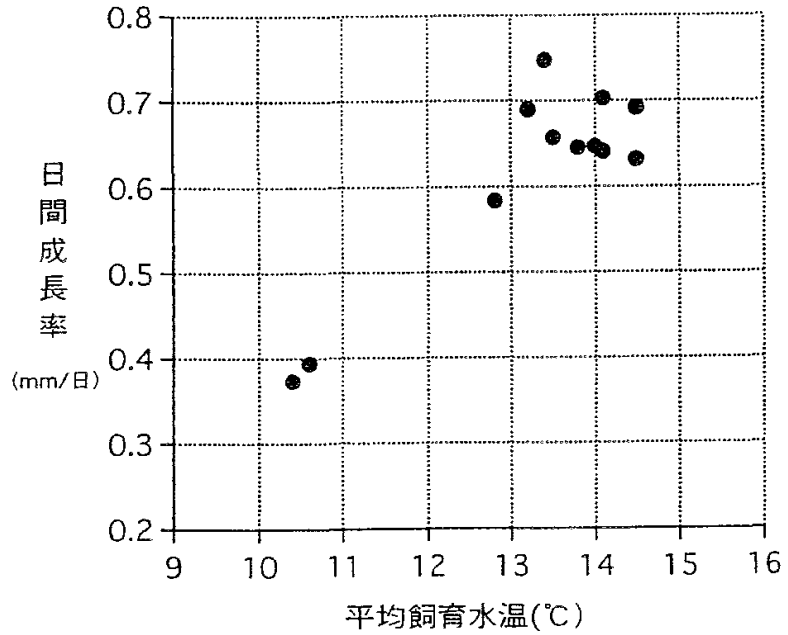


Figure VIII 4-4 Correlation between rearing temperature and daily growth rate. (1983-1986 Akkeshi Station) [y axis] Daily growth rate [x axis] Average water temperature

2) Temperature of the culture water and saving energy

Calculations were performed related to saving energy during fry production. A comparison was made between a case in 2000 when the rearing temperature was set at 13°C, and cases in 1995-1997 when the temperature was 15°C. Calculations were made for culturing the fry up to a total length of 40 mm. To calculate the number of calories, the amount of water required by this culture method was multiplied by the temperature difference. In 2000, the set temperature was 13°C, and the total calories were 33.3 x 10^6 kcal. In 1995-1997, at a set water temperature of 15ºC the calories required were 43.2 x 10^6 kcal. By dropping the set water temperature by 2°C, there was a decrease of 9.9 x 105 kcal, a calculated energy savings of 23% (Table 4-1). Moreover, because of the temperature of the air, there would be radiation out of the water, so it can be assumed that this difference is even greater. From the above results it is believed that there would be large energy saving by using a set water temperature of 13º C.

Table VIII 4-1 Calculation of the savings in energy when rearing herring fry to 40 mm if the set water temperature is dropped from 15ºC to 13ºC.

Set water temperature	**Number of days of culture (days)**	**Accumulated water temperature (Dº)**	**Accumulated water temperature between the natural intake water temperature and the set temperature (Dº)**	**Simple calculation of the accumulated calories (x 10^6kcal)**	**Ratio of simple accumulated calories (13ºC case/15ºC cases) (%)**

水温設定	飼育日数 (日)	積算水温 (D˚)	地先水温と設定水温の差の積算水温 (D˚)	単純試算した積算カロリー (×10^6kcal)	単純積算カロリーの割合 (13℃事例/15℃事例) (%)
15℃	54	810.0	453.8	43.2	-
13℃	59	770.5	358.2	33.3	77.1

5. Survival and production results

(1) Survival estimates

To estimate survival rates, three or four days after hatching, cylindrical type samples are performed at night, and every day the number of mortalities are estimated from the number of dead fish collected during cleaning. When the fry are collected, the number is estimated using a weight method and this is compared with the results mentioned above. There is a tendency for the estimate of the number of surviving fish to be too high. In 14 cases of fry production during 1997-2000, the correlation formula for the estimated number of surviving fish (X: 10,000 fry) and the actual number of surviving fish (Y: 10,000 fry) was Y=0.665X + 3.114 (r^2=0.788). The actual values were about 70% of the estimated values (Figure VIII 5-1).

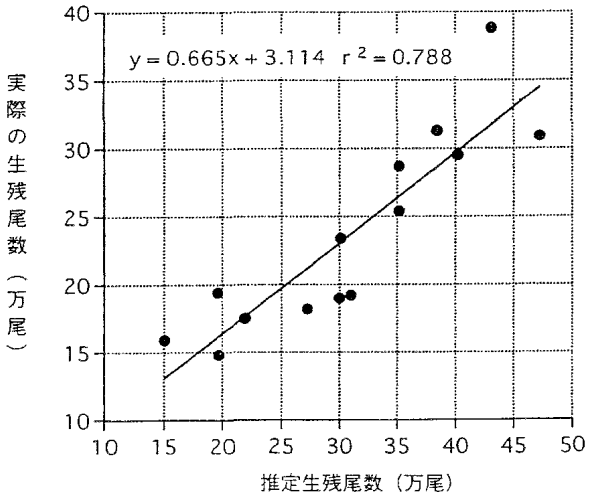
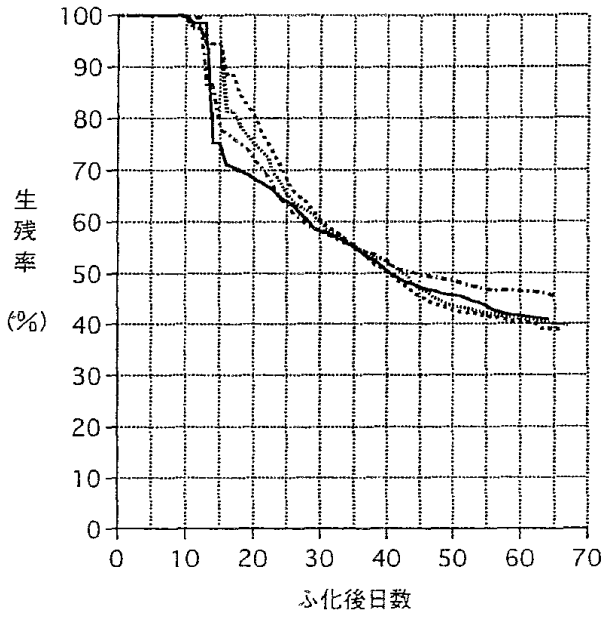


Figure VIII 5-1 Correlation between the actual survival and an estimate based on the number of mortalities during the production of herring fry. [y axis] Actual number of surviving fry (x 10,000). [x axis] Estimated number of surviving fry (x 10,000).

(2) Change in survival rate over time

In culture cases at Akkeshi Station in 1999, there was almost no decline for 10 days after hatching in the herring produced from both Furen Lake and Akkeshi Lake. There was a large natural decline from day 10 to day 15. By the fifteenth day, 10%-30% of the totals had died (Figure VIII 5-2). The daily mortality rate was highest in the period from 10-15 days after hatching (2-7%), and was 1-2% in days 15-30. Thereafter, the rate dropped below 1%, and by the fiftieth day there were few mortalities (Figure VIII 5-3). Starting in 1998, rotifers and *Artemia* were given nutritional enhancement with Aquaran, and as a result the survival rate improved by 10%. Compared to 1997 and before, there was a decline in the mortality rate from day 15 to day 30. Instead there was a tendency for the mortality rate to be comparatively high during the period up to day 15.



図Ⅷ 5-2　1999年のニシン種苗生産における回次別の生残率

風蓮 1　風蓮 2

厚岸 1　厚岸 2

Figure VIII 5-2 Survival rates of cultured herring fry in replicated operations in 1999.

[closely spaced dotted line] Furen 1
[widely spaced dotted line] Furen 2
[solid line] Akkeshi 1
[dot-dash line] Akkeshi 2
[y axis] Survival rate (%)
[x axis] Number of days after hatching
[end figure]

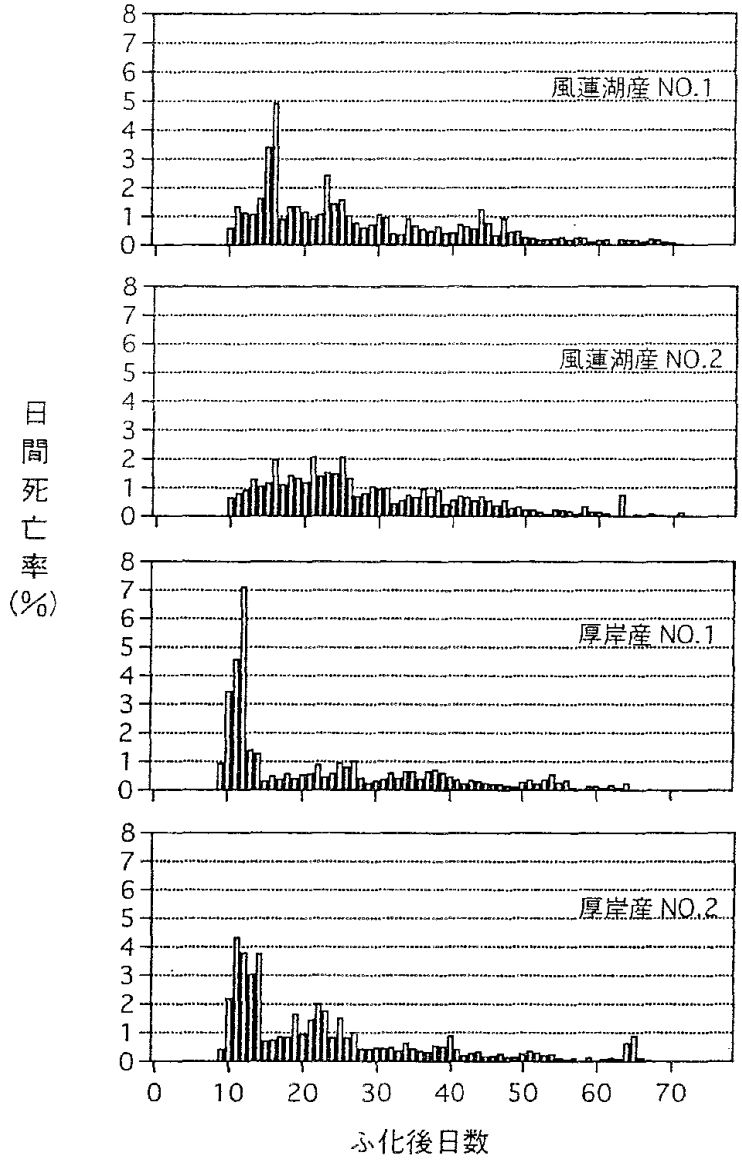


Figure VIII 5-3 Change over time in the daily mortality rate of cultured herring fry (1999 cases). [top figure] Furen Lake production Number 1, [second figure] Furen Lake production Number 2, [third figure] Akkeshi production Number 1, [fourth figure] Akkeshi production Number 2, [y axis] Daily mortality rate (%)
[x axis] Number of days after hatching

Figure VIII 5-4 shows mortality information from cultures in 1996, at the Miyako Station and the Hokkaido Aquaculture Public Corporation, Haboro Station. It shows a comparison of the daily number of mortalities calculated for a 50m^3 tank stocked at 10,000 fish/m^3 (Figure VIII 5-4). At Akkeshi Station there were two peaks in 1997 (on days 15-30 and days 40-50). At Miyako Station there was a single peak at days 10-25. In the same period, at Hokkaido Aquaculture Public Corporation, Haboro Station, the number of daily mortalities on days 5-40 was about 4000 fish/day (the daily mortality rate was about 0.8%), and this was a fairly consistent trend over time. Because of this, the mortality trends in herring fry production cultures are clearly different depending on the fry production facility or the particular culture. It is believed that this reflects differences in the respective fry culture methods.

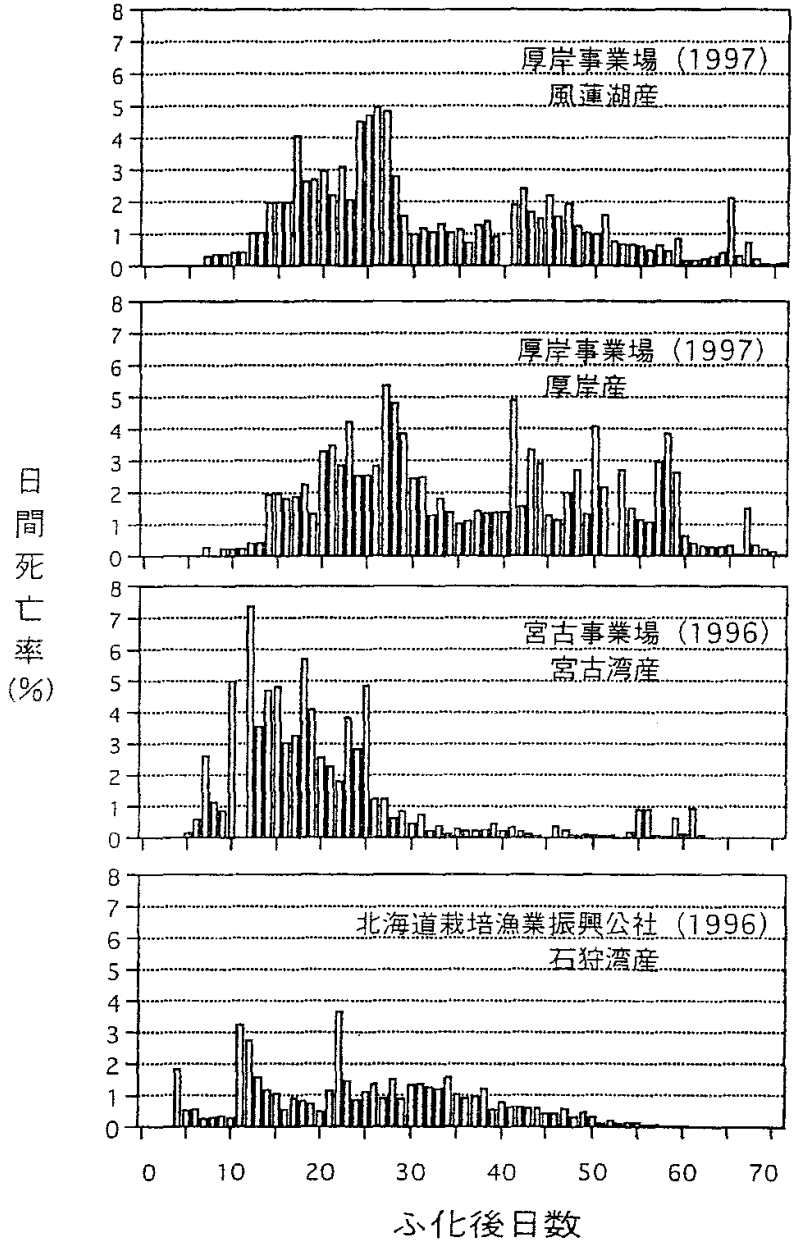


Figure VIII 5-4 Change over time in the daily mortality rate of cultured herring fry in operations at different facilities. [top figure] Akkeshi Station (1999) Furen Lake production, [second figure] Akkeshi Station (1999) Akkeshi production, [third figure] Miyako Station (1996), Miyako Bay production, [fourth figure] Hokkaido Aquaculture Promotion Public Corporation (1996), Ishikari Bay production, [y axis] Daily mortality rate[x axis] Number of days after hatching

(3) Causes of mortalities and countermeasures to improve the survival rate

It is believed that mortalities in herring larvae and fry during fry production occur for such reasons as: 1) Derivation of eggs; 2) Vulnerable development stages; 3) Failure to eat adequate feed when switching feeds; 4) Inadequate nutrition; and 5) ALC labeling treatments.

Iizuka (1962) reported on issues related to egg quality. It is believed that in Akkeshi herring there is a relationship between the size of the yolk and survival. Currently, there is little knowledge related to evaluating yolks. The tendency towards high mortality rates at body lengths between 10 and 30 mm suggests that the change in daily mortality rates over time corresponds to the developmental stages of rapid organogenesis. During this period it is easy for there to be inadequate energy corresponding to metamorphosis. Consideration must be made so that the sequence in changes in feed must be made so that energy reserves do not become exhausted and impact organogenesis (Fukuda, 1986). It is believed that mortalities occur because of this vulnerability. This relates to nutritional deficiencies, such as occurs when nutrient enhancement of live food has been inadequate. In addition, ALC labeling causes a rapid change in the culture environment, and this physical change can raise the mortality rate. Consequently, this tagging operation requires prudent care. Also, as mentioned above, there is a tendency for ALC treatments to cause mortalities when the procedure occurs during sensitive development stages.

Basic countermeasures for mitigating the mortality rate during the process of culturing herring fry, includes providing adequate nutritional enhancement of the live food and feeding to satiation. When changing to formula feed, the amount of artificial feeding must be adequate. In addition with growth it is important to match the amount of water exchanges with thorough bottom cleaning to maintain good water quality conditions. At the same time, herring larvae should have a culture environment where the physical stimuli that are stressors are reduced as much as possible (illumination during culture requires special attention). The important point is to maintain stabile conditions.

(4) Calculating the fry production results and number of surviving fry

The Reference Data shows a summary of the fry production results of the Furen Lake herring and Akkeshi herring that were produced at Akkeshi Station. Initially, production was less than 200,000 fry, but with increases in tanks and improvements in fry production techniques, by 1993 it was possible to produce 500,000 fry. In 1998 the number of fry exceeded 1,000,000 (Table VIII 5-1)

Table VIII 5-1 Change over time of cultured herring at Akkeshi station.

Year	Number of fry produced (10,000 fry)	Average total length (mm)	Average survival rate (%)

年	生産尾数（万尾）	平均全長（mm）	平均生残率（%）
1982	8.4	65.9	46.0
1983	10.3	65.2	38.6 (29.0 ～ 61.8)
1984	18.3	46.1	69.6 (63.6 ～ 81.0)
1985	33.8	63.2 (58.0 ～ 68.3)	58.0 (6.2 ～ 68.2)
1986	25.4	46.4 (45.0 ～ 47.7)	61.8 (22.8 ～ 64.9)
1987	33.6	48.8 (44.5 ～ 53.0)	52.0 (42.9 ～ 56.9)
1988	29.7	52.2 (50.8 ～ 53.6)	26.7 (21.4 ～ 61.1)
1989	39.4	52.3 (50.9 ～ 53.6)	40.0 (36.2 ～ 56.5)
1990	15.6	48.5 (42.5 ～ 54.4)	15.8 (0.0 ～ 52.2)
1991	27.9	42.3 (31.0 ～ 53.5)	30.0 (19.6 ～ 40.4)
1992	37.2	42.4 (41.7 ～ 43.0)	22.0 (15.5 ～ 28.4)
1993	53.5	46.6 (24.4 ～ 70.0)	36.2 (25.3 ～ 47.2)
1994	76.1	44.5 (41.2 ～ 46.9)	34.3 (31.7 ～ 38.4)
1995	90.4	45.8 (43.3 ～ 52.6)	31.1 (27.7 ～ 45.8)
1996	91.7	49.4 (41.4 ～ 60.1)	35.6 (29.5 ～ 45.7)
1997	67.6	42.4 (29.1 ～ 58.1)	33.5 (30.7 ～ 36.6)
1998	111.9	39.4 (27.2 ～ 60.4)	45.7 (31.5 ～ 57.4)
1999	109.9	40.7 (28.3 ～ 55.0)	41.1 (38.9 ～ 45.0)

As stated previously, with the fry production methods that were used, there was an expectation of a survival rate of 40% or more from the period of larval stocking until they were harvested and transferred offshore. With a larval stocking density of 15,000 larvae/m^3, it can be expected that the fry density will be 6000/m^3. Thus, from these results, it can be calculated that it is possible to produce 300,000 or more fry in a single 50/m^3 tank.

6. Morphological abnormalities

Most of the cultured herring fry are released. Fish with morphological abnormalities have low survival rates after release, which means that observations of the fry are important. Also, compared to other production facilities, the there is a higher ratio of abnormalities (especially spinal abnormalities). The results of Akkeshi Station tests for the purpose of preventing morphological abnormalities are introduced below.

(1) External morphological abnormalities

1) Investigation Method

A study on abnormalities was performed on fish at the completion of nursery culture when they measured 70 to 100 mm as this is when it was easiest to evaluate abnormalities. Samples of about 100 fish were anesthetized or were cooled with ice. After measuring total length and body weight, they were visually given an exterior examination.

2) External morphological abnormalities

External morphological abnormalities were categorized as follows: shortened body, opercular defects, protrusion of pharyngeal isthmus, non-alignment of lower jaw, deformity of the upper jaw, deformity of the anterior part of the head, and curvature of the spine (Figure VIII 6-1).

Shortened body This occurs because of spinal abnormalities, especially spinal adhesions, that cause the body to shorten.

Opercular defects The opercular bone is defective and the gill lamella is exposed abnormally.

Protrusion of pharyngeal isthmus An abnormality where there is a protrusion of the lower pharyngeal isthmus.

Non-alignment of lower jaw (mandible) Lack of left-right symmetry of the lower jaw, poor alignment with upper jaw and teeth.

Upper (maxillary) jaw deformity Deformity of the upper jaw so there is poor alignment with the lower jaw.

Deformity of the anterior part of head Abnormal depression on the anterior part of head.

Curvature of the spine Curvature of the spine, causing an abnormal flexing of the body.

At Akkeshi Station the occurrence of exterior morphological abnormalities differs depending on the year and there are differences in the types of abnormal manifestations. The abnormality rate is generally about 5-10%. In 1999 the rate was 6-8% for fry produced both from Furen Lake and Akkeshi. The most common abnormalities tend to be shortened bodies and lower jaw abnormalities (protrusion of lower pharyngeal isthmus, non-alignment of lower jaw).

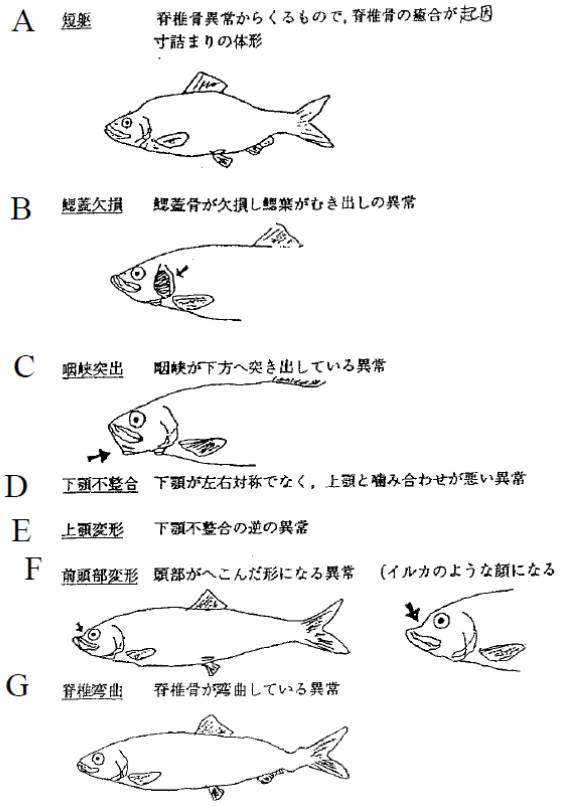


Figure 6-1 Classification of exterior morphological abnormalities in cultured herring fry.

[A] **Short Body** This occurs because of spinal abnormalities, especially spinal adhesions that causes the body to shorten.

[B] **Opercular defects** The opercular bone is defective and the gill lamella is exposed abnormally.

[C] **Protrusion of pharyngeal isthmus** An abnormality where there is a protrusion of the lower pharyngeal isthmus.

[D] **Non-alignment of lower jaw (mandible)** Lack of left-right symmetry of the lower jaw, poor alignment with upper jaw and teeth.

[E] **Upper jaw (maxillary) deformity** Abnormalities of the upper jaw so there is poor alignment with the lower jaw.

[F] **Deformity of the anterior part of head** Abnormal depression on the anterior part of head. The face resembles that of a dolphin.

[G] **Curvature of the spine** Unnatural flexure of the body.

(2) Spinal abnormalities

1) Investigation methods

((1)) Storage of samples

Following nursery culture, samples of the fry were examined with soft x-rays. After taking a random sample, the samples were refrigerated. After measuring the total length and body weight, the herring were arranged on a wrap, and were placed in a tray and frozen [refrigerated is also a possible translation].

((2)) Soft x-ray images

Images of the herring fry samples that have been stored frozen according to the methods described above were made with soft x-rays. Samples were arranged on the exposure film, and a SOF-TEX C-60 is used to take the image. The film was FUJI X-RAY FILM FR cut in 4 pieces (entered in an envelope case). The images were examined with a stereo dissecting microscope, and counts were made of the number of spinal bones that were fused. A classification of the degree of spine bone abnormalities was based on the number of fused spinal bones as follows: mild cases had 1 fusion; moderate cases had 2-5 fusions; severe had 6-10 fusions; and extremely severe had 10 fusions or more.

((3)) transparent dyed specimens of hard bone

The samples were prepared and cleared according to the techniques of (Kawamura & Hosaya, 1991) Potassium hydroxide was used to clear the dyed muscle tissue of the Alizarin red hard bone dye. Xylene was used for delipidation. Following dehydration, there was a replacement with glycerin. The samples that were used had been preserved in 10% formalin for at least 2 weeks.

2) Progressive countermeasures for preventing spinal abnormalities

Because of a high rate of spinal abnormalities in the fry produced at Akkeshi Station, a study was initiated. In the period from 1986 to 1999, an average of 50.4% of the fry produced had spinal abnormalities. The highest rate of abnormalities was 85.6% and occurred in a 1988 culture of herring produced from Furen Lake. The lowest rate of 12.3% occurred in 1988 for herring produced from Akkeshi (Figure VIII 6-2). Most recently, the lowest spinal abnormality rate occurred in a 1995 culture. It was believed that the reason for low spinal abnormalities was because of the type of nutritional enhancement agent use on the live feed, but this was not replicated in the following years. Even though there were later studies on nutritional enhancement agents, the type of formula feed, and the amount of Artemia fed, until 1999, these countermeasures were not effective. In 2000 it was suggested that one of the direct causes of spinal abnormalities was the developmental progression from physical damage that occurred when frightened fry collided with the sides of the tank with their heads. This injured spinal bones. Therefore, to decrease spinal abnormalities by decreasing physical trauma and to stabilize the culture environment, countermeasures were put into place that included the regulation of illumination.

