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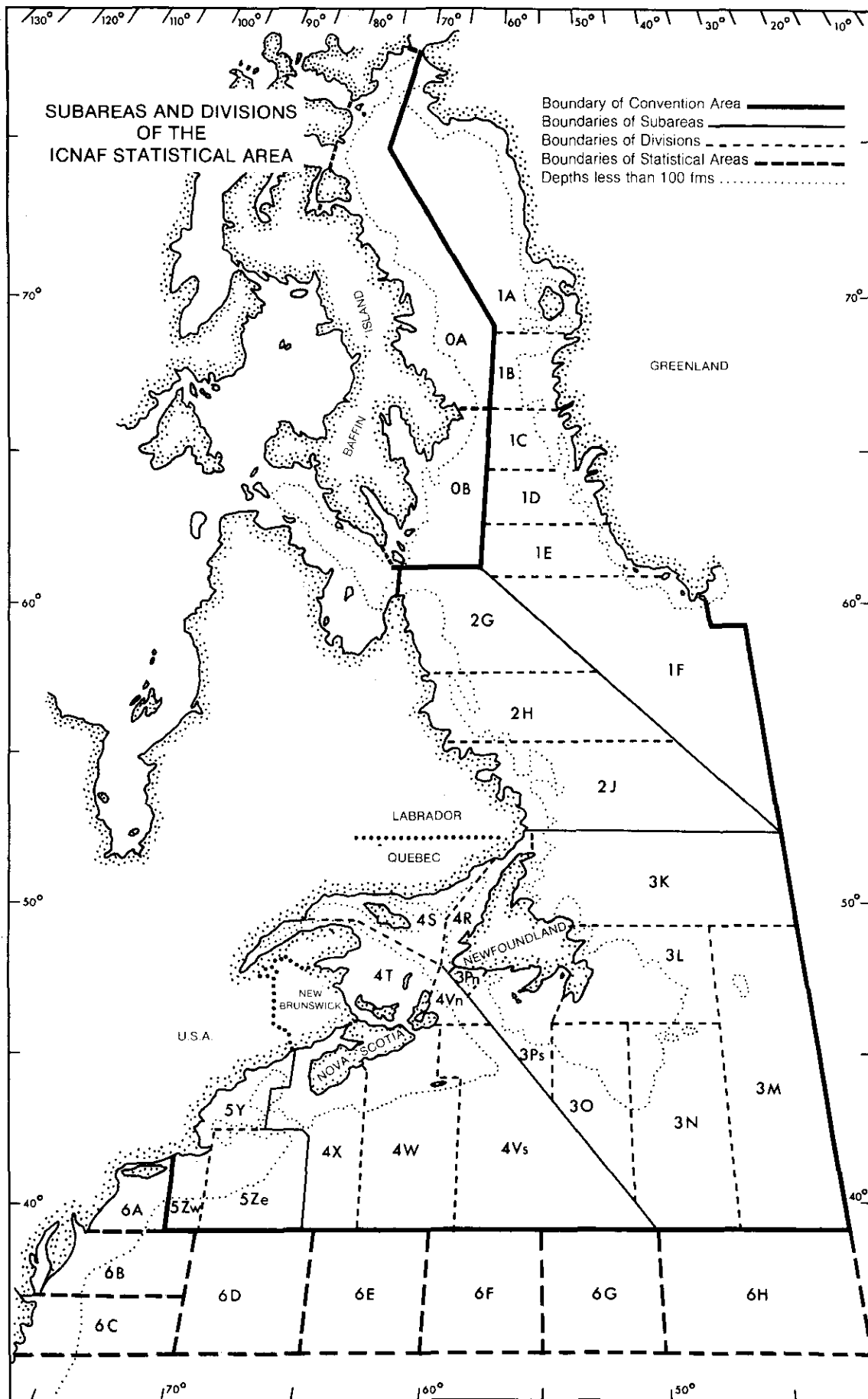
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## NORTHWEST ATLANTIC FISHERIES

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SUBAREAS AND DIVISIONS
OF THE
ICNAF STATISTICAL AREA

Boundary of Convention Area
Boundaries of Subareas
Boundaries of Divisions
Boundaries of Statistical Areas
Depths less than 100 fms

# Contents

# Migration and Intermingling of Stocks of Atlantic Cod, *Gadus morhua*, of the Newfoundland and Adjacent Areas from Tagging in 1962-66

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## Abstract

Recaptures of 32.6% of 47,560 Atlantic cod tagged in 1962-66 have considerably elucidated the migration and intermingling of cod stocks of the Newfoundland area and of the North Shore of the Gulf of St. Lawrence. From taggings inshore at many localities from northern Labrador to the Avalon Peninsula and offshore from Hamilton Bank to the northern Grand Bank, cod of the Labrador-East Newfoundland stock are shown to intermingle and overlap from north to south in their winter-spring spawning areas in deep water on the slopes of the Labrador and Northeast Newfoundland shelves. Cod of this stock tagged offshore in spring on the slopes of Hamilton, Belle Isle and Funk Island banks mainly migrated in summer to coastal waters from mid-Labrador to the Avalon Peninsula. From coastal taggings along eastern Newfoundland, cod migration to spawning grounds off Labrador was predominantly of the smaller sizes characteristic of mature fish off Labrador, whereas many of the larger cod migrated to the Grand Bank where cod mature at and grow to larger sizes. Cod, tagged in inshore and bank areas impinging on the Avalon and St. Pierre channels and in related channels and bays, intermingled enough in summer-autumn and became separated enough in winter-spring to be considered as the Avalon stock complex, consisting of the following components which are named from their wintering and spawning areas: Placentia Bay, St. Mary's Bay, St. Pierre Bank, Halibut Channel, northwestern slope of Grand Bank, and the Avalon Channel. The local populations of the northern Gulf stock, occupying areas north of the Laurentian Channel in the Gulf of St. Lawrence, migrate in winter-spring from all areas of the northern Gulf to and near the north side of Cabot Strait, many migrating through the Strait to the western part of the south coast of Newfoundland, and return before the end of April to the Gulf where they spawn. Cod of the western South Coast (of Newfoundland) stock intermingle greatly with the northern Gulf stock so that both stocks, although spawning separately, are included in the northern Gulf-western South Coast stock complex. For the Flemish Cap cod stock, tagging studies indicate a small percentage of migrants away from the Cap and an even less tendency for cod to migrate to the area.

The tagging experiments indicated that, in summer-autumn of years after tagging, there was usually considerable homing of local populations of cod, tagged in the summer-autumn feeding season, to and near the original tagging locations. However, 27 (0.17%) of the recaptures were reported from outside Canadian east coast waters (ICNAF Subareas 2-4), one from Georges Bank and 26 from Greenland eastward to the Barents Sea.

Spawning times and depths of recapture are discussed and distances between tagging and recapture positions are described and explained for various seasons and cod sizes. Evidence is presented that the main spawning population of cod on the slopes of the northern Grand Bank is not Labrador-East Newfoundland stock.

## Introduction

The main purpose of the tagging experiments in 1962-66 was to discover by migration studies what other cod fisheries were related to those in the various segments of the Canadian coastal waters of ICNAF Subareas 2 and 3 and Div. 4R and 4S where most fishermen are limited by their boats and gear to small fishing areas and the seasonal occurrence of cod. Because of the increased fishing effort during the period, especially over the northern areas previously not fished heavily in winter, it was expected to provide additional and better information on stock divisions at spawning time and of intermingling of stocks during the feeding and migratory seasons. Better knowledge of the migratory range of a stock and of its intermingling with other stocks improves the base for decisions on control and conservation to ensure that the whole spawning and feeding ranges of the stock are adequately covered in the various seasons.

Because of the limitations of ships and climate, most cod were tagged in the feeding season.

In this paper, a population is a group of cod occupying an area at a particular time; a stock is a recognizable unit which has certain area-occupying and migratory patterns but whose spawning is separate from that of other stocks; a local population which may consist of parts of one or more stocks is a population of fish related to a local area from which they usually depart as mature adults for spawning and to which they return for feeding after the spawning season, the local area being presumably also a nursery area where the local population lived as immature fish; a stock complex is a recognizable group of neighboring stocks which at periods other than spawning intermingle or overlap greatly and are different in migratory behaviour from adjacent stocks or stock complexes.

The primary location base of a stock is its spawning area, where the mature spawning fish of the stock are largely separated from other stocks of mature

fish of the same species spawning at the same time. For this paper, in situations where knowledge of the actual spawning times and places is lacking, the primary location base of the stock is its winter-spring location, the presumed spawning area where its genetic continuity is preserved.

Previous accounts of cod tagging in the Newfoundland area were by Thompson (1943), Templeman and Fleming (1962), Sidorenko and Postolaky (MS 1963), Postolaky (1966), Konstantinov (MS 1967), Danke (1967), Templeman (1974), Minet (MS 1975, MS 1976, MS 1977), and for the North Shore of the Gulf of St. Lawrence by Jean (1963) and Marcotte (MS 1964, MS 1965). Rojo (1973) described the location of recaptures by Spanish trawlers of cod tagged by other workers in the Canadian and other areas of the western North Atlantic.

The main cod stocks of the Newfoundland area were discussed and named by Templeman (1953, 1962b) using mainly unpublished information, and by Templeman (1974) on the basis of the results from cod tagging in 1954-55. The much more extensive tagging in 1962-66 and the more intensive fishing, particularly in winter-spring in the northern part of the Newfoundland area in the period following the more recent tagging, provided a much better picture of the migratory interrelationships of most of these stocks or stock complexes and of their various components. Consequently, it is possible to outline the winter-spring location of the mature fish of the Labrador-East Newfoundland cod stock. The new tagging also elucidated the interrelationships of the local populations of cod of the North Shore of the Gulf of St. Lawrence as part of the northern Gulf stock and showed that there is a western South Coast (of Newfoundland) stock which is part of the northern Gulf-western South Coast stock complex. Further insights are provided into the interrelationships of the various local populations of the Labrador-East Newfoundland stock and of the stocks and local populations of the Avalon stock complex, and on the extent of isolation of the Flemish Cap stock. The Newfoundland area was so extensively searched and fished for cod since 1962, that it can be assumed that intensive fishing was carried out on all large and persistent cod concentrations, climatic conditions (ice) permitting, and that the fishery in various months and areas was approximately proportionate to the extent of the numbers and concentrations of cod.

The reporting of recaptures such that they can be assigned to rectangles, as in Fig. 2-14, is most useful for migration studies. However, many other recaptures, especially from offshore Labrador, were reported only by ICNAF division or subarea. Some countries returned tags well and others poorly, the latter relating mainly to offshore rather than coastal

recaptures. Consequently, the actual offshore recaptures were considerably greater than those appearing in Fig. 2-14. Evaluations of these matters, details of tags and tagging methods, and the efficiencies of the tagging methods and of the tags used, will be presented in future papers.

## Materials and Methods

In 1962-66, 47,560 Atlantic cod, *Gadus morhua*, were tagged by the Newfoundland Biological Station at 47 locations in inshore and offshore waters of the Labrador, Newfoundland and adjacent areas. Over 15,500 of the tagged cod were recaptured and the tags and recapture information returned. Tagging and other locations, mentioned in the text, and ICNAF divisions are shown in Fig. 1, and tagging positions, rectangles, dates, depths and number of fish tagged are listed in the Appendix. (As necessary, see Templeman, 1966, for background information on the area, especially fig. 7 for additional geographic information on Subareas 2-5, fig. 9 for prevailing surface currents, fig. 10 and 11 for temperature sections and fig. 13-21 for cod landings up to 1964; also Templeman, 1975, for temperature sections 1951-73 in Subareas 2 and 3.)

The tags used were Petersen disc and dangler types in various combinations, attached by stainless steel wire dorsally in front of the first or between the first and second dorsal fins or around the preopercular bone. The fisheries research ship *A.T. Cameron* was used for most of the offshore tagging operations and the *Investigator II* and *Marinus* for the coastal shelf tagging. Tagging was usually done late in the year when the major fishing efforts for cod were completed or early in the year when migration from the wintering or spawning grounds had not yet occurred or was still in progress. Recaptures were considered by various monthly periods, differing slightly for various areas in relation to the times at which inshore and offshore migrations occurred.

Typically only cod in good condition, 55-90 cm in length from snout to midfork of the caudal fin, were tagged, but, in a few localities where the larger cod were not abundant, small numbers of 50-54 cm cod were also tagged. Fish for tagging were caught near the Labrador coast and at the Virgin Rocks by Norwegian jigger, near the Newfoundland coast and off the North Shore of the Gulf of St. Lawrence by bottom longline, and in the offshore areas, and in the January 1962 tagging in the Gulf of St. Lawrence, by bottom otter trawl.

Recapture data are presented in Fig. 2-14 by rectangles of ½° latitude and 1° longitude, defined by a
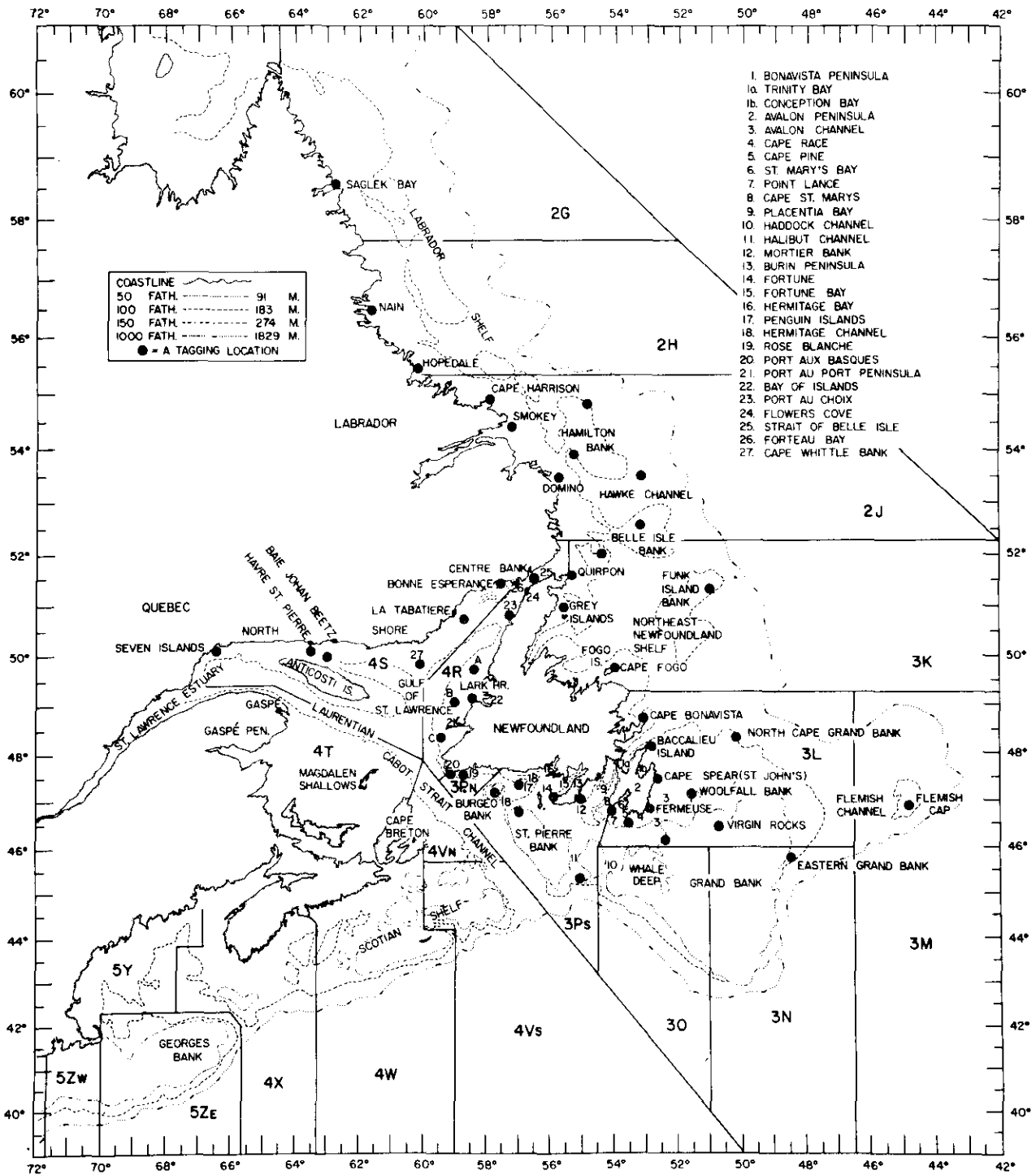
Fig. 1.   Tagging locations, place names, and ICNAF divisions mentioned in the text.

letter (vertical reference) and a number (horizontal reference) system (e.g. K25), but occasionally by two numbers (e.g. 9-24) as in Fig. 7-9 only. Some recapture data (for months other than the principal months of the figure section whose data are shown in rectangles) are presented in circles and in Fig. 12, hexagons, representing rectangles.

