Herring on Canada's Pacific Coast

A.S. Hourston and C.W. Haegele

Canadian Special Publication of Fisheries and Aquatic Sciences 48

Government of Canada
Fisheries and Oceans

Gouvernement du Canada
Pêches et Océans

CANADIAN SPECIAL PUBLICATION OF FISHERIES AND AQUATIC SCIENCES 48

Herring on Canada's Pacific Coast

A. S. Hourston
C. W. Haegele

Department of Fisheries and Oceans
Resource Services Branch
Pacific Biological Station
Nanaimo, B.C. V9R 5K6

DEPARTMENT OF FISHERIES AND OCEANS
Ottawa 1980

Published by

Government of Canada
Fisheries and Oceans

Scientific Information
and Publications Branch

Ottawa K1A 0E6

Publié par

Gouvernement du Canada
Pêches et Océans

Direction de l'information
et des publications scientifiques

Available from:

Department of Fisheries and Oceans
Resource Services Branch
Pacific Biological Station
Nanaimo, B.C. V9R 5K6

Catalog No. Fs 41-31/48E ISSN 0706-6481
ISBN 0-662-11082-X

Printed in Canada
by
Campbell Printing

Correct citation for this publication:

HOURSTON, A. S., AND C.W. HAEGELE. 1980. Herring on Canada's Pacific coast. Can. Spec. Publ. Fish. Aquat. Sci. 48: 23 p.

Contents

List of Figures

Abstract

HOURSTON, A. S., AND C. W. HAEGELE. 1980. Herring on Canada's Pacific coast. Can. Spec. Publ. Fish. Aquat. Sci. 48: 23 p.

Pacific herring are distributed on the continental shelf and inshore waters of the north Pacific from Mexico to Korea. The center of abundance in the eastern Pacific is the coast of British Columbia. Here spawning occurs on vegetation in and below the intertidal zone. About 2 wk after spawning, the eggs hatch into fragile, thread-like larvae that metamorphose into juvenile fish about 10 wk later. Towards the end of the summer, the juveniles migrate in large schools to feeding grounds on the continental shelf, where they remain until they mature, usually after their third growth season. They then join the adult schools for their annual migrations to the spawning grounds. Mortality, mainly from predation, is relatively heavy throughout the life history but is heaviest during the larval stage (99%).

The adult stocks, which currently average about 350 000 tons (33 billion fish) on the British Columbia coast, have been fished commercially for over a century. Between 1909 and 1927, the catch rose from 30 000 to 85 000 tons and then declined again to 30 000 tons by 1934 with the rise and fall of the dry-salted herring market in the Orient. The industry then turned to reduction to fish meal and oil and the catch increased to an average of 100 000 tons between 1938 and 1966. The stocks experienced a sharp decline in abundance over the next 2 yr and the fishery was closed to conserve the resource. This decline resulted from attempts to maintain catch quotas during a period of low recruitment, resulting in overfishing. Following the recovery of the stocks and the development of a lucrative market for herring roe in Japan, a "roe fishery" began in 1972 which accounts for the bulk of the recent catches. Other fisheries are for spawn on kelp, food herring and bait. New management strategies were developed to provide for better protection and use of the resource. Current management practice is geared to providing predetermined spawning escapements, with the surplus allotted to the various fisheries in the form of target catches.

Résumé

HOURSTON, A. S., AND C. W. HAEGELE. 1980. Herring on Canada's Pacific coast. Can. Spec. Publ. Fish. Aquat. Sci. 48: 23 p.

Le hareng du Pacifique est réparti sur le plateau continental et dans les eaux côtières du Pacifique nord, du Mexique à la Corée. Le centre d'abondance dans le Pacifique oriental est la côte de la Colombie-Britannique. Dans cette région, la ponte a lieu sur la végétation à l'intérieur et au-dessous de la zone intertidale. Environ 2 sem après la ponte, les oeufs éclosent en larves filiformes fragiles qui, environ 10 sem plus tard, se transforment en jeunes poissons. Vers la fin de l'été, ces derniers émigrent en grands bancs vers des aires d'alimentation sur le plateau continental. Ils y demeurent jusqu'à la maturité, ordinairement après leur troisième saison de croissance. Les jeunes harengs rejoignent alors les bancs d'adultes et entreprennent leurs migrations annuelles vers les lieux de ponte. Les mortalités, surtout dues à la prédation, sont relativement fortes durant tout le cycle biologique, mais elles le sont particulièrement durant la phase larvaire (99%).

Les stocks adultes, qui sont présentement d'environ 350 000 t (33 milliards d'individus) sur la côte de la Colombie-Britannique sont, depuis plus d'un siècle, l'objet d'une pêche commerciale. De 1909 à 1927, la prise augmenta, passant de 30 000 à 85 000 t pour ensuite diminuer de nouveau à 30 000 t, niveau atteint en 1934, parallèlement aux fluctuations du marché du hareng salé en Orient. L'industrie se tourna alors vers la fabrication de farine et d'huile de poisson; comme résultat, la prise augmenta, passant à une moyenne de 100 000 t entre 1938 et 1966. Dans les 2 années suivantes, les stocks diminuèrent de manière abrupte et l'on dut en interdire la pêche pour conserver la ressource. Cette diminution est due au fait qu'on essaya, durant une période de faible recrutement, de maintenir des contingents de capture. Une fois les stocks rétablis et un marché lucratif de rogue de hareng établi au Japon, une « pêcherie de rogue » commença en 1972; elle représente actuellement le gros des prises récentes. On exploite en outre le frai sur varech, le hareng pour consommation humaine et la boëtte. Dans le but d'en arriver à une meilleure protection et utilisation de la ressource, on a mis au point de nouvelles stratégies de gestion. La gestion courante vise à assurer l'échappement d'un nombre prédéterminés de reproducteurs, le surplus étant réparti entre diverses pêcheries sous forme de prises cibles.

Distribution

Pacific herring *(Clupea harengus pallasi)* are found on the continental shelf and in coastal waters from Baja California in Mexico, northward along the North American coast to the Beaufort Sea, and hence southward along the coast of Asia to Korea. Its northern range extends both east and west through arctic waters over Asia and North America. The center of abundance on the eastern side of the Pacific lies on the British Columbia coast between Puget Sound in the south and Dixon Entrance in the north. Other major concentrations are found in the Bering Sea to the north and in the Yellow Sea to the west. Its closest relative, the Atlantic herring *(Clupea harengus harengus)*, has a similar distribution in the Atlantic Ocean.

Two other members of the same family (Clupeidae) share the distribution of the Pacific herring. These are the Pacific sardine *(Sardinops sagax)* and the American shad *(Alosa sapidissima)*. Both of these species extend farther southward, have their centers of abundance to the south, and are far less abundant than the herring at present. (The sardine was more abundant until the mid-1940s.)

Life History

Egg Stage

Description — Pacific herring eggs are spherical in shape with a diameter of about 1.5 mm and weigh about 0.002 g. They are transparent in appearance and slightly denser than seawater. The incubation period ranges between 10 and 21 d after fertilization, depending on water temperature. During an average incubation period of 2 wk at 8°C, the egg goes through a series of cell divisions for the first 2 d (Fig. 1). It is not until the 3rd d that an embryo can be distinguished, even under a microscope. By the end of the 1st wk, the head is well developed and its large eyes can be readily distinguished by the naked eye of an inexperienced observer. During the last week of incubation, the larva shows further development and growth, curling several times around the yolk, and its jerky movements may be seen with the naked eye. At the end of the 2-wk period, it breaks through the weakened egg membrane head first. Hatching is virtually simultaneous for eggs deposited in a single spawning. At one low tide, the beach is covered with eggs — at the next there is nothing but egg cases! Eggs deposited over a number of days or in two waves of spawning will hatch over a comparable (but usually slightly shorter) time period.

Distribution and abundance — Pacific herring deposit their eggs on vegetation in and immediately below the intertidal zone along the coast of British Columbia (Fig. 8). Most (80%) of the spawn deposition occurs at depths shallower than -1.5 m datum (approx. 6 m below high water). The density of egg deposition decreases rapidly below this point but spawning may extend to depths of up to 25 m below high water. Egg depositions located at these depths have always been extensions of shallower spawnings; there is no evidence to date of spawnings confined to deeper waters such as are found for Atlantic herring. Egg depositions usually range between 1 and 4 layers in thickness. An average deposition of 2 egg layers on filamentous red algae (Fig. 9), which is one of the substrates most extensively utilized, at a normal substrate density of 70% of the bottom covered would result in 8.15×10^5 eggs per square metre of spawning ground. On this basis, a major spawning extending along 2 000 m of coast with an average width of 100 m would contain 1.6×10^{11} eggs and the total number of eggs deposited in British Columbia waters would be 3.0×10^{13}!

Mortality — Smothering: If spawning is intense, eggs may be deposited in several layers. Experiments have shown that hatching success decreases sharply with the thickness of the egg mass. The number of healthy larvae which will hatch from a deposition nine layers thick may very likely be less than for the same area covered by 4 layers. If the spawn is much thicker, all of the eggs may die from lack of oxygen.

Predation: Sea birds are the major predators at this stage. Gulls gather in the tens of thousands and may easily consume two thirds or more of the eggs which are exposed on a beach at low tide (Fig. 7). Fortunately, such instances are limited to spawnings on shallow beaches, only some of which are so affected.

Nevertheless, billions of eggs are lost annually to the gulls. Deeper spawnings are subject to attack by ducks which may dive to depths of 5 m and tear off pieces of egg-laden vegetation which they carry to the surface to consume.

Wave action: Another major source of mortality at this stage is the tearing loose of substrate and eggs by wave action during storms. These eggs are usually washed up on the beach above the normal high water level where they are deposited in windrows which may be up to half a metre deep and extend for hundreds of metres along the beach.

Mortality at the egg stage from all causes is estimated to average about 20%.