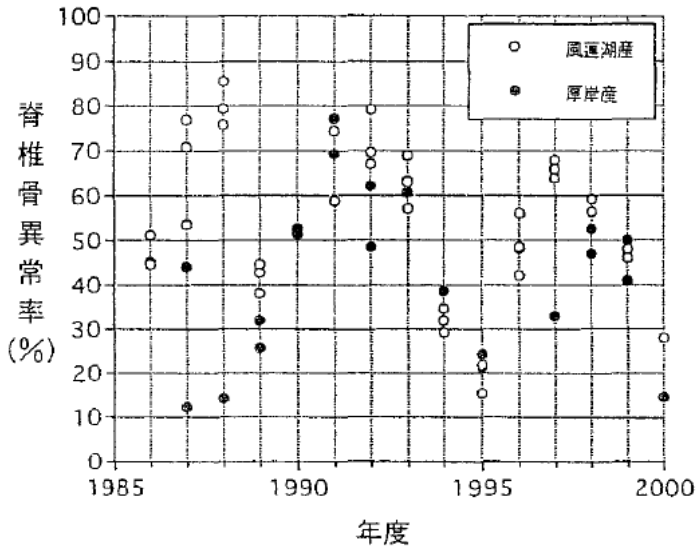


Figure VIII 6-2 Change over time of the spinal abnormality rate of cultured herring fry at Akkeshi Station.
[y axis] Spinal bone abnormality rate (%)
[x axis] Year
[legend]
○ Furen Lake production
● Akkeshi production
[end figure]

3) Spinal abnormalities in wild fish

Kobayashi, (unpublished) studied spinal abnormalities in samples of wild Pacific herring from a number of regions (Table VIII 6-1). The results showed that within Japan coastal herring, there was a tendency for numerous spinal abnormalities in the lake and marsh populations. (Figure VIII 6-3). The highest rate of spinal abnormalities in wild fish was 5.76% and occurred in Yuutounuma herring, and the next greatest was 2.43% at Obuchi marsh. It is common for the spinal abnormality rate to exceed 1% in lake and marsh populations such as from Furen Lake, Notoroko Lake, and Akkeshi. At the same time, In the Mangokuura herring and the Ishikari Bay herring which are oceanic types, the abnormality rates are relatively low at 0.5% and 0.43%, respectively. Also, there is little research on the wild population from Furen Lake and Akkeshi, but in 1998 Kobayashi (unpublished) also found that there was a tendency towards high abnormality rates. (From the above, it can be understood that spinal abnormalities are also found in wild fish, albeit at low rates. The abnormality rate increases as the marsh and lake characteristics become stronger.

Table VIII 6-1 A study on the occurrence rate of spinal abnormalities in Pacific herring (provided by Kobayashi).

Marine area	Collection year	Number measured	Number of fish	Rate of occurrence
Furen Lake				
Furen Lake				
Yuutounuma				
Obuchi marsh				
Mangokuura				
Saroma				
Notoro Lake				
Ishikari Bay				
Rumoi jurisdiction				
Northern Ba (place)*				
Eastern Ba (place)**				
Esashi				
Yuubetsu				
Namuro cape				
Akkeshi offshore				
Akkeshi coast				
Coast of Sakhalin				
Northern part of Okhotsk				
Gizhiga				
Olyutor				
Bering Sea				
Gulf of Alaska				
San Francisco Bay				
Yellow Sea				

*Bottom fishing grounds on offshore from the northern side of Resatsu
**Bottom fishing grounds offshore from
Esashi■1998 portion Akkeshi Station study

海域	採集年	測定尾数（尾）	個体数（尾）	出現率（%）
風蓮湖	1981 - 1987	734	12	1.63
風蓮湖	1998	88	2	2.27
湧洞沼	1979 - 1985	330	19	5.76
尾駮沼	1980 - 1986	206	5	2.43
万石浦	1980 - 1983	153	1	0.65
佐呂間湖	1979 - 1985	464	2	0.43
能取湖	1979 - 1980	222	3	1.35
石狩湾	1980 - 1983	596	3	0.50
留萌管内	1986 - 1987	642	7	1.09
ノース場*	1984 - 1986	657	8	1.22
イース場**	1979 - 1987	1,230	7	0.57
枝幸	1984 - 1987	299	1	0.33
湧別	1987	142	1	0.70
根室海峡	1980 - 1986	1,142	2	0.18
厚岸沖	1980 - 1987	631	9	1.43
厚岸沿岸	1998	189	3	1.59
樺太西岸	1976 - 1988	413	4	0.97
オホーツク海北部	1975 - 1976	181	1	0.55
ギジガ湾	1976	141	3	2.13
オリュートル	1975 - 1976	117	2	1.71
ベーリング海	1979 - 1984	510	2	0.39
アラスカ湾	1979 - 1984	461	7	1.52
サンフランシスコ湾	1979	232	4	1.72
黄海	1984	131	1	0.76

*：利札北側の沖底漁場
**：枝幸沖の沖底漁場
■：1998年度厚岸事業場調査分

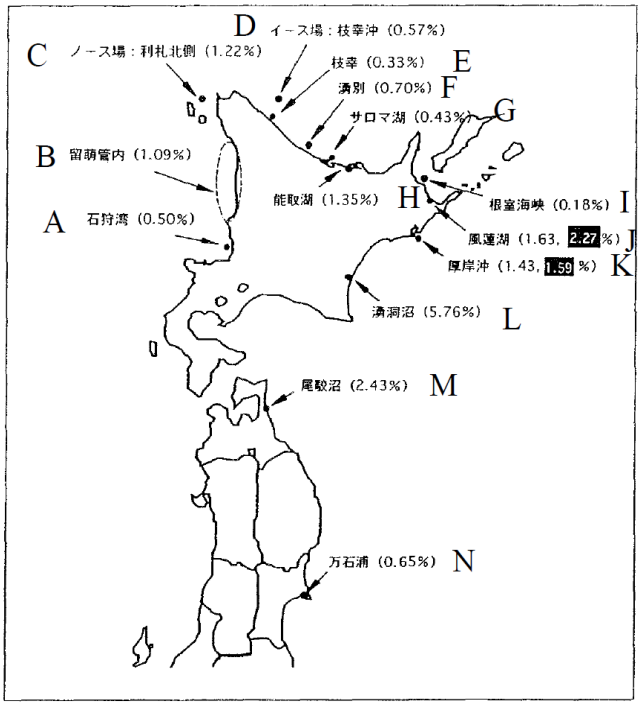


Figure VIII 6-3 Study on the occurrence of spinal abnormalities of Pacific herring in the vicinity of the coasts of Japans (supplied by Kobayashi). Data in reverse printing is from a Japan Aquaculture Association study

[A] Ishikari Bay
[B] Rumoi jurisdiction
[C] Northern Ba, northern side of Resatsu*
[D] Eastern Ba offshore from Esashi
[E] Esashi
[F] Yuubetsu
[G] Saroma Lake
[H] Notoro Lake
[I] Nemuro
[J] Furen Lake
[K] Furen offshore
[L] Yuutounuma
[M] Obuchi marsh
[N] Mangokuura

4) Developmental progression of spinal bones

In order to determine the developmental progression of the vertebral bodies, observations were made of the development of each part of the vertebral bones and vertebral bodies of fry in the size range of 24-59 mm. Measurements were made of the maximum height, maximum width, height of central part, and the gape with the adjacent vertebral body (Figure VIII 6-4). The length of each part was compared with the total length. The developmental progression of the spinal bones that was observed in hard bone stained specimens is shown below (Table VIII 6-2). The development of the vertebral bodies begins at a total length of about 20 mm. At a length of 25 mm they become rectangular, and the rudiments of the neural and haemal spines appear. The gap between neighboring vertebral bodies is characteristically broad (Figure VIII 6-5A). At a total length of 30 mm, the neural and haemal spines elongate (Figure VIII 6-5B, C). At a length of 35 mm, the gape between neighboring vertebral bodies narrows and continues gradually decreasing (Figure VIII 6-6). Rudiments of both joint neural protuberances and both haemal joint protuberances appear (Figure VIII 6-5D). At a length of 40 mm, the central part of the vertebral body becomes clearly hollowed, and has the shape of a drum. At a length of 45 mm, the gape between neighboring vertebral bodies is small. There is clear elongation of both joint neural protuberances and both haemal joint protuberances (Figure VIII 6-5E). The vertebral body is completed with a drum shape at a total length of 50 mm. There is a marked increase in the width of the vertebral bodies. There is reinforcement of the vertebral body in the longitudinal direction by attached protuberances (Figure VIII 6-5F). When the total length exceeds 55 mm, there is stabilization of the relative length of each of the parts of the vertebral bodies (Figure VIII 6-6). At 60 mm the vertebral bones have nearly have the same form as the adult (Figure VIII 6-5G).

Table VIII 6-2 The development and occurrence of spinal abnormalities in cultured herring.

Age in days	Average total length (mm)	Shape of vertebral body	Vertebral body development	Appearance of accessory structures next to the vertebral bodies	Discriminating abnormality
40	25	Rectangular	There is a wide gape between adjacent vertebral bodies	Appearance of neural and haemal spine rudiments	Discrimination not possible
45	30		A depression starts to form in the central part	Elongation of neural and haemal spines	Discrimination not possible
50	35		The gape between spinal bones narrows.	Appearance of rudiments of both joint neural protuberances and both haemal joint protuberances.	Confirmation of abnormalities in the shape of the spinal bones or of slippages
55	40	Changing from rectangular shape to drum shaped	The central area becomes clearly hollowed		Period when hypertrophy, adhesions, and fusions can be confirmed
60	45		The gape between neighboring vertebral bodies is small	Elongation of both joint neural protuberances and both haemal joint protuberances	Increased hypertrophy and fusions are confirmed
65	50	Drum shaped	There is a marked increase in the width of the vertebral bones	Reinforcement of the vertebral body in the longitudinal direction by attached protuberances	Increase in fusions
70	55		Shape of vertebral body = stabilization of the relative lengths of each part		Obvious cases of fusions
75	60	Nearly the same as the adult		Nearly completed	Confirmation of symptoms wherein the body is shortened

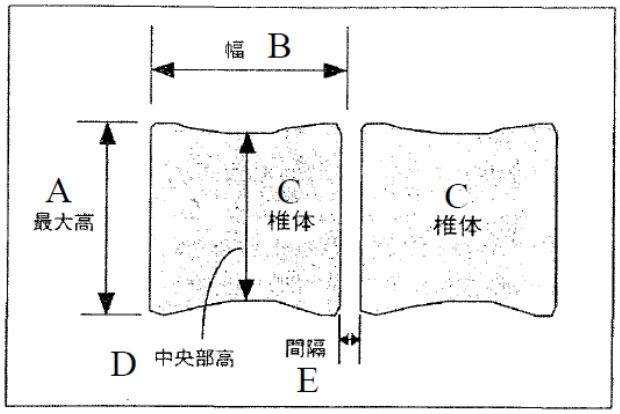


Figure VIII 6-4 Positions of measurements of the vertebra of herring fry.
[A] Maximum height
[B] Maximum width
[C] Vertebral body
[D] Height of central part
[E] Gape

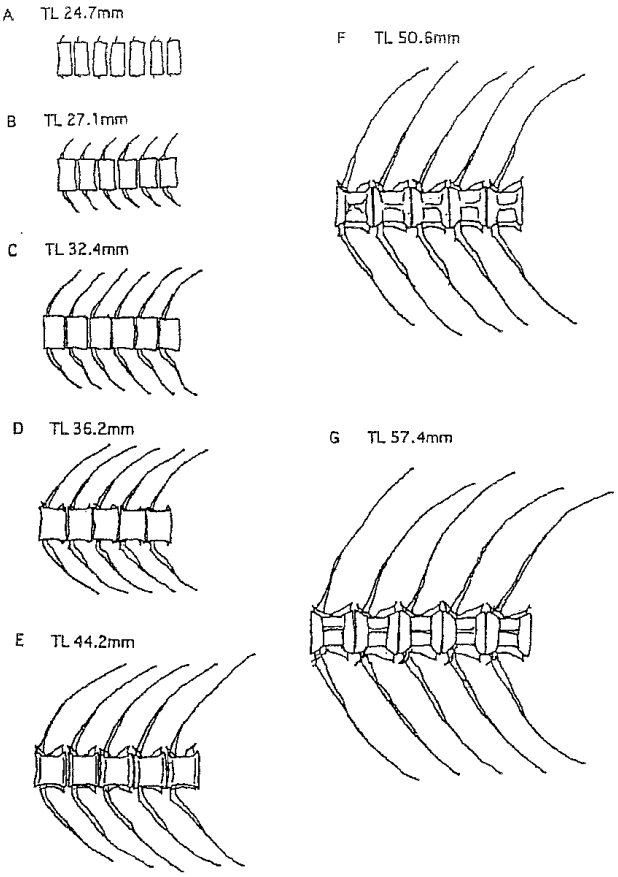


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Figure VIII 6-5 Developmental progression of the spinal bones in cultured herring.

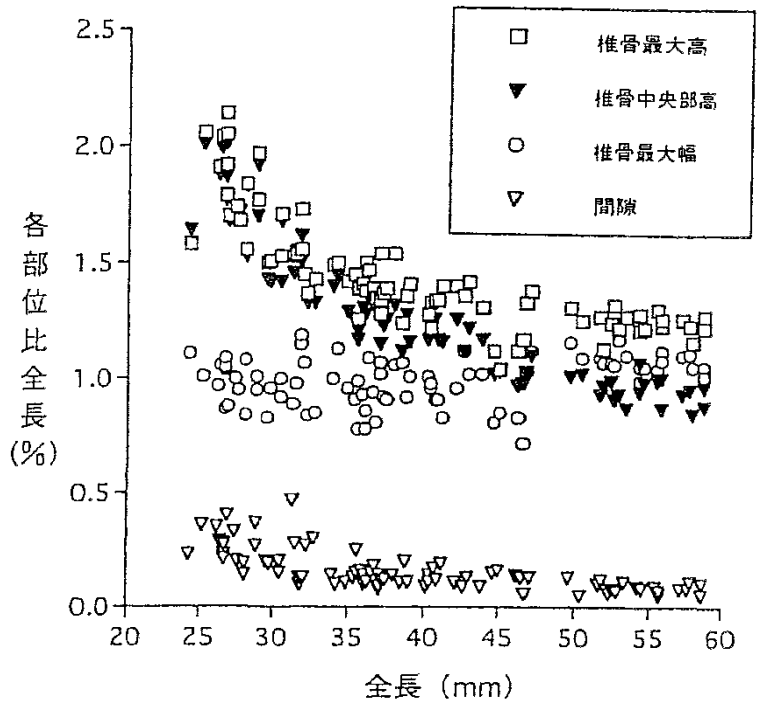


Figure VIII 6-6 The change in body length ratios for each part of the spine with growth in cultured herring fry.
[y axis] Ratio of each body part to total length (%)
[x axis] Total length (mm)
[legend]
□ Maximal height of vertebra
▼ Height of central part of vertebra
○ Maximal width of vertebra
∇ Gape
[end figure]

According to the above, the development of the vertebral bones and ossification of the vertebral body begins at a body length of 20 mm. There are then marked changes in the morphology of the vertebral that occurs especially before a body length of 35 mm. Thereafter, there is rapid progress in the formation of supporting reinforcements of the vertebral bodies until a body length of 50 mm. At that size the shape is nearly the same as for the adult fish.

5) Causes of spinal abnormalities and countermeasures

((1)) Hypotheses and verification of the causes of these manifestations

From the results of the research to date and observations on the herring that were produced in 2000, it was postulated that the reason for the development of spinal abnormalities was due to the physical injuries that were caused to the spinal bones when the herring collided with the sides of the tanks (Figure VIII 6-7). In order to test countermeasures based on this hypothesis, the illumination during culture was decreased to reduce the physical injuries that occur because of stress reactions. During the same period, the culture operations were performed such that they reduced startle reactions.

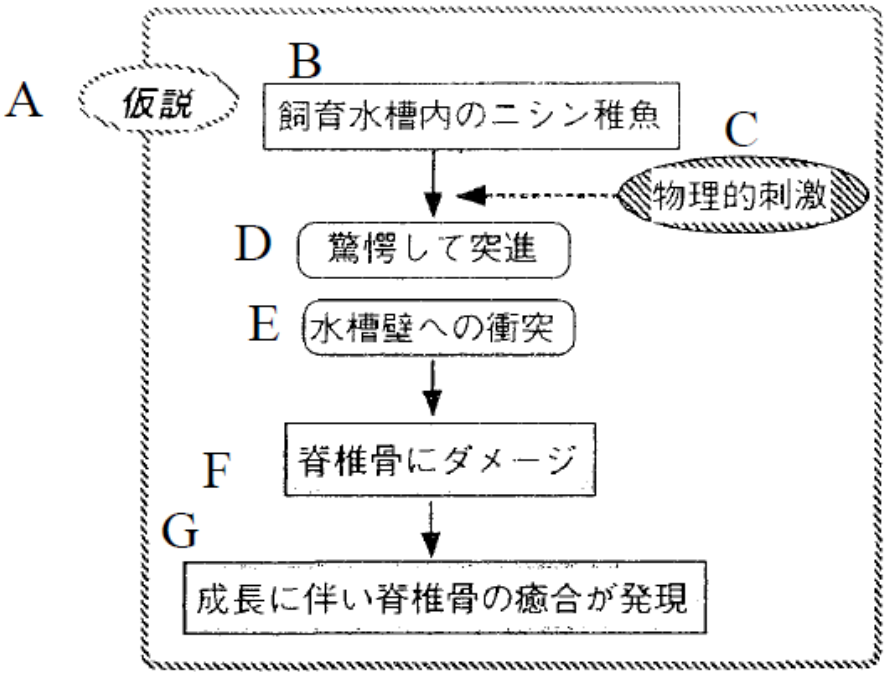
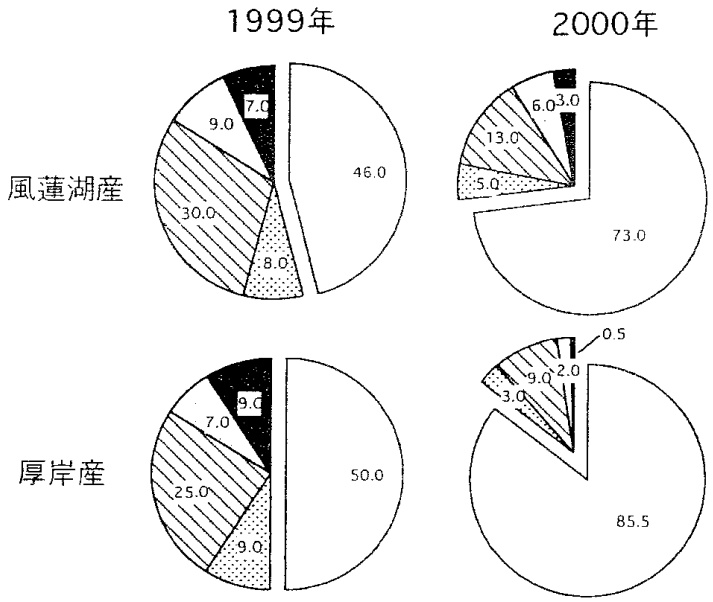


Figure VIII 6-7 Hypotheses on the cause of herring spinal abnormalities
[A] Hypothesis
[B] Herring fry in culture tank
[C] Physical injury
[D] Fright reactions
[E] Collision with walls of tank
[F] Damage to spine
[G] Spinal bones fuse with growth of the fish
[end figure]

The reduction of external stimuli during bottom cleaning operations, etc. must be rigorously implemented. Also, shading cloths are positioned to regulate the amount of illumination in the culture tank, and more fresh water Chlorella is added to the rearing water. In the culture facility at Akkeshi Station, black cloths are hung over the top of the tanks. Even at the same location, there are large differences in illumination. Because of the large variability in illumination at a location, instead of covering the entire surface, the upper shade capacity was made so that it was variable depending on the illumination and location. Also, the period of time when Chlorella was added to the rearing water was lengthened from 30 days to 50 days. The result of these countermeasures was that rearing illuminations of 99 - 30,400 lux were decreased to 2 - 450 lux (Table VIII 6-3). Also, the change in day time illumination was reduced by 260 lux. The amount of illumination during culture at each of the facilities was as follows: Miyako Station, 90 - 1,700 lux; Hokkaido Aquaculture Promotion Corporation Haboro Station, 1 - 903 1ux; and Center for Culturing Herring Fry at Bekkai, 55-850 lux (Table VIII 6-3).



図Ⅷ 6-8　厚岸事業場における1999年と2000年のニシン生産種苗の脊椎骨癒合の比較

□ 正常　▨ 軽度(1)　▧ 中度(2～5)

▩ 重度(6～10)　■ 極めて重度(10<)

Figure VIII 6-8 Comparison between 1999 and 2000 of spinal adhesions in cultured herring fry at Akkeshi Station.

[top left pie chart]

[above chart] Year 1999

[left of pie chart] Furen Lake production

[top right pie chart, above chart] Year 2000

[bottom left pie chart]

[left of pie chart] Akkeshi

□ Normal

[dark stippling] Mild

[cross hatch] Moderate (2-5)

[fine, light stippling] Severe (6-10)

■ Extremely severe (10<)

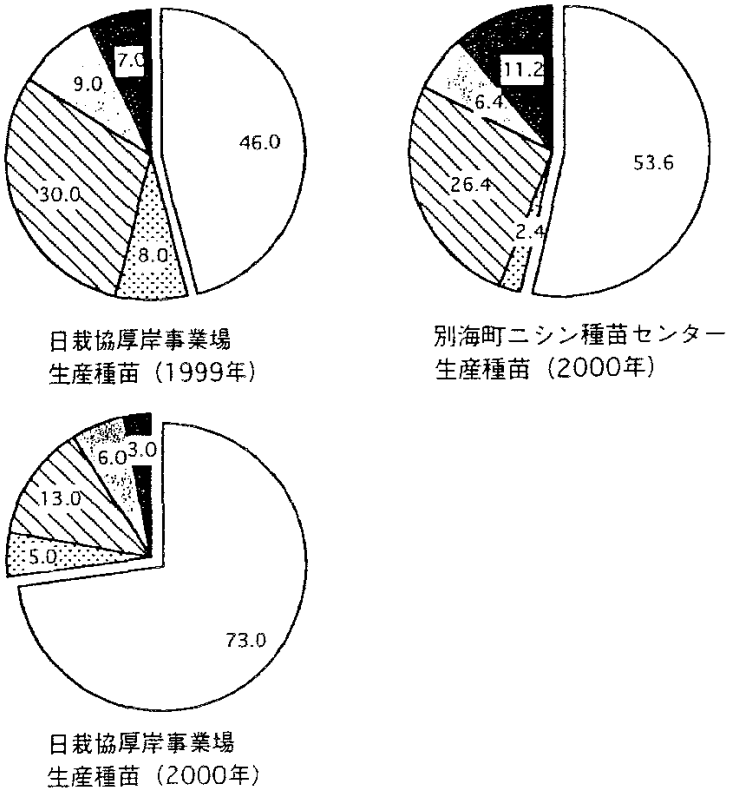
Table VIII 6-3 Method of controlling illumination during culture and the amount of illumination at herring fry culture facilities.

Facility	Illumination on surface	Room lighting	Shade net on upper surface	Shade net on side	Illumination (lux)
Japan Aquaculture Association, Akkeshi Station (previous)	Natural illumination	Present	Present, partial	None	99 – 30,400
Japan Aquaculture Association, Akkeshi Station (current)	Natural illumination	Present	Present, complete, strong	None	2 – 450
Japan Aquaculture Association, Miyako Station	Natural illumination	Present	Present	Present	90 - 1,700
Hokkaido Aquaculture Promotion Corporation, Haboro Station	Artificial illumination	None	None	None	1 – 963
Center for Culturing Herring Fry at Bekkai	Artificial illumination	None	None	None	55 – 850

In 2000 the countermeasures mentioned above were put into place at Akkeshi Station. Even though the transparent cover was put in place on day 30, the fry inside the cover were not skittish. Compared to 1999 there were fewer startle reactions and impacts.

The results of a soft x-ray study on spinal abnormalities for 2000 showed that 73.0% of the Furen Lake produced herring were normal and 85.5% of the Akkeshi produced herring were normal. In 1999 the respective normal rates were respectively, 46.0% and 50.0%, so there had been a 35% improvement (Figure VIII 6-8). Fusions between adjacent spinal bones were determined by soft x-rays. For comparative purposes the fusions were separated into 5 categories. The moderate level (2-5 fused spinal bones) was the most common (Figure VIII 6-8). This was the same trend as observed in 1999.

When fry from Akkeshi Station were compared to those produced at the Center for Culturing Herring Fry at Bekkai from eggs that were collected on the same day, there were about 20% more normal herring. The rate of normal fry at Bekkai was only 53.6% compared to 73.0% at Akkeshi Station (Figure VIII 6-9).



図Ⅷ 6-9 風蓮湖産ニシン生産種苗における脊椎骨癒合の比較

□ 正常 ▨ 軽度（1） ▧ 中度（2～5）

▩ 重度（6～10） ■ 極めて重度（10<）

Figure VIII 6-9 Comparison of spinal adhesions in Furen Lake cultured herring fry. □ Normal, [dark stippling] Mild (1), [cross hatch] Moderate (2-5), [fine, light stippling] Severe (6-10), ■ Extremely severe (10<), [top left pie chart]Japan Aquaculture Association, Akkeshi Station (1999), [top right pie chart]Center for Culturing Herring Fry at Bekkai (2000), [bottom pie chart]Japan Aquaculture Association, Akkeshi Station (2000) , [end figure]

((2)) Category of spinal abnormality and period of occurrence

In order to make a detailed investigation of the condition of spinal abnormalities, hard bone was prepared by staining, and the abnormalities of the vertebral bones were observed microscopically. The vertebral abnormalities were divided into the following six categories: 1) slipped, 2) deformed, 3) hypertrophy, 4) partial adhesion, 5) complete adhesion, and 6) fusion (Figure VIII 6-10). Observations were made of two fry cultures that had high rates of spinal abnormalities (1999 Furen Lake production at Akkeshi Station and 2000 Furen Lake production at the Center for Culturing Herring Fry at Bekkai). Observations were made of spinal abnormalities when the total length of the fry was about 33 mm. The principal abnormalities were slipped and deformed (Figure VIII 6-11). When the total length exceeded 40 mm, there are individuals with severe vertebral body abnormalities. The ratio was highest for adhesions of adjacent vertebral bodies and fusions (Figure VIII 6-11, Photo VIII 6-1). At body lengths of 55 mm or greater, these ratios are also high. Individuals were observed with prominent fusions (Table VIII 6-2).

