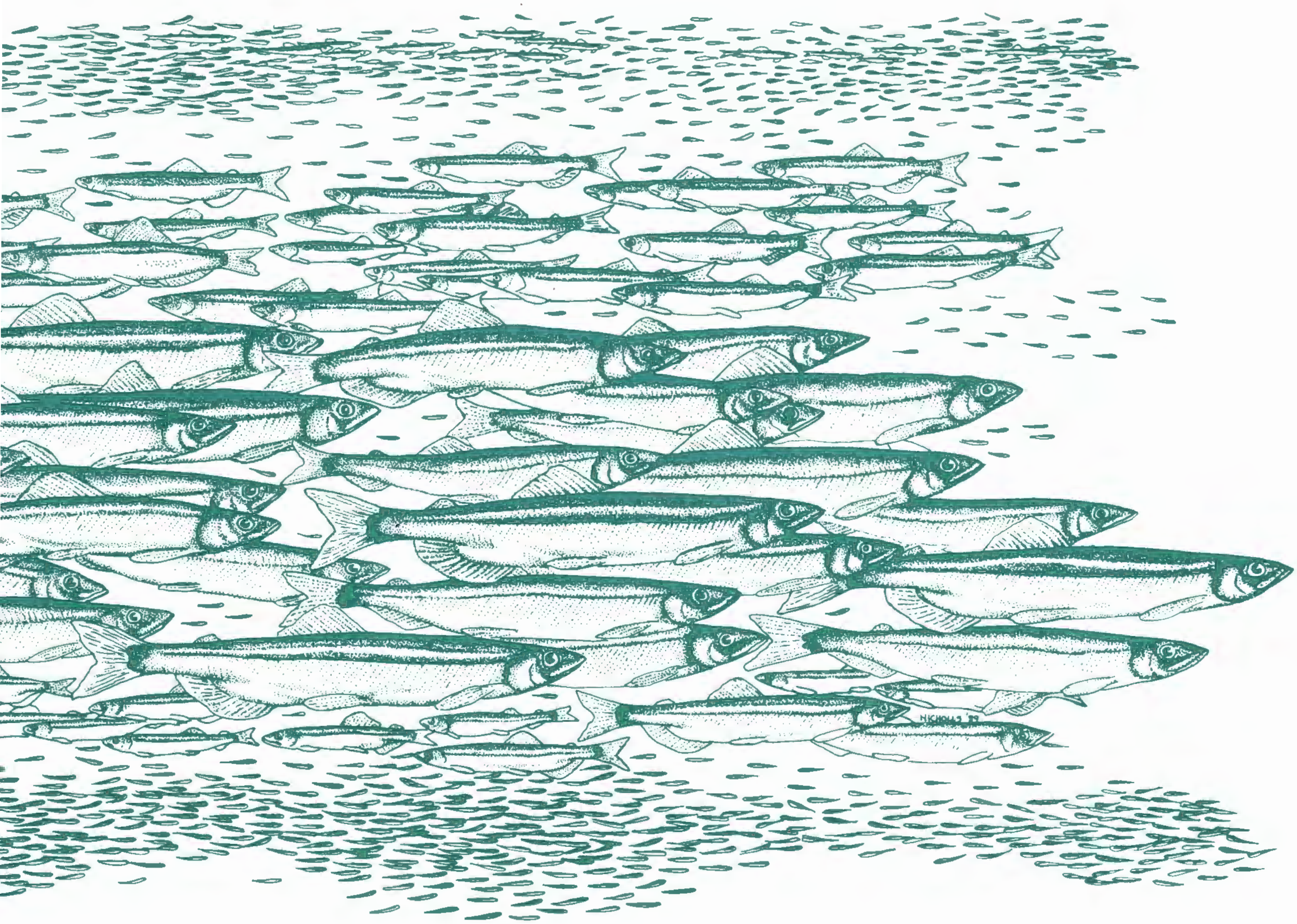
ATLANTIC FISHERIES
ADJUSTMENT PROGRAM

PROGRAMME D'ADAPTATION DES
PÊCHES DE L'ATLANTIQUE

The Science of Capelin

A Variable Resource



Fisheries and Oceans   Pêches et Océans

Canada

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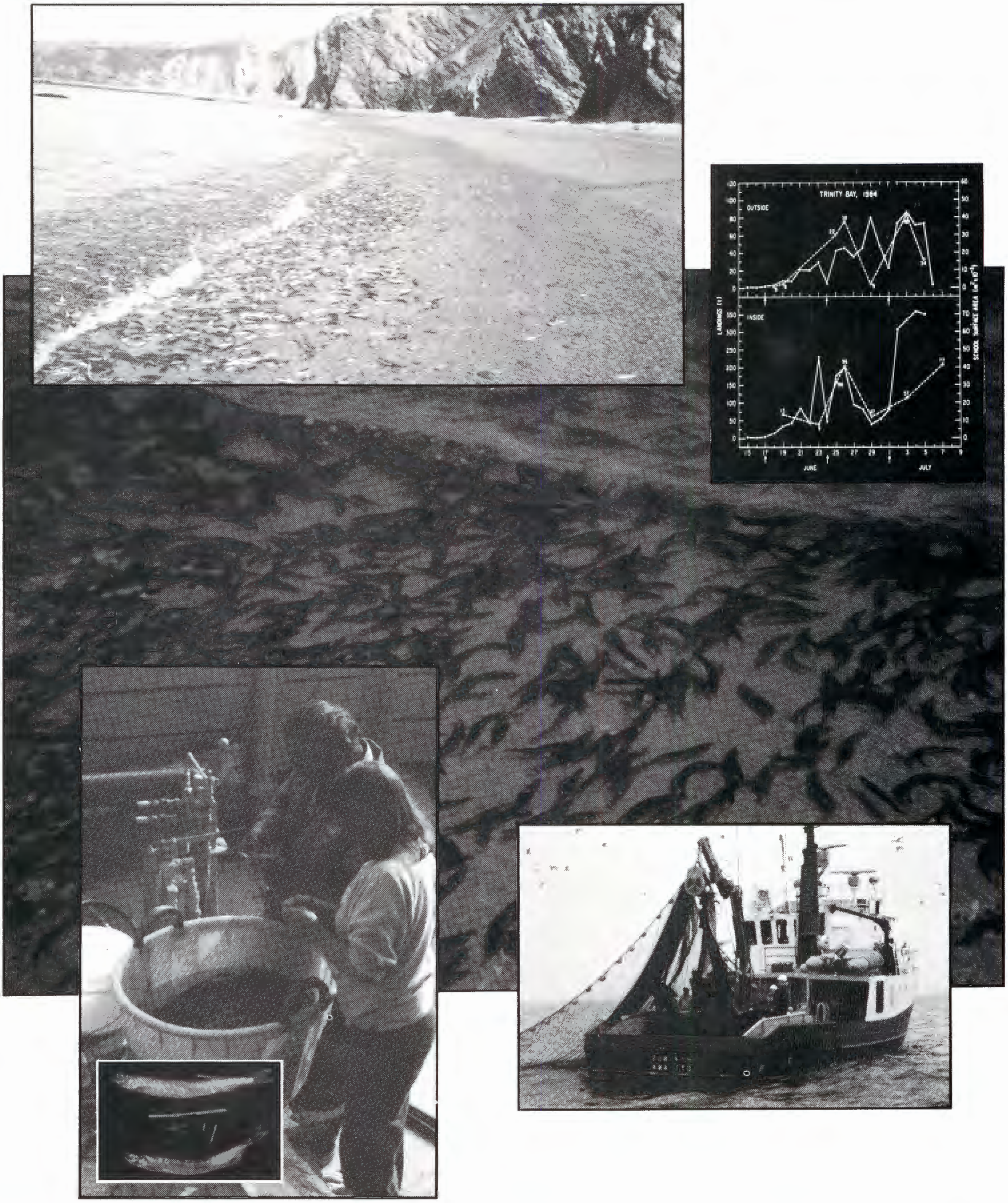
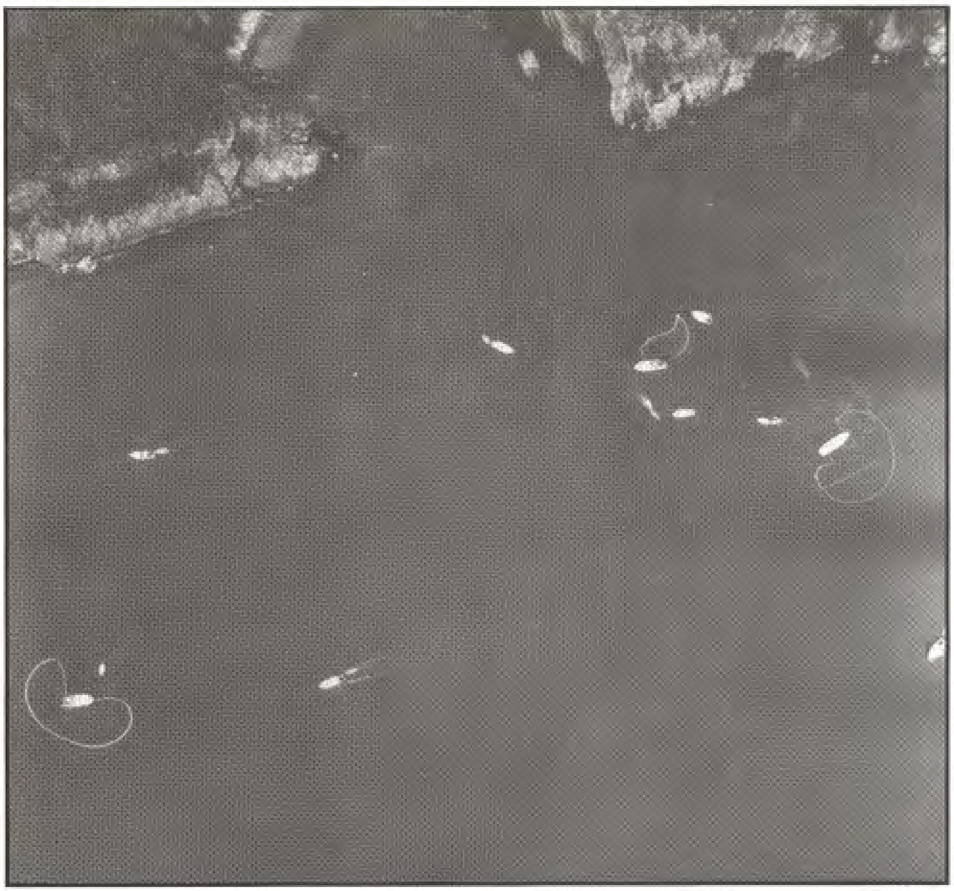

TRINITY BAY, 1984
OUTSIDE
INSIDE
LANDINGS (t)
JUNE
JULY

Capelin — A Variable Resource

Each June, Newfoundlanders eagerly await the annual "capelin scull". People crowd to beaches for the pure fun of harvesting these tiny fish as they "roll" in countless millions to spawn at the water's edge.

Traditionally, the eagerness was for a fresh meal of this tasty species. Many generations of Newfoundlanders have used capelin to fertilize the meager soil of the family gardens. Still others smoked, pickled or dried them. But, for all that, there wasn't much money in capelin.

There's big money in capelin now. The Japanese market for whole roe-bearing female capelin provides an opportunity for quick and significant revenue. In good



years, the economic benefits have been spectacular. Even in average years, the fishery has made significant contributions to inshore earnings.

All this is tempered by the recognition that capelin is a highly VARIABLE resource. Stock levels can change dramatically. In a single year, the biomass or total weight of the stock, can fluctuate, upward or downward, by as much as ten times. At the present time, the resource is healthy. Next year, or the year after that, or beyond, downturns can be expected. These changes in stock status are common to short-lived species such as capelin and are due primarily to environmental influences on the year-to-year survival of young fish. The present total allowable catch (TAC), which is less than 10% of the estimated spawning biomass, is extremely conservative and should not have a significant influence on population size.

There are other reasons why the Department of Fisheries and Oceans has taken a cautious approach in managing the capelin fishery. The species is the primary food item of cod and other commercial and non-commercial species. It plays an extremely important role in the marine ecosystem along the northeast coast of Newfoundland. In the recent report "Independent Review of the State of the Northern Cod Stock", Dr. Leslie Harris and his Panel commented that until we are convinced that we have an adequate understanding of cod-capelin interaction, we should err, if at all, on the side of under-exploitation of capelin. The Department of Fisheries and Oceans agrees with this position.

The enclosed articles describe the work of capelin scientists in the Newfoundland Region. These researchers have had to resort to several innovative techniques (hydroacoustics, aerial photography) to develop a better understanding of the life history of capelin and to assess stock status. These efforts are ongoing. Collaborative ties have been established with scientists in Iceland and Norway and a clearer picture is emerging of the biology of the species from these programs.

We welcome comments on the Science of Capelin. Anyone interested in further information should contact the Science Branch at the Northwest Atlantic Fisheries Centre in St. John's.

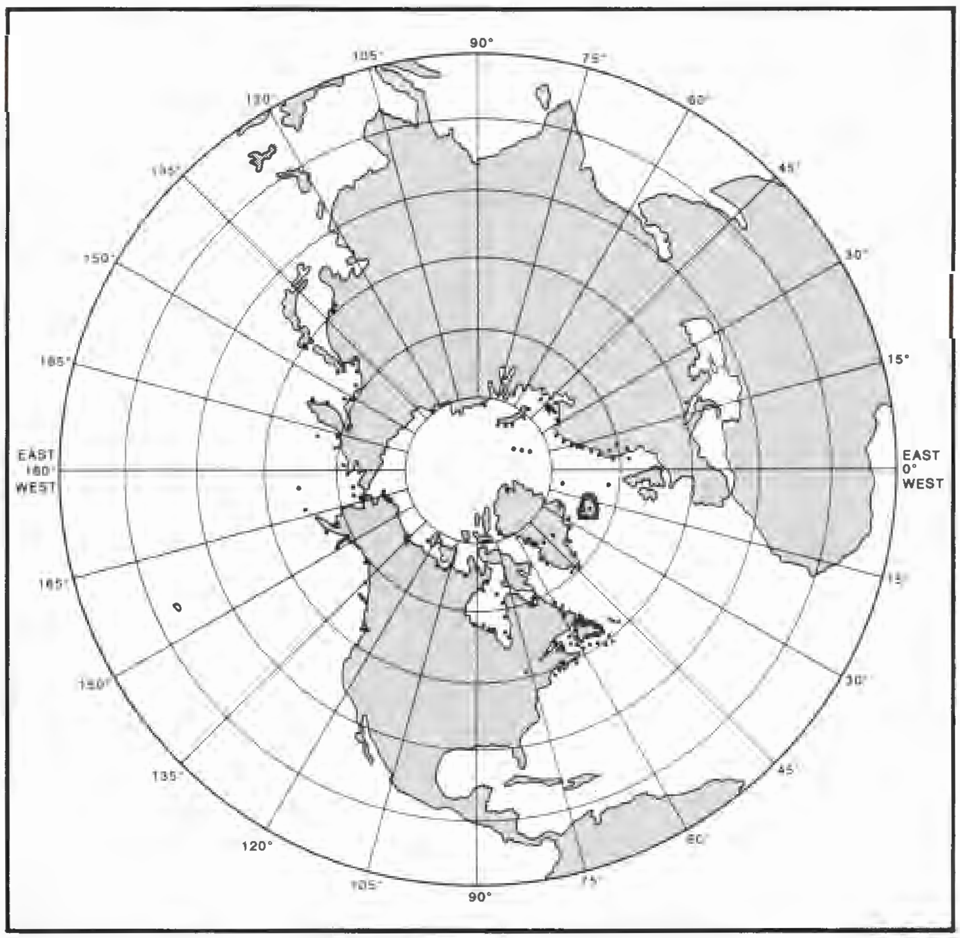
A Cold-Water Fish

The capelin, a close cousin to smelts and a distant cousin to salmon, is a cold-water fish widely distributed in northern oceans. In the north Atlantic they are common around Russia (the Barents Sea), northern Norway, Iceland and Greenland; in Canadian Atlantic waters they range from Hudson Bay south to Nova Scotia. In the Pacific they occur along the coasts of Alaska and British Columbia and, on the Asian side, along the coasts of Russia, Japan and Korea.