Larval Stage

Description — Whitish, thread-like larvae about 9 mm long hatch from the eggs (Fig. 2). These larvae bear little resemblance to the adult fish. They are fragile, transparent creatures with big eyes and a large yolk sac. They swim awkwardly in a snake-like fashion. Immediately after hatching, the larvae derive their nourishment mainly from the yolk sac which is usually used up in 6 d. During this time, the larvae develop their swimming ability and begin to feed on small members of the plankton community. Feeding appears to be a learned rather than an instinctive activity. During the next 5 wk, the body deepens, takes on an opaque, whitish color, and rudimentary fins form from the initial fin fold. At a length of about 25 mm (10 wk past hatching), metamorphosis into the adult form takes place over a period of about 3 wk. The body takes on the appearance of a miniature adult as it deepens, thickens, and takes on pigmentation. The scales appear at this stage.

Distribution and abundance — During the first few days after hatching, herring larvae are at the mercy of the water currents. They remain at the surface where they may be seen as milky patches, usually about 1 m in diameter, near the spawning beaches. Such patches contain millions of larvae. As swimming ability develops, the larvae migrate downwards during the day and back up to the surface at night, presumably following their food supply of small plankton. During this period, the larvae are dispersed farther and farther from the spawning grounds by the local water currents, which are mainly the product of tide and runoff.

Mortality — Mortality is extremely heavy in the highly vulnerable larval stage, probably averaging over 99%. Although the ultimate cause of death is usually some form of predation, other factors play important roles which would lead to the loss of large numbers of larvae even in the absence of predators. Because mortality is both extensive and highly variable at this stage, it is here that year-class strength (the abundance of an age-group at the adult stage) is usually determined.

Physical development: Physical development may be hampered by environmental stress during the egg stage. Under these circumstances, the hatched larvae may be malformed, incompletely developed, or lack sufficient yolk to support their energy needs until they learn to feed. These "weaklings" fall easy prey to predators but would not survive in any case.

Currents: Currents may carry the larvae to places where the food supply is not adequate to support them. In years where runoff is greater than average and/or the wind-driven water transport offshore has a net southward direction, the larvae will be carried farther offshore away from the more abundant food supplies, and will be exposed to additional sources of predation.

Food: The food supply may be inadequate on the normal rearing grounds for a number of reasons. If the hatch is unusually high, the normal food supply may not be sufficient to sustain the larvae and competition for food may result in most of the larvae not getting enough to survive. On the other hand, poor weather conditions (mainly lack of sunshine) may delay the spring bloom of phytoplankton (microscopic plants) and hence zooplankton (microscopic animals) on which the larvae feed. This would result in an insufficient food supply available at hatching to meet the energy needs of even a normal hatch. In either of these instances, even if the food supply is adequate for survival, it may not be sufficient to support

growth at the normal rate. This would increase the susceptibility of the larvae to predation as they would be available for a longer period to small predators which cannot catch or swallow the larger larvae.

Predation: Even when none of the above adverse conditions prevail, the larvae are subjected to intense and highly variable predation. Resident predators such as small perch, comb jellies, arrow worms, and jellyfish probably take a fairly constant toll regardless of the abundance of the hatch. Young salmon can be major predators on the larger larvae when their seaward migration takes them through concentrations of larvae, particularly in years of high abundance. In some locations, there is a type of amphipod *(Hyperoche medusarum)* whose larval form feeds on herring larvae by taking one large bite out of a herring larva and leaving the larva to die. Whenever the hatch of this amphipod corresponds closely in time and place with the herring hatch, these amphipods are capable of almost wiping out, within a few hours, any herring larvae they encounter. Another irregular but potentially devastating source of predation is cannibalism by adult herring. Usually the older herring have left the spawning grounds by the time the eggs hatch. However, on occasions when spawning is drawn out over a long time or there is a second wave of spawning about 2 wk later on the same spawning grounds, adult herring have been observed feeding voraciously on the newly hatched larvae.

Juvenile Stage

Description — The rest of the 1st yr of life (July - March) is known as the juvenile stage. The herring have now assumed their typical form as a bony, soft-rayed fish. They have a deeply forked tail, soft-rayed fins, no teeth, and a protruding lower jaw. The back is blue-green, shading away to silvery white on the sides and the lateral line may be traced down either side of the fish by way of a line of modified scales. At the completion of metamorphosis (June-July) the juveniles are about 35 mm in length and weigh about 5 g. They grow quickly over the summer, achieving a length of close to 100 mm and a weight of about 40 g by fall. There is little growth over the winter.

Distribution and abundance — During the summer the juveniles gather into increasingly larger schools in the protected waters of bays and inlets in the general region (but not necessarily in the immediate vicinity) of the spawning grounds. In Barkley Sound, for example, the vast majority of the spawning takes place along the northwest side (management unit 29 — Fig. 18) but the juveniles are found mainly in the southeast half of the sound. Abundance at this stage appears to be correlated with the abundance of that year-class at recruitment to the adult stocks (i.e. year-class strength has been established). In September, the schools, by now consisting of millions of individuals, gradually move seaward to offshore wintering grounds where they are found mainly at depths of 150–200 m. The main such offshore grounds appear to be off the mouth of Juan de Fuca Strait in the south and in Hecate Strait in the north.

Mortality — Before migrating offshore, the juveniles are preyed upon by local concentrations of fish (such as perch, salmon, and dogfish), mammals (such as seals), and birds (such as gulls and diving ducks). During and after their offshore migration, the juveniles are fed upon by any fish, birds, or mammals capable of catching and swallowing them. In spite of this, mortality at this stage is probably only about 20%. Food is no longer a limiting consideration as they are able to seek out plankton organisms of suitable size (copepods, amphipods, and euphausiids) in sufficient supply.

Immature Stage

Description — This stage includes fish that have completed their 1st yr of life but have yet to undertake their first spawning migration. These are mainly fish in their 2nd yr that are similar in appearance to juveniles but larger. (Small proportions of the 3- and 4-yr-old fish that have yet to mature are also included.) During their second summer, the herring increase in both length and weight by about 50% (to 150 mm and 60 g, respectively).

Distribution and abundance — Immatures are found in the same offshore feeding grounds as the juveniles but usually at shallower depths

(100–150 m). They are more likely to mix with adults than with juveniles. Abundance in terms of numbers of fish is lowest at this stage as natural mortality (mainly predation) has reduced their ranks from the earlier stage and the subsequent adult stage is made up of several year-classes (i.e. fish of age 3 and older). However, the reduction in numbers has been more than balanced by the increase in weight of the survivors so that the total weight of all fish in the year-class (biomass) has continued to increase.

Mortality — As for the juveniles and adults, herring at this stage are fed upon by any fish, birds, and mammals capable of catching and swallowing them. Their increase in size has eliminated some of the smaller predators of the juvenile stage but made them more attractive to larger predators such as brill.

ADULT STAGE

Description — This stage includes all the fish that will mature and spawn during the next spawning season. Three-year-old fish spawning for the first time will have attained an average length of about 185 mm and a weight of about 90 g. During each of the next 2 yr the fish will gain about 30 mm in length and 30 g in weight. In subsequent years the rate of gain will gradually decline. Most of the adult fish taken by the fishery range between 175 and 250 mm in length, from 70 to 200 g in weight, and from 3 to 6 yr in age (Fig. 4). The largest fish officially recorded was 310 mm long, weighed 340 g and was 15 yr old. Mature herring are usually deeper and fuller bodied than their younger brethren, especially at spawning season when the gonads account for one-fourth to one-third of the total body weight.

Distribution and abundance — Adult herring return to their offshore feeding grounds in April and May. As for the juveniles and immature stage, these main feeding grounds are located off Juan de Fuca Strait in the south and in Hecate Strait in the north. The adult fish are generally found in shallower depths (100–150 m) but are occasionally mixed with immatures and/or juveniles. On the average, about 200 000 tons of adults (19 billion fish) are found in several major aggregations of individual schools (each containing between 1 and 10 000 tons) scattered along the edges of banks extending along 100 mi of coast off the mouth of Juan de Fuca Strait. These aggregations may move many miles to the north or south during the summer, presumably following their food supply. The situation in Hecate Strait is thought to be similar except that only half as many fish (100 000 tons) are involved. These two major feeding areas would account for most of the 350 000 tons of adult herring estimated to populate the coast of British Columbia.

Between October and December, the herring gather into larger aggregations and begin their annual migration to their inshore spawning grounds. The fish that have the longest distance to travel tend to leave first. Upon reaching the general vicinity of their spawning ground, the fish stop feeding and remain in the deeper channels and bays during the final stages of maturation.

Spawning behavior — When maturation is complete, the herring move into the shallows and onto the spawning grounds. There, a variety of environmental or physical stimuli, such as storms, contact with nets, or crowding will cause a few of the males to extrude some milt. This initiates ritual spawning behavior activities in individual herring of both sexes in the presence of a suitable spawn substrate such as red algae, sea grasses, rockweed, or kelp. The fish rise to the surface and mill about extending their genital papillae. Searching out an acceptable substrate, they line up along its longitudinal axis. They then arch their back and swim with short rapid body movements, feeling their way along its surface with their pectoral fins and chin, while eggs or sperm are extruded from the papilla which is also in contact with the substrate. Since a female usually lays less than 100 eggs in a single spawning act, each fish would carry out several hundred such acts before its supply of 20 000–40 000 eggs is exhausted. After several such spawning acts, the fish may rejoin a school for several minutes, or even hours, before returning for another spawning act.

While the eggs become attached to the substrate, the milt is dissipated throughout the water column forming the large milky "clouds" in the water which characterize herring spawnings (Fig. 6). At this stage, both eggs and milt

may be released in a midwater spawning frenzy, the eggs sinking to "blanket" the vegetation and rocks on the bottom.

A larger spawning may extend over several days, spreading out for miles in either direction from its point of origin. The width of a band of spawning may vary from a few metres to over 1000 m depending on the slope of the beach and the extent of the vegetation. A larger spawning of this nature may involve over 300 million fish.