((3)) Presumed developmental progression of spinal abnormalities

From the above-mentioned results, at body lengths of 20-35 mm there were large basic changes in the vertebral bodies. This was followed by marked development of the reinforcement of protruding supports of the vertebral bodies. In observations on stained bone specimens, abnormalities first started to be observed at a body length of about 35 mm. It is clear that there is a progression of the degree of the abnormalities with growth. It is surmised that after the injury causing slipped vertebral bones, there was hypertrophy and adhesions of the adjacent surfaces finally resulting in fusion. It is believed that these abnormalities easily occurred during the ossification process. It is known that for madai (red sea bream, *Pagrus major*) and ayu (sweetfish, *Plecoglossus altivelis*) reasons for the occurrence of abnormalities include the culture environment and nutritional deficiencies. In 2000, behavioral observations were made during the culture period. It is believed that slipped and deformed vertebral bodies occurred because of the impact of collisions. As mentioned above, Fukuda (1986) indicated that the period when this occurs is at body lengths of 30 cm or more. Swimming speed increased rapidly with the development of body muscles. This corresponds to the period that there is an increase in swimming rushes and an increase in the strength of impacts. It is believed that this promotes injuries to spinal bones.

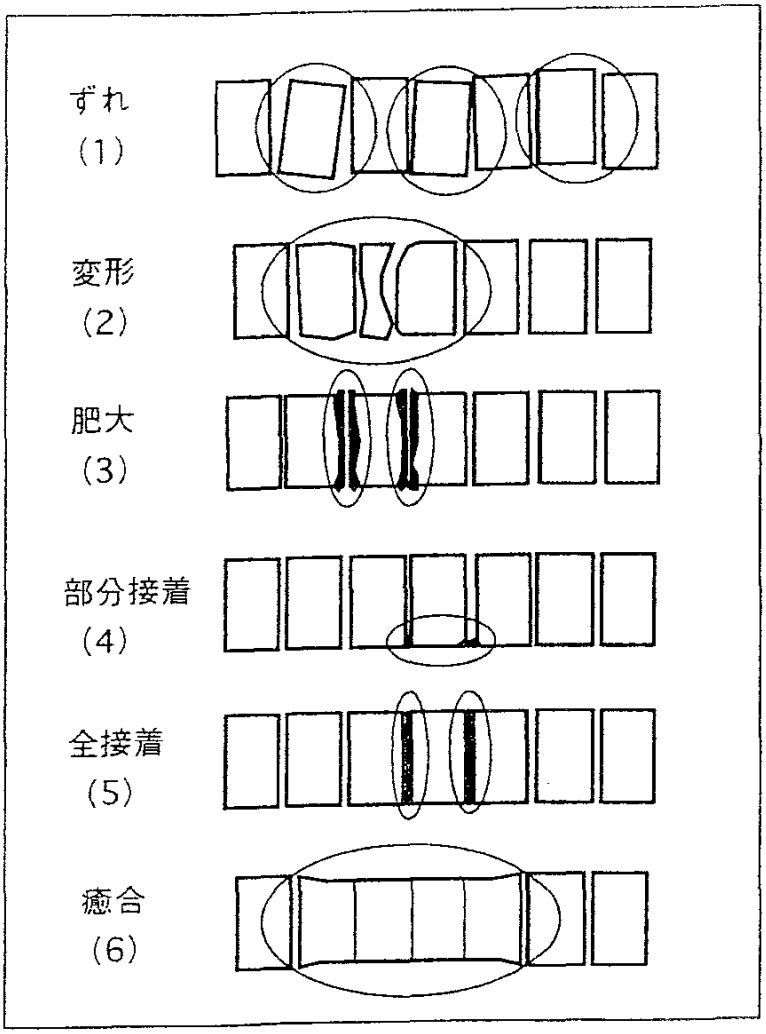


Figure VIII 6-10 Classification of spinal abnormalities
[Top to bottom] Slipped (1), Deformed (2), Hypertrophy (3), Partial adhesion (4) Complete adhesion (5), Fusion (6), [end figure]

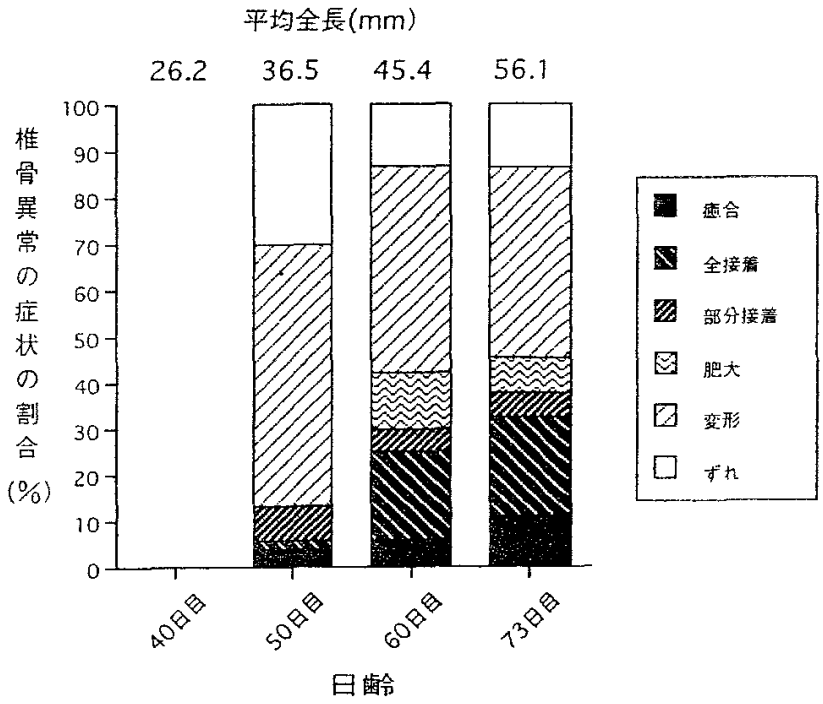


Figure VIII 6-11 Ratio of cultured herring fry with spinal abnormalities at different ages (in days) (example of 1999 Akkeshi Station fry production).

[Phrase on top of figure] Average length (mm), [y axis] Percentage of each type of spinal abnormality (%), [x axis] Age in days, [left to right] 40th day, 50th day, 60th day, 73rd day, [legend, top to bottom] Fusion, Complete adhesion, Partial adhesion, Hypertrophy, Deformed, Slipped [end figure]

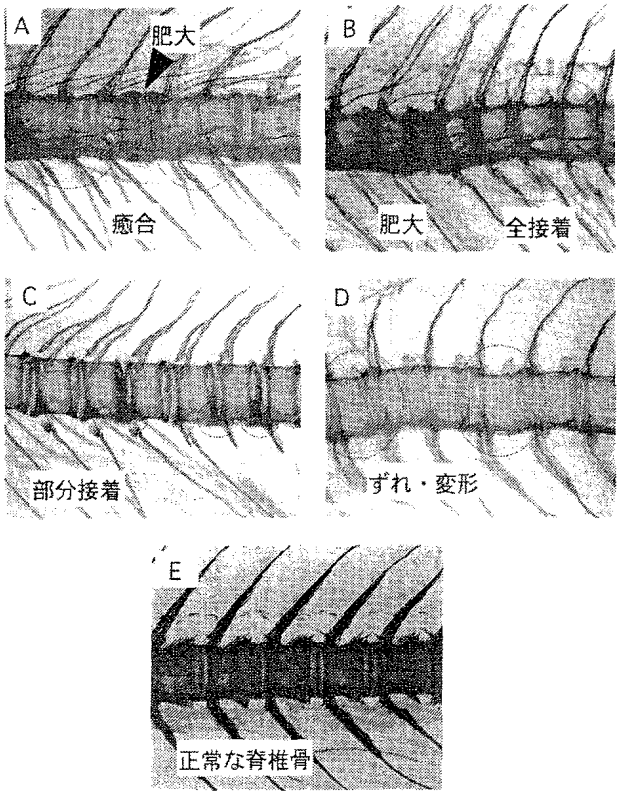


Photo VIII 6-1 Classification of spinal abnormalities in cultured herring fry. [Figure A] [top] Hypertrophy, [bottom] Fusion, [Figure B] [left] Hypertrophy [right] Complete adhesion, [Figure C] Partial adhesion, [Figure D] Slipped and deformed, [Figure E] Normal spinal bones [end figure]

7. Otolith labeling treatment and detection method

There was a herring release study performed on the Doutou Marine area from 1983 to 1989 using an exterior tagging method (Yamamoto & Ohana, 2000). At the time that the fish were tagged, the fish had to be about 10 cm in length. There were many mortalities following tagging, there was a high fall-out rate (90.3% for ribbon tags). Also, because of the amount of time it took to attach the tags, etc. this method is currently not being used. Instead, releases are made of fry that had been tagged internally using a fluorescent otolith method. Two types of tagging compounds have been used with herring, the chemical compounds alizarin complexone (fluorescent metal indicator, hereafter referred to as ALC) and tetracycline hydrochloride (an antibiotic, hereafter called TC). The two types of tagging methods that are used are an immersion method and an oral administration method. Following is a discussion of tests of the two types of tagging compounds in herring.

(1) Submersion Method

1) ALC

According to Yamamoto (1992), the concentration of the ALC tagging treatment, in Doutou sea area herring was studied in herring on day 20 and day 40 after hatching. There was no difference in staining at ALC concentrations between 20 ppm and 40 ppm. No tag could be observed at 10 ppm and below, and massive mortalities occurred at 80 ppm. The results of these experiments indicate that 20 ppm is an appropriate concentration for the tagging solution. Also, a 24-hour labeling treatment was adequate. An important consideration was to add the ALC to the culture water when it is dark. Otherwise, it caused the larval herring to panic, bumping into the walls of the tank which resulted in mortalities. In order to prevent this, the ALC was siphoned into the rearing water slowly. Containers were placed above the culture tank at each of the four corners, and air tubes are used for siphoning. During this period, the culture water was rotated using aeration, so that the ALC solution was rotated from the outside of the tank to the inside. Also, in order to prevent an oxygen deficiency, aeration was provided with an additional 2 dispersion devices using pure oxygen. During ALC submersion, it is normal that the herring are only fed with live feed.

2) TC

Ashimura (2000) performed tests on larval herring at day 47 that were 17-18 mm in total length (water temperature 9ºC). The concentration of the TC was 200 ppm and the time period was 24 hours. Distinct fluorescence could be observed.

(2) Oral administration method

1) ALC

Ohana (1994) used herring fingerlings that were 80 mm in total length. They were fed formula feed with ALC added at concentrations from 0.5-5%. Feeding continued for a period of 10 days, but AL tagging of the otoliths was not observed. It was concluded that it was difficult to apply ALC tags internally by the oral route.

2) TC

Yamamoto (1999) performed tagging experiments using TC supplied through the oral route. Herring fry with an average total length of 60 mm were used, and feeding continued over a 5-day period. The method used was to absorb TC into the formula feed. TC was dissolved in distilled water until the water was a transparent orange color (the objective was 10 g of TC per 25 ml of distilled water). The solution was sprayed onto commercial formula feed where it spread over and was absorbed into the feed. (The amount added was 1% of the formula feed). Before use, the feed was air dried under refrigeration. The food was hand feed four times a day to satiation. When the tagged food made up 5% of the formula, there was fluorescence, but it lacked clarity. However, in the 10% group, fluorescence was clearly observed. It could also be recognized in adult fish that had been continuously cultured for a 2 year period.

(3) Identification of otolith markings

1) Removal and treatment of otoliths

The lapillus otolith, which is the largest, was collected. The lapillus otolith was present encapsulated in the inner ear. It is positioned to the posterior and sides of the cerebellum on the inside of the posterior part of the scull. There are two methods for removing otoliths. A scalpel is used to enter through the upper surface, or it is detached from below through the thin bone with forceps.

((1)) Removal from above (Photo VIII 7-1: provided by Yoshimura from Wakkanai Fisheries Laboratories)

The cranial bones of herring are relatively soft, and can be cut with a scalpel with relative ease. A lateral cut is made with the scalpel on the central, upper part of the head. While cutting downward towards the nose, the back part of the scull is cut open exposing the otolith. The desired position of the incision on the head is just posterior to the posterior of edge of the eye. The cut is slightly inclined towards the posterior. The exposed otolith is removed with forceps while being very careful not to break it.

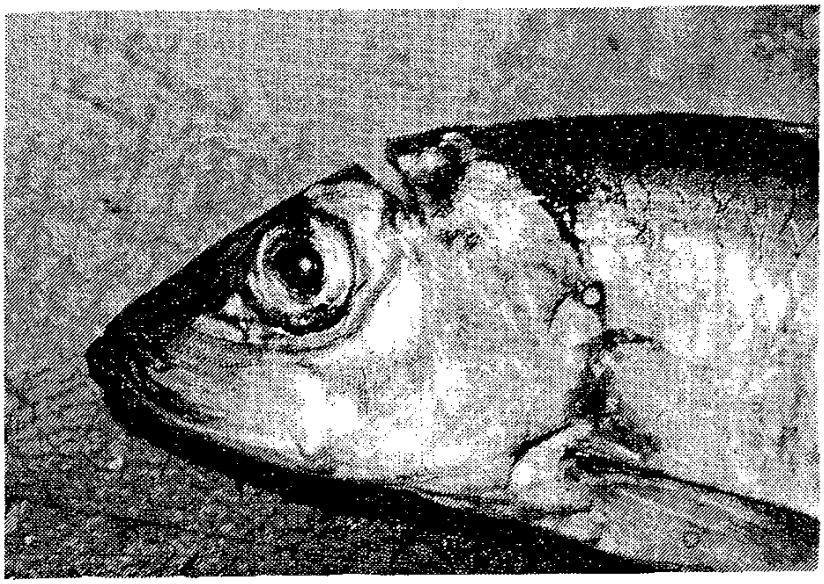


Photo VIII 7-1a Method 1 for removing otolith. An incision is made with a scalpel (Provided by Yoshimura of Hokkaido Wakkanai Fisheries Laboratories).

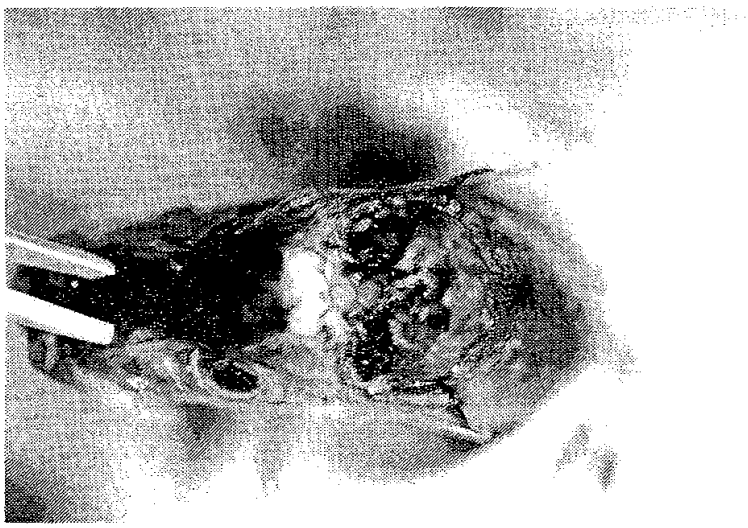


Photo VIII 7-1b Method 1 for removing otoliths. Otolith is removed with a forceps.

((2)) Removal from below (Photo VIII 7-2)[Page 59]

As the otolith is positioned ventrally in the posterior position of the inner ear, the neck of the fish was compressed by hand, forcing and stretching the throat downwards exposing the bottom of the cranial bones. While in a slightly bent position, a forceps was used to remove the bone above and anterior to the base of the gills. This exposed the otolith, and it was removed very carefully so that it was not broken.

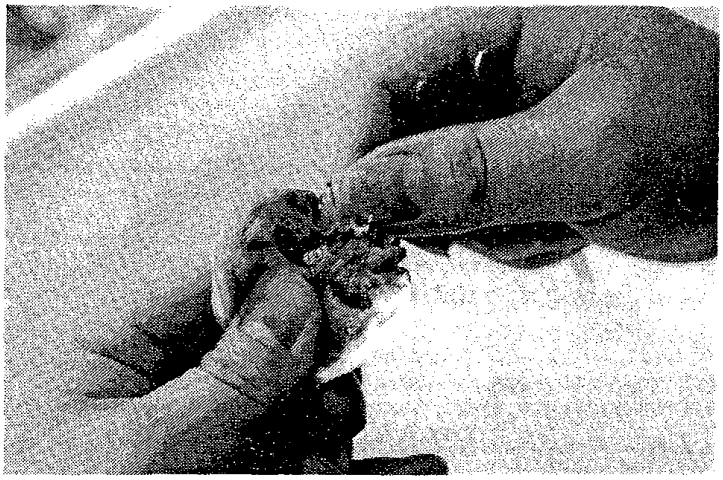


Photo VIII 7-2a Method 2 for removing otoliths. The otolith is detached through the bottom of the cranial bones.

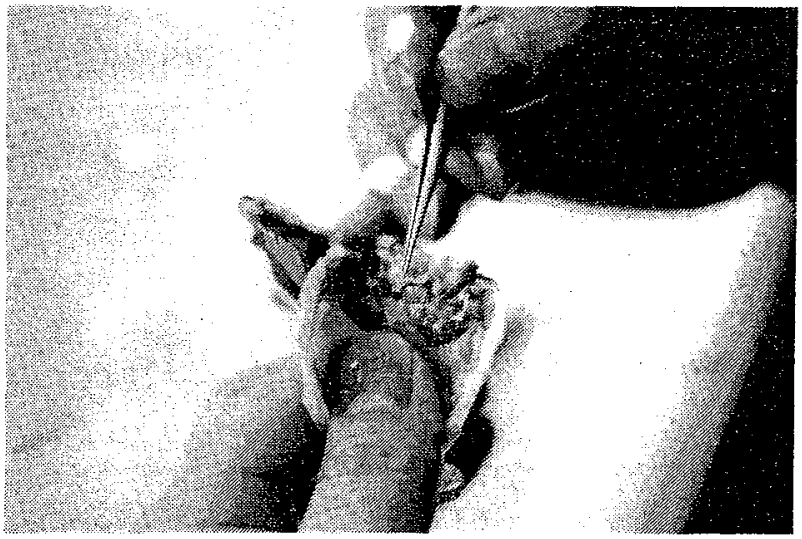


Photo VIII 7-2b Method 2 for removing otoliths. The otolith is removed with forceps.

2) Identification of otolith tags

A fluorescence microscope is used for identifying otolith tags. The otoliths are exposed to luminescence with a red, G-excitation filter for ALC tags and a yellow B-excitation filter for TC. An important issue to keep in mind for TC tags is that once the tags are removed, they are affected by ultraviolet light, causing the TC activity to decrease rapidly. In 10 days the fluorescence becomes extremely weak. Because of this, the identification operation must occur within several days after the otolith is removed. Also, the otoliths must be stored in a dark place. Fluorescence also weakens with desiccation. For this reason it is best to store the otoliths in distilled water.

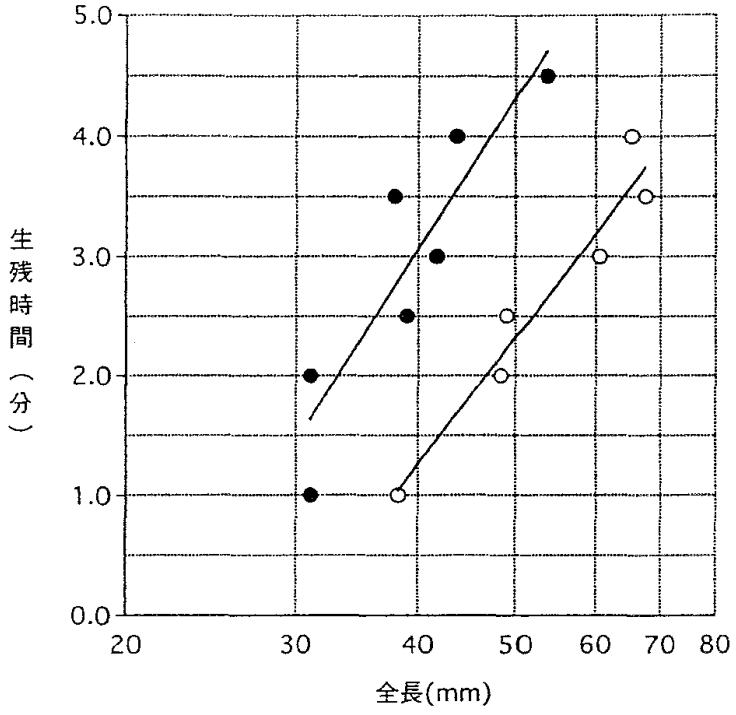
IX. LANDING AND TRANSPORTING THE FRY

In order to estimate the number of fry that have been produced, they are landed with small mesh nets and moved into tanks that can be easily transported offshore. This chapter discusses how the fry are landed, the counting methods and the transportation methods.

1. Landing

(1) Size when the fry are landed

Herring become tolerant to handling when the average body length exceeds 40 mm, which corresponds to day 60 or more after hatching. The ideal body length for landing is believed to be 50 mm. The scales are fully developed at the stage when the total body length is 50 mm (Uchida, et al., 1958). The formation of the bones is also complete, and the development of the vertebral bodies is substantially completed. With the complete formation of the skeletal muscles, the herring become tolerant of handling. They rapidly become tolerant of air exposure at total body lengths of from 40 mm to 50 mm (Figure X [sic. IX] 1-1). Though a body length of 50 mm is ideal, in production tests from 1997 to 2000, average body lengths when the herring were landed was in the range of 37.6-51.7 mm, with the average being 40.8 mm (Table IX 1-1).



図Ⅸ 1-1　ニシン人工種苗の干出試験設定の基準線の推定
● 生残下限　y＝13.0 LOG(x)－17.7　r^2＝0.814
○ 死亡上限　y＝10.9 LOG(x)－16.2　r^2＝0.934

Figure IX 1-1 Estimation of standard criteria for drying exposure for cultured herring fry.
● Lower limits for survival y=13.0 LOG (x) -17.7 r^2=0.814
○ Upper limits for mortalities y= 10.9 LOG (x) -16.2 r^2=0.934
[y axis] Survival period (minutes)
[x axis] Total length (mm)

Table IX 1-1 Mortality rate after cultured herring fry have been landed.

Year	Trial number	Age (days)	Length when landed (mm)	Number of fry landed (10,000 fry)	Culture density (fry/m^3)	Survival rate (%)	Mortality rate after handling (%)
1997	Furen 1						
	Furen 2						
	Furen 3						
	Akkeshi						
1998	Furen 1						
	Furen 2						
	Akkeshi 1						
	Akkeshi 2						
1999	Furen 1						
	Furen 2						
	Akkeshi 1						
	Akkeshi 2						
2000	Furen						
	Akkeshi						
Average							

年度	回次	日令 (日)	取り揚げ全長 (mm)	取り揚げ尾数 (万尾)	生産密度 (尾/㎥)	生残率 (%)	取り揚げ後の死亡率 (%)
1997	風蓮1	64	42.6	14.8	2,960	30.7	1.52
	風蓮2	65	42.9	17.5	3,500	36.6	2.11
	風蓮3	65	43.5	15.9	3,180	36.0	2.67
	厚岸	66	40.6	19.4	3,890	31.6	3.16
1998	風蓮1	63	37.8	19.0	3,810	31.5	4.33
	風蓮2	64	39.7	28.7	5,740	46.6	2.45
	厚岸1	59	39.5	25.4	5,080	46.0	0.53
	厚岸2	60	40.3	38.8	7,760	57.4	1.58
1999	風蓮1	66	40.4	29.5	5,900	39.6	0.78
	風蓮2	62	40.5	30.9	6,180	38.9	1.80
	厚岸1	63	41.2	18.2	3,630	41.0	0.43
	厚岸2	64	41.0	31.3	6,260	45.0	2.21
2000	風蓮	70	45.4	23.4	4,686	45.4	0.42
	厚岸	68	51.7	19.2	3,835	50.9	1.27
平均		64.2	41.9	23.7	4,744	41.2	1.80

(2) Method for landing the fry

1) Landing method using a round haul net (Photo IX 1-1, 1-2, 1-3)

For landing the fry, the bottom of the tank is cleaned and the water level is lowered to about 80 cm. After performing water exchanges for a fixed period at the lower water level, suitably sized fry are collected with a round haul net. The collected fry are scooped up with a hand dip net and are transferred to buckets filled with sea water. They are stocked into nearby tanks that are outfitted with small-mesh netting.

The number of fry landed is determined as part of these operations using a weight method. With using this method, about 5 liters of water from a constant temperature sea water tank is measured into a bucket. The fry are collected with the help of the dip net and are weighed in the buckets. The number of fish is calculated based on the difference between the weight of the water-filled bucket with and without a scoop of fish. An important item of concern when landing the fish is the amount of fry that are accumulated in a single pass of the round haul net (this should be about 15-20 kg).

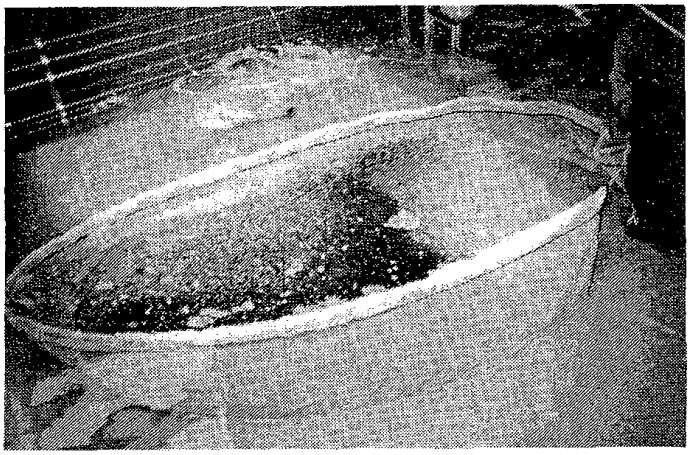


Photo IX 1-1 Landing: Fry are collected in a round haul net.