In Table 2, the data are accumulated from tag returns by rectangles which approximate closely but not exactly the ICNAF divisions, with the addition to Div. 3L and subtraction from Div. 3P of the Placentia Bay area east of 56°W to include with Div. 3L the usual limits of westward coastal migration of the Labrador-East Newfoundland stock.

In Fig. 2-14, recaptures in the following rectangles could be in more than one coastal area or bay: L20, M28, N27, P27, P28. All 117 recaptures checked for L20 were in the Gulf of St. Lawrence in ICNAF Div. 4R. The locations of recaptures in the other four rectangles (Fortune, Placentia, St. Mary's, Trinity or Conception bays) were noted in Fig. 2-14. All miles in the text are nautical miles. All recapture data received up to the end of 1974 were considered. Only three tags were returned in 1974.

The data for minimal distances travelled and depths of recapture from tagging in Gulf of St. Lawrence areas A, B, C, (Fig. 7), a separate experiment with a different pattern of tags from the other taggings, were not included in Tables 4 and 5 and Fig. 16.

All quantities (tons) noted in this paper are metric tons of fresh round cod.

## Cod Stocks of the Newfoundland Area and their Interrelationships

### Labrador-East Newfoundland stock

*Introduction.* This stock was defined by Templeman (1962b), largely on the basis of unpublished data on high vertebral averages, as occupying the coastal shelf and bank regions extending from northern Labrador to Div. 3L where it intermingles with the southern Grand Bank stock and the Avalon stock complex. It contributes to many local populations, each with its own tendency to return to home waters in the summer feeding season and with its own patterns of winter-spring distribution, but with much overlapping with adjacent local populations. There are differences in growth rate and in length at sexual maturity between some of these local populations (Fleming, 1960). The range of apparent spawning area is great, extending for more than 700 nautical miles from north to south. The northern local populations appear to have a higher proportion of fish

spawning farther north than the southern ones although overlapping greatly in all cases. Thus the stock has many of the characteristics of a stock complex, but will be referred to as a stock because of the great intermingling of local populations in the feeding season and later on the spawning grounds.

The new data presented greatly increase knowledge of the seasonal distribution of this stock in its spawning and feeding areas, its migrations, and its interrelationship with neighboring stocks. With present restrictions on offshore fishing for cod and the relative scarcity of cod in many areas, both of which reduce the coverage of the area by fishing vessels, it would be impossible to duplicate the results of these taggings.

*Spawning.* Off Labrador (Subarea 2), cod spawn mainly in March-April in deep water on the continental slopes, with most of the remainder spawning in May (Templeman, 1964, 1965b; Noskov and Zakharov, 1964; Bogdanov et al., 1965; Dias, 1965, 1967). There is, however, a smaller amount of later spawning, at least as late as June, in the colder water of the deep channels and slopes closer to the coast (Templeman, 1964; Chrzan, 1968; Dias, 1972).

In investigations from April to August by the USSR in the Newfoundland area (Serebryakov, 1967), the greatest abundance of cod eggs occurred off Northern Labrador (Div. 2G) and secondly off southern Labrador (Div. 2J), both in April. Off northern Labrador in the first 20 days of April, the eggs were mainly in the earliest stages of development, whereas off southern Labrador in the last third of April they were mainly in later stages of development. Because the direction of the Labrador Current is southward, relatively large quantities of cod must therefore spawn off northern Labrador.

Cod spawning in Div. 3K, at least on what are apparently the main spawning grounds of this division on the outer part of the continental shelf immediately south of Div. 2J, is also largely completed by the end of April (Templeman, 1965b). Again, there is probably additional spawning in May or later in the colder deep water closer to the coast (Dias, 1965).

In Div. 3L at the northern slope of the Grand Bank and in the Avalon Channel and on the northwestern slope of the Grand Bank, cod spawn mainly in April-June (Templeman, 1962a; Templeman and Fleming, 1962; Monteiro and Dias, 1964; Dias, 1968, 1971; and unpublished data of the Newfoundland Biological Station). Most of the spawning is usually over by June, and mature cod reaching the coastal areas of the east coast in the latter half of June are

usually almost all spent. In the northern part of Div. 3L, however, the mature cod typically lie shallower in winter than in Subarea 2 and Div. 3K, and spawning may be delayed in years when unfavorably low temperatures extend deeper than usual. In 1961, spawning was delayed, as many fish examined from the coastal areas of Div. 3L in July had not spawned (Templeman, 1962a). In 1971, spawning in Div. 3L was apparently also delayed, with considerable spawning in June and July (Dias, 1972). After about March, this area should also receive spent fish of the Labrador-East Newfoundland stock retreating from spawning farther north in Subarea 2 and Div. 3K, thus increasing the apparent proportion of spent fish in the local spawning area. In a cruise by the author, 7 spent females were found on the northeastern slopes of the Grand Bank during 26–29 March 1961 and all of the 42 remaining mature females were in early stages of egg development, possessing small opaque eggs 0.3-0.5 mm diameter and none with any clear eggs. First spawning could not be expected before May, and the spent females were apparently unrecovered spents of the previous year.

Whether or not the Labrador-East Newfoundland stock spawns in large numbers as far south as the northern Grand Bank is uncertain. The later spawning in Div. 3L, a more southern area, makes it unlikely that the young produced from the spawning would have the high vertebral numbers characteristic of the Labrador-East Newfoundland stock. On 28–29 March 1961, in an *A. T. Cameron* cruise east of the North Cape of the Grand Bank (Templeman, 1962a, 1965a), vertebral numbers, fish numbers and sizes from bottom otter trawl catches were as in Table 1. The cod population (Imm + Mat) at the shallowest depth had the low vertebral numbers typical of the southern Grand Bank and Avalon stocks. Vertebral numbers increased with depth and at the greatest depths the high vertebral numbers were characteristic of the Labrador-East Newfoundland stock. The numbers and quantities of cod per 30-min otter-trawl set were great at 182 m

(1,830; 3,610 kg) and declined rapidly at greater depths to 147 (96 kg) at 364–446 m. Unusually, the large and mature cod were most numerous at the shallowest depths and lowest temperatures fished. Percentages of mature fish declined rapidly with increasing depth and bottom temperature. In spring, the great masses of spawning and spent cod of the Labrador-East Newfoundland stock off Labrador lie deeper and at higher temperatures than the mature cod on the northeast Grand Bank (Templeman and May, 1965; Table 1). The vertebral means of the immature cod and of the total population of the northern Grand Bank (Table 1) increased significantly with depth between adjacent depth levels 1 and 2 and 2 and 3 and also between depth levels 1 and 3 and 1 and 4 ($P<0.01$ to $P<0.001$). The vertebral means of mature cod at the three shallower depth ranges were not significantly different but those of mature fish at 364–446 m were significantly greater than those at 182 and 223-274 m ($P<0.02$ and $<0.05$). The immature fish of the total population, weighted by the relative numbers of fish and vertebral numbers at various depths, had significantly higher vertebral means than the mature fish ($P<0.05$). It is thus indicated that the mature cod of the northern Grand Bank population sampled predominantly possessed low vertebral counts, characteristic of the southern Grand Bank stock and of the stocks of the Avalon stock complex, and that very small numbers of mature fish with high vertebral counts typical of the Labrador-East Newfoundland stock were present. Therefore, the spawning fish present in large quantities at the shallower depths on the slope east of the North Cape of the Grand Bank in March 1961 were not Labrador-East Newfoundland stock, although many mature fish from this northern stock would presumably return to the northern Grand Bank later from spawning in the northern divisions. Although much more investigation is needed, the division between the main spawning population of the Labrador-East Newfoundland stock and those of the Grand Bank may be hypothesized to be at 49°30'N, just a little north of the southern boundary of Div. 3K.

TABLE 1.    Cod vertebral averages and catches east of North Cape of the Grand Bank[a], 28–29 March 1961. (Vertebral counts include urostylar half-vertebra as one vertebra. Imm = Immature; Mat = sexually mature or maturing to spawn in the year in the year of examination.)

| Depth (m) | Vertebral averages and standard errors (numbers of cod in parentheses) | | | Mature cod % | No. per 30-min set (no. of sets) | Mean weight of cod (kg) | Bottom temp. (°C) |
|---|---|---|---|---|---|---|---|
| | Imm | Mat | Imm + mat | | | | |
| 181–183 | 54.09±0.16 | 53.92±0.18 | 54.03±0.12 (69) | 35 | 1,830 (1) | 1.97 | 1.2 |
| 223–274 | 54.71±0.11 | 54.08±0.22 | 54.60±0.10 (129) | 19 | 584 (2) | 1.40 | 2.3 |
| 315–320 | 55.17±0.13 | 54.33±0.67 | 55.13±0.13 (68) | 4 | 309 (1) | 0.68 | 3.6 |
| 364–446 | 55.35±0.09 | 55.25±0.48 | 55.35±0.09 (117) | 3 | 147 (2) | 0.65 | 3.5 |
| 181–446 | 54.94±0.06 | 54.11±0.14 | 54.82±0.06 (383) | 14 | 600 (6) | — | — |
| 181–446[b] | 54.54±0.12 | 54.06±0.18 | 54.38±0.10 (135) | 25 | — | — | — |

[a]  47°52' to 48°04'N, 48°24' to 49°17'W.