Capelin spawn either on gravel beaches or on bottom in deeper water. In Iceland and Norway, they spawn in water depths of up to 70 m. In Newfoundland most capelin spawn on beaches, but there is one group that spawns on the southern Grand Banks, the Southeast Shoal, on sand and gravel bottom in 50 m of water. Most die soon after they spawn, so that their lives make one brief cycle — they hatch, migrate to sea, feed and grow for three or four years, return to spawning areas, spawn and die.

Capelin are important commercially and also as a food for other fish, marine mammals and seabirds. They have always been fished on a small scale by Newfoundlanders and used as fertilizer for gardens, bait, food for dog teams and for human consumption. In the early 1970s, a large offshore fishery developed off the coasts of Labrador and northeastern Newfoundland and on the Grand Banks. Catches of capelin were taken by large mid-water trawlers and purse seiners. Many countries participated, but Russia and Norway took the lion's share. In the late 1970s and early 1980s, the foreign fishery declined but a Canadian fishery developed because of an interest by Japanese buyers in capelin eggs or roe. Now most of the capelin fishery is geared towards this market.

Scientists have been studying capelin at most stages of their life cycle. The spawning, incubation and hatching of capelin in the bays of eastern Newfoundland and on the Southeast Shoal have come under close scrutiny. Research vessels regularly survey the abundance of juvenile and mature capelin offshore. Many of the studies are conducted to aid directly in management, while others are designed to describe and understand the biology of capelin and what factors affect migrations and abundance. A better understanding of capelin biology is crucial to better management.



Capelin thrive in the cold waters of the upper northern hemisphere.

A Valued Resource

Capelin has always been important in Newfoundland, but no-one could have guessed that it would one day be second only to cod in the total value of the catch. It reached this status in 1986, a remarkable development in a fishery that lasts barely a few weeks.

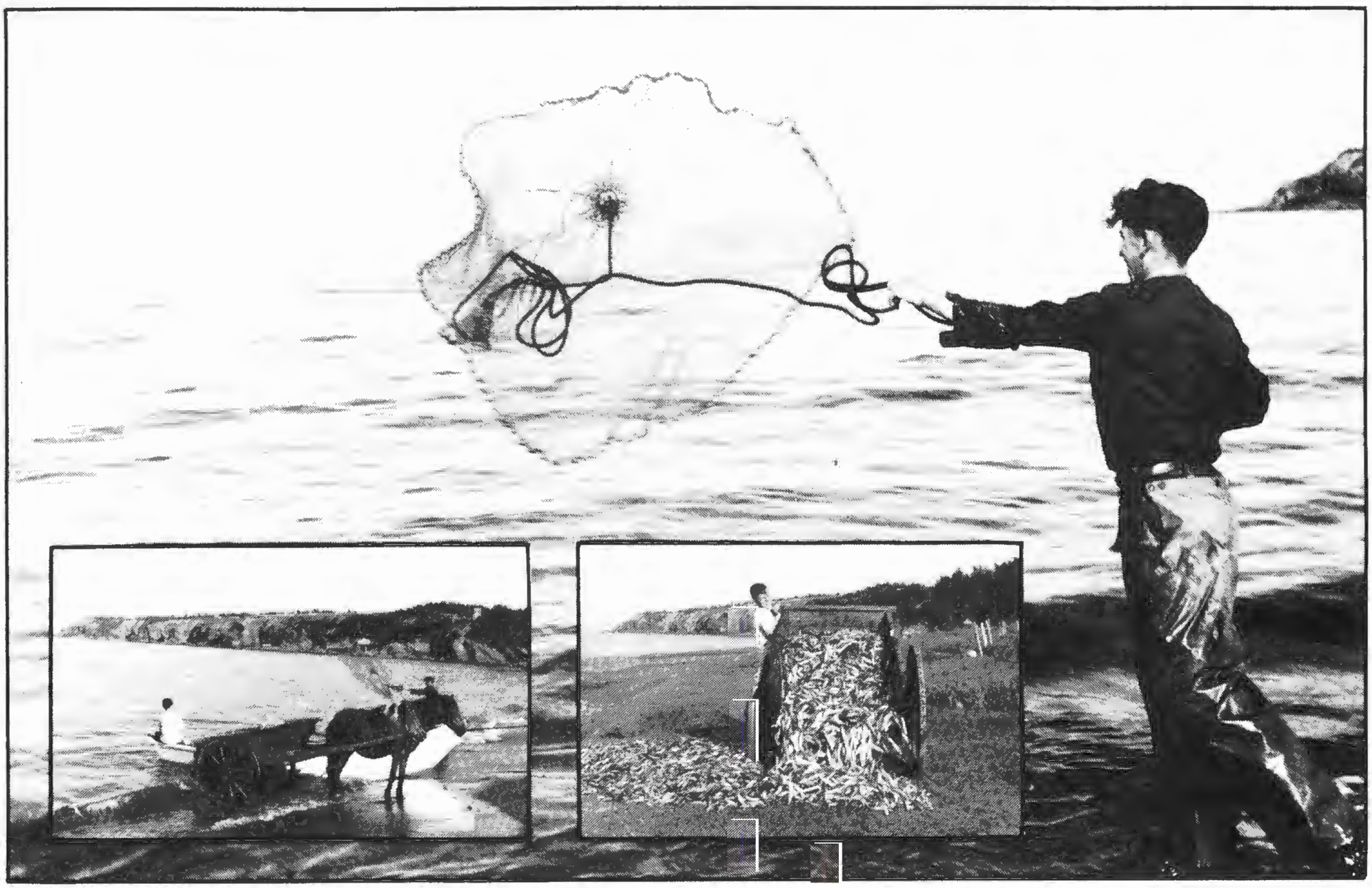
Generations of Newfoundlanders used capelin chiefly as garden fertilizer and bait. Early in this century, the annual catch for these uses was about 25,000 tons. Some people had always put up dried, salted capelin for their own use, and some used it as food for dog teams, but demand was limited.

Commercial production of capelin was even more limited. Experiments in canning began in 1925 and were revived in the early 1930s, but canned capelin was watery and unpopular. Shortly after Confederation, W.J. Bursey improved the process and developed good markets in the U.S. and Canada. He hoped to compete with sardines and canned herring, but his labor costs were high and he was unable to finance automated equipment.

These faltering efforts to make something of the capelin resource continued until the late 1960s. A report from the Fisheries Research Board in 1968 referred to capelin as "a tantalizing undeveloped fishery". At that time, most of the landings were still going to fertilizer and bait, and catches were falling chiefly because demand was very low. The Newfoundland catch hit bottom in 1971, at a mere 2,517 t.

By now, Norway was well embarked on a huge expansion of its capelin fishery, to replace sharply declining catches of herring. Both species were used chiefly for fishmeal and oil. Canada, USSR and Norway all revived efforts to develop popular food products from capelin, but by 1972, when the total world production of capelin reached 2 million t, 96% of that was still going to oil and meal.

The oil was used in food and industrial products, partly to replace declining supplies of whale oil, and the meal was a source of high quality protein for livestock and poultry.



From the days when the main use of capelin was 'to put on the ground' for fertilizer. The ancient technology of the cast net is now seldom seen.

When Soviet and Norwegian herring catches fell drastically in the late 1960s, both countries began to look farther afield. Soviet vessels began to fish for capelin on the Southeast Shoal of the Grand Bank in 1971. Catches were good and by 1973 there were Soviet, Norwegian and Canadian ships in the area. One of the Norwegian vessels was a factory ship producing meal on board, processing the catch from half a dozen other vessels.

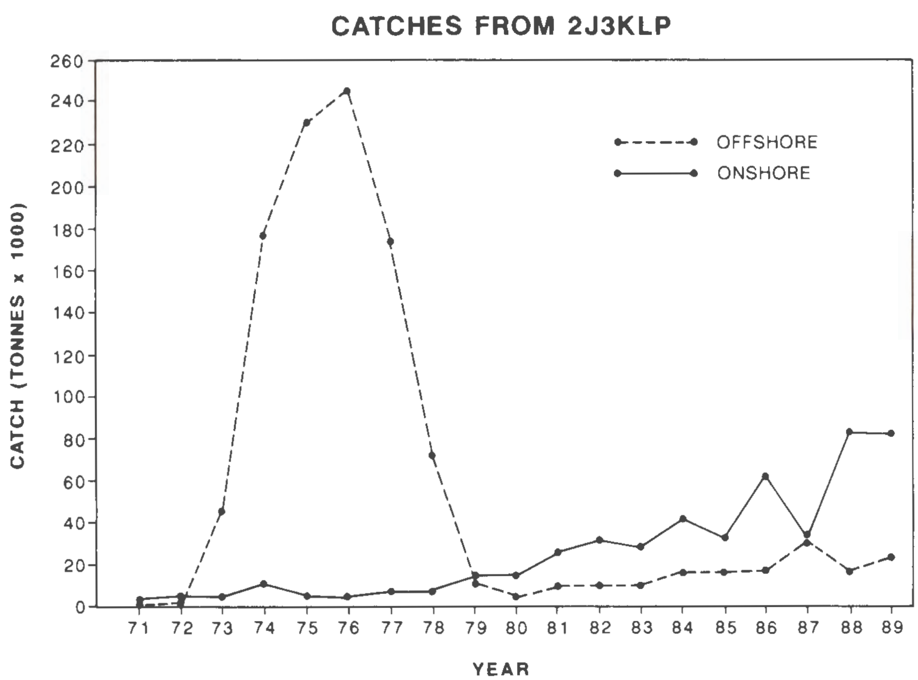
Canadian participation in the offshore capelin fishery reached a peak in 1974, when a disastrous cod fishery prompted Newfoundland firms to enter a joint venture with Icelanders on the Grand Bank. The Canadian catch that year was 15,205 t.

Total offshore catches by foreign vessels continued to rise until 1976, when they peaked at 266,000 t. By now, the USSR, Norway, Iceland, Poland, Spain, Japan, Portugal and East Germany were fishing capelin offshore, primarily on the Grand Bank and Hamilton Bank. The Soviets and Norwegians took about 80% of the total.

Offshore catches dropped off sharply after 1976. Concern for the stock led to severe restrictions in 1978, and the offshore capelin fishery virtually disappeared, although a small USSR fishery continued in Div. 2J3K. In most years catches are about 20,000 t. Since 1987, the fishery has been re-opened on the Grand Banks, in area 3NO. The Soviets take about 5,000 t inside the 200-mile limit, while Japan and Norway between them take about the same amount outside.

By the late 1970's, an inshore capelin fishery had begun, using seines and selling most of the catch for meal. Large purse seiners, facing bankruptcy when the herring fishery collapsed, were allowed to fish capelin for a few years after 1976. The following year saw the introduction of smaller seiners, which soon came to dominate the inshore capelin fishery.

Until 1978, most of the catch was still going to meal. That year, however, saw the entry of Japanese buyers, who have dominated our capelin market ever since. The Japanese want female capelin full of roe, frozen round, and their price quickly put all other capelin products in the back seat.



Total annual capelin catches, 1971-1989, from NAFO areas 2J, 3K, 3L and 3P.

The roe fishery began first in Conception Bay and Trinity Bay, in Div. 3L. It grew fast, propelled by prices that soon had fishermen and processors scrambling to get in on the action. By 1980, federal authorities made capelin a 'limited entry' fishery and began restricting the number of licenses. By then, purse seiners were producing about 60% of the catch, and 80% of total landings were coming from 3L.

Since then, additional fixed-gear licenses have been available, allowing fishermen in all areas of the province to participate in this lucrative business. The number of purse seine licenses has remained relatively stable.

Initially, processors involved in the capelin fishery used the same facilities they normally used for groundfish. Capelin prices were so high that some processors were willing to ignore the cod fishery while the brief capelin season lasted, even if this meant missing the peak of the cod-trap season. As it became clear the capelin roe fishery might be more than a passing bonanza, processors gradually added new plant capacity.

Since shortly after it began, the roe capelin fishery has been managed in terms of the size of the market, not the resource. Capelin stocks would support landings many times higher than those now caught, but the roe capelin market is severely limited. As a result, the total allowable catch is based on the estimate of Japanese demand each year, and is related to Japanese purchasing in other countries.

In an effort to share the opportunity fairly, federal authorities divide the total allowable catch several ways. Quotas are established for each bay. These bay quotas are then subdivided with separate quotas for fixed gear and for purse seiners. In this way, fishermen in the more southerly bays, where capelin tend to appear first, cannot catch the entire allocation before fishermen in more northerly bays have a chance.

A Major Food Item

Capelin have the bad luck to be the most important 'forage' fish in the Northwest Atlantic. Nearly everything that is able to eat them, from whales to puffins, does.

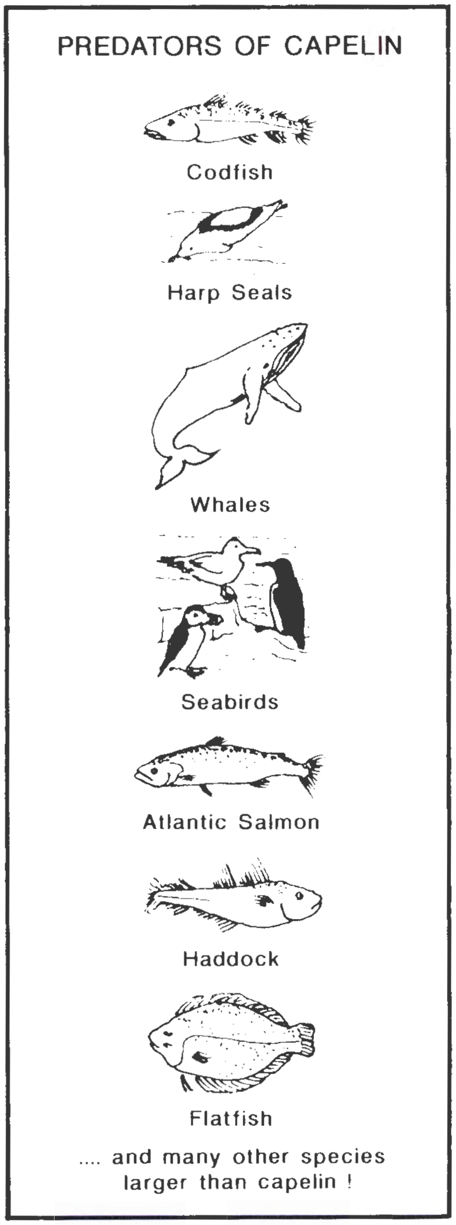
By far the capelin's greatest predator is cod, but the volume of capelin in the cod's diet varies widely from one season and one region to another. For the cod which move inshore in summer, capelin may amount to 98% of the diet. At other seasons, capelin can be a fairly minor food, depending on their abundance and that of other species. Cod must be about 35 cm (14 inches) or larger to tackle a full-grown capelin, but cod as small as 20 cm (8 inches) can feed on the juveniles.

Greenland halibut feed heavily on capelin when they can. So do American plaice and salmon. In fact adult salmon in Newfoundland coastal waters may feed almost entirely on capelin. Seals eat large quantities of capelin, and so do whales and seabirds. The growth of the harp seal herd since the end of the whitecoat hunt has prompted scientists to develop further estimates of the quantity of capelin seals eat.

During the 1970s, when stocks of cod, seals and perhaps also many species of whales were lower than today, scientists estimated that cod ate about 3,000,000 t of capelin. Harp seals ate about 300,000 t, fin whales 250,000 t and minke whales 35,000 t.