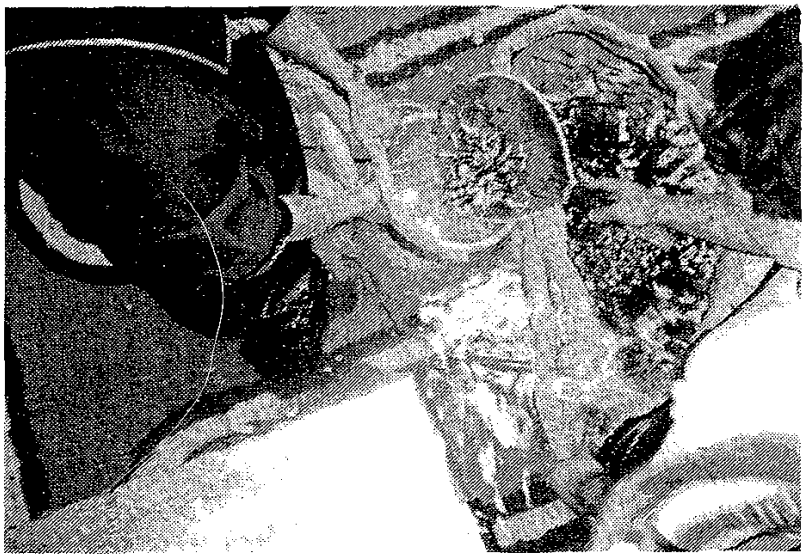


Photo IX 1-2 Landing: Fry are scooped with a dip net and stocked in buckets.

Photo IX 1-3 Landing: A weighing method is used for counting.

Each scoop of the dip net collects about 300 g, and this is repeated three times for each bucket. With this type of operation 300,000 fish can be landed with several dozen scoops. Also a device that disperses oxygen is inserted into position in the bottom of the round haul net. It is important to prevent oxygen deprivation in the round haul net. Another item of concern is to moderate the amount of food on the afternoon of the day before. On the day that the fry are landed until the completion of the operation, there is no feeding.

In the Reference Data, this is the standard provisions for landing the fry by this method.

2) Landing the fry using the fish pump method (Photos XI 1-4, 1-5 [sic IX 1-4a, 1-4b])

The Japan Aquaculture Cooperative Hakata Island Station and the Marine Forum 21 collaboratively developed the use of a fish pump with a 50-mm diameter hose for transferring the herring from the production tank to a small mesh net. With this method the mouth of the fish pump inlet is positioned upwards in the tank about 30 cm below the water surface during the actual pumping operation. The opening where the fish are disgorged is positioned in such a way that the fish do not impact the small mesh net. The hose is positioned about 20 cm below the water surface and is slanted upward. Water is circulated in the landing tank. An automatic feeding device is positioned about 50 cm upstream from the water inlet. As it is provides food the fry gather in the vicinity of the inlet. The fish that have gathered for feeding are gradually drawn into the inlet and are transported. The advantage of this method is that the fry landing operation requires almost no labor. Also, it is not a problem if the destination of the transport is located some distance away.

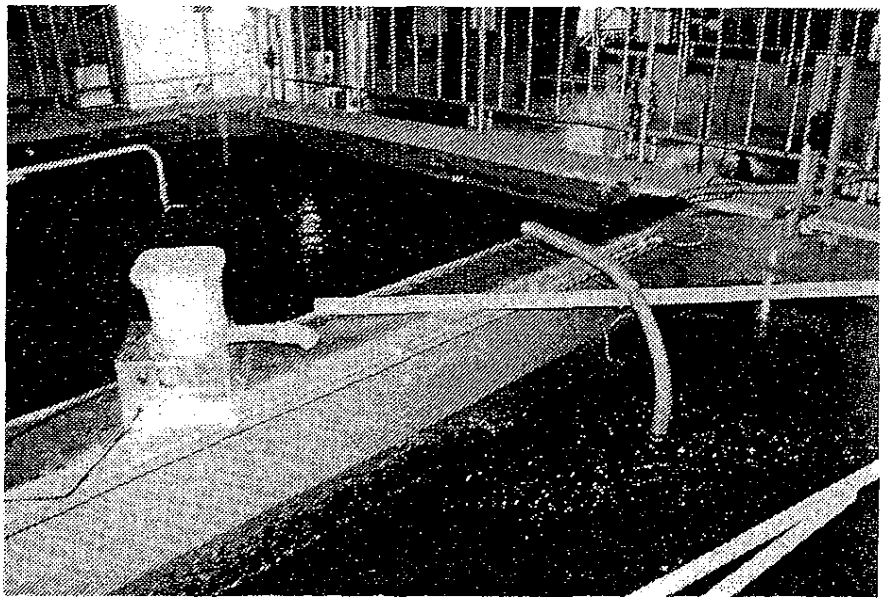


Photo IX 1-4a Transfer with fish pump: inlet: fish are accumulated with automatic feeding equipment (provided by Kawashita, Hokkaido Aquaculture Promotion Corporation).

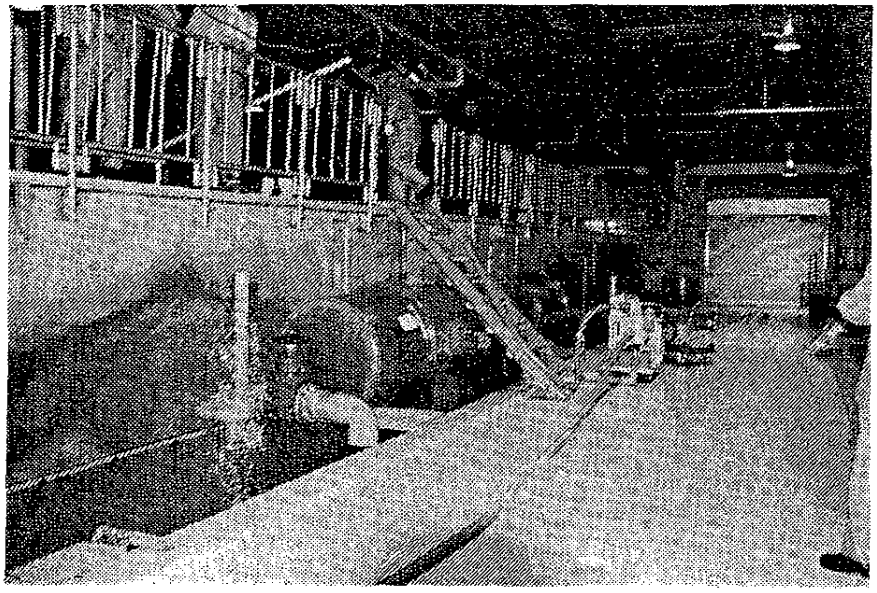


Photo IX 1-4b Transfer with fish pump: In this situation the hose has a diameter of 50 mm.

(3) Time schedule for landing fry

1) Preparations that are made on the previous day

・Secure the personnel necessary for landing (at least 7 people)

・Prepare an oxygen cylinder, (7 m^3).

・Prepare materials for landing fry.

・Starting in the afternoon, discontinue feeding (from the day preceding landing until the completion of landing).

・Set up the small mesh nets and seawater in the transfer tanks (temperature of the water in the transfer tanks is regulated so it is the same temperature, and the water is adequately aerated).

・The tank bottom is thoroughly cleaned (heating pipes, corners, etc.)

2) Time schedule on the day of the harvest (harvest of one tank in the morning)

7:00 AM Bottom cleaning of harvest tank.

7:45 AM Removal of debris and containers for debris.

7:50 AM Discontinue water inflow, start lowering the water level (with a waste water signal).

8:50 Water lowering is stopped when water level is 80 cm. Begin adding water. After lowering water for 1 hour, water replacement is begun. Inspect the small air network at the transfer tank.

9:50 Water exchange is completed. Stop incoming water. Remove waste water signal.

9:55 Airflow of oxygen through two oxygen dispersing devices.

10:00 Begin landing using round haul net. Scoop with dip nets. Stock buckets. Measure weights.

11:40 Complete fry landing. Fish in transfer tank are medicated (10 ppm sodium nifrustyrenate).

11:50 Put away equipment.

(4) Natural decreases that accompany landing

At Akkeshi Station fry production has occurred 14 times in the period from 1997 to 2000. The natural decline that has accompanied landing has average 2.0%; the largest was 4.6% and the smallest was 0.4% (Table IX 1-1). The natural decline that accompanies landing is believed to be principally due to the stress of handling during landing. There is a tendency for the dead fish to be largely those of smaller sizes. Also, there are problems if there was an inadequate amount of water, or if conditions became unsatisfactory because too many fry were landed. There was a case reported from Miyako Station where there was inadequate aeration of the seawater in the transfer tanks. As a result, there was an increase in gas saturation causing losses due to gas bubble disease.

2. Culture after landing

After being moved offshore, the fry do not recover from the handling damage that occurs in the small mesh net during landing and counting until they grow to a total length of 50 mm. If the fry are large during the harvest, this requires several days of culture. If the fry are small during harvest, they may require about 10 days of culture in the small mesh net. When this is the case, and the netting gets dirty, this can cause an inadequate exchange of water leading to oxygen deprivation and suffocation. For this reason, there must be a concern with taking measurements of dissolved oxygen to prevent suffocation. Water may be added in the netting, etc.

3. Offshore transport of transfer tanks

To increase the resistance to handling stress during transport from the fry facility to the offshore nursery facility, it is best to perform this activity when the fry have a body length of 50 mm. This operation consists of the following steps: 1) Landing the fry; 2) Transferring the fry to buckets; 3) Stocking the transport tank; 4) Changing the water in the transport tank; 5) Transport to the offshore nursery culture facility by land and sea; and 6) Stocking the small mesh netting for nursery culture. As the fry are handled twice during these operations, there is a natural decrease due to injury. It is desirable if there is good offshore weather. However, the operation can be performed as long as the rainfall is not so great that it drops the salinity too low. A summary of the standard materials used during transport are shown in the Reference Data.

(1) Transport from the rearing small-mesh net to the transport tank

The sinkers of the small-mesh net of the culture tank are removed, and the fish are gathered up along an edge. To prevent oxygen deprivation, there are two devices for dispersing oxygen. One is positioned in the center of the netting, and the other is positioned under the section that has been gathered up. The fry that have been gathered can be scooped directly with a bucket. A bucket relay is used to stock the transport tank (Photo IX 3-1, 3-2). For 7 minutes, new seawater is added to the transport tank with an underwater pump and oxygenation is performed.

Photo IX 3-1 Offshore release: Operation where fry are scooped with a bucket from the live cage netting

Photo IX 3-2 Offshore release: the buckets with the fry are moved to a transport water tank.

(2) Transport density

The standard for transport density for a transport period of 1.5 to 2.0 hours is 20,000 fry/m^3. In 1993 a higher density was used during transport, but in this case mortalities were observed. At that time the fry measured 49 mm and they were transported at a density of 33,000/m^3. There was no water exchange prior to the transport operation.

(3) Regulating water exchange and oxygen

From the above it has been understood that it is important to change the water prior to transport. The water exchange procedure is that after the fry have been stocked, new seawater is delivered with an underwater pump through a 260 kei minnow net [translator's note: kei is the number of twines in webbing 50 cm wide.]

To exchange water there were two 40-mm hoses used for siphoning water between andon circular tanks. [Translators note: An andon is a Japanese paper lantern. The andon tank looks like a lantern.] A dip net of the type used for gold fish is used to remove dead fish. There is a 5-minute period of water exchanges for a 1 m^3 transport tank. The oxygenation equipment is checked. At the desired oxygen pressure of 0.4, the oxygen bubbles make a circle on the water surface of about 15-20 cm (Photo IX 3-3). After all of the adjustments, a lid is attached to keep the water from spilling, and the tanks are transported.

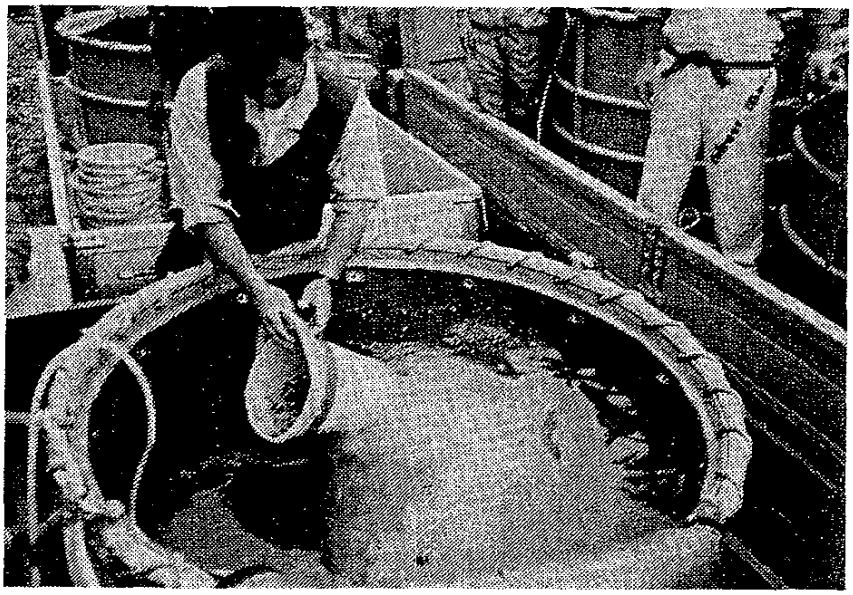


Photo IX 3-3 Offshore release: Appearance of bubbles in a transport tank that is being oxygenated.

(4) Transport

The fry are transported overland from the fry production facility to the fishing harbor. From there the transport tanks are transferred to ships for transport to the nursery culture facility. The truck that is used has a hoist, so the transport tanks can move the tanks to boats (Photo IX 3-4). The tanks are then transported to the nursery facility. To prevent oxygen deficiencies when the transport period exceeds an hour, a DO meter is used to make measurements of the dissolved oxygen, and the condition of the fry in the transport tanks is checked. If these types of checks are not made, it is possible that if trouble develops, the fry can die due to oxygen deficiencies.

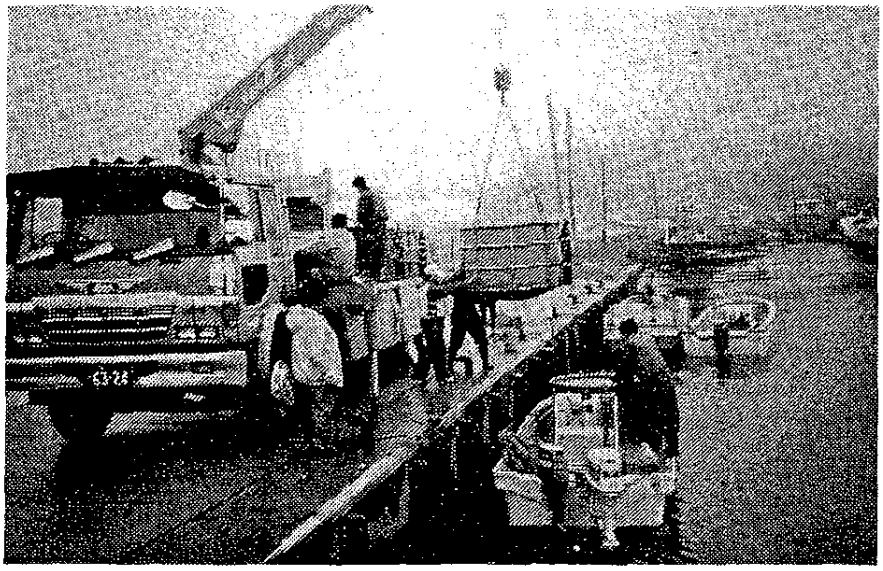


Photo IX 3-4 Offshore: A crane is used to hoist the transport tanks onto the transport boats.

(5) Stocking the fry in the small-mesh net nursery culture

A 50-mm diameter hose is used to carefully siphon the fry into the small mesh net of the nursery culture facility.

The fish are not sucked from the bottom of the tank, and the outlet of the hose is set so that it is centered within the small mesh net in such a way that the flow of the entering water keeps the fry from directly hitting the nets. When the water level is low the hose is inclined to the side. The siphon is used to suction as many fish as possible, and the remaining fry are scooped up with a dip net.

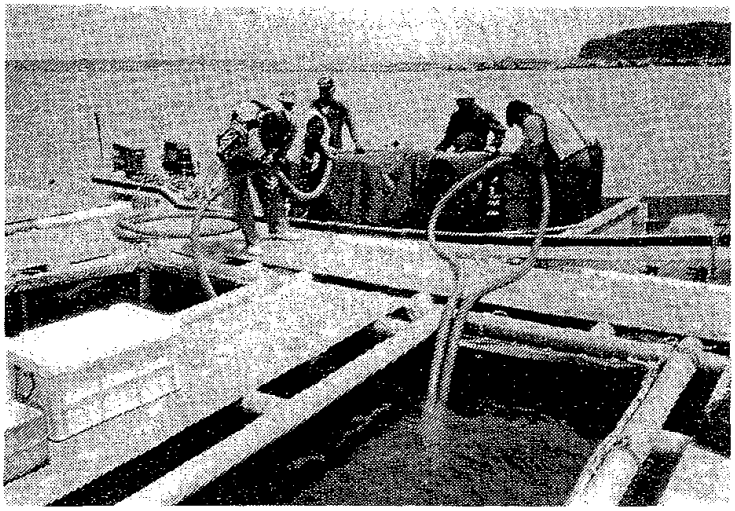
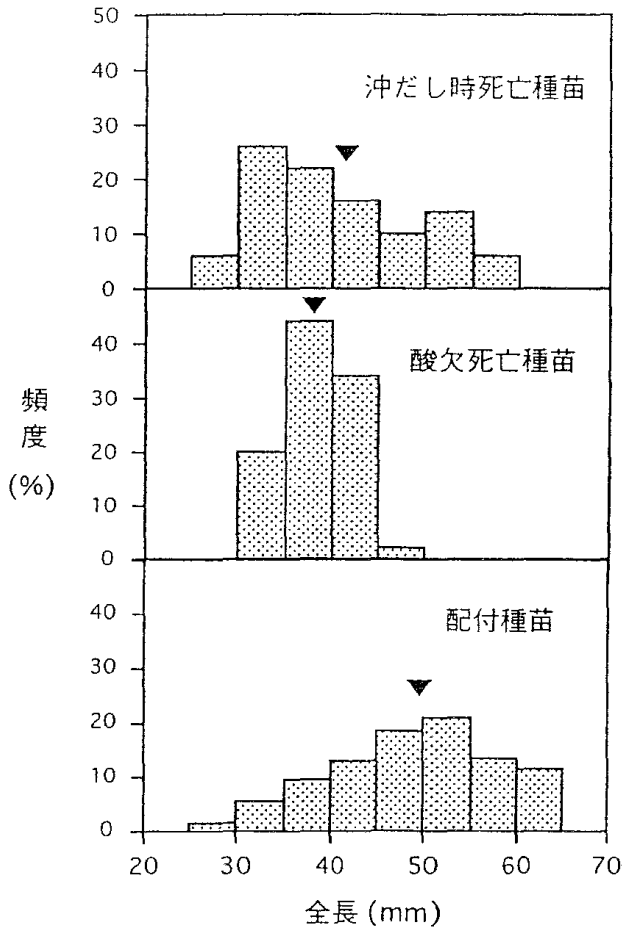


Photo IX 3-5 Offshore: Fry are transferred to small mesh nursery culture pens with a siphon.

(6) Mortalities during the offshore transfer

The herring fry are damaged considerably when they are moved offshore. During movement offshore, the herring experience handling stress in 4 ways: 1) Landing; 2) Transferring with buckets; 3) Colliding with the sides of tanks; and 4) siphoning. These operations require prudent care. Mortalities due to offshore transfer injuries are common for individuals with poor nutritional status, for individuals with severe spinal abnormalities, and for small individuals with delayed growth.

Total length histograms of the dead fry during transfer to the offshore are compared with the fry population that had an average total length of 50 mm. The average length of the fry that died during offshore transfer was smaller; the average total was 41 mm and there was a smaller mode at 30-35 mm. Also, the individual fry that died due to oxygen deficiency had a similar pattern; they were also small with an average body length of 38 mm and there was also a smaller mode was 35-40 mm (Figure IX 3- 1).



図Ⅸ 3-1　厚岸産ニシン配付種苗における酸欠死亡種苗と沖出し後１日目に確認された死亡種苗の全長のヒストグラムの比較
（▼は平均値）

Figure IX 3-1 Comparison of total length histogram of dead fry after stocking into net pens with the histograms of fry that died from inadequate oxygen or that died within a day of the transfer. [top histogram] Fry that died during the transfer to offshore, [middle histogram] Fry that died due to inadequate oxygen, [bottom histogram] Fry that died after they had been stocked in the pens, [y axis] Frequency (%), [x axis] Total length (mm), (▼ average value)

X. NURSERY CULTURE

This chapter deals with the release of the herring fry. It discusses significant aspects of nursery culture and the results of the nursery culture methods that were employed by Akkeshi station at Furen Lake and Akkeshi Bay. Also, it reports on the status of natural foods during nursery culture and how to evaluate the quality of the released fry. There is also a discussion on future trends for nursery culture.

1. Significance of herring nursery culture

Generally, the purpose of nursery culture is to gradually habituate fry to the natural environment. It is believed that the larger the size of the fish, the better their recovery from the effects of transport, the better their ability to catch natural food, and to learn the characteristics necessary for their mode of life. Most cultured fish species have a nursery culture stage, but there are few cases where the conditions mentioned above have been given adequate consideration. In addition, research is necessary on how to assure that the fry accumulate adequate energy reserves so they can tolerate low food conditions, and how swimming ability matches their ability to catch food.

It is significant that local herring differ from most other fish species in that they have a homing pattern for spawning. Thus, it is important to remember that environmental characteristics are imprinted on the fry during nursery culture. The herring homing migrations for spawning are not believed to be as pronounced as they are in salmon species. However, it has been observed that most of the released fish return to the nursery culture area for spawning from where they were released. This factor is extremely important. The mechanism by which the herring become imprinted on environmental characteristics is not clearly understood. It is necessary to clarify at what size the cultured fry become adequately imprinted on the spawning grounds of different marine areas. However, currently there is almost no research on this subject. Putting together a system for researching this subject is urgently important.

Current, nursery culture covers the development period that begins at 50 mm and continues until a total length of 70 mm. At a total length of 70 mm the morphological and functional transition from the fry to the juvenile fish stage is completed. It is believed that if the herring are released when they have grown to this size, this results in an improved survival rate after release. However, however, gradually habituating smaller sized herring is more economical. For this reason the most beneficial size for release requires future in the future.

2. Locations of the nursery culture facilities and the environment

The herring nursery facilities in the marine areas on the east side of Hokkaido are located in Furen Lake. One facility is on the outside of Hashirikotan Harbor, and the other is in the center of Furen Lake and is surrounded by eelgrass beds (Figure X 2-1). At Nokke and Akkeshi the nursery cultures occur in the harbors. At both locations there are tidal currents, but the flow is comparatively slow. Locations are selected where the water is deep enough that the small-mesh nets do not touch bottom.

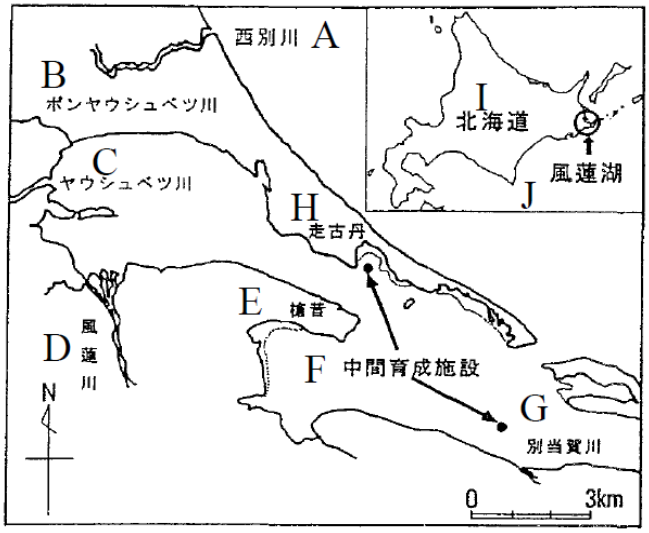


Figure X 2-1 Location of nursery culture facilities for herring in Furen Lake (Horii, 2000).

[A] Nishibetsu River
[B] Bonyaushubetsu River
[C] Yaushubetsu River
[D] Furen River
[E] Yarimukashi
[F] Nursery Culture Facilities
[G] Bettoga
[H] Hashirikotan
[I] Hokkaido
[J] Furen Lake

In Furen Lake it is easy for the environment at the nursery culture areas to be affected by weather which causes considerable variation. In 1985, especially, during the nursery culture period from mid July to early August, the temperature fluctuated from 13.5ºC to 22.2ºC. On several days there was an 8ºC fluctuation in temperature. The daily fluctuation was 5ºC. However, fry mortalities were not observed within these water temperature ranges. There were also large salinity fluctuations. Due to the effects of heavy rainfall, the salinity of the water surface has falls to very low levels. So far heavy rain fall during the offshore stage have resulted in mortalities of 10%. Research is necessary to determine suitable modifications in the procedures when there heavy rainfall.

3. Nursery culture facilities (Photo X 3-1) The raft used for nursery culture at Furen Lake, Akkeshi Bay, etc. measures 4 x 4 x 2.5 m), and has four compartments for the small mesh nets (actual volume 32 m^3). The small mesh minnow netting net is a Russell type nylon minnow net with a mesh size of 4 mm.

The raft is anchored. A 5-kg sinker is attached to each corner of the small mesh net. If necessary, depending on the currents, additional weights can be added as required. Also an overpass walkway is placed over the small mesh netting, and an automatic feeding device is placed in the center. In order to prevent bird damage, a covering net is set up over the small-mesh nets.