[b]  Converted to frequency for total population in proportion to number of fish in catch frequency with conversion factor at shallowest depth and greatest catch = 1.
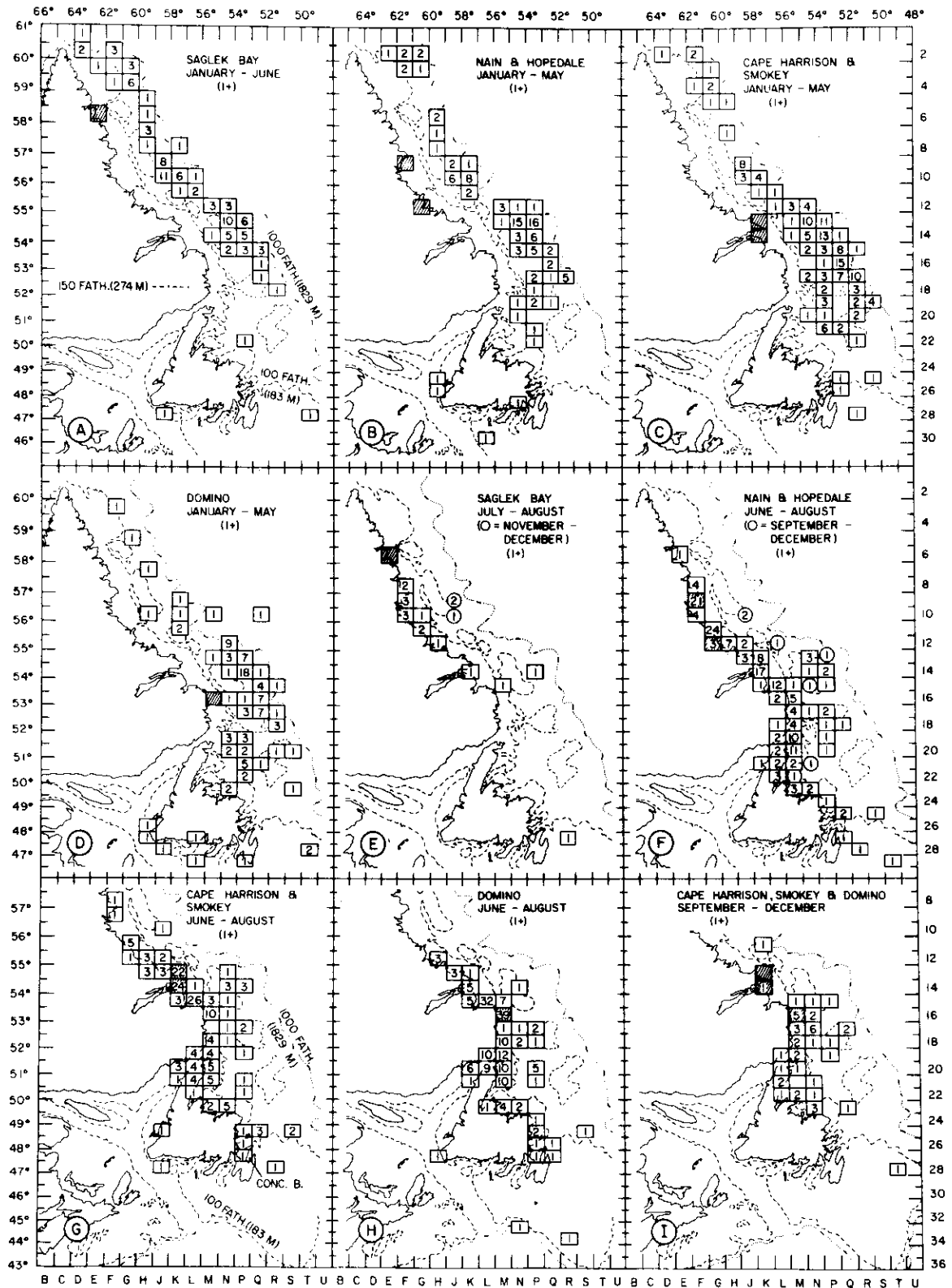
Fig. 2.   Location of returns in various monthly periods from cod tagged in inshore Labrador waters, 1962-64: Saglek Bay (A, E); Nain and Hopedale (B, F); Cape Harrison and Smokey (C, G, I); Domino (D, H, I). [See Appendix for details of tagging. In this and subsequent figures, the shaded rectangles contain the tagging areas, (0) represents recaptures in the calendar year of tagging and (1+) indicates recaptures in the first and ensuing years after the tagging year.]
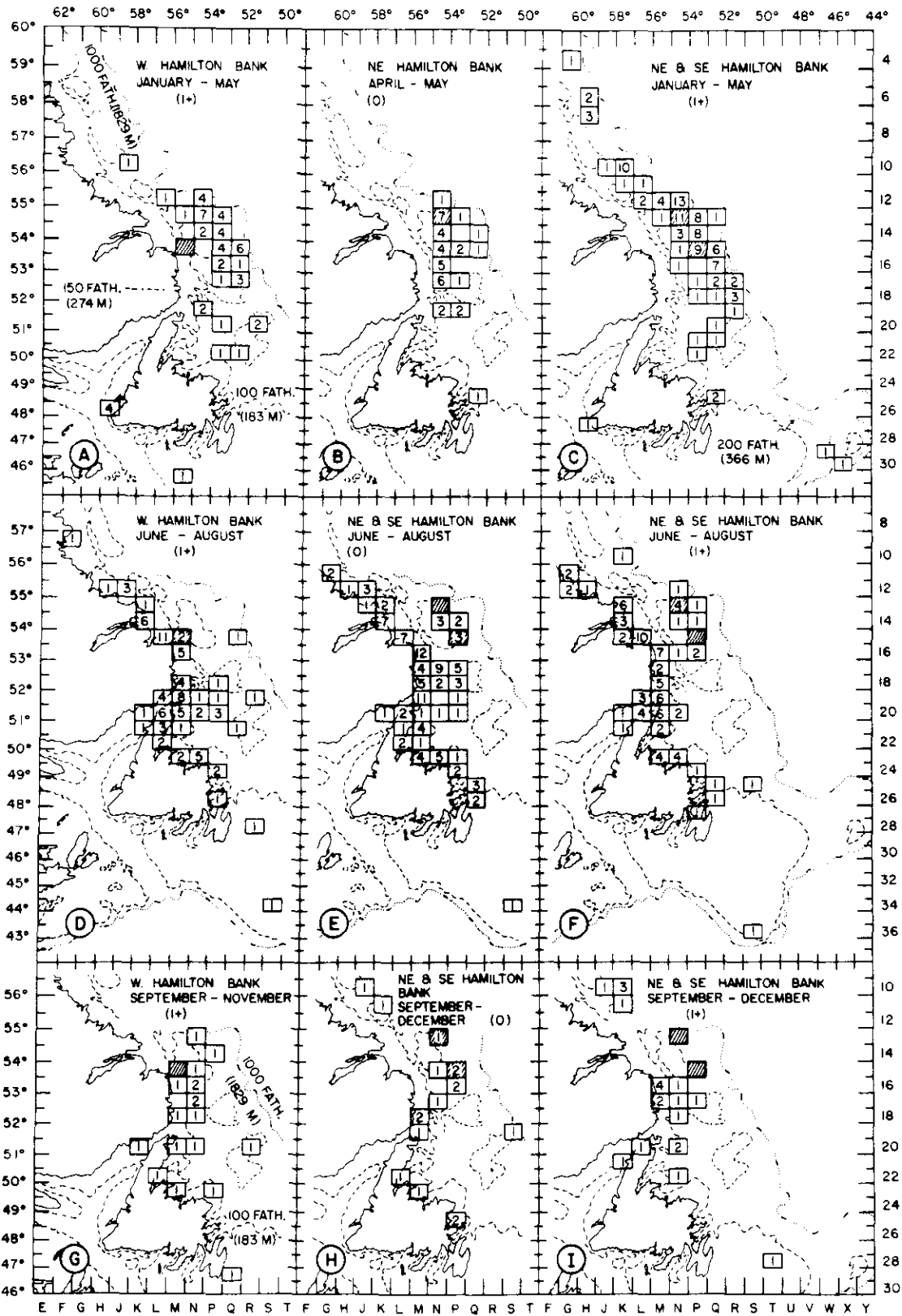
Fig. 3. Location of returns in various monthly periods from cod tagged offshore on Hamilton Bank, 1962-66: Western Hamilton Bank (A, D, G); Northeast Hamilton Bank (B, C, E, F, H, I); Southeast Hamilton Bank (C, E, F, H, I). (See Appendix for details of tagging.)
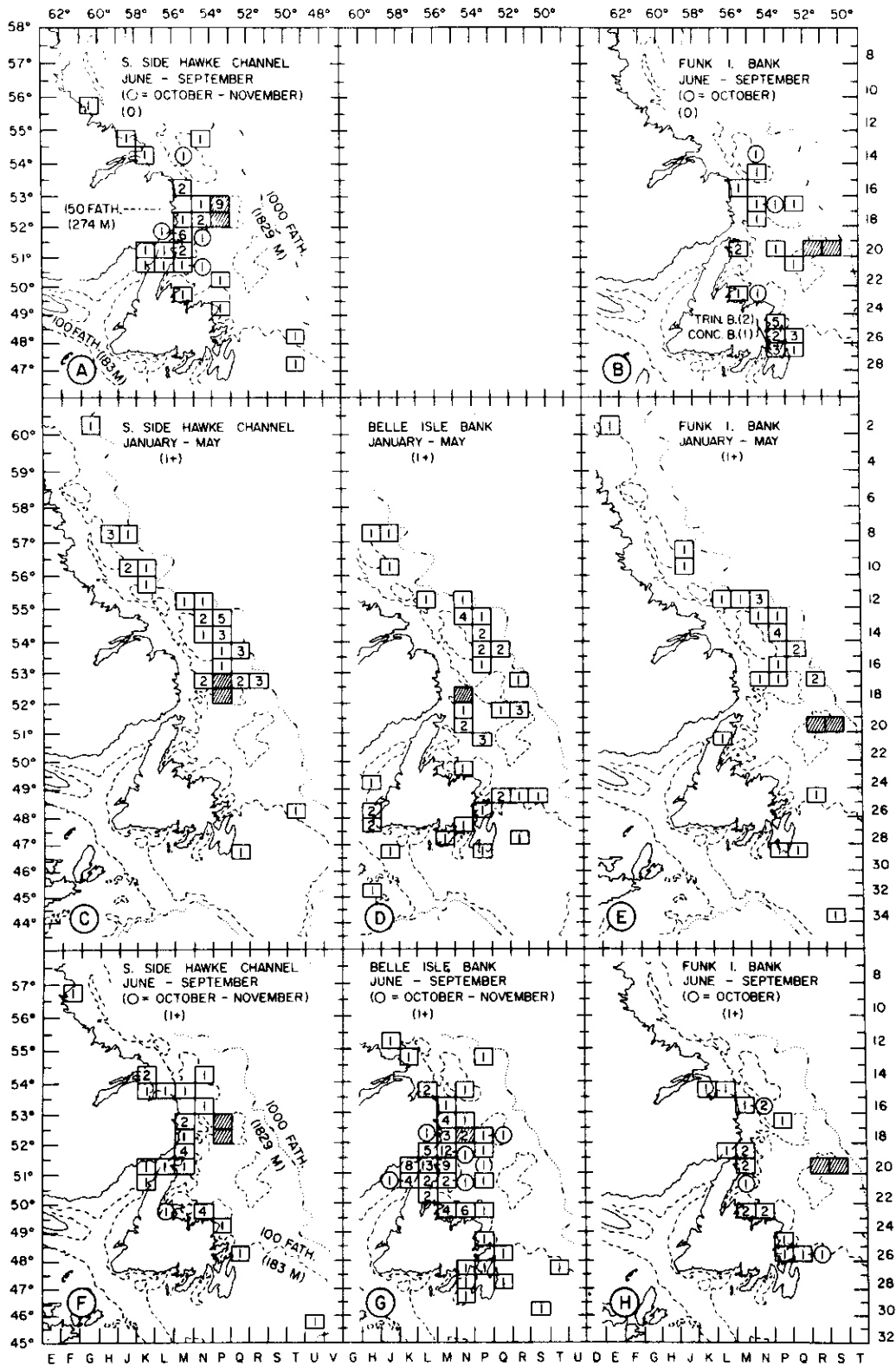
Fig. 4.   Location of returns in various monthly periods from cod tagged offshore off southern Labrador and on the Northeast Newfoundland Shelf, 1962-64: on Belle Isle Bank south of Hawke Channel (A, C, F); Belle Isle Bank (D, G); Funk Island Bank (B, E, H). (See Appendix for details of tagging.)

Fig. 5.   Location of returns in various monthly periods from cod tagged inshore off northeastern and eastern Newfoundland, 1962-
64:off Quirpon (A,D); off Grey Islands (B,E); off Cape Fogo (C,F); off Bonavista (G,H,I). (See Appendix for details of tagging.)
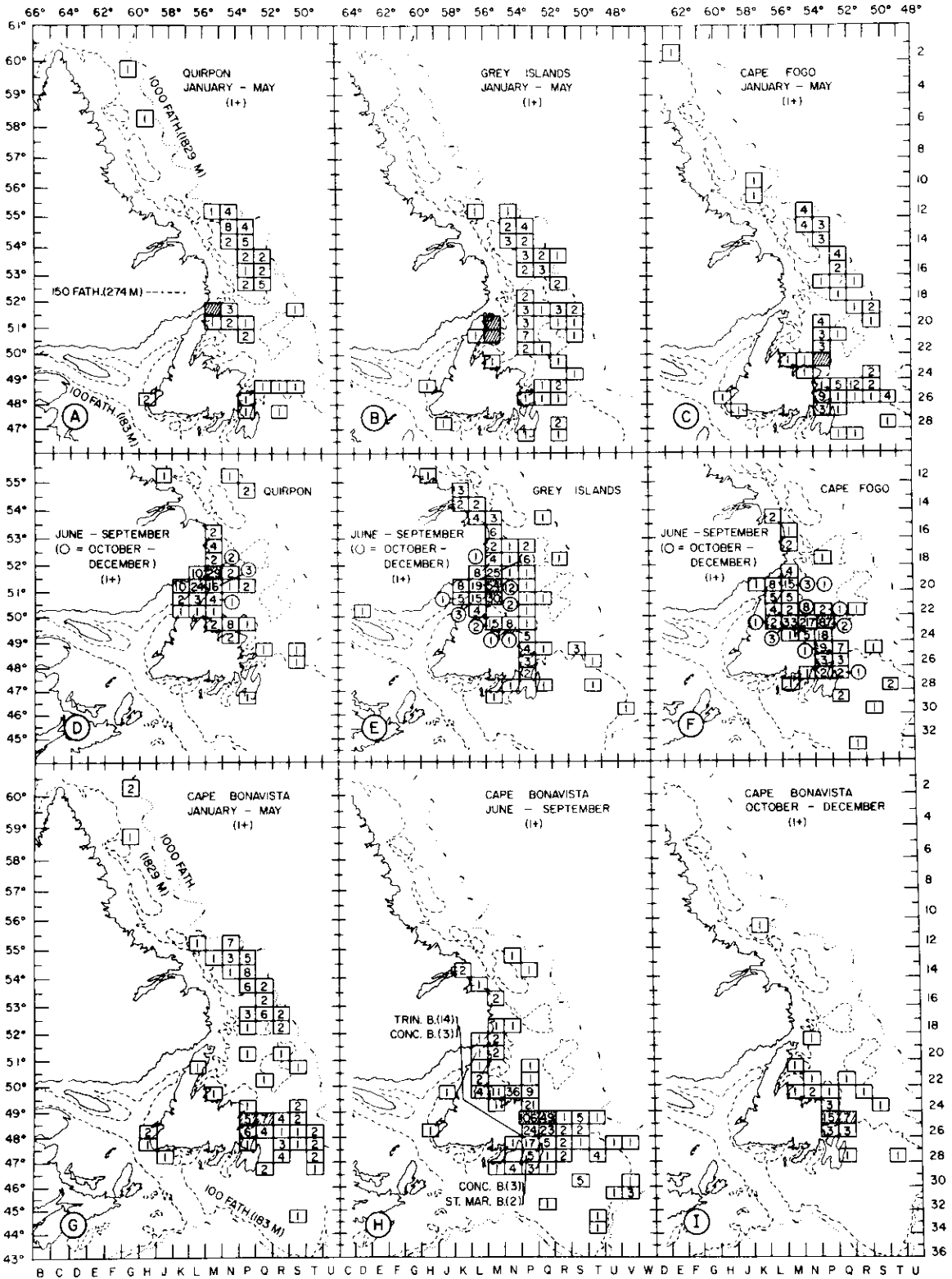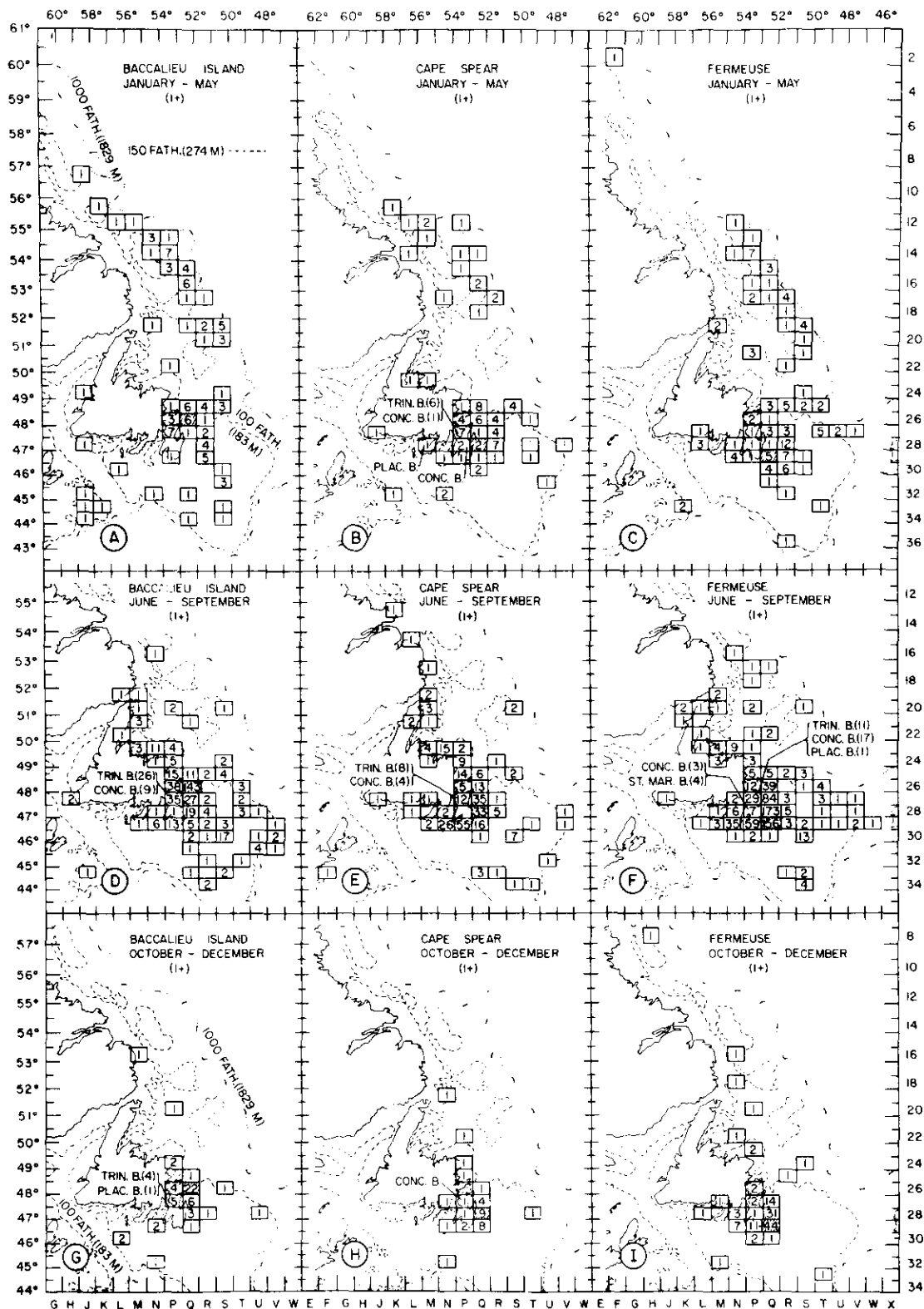
Fig. 6.    Location of returns in various monthly periods from cod tagged inshore off southeastern Newfoundland, 1962–65: off Baccalieu Island (A, D, G); off Cape Spear (B, E, H); off Fermeuse (C, F, I). (See Appendix for details of tagging. The single return plotted in rectangle W 29 of F was recaptured on Flemish Cap.)