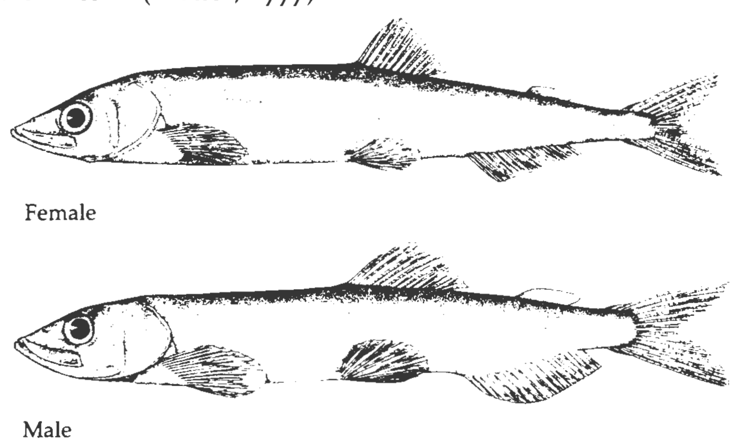
The total of these estimates is 3,585,000 t. By comparison, back in the days when most Newfoundlanders had gardens and many had dog teams — when people hauled cartloads of capelin off the beaches for fertilizer, dogfood, human food and bait — the total human catch was only about 25,000 t, or 1/40 of what the cod, seals and whales are thought to have eaten at that time.

Today, with stocks of cod and seals up sharply from 1970's levels, the total consumption of capelin by these predators is undoubtedly higher, at least when capelin are abundant. However, the abundance of capelin varies widely, regardless of human fishing effort, and few predators can afford to depend on them completely.



The capelin is its neighbours' favourite lunch, making it one of the most important species in the northwest Atlantic.

Mallotus villosus (Müller, 1777)



Capelin or Caplin?

How do you spell cap(e)lin? The 'proper' English spelling is *capelin,* but in Newfoundland a long-standing traditional spelling has been *caplin.* Take your pick! Of if you want to be scientific, the genus and species are *Mallotus villosus.*

Feast and Famine

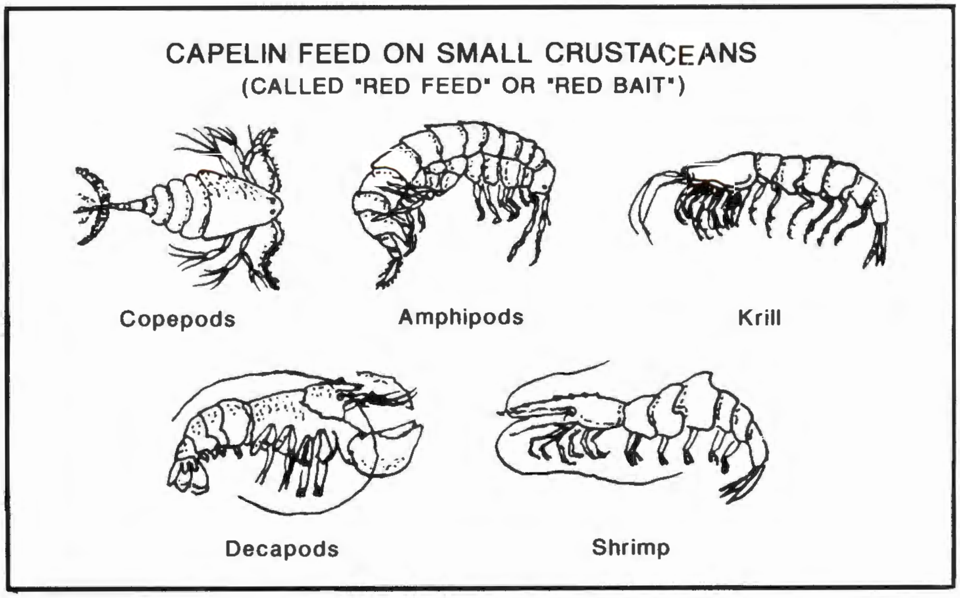
Capelin feed on the tiny creatures many fishermen call 'bait. There are many varieties, with difficult names like euphausiids, copepods (redfeed) and amphipods, but all are forms of plankton which live in the upper layers of the ocean. Some are much like tiny shrimp.

Capelin are 'filter feeders', which means they gulp a mouthful of plankton and water, then use a straining system near their gills to hold the food while they expel the water.

For humans who try to eat three meals a day, often with a snack or two at night, it is hard to imagine eating as a seasonal activity. But feeding is highly seasonal for capelin, because the forms of plankton on which they feed are most abundant in spring-summer. Capelin seem to be able to suspend their feeding for long periods, living off the fat they accumulate during periods of heavy feeding.

Immature capelin feed throughout the spring and summer. The few mature fish which survive spawning feed heavily from August through November. By then their bodies contain as much as 23% fat, compared to 1% in capelin which have exhausted themselves in spawning.

During the winter, when they are in deep water, capelin seem to stop feeding until they return to the surface layers in late winter and early spring. They resume feeding then, and continue until shortly before spawning begins.



A variety of plankton are the capelin's main food source.

Sleggs and Templeman

The earliest scientific studies of capelin in Newfoundland were carried out by G. Sleggs and W. Templeman.

Sleggs was a professor of biology at Memorial University College and held a joint appointment with the Fisheries Research Laboratory which opened at Bay Bulls in 1931. He began research on capelin at Raleigh on the Northern Peninsula in July 1929 and continued at the Bay Bulls lab in 1931 and 1932. His research addressed several questions:

- relation between water temperature and the availability of capelin
- determination of the age of spawning capelin
- distribution and movements of fry (newly hatched capelin) in the waters around Newfoundland
- spawning habits and the factors influencing egg mortality.

Templeman served as Director of the Fisheries Research Laboratory on Water Street east in St. John's from 1944 to 1972. The lab became the Newfoundland Biological Station, Fisheries Research Board of Canada, in 1949. His work on the life history of capelin began, incidental to cod research, at Fogo in 1940. The main field studies were carried out in 1941 at Holyrood and Chapels Cove in Conception Bay and Grand Beach in Fortune Bay. Additional information and samples were obtained from fisheries inspectors, rangers and constables throughout Newfoundland and Labrador. Capelin larvae were also collected from research vessels.

Templeman's studies were undertaken as part of a general program of study of the cod fishery and the bait and other fisheries related to it.

Due to the difficulty of working offshore in the war years, Templeman chose capelin as a primary line of research.

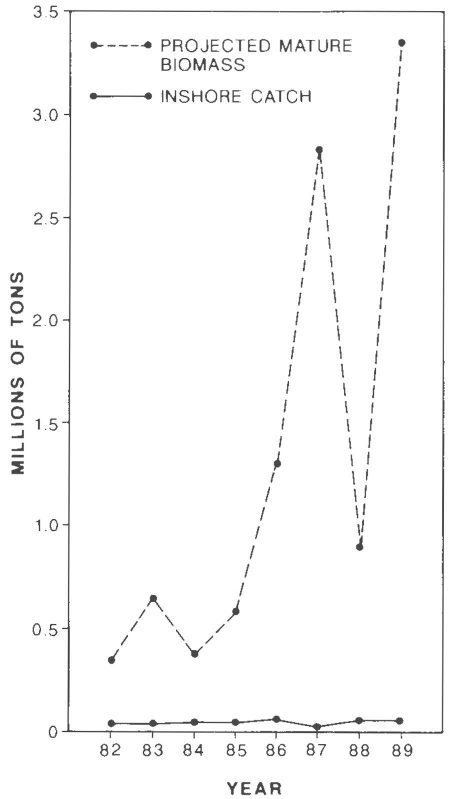
Stock Assessment

Capelin are tricky to count. To arrive at good estimates of their number, scientists have had to discard the methods they use with other species and work out new techniques.

One is hydroacoustics. In a refinement of the 'sounder' or 'fish finder' equipment many fishermen use, scientists on survey cruises can detect capelin schools by the echo from signals sent out from the ship, and make estimates of capelin abundance by the size, number and density of the schools.

Another technique is aerial photography. Systematic surveys of spawning beaches from a plane, and computer analysis of photographs of every school, can help fill in the picture. Combined with log-books which document the daily effort of several hundred inshore capelin fishermen, this provides a way to check the estimates made from surveys offshore.

Capelin don't live long enough for the stock assessment techniques that work with other species. Cod, for example, come into the fishery at about age four and can live for 20 or more years. Counting the number of each age in samples of the commercial catch, comparing this to other years and to samples taken from test fishing offshore, scientists can gradually put together a detailed picture of a cod stock — right down to estimates of the number and weight of fish at each age. The estimates aren't perfect, but new information is available each year. Each new set of data sheds new light on interpretations made the year before. Since cod numbers don't change drastically from one year to the next, this gradual accumulation of data helps clarify the picture.



Mature biomass predicted to come inshore, and actual inshore catches, 1982-89, for NAFO area 3L.

Capelin are very different. They don't offer a long series of clues to their abundance. Since most die the same year they are available to the roe fishery, estimates must be based on juvenile capelin to be of any use in fisheries management. And the numbers of juvenile capelin swing wildly up and down. One generation or year-class can be more than 30 times more abundant than the one the year before, regardless of how many are taken in the fishery.

The mathematical techniques used in estimating groundfish stocks would have little chance of reflecting swings like that. With capelin, each year-class is a new ball game.

Separating Stocks

Of all the things authorities need to know in order to properly manage fish resources, the existence of different stocks is the most basic. Until the number of stocks and the boundaries between them are clear, fisheries managers have no way to forecast the outcome of decisions on fishing seasons, licenses and quotas.

A fish stock is like an isolated human community; its members are able to mingle and mate with other groups, and some do. But most do not, so that changes to one community usually do not seriously affect another. A group of fish is regarded as a separate stock if it keeps to itself enough that it can be fished without making much difference to other groups of the same species.

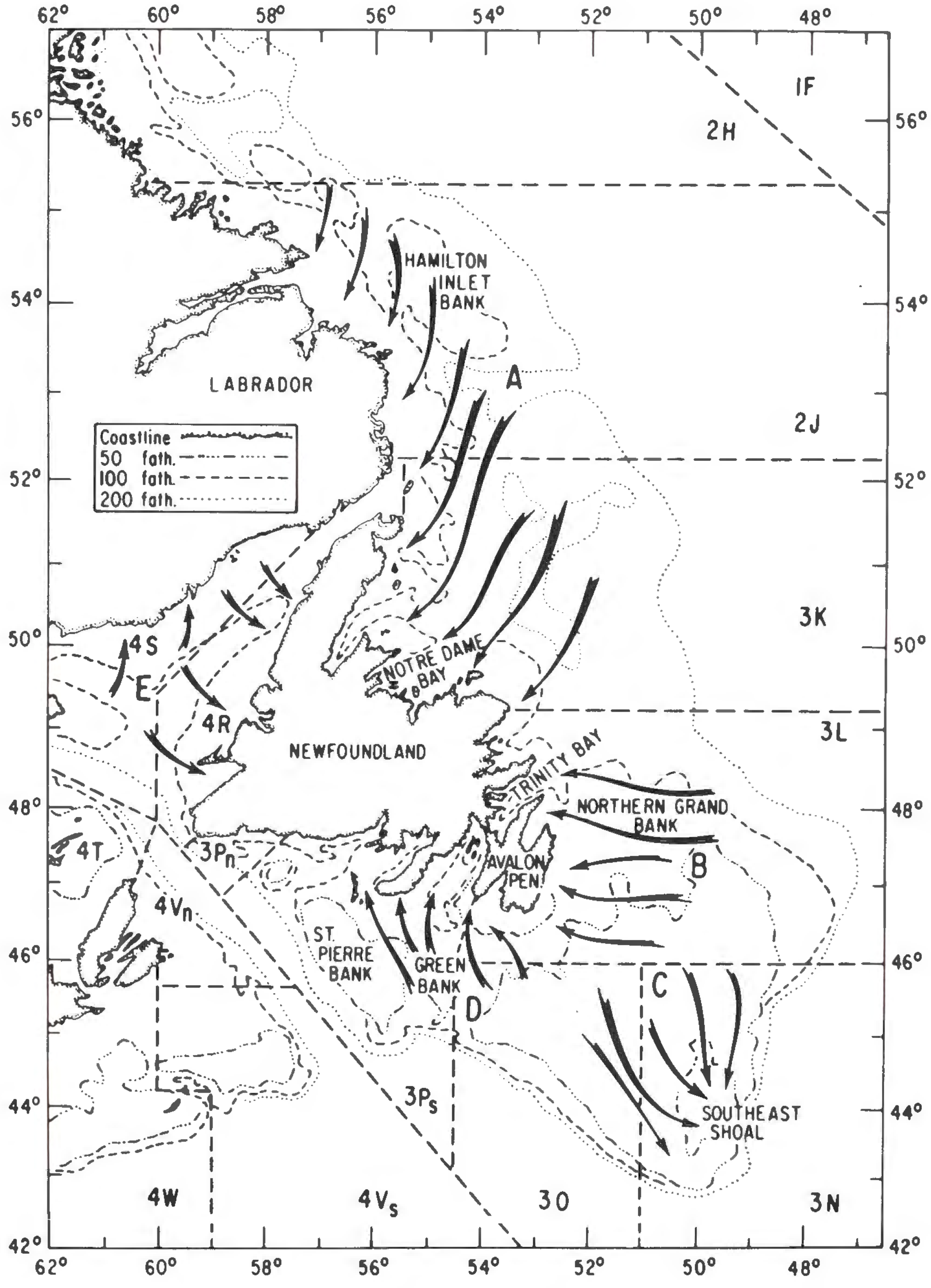
Of the five stocks of capelin in Newfoundland waters, each is oriented to a different offshore bank or a different spawning area. There is some overlap or mingling between several of the stocks, and several may contain smaller substocks within them, but the broad picture is clear:

- Capelin from the Labrador-Northeast Newfoundland stock spend most of their lives on the Hamilton, Belle Isle and Funk Island Banks, and migrate to the beaches in Labrador and northeast Newfoundland to spawn.

- Another large stock spends most of its life cycle on the northern Grand Bank but is thought to spawn on beaches from St. Mary's Bay to Bonavista Bay.

- A related stock is believed to mix at times with the northern Grand Bank stock, but migrates to the Southeast Shoal to spawn. This is the only Newfoundland stock which is known to spawn offshore. The spawning occurs here at the same time as spawning on the beaches.

- The St. Pierre-Green Bank stock lives on the banks south of Newfoundland and migrates to the south coast, chiefly to beaches in Placentia Bay and Fortune Bay.



Five major stocks of capelin have been identified in the waters off Newfoundland and Labrador. One, the Southeast Shoal Stock, does not migrate inshore to spawn.

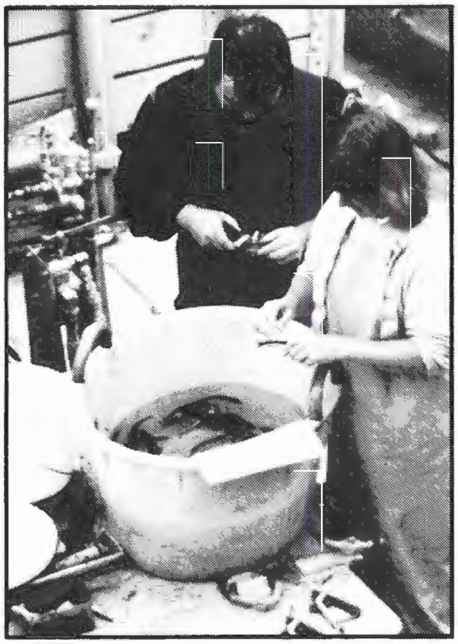
• The Gulf of St. Lawrence stock may actually be comprised of several stocks. Studies of this have just begun. These capelin spawn on beaches of the Gaspé Peninsula, in the estuary of the St. Lawrence River, on the Quebec north shore and on the west coast of Newfoundland.

Scientists want to refine their understanding of these stocks primarily for management purposes, but also because capelin is important as food for cod, salmon and other species. One way of improving our ability to distinguish between different stocks has been to look for physical differences between them, like the differences in skin color, hair and facial features between races of humans.

Capelin vary widely in things like their average length, their rate of growth, the number of bones in their spine, the age of sexual maturity, the average number of eggs each female lays and the types of parasites they have. But relating these variations to different stocks has not been easy. In most cases there is more change between different year-classes within the same stock than there is between different stocks. So none of these things is an obvious 'tag', distinguishing one stock from another.