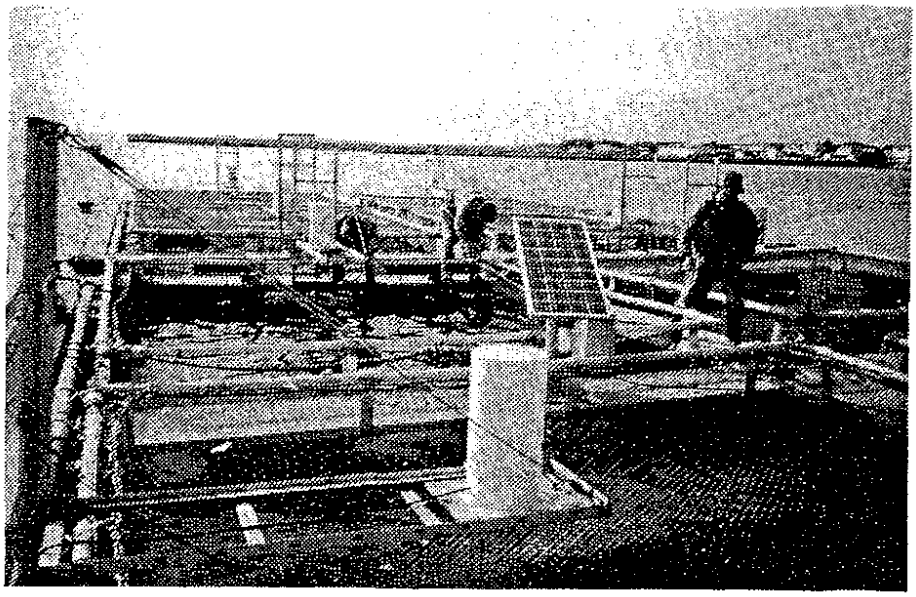


Photo X 3-1 General scene of nursery culture facility (Furen Lake).

4. Nursery culture methods and current situation

(1) Size of fry and mesh size of small mesh net

Ishisaki (2000) used fry that were at the size when offshore transfers occur to test the size mesh that would prevent escapes. At a mesh size of 5 mm. it was pointed out that it was possible for fry 46 mm or less in body length to fall through the mesh. Mesh selectivity depends on the body depth of the fry. The correlation formula that was obtained between body length and body depth in cultured herring fry from Akkeshi was BD = 0.208TL - 2.448 (r^2 = 0.962) (Figure X 4-1).

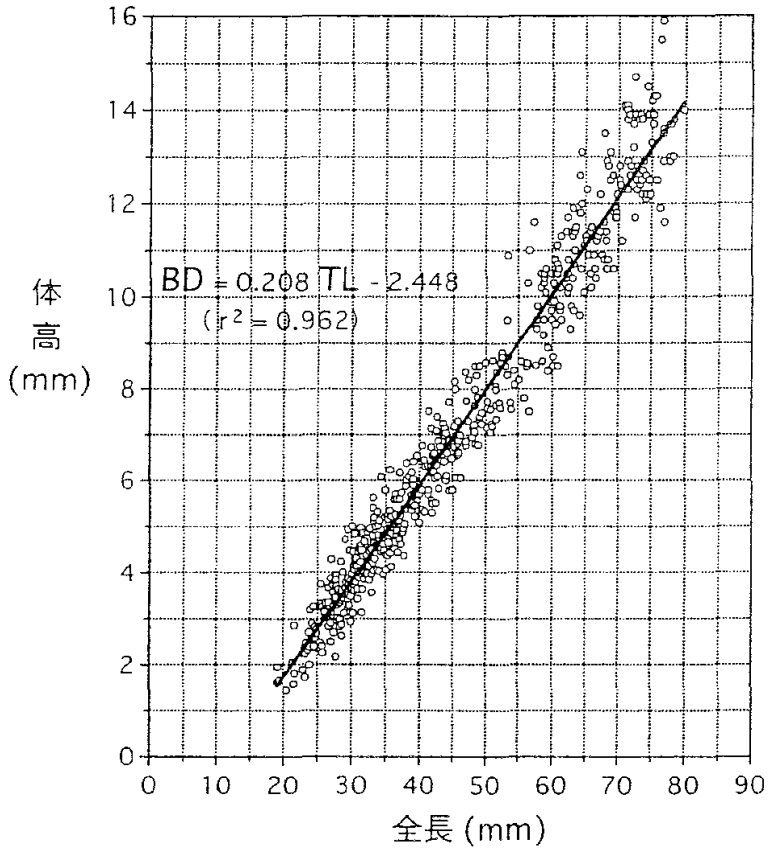


Figure X 4-1 Correlation of total length (TL) of cultured herring fry and body depth (BD). [y axis] Body depth (mm), [x axis] Total length (mm)

(2) Stocking number

The standard number of fry that are stocked in each of the small mesh nets during nursery culture is 40,000 fry per net. To determine the feasibility of increasing the number of fry, the stocking number at Akkeshi in 1999 was doubled to 80,000 fry/net. In this case the survival rate was very high (99.6%). The standard feed was 10% of the fish weight. When growth was examined after two weeks, the average total length was 57.9 mm and the average body weight was 1.33 g. These results were poorer than the other nursery culture area, and the previous year the average length in the culture had been 70 mm. It is clear that further research is necessary to determine the optimal culture density during the nursery culture period.

(3) Amount of food and feeding method

The same type of commercial formula feed is used as the feed for ayu (sweetfish) or salmon. The amount of feed is increased with growth. The feeding criterion is 10% of the body weight. Feed is generally provided using automated feeders. I some nursery facilities, feeding is done by hand twice a day. In 1999 the average amount of formula feed fed over a 14 day period at 4 locations (Bekkai, Wanchu, Nokke, and Akkeshi) was 22 kg/10,000 fry.

(4) Growth and survival

1Growth,

Currently, the general period for nursery culture is 14 days. In this period, 50-cm fry grow to a total length of 70 mm (Photo X 4-1). Body weight increases from an average of 0.7 g to 2.7 g. The growth rate is faster than in the land-based tanks. The reason is that the stocking density in the nursery culture is lower than in the land-based cultures. Also, the fry are able to catch natural prey organisms such as calanoid copepods in addition to the formula feed.

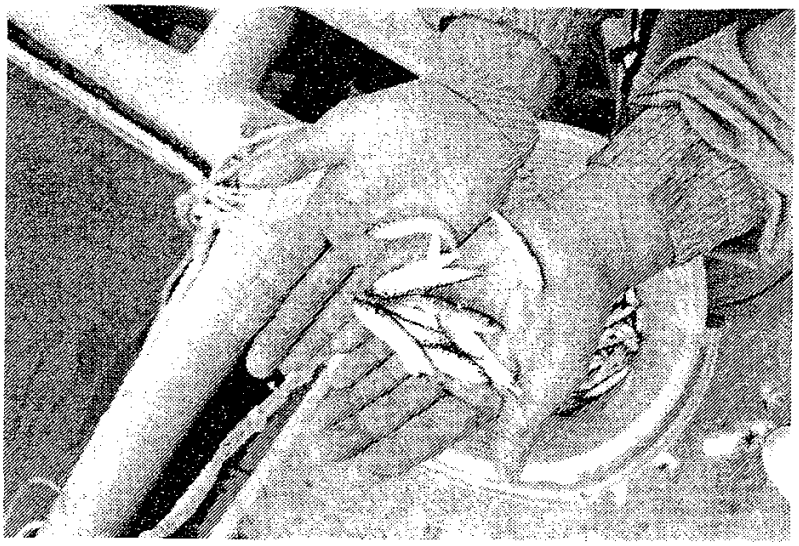


Photo X 4-1 Fry are released when they measure about 7 cm in total length.

2) Survival

At least three survival observations are performed during nursery culture (Photo X 4-2). The test method is to pull a section of netting by hand, remove the dead fish with a scoop net, and make a count. Also, 7 days after the offshore transfer, a sample is taken of the fry, and the small-mesh net is cleaned. At Furen Lake, the survival rate during the nursery culture period is 90% or more (Table X 4-1). However, in 1987 and previously, the size set for release was set at 10 cm, so the culture period was longer. It was common that the survival rate was also lower (50% or less).

Photo X 4-2 Nursery culture operations (survival study)

Starting in 1992, the nursery culture period was shortened (releases occurred after two weeks). With the improvements in the handling system, it is estimated that there was a 90% survival. In 1994, a no-feeding test was performed at Hashirikotan in Furen Lake. The results were that about half died (the survival was 55%). By comparison, little mortality was observed in a 1998 no-feeding test that occurred in Akkeshi Bay, and the fry also grew (Figure X 4-2). However, after 14 days the fry were extremely thin (Figure X 4-3), so the amount of food was inadequate.

The amount of natural food consumed per day was determined (Table X 4-2), and is believed that during nursery culture there is a large degree of effectiveness from natural food. Thus, it is important that when selecting a location for nursery culture, the natural feeding conditions are considered.

Table X 4-1 Summary of nursery culture results of Furen Lake produced herring. [Translator's note: This is a very wide table and has been broken into 3 sections. Each section is for a different fisheries cooperative.]

Bekkai Fisheries Cooperative						
Year	When stocked		When released			
	Number of fish (10,000 fry)	Average total length (mm)	Number of days	Number of fish (10,000 fry)	Average total length (mm)	Survival rate (%)
1983						
1984						
1985						
1986						
1987						
1988						
1989						
1990						
1991						
1992						
1993						
1994						
1995						
1996						
1997						
1998						
1999						
2000						

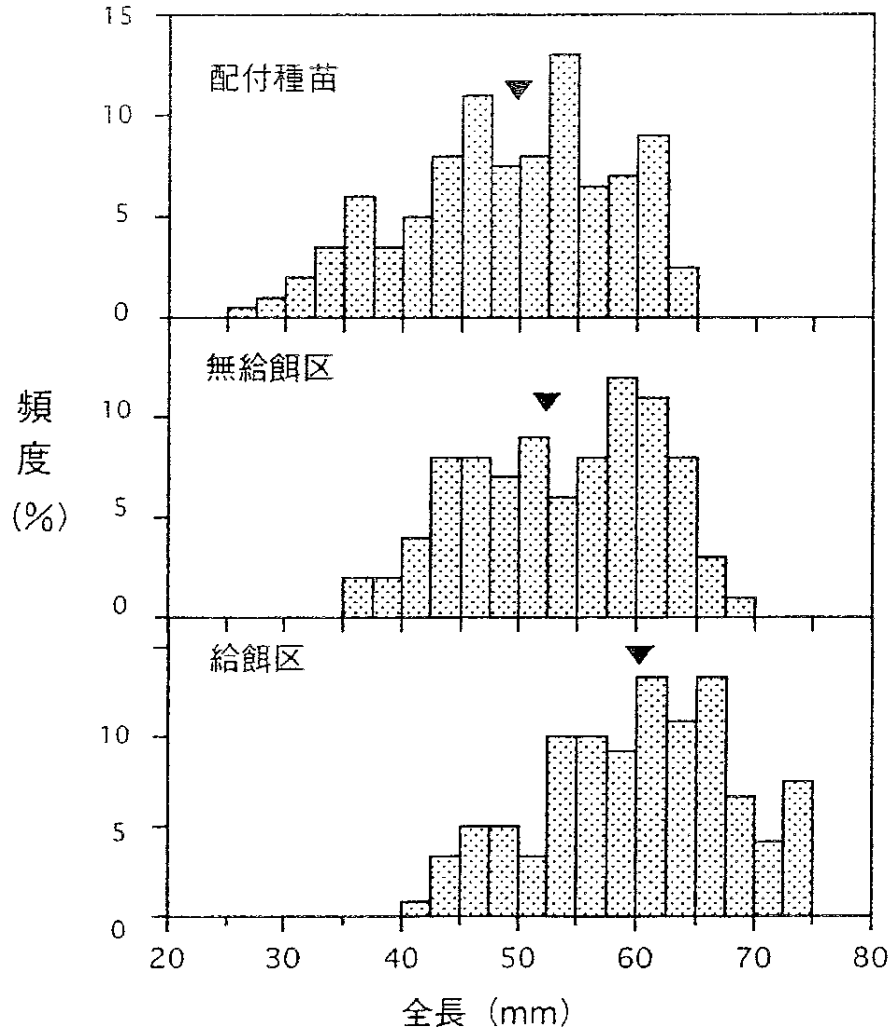
Nemuro Wanchu Fisheries Cooperative						
Year	When stocked		When released			
	Number of fish (10,000 fry)	Average total length (mm)	Number of days	Number of fish (10,000 fry)	Average total length (mm)	Survival rate (%)
1983						
1984						
1985						
1986						
1987						
1988						
1989						
1990						
1991						
1992						
1993						
1994						
1995						
1996						
1997						
1998						
1999						
2000						

Notsuke Fisheries Cooperative						
Year	When stocked		When released			
	Number of fish (10,000 fry)	Average total length (mm)	Number of days	Number of fish (10,000 fry)	Average total length (mm)	Survival rate (%)
1983						
1984						
1985						
1986						
1987						
1988						
1989						
1990						
1991						
1992						
1993						
1994						
1995						
1996						
1997						
1998						
1999						
2000						

* There is no data for 1999 because there were mass mortalities due to ALC tagging.

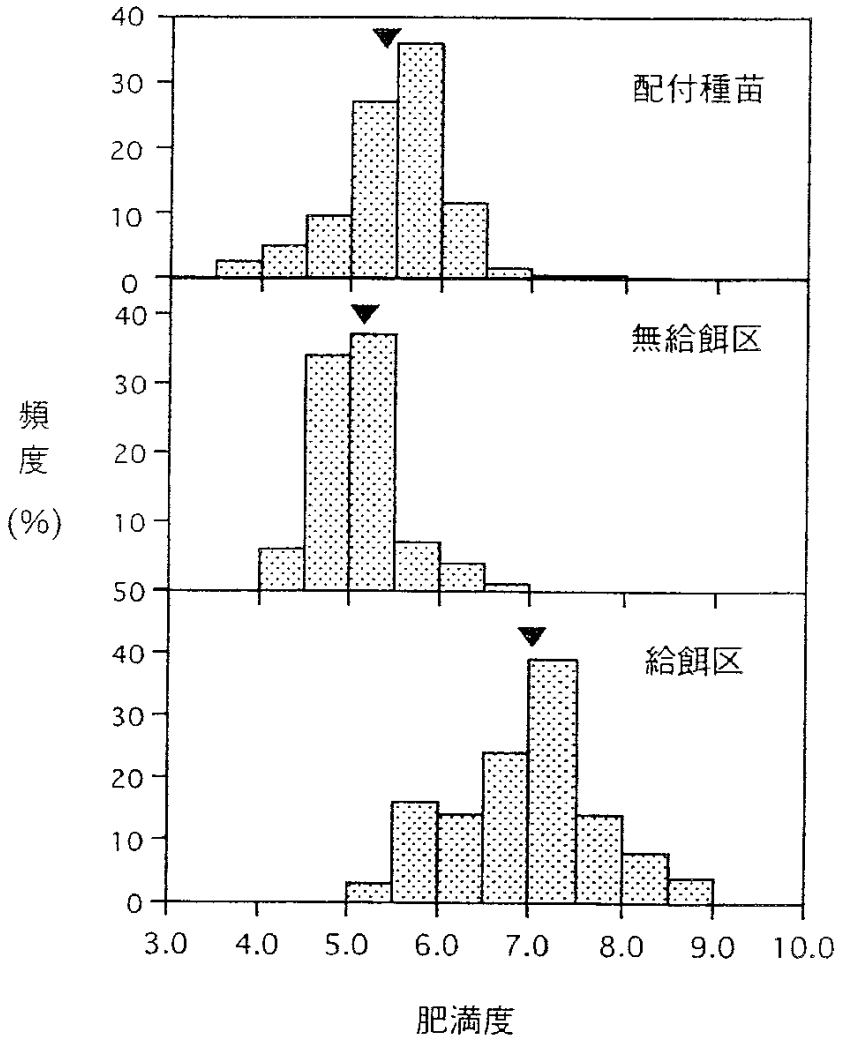
	別海漁協						根室湾中漁協						野付漁協					
	収容時		放流時				収容時		放流時				収容時		放流時			
年	尾数 (万尾)	平均全長 (mm)	日数 (日)	尾数 (万尾)	平均全長 (mm)	生残率 (%)	尾数 (万尾)	平均全長 (mm)	日数 (日)	尾数 (万尾)	平均全長 (mm)	生残率 (%)	尾数 (万尾)	平均全長 (mm)	日数 (日)	尾数 (万尾)	平均全長 (mm)	生残率 (%)
1983	3.8	60.1	93	0.6	101.0	14.6												
1984	11.9	53.0	71	0.8	79.5	6.5												
1985	16.9	55.4	73	1.3	89.7	7.7	2.4	67.5	53	0.4	118.7	17.1						
1986	16.0	46.9	16	9.5	57.0	59.4	6.0	46.9	17	4.8	61.0	80.0						
1987	8.3	51.8	11	6.8	59.0	81.8	7.1	53.0	16	7.0	64.0	98.6						
1988	5.9	53.7	14	5.5	74.5	93.2	4.8	50.2	18	4.3	70.0	89.6						
1989	14.9	60.4	10	8.7	71.0	58.3	10.2	59.2	20	9.4	75.0	92.3						
1990	-	-	-	-	-	-	-	-	-	-	-	-						
1991	7.3	45.9	13	6.8	59.4	93.2	6.3	47.2	20	6.0	72.5	94.5						
1992	20.2	43.5	14	20.0	67.5	99.0	10.2	42.0	23	10.2	61.8	99.9						
1993	22.6	48.0	17	22.2	72.0	98.0	16.0	44.9	21	16.0	65.2	100.0						
1994	31.4	46.9	16	28.4	70.9	90.4	16.1	45.0	15	16.1	65.5	99.7						
1995	31	46.5	14	30.6	65.5	97.6	15.7	46.5	14	15.7	66.2	99.7	4.4	54.7	14	4.4	72.9	99.8
1996	33	49.9	14	31.5	63.4	96.0	23.5	49.9	14	23.2	66.7	98.7	7.9	49.9	14	7.9	70.3	99.4
1997	20	43.6	15	19.4	58.9	98.2	14.9	43.6	15	14.8	59.3	99.7	7.0	48.0	14	6.3	58.9	90.0
1998	21.0	48.5	13	18.9	70.4	90.0	18.0	48.5	16	18.0	62.7	99.9	6.0	48.5	12	5.0	66.4	83.3
1999	37.2	42.6	22	35.7	66.3	96.0	14.1	43.5	19	14.0	63.9	99.3	7.7	45.2	12	6.0	63.5	77.9
2000	4.6	49.8	16	4.4	65.8	95.0	9.3	49.8	9	9.1	57.1	98.0	9.3	49.8	14	9.0	62.2	97.0

*1990年はALC標識時の大量減耗で配付できなかった



図X 4-2 厚岸産ニシンの中間育成無給餌試験における沖出し15日後の全長組成の比較
(▼は平均値を示す)

Figure X 4-2 Comparison of total length composition 15 days after offshore transfer of Akkeshi produced herring in nursery culture when fed and unfed.
[top histogram]
Fry that had been stocked into the net pens
[middle histogram]
Unfed group
[bottom histogram]
Fed group
[y axis] Frequency (%)
[x axis] Total length (mm)
(▼ average value)



図X 4-3　厚岸産ニシンの中間育成無給餌試験における沖出し15日後の肥満度の比較
(▼は平均値を示す)

Figure X 4-3 Comparison of degree of fatness 15 days after offshore transfer of Akkeshi produced herring in nursery culture when fed and unfed.
[top histogram]
Fry that had been stocked into the net pens
[middle histogram]
Unfed group
[bottom histogram]
Fed group
[y axis] Frequency (%)
[x axis] Fatness (mm)
(▼ shows average value)。

Table X 4-2 Results of a study on the gut contents of herring fry that were reared without feeding in Akkeshi Bay.

		1st day	5th day	10th day
Body length (mm)				
Body weight (g)				
Fatness index				
Index of extent to which the digestive system was full*1				
Ratio of individuals taking food (%) *2				
Contents of the digestive system *3	Copepodites of calanoid copepods			
	Nauplius of calanoid copepod			
	Podon sp.			
	Bivalve larvae			
	Barnacle larvae			
	Decapod crustacean larvae			
	Polychaete crustacean larvae			
	Diatoms			

*1 Digestive system fullness index 0: Nothing present
1: Some material present but largely empty
2: Some parts of the digestive system contain food, but portions are empty
3: Largely filled, but there is still space available.
4: Nearly filled but there is still remaining space along the walls of the gastrointestinal tract
5: Gastrointestinal tract even along the walls is nearly filled.
*2 Proportion of individuals taking food.
*3 The number of individual animals and cells that could be recognized in the digestive system.

		1日目	5日目	10日目
全長(mm)		55.7 ± 6.4	55.0 ± 3.3	60.4 ± 3.2
体重（g）		1.1 ± 0.3	0.9 ± 0.2	1.2 ± 0.2
肥満度		6.0 ± 0.4	5.5 ± 0.5	5.4 ± 0.5
胃充満度指数*1		3.6 ± 1.1	1.0 ± 0.5	0.8 ± 0.4
摂餌個体率（%）*2		100.0	90.0	80.0
胃*3内容物	かい脚類copepodate	620.7 ± 298.6	5.3 ± 5.7	1.4 ± 1.7
	かい脚類nauplius	1.1 ± 1.4	0.2 ± 0.6	2.3 ± 5.5
	Podon sp.	59.7 ± 25.7	0.7 ± 0.7	0.4 ± 0.7
	二枚貝幼生	0.4 ± 0.7	8.0 ± 8.3	0.0
	蔓脚類幼生	0.2 ± 0.4	0.4 ± 0.5	0.0
	長尾類幼生	0.2 ± 0.4	0.0	0.0
	多毛類幼生	0.9 ± 1.0	0.0	0.0
	珪藻類	0.0	0.4 ± 0.8	21.4 ± 77.3

*1 胃充満度指数 0：内容物なし、1：僅かに入っているが大部分は空
2：一部に餌が入っていない部分が存在、3：全体に入っているが間隙がある
4：ほぼ充満しているが消化管内壁のしわが残っている、5：消化管内壁のしわがなくなるほど充満している
*2 摂餌個体率：摂餌個体の割合
*3 胃内容物は個体数及び細胞数で表す

5. Using natural food during nursery culture

(1) Study of natural foods at the nursery culture locations

1) Species available and biomass

((1)) Akkeshi Bay, Akkeshi Lake (Study locations: Figure X 5-1)

According to the study that was performed in 1997, calanoid copepods were the principal planktonic organisms in the vicinity of Akkeshi during the nursery culture period. There were also polychaetes, crustacean larvae, rotifers, barnacle larvae, and tintinnid ciliates. The majority were calanoid copepods and tintinnid ciliates. With the exception of the tintinnid ciliates, all of these species are suitable food items. The majority of the copepods were in the Calanoida order, especially the genus *Acartia* genus (*A. hudsonica*, *A. longiremis*). Other species were *Paracalanus parvus*, *Pseudocalanus newmani*, *Eurytemora herdmanii*, *Oithona similis*, *Metridia* sp., and *Harpacticoida* sp. Also, in the period from mid June to late July, species of rotifers were comparatively abundant (Husa rotifers and a species that was not identified).

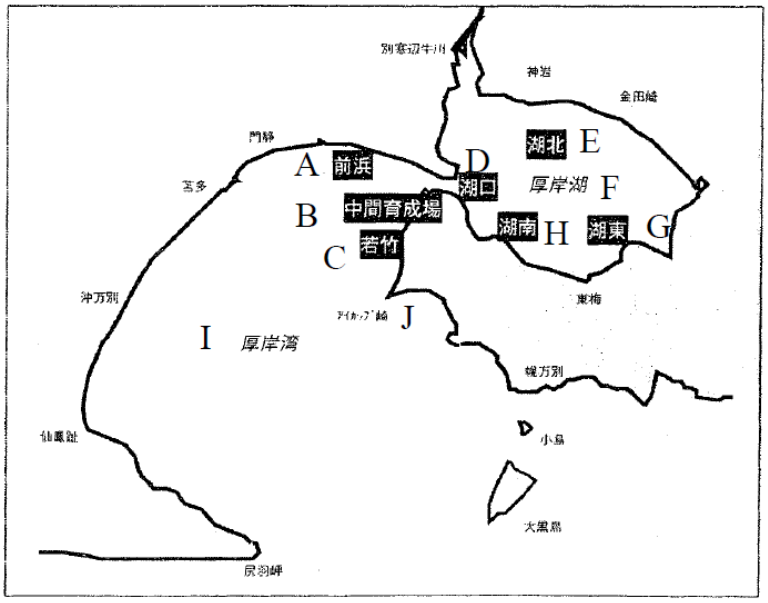
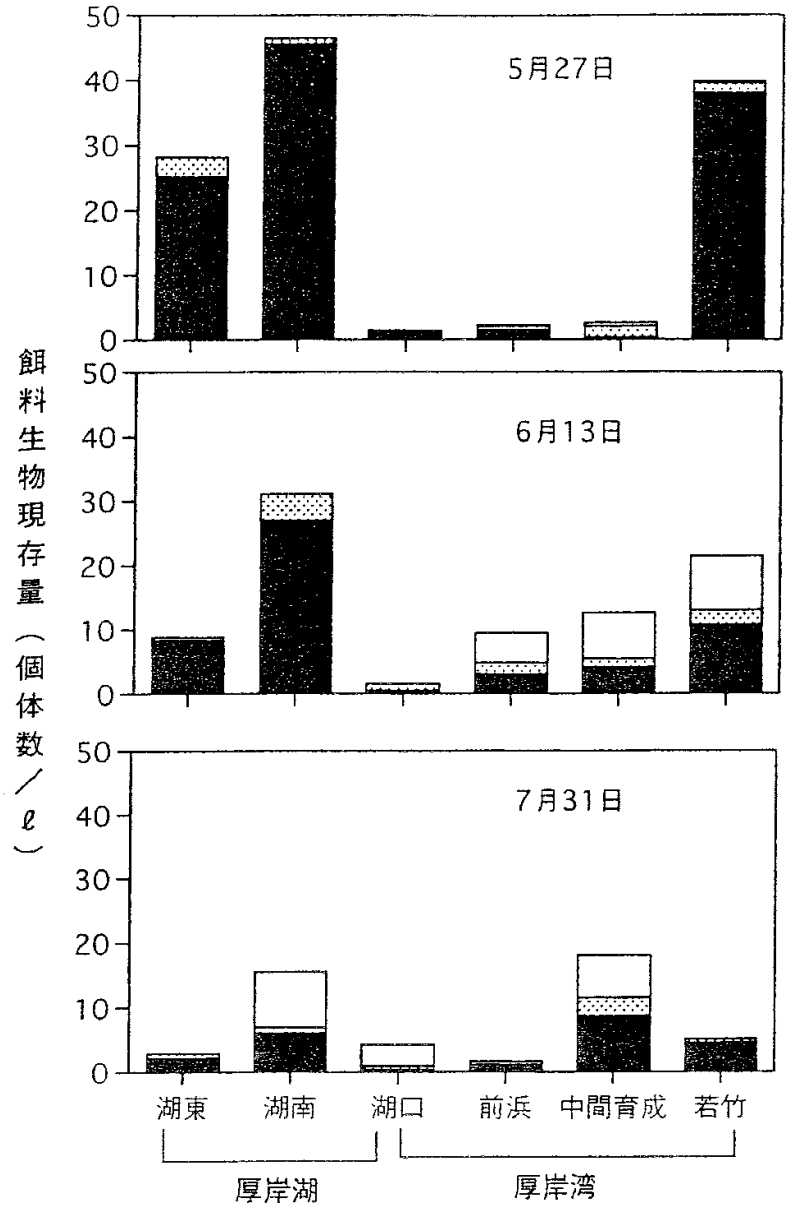


Figure X 5-1 Zooplankton survey study locations in Akkeshi Lake and Akkeshi Bay.
[A] Maehama
[B] Nursery culture grounds
[C] Waketake
[D] mouth of lake
[E] Lake – North
[F] Akkeshi Lake
[G] Lake- East
[H] Lake South
[I] Akkeshi Bay
[J] Aikappu Cape



図X 5-2　1997年度の厚岸周辺海域の表層におけるニシン仔稚魚に有効な餌料*となるプランクトンの現存量の比較
＊ニシン仔稚魚に有効な餌料となるプランクトン
(サイズ200～1,000μm)
対象：■ かい脚類 copepodite　▨ 多毛類幼生　□ ワムシ類

Figure X 5-2 Comparison of the different species available as food for herring in the plankton in the vicinity of Akkeshi in 1997.