After spawning is completed, the fish begin feeding voraciously as they migrate back to their offshore feeding grounds.

Mortality — Mortality from "natural" causes during the adult stage probably averages about 30% per year. It appears to increase with age, especially for males. (Most of the older fish are females.) In addition to the type of predation experienced by juveniles and immatures on the offshore feeding grounds, the adults run a gauntlet of additional stocks of predators on their spawning migration. They are most susceptible when massed on the spawning grounds and preoccupied with spawning activites. Large herds of seals and sea lions, pods of killer whales, flocks of gulls, cormorants and puffins, and schools of dogfish gather from miles around at major spawning grounds to eat their fill from the bounteous supply of herring which is so readily accessible. After spawning, the survivors, weak from lack of food and from spawning activity, must again run a gauntlet of predators on the return migration to their offshore feeding grounds.

An additional major source of mortality, currently limited to the adult stage, is the fishery. Present management practices allow for the harvesting of about one-quarter of the run. Since many of the fish taken by the fishery would have been susbsequently lost to natural predators during the remainder of their spawning migrations, the total annual mortality in somewhat less (about 50%) than the sum of the two parts considered separately.

Fortunately, other potential sources of mortality, such as disease and pollution, have rarely been the direct cause of appreciable mortalities in British Columbia waters to date. However, these sources have been blamed for major declines in the stocks of herring and related species elsewhere in the world and the same thing could happen here. A few traditional herring spawning areas have already been abandoned following degradation of the grounds by industrial pollution. It is not possible at this stage to determine whether the stocks which formerly spawned on these grounds have been lost to the resource or now spawn elsewhere. It is obvious, however, that there are limits to the amount of prime spawning grounds that can be despoiled without seriously affecting the abundance of adult herring in British Columbia waters.

Fisheries

HISTORY

Ancient fisheries — The herring was one of the first coastal fishes to be utilized by man. In northern Europe, herring were a source of food before written history. In excavations of human settlements dating back to 3000 BC on the Danish coast, the remains of herring bones have been found along with those of cod and eel. The existence of a herring fishery near Yarmouth, England, has been traced back to 500 AD. Man's interest in herring has led to the development of merchant fleets, the expansion of trade routes, the enactment of treaties and laws, the location of towns, and, inevitably, battles and wars. At least one battle was even named after this fish (Battle of Herrings, 1429). On the Canadian side of the Atlantic Ocean, the herring fishery developed along with the cod fishery as a source of bait for the latter and probably predates Columbus.

Early fisheries on Canada's west coast — The history of man's utilization of herring along Canada's Pacific coast is, like other aspects of the early history of this area, less well documented. Herring and herring spawn are known to have been used as food and for barter by Pacific coast Indians whose settlements go back to 800 BC. The oldest known written record of herring in these waters appeared in the diary of Archibald Menzies, naturalist aboard H.M.S. *Discovery* commanded by Captain George Vancouver. While mapping the British Columbia coast in July 1792, herring were purchased for the ship's mess from Indians at Stuart Island. The first commercial catch recorded was 75 tons taken in 1877.

The recorded catch of herring from British Columbia waters remained quite small (between 130 and 650 tons) until the end of the 19th century. Fishing was carried out mainly with small beach seines.

Dry-salted fishery 1904–34 — Between 1904 and 1907, a market for dry-salted herring was developed in the Orient and drift netting became the major mode of fishing. The catch increased to about 30 000 tons, where it held until 1919. It was during this period that purse seining was introduced into the fishery (1913). Between 1919 and 1927, the annual catch rose to 85 000 tons and then declined back to 30 000 tons in 1934 with the rise and fall in the dry-salted herring market (Fig. 19).

Reduction fishery 1935–67 — The introduction of a meal and oil (reduction) industry in 1935 almost doubled the catch in each of the following 2 yr (Fig. 19) and catches leveled off at about 100 000 tons for the next 10 seasons (1938–47). By this time the fishery was conducted almost exclusively by purse seine. The fishing season extended from November to March during the inshore migration of the spawning runs. In 1947–48 the catch jumped to 172 000 tons and hovered around the 200 000 ton mark until 1965–66 (except for 1952–53 and 1957–58 when the catch was held down by industrial disputes). In 1962–63, a record catch of 264 000 tons was taken, followed by a near record 260 000 tons in the following season. (The previous record of 251 000 tons was set in 1955–56 when an isolated incidence of phenomenal abundance in the Queen Charlotte Islands produced a catch there of 92 000 tons).

Up to this point, catches had been limited by the markets available for the products and, in the earlier years, by the processing capacity of the plants and the catching capacity of the fleet. As demand increased, the fleet ranged farther afield and by 1940, virtually the entire coast was being extensively fished. The introduction of echo sounders and radio-telephones in the 1940s, powered hauling blocks in the 1950s, and sonar, drum seining, and mercury arc lights (to attract fish) in the 1960s, increased the catching capacity of the fleet. In addition, larger, faster vessels decreased the amount of time lost for travel and weather.

Concern for conservation of the stocks led to the establishment of catch quotas on the Lower East Coast and West Coast of Vancouver Island in the 1936–37 season, on the Middle East Coast in 1940–41, and on the Northern and Central coasts in the following season. However, these quotas had a limited effect on the catch as extensions were frequently granted (and not always taken). The quota for the West Coast of Vancouver Island was discontinued in 1946–47 and there never was a quota for the Queen Charlotte Islands. Nevertheless, the quota system succeeded in distributing fishing effort more evenly over the coast and thus provided some protection for the most accessible populations (Lower and Middle East Coast of Vancouver Island).

During most of the 1964–65 season, a good catch (241 000 tons) was taken, but the fishermen had more difficulty in locating quantities of fish. Spawn deposition was down somewhat (especially for the heavily exploited stocks on the Lower East Coast of Vancouver Island). This trend continued for the following two seasons, when the catches were 181 000 and 135 000 tons, respectively. The proportion of small, immature fish in the catch rose noticeably. In spite of these ominous indicators, there was a reluctance to believe that these herring populations could be overfished since they had supported large and almost unrestricted catches for over two decades. However, fishing efficiency had increased to the point where a sharp decline in abundance resulting from the recruitment of a series of poor year-classes in the mid-1960s had relatively little effect on the ability of the fleet to maintain catches at their former levels. Finally, when the downward trend continued in 1967–68, the fishery was closed early in the season. Only the traditional minor fisheries for local food and bait were permitted for the next 4 yr. Production of fish meal and oil from British Columbia herring is now limited to the utilization of residues from other forms of herring products.

Current Fisheries

Roe fishery — Cessation of the intensive reduction fishery resulted in a gradual recovery of stocks. Subsequently, a shortage of herring in other parts of the world created a demand for prime quality herring roe on the Japanese

market. Herring roe (Fig. 17) is considered to be a great delicacy by the Japanese people and commands a high price. Consequently, during the 1971 season, in addition to the small traditional food and bait fishery that was allowed to continue operating throughout the closed period, a new fishery became established for roe herring.

To satisfy the Japanese market, herring roe must be at the right stage of ripeness. This stage occurs just prior to spawning and lasts only for a few days. Consequently, roe fisheries are conducted on or adjacent to spawning grounds (Fig. 14) and must take place within a few days in any one locality. Because the eggs take on water and swell up at this stage the weight of the egg sacs increases dramatically, accounting for 20–35% of the body weight (Fig. 16). The fish are judged "ready" when test sets show ripe roe making up 10% or more of a random sample of fish of both sexes. After spawning, the spent fish mix with the remaining ripe fish and the "roe content" gradually drops below 10%. The fishery is then closed.

Although this was initially a purse-seine fishery, gill nets have assumed an increasing role and presently account for about half of the catch. The main advantage of fishing roe herring by gill net is that the nets can be set near spawning grounds, intercepting only ripe herring about to spawn while the main body of fish farther offshore may be made up of immature or spent fish. The main advantage of the seiners is their ability to catch large quantities of fish in a short time in a small area. Consequently, gill nets are most effective when spawning is spread over a longer distance of coastline and continues for several days (e.g. the east coast of Vancouver Island). Seines are most effective where spawning is concentrated and is over in a few hours (e.g. the southern tip of the Queen Charlotte Islands). Some grounds can be fished effectively by either gear (e.g. Barkley Sound on the west coast of Vancouver Island).

The specialized nature of the fishery has led to adaptations by both types of gear. The need for shallower seines and quicker sets has brought drum seiners (Fig. 13) into prominence, although table seiners with power blocks (Fig. 12) are also quite effective. Seiners usually take between 50 and 150 tons in a set but sets of up to 500 tons are taken occasionally. The catch (Fig. 15) is pumped from the net into the hold of the seiner or another vessel for transport to a processing plant where it is pumped for a second time from the vessel into the plant.

Gill nets are fished from aluminum skiffs (Fig. 10) developed especially for this fishery. The nets (Fig. 11) are pulled in over rollers, the fish are shaken out into the skiff, and the net is reset over the other side of the skiff. Improved technology has produced larger skiffs with powered pullers and shakers and their own fish finding, radio telephone, and other electronic aids. Such skiffs may take 8 tons over a 24 h period when fishing is good. Gillnet catches are unloaded on the grounds where they are pumped to large packers or brailed into totes on barges, etc., for transport to a processing plant. Frequently, the totes are transported on trucks by road to processing plants.

In the 1st yr of the roe fishery (1971) 11 000 tons was landed. The catch increased to 38 000 tons in 1972 and to 56 000 tons in 1973 (Fig. 19). It remained in the 50 000 ton range over the next 2 yr and then jumped to 87 000 tons in 1976. In 1977 and 1978, the roe catch declined to 81 000 tons and 70 000 tons, respectively, as catches by other fisheries on these stocks went up. In 1979, the catch dropped to 45 000 tons following a period of low survival during the early stages of the life history. However, the landed value of the catch continued to rise over this entire period from $0.6 million in 1971 to $126.6 million in 1979.