Tagging Capelin

Scientists need to know more about the movements of capelin to better understand the factors controlling the timing and extent of their migration. Information of this type also helps to understand the relationship between capelin movements and cod movements.



Tagging capelin offshore onboard a DFO research vessel.

Researchers began tagging capelin in 1983. In the bays and along the coast, up to 15,000 capelin have been tagged each year (late May and early June) from purse seine catches. These numbers are high but compared to the number of capelin which come ashore to spawn each year, the proportion of tagged fish is very small.

Tagging capelin is not an easy task due to the small size and "delicate" nature of these fish. Each fish is tagged quickly and carefully with a small plastic streamer. The tag is bright yellow which makes it easy to see. Each streamer has its own unique number which tells where and when each fish was tagged.

The success of the tagging programme is highly dependent on the goodwill of fishermen, plant workers and the general public. Advertisements through posters and the "Fisheries Broadcast" are used to prompt people to look for tagged fish.

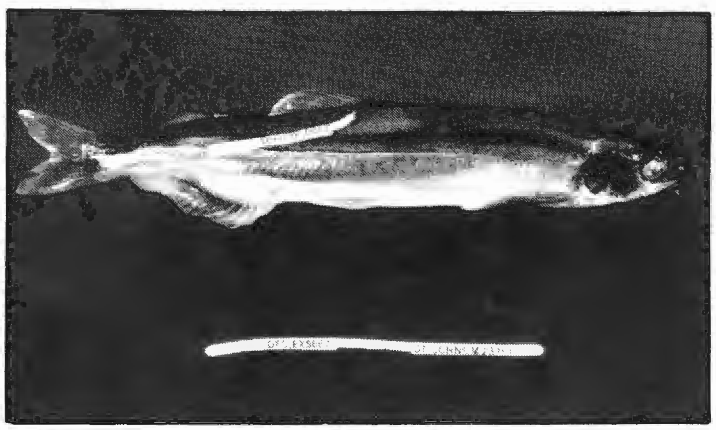
In 1988, scientists expanded the tagging programme to tag capelin offshore, prior to their arrival in the bays. This step required the use of midwater trawls to capture capelin. Through trial and error, scientists have managed to adapt the trawling procedure and handling of capelin on deck to keep fish alive for tagging purposes. Much to their surprise, capelin survive quite well after being hauled up from as much as 100m. While still preliminary, if the method proves successful scientists will be able to tag capelin earlier in the year and further away from spawning areas. The information from the offshore tagging programme will provide another source of information on inshore movements.

Tagging returns to date have given us a general idea of migration patterns:

- capelin moving inshore tend to strike in on the northwest corners of bays along the NE Newfoundland coast
- depending on the level of maturity of capelin when they arrive inshore, some will stay in the bays in which they first arrive; others will move north to other bays
- some returns have been from locations only a few kilometers away from where the fish was tagged; other returns have been from areas a few hundred kilometers away
- there is one record of a capelin tagged near Harbour Grace which was recovered by a fishermen at St. Anthony eight days later
- offshore returns have so far been poor but there appears to be a general northward movement from tagging sites. Migration patterns will vary from year to year as environmental and other factors change. Further studies will improve our general understanding and determine the degree of mixing of stocks.

$5.00 REWARD

CAPELIN TAG



A reward of $5.00 will be paid for the return of each tag with (1) the date of capture, (2) the place of capture, and (3) how it was caught.

Return tags with your Name, Address and Telephone number to:

DEPARTMENT FISHERIES AND OCEANS
SCIENCE BRANCH
P.O. BOX 5667
ST. JOHN'S, NEWFOUNDLAND
A1C 5X1

Information from returned tags is an important research tool for capelin scientists.

How Old?

Scientists age fish by examining hard structures such as scales, otoliths, and fin rays. For capelin, the otolith or ear bone provides the clearest picture of how old the fish is. On each otolith there are annuli, which are similar to the growth rings laid down across tree trunks. Each annulus consists of a period of rapid growth during the spring and summer when food is abundant, and a period of little or no growth during the late fall and early winter when capelin cease feeding. These periods translate into wide white bands and narrow darker bands. Each pair of bands represents a year in the life of the fish.

To prepare the otolith for age reading, each is laid with the flat side up. A drop of alcohol is placed on the otolith to "clear" it and the annuli, or rings, are counted while looking through a microscope.

Ageing of capelin is very important to the assessment process because of the need to predict year-class strength. This is especially important when you consider that each year's spawning population is dominated by one or two year-classes. Errors are minimized by having ages read by an experienced otolith reader or by more than one reader.

A DFO research technician studies otolith growth rings through a microscope.

The Earbone Factor

As with a tree, the growth rings on a capelin's earbone or otolith indicate how old the fish is. Each pair of light and dark (summer/winter) rings represents a year's growth. (The large white area from the center out to and including the first dark ring represents approximately the first year and a half of the capelin's life, from its birth, usually in August, through its first two winters. There is no identifiable dark ring for the first winter.) The capelin from which this otolith was taken was an unusual one. Seven sets of growth rings, including the central area and first dark winter ring, are clearly visible. And although the photo is about 25 times larger than the actual otolith, there are three other sets of rings only visible under a powerful microscope. This was a 10-year-old capelin. Few capelin live beyond four years; five-year-old capelin are scarce. A 10-year-old capelin is an extremely rare phenomenon indeed.

The age of a capelin may be read from the annuli or growth rings visible in the cross-section of its otolith (earbone).

Spawning

Capelin fishermen know that the spawning season is brief and intense in any one bay. Yet the season throughout Atlantic Canada covers nearly five months.

The earliest to spawn are the capelin in the upper Gulf of St. Lawrence which spawn in April. The latest are those which spawn in Labrador, sometimes as late as August. For most of Newfoundland, the spawning time is normally in June and July. Spawning is also spread out by age and size. Early spawners are larger; late spawners are smaller.

Capelin won't spawn till they're 'ripe' — that is, when the eggs are ready. As they approach their spawning grounds, water temperature controls the rate of egg development. Capelin spawning on beaches prefer water temperatures between about 5 and 8°C.

For the majority of capelin spawning on beaches, the strength and direction of wind can make quite a difference. Strong onshore winds push warmer surface waters toward the coast, piling up a layer of warm water near the shore. If this warms the water to the temperature range capelin prefer, spawning may begin. On the other hand, strong offshore winds can drive the warmer layer away from the coast. Then colder water can well up from below, driving the capelin away.

On the west coast of Newfoundland, which is out of the path of the chilly Labrador Current, the water in the bays can sometimes get too warm. When that happens, capelin retreat to cooler water. This sometimes happens on the east coast of Newfoundland as well. Water temperatures near the beach may become too warm and capelin will move to deeper water and spawn on the bottom.

As spawning time approaches, males wait near the beach while the females wait farther off. When a female is ready, she heads for the beach, where one or two males join her. Riding a wave, they swim as far up on the beach as possible, then settle in as the wave withdraws. The ridges along the sides of the males appear to hold the more slender females in place. Flicking their tails and fins rapidly, they scoop out a slight hollow, deposit the eggs and milt, then lie still for a second, as if exhausted, before trying to get back to deeper water with the next wave.

The females, which may produce as many as 50,000 eggs, lay them all at one time. The males, however, spawn more than once and linger at the beach. They are exhausted by the end, and battered by repeated tumbles in the surf. Very few survive. Most females die soon after spawning as well, but not right away, so the dead capelin which litter the beach after spawning are nearly all male.

Seeming almost like an annual miracle, millions of capelin 'roll' ashore to perform the yearly rituals of reproduction.

Late Spawning

Cold water conditions inshore in 1985 delayed maturation and capelin arrived several weeks late on the beaches along much of the northeast Newfoundland coast.

While delays of this kind are relatively rare, the same thing happened in 1941. In a 1948 report on the life history of capelin, Dr. Wilfred Templeman of the Newfoundland Government Laboratory stated:

> *"The unusual abundance of caplin on the south coast in 1941 and their appearance in areas on the south coast where they had not been seen for many years, the many reports of caplin being caught during the autumn and the beach spawning of caplin in late August at Holyrood were probably due to colder water conditions than usual during this year.*
>
> *Ranger V.P. Duff of North-West River, Labrador, reported in 1941: This season is one of the most backward ever experienced at Smokey, Indian Harbour and that vicinity. Up to well in the middle of July there was a solid jam of ice reaching north; this was a serious setback to the fishermen in that vicinity, who ordinarily would have begun fishing by that time."*
>
> *Ranger Sergeant C.L. Summers of Cartwright, Labrador, 1941, says: "Late ice made for an abnormal year. The whole run of capelin seemed to have been delayed in coming."*
>
> *Ranger Christian, Battle Harbour, Labrador, states for 1941: "From personal observations and information gathered from fishermen it is known that the capelin were much later leaving the coast this season than they have been in former years"."*

Two Males or One?

Extract from 1932 article by G. Sleggs, Memorial University campus:

> *"According to our observations the female is not necessarily accompanied by two males, the spawning act as often as not taking place in association with one male. In the latter case the pair swim, or wriggle, upon the shingle with a rapid undulatory movement, resembling a single fish, though the unusual flickering effect catches the eye, when the two individuals will be seen to separate after travelling a short distance. The pectoral and pelvic fins are much larger in the male, and the female is presumably held by the combined action of the fins and the spawning ridges. It is very likely that the fins are used mainly to etablish the initial contact and that the female is held during the act by a suctorial effect against the body of the male. Otherwise a remarkably specialized reflex mechanism must be postulated to enable the two individuals to perform the rapid undulations synchronously. Since the association is merely a matter of lateral contact it is not surprising that two males will accompany one female. The latter phenomenon is, of course, more striking, and the fact that in as many cases or even more only a pair of fish run together may escape notice, giving rise to the idea that the female is invariably attended by two males. We have made close observations (from a dory drawn up against the beach of a small gravel cove) in order to ascertain whether the sexual association took place otherwise than in the ebb of the waves. It was to be seen that the fish swimming in mid-water made no attempt to associate, the sexes being apparently indifferent towards each other, but that the males seek the females precisely at the instant when the shoal is hurled forward upon the beach. This suggests that the peculiar conditions in question are related to the mechanics of the spawning association, in other words that the fish can only maintain their association when assisted by their pressure upon the gravel. A male and a female kept alive in a bucket of water remained indifferent."*

Photos and Logs

Capelin are the only fish in the country for which aerial photos are used to help measure abundance. Aerial surveys have been conducted since 1982, but improvements to the techniques used to study the photos could make this approach even more useful in future.

In the meantime, selected capelin fishermen provide another measure of capelin abundance by keeping close track of their catches and fishing effort.

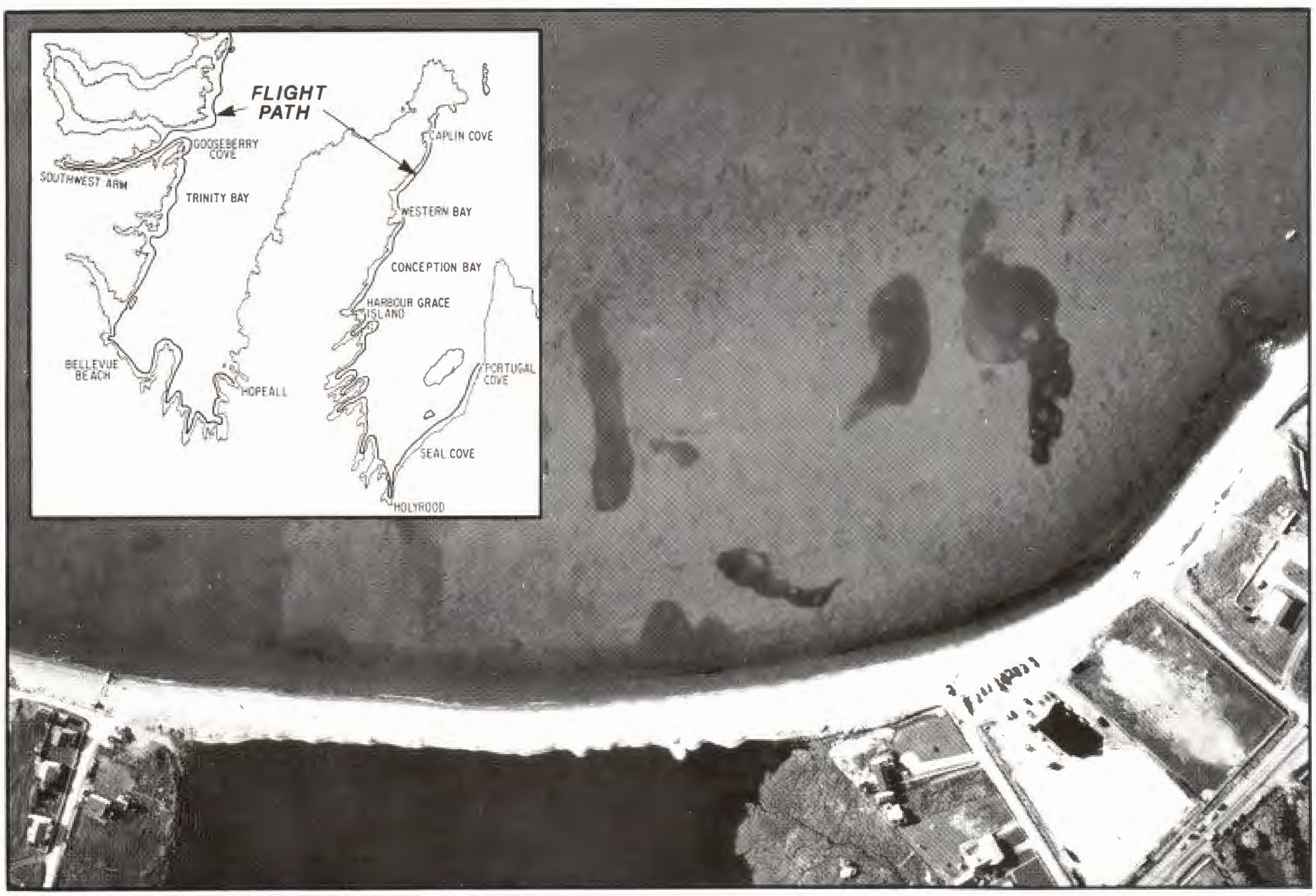
The aerial surveys cover four transects, or flight paths, along the shores of Trinity and Conception Bays. Because waves and the glare of reflected sunlight can hide capelin schools, the best conditions are usually in the morning when the sun is low and winds are light.

The plane, a light aircraft, flies at 475 m (1,500 feet) above sea level and carries a large camera mounted under its belly. The crew includes the pilot, a navigator/photographer and two observers. One observer spots the capelin schools and directs the flight while the other records information, so that each photo is keyed to its time and place. Photos usually contain some shoreline as a way of pinpointing the location.

Interpreting the photos involves trying to calculate the amount of capelin from the size of the schools. This is difficult and time-consuming work. Capelin schools are such irregular shapes, calculating the size of a school on the photograph is tricky.

Once this is done, calculating the actual size of the school in the water is more straightforward. The optics of the camera lens and the height from which the photo was taken influence the size of the image, but correcting for these factors is a matter of simple arithmetic.

Still, there are thousands of calculations. At the peak of the season there can be hundreds of schools in the survey area at any one time. On July 2, 1985, for example, there were 130 schools in the inside part of Trinity Bay between Gooseberry Cove and Hopeall. Altogether they covered nearly 200,000 square meters, equivalent to an area 200 meters wide by one kilometer long.



Air photos of schooling capelin (the dark masses in the water) are used to estimate the abundance of the fish moving inshore. Map shows the flight path of a typical photo reconnaissance flight over capelin schools inshore.

Working out the area of capelin schools on the photos is only part of the picture. What is really important is the volume. But calculating the volume of capelin when you only know how much surface they cover is like estimating the capacity of a box when you only know the size of the lid. The depth of the capelin school and the density of fish within it — how tightly they crowd together — are equally important but much harder to determine.