*Inshore-offshore migrations.* Cod tagged in the coastal waters of Labrador in summer were found mainly in the spawning areas at the outer slopes of the Labrador and Northeast Newfoundland shelves in winter-spring (Fig. 2ABCD). Similarly, cod tagged offshore in deep water off southern Labrador in spring and autumn were recaptured in summer (or summer-early autumn) mainly near the coast of southern Labrador and near and in the Strait of Belle Isle (some penetrating this strait), and in gradually declining numbers along the east coast of Newfoundland to the northern part of the Avalon Peninsula (Fig. 3DEF, 4AF).

Offshore tagging on Belle Isle Bank, 23-26 September (closer to the coast than the Belle Isle Bank tagging south of Hawke Channel, shown in Fig. 4AF), indicated much greater summer migration into the Strait of Belle Isle (June-September, Fig. 4G) than the other offshore Labrador taggings. This indicates that many cod from the Strait of Belle Isle and its southern approaches had migrated out of the strait to the vicinity of Belle Isle Bank before they were tagged in late September and had returned to the strait presumably in early summer of the ensuing years.

The offshore tagging in May in deep water on the northern part of Funk Island Bank gave inshore recaptures in June-September (Fig. 4BH) from southern Labrador to the Avalon Peninsula, with relatively more recaptures on the east coast of Newfoundland than from the more northern offshore taggings.

Cod tagged near the east coast of Newfoundland in seven localities from Quirpon to Fermeuse in August-December (mainly August-November) had approximately similar northward January-May distributions, mainly offshore on the slopes of Hamilton Bank and vicinity and the Northeast Newfoundland Shelf. From these taggings, however, the numbers of migrants in January-May to the northern and western Grand Bank, relative to those farther northward, gradually increased from north to south (Fig. 5, 6).

Recaptures in the tagging year help to elucidate offshore migrations from the coastal areas. From coastal cod taggings off northern Labrador (at Saglek, Nain, and Hopedale in August 1962-64), in the tagging year 6 coastal recaptures (all from Nain and Hopedale taggings) were made in August and 2 in September near the tagging locations, but no recaptures were made in offshore areas. From coastal cod taggings in Div. 2J off southern Labrador (at Cape Harrison, Smokey and Domino in July and August 1962-64), in July and August of the tagging year there were 3 and 51

coastal recaptures respectively near the tagging areas and no offshore recaptures. In autumn of the tagging year, there was only 1 coastal recapture in October and 19 offshore recaptures by European trawlers: 1 in September, 11 in October and 7 in November. The lack of offshore recaptures in autumn of the tagging year from the northern taggings at Saglek, Nain, and Hopedale indicates that, although these cod presumably migrated offshore in autumn like the more southern fish, they remained until at least November north of the main autumn fishery on Hamilton and Belle Isle banks. The lack of offshore recaptures (of cod tagged in inshore Labrador waters) in the tagging year in Div. 2J before October, although the trawler fishery in this division was over half as large in September as in October, indicates that the tagged fish, migrating out from the coast, mostly did not reach the offshore fishing grounds before October.

In September-December of the years when these cod from Labrador inshore taggings were being recaptured, there was little coastal fishing in Labrador except immediately north of the Strait of Belle Isle. Some coastal recaptures were made at this time in the most southern Labrador areas and off the north-east coast of Newfoundland (Fig. 2I). In September-December the intensity of the cod fishery is low compared with that in summer and winter-spring, and a much higher number of tagged cod was recaptured in the offshore than in the inshore Labrador area.

From inshore taggings in seven areas of the east coast of Newfoundland from Quirpon to Fermeuse, most of the recaptures from October to December (Fig. 5DEFI, 6GHI) were from the coastal rectangles of and near the tagging areas. There were some offshore recaptures in October-December from rectangles not associated with the coast, from north to south: 0, 0, 10, 16, 13, 12, 8% of the total recaptures in these months.

From tagging by the USSR in deep water off northern Labrador in April, there were coastal recaptures in summer off southern Labrador and off the east coast of Newfoundland. From tagging by the USSR on and near Hamilton Bank off southern Labrador in April-May, there were coastal recaptures in summer from southern Labrador and along the east coast of Newfoundland as far south as the Avalon Peninsula (Postolaky, 1966).

*Winter-spring spawning concentrations.* In January-May, recaptures of cod from tagging off the east coast of Newfoundland and Labrador (Fig. 2-6, 14: Table 2) were mainly in relatively deep water on the continental shelf and slopes of the banks and coastal shelves. By May in the southern areas, there was some

TABLE 2. Percentage recaptures in January–May of years after tagging year for cod tagged at various localities from northern Labrador to southeastern Newfoundland, 1962–66.

| Tagging Locality (ICNAF division and Figure reference in parentheses) | Percentage recaptures by ICNAF divisions | | | | | | | | Total recaptures |
|---|---|---|---|---|---|---|---|---|---|
| | 2G | 2H | 2J | 3K | 3L | 3NO | 3P+ 4Rs | 4T+ 4VW | |
| Saglek Bay (2G; Fig. 2A) | 23 | 33 | 39 | 2 | 1 | 0 | 1 | 0 | 94 |
| Nain & Hopedale (2H; Fig. 2B) | 10 | 18 | 61 | 7 | 1 | 0 | 3 | 0 | 109 |
| Cape Harrison & Smokey (2J; Fig. 2C) | 6 | 11 | 64 | 17 | 3 | 0 | 0 | 0 | 160 |
| Domino (2J; Fig. 2D) | 3 | 6 | 60 | 24 | 3 | 0 | 5 | 0 | 109 |
| W Hamilton Bank (2J; Fig. 3A) | 0 | 2 | 75 | 13 | 0 | 0 | 9 | 0 | 53 |
| NE & SE Hamilton Bank (2J; Fig. 3C) | 5 | 11 | 70 | 9 | 4 | 0 | 1 | 0 | 114 |
| Belle Isle Bank (2J; Fig. 4C) | 3 | 22 | 69 | 0 | 6 | 0 | 0 | 0 | 36 |
| Belle Isle Bank (3K; Fig. 4D) | 0 | 7 | 33 | 24 | 18 | 0 | 16 | 2 | 45 |
| Funk Island Bank (3K; Fig. 4E) | 6 | 13 | 50 | 6 | 19 | 6 | 0 | 0 | 16 |
| Quirpon (3K; Fig. 5A) | 3 | 0 | 66 | 17 | 10 | 0 | 3 | 0 | 58 |
| Grey Islands (3K; Fig. 5B) | 0 | 0 | 38 | 43 | 16 | 0 | 3 | 0 | 69 |
| Cape Fogo (3K; Fig. 5C) | 1 | 2 | 24 | 21 | 49 | 0 | 2 | 0 | 91 |
| Cape Bonavista (3L; Fig. 5G) | 3 | 0 | 41 | 8 | 44 | 1 | 4 | 0 | 115 |
| Baccalieu Island (3L; Fig. 6A) | 0 | 2 | 27 | 13 | 43 | 8 | 3 | 4 | 106 |
| Cape Spear (3L; Fig. 6B) | 0 | 1 | 17 | 4 | 74 | 2 | 1 | 1 | 84 |
| Fermeuse (3L; Fig. 6C) | 1 | 0 | 18 | 11 | 61 | 3 | 3 | 2 | 122 |
| Cape Pine & Point Lance (3L; Fig. 14A) | 1 | 0 | 6 | 2 | 72 | 4 | 16 | 1 | 224 |

movement to shallower water. Most of the cod caught in January–May, however, were taken from the offshore pre-spawning, spawning and post-spawning concentrations and on their migrations to and from the spawning grounds. The main areas of concentration in January–May range from the northern part of the Labrador Shelf to the northern Grand Bank. The most northern taggings, inshore at Saglek Bay, Nain and Hopedale (Fig. 2AB), showed the greatest relative numbers of recaptures in the northern Labrador (Div. 2G and 2H), but even for these taggings there were more recaptures in Div. 2J, presumably because the fishing effort was so much greater in this division. The greatest amount of winter-spring overlapping between the local populations tagged from Saglek Bay to Fermeuse (Fig. 2–6; Table 2) occurred in Div. 2J and secondarily in Div. 3K and 3L. There was, however, a gradual decline in recaptures in Div. 2J from 60–75% for tagging from Nain and Hopedale to Belle Isle Bank south of Hawke Channel to 17–18% in the southerly tagging at Cape Spear and Fermeuse, and to 6% at Cape Pine and Point Lance. Recapture percentages in January–May in Div. 3K were irregular with no north-south trend. Most recaptures in Div. 3K were from taggings in southern Div. 2J and in Div. 3K. Recaptures in Div. 3L in January–May increased gradually from 0 to 6% from the northern taggings to 74, 61 and 72% from taggings off Cape Spear, Fermeuse, and Cape Pine and Point Lance. The percentages migrating to or within Div. 3L were especially high from the more southern taggings from off Cape Fogo to Point Lance (Table 2).

The higher percentage, from the more southern Fermeuse tagging than from that off Cape Spear, reaching north of Div. 3L in January–May, is very likely due to the relative lateness of the tagging off Cape Spear and the consequent greater depths at which tagging occurred (Fermeuse, 5–25 October, 18–110 m; Cape Spear, 22 November–18 December, 37–146 m). Unpublished cod vertebral numbers reveal that the smaller cod in shallow water in the St. John's (Cape Spear) area are predominantly high-vertebral-count northern fish and the large cod, which tend to lie deeper, are mostly lower-vertebral-count fish related to more southern areas.

Cod from the southern areas (Grey Islands to Point Lance) must pass through Div. 3L and 3K to reach more northern areas and be subject to capture in these divisions on their northward and southward migrations, so that the numbers recaptured north of Div. 3L or 3K or both were minimal. The reverse argument is appropriate for tagging localities in or north of Div. 3K from which the numbers recaptured in January–May south of Div. 3K were minimal.

*Homing.* In June–September, the main feeding and growing period, the most obvious migratory characteristic was the homing of most of the coastally tagged cod to or near the tagging area. Thus, local populations have a large amount of separation in the summer feeding season. There was enough lack of homing in summer that some of the fish tagged in any one area could belong to neighboring and other local populations. Some are also caught in an area while on their way to another area.

Recaptures in summer in and near the tagging rectangles were relatively less from northern than from southern inshore taggings. From the most northerly tagging at Saglek Bay, there were no coastal

recaptures in June and few in July–August (Fig. 2E) compared with the considerably larger numbers taken offshore in winter-spring (Fig. 2A). Also, none were taken in or near the tagging rectangle. Presumably the Saglek Bay fish returned in July–August to the northern part of the Labrador coast where there was little or no coastal fishing. In Div. 2G, in which Saglek Bay is located, cod landings from the inshore fishery (by Newfoundland) were only two tons in each of the years 1962-65, 1967, and zero in 1966 and 1968-72. Also, in many observations during sampling surveys of the area in July–August by the Newfoundland Biological Station, baby cod were not noted in shallow waters near the coast of northern Labrador in Div. 2G and 2H, although they are present but not usually very plentiful at several meters depth in the coastal areas of Div. 2J. Thus, the preliminary condition for the formation of large local population, many immature cod resident in the local nursery area, may not be present in northern Labrador.

Because most of the June recaptures were usually from coastal rectangles, it was necessary to associate June with July–August or July–September. However, the migration to shore (especially toward the north) was still proceeding in June and hence many cod recaptured offshore in June would otherwise have migrated to shallow coastal waters. In the 10 inshore taggings from Saglek to Fermeuse (Fig. 2, 5, 6), the following percentages of recaptures in June–August* and June–September for years after the tagging year in the offshore rectangles (those not impinging on the coast) were taken in June: 75*, 76*, 71*, 81*, 30, 60, 56, 35, 29, 34, 26. In the offshore tagging before June on Hamilton Bank and Belle Isle Bank, offshore recaptures in June of the tagging year (Fig. 3E, 4A) were 74 and 69% respectively of the June–August and June–September offshore recaptures. From three taggings on Hamilton Bank and two on Belle Isle Bank, offshore recaptures in June of the years after the tagging year in rectangles not associated with the coast were 41 and 23% respectively of the June–August and June–September recaptures in these rectangles.

In the offshore tagging in May from the Northeast Newfoundland Shelf to Hamilton Bank, most of the recaptures in January–May of years following the tagging year were taken north of the tagging rectangle: Funk Island Bank, 17–18 May, 81%, Fig. 4E; Belle Isle Bank south of Hawke Channel, 15–16 May, 75%, Fig. 4C; and Hamilton Bank, tagging rectangle P15, 10–14 May, Fig. 3C, 65%. From tagging on Hamilton Bank in N13, 20–22 April, 33% were north of the tagging rectangle in January–May (Fig. 3C). These data offer strong evidence that most of the fish tagged offshore in May had already migrated southward from spawning farther northward on the Labrador Shelf and that fewer of those tagged in April had migrated southward from

spawning farther northward. Postolaky (1966) and Danke (1967) reported rapid migration of tagged and presumably spent cod, as much as 22 and 20 nautical miles per day, from the spawning schools off north Labrador in April to south Labrador in late April–May of the same year, distances of about 400 and 350 nautical miles.

*Southern limits of intermingling.* From the tagging experiments north of Bonavista (Fig. 2–5), there was either little or no migration to the southern Grand Bank south of 46°N into Div. 3N and 3O, the basic area of the southern Grand Bank stock. From inshore taggings in seven localities, extending in order southward from Quirpon to Fermeuse (Fig. 5, 6), the percentages of total recaptures in January–May in Div. 3N and 3O were 0, 0, 0, 1, 8, 4, 3, and in June–September 0, 0, 0.2, 2, 3, 2, 1. The previous tagging at Fermeuse in 1954 (Templeman, 1974) showed a greater relationship with the southern Grand Bank, but some cod larger than 90 cm were tagged which were more likely to be related to the southern Grand Bank. Also, the haddock fishery on the Grand Bank was heavily prosecuted in the years following the 1954 tagging whereas it was at a low level in the years following the 1962–66 tagging, and many cod were taken incidentally to this early fishery. On the northern part of the Grand Bank, however, which is included in the migrating area of the southern Grand Bank stock, there is intermingling of the northern and southern stocks.

Increasingly in taggings from north to south off Labrador and the east coast of Newfoundland, there were migrations to and around the Avalon Peninsula, but there were relatively few recaptures west of Placentia Bay from these taggings.

*Migrations through Strait of Belle Isle to Gulf of St. Lawrence and Cabot Strait.* The numbers of cod entering the Strait of Belle Isle from the east in summer were directly related to the distance of the tagging location from the strait. Percentages of all recaptures in June–September (June–August* in northern areas) taken in the Gulf of St. Lawrence (west of 56°W at the Strait of Belle Isle) in the years after the tagging year were, in order from north to south: Labrador coastal taggings, Saglek-Domino (Fig.2), 0*, 3*, 7*, 14*; Hamilton Bank closest to the coast (Fig. 3D), 14*, and farther offshore (Fig. 3F), 10*; Belle Isle Bank closer to the Strait of Belle Isle (Fig. 4G), 30, and farther offshore (Fig. 4F), 12; Funk Island Bank (Fig. 4H), 6; east coast of Newfoundland, Quirpon-Fermeuse (Fig. 5DEFH, 6DEF), 35, 16, 2, 1, 0.3 (2 fish in Cabot Strait not included), 0, 1. These Gulf recaptures were almost all in the Strait of Belle Isle and its southern approaches. From all of these taggings, there was only one recapture (Fig. 5E) off the North Shore of the Gulf to the west of the Strait of Belle Isle and its approaches.