The carcasses remaining after extraction of the roe are processed into fish meal, mostly for use as poultry food. Up to 9000 tons of meal are produced from this source annually.

Spawn on kelp fishery — The harvest of herring eggs on kelp for export is a relatively new industry to British Columbia. Most of the spawn on kelp is exported to Japan where it is greatly prized as a traditional delicacy, particularly during New Year festivities. Traditionally, this product was harvested from natural spawnings by Indians for personal food consumption. However, it was found that spawn on kelp obtained in impoundments was a better product with more even coverage of eggs on both sides of the kelp frond. The method that works best appears to be to construct floating ponds of webbing suspended from logs, suspend the kelp in the pond and then introduce seine-caught, sexually mature herring.

After the eggs are laid and fertilized, the spawn is allowed to remain in the water for 3–4 d, after which the product is removed and heavily salted.

Permits for commercial spawn on kelp production were issued beginning in 1975, when 13 permits were issued. In 1979, this number had increased to 28, with each permit allowing for 8 tons of product, a quantity not always met. Permits are issued, on application, to individuals with experience in live-holding herring with special consideration given to native Indians, who presently hold over half the permits. Production has increased from 16 tons of spawn on kelp in 1975 to 168 tons in 1978 with average prices per pound increasing from $3 to $6 over the same years. In 1979, a bonanza year for roe herring, spawn on kelp prices also increased drastically with up to $14 per pound paid to the producer for a high quality product.

Spawn on kelp operations in northern British Columbia have generally been more successful because of the local availability of the giant kelp *Macrocystis,* which does not grow in large quantities in the Strait of Georgia. Here, laminarians have been tried as a substrate, but less successfully. Care has also to be taken to locate ponds in areas that are free from oil pollution as this can render the product unsuitable for human consumption.

Food fishery — The herring food fishery is overshadowed by the very lucrative and dramatic roe fishery. Landed price for food fish have generally been one-fifth of prices paid for roe fish. The food catch has fluctuated over recent years according to market demands and negotiated prices between labor and management. In 1971–72, 2500 tons were landed and in 1972–73, 3800 tons. For 1973–75, catches were very small because of contract disputes between labor and management. In 1975–76, 5700 tons were landed and sold mostly to companies involved in a Canadian international food aid program. The product was mostly canned herring with a small portion of the catch also marketed dried to the Oriental food market. In 1976–77, a catch of 6500 tons with a landed value of $822 000 was sold mostly to Japan as frozen whole fish, with a small portion sold to Europe as butterfly fillets. A recent record of 20 000 tons of food herring with a landed value of $4 million were caught in 1977–78 and again exported frozen whole, to Japan. In 1978–79, 14 000 tons were taken with a landed value of $3.3 million. Of this, 1837 tons were processed as frozen fillets that were sold to West Germany and 1161 tons were salted whole and exported to the U.K. and Europe. The remainder was frozen whole or processed otherwise. The local food market for fresh, smoked, salted, and pickled herring is fairly stable and accounts for 1000 tons of fish per year.

The food fishery was dominated by seiners until 1977–78 when trawlers took 16% of the catch. This share increased to 19% in 1978–79. The fleet participating in the food fishery is considerably smaller than that of the roe fishery. In 1978–79, 130 seiners and 35 trawlers fished for food herring, while over 200 seiners and 1300 gill netters fished for roe herring.

The food fishery takes place mainly between November and January, as the fish are intercepted on the migration routes to the spawning grounds. Also, most of the fishing takes place close to the processing plants so that the product can be landed fresh. In addition, there is a minimum preferred weight and size of 120 g and 20 cm for food fish by companies, and in 1978–79, bonuses of $120 per ton were paid for catches that had 60% of fish in that category. The major fishing area is the Strait of Georgia, where 86% of the catch was obtained in 1978–79. Comparable percentages for 1977–78, 1976–77, and 1975–76 are 68, 79, and 89%. The North coast contributed 12, 17, 12, and 10% respectively, for the same fishing seasons. In 1977–78, the West Coast of Vancouver Island contributed an appreciable portion of the food catch (13%) for the first time.

The herring food fishery and industry is still in a state of development. As markets for a variety of products are established in the world market place, this fishery could become as important and financially rewarding as the roe fishery.

Bait fishery — The herring bait fishery, for which the market is relatively constant, amounts to 1000–2000 tons per season. The fish are taken during the food fishing season and under special permits. The usual method of capture is by seine although trawls and gill nets are also used. Bait, usually frozen, is used commercially by long line operations for halibut and sablefish, and to a lesser extent for cod. Live

bait for cod is usually kept in small quantities (50 kg) in wooden slat boxes or in the holds of the fishing boats. Sport bait is sold live from net ponds or barges at major marinas where herring can be fished locally. Otherwise, bait herring are frozen whole or as strip for sale at various retail outlets. Most of the ponds and permits are for Johnstone and Georgia straits. Most of the bait catch is marketed locally although some bait is exported to the U.S. A high quality bait herring comparable to food herring is sold as animal food to aquariams and zoos.

Fishermen fishing commercially for bait herring usually do so to supplement their income. There are a few small companies (five or more) that specialize in producing frozen bait herring.

Resource Management

Best Use Principle

Prior to the closure of the reduction fishery, the fisheries on Canada's west coast herring resource were managed on the principle of maximum sustainable yield (i.e. to take as great a tonnage of fish as possible on a continuing basis). As the stocks recovered from their decline in the mid-1960s, this approach was replaced by the "Best Use" principle. The new approach was concerned with maximizing the value to the Canadian economy (by processing the annual catch into quality products which demand a high price on world markets), diversifying the markets for the products (to provide more stability to the industry), and promoting jobs for Canadians (by increasing the amount of processing done in Canada).

Stock Identification

For the purposes of resource management, a stock may be considered as a body of fish which occupies the same distinct fishing ground during the fishing season over a succession of years. Thus, during the reduction fishery, stocks (populations) were identified along 10 major migration routes from offshore feeding grounds to inshore spawning grounds where the major fisheries took place. With the advent of the roe fishery, stocks (management units) were identified for 16 major clusters of spawning grounds capable of supporting appreciable roe fisheries (Fig. 18). Clusters of smaller spawnings, which support irregular small roe fisheries and/or local food and bait fisheries, account for another 18 management units. Fisheries for food exports operate on mixtures of these roe stocks as they migrate to their spawning grounds.

Since the various stocks mix on the offshore feeding grounds and on their migration to and from these grounds, there is ample opportunity for fish to end up schooled with a different stock on their next spawning migration. Even the 10 major populations fished by the reduction fishery showed up to 25% immigration to other stocks! In general, however, this immigration was usually matched by emigration from other stocks so that the status of the individual stocks was unaffected.

The indentification of stocks is not of major concern in conservation of the resource under present circumstances. Since the major (roe) fisheries take place on fish already committed to individual spawning grounds (management units), maximum production from any 1 yr of spawning may be assured by allowing the optimum density of eggs to be deposited on that spawning ground and allowing the fishery to take any excess of fish over the amount required for this purpose. It does not matter where the fish spawned previously or where they will spawn is subsequent years.

Stock identification becomes crucial, however, in allocating catches to food fisheries on mixed stocks. Some of the fish taken by such fisheries would be from stocks which are not exploited by the roe fishery and hence would not be utilized if not taken at this stage. Others would be from "roe" stocks and could be more valuable if caught at that stage. Moreover, if any of these roe stocks are at a low point in their normal range of variability in abundance, any appreciable exploitation could reduce the spawning escapement below optimum levels even without a subsequent roe fishery!

Stock Assessments

The status of individual stocks is assessed annually on the basis of three different sources of data. *Catches* are estimated daily on the fishing grounds and subsequently recorded by date and locality and gear on sales slips throughout the year. Catches from each of the

fisheries are *sampled* to determine age compositions (Fig. 3 and 5), and the average length, weight, sex ratio, and maturity for each year-class represented. *Spawn* depositions are surveyed to determine their area and density. These data are fed into a computer model which produces estimates, in both numbers and tons of fish, of the abundance of each year-class in each stock.

Assuming average recruitment (fish maturing and joining the spawning run for the first time) and average survival rates for the various age-groups of repeat spawners, the computer then *forecasts* the abundance of each of the stocks for the forthcoming season. The optimum spawning escapement is estimated for each stock on the basis of the area of suitable spawning grounds available and the density of egg deposition considered to be most productive for each spawning ground. The differences between these two sets of estimates provide estimates of the total allowable catch (TAC) for each stock during the next fishing season.

Guidelines For The Fisheries

Guidelines for the various herring fisheries are developed annually by a committee of fisheries managers, biologists, economists, and quality control experts in consultation with an advisory committee made up of representatives of the various segments of industry. These guidelines are based on the biologically determined TAC's, the practical limitations of controlling exploitation of small stocks by a large fleet, the need to maintain quality by proper handling and speedy processing, and world market conditions. Superimposed on these basic requirements of "best use" is the recognized obligation to distribute the catch as equitably as possible among the various types of gear and fishing communities scattered throughout the province. On this basis, *anticipated catches* are established for each gear type in each individual fishing area (management unit) for the roe and other fisheries. Guidelines are then published for industry listing anticipated catches and the regulations to be enforced to control the various fisheries. This enables fishermen, fish processors, and government field managers to plan their activities for the forthcoming fishing season.

In-Season Management of the Fisheries

Managers in the field (Fisheries Officers) are faced with the awesome task of controlling the roe fishery in their area so that the desired (optimum) spawning escapement is achieved, while permitting the various gear types to catch the remainder in the proportions given in the guidelines. The anticipated catches forecast for the fisheries in his area assumes that recruitment is average. This may be checked by sampling test sets prior to opening the fishery to determine the proportion of smaller fish (recruits) present. Anticipated catches may then be revised accordingly, in consultation with biologists. Anticipated catches also assume that ocean survival was average and that the distribution of the spawning runs has not been disrupted by changes in oceanographic conditions. This may be checked by echo-sounder surveys immediately prior to the fishery to estimate the tonnage present. However, it is difficult to locate a varying proportion of the fish at this stage as they may be too close inshore for the vessels to operate, move about so much that schools may easily be missed or counted more than once, or distributed over too wide an area to be encompassed in such surveys. Nevertheless, the field officer must come up with his best estimate of the available catch, and, in daily consultation with senior management who maintain a coastwise overview of the situation, plan his fishery accordingly.