* For herring fry the effective size for planktonic feed is in the range of 200 to 1,000μm. Comparison of different foods available for herring fry in the surface water.
[Top figure] May 27, [Middle figure] June 13, [Bottom figure] July 31
[y axis] Amount of live food present (number of individuals/ℓ) [x axis, tic marks left to right] Kotou (Lake – east), Lake – south, Lake – mouth, Maehama Nursery culture, Wakatake , [x axis, left to right below the information on the tic marks] Akkeshi Lake, Akkeshi Bay

Species: ■ Copepodites of calanoid copepods, [stippled] Polychaete larvae □ Rotifer species

There was a tendency for a larger planktonic biomass at Akkeshi Lake and Wakatake (Figure X 5-2). In the study performed on May 27, 1997, it was determined that there was a very large biomass at Kotou. This suggests that there were good feeding conditions for the herring larvae and fry in Akkeshi Lake.

((2)) Furen Lake, Nokke nursery grounds

On August 6, 1997, just prior to the release, there was a study of the herring nursery site. The planktonic species were roughly similar to those occurring along the coast. A comparison of the number of food items occurring at each of the nursery culture sites was as follows: 12 at Bekkai, Furen Lake (Hashirikotan); 9 inside Furen Lake and Bay (Kawaguchi - river mouth); 13 at Odaitou Harbor, and 16 at Akkeshi Bay. This shows a tendency towards a low number of prey items. Other characteristics were that at Furen Lake (Bekkai, and Wanchu), there was an abundance of diatoms.

In the 1997 survey on the occurrence of the biomass of effective food items, the number of calanoid copepod copepodites at Bekkai was 2.7 copepodites/ℓ; at Wanchu 2.4 copepodites/ℓ; at Nokke 5.4 copepodites/ℓ, and at Akkeshi 7.7copepodites/ℓ. This was the same type of low biomass pattern.

2) Size of food organisms

①Akkeshi Bay, Akkeshi Lake

The body length of the nauplius of calanoid copepods is in the range of 75-500 μm with the majority 100-300 μm. Also, the body length of the copepodite of calanoid copepods is in the range 250-1,750 μm, with the majority 350-800 μm. Members of the genus *Euecalanus* are especially large.

The size of the planktonic organisms ranged from 75 to 750 μm, with the predominant size 200-800μm. For the larvae of herring larvae and fry, these are suitable as food.

((2)) The Furen Lake and Nokke Bay nursery culture sites

The average body length and the standard deviation of the copepodites of calanoid copepods at Bekkai was 365.6 ± 67.9 μm (range 250-500); at Wanchu 390.5 ± 90.2 μm; and at Nokke 393.8 ± 90.0 μm (250-650) These were relatively smaller than the average at Akkeshi which was 490.5 ± 149.7 μm.

(2) Using natural food

In the vicinity of the Akkeshi Bay nursery culture, there was a relative tendency for the planktonic biomass to be of the effective size for feed in June and July. The results of a study on the contents of the gastrointestinal tract of herring in nursery culture was that despite the fact that there was an adequate amount of formula feed, 7 days after being moved offshore, the volume percentage of natural food made up 56.0%, and after 14 days the percentage was 9.3%. Nearly all of the food items were species of calanoid copepod, and there were small amounts of cladocera (branchiopods, water fleas, *Podon* sp.) By comparison, except for Akkeshi, the amount of natural food at nursery culture sites was small. Fourteen days after the offshore transfer, the amounts in Furen Lake at Bekkai (Hashirikotan) and Wanchu (Kawaguchi river mouth) were 0.6 and 0.2%, respectively. Nokke (Kounai, Wanchu) had a relatively high value of 6.7% (Figure X 5-3). It is believed that this difference is due to the biomass of the natural foods in the vicinity of the nursery culture sites and to either favorable or unfavorable effects of currents.

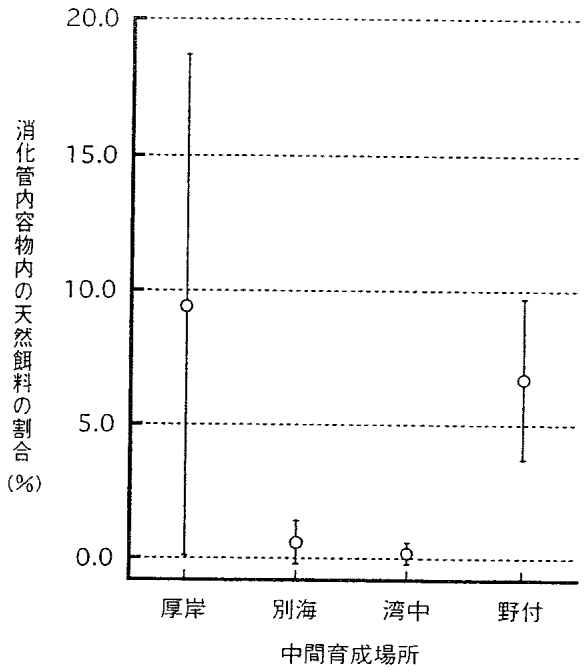
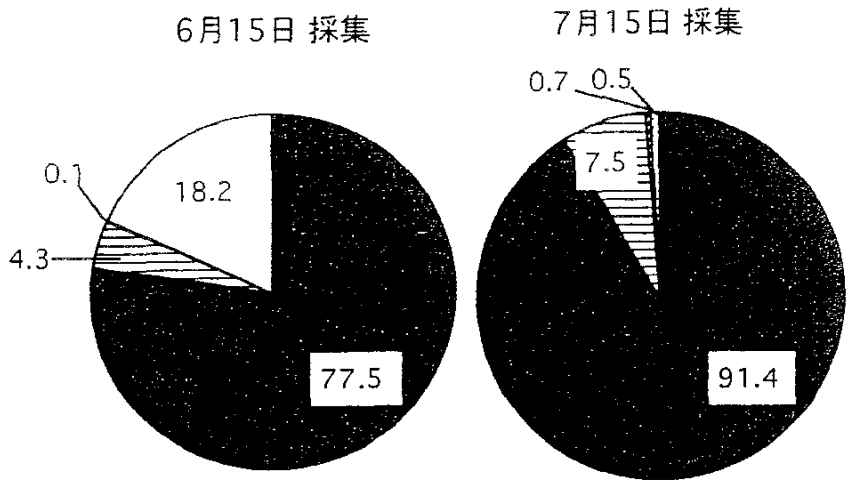


Figure X 5-3 Proportion of different natural foods in the gastrointestinal tract of herring fry that were released in 1997 at each of the nursery locations.
[y axis] Proportion of natural food in the gastrointestinal tract
[x axis] Location of intermediate culture
[x axis tic marks, left to right]
Akkeshi
Bekkai
Wanchu
Nomura

The reason why Akkeshi had the highest relative plankton biomass in the vicinity of the nursery culture site is that it has the best currents. It is presumed that the currents can easily supply necessary nutrients to the plankton. It is believed that this is the reason for the abundance of feed in the natural plankton. Also, it is clear that this is why there was a large amount of natural food that had been consumed 7 days after intermediate culture. It is presumed that from the standpoint of feeding, this is an excellent habituation to the natural environment.

(3) Study on the stomach contents of natural fry

In 1998 natural herring fry collected from Furen Lake, and feeding condition was evaluated according to an index value on the fullness of the stomach. The average values were relatively low; on June 15 it was 2.2, and on July 15 it was 2.5. On June, 15, two of the 11 specimens had empty stomachs, but on July 15 all of the sampled individuals had been feeding.



図X 5-4 1998年に採集された風蓮湖天然ニシン稚魚の体積比で示した消化管内容物組成の比較
■ アミ類 ▤ かい脚類 ▨ 端脚類
▩ フジツボ幼生 □ 無し

Figure 5-4 Comparison of the volumetric contents of the gastrointestinal tract of wild herring fry collected at Furen Lake in 1998. [pie on left] Collected June 15, [pie on right] Collected July 15, ■ Mysids, [pie piece with horizontal markings] Calanoid copepods, [pie piece with cross hatching] Amphipods, [dotted pie piece] Barnacle larvae, □ None

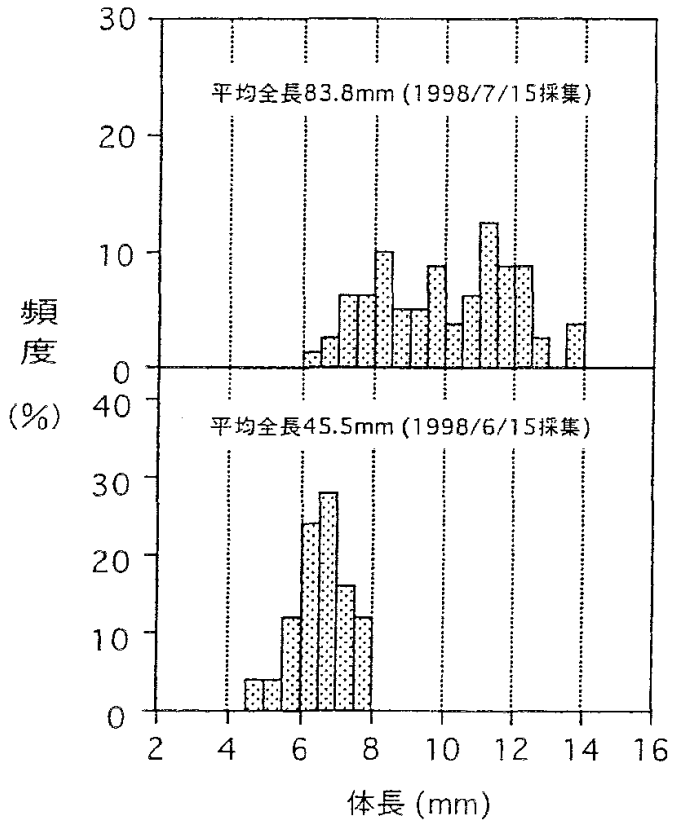


Figure X 5-5 Body length composition of mysids consumed by wild Furen Lake herring collected in 1998. [upper figure] Average total length of herring 83.8 mm (collected July 15, 1998). [lower figure] Average total length of herring 45.5 mm (collected June 15, 1998). [y axis] Frequency (%), [x axis] Body length of mysids (mm)

In both samples the dominant species in the stomach was mysids. On June 15, the average number of mysids was 4.1 and on July 15th the number was 14.8. The average volume rate on June 15 was 77.5% which increased to 91.4% on July 15 (Figure X 5-4). The next most abundant species were copepodites of calanoid copepods; the average volume rate on June 15 was 5.7% and on July 15 it was 7.5%. Other species included some amphipods and barnacle larva.

Measurements were made of body lengths of the mysids in the stomach contents. The average body lengths of the mysids collected on June 15 from herring with an average body length of 45.5 mm was 6.5 mm (4.7-7.9). The average body lengths of mysids collected on July 15 from fry with an average body length of 83.8 mm was 10.0 mm (6.2-13.8) (Figure X 5-5).

Sasaki (2000) studied feeding of herring fry measuring 30-80 mm that were collected from late May to early August during 1996 to 1998 along the Akkeshi coast and the area in close to the mouth of Ishikara River. At a total length of 30-40 mm, the principal foods were calanoid copepods *(Oitona similis, Palacalanus parva, Clausocalanus pergens*, etc.) At a total length of 40-60 mm, other calanoid copepods included such species as *Acartia* sp. *Eurylemora* sp. and *Harpacticoida.* At a total length of 60-70 mm, there were *Harpacticoida*, euphausids, and amphipods. At a length of 80 mm and larger, the dominant foods were fish and mysids. Also, in the period from 1996-1998, Ashimura (2000) studied larval herring that were collected from early May to late June along the Rumoi coast. The results were that larval fish measuring 14-17 mm consumed small calanoid copepods and nauplius larvae. Fry at a total length of 50-60 mm principally consumed calanoid copepods and amphipods.

From these reports it can be understood that the principal foods for larval herring are calanoid copepods, mysids, and amphipods.

6. Quality evaluation of nursery cultured fry

Fish store energy principally in the liver, as intraperitoneal fat bodies, and in the muscle. The predominant component is neutral lipids. When neutral lipids are being stored, the liver enlarges and there is an increase in the intraperitoneal fat bodies. The ratios of both of these to the body weight (the liver weight ratio and the intraperitoneal fat body ratio, respectively) were compared for nursery cultured for 4 months (Figures X 6-1, X 6-2). The values of the liver weight ratios and the intraperitoneal fat body ratios were highest at Bekkai. For each case, there was a tendency towards high values. The results of visual observations were that the surface of the gastrointestinal tract was covered with intraperitoneal fat bodies. It was believed that the energy stores were good for all the fry. Also, as there was no differences in the fatness index in the four (about 7.1), it is believed that there was good energy storage during nursery culture

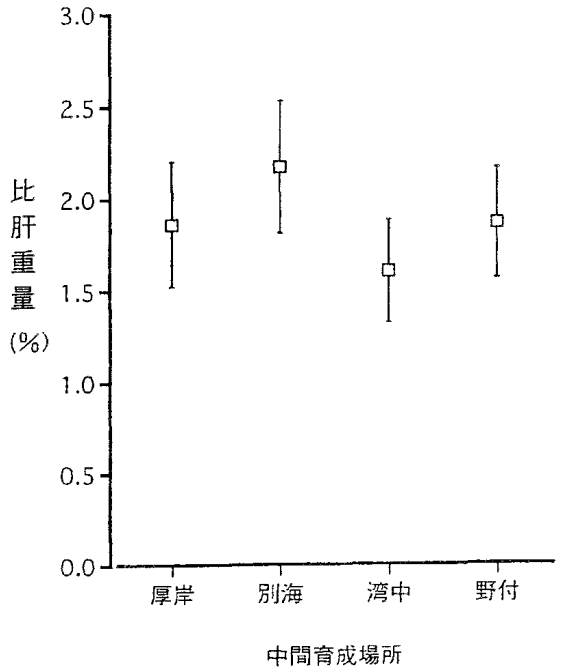


Figure X 6-1 Liver weight percentage in released herring fry at different nursery culture facilities in 1997.
[y axis] Ratio of liver weight (%), [x axis] Location of intermediate culture, [x axis, tic marks from left to right] Akkeshi, Bekkai, Wanchu, Nomura

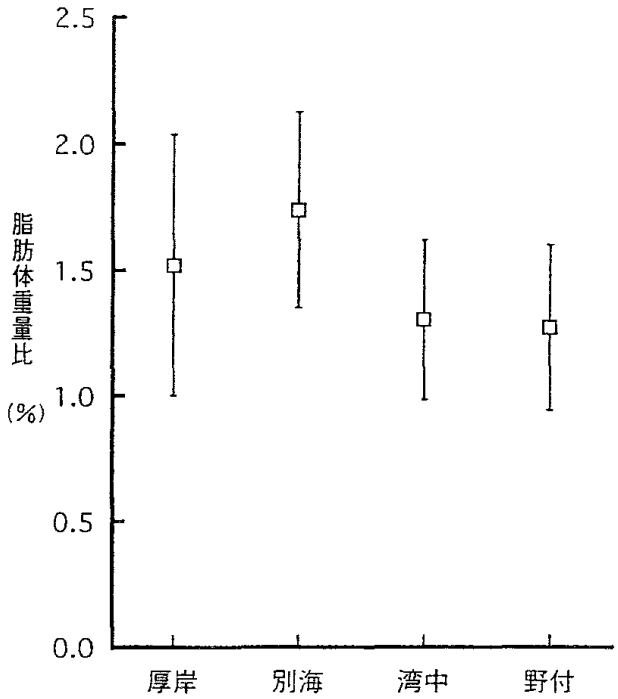


Figure X 6-2 Fat weight percentage in released herring fry at different nursery culture facilities in 1997.
[y axis] Ratio of fat weight (%)
[x axis] Location of intermediate culture
[x axis, tic marks from left to right]
Akkeshi
Bekkai
Wanchu
Nomura

XI. THE FUTURE TASKS AND PROSPECTS

Large scale herring fry production has been possible since 1982. The techniques for herring fry production have improved and stabilized as a result active technique development at each facility and especially through the efforts of the Japan Aquaculture Association. In Furen Lake on the eastern side of Hokkaido, there has been proactive resource enhancement along with the development of fry production techniques. In the Japan Sea, there have been large scale resource enhancement projects such as the herring resource enhancement project. Herring resource movements have also been elucidated. Currently, there is high enthusiasm for herring propagation. Recently, because of collapses in herring resources, the fishermen have had high expectations for culture, especially in Hokkaido.

Currently, studies on herring propagation have been limited to herring populations that repeatedly spawn at the same location. Herring with localized characteristics live in comparatively restricted areas; and with maturation, they return to coastal areas to spawn. These herring repeatedly return to spawn in limited spawning areas, so it is comparatively easy to determine the size of the resource and to obtain results from releases. Because these herring have the characteristic that they repeatedly return in the spawning season to limited fishing grounds, it is easier to obtain information than for other species of fish. This chapter discusses the future tasks and prospects of herring resource enhancement from the standpoint principally of fry production techniques.

1. Broodstock

Wild caught fish are generally used to assure a supply of fertilized eggs for herring fry production. It is necessary to assure a consistent supply of fertilized eggs, but currently the fish catches every year are very unstable. In response, there has been research to develop techniques for culturing broodstock. The techniques for maturing broodstock and reliably obtaining fertilized eggs have been developed (refer to chapter V). However, it is clear that it is desirable that during the year, the temperature for broodstock maturation should be 20ºC or less. Currently, these conditions are only met in the fry production facilities on the marine areas on the eastern part of Hokkaido. Even when the water temperature of the intake water is high, it can be used if it is cooled. Experimentally, it has been possible to mature broodstock. However, when considering maintaining the supply of fertilized eggs on a large scale, it would be difficult to rely entirely on cultured broodstock for fertilized eggs at all of the facilities. In current operations, the method for maintaining good quality broodstock is to catch herring specifically for this purpose, or to rely on selected fishermen to provide broodstock. However, it is possible to maintain and mature broodstock from each of the local stocks, which is important as some localized stocks are on the verge of extinction.

There are questions about egg quality. At Akkeshi it was reported that survival was related to differences in the size of the egg yolk (Iizuka, 1962). However, except for this report, there has been almost no research on this topic even though it is believed that egg quality has a large effect on fry production. At some facilities there have been cases where mortalities occurred during egg development. So developing methods for evaluating egg quality is a task that remains to be achieved.

In order to maintain genetic diversity of the cultured fry, there must be concern about using an adequate number of broodstock. Currently, at least 100 of both males and females are used for the broodstock when producing herring fry. According to an isozyme analysis, there were no problems when comparing the wild broodstock group with the cultured fry (Anzou, unpublished table). However, as wild lake and marsh type herring tend to have a comparatively high rate of fish with spinal abnormalities, it would be desirable to study details so that in the future genetic markers can be used.

2. Fry Production

Though there have been improvements in techniques for producing herring fry, there are a number of issues remaining. One is the health and viability of the artificially produced fry. Especially important is lowering morphological abnormalities, in particular individuals with severe spinal abnormalities. This is a major problem because this abnormality can cause them to become shorter which means they lose their economic value. In 2000 there was an effort to determine the specific causes of spinal abnormalities and the developmental progression of these abnormalities. This is still an issue that urgently requires a solution. Also, it is important to enhance the survival rate after the fry are released. There has been almost no research on the ability of the fry to escape from predators. It is necessary to make these assessments as part of the evaluation methods. Until recently in Japan there has been little problem with diseases other than gas bubble disease. Bacterial and viral diseases have not caused major problems. However, wild Atlantic herring are known to be susceptible to viral hemorrhagic septicemia (VHS). VHS has also been observed in Japan in species of fish, though not in herring. It is necessary to study countermeasures for this disease for herring during the fry production stages. As larval development of herring fry resembles that of ayu (sweetfish), initially many of the production techniques were based on techniques used with ayu. The production of ayu fry occurs in numerous facilities throughout Japan, and development of techniques has been very diverse. Currently, there are stable fry production development techniques for herring. However, labor-saving techniques have been introduced in ayu production facilities, and in the future it is believed that these techniques must be introduced to herring culture. In addition, the variety of reports on fundamental research concerning production techniques during the development of the white (shirasu) larvae and fry periods needs to be systematically organized.

3. Nursery culture

When the economics of nursery culture are considered for large scale releases, it would be desirable it the fry were transferred offshore at a smaller size. However, in order to achieve this objective, there has to be a method for evaluating how well the fry can tolerate handling and how well they can become habituated to the environment. There is an acute need for research related to methods for landing and transporting the fry.

There needs to be research on using natural feeds effectively during nursery culture. As suggested in previous chapters, with the herring located near the sea surface, it is possible to replace a portion of the artificial feed with natural feed. The effect of this is that rearing costs are reduced and this can speed up habituation of the cultured fry to the natural environment. In order to increase the effectiveness of the use of natural foods (natural plankton), there must be good management of the small mesh nets during nursery culture. With the sandfish, an effective method is to use lamps during the night to attract plankton. If the nursery culture locations are located in areas with good currents, the currents will gradually replace the planktonic organisms, so the selection of nursery culture locations is extremely important. Hereafter, it would be useful to perform a systematic study of the environmental conditions of each of the marine areas from the standpoint of fry quality enhancement and speeding up the habituation to the natural environment by the fry. This will also increase the efficiency of nursery culture from the standpoint of economics. Herring have characteristic spawning migrations, so it is believed that the imprinting on environmental characteristics that occurs during nursery culture is extremely significant for the herring to return to the spawning grounds. However, migratory behavior is extremely difficult to study, as this is a topic that cannot be directly controlled. The size of the fry at the time that they imprint on the environmental conditions during nursery culture is not known. It is important to perform fry-release testing to examine issues related to the imprinting period. It is believed this would be a good method for determining the most appropriate size for releases.

4. Cost of producing fry

The subject of reducing fry production costs continuously throughout the fry releasing operations is important. Topics that have already been examined but require further technical development include reducing the amount of expensive *Artemia* food, shortening the period for rotifer feeding, modifying the set water temperature to conserve energy, and shortening the period required for the operations. A calculation was made of costs based on the costs of the herring operations performed by Akkeshi Station and the expectations after release (recovery rate 10%, fish prices 800 yen/kg). Currently, when the number of fry released is 1,000,000 fry, the unit cost is 19 yen/fry. Compared to the production expenses, the recovery rate is a low (0.6), so it is not possible to recover the production costs. In order for the income and expenditures to be equal (1.0), it is necessary that the unit price of the released fry is on the order of 10 yen per fry.

5. Seaweed spawning grounds and resource management

The fry that are released repeatedly return and mature to spawn. The environment of the spawning grounds is the most important factor. The presence of functional seaweed grounds is essential, especially for herring spawning (Figure XIII 3-1). Spawning substrates of the Pacific herring are eel grass or other aquatic plants (Photo XI 4-1). Observation shows that spawning does not occur when the surfaces of the aquatic plants are covered with mud. Therefore, in order to maintain the seaweeds grounds in an optimal condition for spawning, it is desirable to have research on the condition of spawning grounds. When there has been a decline in the quality of the spawning grounds, it is important to develop new seaweed grounds or set up artificial seaweed grounds.

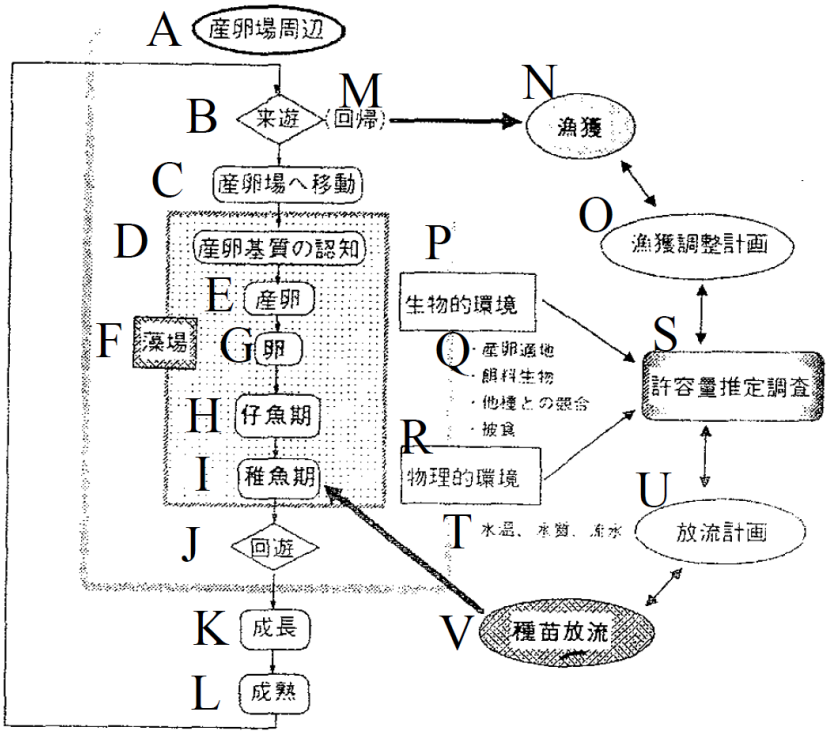


Figure XI 3-1 Flow chart for maintaining and enhancing herring stages and resources. [A] Vicinity of spawning grounds, [B] Migration, [C] Movement to spawning grounds [D] Recognition of spawning substrates, [E] Spawning, [F] Seaweed areas, [G] Eggs [H] Larval period, [I] Fry period, [J] Circular migrations, [K] Growth, [L] Maturation [M] Repeated homing, [N] Fish catch, [O] Plan for regulating the fishery, [P] Biological environment, [Q, top to bottom], · Spawning ground · Amount of live feed · Competition with other species · Prey, [R] Physical environment, [S] Study to estimate the desired stocking volume, [T] Water temperature, water quality, spawning water, [U] Plan for release, [V] Release of fry.