So far, researchers have had to assume that all schools were equally dense, even while they knew that was not true. Flights on June 26, 1982, for example, found that capelin gathered in 34 schools in the morning had reassembled into 20 schools by the afternoon. And although there were fewer schools, their total surface area was almost double, so it was clear the fish were more loosely gathered in the afternoon.

Having to assume that schools are equally dense is an obvious problem, but until now researchers have had to live with it, hoping errors would tend to cancel each other out. Now, however, there is hope that computer analysis may help. If the photos are 'digitized' — put into a form that a computer can read — the computer might be able to work out a connection between the color intensity of a school and the density of capelin within it.

Date: ______________________ Time Search Started: ______________________

Area Fished/Searched	Time Set Started	Total capelin Caught (lbs)	Capelin Landed (lbs)	Percent Females	Estimate and Reason for discarding (lbs)

Date: ______________ Location of Gear: ______________ Depth Fished: ________

Time Checked	Total capelin Caught (lbs)	Capelin Landed (lbs)	Percent Females	Bycatch by Species (lbs)	Estimate and Reason for discarding (lbs)

Fishing logs kept by fixed gear fishermen and seiners complement aerial photo information to provide better estimates of capelin abundance inshore.

Researchers can detect different shades in the photos of capelin schools, but not with enough precision to estimate the density. If the photos are clear enough, a computer might have more success. Recently, researchers have also begun experiments to measure the density of capelin schools directly, with hydroacoustics.

The biologists involved in photographing capelin have also distributed log books to inshore capelin fishermen. When the logs are faithfully kept, they reflect both daily catches and the amount of fishing effort — the number of sets of capelin seine and the number of visits to capelin traps. This gives the key measure of fishing success, the 'catch rate' or 'catch per unit effort'.

About 185 fishermen cooperate in the log-book program, and 125 of them have been involved almost from the beginning. Grateful for their help and anxious that fishermen understand the value of this cooperation, biologists try to visit them each fall to report on the season's work. A written report is also sent to each fisherman who helps in the log-book program. This report contains the overall results from all the gear types fished so each fisherman can compare his own fishing success with the average.

When the abundance of capelin calculated from photos is compared to the catch rates of fishermen, the two correspond fairly well. Between them, these two methods provide a way to confirm the predictions made through hydroacoustic surveys offshore.

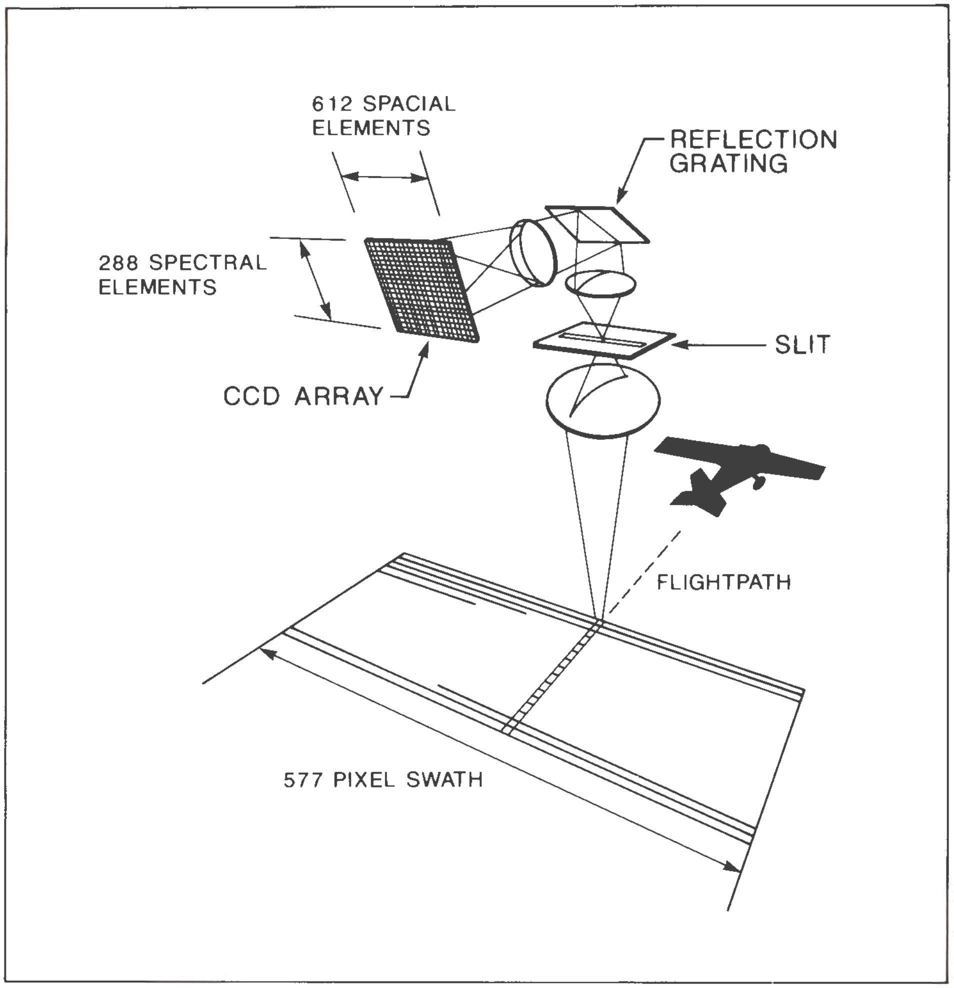
Better Photos

Through a joint project with G.A. Borstad Associates Ltd. based in Sidney, British Columbia, capelin scientists in the Newfoundland Region have developed a method to detect, collect, and analyze data on capelin schools employing a recently developed computer-based imaging technique.

The Component Airborne Spectrographic Imager (CASI) is portable, easily installed in small aircraft, has high sensitivity, and can be programmed during flight to collect various kinds of data. The instrument acts like a high resolution camera in that it measures the wavelength of light reflected from the earth's surface. The portion of the wavelength that is collected and recorded by the CASI is predetermined by the operator. For capelin surveys researchers are more interested in wavelengths in the blue-green range where capelin schools generally are observed.

In comparison to aerial photography, the quality of the data is comparable given optimal altitude and ground speed conditions. There are distinct advantages to using the new method over the current photographic techniques. The data can be processed immediately, it is a more objective way to estimate school areas, and there is a potential to utilize the information in other types of computer analysis.

The study has also demonstrated that schools which are difficult to see in the photographs can be made more distinct through image enhancement techniques. Also the collected data can be easily stored and are easier to use in statistical analysis. As the CASI undergoes further development and more software is written to analyze the digital data, we will begin to realize the potential for using aerial survey techniques to examine the distribution, behavior, and abundance of capelin schools. This in turn may lead to answers regarding the variation in catches experienced by capelin fishermen and variation in the occurrence of capelin spawning from one beach to another.



Borstad and Hill 1989.

CASI (Component Airborne Spectographic Imager) advances aerial photography into ultra-modern computer-age technology, promising more efficient and more effective data collection and analysis techniques.

Cod and Capelin

For many Newfoundland fishermen, the most important thing about capelin is that cod eat them by the ton. Especially for trap fishermen, depending on cod to migrate inshore, the capelin fishery has been a worry.

To many such fishermen it is obvious that when cod come inshore they are chasing capelin. To a scientist, however, even the 'obvious' requires checking and confirmation.

It is possible, perhaps even likely, that cod are chasing capelin when they come inshore and that a good cod-trap fishery depends on the abundance of capelin. But in scientific terms the proof is not yet in. However, it is clear that capelin are the most important item in the cod diet, especially inshore in spring and summer. It is estimated that each cod consumes between 0.8 and 2.4 times its own weight in capelin each year. Keep in mind that at a water temperature of 2°C, it takes a cod about four days to digest a capelin.

What is not clear is exactly how changes in the abundance of capelin affect cod. The question is important, because capelin numbers fluctuate wildly regardless of the capelin fishery. When this happens, the effects on cod could take a number of forms:

• Access to abundant capelin could mean that cod grow faster and mature at a younger age, and that females lay more eggs. These effects would mean a growth in the biomass of cod.

• Abundant capelin might cut down cannibalism among cod. That is, if older cod have access to plenty of capelin, they might eat fewer young cod.

• On the other hand, little is known about the interaction of capelin and young cod. It is possible that an exceptionally strong year-class of capelin could affect the survival rate of young cod. This could happen, for example, if cod larvae and capelin larvae compete for the same food, if juvenile capelin eat cod eggs or larvae, or if adult capelin and juvenile cod compete for the same food.

• If cod do follow capelin inshore, the abundance of capelin may affect the movements of cod. In 1986, for example, a huge supply of immature capelin on the Grand Bank may have interfered with the normal inshore migration of cod. Food was so abundant offshore, most cod may have just stayed out there all summer rather than follow the much smaller schools of spawning capelin to inshore waters. Yet in 1988 there was a good inshore cod fishery in many areas despite a large year-class of age-two capelin outside.

It is difficult to prove any of these possibilities. You can't duplicate the ocean in a laboratory, to watch what cod eat when capelin are scarce or how they behave when capelin are abundant.

What you can do is what federal fisheries scientists have been doing for years now: looking for patterns in masses of data. They study information on the stomach contents of cod, on the estimated growth rates of each year-class of cod, and on any changes to cod migration. They then try to relate these to changes in the abundance of capelin.

Even this is tricky, because each year's data represent only one point on a graph. A pattern may have to be repeated several times to be convincing, because other factors come into the picture. Water temperature and weather conditions, for example, may influence cod migration, the survival rate of cod larvae, or the abundance of other species cod can eat when capelin are scarce. So far it seems that other species are an inadequate substitute for capelin. Cod do eat sand launce, Arctic cod, crabs, shrimp and various small shrimp-like creatures. But they don't seem to eat much more of these when capelin are scarce. It may be that capelin offer the most or best food for the least effort, and that cod must spend more energy getting enough of these other species.

The importance of capelin in the cod diet varies by season and by region. Off northeast Newfoundland and Labrador, cod eat capelin mainly in the summer and autumn. On the northern Grand Bank, they eat capelin all year long. On the southern Grand Bank, cod eat capelin mainly in spring and summer.

Because cod obviously depend on capelin, though no-one can yet be sure how much, authorities are playing it safe with the capelin fishery. The total allowable catch recommended by scientists is set at 10% of the projected mature capelin biomass. The quota set by managers, in consultation with industry, has actually been much less than 10%. In other countries where the capelin fishery has long been important, the catch is more like 35%.

Homing

A mass of capelin rolling on the beach is one of the classic sights of Newfoundland rural life. Yet some of the most basic features of this event are still unclear.

It could be, for example, that capelin return to the same beaches on which they were hatched. However, this would be hard to prove. Scientists have noticed that along the east coast of Newfoundland, maturing capelin move in a south to north direction along the coast. But do they follow the coast till they find the beach they 'remember', or do they simply cruise till conditions are right, then pick the nearest suitable beach?

We know that salmon, which are distantly related to capelin, have a 'homing instinct' which seems to be based on smell. Of all the rivers entering the coast, spawning salmon choose the one they know and follow it past all the incoming branches until they return to the same stretch of river they left years before.

With salmon, this is easier to prove. Young salmon spend several years in their home rivers before they migrate to salt water; by the time they leave they are large and hardy enough to tag. The recovery of the same tags on adult salmon in the same river years later proves the homing ability without question.

Young capelin, however, move away from shore almost as soon as they hatch. They are far too tiny and delicate to tag. Even if it could be shown that capelin return to the same beach, that still leaves the question, How? Are they following a scent, like salmon, picking up the odor of a particular stream or a bog seeping into the bay?

It may be years before we know.

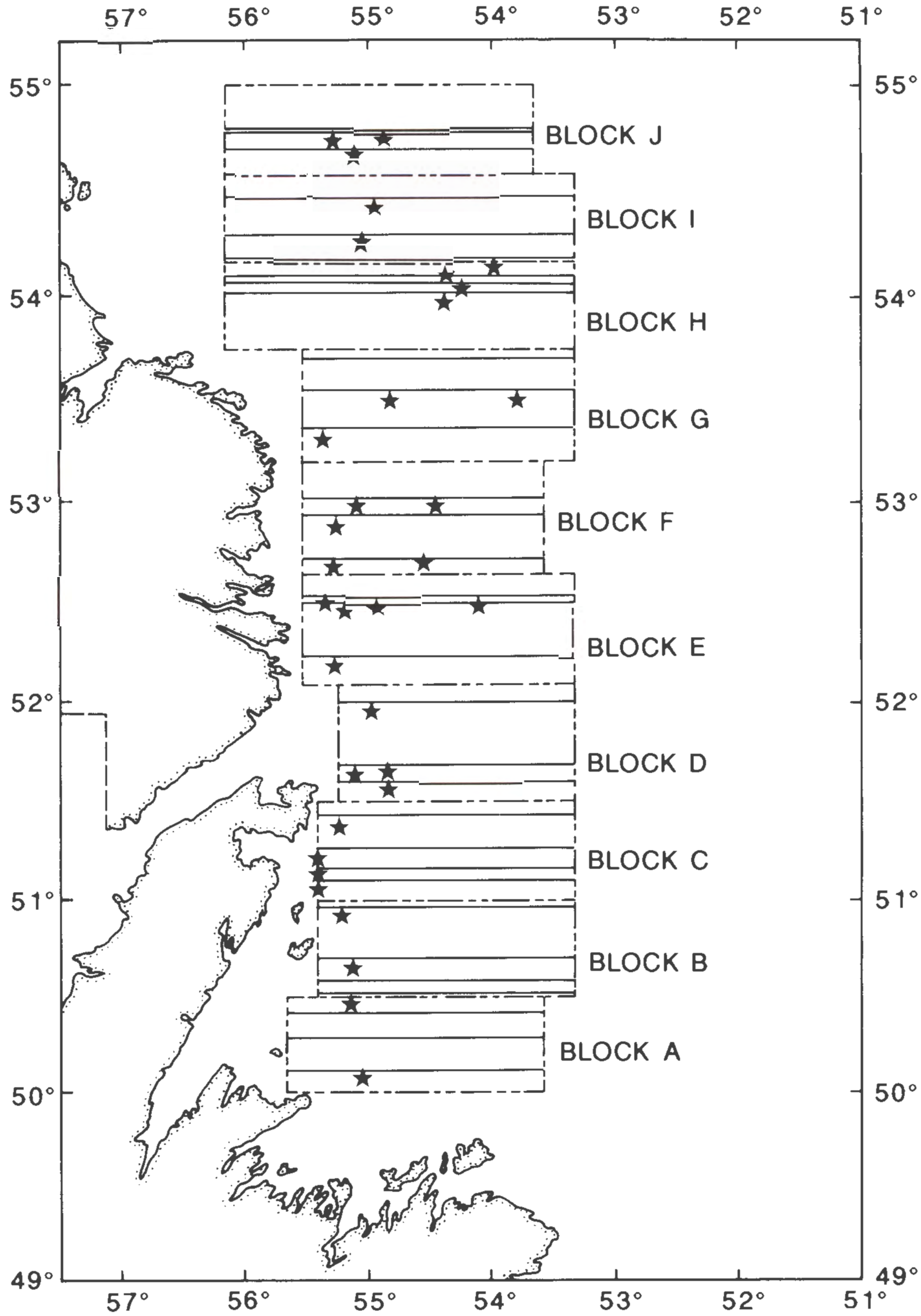
'Sound' Science

Estimating the abundance of fish by hydroacoustics is just coming into its own. New techniques offer much greater precision, even detecting young fish which were formerly 'invisible' to this method. New ways of measuring the strength of signals bouncing back from schools of fish permit better estimates of the density of the schools and the weight of fish under each square meter of the survey track.

There are normally three capelin surveys a year, lasting seven or eight weeks in total. The survey ship steams back and forth over the capelin schools in a pattern calculated to sample them consistently each trip. Instruments on the ship emit a stream of sound signals and then record the echoes reflected back from the bodies of fish.

While the system is similar to the sounders used by many fishermen, the equipment has a much higher resolution. Sounders familiar to fishermen have their 'transducer' mounted on the hull. There it serves as an underwater microphone, picking up the echoes but picking up a lot of other noise as well. In the acoustic system used on capelin surveys, the transducer is mounted in a torpedo-shaped body towed behind and below the ship. This keeps it away from the commotion of the sea surface and the bubbles and prop noise generated by the vessel itself. Removed from this interference, the transducer can detect much more subtle differences in the echoes it receives.