Compared with the numbers recaptured in January–May in and near Cabot Strait from taggings in the Gulf, in and near the Strait of Belle Isle (Fig. 8-9; Templeman, 1974), there were relatively few recaptures in winter-spring in Cabot Strait and vicinity from the Labrador and eastern Newfoundland taggings. This affords further evidence that these summer penetrations of the Strait of Belle Isle from the east were predominantly by cod of the Labrador-East Newfoundland stock, and that these cod mainly moved east through this strait again in late summer and autumn instead of migrating southward with the northern Gulf stock to Cabot Strait. The movement described agrees with the presence of cod with high vertebral counts, typical of the Labrador-East Newfoundland stock, on the southern side of the Strait of Belle Isle and its approaches (Templeman, 1962b).

*Northern Grand Bank.* Cod tagged on the northern Grand Bank in April–May partially remained on the northern Grand Bank in June–September (Fig. 12Cl). At this time, they also intermingled with the Labrador-East Newfoundland stock along the east coast of Newfoundland, the mixture of Labrador-East Newfoundland and Avalon stocks around the Avalon Peninsula, and with the Virgin Rocks local population. In winter-spring of ensuing years (Fig. 12F), some cod remained on the northwestern Grand Bank, while others, presumably of Labrador-East Newfoundland stock, migrated northward and joined the spawning schools of this stock off southern Labrador, and some joined the southern Grand Bank stock on the southwestern slope of the Grand Bank.

*Trans-Laurentian Channel migrations.* From the Labrador coastal taggings and from the offshore taggings from Hamilton Bank to Funk Island Bank (Fig. 2-4), only 1 cod (from the Belle Isle Bank tagging, Fig. 4D) was recaptured south of the Laurentian Channel. From the seven inshore taggings on the east coast of Newfoundland (Quirpon-Fermeuse, Fig. 5, 6), from north to south, recaptures south of the Laurentian Channel as percentages of all located recaptures in all seasons were: 0, 0, 0, 0, 1, 1, 0.2. Of 10 recaptures, 8 were taken in January–May. All 10 were taken on the Scotian Shelf, 9 on the northeastern corner, indicating that the crossings of the Channel were most likely from the southern part of St. Pierre Bank.

### The northern Gulf-western South Coast stock complex

*Introduction.* The results of the 1962–66 tagging (Fig. 7-9) and available information on spawning show that most cod north of the Laurentian Channel, from Cabot Strait to the Strait of Belle Isle and from the west coast of Newfoundland to the North Shore of the Gulf of St. Lawrence, belong to the northern Gulf stock, in part described by Templeman (1962b) as the western

Newfoundland stock and by Templeman (1974) as the northern Gulf stock complex. There are also cod which spawn, and partly reside in summer, on the western part of the south coast of Newfoundland (Fig. 10, 11, 14) and belong to the western South Coast stock. The data also indicate that there is enough intermingling between these stocks that they form a northern Gulf-western South Coast stock complex.

*Spawning in northern Gulf and adjacent areas in relation to migrations and stocks.* In Subdiv. 3Pn, adjacent to the Gulf of St. Lawrence at Cabot Strait, late maturing stages and spawning were not observed in 218 mature female cod examined in February–March, but 4% of 114 mature females were spent in April and 87% of 47 mature females were spent in early June. In Subdiv. 3Ps coastal bank areas on Burgeo Bank and off Ramea, no spent cod were observed in 48 mature females examined on 4 March and in 31 examined on 10 April, but 67% of 114 mature females were spent in May and 87% of 37 mature females were spent in June (unpublished Newfoundland Biological Station data). By our definition, cod spawning in Subdiv. 3Pn or in the above mentioned Subdiv. 3Ps localities belong to the western South Coast stock.

In Div. 3P (apparently on Rose Blanche and Burgeo banks), Minet (MS 1976) reported that 7% of the mature cod taken during 12–23 February 1975 and 6% during 2–10 March 1976 were in Stage 3 (with some clear eggs in ovaries), and that none were spawning or spent.

In the main part of Div. 4R south of 51°N, in January all of 161 mature females were either spents of the previous year on in the earliest maturing stage with no clear eggs, but by 21–27 May, 69% of 207 mature females were spent. Even in July–September, there were small percentages of female cod that had not spawned but were preparing for spawning in the year of examination (unpublished Newfoundland Biological Station data).

Minet (MS 1976) found, in Div. 4R during 10 January–3 February 1975 and 1976, 8% of the mature cod in Stage 3 and none spawning or spent. These results are similar to those previously found by Minet (MS 1973) for cod in 4R during 22 January–2 February 1973.

Observations during 16–27 March 1958 (McCracken and Clark, MS 1958), on French and Portuguese trawlers fishing in the southern part of Div. 4R (47° 41'N - 48° 59'N, 130–245 m), showed 77% of 124 mature female cod ripening, 13% ripe, 4% spawning and 6% spent recovering. Most of the 6% spent recovering were very likely unrecovered spents from

late summer-early autumn spawning of the previous year. It was indicated, however, that spawning was beginning in the latter part of March.

Experimental longline and handline fishing for cod was carried out by the St. John's Biological Station in St. George's Bay (Div. 4R), in 22–64 m from 4 June to 28 August 1945. Throughout the whole period the ovaries of the cod were extremely large and, apart from a very small percentage of spent fish, were in stages preliminary to spawning. In the last week of May 1955, the author observed that the ovaries of cod in St. George's Bay were full but that spawning had not yet occurred. This is an area with abundant migrating cod in winter-spring to early June and with a much smaller residential population throughout the summer. The area appeared to be one where the resident summer cod were almost all preparing for an autumn spawning, but further study is needed as these observations differ from more recent ones for many other northern Gulf areas.

In the northern part of Div. 4R in and near the Strait of Belle Isle, the percentages of mature females spawning or preparing for spawning in July were 12% (of 169) for the colder Labrador side, and 2% (of 138) on the warmer (Huntsman et al., 1954) Newfoundland side where the population is strongly influenced by inward migration of Labrador-East Newfoundland stock. The remainder were spent. In Div. 4S in late May, a much smaller percentage (28% of 101 mature females) was spent than in Div. 4R at the same period and year (1973), but the percentages in late stages of development were relatively high and peak spawning in Div. 4S was evidently occurring in late May-early June (unpublished Newfoundland Biological Station data). In the southern Gulf off Chaleur Bay and vicinity south of the Laurentian Channel (Div. 4T), cod spawning occurred from May to September with peak spawning at the end of June (Powles, 1958) which is later than in Div. 3P, 4R and 4S. In Subdiv. 3Pn and in the adjacent portion of Subdiv. 3Ps overlapped by the Gulf stock in winter and early spring, most cod spawning appears to occur between the last third of April and the end of May.

Most cod of the northern Gulf stock, approaching or passing out of Cabot Strait, are evidently within the Gulf by the end of March, and yet catches in the northern Gulf are at a low ebb in April and especially during May which is probably the main spawning month in Div. 4R. It is thus probable that most of the cod appearing in shallow water in June-August and responsible for the increase in catches in Div. 4R and 4S at this time are spent. Much of the spawning could occur during the migration toward the summer feeding areas. The summer concentrations of Gulf cod in and near the Strait of Belle Isle and other concentrations of

tagged cod near their autumn tagging areas are thus feeding concentrations.

For the present, with knowledge lacking of the location of separate spawning concentrations in the northern Gulf and with similar general patterns of winter migrations, the cod population spawning in the Gulf north of the Laurentian Channel may for convenience be referred to as the northern Gulf stock. Further knowledge of spawning concentrations and of the existence of relatively separate spawning stocks could make it the northern Gulf stock complex. A similar statement can be made for the western South Coast spawning stock.

*Migrations eastward through Cabot Strait and along the south coast of Newfoundland.* It is evident, from Fig. 7-9 and Thompson (1943), Templeman and Fleming (1962), Jean (1963), Marcotte (MS 1964, MS 1965), and Templeman (1962b, 1974), that the major winter migration of cod from all areas of the Gulf of St. Lawrence north of the Laurentian Channel is southward or eastward to Cabot Strait and vicinity and that relatively little of the outward migration to and through Cabot Strait is completed by the end of December. Cod tagged in the Gulf of St. Lawrence off the west coast of Newfoundland during 20-23 January were at that time migrating southward from the Gulf to Cabot Strait and adjacent areas (Fig. 7ABC). Recaptures in March-May of the tagging year (Fig. 10AG) of cod tagged on Burgeo Bank during 30 March-7 April and off Port aux Basques and Rose Blanche during 14-26 March showed that there was very little movement of the tagged fish eastward along the south coast after these tagging dates.