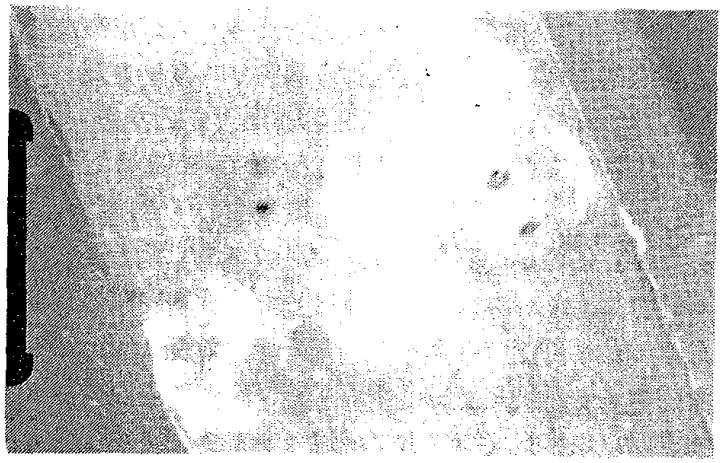


Photo XI 4-1 Eggs spawned at Amamo (just before hatching).

As most of the lake and marsh type herring return to specific spawning grounds during the spawning season, if there is intense fishing pressure during the spawning season, it is known that this can lead to a depletion of the lake and marsh herring populations. Without fish catch regulations during this stage, depletion can be expected. Fish catch regulations have had a big effect in the resource recovery of Atlantic herring. Countermeasures at Furen Lake that are believed to increase the resource include no fishing areas, limits on the fishing season, and regulations on the fishing gear. Currently, the condition of the lake and marsh herring is extremely serious, and in Japan there has been a marked decline in the size of some herring populations. Some populations have collapsed to such low numbers that they have been listed as endangered. It is believed that the reason for the decline in the size of the resource is due to changes in the environment of the spawning grounds. Spawning grounds are closed marine areas, and the areas are comparatively restricted. So when artificial structures are built it is easy for there to be sudden changes in the quality of the water and the bottom. This is especially important when there is an effect from fresh water on spawning ecology. Changes in water quality are detrimental to herring spawning. In the case of the lake and marsh type herring, fish do not migrate from other areas. Thus, once the resource has collapsed, recovery may not be possible, and there is a large possibility of complete disappearance of the stock. To prevent the elimination of these stocks, their must be proactive countermeasures for managing and protecting wild broodstock and releasing fry.

6. Conclusion

Herring resources that consist of populations with fishery catches of several thousand tons to several tens of thousands of tons can be dramatically increased. So far local type herring have not been increased to levels producing a large resource. Instead of enhancing the resource from fry releases, it should be possible to maintain the resources in the level from several hundred tons to several thousand tons. If there are consistent fish catches, it would be possible to have a commercial structure based on the associated herring. Also, in order to stabilize the fish prices at a high level, it is necessary to proactively promote the development of local type herring brands. This includes developing new recipes, etc. that taste good and make the herring desirable for consumers. It is believed that creating regionally based industry is a necessary planning step.

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XIII. REFERENCE DATA

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Table Schedule of herring fry production and nursery culture operations. [Translator's note: This table is so wide that there was not room for "Early Mid Late" to be on a single line from April to December.]

		Month	1	2	3	4	7	6	7	8	9	10	11	12
		Part of month	Early Mid Late	Early Mid Late	Early Mid Late	Early Mid Late	Early Mid Late	Early Mid Late	Early Mid Late	Early Mid Late	Early Mid Late	Early Mid Late	Early Mid Late	Early Mid Late
		Operation												
Egg collection		Preparations for egg collection												
		Collecting eggs												
		Egg culture												
Producing fry	Fry culture	Preparations for production												
		Maintenance Stocking and hatching												
		Management of bottom cleaning												
	Feeding	Feeding with rotifers												
		Feeding with *Artemia*												
		Formula feeding												
	Marking	Otolith marking												
Landing		Landing preparations												
		Landing and transport												
Intermediate culture		Intermediate culture, release												
Feed culture		Maintaining rotifer cultures												
		Rotifer production												
		Hatching *Artemia*												

Table List of Furen Lake herring fry production operations.

Year	Number of times	Tank volume (m^3)	Stocking			Fry produced						
			Month and day	Number of fry	Density (fry m^3)	Month and day	Number of days	Total length	Number of fry	Density (fish/m^3)	Survival rate	

				(10,000)			of culture	(mm)	(10,000 fish)		(%)	
1983			May 5			August 9						
			May 6			August 29						
1984			May 9			July 20						
			May 9			July 20						
			May 9			July 19						
1985			April 26			August 23						
			April 26			July 25						
			April 26			July 5						
1986			May 4			July 7						
			May 4			July 8						
1987			April 29			July 3						
			April 29			July 2						
			April 29			July 3						
1988			April 29			July 7						
			April 29			July 7						
			April 29			July 8						
1989			May 3			July 3						
			May 3			July 5						
			May 3			July 4						
1990			May 6									Complete loss from ALC tagging
			May 6									Complete loss from ALC tagging
			May 6									Complete loss from ALC tagging
			May 6									Complete loss from ALC tagging
			June 4									Complete loss from ALC tagging
			June 4									Complete loss from ALC tagging
			June 4									Complete loss from ALC tagging
1991			May 9			July 16						
			May 9									Complete loss from sudden water quality change
			May 9									Complete loss from sudden water quality change
			May 20			July 16						
1992			May 17			July 22						Mortalities from gas disease
			May 17			July 22						Mortalities from gas disease
			May 17			July 22						
1993			May 10			July 19						
			May 10			July 20						
			May 10			July 19						
			May 10			July 19						
1994			May 12			July 14						
			May 12			July 14						
			May 12			July 15						
1995			May 12			July 13						
			May 12			July 14						
			May 12			July 14						
1996			May 15			July 22						
			May 15			July 22						
			May 15			July 22						
1997			May 13			July 16						
			May 13			July 17						
			May 13			July 17						
1998			May 11			July 13						
			May 11			July 14						
1999			May 1			July 6						
			May 1			July 2						

年度	回次	水槽容量	収容			取り揚げ						備考
			月日	尾数	密度	月日	飼育日数	全長	尾数	密度	生残率	
		(㎥)		(万尾)	(尾/㎥)			(mm)	(万尾)	(尾/㎥)	(%)	
1983	1	15	5月5日	7.8	5,200	8月9日	96	55.6	4.8	3,200	61.5	
	2	20	5月6日	18.9	9,470	8月29日	115	72.6	5.5	2,750	29.1	
1984	1	20	5月9日	17.2	8,620	7月20日	72	45.5	10.9	5,450	63.4	
	2	15	5月9日	6.8	4,900	7月20日	72	47.3	5.8	3,867	85.3	
	3	15	5月9日	2.2	1,570	7月19日	71	45.9	1.5	1,000	68.2	
1985	1	20	4月26日	9.2	4,600	8月23日	119	77.6	0.6	300	6.5	
	2	50	4月26日	10.9	2,180	7月25日	90	58.0	6.8	1,360	62.4	
	3	50	4月26日	36.3	7,260	7月5日	70	46.5	25.3	5,060	69.7	
1986	1	50	5月4日	25.0	5,000	7月7日	64	46.7	15.3	3,060	61.2	
	2	50	5月4日	13.0	2,600	7月8日	65	47.7	9.3	1,860	71.5	
1987	1	50	4月29日	14.0	3,500	7月3日	65	45.2	7.2	1,440	51.4	
	2	50	4月29日	19.0	4,800	7月2日	64	46.8	9.2	1,840	48.4	
	3	50	4月29日	9.0	2,300	7月3日	65	44.5	4.7	940	52.2	
1988	1	50	4月29日	30.6	6,100	7月7日	69	50.2	4.8	960	15.7	
	2	50	4月29日	30.7	6,100	7月7日	69	55.1	8.4	1,680	27.4	
	3	50	4月29日	28.6	5,700	7月8日	70	53.7	5.9	1,180	20.6	
1989	1	50	5月3日	27.5	5,500	7月3日	61	53.8	10.3	2,060	37.5	
	2	50	5月3日	27.5	5,500	7月5日	63	51.4	8.8	1,760	32.0	
	3	50	5月3日	25.3	5,060	7月4日	62	55.5	9.8	1,960	38.7	
1990	1	50	5月6日	25.0	5,000	-	-	-	0	-	0.0	ALC標識時に全滅
	2	50	5月6日	21.8	4,360	-	-	-	0	-	0.0	ALC標識時に全滅
	3	20	5月6日	11.2	5,660	-	-	-	0	-	0.0	ALC標識時に全滅
	4	20	5月6日	9.0	4,500	-	-	-	0	-	0.0	ALC標識時に全滅
	5	50	6月4日	-	-	-	-	-	0	-	0.0	ALC標識時に全滅
	6	20	6月4日	-	-	-	-	-	0	-	0.0	ALC標識時に全滅
	7	20	6月4日	-	-	-	-	-	0	-	0.0	ALC標識時に全滅
1991	1	50	5月9日	50.5	10,100	7月16日	68	47.2	13	2,600	25.7	
	2	50	5月9日	55.2	11,000	-	-	-	0	-	0.0	水質急変による全滅
	3	20	5月9日	30.0	15,000	-	-	-	0	-	0.0	水質急変による全滅
	4	20	5月20日	6.8	3,400	7月16日	57	40.0	1.3	650	19.1	
1992	1	50	5月17日	67.7	13,500	7月22日	66	42.0	10.4	2,080	15.4	ガス病による斃死
	2	50	5月17日	59.0	11,800	7月22日	66	40.7	14.0	2,800	23.7	ガス病による斃死
	3	20	5月17日	24.9	14,600	7月22日	66	49.4	6.6	3,300	26.5	
1993	1	50	5月10日	38.7	8,600	7月19日	70	44.9	16.3	3,260	42.1	
	2	50	5月10日	42.4	9,400	7月20日	71	45.9	13.4	2,680	31.6	
	3	20	5月10日	18.8	11,000	7月19日	70	51.4	4.7	2,350	25.0	
	4	20	5月10日	18.4	10,800	7月19日	70	52.1	5.0	2,500	27.2	
1994	1	50	5月12日	47.8	9,500	7月14日	63	46.9	15.7	3,140	32.8	
	2	50	5月12日	49.5	9,900	7月14日	63	45.7	16.7	3,340	33.7	
	3	50	5月12日	50.6	10,000	7月15日	64	45.0	16.0	3,200	31.6	
1995	1	50	5月12日	82.1	14,900	7月13日	62	43.3	23.5	4,300	28.6	
	2	50	5月12日	75.4	13,700	7月14日	63	48.2	23.5	4,300	31.5	
	3	50	5月12日	74.4	13,500	7月14日	63	44.6	20.9	3,800	27.7	
1996	1	50	5月15日	63.2	12,600	7月22日	68	51.2	21.5	4,300	34.1	
	2	50	5月15日	65.0	13,000	7月22日	68	48.5	22.4	4,500	34.4	
	3	50	5月15日	68.9	13,800	7月22日	68	49.9	20.3	4,100	29.5	
1997	1	50	5月13日	48.2	9,640	7月16日	64	42.6	14.8	2,960	30.7	
	2	50	5月13日	47.8	9,560	7月17日	65	42.9	17.5	3,500	36.6	
	3	50	5月13日	44.2	8,840	7月17日	65	43.5	15.9	3,180	36.0	
1998	1	50	5月11日	60.4	12,080	7月13日	63	37.8	19.0	3,810	31.5	
	2	50	5月11日	61.5	12,300	7月14日	64	39.7	28.7	5,740	46.6	
1999	1	50	5月1日	74.5	14,900	7月6日	66	40.4	29.5	5,900	39.6	
	2	50	5月1日	79.3	15,860	7月2日	62	40.5	30.9	6,180	38.9	

Table List of Akkeshi herring fry production operations.

Year	Number of times	Tank volume (m^3)	Stocking			Fry produced						Source of broodstock	Comments
			Month and day	Number of fry (10,000)	Density (fry m^3)	Survival rate (%)	Month and day	Number of days of culture	Total length (mm)	Number of fish (10,000 fish)	Density (fry/m^3)		
1987			May 22				July 23					Cultured broodstock	
			May 22				July 24					3 year old fish from 1984	
1988			May 22				July 19					Cultured broodstock	
			June 8				August 3					4 year old fish from 1984	
1989			May 25				July 20					Cultured broodstock	
			May 25				August 3					2 year old fish from 1987	
1990			May 16				July 14					Cultured broodstock	
			May 16				July 14					3 year old fish from 1987	
1991			May 20				July 15					Cultured broodstock	
			May 20				July 15					4 year old fish from 1987	
1992			May 18				July 15					Cultured broodstock	Died from gas disease
			May 18				July 15					2 year old fish from 1991	
1993			May 10				July 12					Wild broodstock	
1994			May 15				July 15					Wild broodstock	
1995			May 11				July 13					Wild broodstock	
1996			May 15				July 25					Wild broodstock	
1997			May 13				July 18					Wild broodstock	
1998			May 17				July 15					Wild broodstock	
			May 17				July 16					Wild broodstock	
1999			May 5				July 7					Wild broodstock	
			May 5				July 8					Wild broodstock	

年度	回次	水槽容量 (㎥)	収容 月日	収容 尾数 (万尾)	収容 密度 (尾/㎥)	取り揚げ 月日	取り揚げ 飼育日数	取り揚げ 全長 (mm)	取り揚げ 尾数 (万尾)	取り揚げ 密度 (尾/㎥)	取り揚げ 生残率 (%)	親魚の由来	備考
1987	1	20	5月22日	10.6	5,900	7月23日	62	42.2	5.9	2,960	56.0	人工養成親魚	
	2	20	5月22日	8.5	4,700	7月24日	63	47.0	4.9	2,470	58.0	1984年種苗3歳	
1988	1	20	5月22日	10.0	5,000	7月19日	58	48.9	6.1	3,050	61.0	人工養成親魚	
	2	20	6月8日	6.0	3,000	8月3日	56	54.0	3.7	1,840	61.2	1984年種苗4歳	
1989	1	20	5月25日	6.5	3,250	7月20日	56	49.4	3.5	1,750	53.8	人工養成親魚	
	2	20	5月25日	6.4	3,200	8月3日	70	54.0	3.7	1,840	59.2	1987年種苗2歳	
1990	1	50	5月16日	10.9	2,180	7月14日	59	48.3	5.1	1,010	47.2	人工養成親魚	
	2	50	5月16日	15.3	3,060	7月14日	59	46.0	7.9	1,580	51.8	1987年種苗3歳	
1991	1	50	5月20日	31.2	6,200	7月15日	56	42.4	9.0	1,790	28.8	人工養成親魚	
	2	20	5月20日	11.5	5,700	7月15日	56	42.4	4.6	2,310	40.4	1987年種苗4歳	
1992	1	50	5月18日	24.2	4,800	7月15日	58	40.5	3.8	760	15.7	人工養成親魚	ガス病による斃死
	2	20	5月18日	8.1	4,700	7月15日	58	43.6	2.3	1,350	28.4	1991年種苗2歳	
1993	1	50	5月10日	29.5	6,500	7月12日	63	45.5	13.9	3,090	47.2	天然親魚	
1994	1	55	5月15日	58.4	10,600	7月15日	61	44.3	22.1	4,000	37.9	天然親魚	
1995	1	50	5月11日	48.9	8,900	7月13日	63	45.9	18.1	3,300	45.9	天然親魚	
1996	1	50	5月15日	60.2	12,000	7月25日	71	48.1	27.5	5,500	45.7	天然親魚	
1997	1	50	5月13日	61.6	12,320	7月18日	66	40.6	19.4	3,890	31.6	天然親魚	
1998	1	50	5月17日	55.2	11,040	7月15日	59	39.5	25.4	5,080	46.0	天然親魚	
	2	50	5月17日	67.6	13,520	7月16日	60	40.3	38.8	7,760	57.4	天然親魚	
1999	1	50	5月5日	44.3	8,860	7月7日	63	41.2	18.2	3,630	41.0	天然親魚	
	2	50	5月5日	69.5	13,900	7月8日	64	41.0	31.3	6,260	45.0	天然親魚	

Table Results of fry production from different facilities that produced herring seed.

Name of Facility: Miyagi Prefecture Aquaculture Center			
Year	**Location**	**Body length (mm)**	**Number of fry (10,000 fish)**
1982			
1983			
1984			
1985	Ishinomakikou Bay		
1986	Ishinomakikou Bay		
1987	Ishinomakikou Bay		
1988	Ishinomakikou Bay		
1989	Ishinomakikou Bay		
1990	Ishinomakikou Bay		
1991	Ishinomakikou Bay		
1992	Ishinomakikou Bay		
1993	Ishinomakikou Bay		
1994	Ishinomakikou Bay, Matsushima Bay		
1995	Matsushima Bay		
1996	Ishinomakikou Bay, Matsushima Bay		
1997	Matsushima Bay		
1998	Ishinomakikou Bay, Matsushima Bay		
1999	Matsushima Bay		

Name of Facility: Japan Aquaculture Association Miyako Station (Corporation)			
Year	**Location**	**Body length (mm)**	**Number of fry (10,000 fish)**
1982	Man'ishi Inlet		
1983	Man'ishi Inlet		
1984	Man'ishi Inlet		
1985	Man'ishi Inlet		
1986	Man'ishi Inlet		
1987	Man'ishi Inlet		
1988	Man'ishi Inlet		
1989	Man'ishi Inlet		
1990	Man'ishi Inlet		
1991	Man'ishi Inlet		
1992	Man'ishi Inlet		
1993	Man'ishi Inlet		
1994	Man'ishi Inlet		
1995	Man'ishi Inlet, Matsushima Bay		
1996	Matsushima Bay, Miyako Bay		
1997	Matsushima Bay, Miyako Bay		
1998	Matsushima Bay, Miyako Bay		
1999	Matsushima Bay, Miyako Bay		

Name of Facility: Japan Aquaculture Association Akkeshi Station (Corporation)			
Year	**Location**	**Body length (mm)**	**Number of fry (10,000 fish)**
1982	Furen Lake, Notoro Lake		
1983	Furen Lake		
1984	Furen Lake		
1985	Furen Lake , Saroma Lake		
1986	Furen Lake		
1987	Furen Lake, Akkeshi		
1988	Furen Lake, Akkeshi		
1989	Furen Lake, Akkeshi		
1990	Furen Lake, Akkeshi		
1991	Furen Lake, Akkeshi,		
1992	Furen Lake, Akkeshi,		
1993	Furen Lake, Akkeshi		
1994	Furen Lake, Akkeshi, Notsuke Bay		
1995	Furen Lake, Akkeshi, Notsuke Bay		
1996	Furen Lake, Akkeshi		
1997	Furen Lake, Akkeshi		
1998	Furen Lake, Akkeshi		
1999	Furen Lake, Akkeshi		

Name of Facility: Hokkaido Aquaculture Association promotion (Public Corporation), Haboro Station			
Year	**Location**	**Body length (mm)**	**Number of fry (10,000 fish)**
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992			
1993			
1994			
1995			
1996	Atsuta		
1997	Atsuta, Rumoi		
1998	Atsuta, Rumoi, Wakkanai		
1999	Atsuta, Rumoi		

Name of Facility: Aomori Prefecture Aquaculture Center			
Year	**Location**	**Body length (mm)**	**Number of fry (10,000 fish)**
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991	Nohenchi Bay		
1992	Miyako Bay		
1993	Miyako Bay		
1994	Miyako Bay		
1995	Nohenchi Bay, Miyako Bay		
1996			
1997			
1998			
1999			

Name of Facility: Hokkaido Aquaculture Composite Center			
Year	**Location**	**Body length (mm)**	**Number of fry (10,000 fish)**
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992			
1993			
1994			
1995			
1996			
1997	Sakhalin		
1998	Sakhalin		
1999			

機関名：　宮城県栽培漁業センター

年度	産地	全長（mm）	尾数（万尾）
昭和57			
昭和58			
昭和59			
昭和60	石巻湾	48.0	14.4
昭和61	石巻湾	51.0	26.0
昭和62	石巻湾	45.0	57.0
昭和63	石巻湾	43.0	54.0
平成元	石巻湾	47.0	52.0
平成2	石巻湾	48.1	50.0
平成3	石巻湾	43.2	22.0
平成4	石巻湾	45.8	45.2
平成5	石巻湾	52.3	79.9
平成6	石巻湾，松島湾	46.2	112.0
平成7	松島湾	54.2	48.0
平成8	石巻湾，松島湾	45.8	43.6
平成9	松島湾	48.6	62.0
平成10	石巻湾，松島湾	44.1	70.0
平成11	松島湾	43.6	156.0

機関名：　（社）日本栽培漁業協会宮古事業場

年度	産地	全長（mm）	尾数（万尾）
昭和57	万石浦	29.6	5.6
昭和58	万石浦	63.3	10.3
昭和59	万石浦	41.1	23.7
昭和60	万石浦	42.5	32.3
昭和61	万石浦	46.2	30.0
昭和62	万石浦	43.0	30.9
昭和63	万石浦	38.4	55.0
平成元	万石浦	45.3	22.1
平成2	万石浦	41.5	36.0
平成3	万石浦	54.5	49.9
平成4	万石浦	44.5	100.1
平成5	万石浦	46.8	58.7
平成6	万石浦	47.4	82.5
平成7	万石浦，松島湾	52.5	98.4
平成8	松島湾，宮古湾	42.1	76.7
平成9	松島湾，宮古湾	-	0.0
平成10	松島湾，宮古湾	39.6	84.0
平成11	松島湾，宮古湾	40.3	129.0

機関名：　（社）日本栽培漁業協会厚岸事業場

年度	産地	全長（mm）	尾数（万尾）
昭和57	風蓮湖，能取湖	65.9	8.4
昭和58	風蓮湖	65.2	10.3
昭和59	風蓮湖	46.1	18.3
昭和60	風蓮湖，サロマ湖	63.2	33.8
昭和61	風蓮湖	46.4	25.4
昭和62	風蓮湖，厚岸	48.8	33.6
昭和63	風蓮湖，厚岸	52.2	29.7
平成元	風蓮湖，厚岸	52.3	39.4
平成2	風蓮湖，厚岸	48.5	15.6
平成3	風蓮湖，厚岸	42.3	27.9
平成4	風蓮湖，厚岸	42.4	37.2
平成5	風蓮湖，厚岸	46.6	53.5
平成6	風蓮湖，厚岸，野付湾	44.5	76.1
平成7	風蓮湖，厚岸，野付湾	45.8	90.4
平成8	風蓮湖，厚岸	49.4	91.7
平成9	風蓮湖，厚岸	42.4	67.6
平成10	風蓮湖，厚岸	39.4	111.9
平成11	風蓮湖，厚岸	40.7	109.9

機関名：　（社）北海道栽培漁業振興公社羽幌事業所

年度	産地	全長（mm）	尾数（万尾）
昭和57			
昭和58			
昭和59			
昭和60			
昭和61			
昭和62			
昭和63			
平成元			
平成2			
平成3			
平成4			
平成5			
平成6			
平成7			
平成8	厚田	45.5	20.6
平成9	厚田，留萌	45.4	51.5
平成10	厚田，留萌，稚内	46.4	148.5
平成11	厚田，留萌	42.6	226.3

機関名：　青森県水産増殖センター

年度	産地	全長（mm）	尾数（万尾）
昭和57			
昭和58			
昭和59			
昭和60			
昭和61			
昭和62			
昭和63			
平成元			
平成2			
平成3	野辺地湾	45.2	3.3
平成4	宮古湾	78.3	4.8
平成5	宮古湾	43.1	6.0
平成6	宮古湾	54.3	11.2
平成7	野辺地湾，宮古湾	41.8	5.8
平成8			
平成9			
平成10			
平成11			

機関名：　北海道栽培漁業総合センター

年度	産地	全長（mm）	尾数（万尾）
昭和57			
昭和58			
昭和59			
昭和60			
昭和61			
昭和62			
昭和63			
平成元			
平成2			
平成3			
平成4			
平成5			
平成6			
平成7			
平成8			
平成9	サハリン	42.6	1.9
平成10	サハリン	44.1	2.7
平成11			

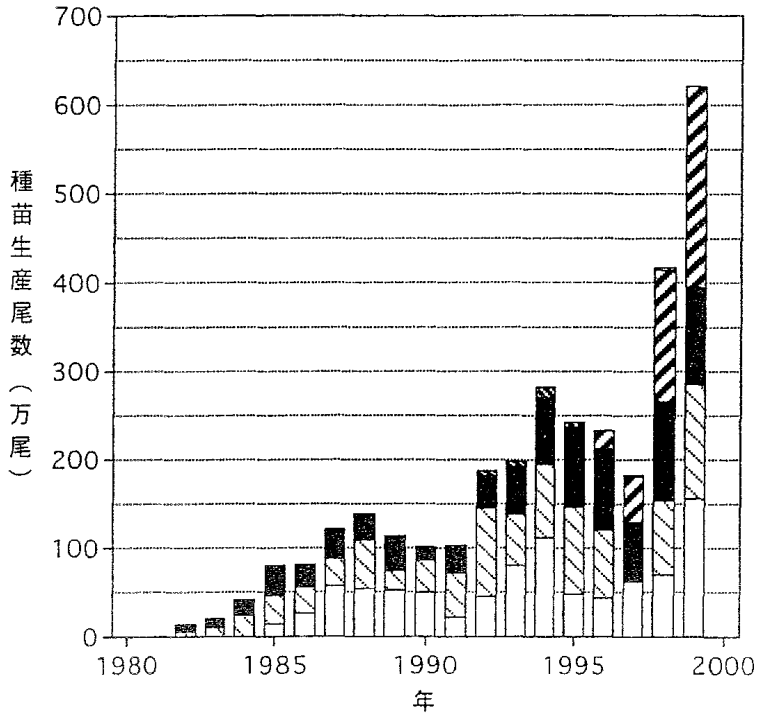

図　全国の種苗生産機関のニシン種苗生産尾数の年度別推移

□ 宮城県栽培漁業センター　▨ ㈱日本栽培漁業協会宮古事業場
■ ㈱日本栽培漁業協会厚岸事業場
▨ ㈱北海道栽培漁業振興公社羽幌事業所
▩ 青森県水産増殖センター　▥ 北海道栽培漁業総合センター

Figure Change over multiple years in the number of herring fry produced throughout Japan.
[y axis] Number of fry produced (10,000 fry)
[x axis] year
□ Miyagi Prefectural Aquaculture Center
□ [Crosshatching with light backward slash (\)] Japan Aquaculture Association, Miyako Station (Corporate)
■ Japan Aquaculture Association, Akkeshi Station (Corporate)
□ [Crosshatching with bold forward slash (/)] Hokkaido Aquaculture Promotion Corporation, Haboro Station (Corporate)
□ [Crosshatching with bold backward slash (\)] Aomori Prefectural Aquaculture Center
□ [Crosshatching with vertical lines (|)] Hokkaido Aquaculture Composite Center

Table List of herring egg collection test results at Akkeshi Station.