The signals are sent up the towing cable to the ship, where they can be displayed on a screen or printed on a graph. However, refinements now permit computer analysis of signal strength, so the data are fed to a computer and recorded on tape. These instruments can make and record thousands of measurements of echo strength every second. The use of powerful computers allows a prompt calculation of the abundance of capelin in the area surveyed.



Map showing cruise tracks and fishing locations of DFO research vessel GADUS ATLANTICA on a typical research cruise in northern Newfoundland waters.

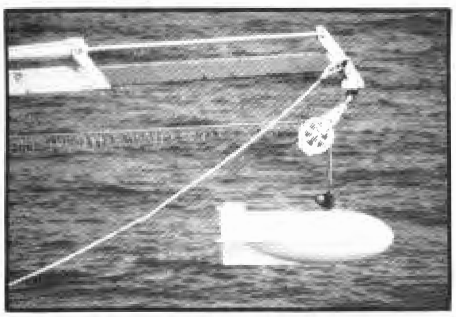
The research vessel is equipped for trawling and makes three or four sets each day. This allows the scientists to confirm that the echo returns are capelin. It also provides biological information such as age and sex of the fish caught.

Of the three annual capelin voyages, two survey chiefly the two-year-old juvenile capelin, most of which will spawn the following year. The third surveys adult capelin shortly before they spawn.

Results from a survey cruise on the northern Grand Bank in May 1989, illustrate the kind of information this system can provide. Crossing back and forth over the grounds, the ship surveyed about 70,000 sq km of ocean. Computers on the ship analyzed the strength of signals reflected from each school on the survey track and calculated a total biomass of 3,800,000 t of capelin in the area surveyed.

Samples of 200 capelin from each of 26 towing sets provided data on age, length, sex and maturity. The proportions of each age class in the samples indicated the number and weight of each age in the stock as a whole.

On the basis of this, scientists calculated there were 1,800,000 t of two-year-old capelin on the northern Grand Bank. This is about as large as the largest class of two-year-olds recorded in 1985 and 1988.



Launching the 'towed body', a hydroacoustic survey instrument used to locate and estimate the size of capelin stocks in deep offshore water.

Capelin shining eerily in the glare of an underwater camera light. Deep-water photos, and mid-water trawls, are used to confirm the findings of hydroacoustic survey instruments.

Year-Class

In fisheries management, a 'year-class' is all the fish of a given stock that hatch in the same year. Scientists can judge the state of the stock as a whole by following the progress of each year-class as it matures. Fisheries managers can better manage the resource if they know roughly how many fish are coming to the age when they can spawn or be taken in the fishery.

In a short-lived species like capelin, the fate of each year-class is critical because the fishery depends on fish which are nearly all of the same age. If something drastic affects one year-class, the fishery will suffer when that group is the main one heading for the beaches. This is why the acoustic surveys are timed to estimate the number of juvenile fish that will move inshore to spawn and be available to a fishery the following year.

In longer-lived species like cod, where the catch includes fish of many different ages, a change in the abundance of any one age will not affect the total abundance very much. As a result, the volume of fish available to the fishery is unlikely to vary as widely. Unfavorable weather and ice conditions may still play havoc with the catch, but the 'biomass' or total weight of fish available is much more stable. Major changes in either direction take several years to develop.

In capelin, the numbers can swing widely from one year to the next. Acoustic surveys on the northern Grand Bank, for example, found 2,000,000 t of two-year-old capelin in 1985. In 1986 the biomass estimate for two-year-olds was less than one-fifth of the figure for 1985,and in 1987 the estimate was about one-third the 1985 figure. But in 1988 and 1989, the estimate was about the same as the 1985 figure.

Studying the connection between environmental conditions — chiefly wind and temperature — and the abundance of capelin, scientists have found that weather alone can explain about 60% of the year-to-year variation in year-class abundance. When conditions permit a large proportion of capelin larvae to escape the hazards of the shore and make their way to sea, a strong year-class is more likely to result.

In many species, fisheries scientists are concerned with 'spawning escapement' — the number which escape the fishery and other dangers and live long enough to spawn. If this number is too low, there is a danger the stock will not produce enough young to compensate for all those which die at different stages of the life cycle. The stock will decline. When authorities restrict the commercial salmon season and cut back on anglers' daily limits, for example, they have the spawning escapement in mind. They are trying to make sure that more adult salmon will make it upstream to spawn.

Spawning escapement seems much less critical with capelin. As soon as conditions permit, they bounce back quickly. Because of this, the abundance of a capelin year-class is probably more important to major predators than it is to the capelin stock itself.

*(**Note:** Spawning escapement is a major part of the Norwegian and Icelandic stock assessments for capelin. It has also been used as a basis for fishery closure on the Southeast Shoal capelin stock.)*

Early Life History

Of all the things that happen to capelin in the three or four years they normally live, nothing makes nearly as much difference as the wind in the first few days.

Recent studies reveal that the strength and direction of wind soon after capelin eggs hatch, and the water temperature in which they live, may account for about 60% of the year-to-year change in the numbers of young capelin which survive to maturity. Nothing else — not even the huge volumes eaten by cod, seals and whales, or the much smaller amount caught by fishermen — has anywhere near that much effect.

In fact, the wind has a strong influence on capelin even before they hatch. When offshore winds push warmer surface water out to sea, cold water flows in from below to replace it. Seeping down over capelin eggs as the tide rises, this cold water slows down their incubation and reduces the risk of larvae emerging at a poor time.

Scientists compare this to the strategy of some plants which live in harsh conditions. They produce seeds which can remain dormant, or inactive, for months or even years; the seeds then spring to life and germinate when conditions are right, when the seedlings have a much better chance to survive.

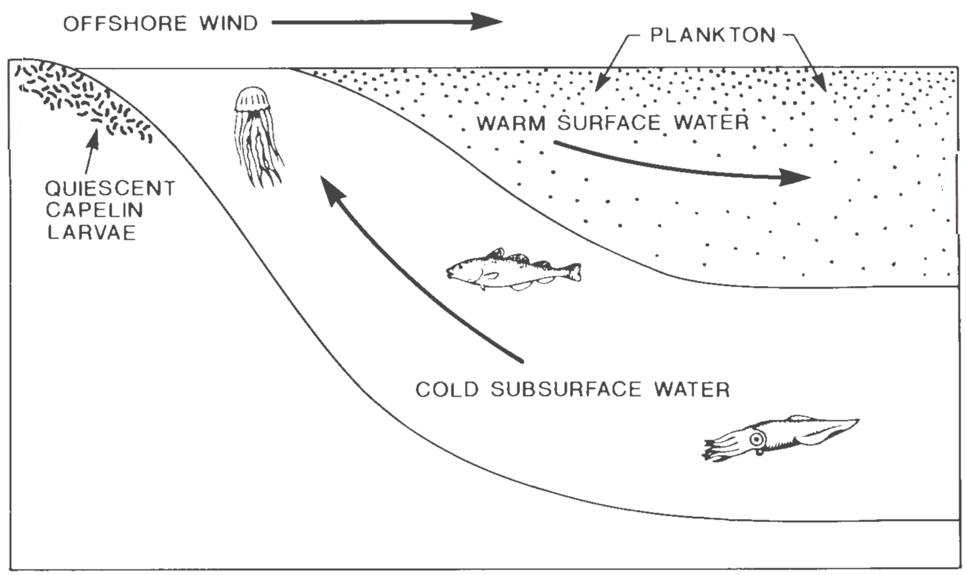
Capelin eggs, mixed in with the pebbles on a beach and maturing at a pace controlled by their environment, incubate for up to several weeks before they hatch. The process can last as long as 55 days in very cold water, or as little as two weeks at water temperature of 20 degrees Celsius.

However, it is after the eggs hatch that wind conditions can have the most striking effect. As they pull away from their eggs, capelin larvae carry a yolk sack which supplies their food for the first few days of life. They remain in the gravel, living off their yolk sacks and waiting. Like sailors, they're waiting for the right wind before they set out. What they want is a strong onshore wind, which offers them four advantages:

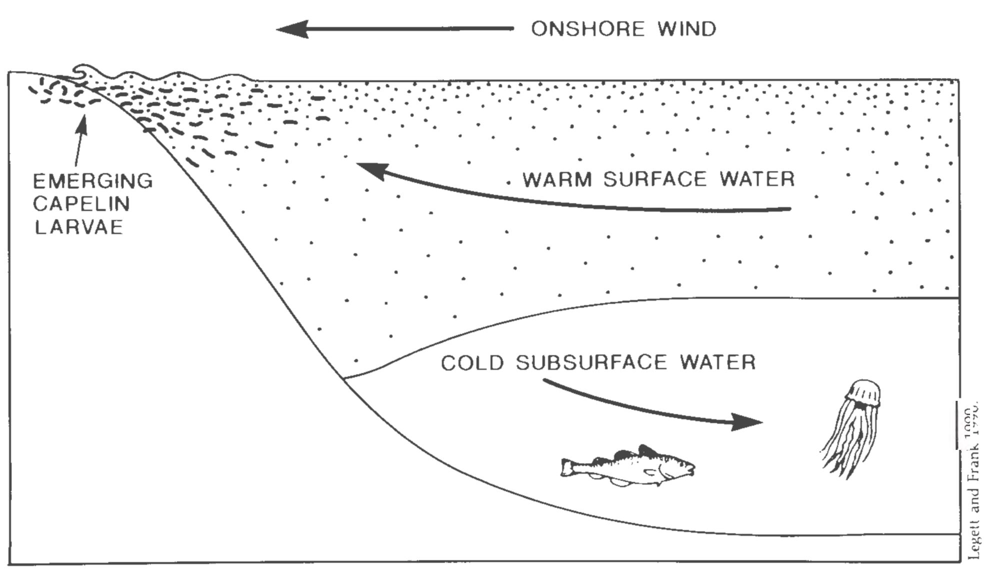
1. Waves generated by an onshore wind stir up the beach, making it easier for deeply-buried capelin larvae to get out.

2. An onshore wind quickly improves the environment they will enter when they leave the beach. Warmer, fresher water driven in from offshore replaces the cold, salty water of the bay.

3. Changing the water mass like this flushes away many of the predators like jellyfish which can prey on the larvae as they make their way to sea. Those predators which remain are soon glutted, so that more larvae will get away.



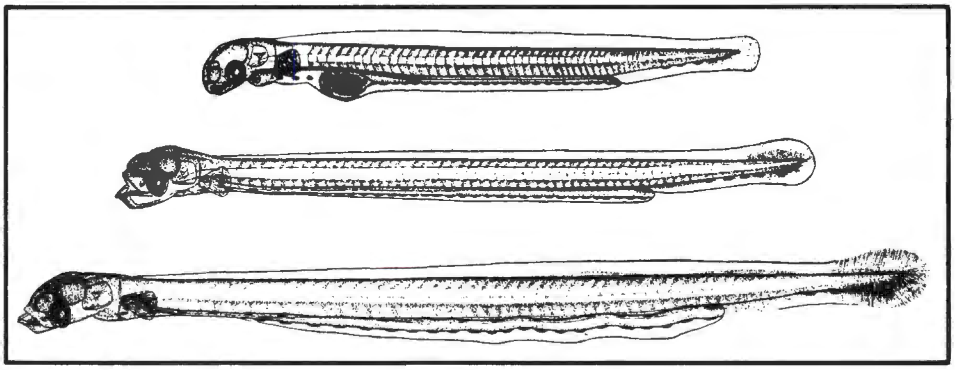
NEWLY HATCHED LARVAE accumulate on land as long as offshore winds prevail. The winds drive surface water seaward, so that colder water rich in predators and poor in prey wells up in its place, making the near-shore region inhospitable to the larvae.



FIRST-FEEDING LARVAE leave their gravelly strongholds for the sea in vast numbers when onshore winds blow warm surface water onto the beach, signaling the relative abundance of suitable food and the relative scarcity of predators, such as jellyfish.

4. The warmer water driven inshore by wind is two or three times richer in plankton than the water it replaces. Access to more food can mean a fivefold increase in the daily growth rate, so that larvae emerging under ideal conditions get off to a vigorous start.

If capelin eggs hatch under poor conditions, the larvae can wait in the beach pebbles for a few days, living off their yolk. However, five days is roughly the limit. Beyond this, their yolk sack is empty. Larvae setting out hungry have a much poorer chance.



The tiny capelin larvae are individually helpless against predator attack, but many survive because of their sheer, overwhelming numbers.

A study of weather records at some important spawning beaches shows that the average interval between onshore winds is 3.5 days, so that five days of rations in the larval yolk sack should normally be enough.

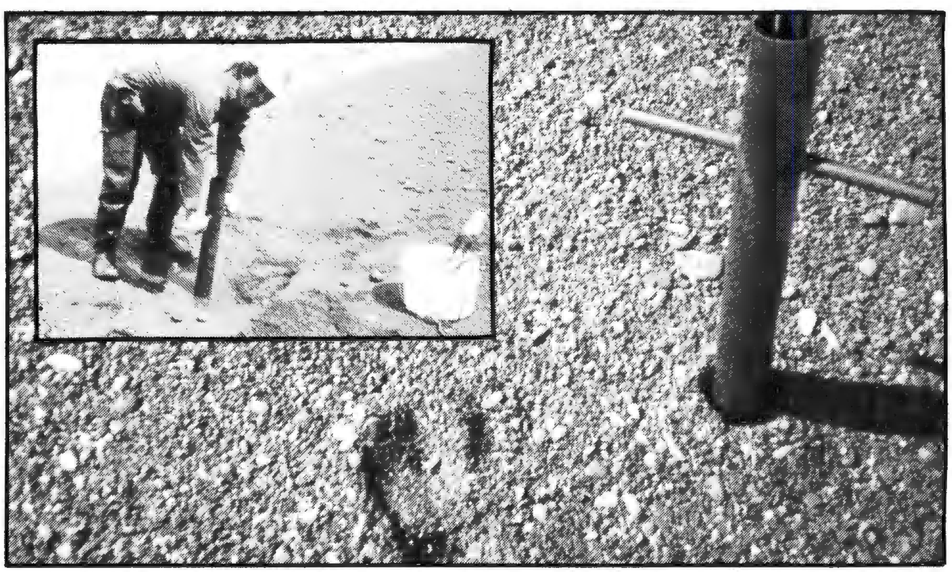
It was not clear until recently whether the larvae can make their own way out of beach gravel to the water, or whether they must wait for waves to stir it up. However, scientists have incubated eggs in an aquarium set up to mimic all the ingredients of a beach except the waves. They found most larvae left the gravel when water temperatures were optimum, indicating that temperature as well as the mechanical action of the waves triggered the larval emergence.

If they can but normally don't, this suggests they are 'programmed' to choose the moment, using waves as a signal that conditions are right.

In the dog-eat-dog world most creatures inhabit, some predators schedule their own behavior to take advantage of times when their prey are most vulnerable. Owls, for example, have their young earlier than most birds and small mammals; by the time young owls have big appetites, the young of these other species are at their most abundant.

Capelin seem to have outwitted their predators with a similar approach. They are at their most vulnerable just as they emerge from the gravel, but by timing this to coincide with an unpredictable event — a strong onshore wind — they keep their predators off balance. As the small capelin leave the gravel in large numbers, predators are soon swamped with them. As a result, most larvae can escape. If only a few larvae escaped at a time, the predators could eat these few individuals over a longer time period and do more damage to the population of young fish.

The preceding research refers only to survival in the first few weeks of a capelin's life. It would be extremely useful if researchers could make accurate predictions of recruitment to the fishery based on observation during this period, but this has not yet been possible. This is not to say that wind conditions at hatching do not have the predicted effects — it's just that capelin larvae must survive up to one year as larvae — a time when other factors have a bearing on survival.



DFO research technician taking core samples of beach material containing capelin spawn. The samples are analyzed to study the egg maturation rate and other aspects of the reproduction process.