It is apparent, from the January-May recaptures along the south coast of Newfoundland, that relatively few cod from the winter-spring migrations eastward through Cabot Strait from Gulf taggings reach Fortune Bay and that the migrations usually do not extend beyond Fortune Bay (Fig. 7-9). From the most southern tagging at Lark Harbour (Fig. 8A), the fish would be expected to move farthest east, but the most easterly recapture along the south coast was in Fortune Bay. For the remaining autumn Gulf taggings off western Newfoundland and in or near the Strait of Belle Isle, the numbers recaptured on the south coast east of Fortune Bay and of 55° W in January-May were: Port au Choix, 0 (Fig. 8D); Bonne Esperance, 1 (Fig. 8J); Centre Bank, 4 (Fig. 8G). The amount of apparent migration eastward from Cabot Strait along the south coast in January-May was much less from the Centre Bank than from the other taggings. No cod from the Centre Bank tagging were taken in Fortune Bay and only two from 57° W east to Fortune Bay. Yet this tagging showed the greatest migration to the Avalon Peninsula.
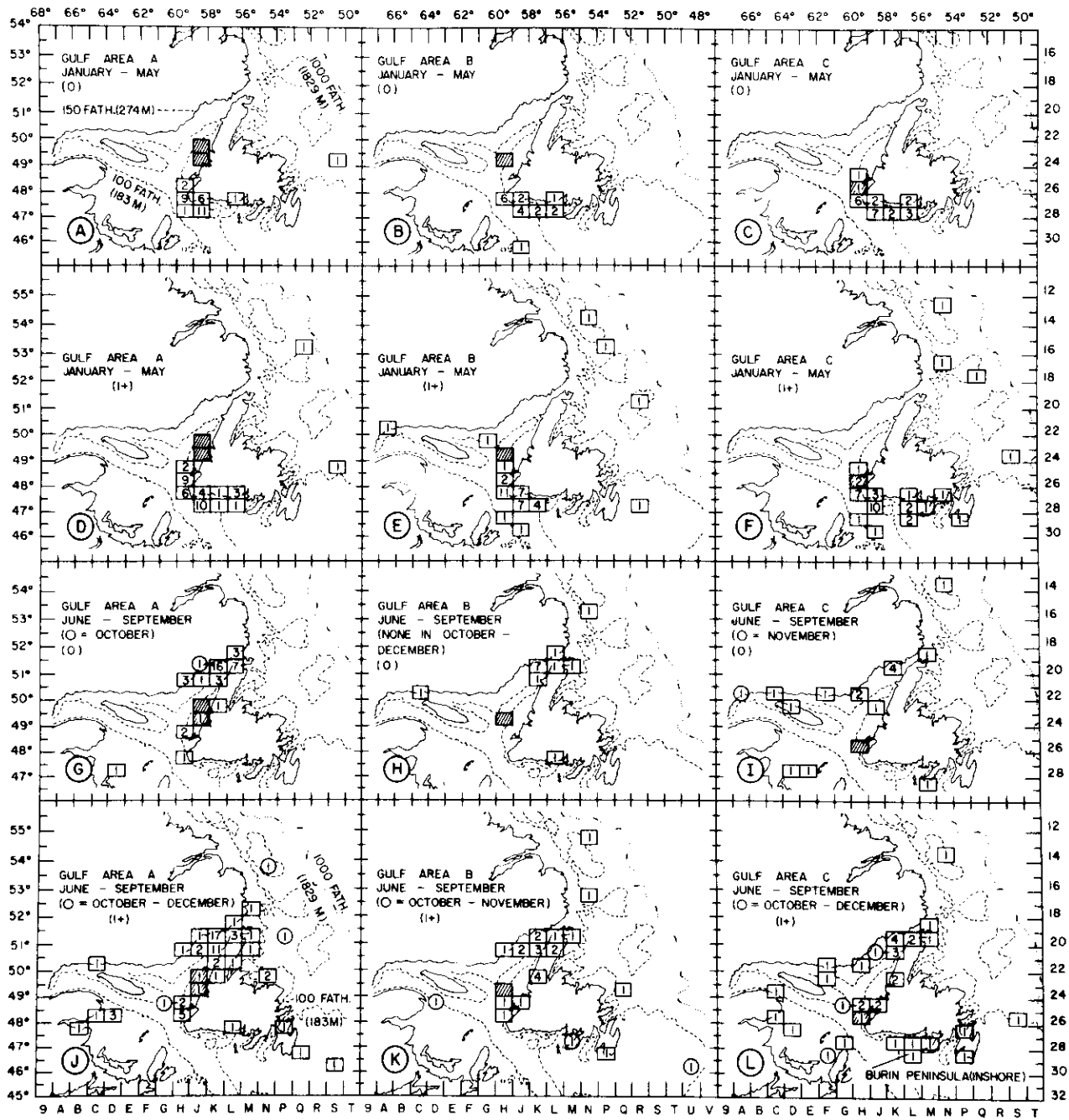
Fig. 7.  Location of returns in various monthly periods from cod tagged off western Newfoundland, 1962: Gulf Area A (A, D, G, J); Gulf Area B (B, E, H, K); Gulf Area C (C, F, I, L). (See Appendix for details of tagging.)
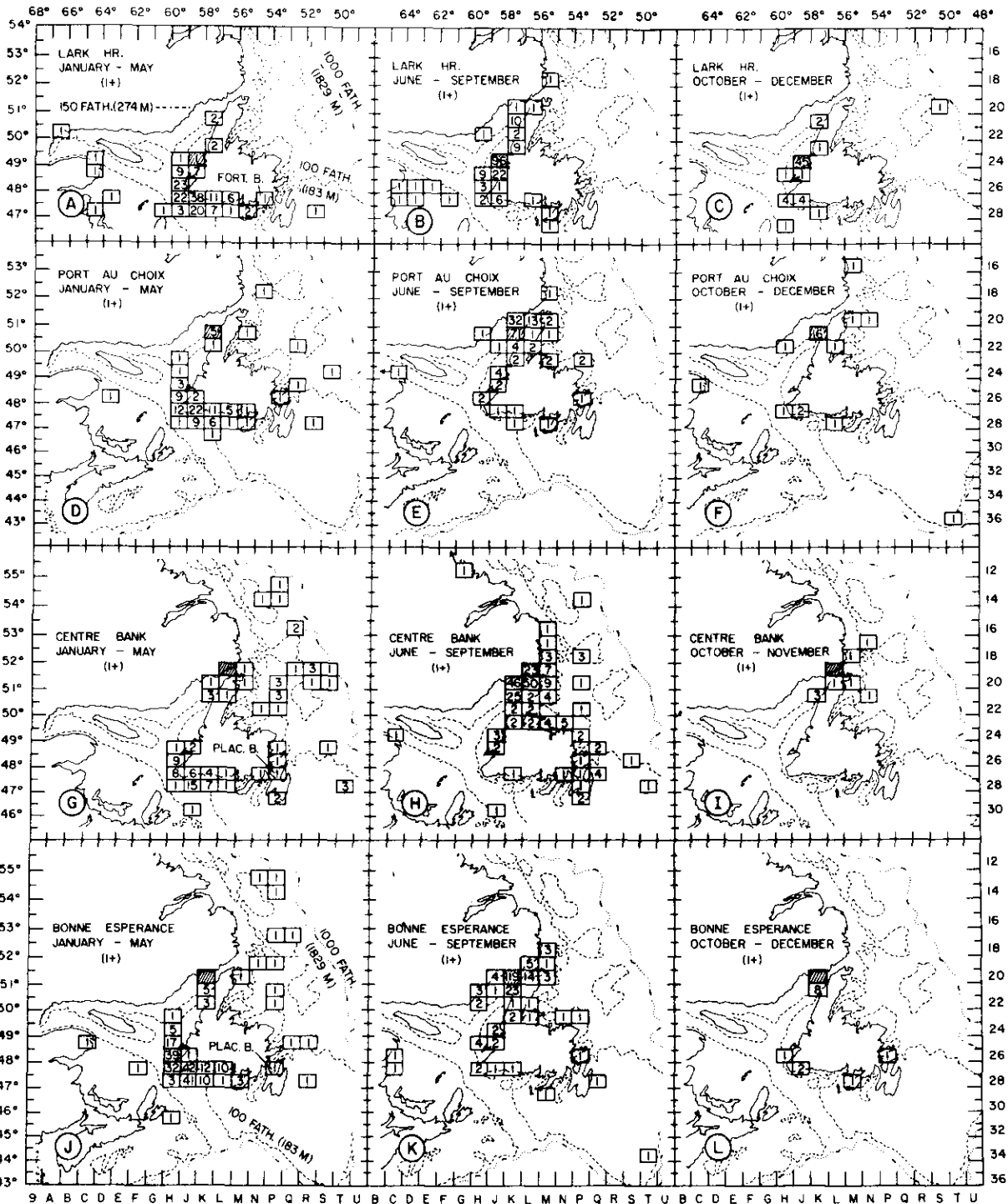
Fig. 8. Location of returns in various monthly periods from cod tagged off western Newfoundland to Strait of Belle Isle, 1962-1964: off Lark Harbour (A, B, C); off Port au Choix (D, E, F); Centre Bank (G, H, I); off Bonne Esperance (J, K, L). (See Appendix for details of tagging. The most westerly recapture in E should be three rectangles farther west, and the most northerly recapture in H should be farther north in rectangle F9.)
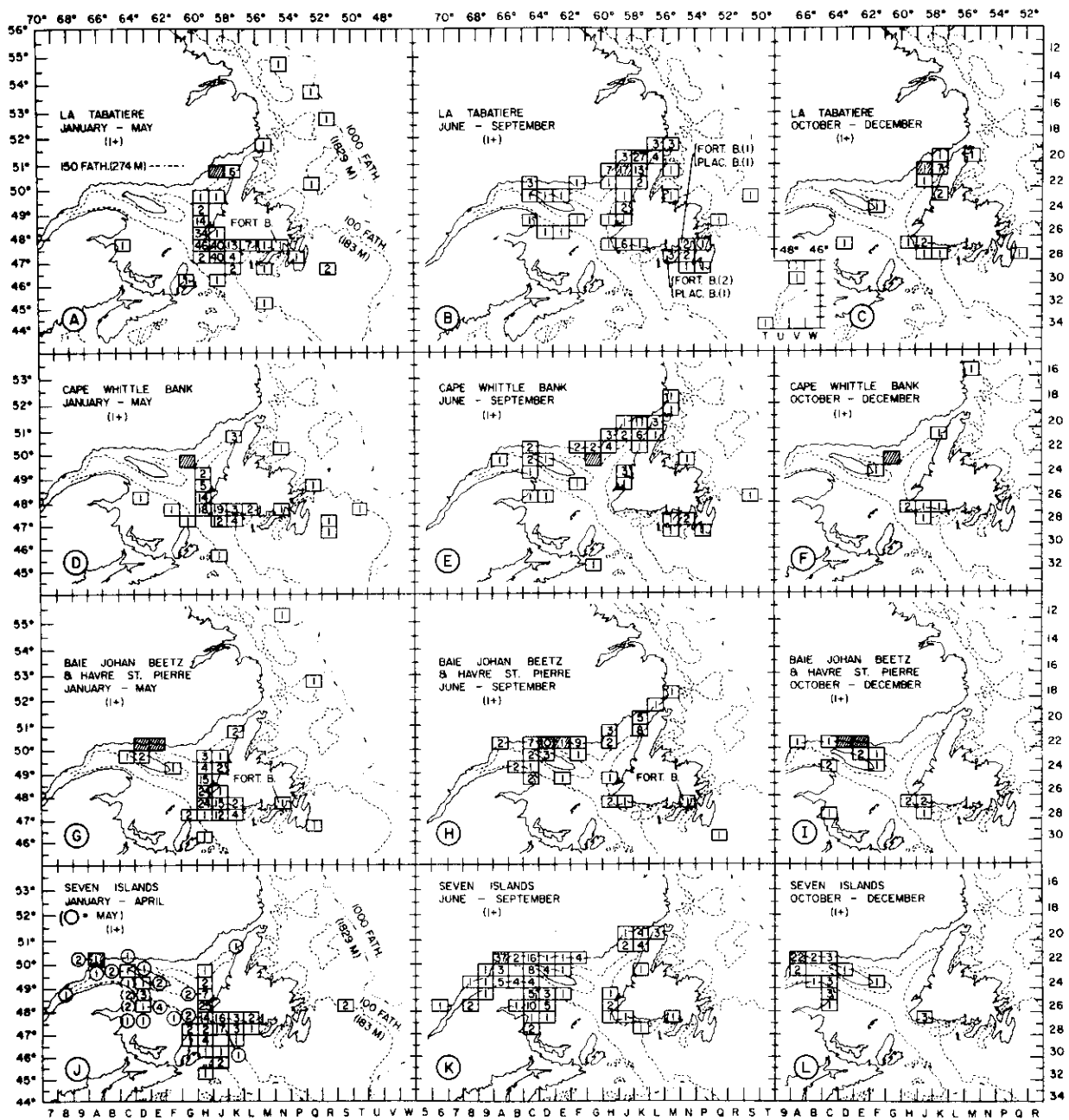
Fig. 9.   Location of returns in various monthly periods from cod tagged off the North Shore of the Gulf of St. Lawrence, 1962-64: off La Tabatiere (A, B, C); Cape Whittle Bank (D, E, F); off Baie Johan Beetz and Havre St. Pierre (G, H, I); off Seven Islands (J, K, L). (See Appendix for details of tagging.)
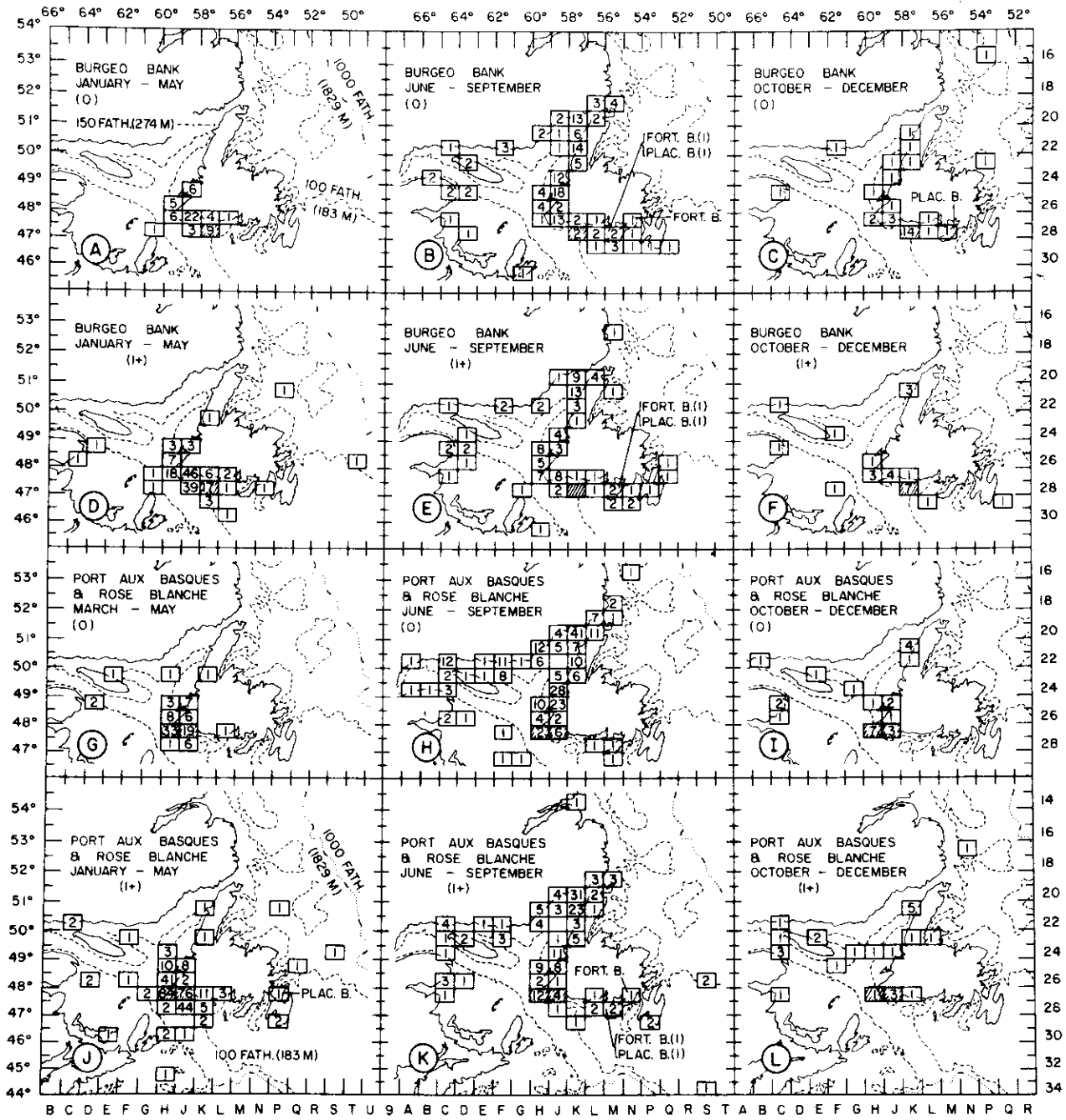
Fig. 10. Location of returns in various monthly periods from cod tagged off the southwest coast of Newfoundland, 1963: Burgeo Bank (A to F); off Port aux Basques and Rose Blanche (G to L). (See Appendix for details of tagging.)

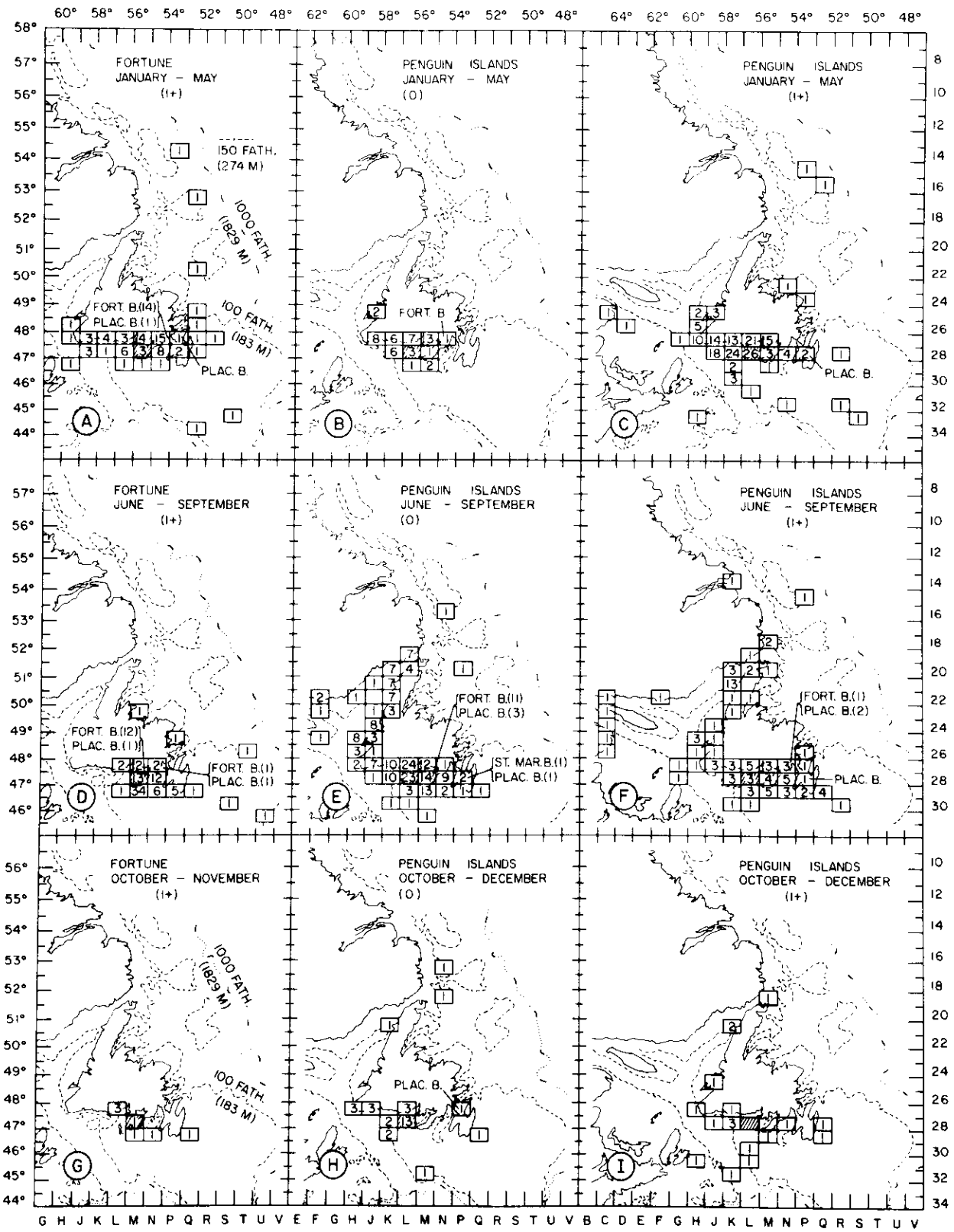Fig. 11. Location of returns in various monthly periods from cod tagged inshore off southern Newfoundland, 1963-65: off Fortune (A, D, G); off Penguin Islands (B, C, E, F, H, I). (See Appendix for details of tagging.)

In June–December, recaptures from Fortune Bay west along the south coast of Newfoundland were relatively much less for the Centre Bank tagging (Fig. 8HI) than for the more southern taggings (Fig. 8BC, 8EF, 8KL). The percentages in rectangles touching the Avalon Peninsula as far west as Placentia Bay were, however, much greater for the Centre Bank tagging: Lark Harbour, 0; Port au Choix, 1; Bonne Esperance, 1; and Centre Bank, 4. Also the percentages of recaptures in all seasons in rectangles touching the Avalon Peninsula increased in taggings from south to north: Lark Harbour, 0; Port au Choix, 1; Bonne Esperance, 1; and Centre Bank, 5.

These comparisons, and the discussion later in relation to migrations through the Strait of Belle Isle, indicate that, in general, the recaptures off the east coasts of Labrador and Newfoundland (including the Avalon Peninsula and the Grand Bank), from the Gulf taggings, came from an outward migration through the Strait of Belle Isle and not from an eastward migration from Cabot Strait. However, all five recaptures on St. Pierre Bank from the Gulf taggings (Fig. 7F, 8D, 9A) were taken on the northwestern fringe of this bank in January–May and, from the distribution of adjacent recaptures, were evidently from the winter migration out of Cabot Strait.