Year [translator's Note: this column was for years in Japanese format]	Western Year	Furen Lake (wild)			Akkeshi Lake (wild)			Akkeshi Lake (cultured)				Other			
		Number of broodstock		Number of eggs collected (10,000 eggs)	Number of broodstock		Number of eggs collected (10,000 eggs)	Number of broodstock		Number of eggs collected (10,000 eggs)	Fry history	Location	Number of broodstock		Number of eggs collected (10,000 eggs)
1982	1982											Notsuke Bay			
1983	1983														
1984	1984											Akkeshi Lake (wild cultured)			
1985	1985											Saroma Lake			
1986	1986														
1987	1987										1984 fry 3 years old	Akkeshi Lake (wild cultured)			
1988	1988										1984 fry 4 years old				
1989	1989										1987 fry 2 years old				
1990	1990										1987 fry 3 years old				
1991	1991										1987 fry 4 years old				
1992	1992										1990 fry 2 years old				
1993	1993														
1994	1994											Notsuke Bay			
1995	1995											Notsuke Bay			
1996	1996														
1997	1997														
1998	1998														
1999	1999														

Table Examples of herring egg treatments (1997). Natural seawater temperature group.

Month and year	Water temperature (ºC)			Production test: Akkeshi Lake				Summary
						*Egg development	Number of larvae hatched	
	Day of week	AM	PM	Number of days	Accumulated water temperature (ºC)	Stage	(Individual fish)	
April 9	Wednesday							Eggs collected from Akkeshi Lake at 11:40 AM were transferred to 127 hatching screens.
April 10	Thursday							
April 11	Friday							
April 12	Saturday							
April 13	Sunday							
April 14	Monday							
April 15	Tuesday							
April 16	Wednesday							
April 17	Thursday							
April 18	Friday							
April 19	Saturday							
April 20	Sunday							
April 21	Monday							
April 22	Tuesday							
April 23	Wednesday							
April 24	Thursday							
April 25	Friday							
April 26	Saturday							
April 27	Sunday							
April 28	Monday							
April 29	Tuesday							
April 30	Wednesday							
May 1	Thursday							
May 2	Friday							
May 3	Saturday							
May 4	Sunday							Hatching observed
May 5	Monday							
May 6	Tuesday							
May 7	Wednesday							
May 8	Thursday							
May 9	Friday							
May 10	Saturday							
May 11	Sunday							
May 12	Monday							All eggs stocked on hatch screens between 10:30-11:25 AM
May 13	Tuesday							
Total								

Seawater at 10ºC temperature group.

Month and year	Water temperature (ºC)			Production test number 3: Akkeshi Lake				Summary
						*Egg development	Number of fry hatched	
	Day of week	AM	PM	Number of days	Accumulated water temperature (ºC)	Stage	Individual fish	
May 1	Thursday							No. 3 egg harvest at Akkeshi Lake. Put on 13 hatch screens at 11:30 AM.
May 2	Friday							
May 3	Saturday							
May 4	Sunday							
May 5	Monday							
May 6	Tuesday							
May 7	Wednesday							
May 8	Thursday							
May 9	Friday							
May 10	Saturday							
May 11	Sunday							
May 12	Monday							Hatching observed
May 13	Tuesday							
May 14	Wednesday							
May 15	Thursday							Nearly all hatched
May 16	Friday							Total number of larvae observed
Total								

*Egg development stages are based on tests for commercializing new culture techniques at Hokkaido Fisheries Research Lab in 1972.

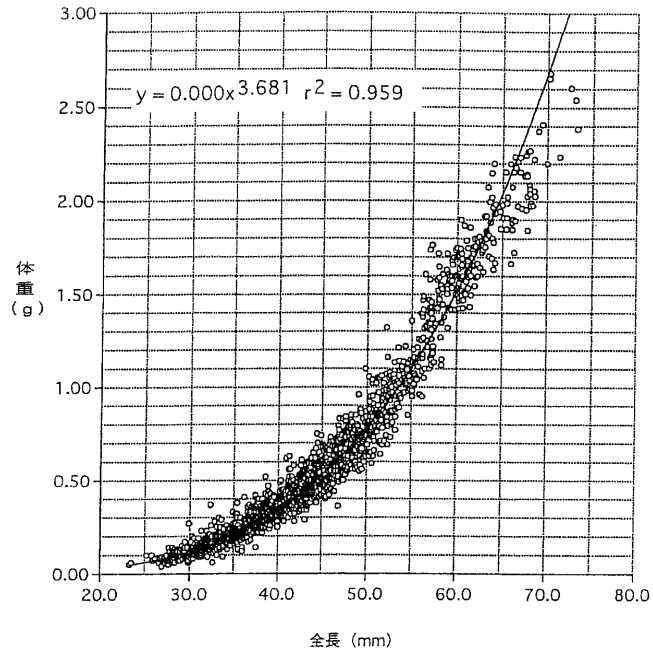

Figure Relationship between total length and weight of cultured herring fry.
[y axis] Body weight (g)
[x axis] Total length (mm)

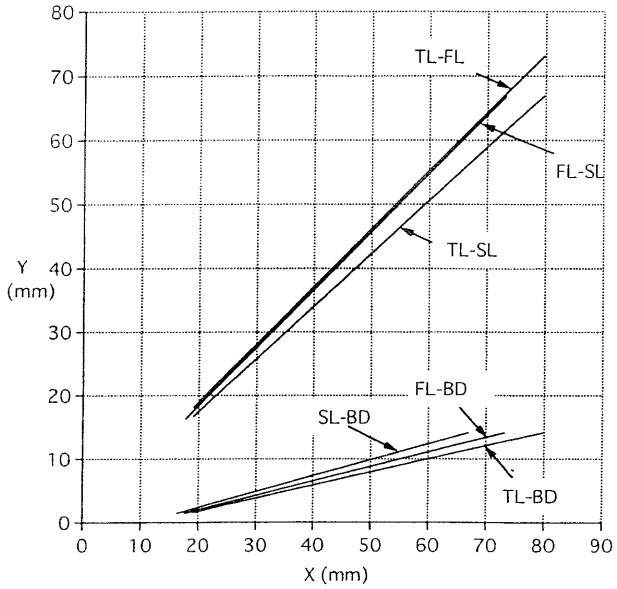

Figure Correlation between total length, fork length, body length, and body depth in culture herring fry.
X: Total length (TL). Y: Fork length (FL) $y=0.907x + 0.841$ $r^2=0.995$
X: Total length (TL). Y: Body length (SL) $y=0.828x + 0.909$ $r^2=0.996$
X: Total length (TL). Y: Body depth (BD) $y=0.208x - 2.448$ $r^2=0.962$
X: Fork length (FL). Y: Body length (SL) $y=0.910x + 0.259$ $r^2=0.995$
X: Fork length (FL). Y: Body depth (BD) $y=0.229x - 2.623$ $r^2=0.963$
X: Body length (SL) Y: Body depth (BD) $y=0.25lx - 2.656$ $r^2=0.962$

Table List of equipment used for collecting eggs (in the case when 5,000,000 eggs are collected).

Item	Check box	Name of item	Number or amount
Taking measurements and making counts	□	Plank for measuring total length	
	□	Electronic balance	
	□	Plastic plates (for use in measurements)	
	□	Field notebooks	
	□	Calculator	
	□	Writing instruments	
	□	Ethanol	
	□	Sample bottles	
Egg collection	□	Dissection scissors	
	□	Spoon for weighing eggs	
	□	Rubber spatula	
	□	Small container (for removing eggs)	
	□	Netting for squeezing testis	
	□	Strainer for holding eggs and bowl for holding sperm	
	□	Large container (when attaching eggs to the hatching trays)	
	□	Feather brush	
	□	Mabushi brush made of hemp palm	
	□	Bucket	
	□	500ℓ hydrosulfite tank (filled with filtered seawater)	
	□	ϕ25 mm diameter hose, 7 m, with attached valve	
	□	1 ton FRP water tank (stocked with Mabushi hemp palm brushes)	
		ϕ40 mm diameter hose for use as a siphon	
Transport	□	Urathane mats (used for maintaining temperature during transport	
	□	Container for storing equipment (with lid attached)	
Other	□	Water thermometer	
	□	Storage containers for storing small items	
	□		

Table List of equipment for landing herring

Item	Check box	Name of item	Number or amount
	□	Large compressed oxygen cylinder	
	□	Oxygen regulator	
	□	Dispersion device	
Landing	□	Six connector oxygen regulating device	
	□	Minnow nets for landing fry (racquet type)	
	□	Small mesh, (260 kei [number of twines in 50 cm]) (2 attached to J water tank)	
	□	Buckets	
	□	Round net	
	□	Ledger	
	□	Calculator	
	□	Memo pad, writing instruments	
	□	Digital scale	
	□	Counter	
	□	The drug Erubaajyu (sodium nifrustyrenate) (400 g/tank)	
	□	Small underwater pump for filling buckets	
	□	400 W underwater pump for transferring culture water	
	□	50-mm hose (30 m)	
	□	Extension cords (for 3 pumps, for 1 scale)	
	□	500 ml sample bottles	
	□	Foot stool for inside water tank	
	□	Required personnel	

Table List of required offshore materials

Item	Work stations	Check box	Name of item	Number or amount
			Compressed oxygen cylinder, large	
			Compressed oxygen cylinder, small	
			Water tanks for transport	
Distribution			Air dispersion devices used for transport	
			Air dispersion devices used for landing	
			Air dispersion devices plus air hose (1.5 m)	
			Oxygen regulator	
			Wire to use with the transport tanks (2 per tank)	
			Distribution records	
	5 stations		Buckets	
			50-mm hose for stocking nets (6 m)	
			PVC pipe stands under transport tanks	
			Net support rods (bamboo)	
			Dip nets for landing (racket type)	
	2 stations		Large goldfish dip nets	
			Camera	
			50-mm underwater pump, 400 W	
			50-mm hose (30 m)	
			Andon circular tanks with 260 kei netting [kei is the number of twines in 50 cm] used for transport tank water exchange	
			40-mm hoses for andon circular tank discharge water	
			Extension cords (for underwater pump)	
			Adequate personnel	

Table Calculation 1 of production costs when the number produced is 1,000,000 herring fry.

	Name of item	Number or amount	Units	Unit cost	Total cost	Years for depreciation	Amortization calculation	Use and details
Material costs	Egg collecting gear		1 set					Feather brushes, rubber spatula, containers, dissection scissors, bowl, measuring spoon, gloves,
	Hatching screen		Screen Layer					Wooden frames, nylon netting, nails, stapler
	Hatching screen frames		Each					Frames made of stainless steel and accommodating 15 hatching screens
	Container used for hatching eggs		Each					60 ℓ container
	Materials for water supply and water drainage		1 set					Canaline hose (diameter 25, and 50 mm), vinyl chloride fittings, adhesives
	Frames for andon circular tank drainage		Each					Securing cables made of stainless steel, 2 water tanks
	Nets for andon circular tank drainage		Layers					4 types with different meshes, reinforced edges, securing cords.
	Aeration materials		1 set					Air stones x 4, 50-m air tubes, air hose x 4
	Rotifer culture materials		1 set					Air stones x 20, 50-m air tubes, contact aeration materials, refuse mats x 5; 100ℓ Panlite water tanks
	Rotifer harvesting materials		1 set					64μ nylon netting, container for harvesting 200ℓ, vinyl chloride fittings, buckets, measuring cups, 0.5m^3 Panlite water tanks
	Rotifer and *Artemia* culture materials		1 set					Air stones x 25, air tubes 100 m
	Artemia harvesting materials		1 set					300μ nylon netting, stainless frame, containers for harvesting 50ℓ, vinyl chloride fittings, buckets, measuring cups, 0.5m^3 Panlite water tanks
	Netting materials for harvesting		1 set					Round haul net, minnow netting
	Landing materials		1 set					Buckets x 50, Canaline hose (diameter 50 mm), foot stand
	Small mesh netting for stocking		1 set					5 water tanks x 2
	Transfer materials		1 set					Dispersal devices, hose for use with oxygen, buckets x 5, Canaline hose (diameter 50 mm, minnow netting
	Bottom cleaning materials		1 set					Water tanks for accepting drainage water, retrieval netting, 25-mm diameter Canaline hose, vinyl chloride tubes, wood poles
	Materials for making tags		1 set					100ℓ Panlite water tank x 2, air stone+ hoses x 2, buckets
	Materials used for making measurements		1 set					Measuring tray, various types of forceps, various types of syringes, plates, haemocytometer, glass slides, cover glasses, harvesting equipment
	Materials for sampling		1 set					Sampling bottles, organizing boxes, labelling materials
	Subtotal							

Table Calculation 2 of production costs when the number produced is 1,000,000 herring fry.

Material costs	Name of item	Number or amount	Units	Unit cost	Total cost	Years for depreciation	Amortization calculation	Use and details
	Tanks for feed		Tank					Commercial *Artemia* hatching tank (1 m^3)
	Experimental tanks		Tank					Panlite polycarbonate resin water tank (0.5 m^3)
	Pump for fixed amount of rotifer yeast		Each					Mate
	Underwater pump for waste water		Each					400 W for 50 mm diameter hose
	Automatic bottom cleaning equipment		Each					Yamaha (conversion)
	Automatic feeding equipment		Each					Yamaha
	Water tanks for transport		Tanks					Volume 1 m^3
	High speed mixer		Each					Mixing yeast
	Desk top mixer		Each					Emulsification of nutritional enhancement factors
	Digital scale		Each					Weighing feed, etc.
	Electric balance		Each					Body weight measurements
	Digital callipers		Each					Body length measurements
	Transmission microscope		Each					Observational measurements
	Stereo dissecting microscope		Each					Observation
	All purpose projector		Each					Observation, body length measurements
	Fluorescence microscope		Each					Otolith tag recognition
	Incubator		Each					Rotifer storage
	Chemical cabinet		Each					Storing chemicals and glassware
	Refrigerator		Each					Storing chemicals and feed-enhancement compounds
	Freezer		Each					Sample storage
	Laboratory testing benches		Each					Used for sample preparation, measurements
	Water thermometer, pH meter		Each					Water quality measurements
	DO meter		Each					Water quality measurements
	Salinity meter		Each					Water quality measurements
	Personal computer		Each					Used for data manipulation
	Oxygen aeration regulator		Each					Used for transport
	1 KW heater thermostat		Each					Used for heating
	Washing equipment		Each					Washing nets, tanks, etc.
	Subtotal							

Table Calculation 3 of production costs when the number produced is 1,000,000 herring fry.

	Name of item	Number or amount	Units	Unit cost	Total cost	Years for depreciation	Amortization calculation	Use and details
Drug costs	Sodium hypochlorate		Each					Disinfectant used for tanks, 20 ℓ containers
	Sodium thiosulfate		Bag					Used to neutralize hypochlorate, 20 kg
	Fisheries grade Isojin Disinfectant (isodine, an iodine disinfectant)		Each					Used as an egg dip, 3ℓ
	Formalin		Each					Storage of samples, 20ℓ containers
	Sodium nifrustyrenate for use in fisheries		kg					Used for transfer tanks during the transfer, 1 kg
	ALC		Container					Otolith tagging, 100 g
	Tetracycline hydrochloride		Kg					Otolith tagging
	FA-100		Container					Used for anaesthesia, 100 ml
	Potassium iodide		Container					Used to determine if there is residual chlorine, 500 g
	Subtotal							
	Yeast		Box					15 kg/box, used to feed rotifers
	Fresh greens		Each					Used to feed rotifers, 20ℓ container
	Artemia		Can					500 g/can
	Frozen concentrated Nanno		Each					Nutritional green water additives, 15ℓ
	Aquaran		kg					Nutritional enhancement of rotifers and *Artemia,* 1 kg
	Formula feed Kyowa Fermentation B-400		Kg					5 kg/box
	Formula feed Kyowa Fermentation C-700		Kg					10 kg/box
	Formula feed Kandei Feeds Otohime A2		Kg					2 kg/box
	Formula feed Kandei Feeds Otohime B2		Kg					5 kg/box
	Formula feed Kandei Feeds Otohime Number 1		Kg					10 kg/box
	Subtotal							
Brood stock costs	Landing herring		kg					1000 yen/kg
	Subtotal							

Table Calculation Number 4 of the production costs per 1,000,000 herring fry

Light and heating costs	Heating expenses	A fuel oil		Month					Calculated at 200,000 per month (early April to late July)
		Electric costs		Month					Calculated at 400,000 per month (early April to late July)
		Water costs		Month					Calculated at 50,000 per month (early April to late July)
	Subtotal								
Labor costs	Researchers			Person					250,000 yen x 18 months
	Part time			Person					100,000 yen x 12 months
	Subtotal								
Facility costs	Exchanging sand filters			Filters					Once in 5 years
	Pump maintenance			Pump					Once in 3 years
	Cleaning plumbing			Time					Once in 2 years
	Boiler maintenance			Boilers					Once a year
	Electric inspections			Inspection					Contracted
	Construction work			Time					
	Subtotal								
Vehicle costs	Truck (1.5 t)			Truck					
	Forklift			Truck					
	Subtotal								

Table Cost of producing herring seed (1,000,000 fry produced)

Item	Total costs (yen)	Percentage (%)
Material costs		
Equipment		
Medications		
Feed costs		
Costs for adult parent fish		
Light and heating costs		
Labor costs		
Facility costs		
Vehicle costs		
Total		

Unit seed costs 18.9 yen/fish

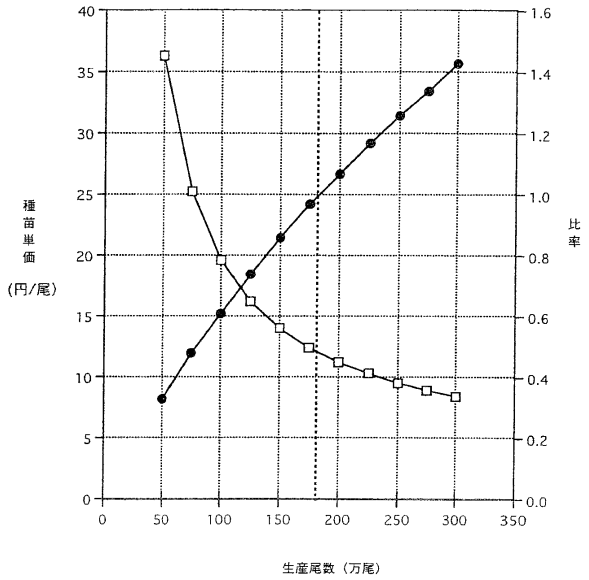

図 ニシン種苗生産の生産尾数と生産単価及び予想される収支比率の関係
—□— 種苗単価 —●— 比率（回収／経費）

Figure Number of herring seed produced, unit production costs, and estimated net expenditures. -□- Unit seed cost, -●- Ratio (recovery/costs), [y axis left] costs per seed (yen/fish), [y axis right] Ratio, [x axis] Number of fish produced (10,000 fish)

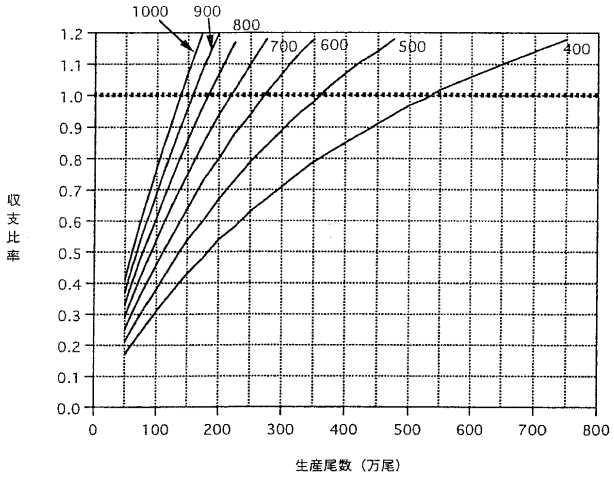

図 異なる市場単価別のニシン種苗生産尾数と収支比率の関係
（図中の数字は市場単価（円/kg）を示す）

Figure Relationship between different commercial unit costs for the number of herring produced and net expenditures. (The numbers in the figure represent market value unit prices (yen/kg). [y axis] Expenditure ratio, [x axis] Number of fish produced (10,000 fish)

Table Summary of rearing and culture water tanks at the Bekkai town herring seed production center

Type	Water capacity	Material	Dimensions	Number	Use
Rectangular					Seed production
Rectangular					Rotifer culture
Rectangular					Feed enhancement
Rectangular					Feed enhancement
Circular					Feed enhancement
Circular					Hatching *Artemia*

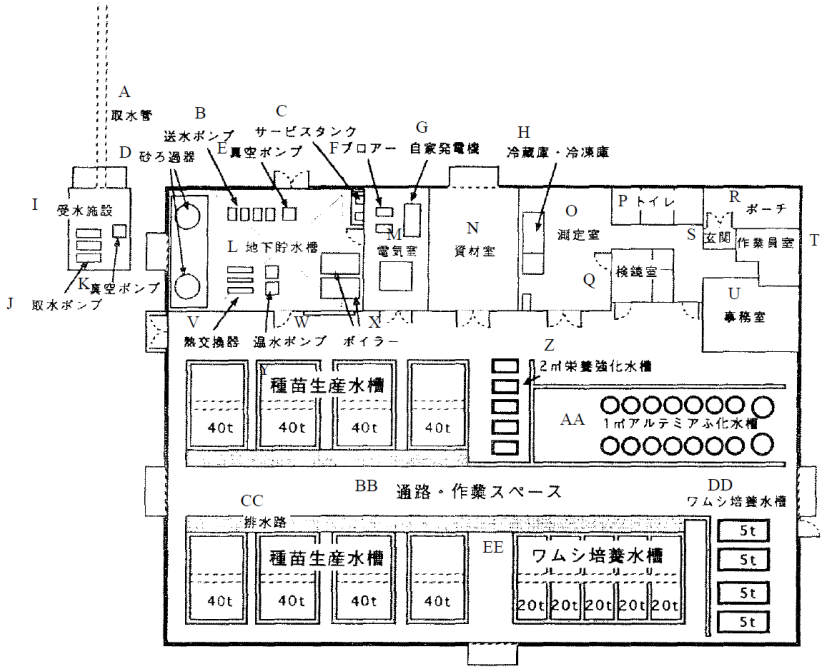

Figure Culture facilities at Bekkai town for producing herring seed. (Modifications in the equipment at the herring seed production center facility at Bekkai town.)
[A] Water pipes from freshwater source
[B] Transfer pump
[C] Service tank
[D] Sand filter
[E] Vacuum pump
[F] Blower
[G] Automatic generator
[H] Refrigerator and freezer
[I] Incoming water treatment
[J] Pump for water from freshwater source
[K] Vacuum pump
[L] Underground water storage tanks
[M] Electric power room
[N] Storage room

[O] Measurement room
[P] Toilet
[Q] Microscope room
[R] Porch
[S] Entrance
[T] Employee room
[U] Office
[V] Heat exchanger
[W] Warm water pump
[X] Boiler
[Y] Larval culture tanks
[Z] 2 m^3 nutritional enhancement tanks
[AA] 1 m^3 *Artemia* hatching tank
[BB] Walkway and operational space
[CC] Water discharge route
[DD] Rotifer culture tank
[EE] Rotifer culture tank

Table List of people responsible for herring seed production at Akkeshi Station.

Year	Person responsible	People with secondary responsibility	
1981	Kazuhisa Yamamoto		
1982	Kazuhisa Yamamoto	Akio Yamamoto	Chokujin Samurakami
1983	Kazuhisa Yamamoto	Shoukou Kamoshita	
1984	Kazuhisa Yamamoto	Shoukou Kamoshita	
1985	Kazuhisa Yamamoto	Shoukou Kamoshita	
1986	Kazuhisa Yamamoto	Tadahiko Nario	
1987	Kazuhisa Yamamoto	Tadahiko Nario	
1988	Kazuhisa Yamamoto	Tadahiko Nario	Akira Katahashi
1989	Kazuhisa Yamamoto	Tadahiko Nario	Akira Katahashi
1990	Kazuhisa Yamamoto	Masahiro Nakagawa	Katsumi Tsurumaki
1991	Kazuhisa Yamamoto	Masahiro Nakagawa	Katsumi Tsurumaki
1992	Kazuhisa Yamamoto	Masahiro Nakagawa	Hiroyuki Ohana
1993	Kazuhisa Yamamoto	Hiroyuki Ohana	
1994	Kazuhisa Yamamoto	Hiroyuki Ohana	
1995	Hiroyuki Ohana	Shigenori Suzuki	
1996	Hiroyuki Ohana	Akira Nakagawa	
1997	Kazuhisa Yamamoto	Akira Nakagawa	
1998	Kazuhisa Yamamoto	Shouichi Ashitate	
1999	Kazuhisa Yamamoto	Shouichi Ashitate	Takurou Hotsuta
2000	Kazuhisa Yamamoto	Shouichi Ashitate	