If there are enough fish present to warrant a fishery, the field manager must next determine when the fish are sufficiently ripe to open the fishery. Opening too soon would result in too much immature roe and a drastic reduction in the value of the catch, while opening too late would result in large numbers of spawned out fish in the catch. If both gill net and seine gear are involved, he must ensure that the gill nets have sufficient opportunity to take most of their share before letting the seines have their turn immediately before spawning. (There is usually an opportunity for a "mop up" gillnet fishery after spawning begins.)

Finally, since the field manager has little control over the amount of gear present, he must estimate the fishing capability of the gear on the grounds and time the duration of his opening accordingly. This situation is most acute for seine fisheries where the catching

capacity of the fleet is so great that openings are usually limited to a couple of hours in any one area. Sometimes the fishing capacity is large enough that conservation requirements would be threatened if all or even most of the vessels succeeded in making one successful set. This has led to openings as short as 15 min so that only a part of the fleet will have an opportunity to complete a set on fish. Similarly, gillnet fisheries which usually extend over a week or two, may be limited to a couple of days when the ratio of gear present to available catch is high.

This type of situation has led to a "gold rush" atmosphere in the roe fishery. The financial stakes are high! One 6- to 8-man seine set may have a landed value of over $1 million and 2-man gillnet skiffs frequently take $20,000 worth of fish per day when fishing is good. Consequently, there is a frantic movement from one fishing ground to another to be in the right place at the right time, and competition is keen for the best fishing spots on the grounds. The right move could produce a small fortune while the wrong move could result in missing out completely. Vessels put to sea in weather which they would normally avoid. Seiners risk collisions in setting their nets. Gill nets are set so close together that they may cross over or become entangled. It is in this atmosphere that the field manager must ensure that fishing is limited to the designated area and time period. Moreover, checks must be carried out to ensure that boats and fishermen are duly licensed and that net sizes and meshes conform with regulations.

In-season management of the other herring fisheries is less exacting: Boats, fishermen, and nets must still be checked for conformity to regulations. However, control over the tonnage caught is limited to ensuring that area quotas and/or vessel permit limits are not exceeded and that area and time restrictions are met.

Prospects for the Future

Management of the fisheries to meet the desired levels of spawning escapement for individual stocks should prevent depletion by overfishing as occured under the former catch quota system. Continuing research to improve our understanding of the population biology of Pacific herring will improve both the extent and quality of the information base. Research on stock assessment procedures will continue to improve their reliability. This has the dual benefits of providing a better measure of continuing protection of the resource and increasing the available catch as "safety factor" components are reduced correspondingly. Research on the early life history stages will have corresponding effects on target levels of spawning escapement. It would, therefore, appear that, barring any environmental catastrophies (pollution or destruction of spawning grounds, major oceanographic changes etc.), the resource can be maintained at a productive level in perpetuity. Moreover, it should be possible to detect any such catastrophies at a relatively early stage and hence to mitigate their effects to some extent through constructive intervention.

Acknowledgments

The authors thank R. D. Humphreys for reviewing the manuscript and D. N. Outram and L. A. Webb for major contributions of photographs. All of the above are or were with the Department of Fisheries and Oceans, Pacific Region. We also express our appreciation to the many researchers in this field over the years whose published reports have contributed to the information base for this report.

Related Reading

HAEGELE, C. W., AND D. N. OUTRAM. 1978. The effects of diet and ration on the growth and survival of Pacific herring *(Clupea harengus pallasi)* larvae. Fish. Mar. Serv. Tech. Rep. 767: 41 p.

HAEGELE, C. W., A. S. HOURSTON, R. D. HUMPHREYS, AND D. C. MILLER. 1979. Eggs per unit area in British Columbia herring spawn depositions. Fish. Mar. Serv. Tech. Rep. 894: 30 p.

HOURSTON, A. S. 1978. The decline and recovery of Canada's Pacific herring stocks. Fish. Mar. Serv. Tech. Rep. 784: 19 p.

1979. Stock assessments for British Columbia herring management units in 1978 and forecasts of the available roe catch in 1979. Fish. Mar. Serv. MS Rep. 1493: 19 p.

HUMPREYS, R. D., AND A. S. HOURSTON. 1978. British Columbia herring spawn deposition survey manual. Fish. Mar. Serv. Misc. Spec. Publ. 38: 40 p.

OUTRAM, D. N. 1965. Canada's Pacific herring. Dep. Fish. Ottawa, Canada. 23 p.

OUTRAM, D. N., AND R. D. HUMPHREYS. 1974. The Pacific herring in British Columbia waters. Fish. Mar. Serv. Pac. Biol. Stn. Circ. 100: 26 p.

TAYLOR, F. H. C. 1964. Life history and present status of British Columbia herring stocks. Fish. Res. Board Can. Bull. 143: 81 p.

WEBB, L. A., AND A. S. HOURSTON. 1979. Review of the 1976–77 British Columbia herring fishery and spawn abundance. Fish. Mar. Serv. Ind. Rep. 110: 47 p.

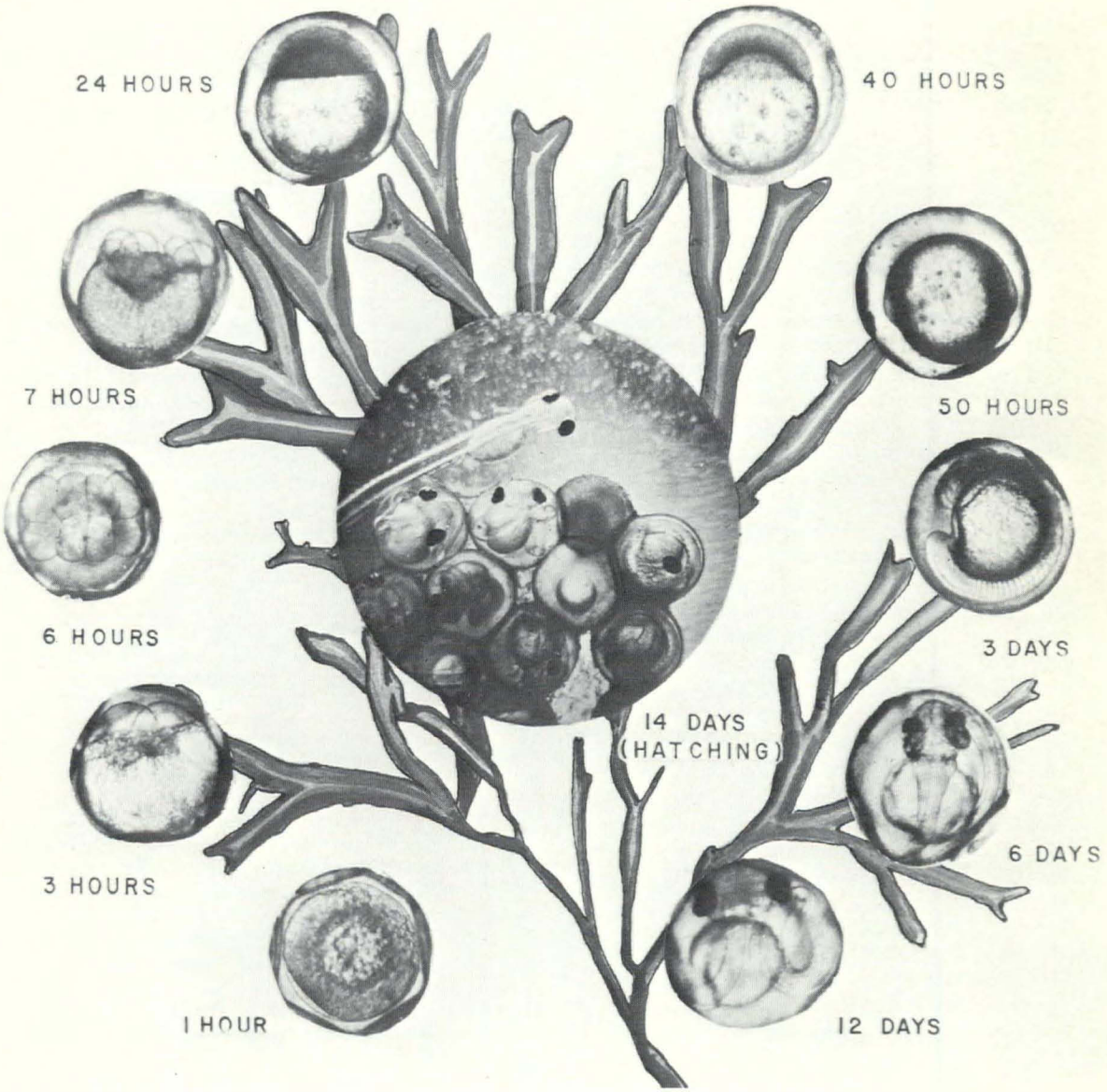


FIG 1. DEVELOPMENT OF THE PACIFIC HERRING EGG — The 1.5 mm diameter herring eggs, as seen through a microscope, are enlarged 17 times. After fertilization, the egg goes through a series of cell divisions that result in a cap of cells on top of the yolk mass (24 h). The embryo forms from this cap and encircles the yolk by day 3. The embryo is well formed by day 6 and undergoes periodic convulsive movements. At hatching, when the larva breaks through the egg membrane head first, the embryo encircles the yolk 2.5 times.