It is apparent that few cod, tagged in the Gulf, moved eastward along the south coast beyond Fortune Bay. However, for the taggings on the western South Coast from Port aux Basques to Fortune Bay and northern St. Pierre Bank (Fig. 10, 11, 14), the recaptures, especially in June–September, extend along the whole south coast of Newfoundland. There is also no considerable outward migration from these taggings through the Strait of Belle Isle and to the northeast coast of Newfoundland. It is thus evident that some cod from these western south coast taggings moved eastward in summer along the south coast east of Fortune Bay. It is apparent, also, that these western south coast fish were related to the coast and the coastal banks. From the taggings off the south coast west and north of St. Pierre Bank there were relatively few recaptures on St. Pierre Bank except on its northern part and few on the Grand Bank.

The feeding movements eastward along the south coast beyond Fortune Bay in June–September were greatest for the most eastern taggings off the south coast: northern St. Pierre Bank (Fig. 14FH), Fortune and Penguin Islands (Fig. 11DEF), and least for the most western taggings at Port aux Basques and Rose Blanche (Fig. 10HK). Indeed, for the latter taggings, which were in or close to Cabot Strait, the recaptures in rectangles associated with the Avalon Peninsula could equally well, especially in Fig. 10J, be from migration out of the Strait of Belle Isle. By October–December

(Fig. 10CF, 11GHI, 14HI) most of the eastward migrants had apparently returned westward.

*Migrations westward to Cabot Strait and into the Gulf of St. Lawrence.* The return migrations of Gulf-tagged cod through Cabot Strait to the Gulf were discussed by Templeman and Fleming (1962), Templeman (1974), and additional evidence is presented in this paper (Fig. 7–9). In all, the June–September patterns are similar. Recaptures were mainly in the Gulf and there were relatively few fish, from taggings in and near the Strait of Belle Isle, recaptured on their northward migration along the west coast of Newfoundland from their winter-spring abode in and adjacent to Cabot Strait. Also, relatively few Gulf-tagged cod remained on the south coast of Newfoundland in summer. Thus, almost all of the return migration into the Gulf was accomplished before June.

From taggings in March near the eastern entrance to Cabot Strait at Port aux Basques and Rose Blanche and during 30 March–7 April 1963 somewhat farther east on Burgeo Bank, recaptures in summer-early autumn were mainly in the Gulf (Fig. 10). Cod tagged on Burgeo Bank during 22 April–14 May 1954 (Templeman, 1974) were mainly recaptured in May–December (of the tagging and ensuing years), along the south coast of Newfoundland. Evidently, most of the northern Gulf stock had left Burgeo Bank on their way to the Gulf by the time of the 1954 tagging, leaving on the bank mainly fish of the western South Coast stock. These results illustrate the importance of tagging in the same area at different times during the year. Small differences in time of tagging can result in the tagging of far different proportions of intermingling stocks and thus produce large differences in migration pattern.

Only a little farther east along the south coast, near the Penguin Islands, many of the cod tagged during 30 March–13 April (Fig. 11) were within the Gulf in summer-early autumn. Including returns in the tagging year, however, most of the Penguin Islands cod remained on the western part of the south coast in the summer-autumn feeding season.

From recaptures during several months after tagging, of cod tagged off the western part of the south coast of Newfoundland from Port aux Basques to Penguin Islands in late March to early April (Table 3), it is evident that the dates of entrance to the Gulf were progressively later and the percentages of cod recaptured in the Gulf of St. Lawrence gradually lower from the western to the eastern taggings. Similarly, the relative numbers recaptured farther north in Div. 4S declined rapidly with increasing distance of the western south coast tagging area from Cabot Strait (Table 3). This could have been because the Div. 4S cod did not migrate as far eastward along the south

TABLE 3. Percentages of recaptured cod in various periods after tagging in 1963 in the Gulf of St. Lawrence (Div. 4RST), from tagging at four localities from west to east on the western part of the south coast of Newfoundland. (See Fig. 1 for tagging locations; inclusive tagging dates are indicated for each location.)

| Recapture periods 1963 | Port aux Basques (3Pn) 14-26 Mar 1963 | | | | Rose Blanche (3Pn) 20-25 Mar 1963 | | | | Burgeo Bank (3Ps) 30 Mar-7 Apr 1963 | | | | Penguin Islands (3Ps) 30 Mar-13 Apr 1963 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4RST % | 4R % | 4S % | Total fish | 4RST % | 4R % | 4S % | Total fish | 4RST % | 4R % | 4S % | Total fish | 4RST % | 4R % | 4S % | Total fish |
| 16 Mar-15 Apr | 27 | 27 | 0 | 26 | 4 | 4 | 0 | 26 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 2 |
| 16-30 Apr | 86 | 86 | 0 | 7 | 33 | 33 | 0 | 2 | 10 | 10 | 0 | 20 | 0 | 0 | 0 | 11 |
| 1-15 May | 93 | 79 | 7 | 14 | | | | 1 | 29 | 29 | 0 | 17 | 7 | 7 | 0 | 15 |
| 16-31 May | 82 [a] | 64 | 0 | 11 | 50 | 50 | 0 | 2 | 31 | 25 | 0 | 16 | 8 | 8 | 0 | 12 |
| 1-15 Jun | 92 | 60 | 24 | 25 | 93 | 73 | 20 | 15 | 87 | 73 | 9 | 22 | 30 | 27 | 3 | 30 |
| 16-30 Jun | 97 | 52 | 45 | 62 | 96 [a] | 65 | 27 | 26 | 84 | 65 | 19 | 48 | 45 | 45 | 0 | 47 |
| 1-15 Jul | 95 | 47 | 39 | 38 | 100 | 50 | 32 | 22 | 65 | 43 | 13 | 23 | 35 | 27 | 8 | 48 |
| 16-31 Jul | 100 | 38 | 57 | 21 | 100 | 67 | 33 | 3 | 88 | 53 | 24 | 17 | 32 | 24 | 8 | 25 |

[a] Includes one fish from Div. 2J because it presumably migrated through the Gulf.

coast in winter and/or because they began their migrations westward at an earlier date. From tagging at Fortune during 23 October-11 November, most of the recaptures in January-May (Fig. 11A) were off the western part of the south coast of Newfoundland, and Fortune Bay cod may be considered to be part of the western South Coast stock. From this tagging, there were no recaptures in the Gulf in June-December (Fig. 11DG). Previous tagging off Fortune in June-July (Thompson, 1943) also showed migration along the western part of the south coast and none to the Gulf. Thus, Gulf cod reaching Fortune Bay in winter-spring had usually not arrived by October-November and had usually left before June. If tagging had been in late winter or early spring some of the Gulf migrants could have been tagged and later migrated back to the Gulf. An analysis of landings of inshore cod in 1947-49 (Templeman, 1958, 1966) showed relatively small quantities taken in Fortune Bay, so that only relatively small numbers of cod are native to Fortune Bay or migrate there either from west or east.

Cod tagged on the slope of northwestern St. Pierre during 3-24 May were found, in January-May of ensuing years, principally off the western part of the south coast of Newfoundland (Fig. 14C) and these were assigned to the western South Coast stock. Judging from the Burgeo Bank taggings, the northern St. Pierre Bank tagging dates were a month or more too late to have a large northern Gulf component. Only 2% of June-September recaptures from this tagging (Fig. 14FH) were taken in the Gulf. It is indicated, however, by the recaptures from the Gulf tagging, that only a very small proportion of Gulf-tagged cod normally reach St. Pierre Bank on their winter migration.

The average monthly catches of cod in hundreds of metric tons in Subdiv. 3Pn and Div. 4R and 4S for the years 1963-66, the main years of recapture for the 1963 taggings, were:

| Month | 3Pn | 4R | 4S |
|---|---|---|---|
| Jan | 8 | 3 | 0.2 |
| Feb | 34 | 132 | 2 |
| Mar | 74 | 73 | 1 |
| Apr | 19 | 17 | 0.2 |
| May | 7 | 11 | 4 |
| Jun | 2 | 77 | 25 |
| Jul | 2 | 76 | 35 |
| Aug | 2 | 54 | 12 |
| Sep | 2 | 18 | 8 |
| Oct | 3 | 7 | 5 |
| Nov | 5 | 3 | 3 |
| Dec | 4 | 3 | 1 |

The cod catches in Subdiv. 3Pn and Div. 4R were relatively high in February-March. In Subdiv. 3Pn they declined rapidly in April-May and remained low for the remainder of the year, increasing slightly in November-December. These catches make it apparent that a large proportion of the Gulf cod approaching Cabot Strait probably do not leave the Gulf and that almost all inward migration through Cabot Strait occurs before the end of April, with a much smaller number entering the Gulf in May. In Div. 4R, the larger catches in February-March are usually off the southern part of the west coast of Newfoundland. At this time, cod which summer in both Div. 4R and 4S are being caught in Div. 4R. Cod catches in Div. 4R declined rapidly in April and May as cod became less available, scattering and migrating, probably often pelagically, toward their spawning and feeding areas. Catches in Div. 4R rose to a new maximum in June-August as cod became available in shallow water near shore during and after the herring and capelin spawning seasons. In Div. 4S, because of ice conditions and presumably lack of cod, few cod were taken in winter and spring and most were caught in June-July, with a rapid decline over the remainder of the year.

*Homing.* From the tagging in seven coastal localities of the Gulf of St. Lawrence during 31 August–19 November, a large percentage of the recaptures from each tagging, in June–September of the years after the tagging year (Fig. 8BEHK, 9BHK), was in and near the tagging area. The homing was sufficient to indicate local populations in these localities. There was no evidence of homing to Cape Whittle Bank (Fig. 9E), but this may have been because the fish tagged there in late October were migrants in passage from other areas of the northern Gulf. Also, there was no homing in June–September to Gulf Areas A, B, C (Fig. 7) because the cod tagged in these areas in January were southward migrants.

From tagging on the western part of the south coast of Newfoundland in March–April, some of the cod were evidently local, remaining on this part of the coast in summer, and some returned to the Gulf. Passing eastward along the south coast of Newfoundland from Port aux Basques and Rose Blanche to Burgeo Bank and Penguin Islands (Fig. 10HK, 10BE, 11EF), the percentages of recaptures taken in June–September in the Gulf (including rectangles H27 and M18–20) decreased (93, 76, 36) and the corresponding percentages taken off the south coast (including all rectangles prefixed J to P and Q29) increased (6, 21, 61). From these taggings in March–April on the western part of the south coast of Newfoundland, there were two major areas of concentration in June–September in the Gulf: the Strait of Belle Isle and its southern approaches, and off Bay of Islands and the Port au Port Peninsula on the southern part of the west coast of Newfoundland. These areas showed especially good homing from taggings in autumn in the Gulf.

In January–May of years after the tagging year, from these south coast spring taggings (Fig. 10DJ, 11C), there was considerable homing to and near the tagging rectangles as the recently migrated cod from the northern Gulf again joined the resident western South Coast stock.

*Migrations northward, and eastward and southward from the Strait of Belle Isle.* From the Penguin Islands tagging in March–April, one recapture was made near Hamilton Bank and one on the Northeast Newfoundland Shelf in June–September of the tagging year (Fig. 11E). From the distribution pattern of the recaptures, it is probable that these fish were part of the northward movement through the Gulf and passed outward through the Strait of Belle Isle.

A cod tagged on 4 April 1963 on Burgeo Bank at 91 m depth was recaptured by the *Investigator II* on 21 November 1963 at 27 m off Fogo Island on the east coast of Newfoundland. The fish was released again in good condition and was caught in winter–spring 1966 off Rose Blanche at 183 m, 36 nautical miles northwest of the original tagging position. The cod had thus migrated to the northeast coast of Newfoundland, a distance of about 500 nautical miles, and returned again to near the tagging location, presumably, judging by other recaptures, via the Strait of Belle Isle in both cases.

From tagging off Port aux Basques and Rose Blanche, in June–September of the tagging year (Fig. 10H) four cod evidently passed outward through the Strait of Belle Isle. The relatively small numbers passing out of the Gulf were confirmed by the very small numbers from this tagging recaptured at any season east of Newfoundland or Labrador (Fig. 10JKL).

From taggings in January off the west coast of Newfoundland in three areas, A, B, C from north to south, occasional tagged cod passed northward through the Strait of Belle Isle in the summer–autumn of the tagging year and were recaptured near the northern entrance of this strait and on the southern Labrador Shelf (Fig. 7HI).

From taggings in autumn in the Gulf of St. Lawrence at Lark Harbour and in three localities in or near the Strait of Belle Isle, recaptures on the Labrador and Northeast Newfoundland shelves, southward along the east coast of Newfoundland to and including the Avalon Peninsula, and on the Grand Bank, increased greatly from the most southern to the northern taggings in percentages of total recaptures in January–May, (Fig. 8AJDG): Lark Harbour (1), Bonne Esperance (6), Port au Choix (7), and Centre Bank (35); and in June–September (Fig. 8BKEH): Lark Harbour (1), Bonne Esperance (7), Port au Choix (8), and Centre Bank (29).

From taggings in September–October in four areas along the North Shore of the Gulf of St. Lawrence (Fig. 9), from Seven Islands to La Tabatiere, percentage recaptures east of the Strait of Belle Isle (56°W) and southward, along the east coast of Newfoundland to and including rectangles associated with the Avalon Peninsula, and to the Grand Bank, increased from the western to the eastern taggings: 1, 2, 9, 7.

From all Gulf taggings (Fig. 7–9) only 28 recaptures were from the northern Grand Bank, predominantly from its northern slopes, and 3 were from the southern Grand Bank (south of 46°N). From these taggings, the very small number of recaptures on St. Pierre Bank were all on its northwestern slope and had obviously migrated through Cabot Strait. From the above and the earlier discussion in relation to

movements outward through Cabot Strait, it can be concluded that, for the Gulf taggings, the distribution of recaptures east of Newfoundland and Labrador southward to the Avalon Peninsula was related to migration out of the Strait of Belle Isle. It is consequently also concluded that migrants from the Gulf generally reached the Grand Bank by the northern (Strait of Belle Isle) rather than the southern (Cabot Strait) route.

*Migrations to the northwestern Gulf.* From tagging at Lark Harbour and in three localities in and near the Strait of Belle Isle (Fig. 8), only one recapture (from the Lark Harbour tagging, Fig. 8A) was made on the North Shore of the Gulf west of 60°W. Recaptures in May in the Gulf west of 63°W were considerably more numerous from the Seven Islands tagging (Fig. 9J) than from the more easterly taggings off the North Shore (Fig. 9ADG). In order from Seven Islands to La Tabatiere, recaptures in May were 7, 2, 1 and 0.3% of total recaptures after the tagging year. From taggings in three eastern areas of the Gulf in January (A, B, C from north to south, Fig. 7), recaptures on the North Shore west of 60°W were 1, 3 and 5% of total recaptures respectively. From taggings in March–April in localities from east to west on the western part of the south coast of Newfoundland (Fig. 10, 11), the following percentages of total recaptures at all seasons were taken on the North Shore and north of Anticosti Island west of 60°W and west of 63°W: Penguin Islands, 1 and 0.4; Burgeo Bank, 2 and 1; and Port aux Basques and Rose Blanche, 7 and 3. It is evident that at the time of tagging, both in January and in March–April, more fish related to the western Gulf were near Cabot Strait rather than farther north in January or east in March–April.

*Trans-Laurentian Channel crossings.* From tagging areas related to the western South Coast (Fig. 10, 11, 14), the following percentages of recaptures during and after the tagging year were taken south (or west) of the Laurentian Channel: Fortune (after the tagging year), 1; northern St. Pierre Bank, 0 and 4; Penguin Islands, 0 and 4; Burgeo Bank, 5 and 5; Port aux Basques and Rose Blanche, 4 and 4. Trans-Channel crossings from the tagging on Burgeo Bank in 1954 were similarly large (Templeman, 1974). Six of the trans-Laurentian Channel recaptures from the northern St. Pierre Bank tagging were on the Scotian Shelf and the remaining 2 were off Cape Breton, indicating a crossing of the Channel outside the Gulf between Cabot Strait and southern St Pierre Bank. Of 81 trans-Channel recaptures from the above taggings, 36% were taken in January–May, 49% in June–September and 15% in October–December.