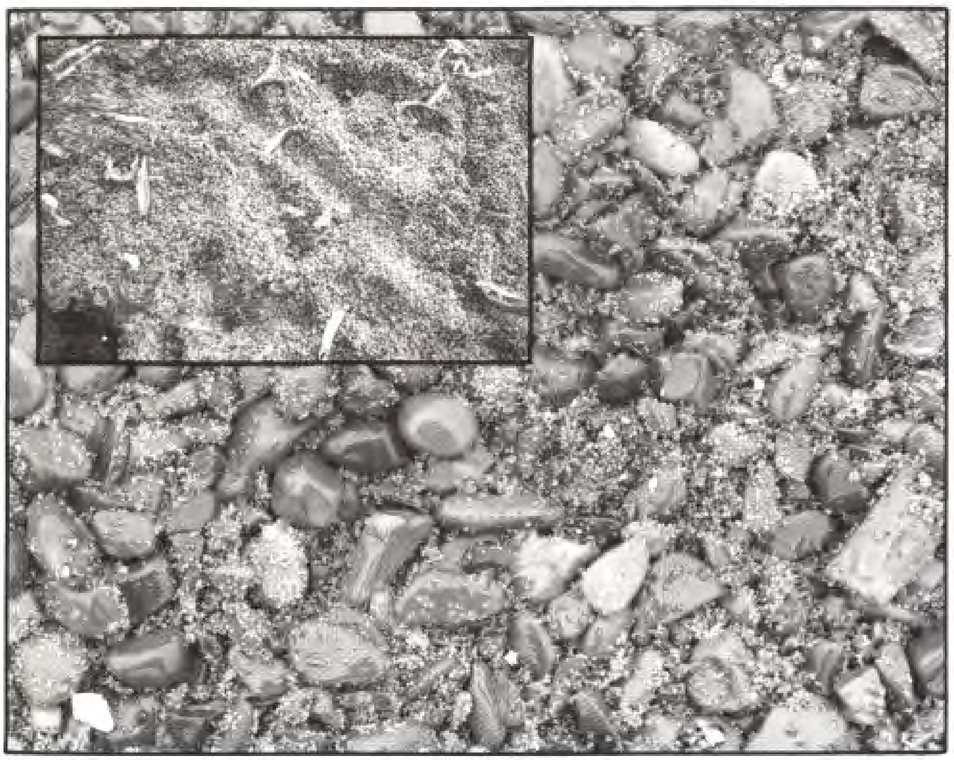
A Tough Start

When capelin deposit their eggs on a beach, they leave them in one of the most turbulent environments on earth. Any place that can polish boulders and grind the sharp edges off a billion bits of rock hardly seems the place for eggs.

But capelin eggs are remarkably tough, and they're sticky. They attach themselves to grains of sand and gravel with an adhesive so strong, scientists who want to study the eggs have to soak them in a solution for 36 hours or more to get them off.

Without this glue, waves would quickly wash the eggs away, leaving them in places where they could not hatch at all, or where the capelin larvae that emerge a few days later would have little chance to survive. As it is, most eggs are mixed into the top 20 cm of sand and pebbles on the beach, between high and low tide, glued to their tiny stone anchors in exactly the environment they need in order to hatch.

Capelin eggs can also survive temperatures from below freezing up to 20°C and they can tolerate very low salinities. This allows them to survive stuck to the beach gravel where they are sometimes exposed to warm, sunny weather and rainstorms.



Capelin spawn, stuck individually to the rocks or laid down in spongy beds several inches thick (inset), is an almost universal sight on Newfoundland beaches in June and July.

Growth and Maturation

When capelin hatch and emerge from the gravel on Newfoundland beaches, getting washed out to sea, most are smaller than a pea. By the beginning of their first winter they are still less than 4 cm, or about the length of the first joint on a person's thumb. They change from larvae to juveniles and attain a digestive system able to handle larger prey, at about eight months.

Most of their growth comes in their second and third year. Just as with humans, a shortage of food in this period can limit the size of the adult. Those which do grow fast in response to abundant food tend to become mature at an earlier age. However, by age 5, for the few which live that long, growth is complete.

A few capelin mature and spawn at age 2, but the majority reach maturity at 3 or 4. The schools of spawning capelin so familiar in parts of Newfoundland are mostly 3 and 4-year-olds, but a few 2-year-olds and some as old as 6 and 7 may be present in the spawning schools as well. Since the majority spawn by age 3 or 4 and most die soon after spawning, these few older capelin are probably those which have survived one or more spawning seasons.

Male capelin tend to grow faster than females during their second year, but they look much alike until the spawning season approaches. About a month before spawning, the fins of males grow noticeably larger and stick out farther from the body. An even more distinct change is the 'spawning trigger' or 'rollers' which develop on each side of the male's body. In two bands on each side, scales grow extra long, forming soft ridges which bulge out from the capelin's normally slender shape. The Norwegian name for capelin is 'lodde' which means 'hairy', an obvious reference to the texture of these ridges.

The 'ripeness' or spawning readiness of female capelin is of great interest to fishermen, because capelin acceptable to the Japanese market are available only for a brief period each summer. The Japanese want females with a roe content of at least 16%. If the females are 'over-ripe', so that eggs squirt out at the least pressure, buyers reject them. They are also rejected if they are under-ripe.

The ripening of female capelin is largely controlled by water temperature. As water temperatures increase, the rate at which eggs develop increases as well. But if water temperatures are cold, the development of eggs is slowed. In 1985, there were unusually prolonged cold water conditions inshore and capelin spawning was delayed several weeks, to July and August.

The Southeast Shoal

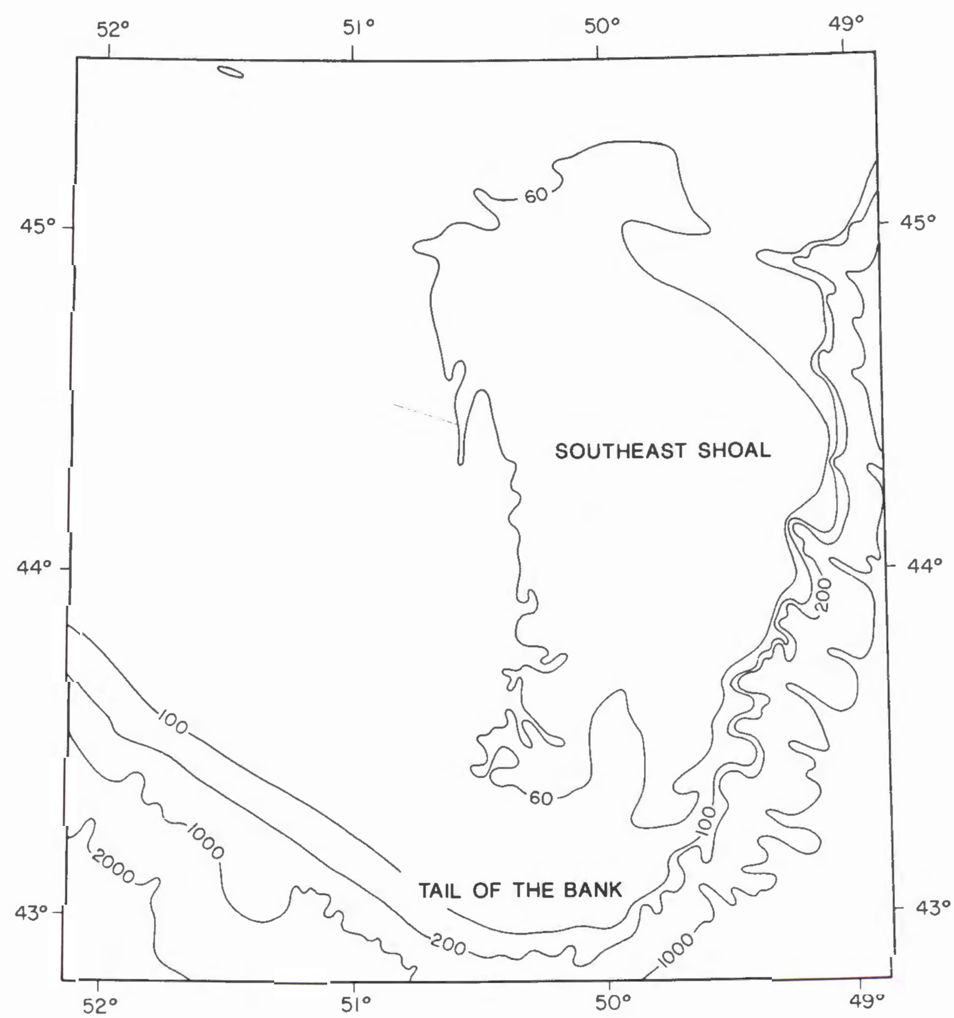
Tropical Storm Charley may have had a big hand in the abundance of the 1986 year-class of capelin on the Southeast Shoal. In fact it appears that a strong wind may be as important to capelin larvae on the Shoal as it is to their cousins on the beach. Research on this subject has just begun, but the early results are striking.

The Southeast Shoal stock is the only one in Newfoundland waters which spawns offshore. This underwater environment imposes a whole new set of conditions for the adults as they choose a suitable spawning site, for the eggs as they incubate and for the larvae as they emerge from the sand and make their way to the surface to feed.

However, despite the obvious differences between spawning at sea level and spawning at 25 fathoms, there are remarkable similarities as well.

A major difference is that the water is much colder. The warmest temperatures recorded at the bottom on the Southeast Shoal are below the coldest water temperatures beach-spawning capelin seem to tolerate.

Another big difference is the task that awaits capelin larvae when they emerge from the sand or gravel where they hatch. Their food is the plankton that grows near the ocean surface, in the right blend of sunlight, water temperature and nutrients. The larvae of cape-



The capelin stock on the Southeast Shoal, on the 'tail' of the Grand Bank, is the only one of Newfoundland's five major stocks that stays offshore to spawn.

lin spawned on beaches are already at the surface, but inshore; their mission over the next few weeks is to make their way to offshore feeding areas. Larvae of capelin spawned on the Southeast Shoal are already offshore but they have to reach the surface.

It isn't always easy. Waters off Newfoundland are strongly layered in summer, with sharp differences in temperature, salinity and density between the layers. These boundaries seem to serve as a barrier to capelin larvae, especially when they're very young.

Another difference between the offshore and beach-spawning capelin is the size of the grains of sand and gravel in which they spawn. Inshore, they favor small pebbles. On the Southeast Shoal, they spawn on sandbeds where the grain size is much smaller — about 2 mm.

Yet in both cases the choice fits. Capelin eggs are sticky and attach themselves to sand and pebbles as soon as they are laid, probably to avoid being swept away. On the beach or offshore, they become mixed in the gravel to a depth of 15-20 cm. On the beach, wave and tidal action is enough to stir up the gravel. On the Southeast Shoal, water currents or the rapid movements of the capelin themselves may help to bury the eggs. No-one has been able to observe capelin spawning in deep water, but those which spawn on beaches scoop out a small hollow by rapidly flicking their fins and tails.

So capelin appear to choose a grain size heavy enough to anchor the eggs and light enough to allow easy burial. The coarse sand of offshore spawning beds is also light enough to allow easy emergence of larvae when the time is right.

Scientists have worked out the currents required to move different sizes of sand, as well as the kind of waves required to generate such currents underwater. It is clear from weather data that storms violent enough to shift the sands on the Southeast Shoal are common. Waves created in August 1986 by Tropical Storm Charley, for example, were enough to generate currents of 1.6 km/hour at a depth of 45 meters — more than enough to shift sand grains of the size offshore capelin choose for spawning.

The other role wind seems to play in the life of these capelin is to stir up the water. Just as an onshore wind rolls over the water in a bay, offshore storms cause a mixing of layers. During Charley, for example, surface temperatures fell from 15 to 5°C; bottom temperatures must have risen almost as sharply.

So a storm at the right time may achieve several benefits for capelin larvae ready to emerge from the bottom. The shifting sands or the sudden increase in water temperature, or both, could signal that conditions are right. The mixing of normally stable water layers could make it much easier for emerging larvae to reach the surface, and would scatter the predators that await them at this hazardous stage in their lives.

Moreover, studies have shown that the offshore production of plankton, their only food, is improved by storms. So not only do more larvae reach the surface, but a richer environment awaits them when they do.

Intensive study of beach-spawning capelin and the survival of larvae has been underway for several years. Results so far suggest that the wind at the time of larval emergence has more influence on year-class abundance than any other factor. While similar studies on the Southeast Shoal have barely begun, the same seems to be true even there, 50 meters underwater.

The PISCES submersible is a piloted mini-submarine capable of taking two observers more than 1000 metres (3000 ft.) beneath the ocean's surface. Here it is being used to find capelin spawn on the Southeast Shoal.

Loyalty

Fisheries scientists believe that capelin have been spawning on the Southeast Shoal for 200 centuries or more. If so, they have adopted to profound changes, because 20,000 years ago much of the Grand Bank was above water. Capelin spawning there would have spawned on beaches, as all other stocks of Newfoundland capelin do today.

During the last Ice Age, glaciers covered most of Newfoundland, including the Avalon Peninsula. Ocean levels were lower then, and much of what is now the Grand Bank was probably a barren plain. As the ice melted, water levels rose and the Grand Bank subsided. The shallowest area, the Southeast Shoal, was the last to go under.

While it still remained above the water it would have been a region of beaches battered and eroded by storms. Part of the evidence of this is the character of sand on the bottom today, some of which is typical of the sand created when surf pounds a beach.

When the Grand Bank was above water, there may have been other areas suitable to capelin spawning. Now that the whole region is flooded, however, probably only the Southeast Shoal has the right combination of water temperature and coarse sand. Tracking these capelin at spawning time by hydroacoustics, scientists have found the largest concentrations in areas of warm water. In fact they gathered in the dense schools typical of spawning capelin only where the bottom temperature exceed 2°C.

Capelin may have spawned on other areas of the Grand Banks which have suitable bottom as well. However, other factors may not have been suitable to allow survival of eggs and larvae. Bottom temperatures are lower than on the Southeast Shoal so the eggs may not hatch at all. Even if they did, the water may be too deep to permit the small newly-hatched capelin to reach the warm, food-rich surface waters. It takes the right combination of environmental conditions to allow a population to thrive and reproduce. This is especially true for eggs and young fish which are helpless and subject to whatever Mother Nature gives them. The Southeast Shoal seems to be the only place offshore that provides all the appropriate conditions to allow a capelin population to survive.

Capelin on the Southeast shoal, just prior to spawning.

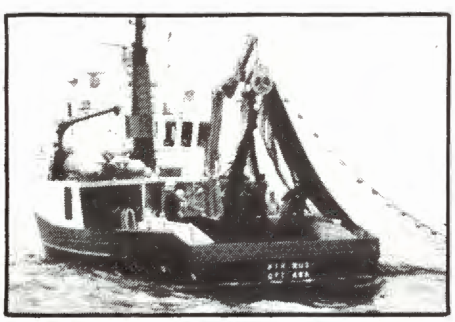
The Good News Fishery

The traditional fixed-gear traps are also a highly efficient technology for harvesting the dense schools of capelin as they swarm inshore.

For two or three weeks every year, capelin is king. When the market picture is clear the capelin fishery can be an extremely busy and lucrative period. The key is to get an early fix on a firm price.

In a good year, like 1986 or 1988, the rewards can be spectacular. Even in an average year, capelin can be a major factor in the annual earnings of the fishermen and processors involved.

When the price is good, capelin offers the chance of fast cash. For fishermen who may have been out of work since the previous fall, a couple of weeks of good money makes a wonderful start to a new season. Landings of three to five tonnes a day are common for capelin trap and beach seine fishermen. For seiners, which need larger catches to cover much higher costs, landings of 10 to 13 tonnes a day are common, and look pretty good when the price is high.



Mobile-gear seiners operate at a frantic pace during the capelin fishery, often landing 10-13 tonnes of fish in one haul.

For plant operators, too, capelin offers quick revenue. Japanese buyers pay promptly, which helps the operator finance his purchase of other species as the season progresses.