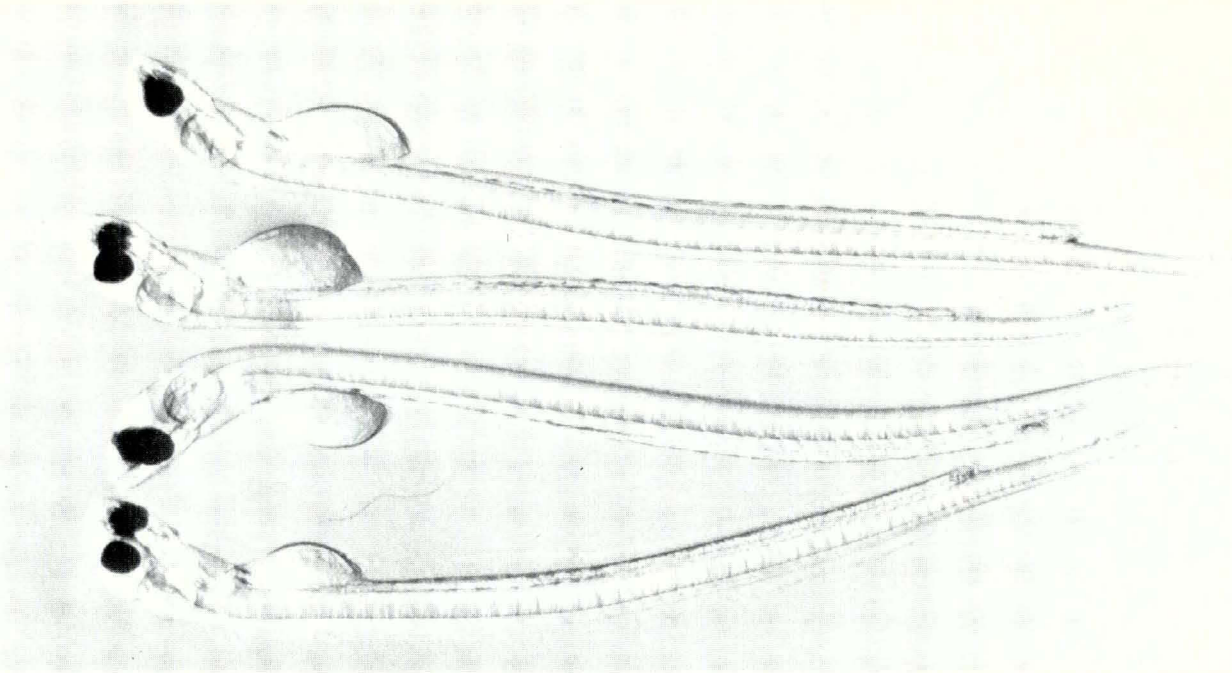


FIG. 2. HERRING LARVAE — These 1-d-old, 9 mm long larvae are enlarged 18 times. The bodies are transparent and characterized by the large eyes and otic capsules.

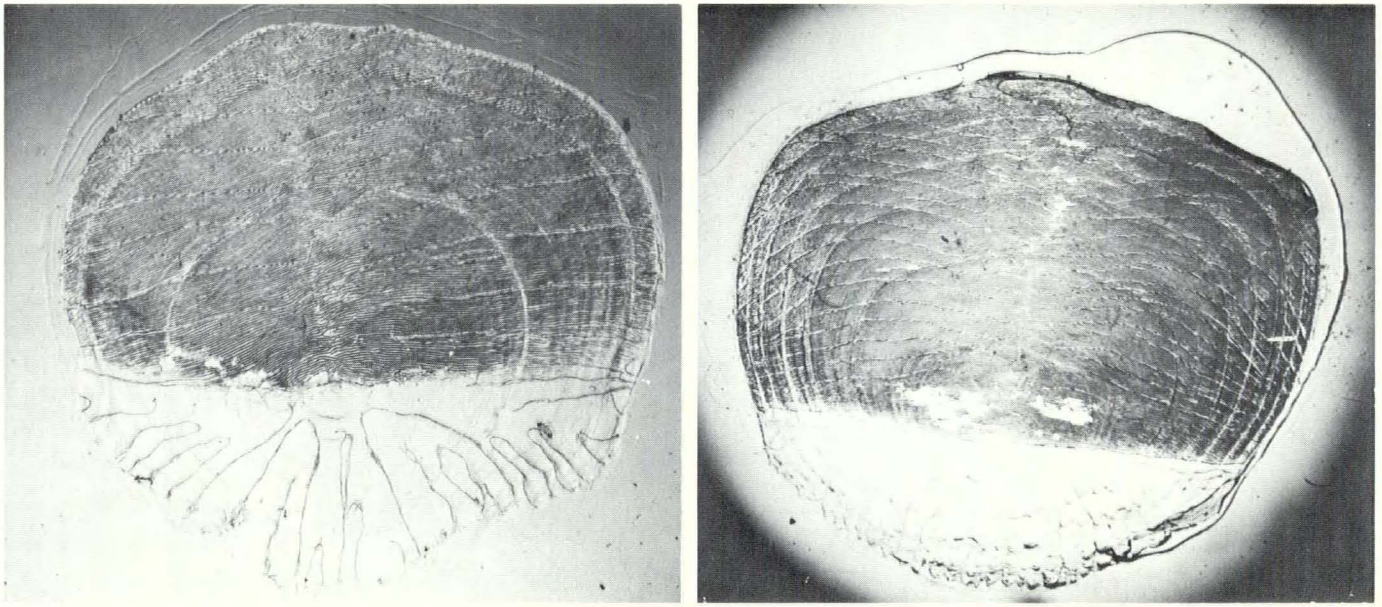


FIG. 3. HERRING SCALES — The age of herring can be determined from rings formed annually in their scales. The scale on the left has 2 rings and was taken from a herring in its third year of life. The scale on the right has 6 rings.

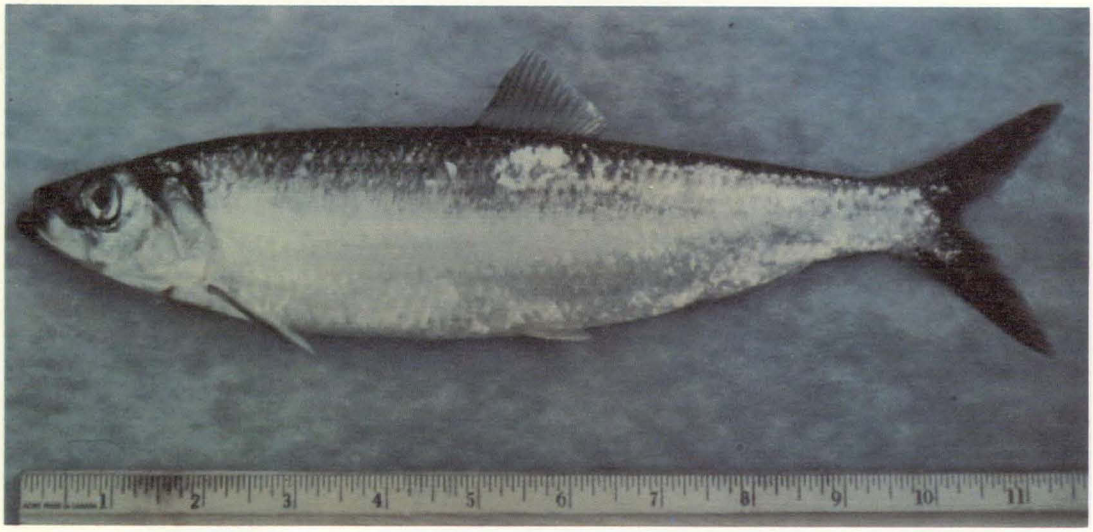


FIG. 4. ADULT HERRING — The above adult herring measures 253 mm long (standard length) and is 5 yr old.

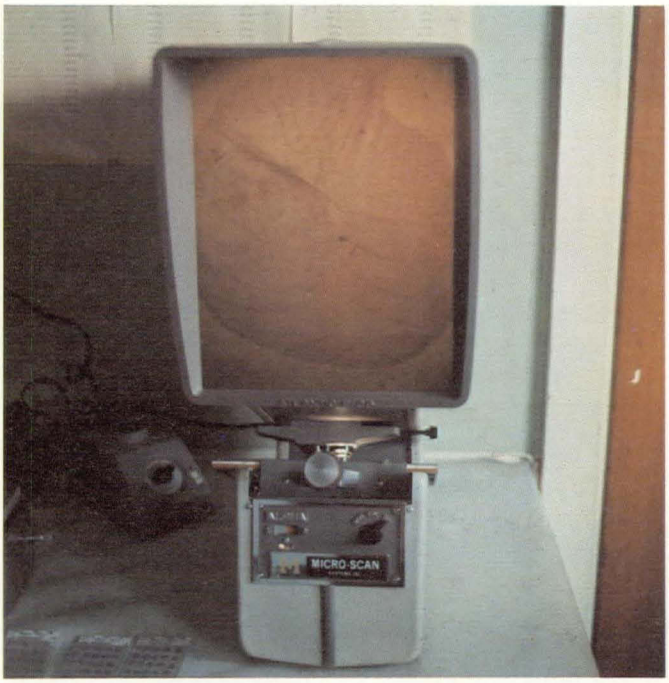


FIG. 5. AGE DETERMINATION — Herring scales are removed from the fish, dyed, and mounted on glass slides in rows of 5 (lower left of figure). The mounted scales are then enlarged on a projector for age determination from rings.

FIG. 6. HERRING MILT — The release of milt by the male during herring spawning results in a milky discoloration of the nearshore waters.

FIG. 7. EGG PREDATORS — When herring spawn becomes exposed to the air on receding tides, flocks of birds may gather to consume large quantities of eggs. Gulls are one of the chief predators.

FIG. 8. HERRING SPAWN — A section of beach with herring eggs adhering to eelgrass. At a higher tide, this spawn would be submerged.

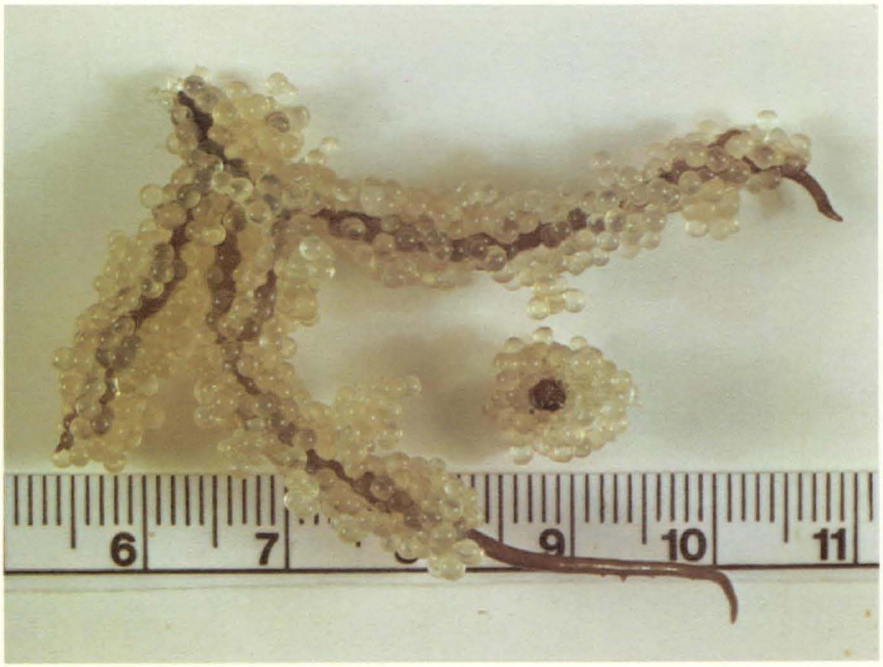


FIG. 9. SPAWN ASSESSMENT — For assessing herring spawnings, the density of egg deposition and the type of spawn substrate has to be determined. Pictured above is a heavy deposition of 7 egg layers on a filamentous red algae.

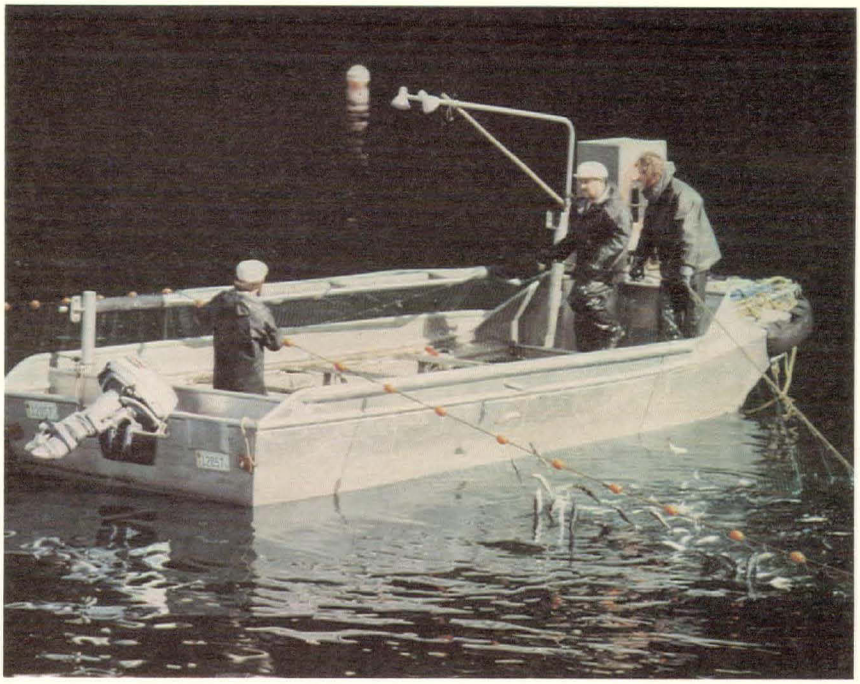


FIG. 10. GILL NETTING — Herring gill nets are fished from aluminum skiffs. The net is pulled in one side of the skiff, the fish are shaken out of the net into the skiff, and the net is reset over the other side of the skiff.

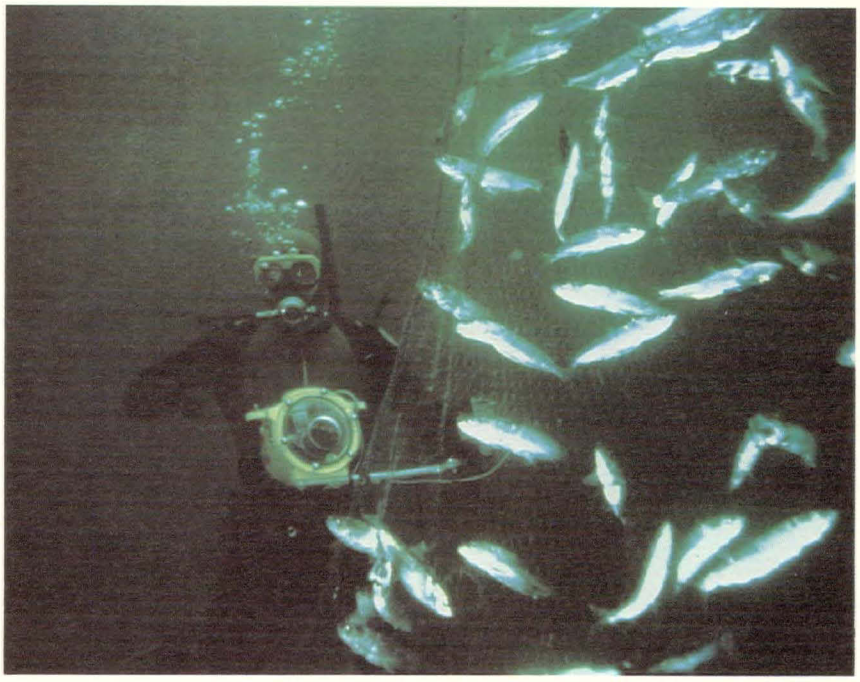


FIG. 11. GILL NET — Fish swim into the gill net and are retained by the fine monofilament mesh encircling the body behind the gill covers.

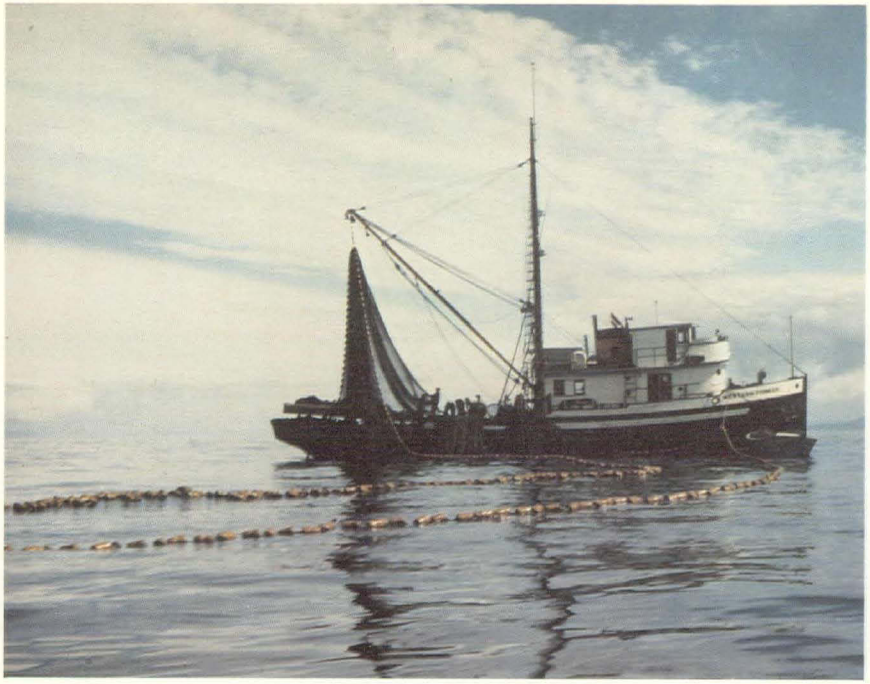


FIG. 12. TABLE SEINER — The table seiner is the older configuration of seine boat used on the Pacific coast. The net is retrieved with a power block suspended from the boom.

FIG. 13. DRUM SEINER — The drum seiner is the more common configuration for today's seine boat. The net is set from and retrieved by a hydraulically powered drum.

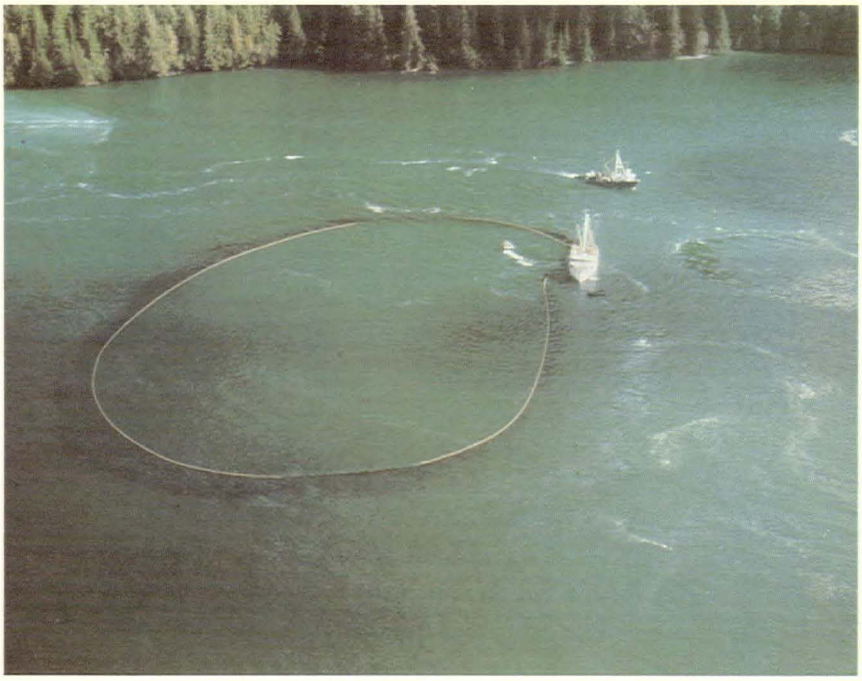


FIG. 14. SETTING A SEINE — The 300 fathom long seine has been set in a circle to capture some of the sexually mature herring heading towards the shore to spawn.