For plant operators and for some fishermen, the capelin fishery may conflict with the peak of the cod season. For most of those involved, however, the profits make it worthwhile. This is reflected in the increasing numbers involved. In 1986 there were 82 plants processing capelin, compared to 67 in 1982. That same year there were 1,790 licenses to fish capelin, double the number three years before. Approximately 2,500 capelin licenses (fixed gear and purse seine) were issued in 1989.

However, the Japanese market remains strictly limited, and Newfoundland's share of that market may decrease as the stock of one of Japan's other traditional suppliers, Norway, recovers. Over-supply one year can mean lower sales the next. And a tight market means that the Japanese buyers can and do use factors such as quality and size in setting prices and purchase limits.

The annual round of bargaining over prices and other aspects of the capelin fishery may be the toughest set of negotiations any sector of the industry faces in a given year. There are years when no one is happy with the outcome.

In spite of these problems, capelin still provide many fishermen and others with an excellent opportunity to make a good dollar in a very short time. If we can hold our market share and maintain high quality and size standards, the fishery will continue to make an important contribution to inshore livelihoods.

Consulting with the Players

Using scientific advice, market information and the knowledge of past experience, fishermen, processors, fisheries management personnel and other players hammer out a plan for the annual capelin fishery at meetings of the Small Pelagics Advisory Committee.

Each year the roe capelin fishery has only a few weeks to make the most of what is sometimes a $70 million opportunity. Key players — the fishermen, the plant operators and government — work closely to avoid the conflicts or confusion that can fool up a good season.

Planning begins early in the year, when federal authorities monitor the European capelin fishery, which opens long before ours and supplies the same type of product to the Japanese. When the Norwegian and Icelandic catch is very low, things look good for Newfoundland.

In late spring, when it is clear how much roe capelin the Japanese still need, DFO convenes a meeting of its Small Pelagics Advisory Committee, which represents the capelin fishermen and processors, and the federal and provincial governments. The task is always to match the fishery to the size of the market.

With many plants and fishermen competing for their share of a small pie, these meetings rarely produce a consensus. However, they do give all sides a chance to put their case, and supply authorities with the information on which to base difficult but unavoidable decisions.

Shortly after this step, DFO releases the annual capelin fishing plan, which sets out the total allowable catch and breaks it down by area and gear type. The plan also publishes the terms of licenses and the regulations on catching and handling capelin. In addition, the plan provides for the harvest of capelin for frozen males, zoo food, aquaculture feed, bait, etc.

As the fishery progresses, DFO monitors the catch to enforce the quotas, and ensures handling and freezing regulations are complied with.

During recent seasons, DFO also held frequent conference calls with representatives of fishermen and plant operators, to allow them to raise problems and contribute to the process of governing this hectic business fairly.

Calendar

January
- Scientists prepare for capelin assessments.

February
- Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) Pelagic Subcommittee meets to assess capelin stocks in NAFO Subarea 2 + Division 3K, Div. 3Ps and Gulf of St. Lawrence.

March
- CAFSAC Steering Committee meets and provides scientific advice.
- Fisheries in Norway and Iceland monitored to determine Newfoundland market.

April
- Meeting of Small Pelagics Advisory Committee (SPAC) composed of representatives from DFO, fishermen, processors and provincial government to discuss proposed capelin management plan.

May
- Capelin management plan developed by DFO from discussions in SPAC.
- Acoustic survey in Div. 3L to assess biomass of juvenile capelin.

June
- Capelin management plan approved by Minister, Fisheries and Oceans and put into effect.
- Northwest Atlantic Fisheries Organization (NAFO) meet to assess capelin in Div. 3L, using results of May survey, and in Div. 3NO.
- Aerial survey to estimate capelin abundance inshore.
- Logbook survey of inshore fishery.
- Acoustic survey of spawning stock in Div. 3NO.
- Capelin egg survey on spawning beaches.

July
- June surveys continue.

August
- Scientists analyze data and prepare for fall surveys.

  Fishermen receive summary of results from logbook survey in which they participated.

September
- Larval survey of capelin in Div. 3NO.

  NAFO annual meeting to discuss and provide scientific advice for Div. 3L and Div. 3NO capelin.

October
- Acoustic survey of capelin in Subarea 2 + Div. 3K.
- Scientists attend International Commission for Exploration of the Seas (ICES) meeting to assess capelin stocks in Iceland and Norway.

November
- Larval survey of capelin in Div. 3NO.

December
- Small Pelagics Advisory Committee meeting to discuss problems of past year's fishery in preparation for next year's fishery.

Redfeed

Redfeed is a name that covers several types of pink or red-colored organisms eaten not only by capelin but by herring and mackerel, the other pelagics in Newfoundland waters. Redfeed live in large patches in the water, and tend to flourish in spring and summer. Capelin usually gorge on redfeed when they find it.

After such a feast, their stomachs become swollen. Normally their digestive juices break down the food quickly, converting it to a form the capelin can absorb into their own bodies. However, when capelin are caught, the catch must be processed quickly and carefully to avoid 'bellyburn'.

'Bellyburn' can result in either of two ways. When the capelin stomach is swollen and stretched, rough handling tears the stomach lining and allows digestive juices to get at the flesh. Or, even if the capelin is handled gently, delays in processing may give digestive juices time to eat through the stomach lining to the belly cavity. Either way the result can be a gaping hole, created when stomach acids digest some of the capelin itself.

Freezing stops the action of digestive juices, so that if a capelin full of redfeed is quickly frozen there is no loss of quality. However the digestive process resumes when the capelin is thawed, and substantial 'bellyburn' can occur during the processing of thawed capelin with even a very low level of redfeed.

It is generally accepted that heavily feeding fish are the most susceptible to 'bellyburn'. Consequently, market specifications requiring that frozen female capelin contain very limited levels of redfeed are a source of great concern for Newfoundland fishermen and processors. Heavily feeding female capelin are also of concern in the Icelandic and Norwegian capelin fisheries.

Researchers have proved that acceptable products can easily be produced using capelin with a high level of redfeed. Improving iced storage, frozen storage and thawing times/conditions appear to be effective means of reducing 'bellyburn'.

For fishermen, redfeed is usually a problem only at the beginning of the season. Capelin normally stop feeding before they spawn, so that in a normal season they may be free of redfeed by the time the females are ripe. However, when cold water delays the spawning, capelin may continue feeding right up to the time they are ready to head for the beach. This happened in many areas in 1985.

Feeding patterns and redfeed counts can vary a great deal from place to place and from day to day. Often capelin caught in schools close together have very different redfeed counts.

Fixed-gear fishermen using capelin traps and beach seines catch capelin a few days later in the spawning cycle than the mobile seiner fleet fishing farther off. As a result, the seiners commonly have more trouble with redfeed. Perhaps partly for this reason, the Japanese seem to prefer the catch of the fixed-gear fishermen and have bought more of their total supply from this sector of the fishery in recent years.

Timing is Everything

With the landings to be made in just a few weeks, the timing of the capelin fishery is critical.

Female capelin must meet certain criteria to be acceptable for the Japanese market and therefore must be caught at the proper time. The roe (eggs) must be properly developed, neither under or over-ripe, and must make up at least 16 per cent of bodyweight. As well, the capelin must be relatively free of 'redfeed'.

Water temperature controls the rate of egg development, and also strongly influences the 'plankton bloom' upon which capelin may feed until shortly before spawning. Cold temperatures can delay the date of spawning by several weeks. Then, when capelin do show up they may arrive in a rush, still full of 'redfeed'.

Several years ago DFO instituted an intensive sampling program to monitor roe development and redfeed levels in capelin concentrations. These conditions were used to determine the opening dates for the capelin season. The season was opened when the capelin were deemed to be suitable for the Japanese market.

However, there were problems with this approach, so for a number of years a fixed opening date was set — usually June 1 — with processors deciding when to start buying from fishermen.

In 1990 an industry-sponsored sampling program was instituted. Fishermen and processors agreed on a set of criteria to determine the opening dates in different areas. Based on sampling information from pre-selected sites in each area, local committees made recommendations to DFO for season openings.

Monitoring the Quotas

Elaborate quotas are devised to share the earning opportunity among different sectors of the capelin fishery in different bays.

In a typical year the total catch is divided more than 20 ways, with separate allocations for fixed gear and purse seine fishermen in each of nine different areas.

DFO has a central team in contact with all the plants, which supply daily landings broken down by gear type and area. Fisheries officers also keep an eye on landings and check the progress of the fishery by talking with fishermen and plant operators.

DFO's statistics group pulls together daily reports from all these sources. Forecasting the next day's landings on the basis of today's catch rates, they can estimate when each sector will have caught it's share. DFO works closely with the popular CBC radio program "Fishermen's Broadcast" to be sure its announcements reach their target.

Closure of a valuable fishery is rarely popular. It hurts to quit fishing when the bay is full of capelin and you still face big payments on your boat. Fishermen are more used to limited fish than limited markets.

Marketing

Newfoundland's roe capelin fishery suffers an unusual problem: a limited demand and an abundant supply. This usually put buyers in control.

The Japanese are the world's largest consumers of fish; they eat about five times more of it than Canadians. One of hundreds of fish products they enjoy is 'shishamo', frozen female capelin full of roe. Each year they eat about 32,000 t of it. Until the 1950s, the Japanese supplied the shishamo market from their own stocks of capelin. When these were depleted they turned to Norway, the USSR, Iceland and eventually to Canada.

Newfoundland is still the last in line, because the spawning season in those countries begins several months before ours. Both the volume the Japanese will buy and the price they are willing to pay depends on how much they have been able to buy before our fishery begins. There are other factors at play such as size preference and fat content.

Over the last few years our share of the total market has increased to about 88% of Japanese imports. Norway has been our chief competitor in the Japanese market. The Icelandic share of the market has held fairly steady, but there is some concern that our market share will decline sharply when Norwegian stocks recover. Yet the Japanese may prefer to keep all sources of supply open, if only to give them more bargaining power with suppliers. Canadian producers who worry abut holding our market share know that high and consistent quality is essential. Japanese consumers are quality conscious, so that second-rate products have little chance in their market.

One advantage the Norwegians enjoy is that their roe capelin business is conducted secondarily to their intensive meal and oil fishery. When capelin are plentiful off Norway, this one species alone supplies more than half the country's total fish catch. About 98% of it goes to fish-meal and oil. Roe capelin is a tiny but lucrative by-product in a much larger industry, with most of its costs already covered by other forms of production. In Newfoundland, the roe-capelin fishery is the primary focus, with only small quantities of other products being generated.

Finding other markets for our capelin would undoubtedly strengthen the industry, reducing our dependence on Japanese buyers and resulting in greater use of the resource with higher landings. But it won't be easy. Limited markets currently exist for large male capelin for zoo food, mixed capelin for bait and aquaculture feed, plus secondary process capelin for canning and smoking. The other large market for pelagics is in the form of fish-meal and oil, where it competes with vegetable sources of oil and protein, like soya beans. Some fishermen are opposed to further development of the fishery due to the importance of capelin as food for cod and other commercial species. The bottom line is that in recent years the total allowable catches have been higher than the market need. Resource size will undoubtedly be a factor if market needs increase.

A lot of work went into the development of capelin products as human food in the mid-1970s, though little has come of this yet. The research made it clear, however, that capelin has an exceptional storage life when frozen. The flavor and texture of capelin remain acceptable even after months of frozen storage. This offers some hope for the development of products from the male capelin now largely wasted in the Newfoundland fishery.

Cod, Herring and Capelin in Norway

In the highly competitive international fishery, one nation's downturn can be another's good fortune. Newfoundland's recent prominence in the capelin roe fishery followed the collapse of capelin stocks first around Iceland and then Norway. Iceland's capelin stocks have recovered. The situation in Norway, however, is of special interest because it shows how drastically stocks of pelagic fish can drop and how the whole marine system can be thrown out of kilter when they do.

It is not clear how much over-fishing has contributed to this. Pelagic fish stocks can collapse with no help from man. However, Norwegians and other Europeans do tend to fish their stocks more intensively than Canadian authorities permit, leaving less margin for error.

There are three major species that interact in Norwegian waters — cod, which is a predator, feeding on herring and capelin. All three are heavily fished. The herring stock was once very large, estimated at 7 to 10 million t in the 1950s. However, fishing pressure increased and by the late 1960s the herring stock had been drastically reduced by fishing. There has been a slight recovery during the mid-1980s, but the herring biomass is still only about 10% of what it once was.

The capelin stock has also fluctuated widely. The Norwegian capelin fishery, which became intensive after herring stocks declined in the 1950's, suffered a total failure in 1962 but steadily recovered for ten years after that. The fishery increased greatly after 1968, with a record catch of 2.9 million t in 1977. Then in the mid-80s the stock declined again, so seriously that the fishery was closed altogether in 1986. Now, stocks are recovering enough that authorities may re-open the capelin fishery in 1991.

The cod stock has also shown increases and declines due to fluctuations in recruitment. During 1976-81, recruitment was poor and the stock declined. From 1982 onwards, several good year-classes occurred. However the stock biomass did not increase as expected because growth was poor due to a lack of suitable food. There is even evidence of increased cannibalism. There is now a serious crisis in the coastal Norwegian cod fisheries.

There is a debate among scientists over the exact causes of the declines in the capelin and cod stocks. There is no consensus about whether over-fishing of capelin and cod stocks has caused the decline and exactly what role herring play. It seems clear that cod and other marine animals such as seals and seabirds are suffering because of lack of food, but it is not obvious whether the decline in capelin occurred because of over-fishing, natural fluctuations or a combination of both.

While the situation in Norway is serious, Canadian scientists are learning from the Norwegian experience. DFO scientists are collaborating with Norwegian scientists to learn more about the interactions between the predators (including man) and the prey, and what causes the fluctuations in abundance.

A Canada/Norway Cod-Capelin-Marine Mammal Workng Group was established in 1989 and the first meeting held in St. John's, Newfoundland in November of that year. Several Icelandic scientists were sufficiently interested to join the group. In April and December, 1990, scientists met again in Bergen, Norway, and Woods Hole, Massachusets, planning work on these important questions over the next several years.

'Shishamo'

The Japanese process our female capelin into a product called 'shishamo', a snack food popular in Japan. Female capelin with a high roe content are cured in a brine solution, semi-dried on skewers, then cooked and eaten.

Future Research

DFO scientists are initiating new research annually to provide more accurate stock assessments and to better understand the biology of capelin and the importance of capelin in the ecosystem.

Norwegian, Icelandic and Canadian scientists will continue to work closely together to identify pattems in the interrelationships between cod, capelin, and marine mammals. Studies of the ecosystem by three countries permit scientists to compare the same animals living under different conditions to better understand the factors affecting each species and their interrelationships.

A joint project between Norway and Canada recently started, under which Canadian scientists will use special Norwegian fish-rearing facilities to study the biology of capelin during the first few months of life. This is the life stage at which the year-class abundance of capelin is believed to be established.

The remarkable discovery that capelin have been spawning on the southern Grand Bank for at east 8,000 years has prompted DFO and university scientists to begin studying the evolution of capelin worldwide. They plan to compare samples of capelin from Iceland, the Soviet Union, Alaska, Greenland and Canada. Using a powerful new biochemical technique called "mitochondrial DNA analysis", they hope to work out the origin of today's capelin population from information stored in bits of matter in their cells.

Biomass estimates of capelin are being improved through the adoption of statistically superior survey designs during offshore acoustic surveys.

Aerial surveys of capelin during their inshore spawning migration have been conducted for a number of years. In collaboration with the private sector, DFO scientists are now applying a new technology whereby capelin schools are automatically recorded during the flights and the amount of capelin is estimated using state-of-the-art computerized image analysis systems. This technology provides a more rapid and accurate assessment of the amount of capelin detected during the aerial survey.

Inshore and offshore capelin research undertaken by DFO scientists provides a biological basis from which we can identify and predict fluctuations in population abundance, and also predict distribution over areas. Abundance levels can change dramatically from year to year, for natural reasons having nothing to do with fishing activity. Annual assessments alert the industry to rises and falls in stock size. Future research will provide ways and means of doing improved assessments and explaining changes in stock size and other characteristics of the capelin resource.

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