FIG. 15. SEINE CATCH — The net has been pursed up and the catch of herring is ready to be pumped aboard.

FIG. 16. HERRING ROE — Female herring have had the roe extracted from the body. When ripe, the roe may constitute up to 30% of body weight.

FIG. 17. ROE PROCESSING — Herring roe is being sorted for quality in a processing plant. Several thousand shoreworkers are employed in plants during the herring season.

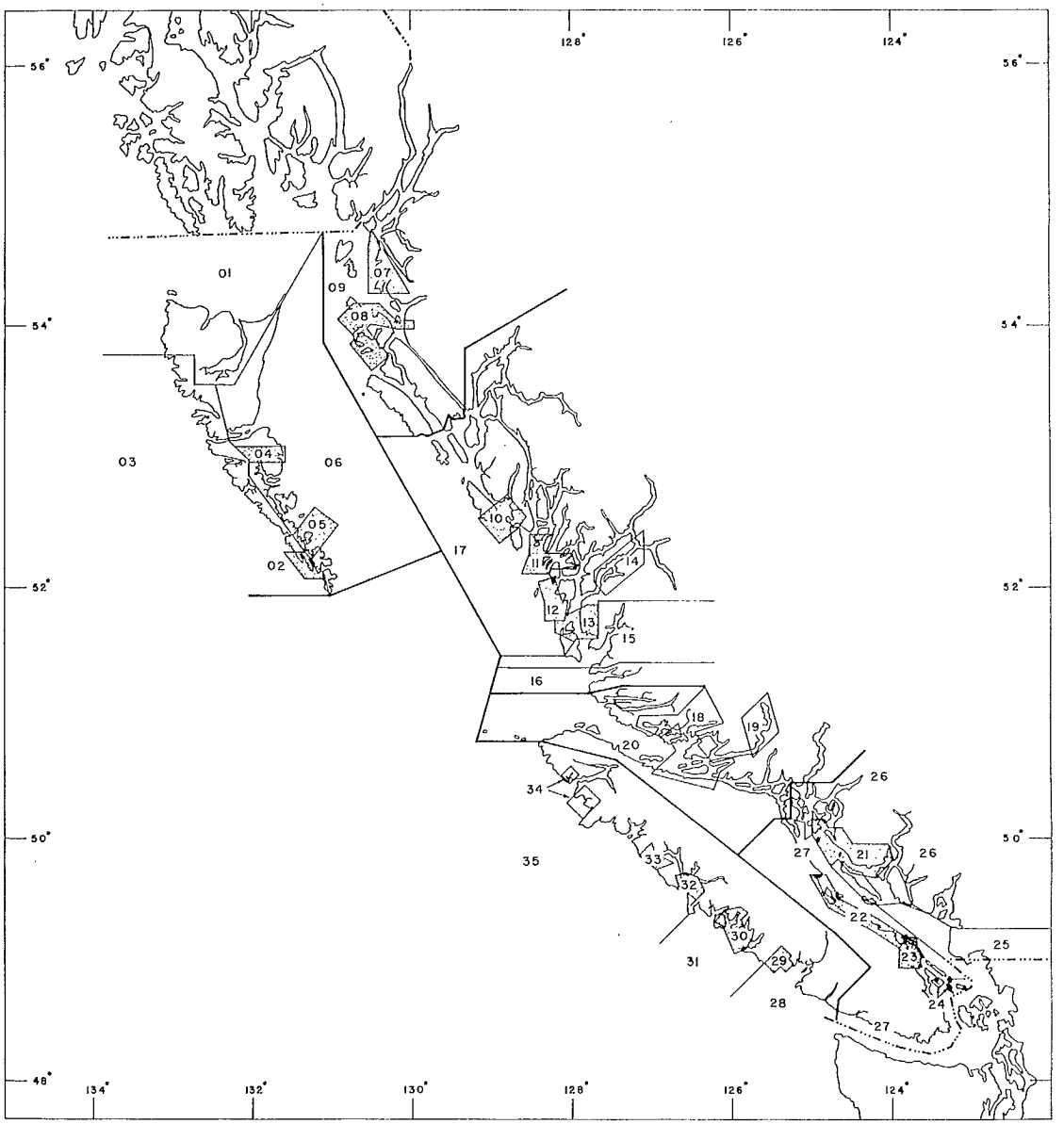


FIG. 18. HERRING STOCKS — For the roe fishery, stocks (management units) are identified for 16 major clusters of spawning grounds (stippled sections) capable of supporting appreciable fisheries. Clusters of smaller spawnings, which support irregular small roe fisheries and/or local food and bait fisheries, account for another 18 management units.

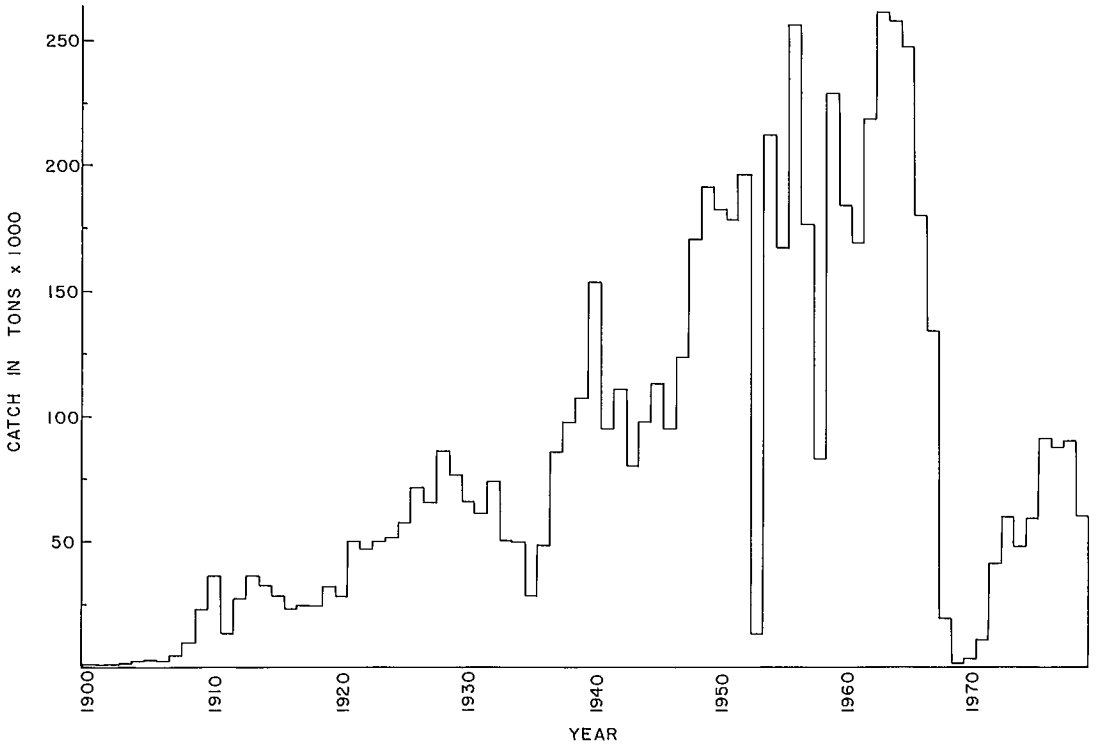
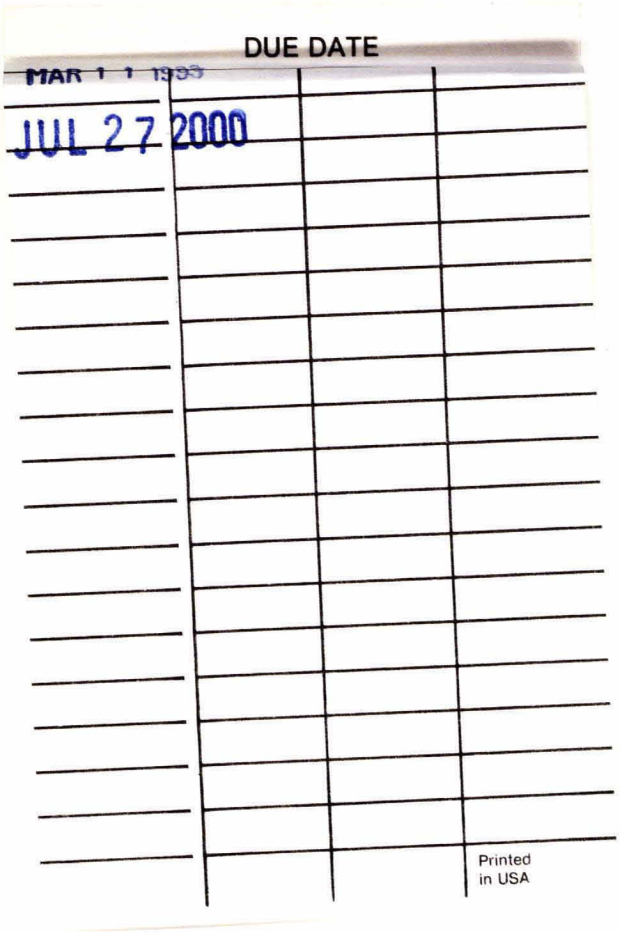


FIG. 19. HERRING CATCHES — Herring catches in British Columbia from 1900 to 1979 fluctuated widely with market demand and stock strength. From 1904 to 1934, the major market was for dry-salted herring, for 1935–67 for meal production, and for 1971 to the present for roe.


DUE DATE
MAR 1 1 1999
JUL 27 2000
Printed
in USA