The percentages of tagged cod from the Gulf taggings recaptured south of the Laurentian Channel increased in relation to the proximity of the tagging area to the Channel: Centre Bank, 1; Bonne Esperance, 1; Port au Choix, 1; La Tabatiere, 2; Gulf Area A, 3; Lark Harbour, 3; Gulf Area B, 4; Cape Whittle Bank, 5; Baie Johan Beetz and Havre St. Pierre, 5; Gulf Area C, 8; and Seven Islands, 24 (Fig. 7, 8, 9).

The unusually large percentage of trans-Channel recaptures from tagging at Seven Islands is similar to that reported by Jean (1963) from cod tagging in this area. The distribution of recaptures around the northern shore of the Gaspé Peninsula from the Seven Islands and the Baie Johan Beetz–Havre St. Pierre taggings indicates that many of the cod crossing the Laurentian Channel do so in the St. Lawrence Estuary. Many of these fish wandered considerably farther westward from Seven Islands into the Estuary, and as the Channel narrows it becomes increasingly easy to cross. Recaptures off Cape Breton and on the northern part of the Scotian Shelf from the Seven Islands tagging were relatively more numerous than from any other taggings in the northern Gulf, but by far the greatest number of January–April recaptures from this tagging were on the northern side of the Laurentian Channel near Cabot Strait. Previous cod tagging at Seven Islands (Jean, 1963) gave similar results. Of 147 trans-Channel recaptures from the Gulf taggings, 37% were taken in January–May, 52% in June–September, and 11% in October–December. From the predominance of these trans-Channel recaptures within the Gulf in June–September, it is very likely that many of the crossings occurred on the return migration in spring from Cabot Strait or from fish that spent the winter in the deep water of the Laurentian Channel.

For cod tagging in an adjacent area off the western part of Anticosti Island in September 1963, Marcotte (MS 1965) reported that 21.6% of all recaptures had crossed the Laurentian Channel southward, mainly into Div. 4T (20.5%).

### Flemish Cap stock

From tagging on Flemish Cap, 1 in 98 recaptures during the tagging year and 6 of 40 recaptures after the tagging year were reported from west of Flemish Channel, which separates Flemish Cap from the eastern Grand Bank and is more than 1,000 m deep (Fig. 12ADG). Of 15,350 recaptures from the other taggings (Fig. 2–14), only 4 were reported from Flemish Cap (Fig. 3C, 6F, 12F). It was not possible to authenticate these recaptures showing cod movements to and from Flemish Cap, and some may be migrations of ships rather than of cod. Occasionally, cod cross oceanic depths and travel great distances (Templeman, 1974, and this paper). It is very likely, therefore, that some cod leave Flemish Cap and that

others migrate to it from adjacent areas. The reported recaptures indicate that cod are more likely to leave the Flemish Cap than to be recruited to it. Cod feeding pelagically in the upper water layers may have a greater tendency to move westward towards the colder water of the eastern Grand Bank rather than in the opposite direction toward the warmer water of Flemish Cap.

Konstantinov (1970) noted 15 recaptures on Flemish Cap from tagging in that area in 1961–66 and no recoveries outside the area. Also, there were no records of tagged cod migrating to Flemish Cap from the 35,000 cod tagged by the USSR in Subareas 2 and 3 from 1960 to 1966. However, the USSR tagging was from trawl catches in deep water and consequently the rate of recapture was low: 971 recaptures up to March 1967 from 35,293 cod tagged (Konstantinov, MS 1967).

In previous Canadian tagging during 1954–55 (Templeman, 1974), no recaptures were reported from Flemish Cap. These taggings, however, were mainly in Newfoundland coastal areas at considerable distances from Flemish Cap.

Other evidences of the relative isolation of the Flemish Cap cod stock are: the absence of the cod nematode, *Terranova* (=*Porrocaecum*) *decipiens*, in cod fillets from the Cap (Templeman *et al.*, 1957); the earlier spawning (mainly in March) on Flemish Cap than on the adjacent eastern Grand Bank (Templeman, 1962a, 1976); the lack of infestation of Flemish Cap cod by *Lernaeocera branchialis* (Templeman and Fleming, 1963a; Templeman *et al.*, 1976); and the highly significant differences in transferrin allele frequencies in blood sera between cod of Flemish Cap and those of the neighboring northeastern Grand Bank (Jamieson, 1975). Cod vertebral samples from Flemish Cap also have significantly lower variances than those from the neighboring northeastern Grand Bank (unpublished Newfoundland Biological Station data).

**The Avalon stock complex and adjacent stocks**

*Introduction.* The Avalon stock complex (Avalon–Burin stock complex of Templeman 1962b, 1974) is principally associated with the Avalon Peninsula, the eastern and southern sides of the Burin Peninsula, the Avalon and St. Pierre channels and adjacent channels, bays, banks and slopes. This stock complex includes an intermediate and seasonally overlapping group of smaller stocks between the larger and better defined northern Gulf–western South Coast stock complex, the Labrador–East Newfoundland stock, and the southern Grand Bank stock. It is, therefore not so readily and clearly defined. The problems are: how much is basic Avalon stock complex, whether the immature residents and the

seasonal immigrants from the other stocks mentioned form the main population of this intermediate group, and how many of the populations considered below are representative of stocks closely enough intermingled in local populations of mature fish in feeding season and of immatures at all seasons to be included in the Avalon stock complex. The stocks of the Avalon stock complex are named from their winter–spring abodes and presumably spawning areas.

*Spawning in and near the area of the Avalon stock complex.* From unpublished Newfoundland Biological Station records, cod spawning on the northwestern Grand Bank, in ICNAF Div. 3L west of 50°W, typically begins in April and most spawning is completed in May and early June. Spawning on the northeastern part of the Grand Bank, in Div. 3L east of 50°W, probably occurs similarly in time and is almost complete by mid-June. Cod spawning on St. Pierre Bank occurs mainly in April–June with most spawning in May and June. Cod of the southern Grand Bank (Div. 3N and 3O) spawn mainly in April–June with most of the spawning probably occurring from the latter half of April to early June. The mature cod arriving inshore in eastern and southeastern Newfoundland with the capelin in the latter half of June are typically spent.

*Eastern Grand Bank.* There were few recoveries from cod tagged during 25–27 April on the eastern Grand Bank in the northeastern corner of ICNAF Div. 3N (Fig. 12BEH). Studies of vertebral numbers (unpublished data of the Newfoundland Biological Station) have indicated that cod of this area may be relatively pure schools of Labrador–East Newfoundland, southern Grand Bank or other stocks or a mixture. Evidently the group tagged was most related in summer–autumn to the Virgin Rocks local population. There was also a strong relationship with the southern Grand Bank stock and some coastal relationship in summer, mainly around the Avalon Peninsula, with the Labrador–East Newfoundland stock and the Avalon stock complex.

*Virgin Rocks.* The homing of large numbers of cod from the Virgin Rocks tagging, in June–September of the years after tagging (Fig. 13D, and Templeman, 1974), shows that the shallow water of the Virgin Rocks is the focus of a local population similar to those of the adjacent coastal shallow–water areas. The winter–spring relationships of the Virgin Rocks local population (Fig. 13A, and Templeman, 1974) show that it contains fish of a number of stocks: the Labrador–East Newfoundland stock in the southern part of its spawning range from Hamilton Bank to Funk Island Bank; chiefly the western Grand Bank spawning stock of the Avalon stock complex on the northwestern slopes of the Grand Bank; the immature Labrador–East
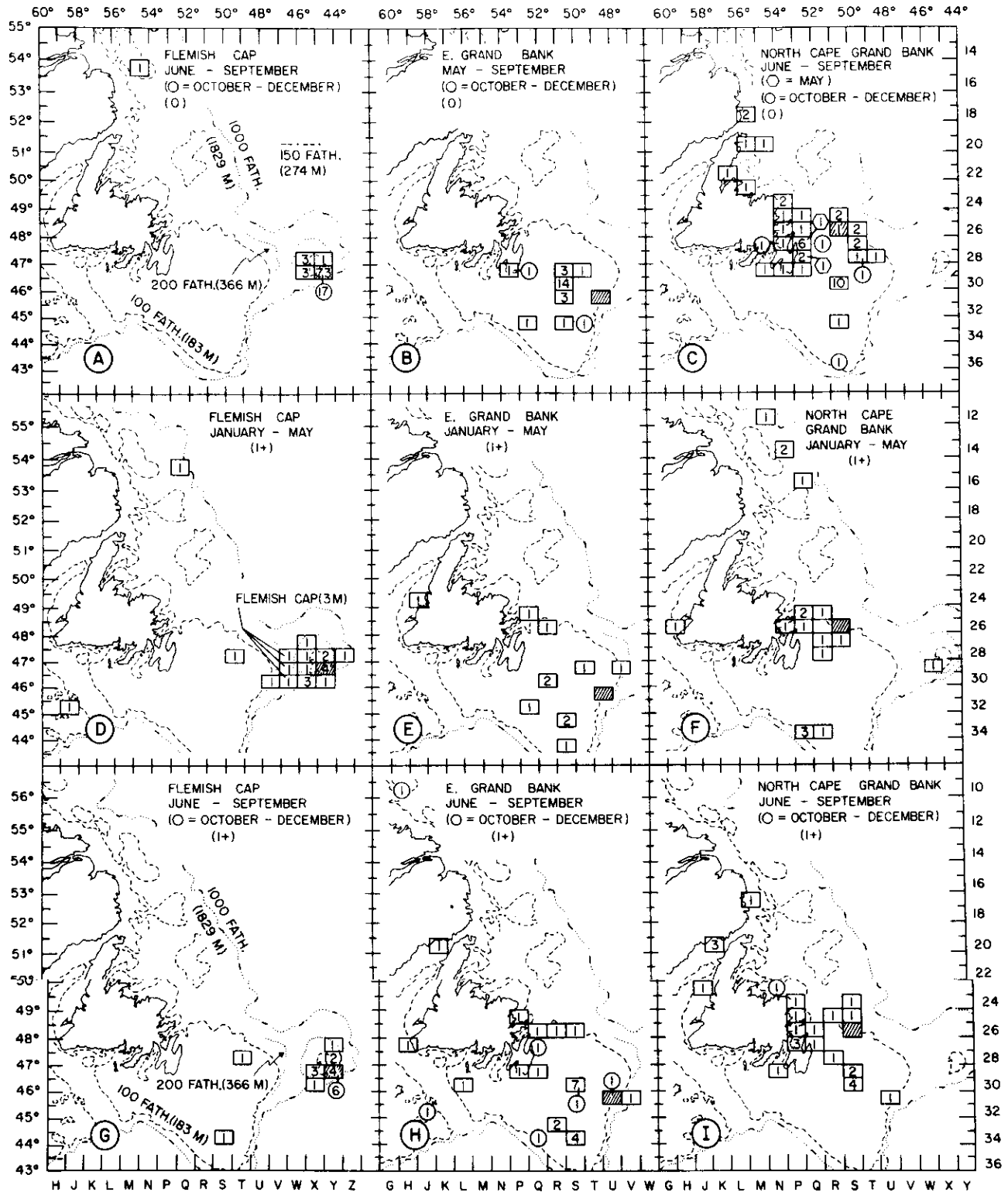
Fig. 12.   Location of returns in various monthly periods from cod tagged on Flemish Cap and northern and eastern Grand Bank, 1962-64:
         Flemish Cap (A, D, G); eastern Grand Bank (B, E, H); northern Grand Bank (C, F, I). (See Appendix for details of tagging.)
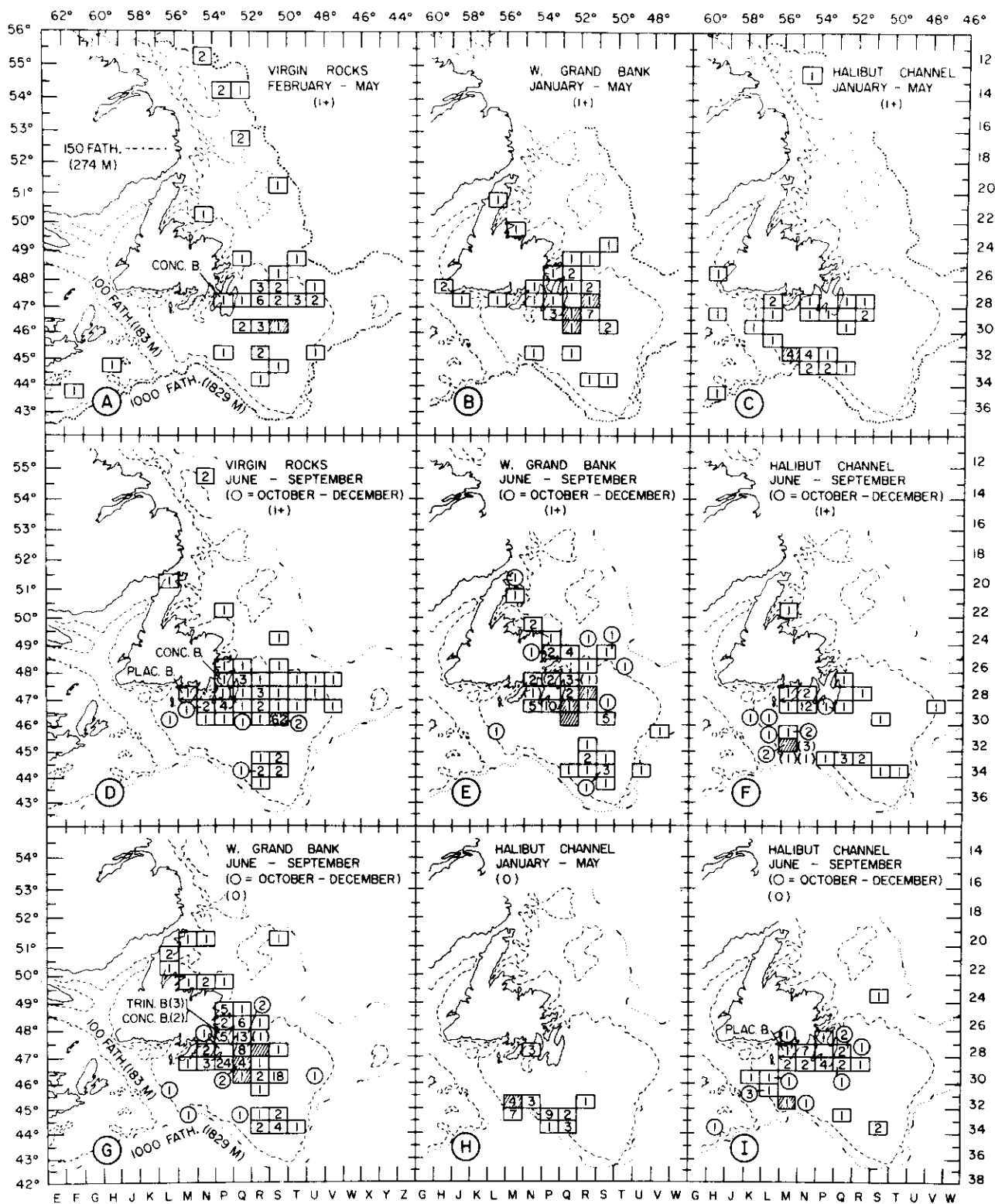
Fig. 13.   Location of returns in various monthly periods from cod tagged on northwestern Grand Bank and in Halibut Channel, 1963-65:
Virgin Rocks (A, D); Woolfall Bank and off Cape Race (B, E, G); Halibut Channel (C, F, H, I). (See Appendix for details of tagging.)
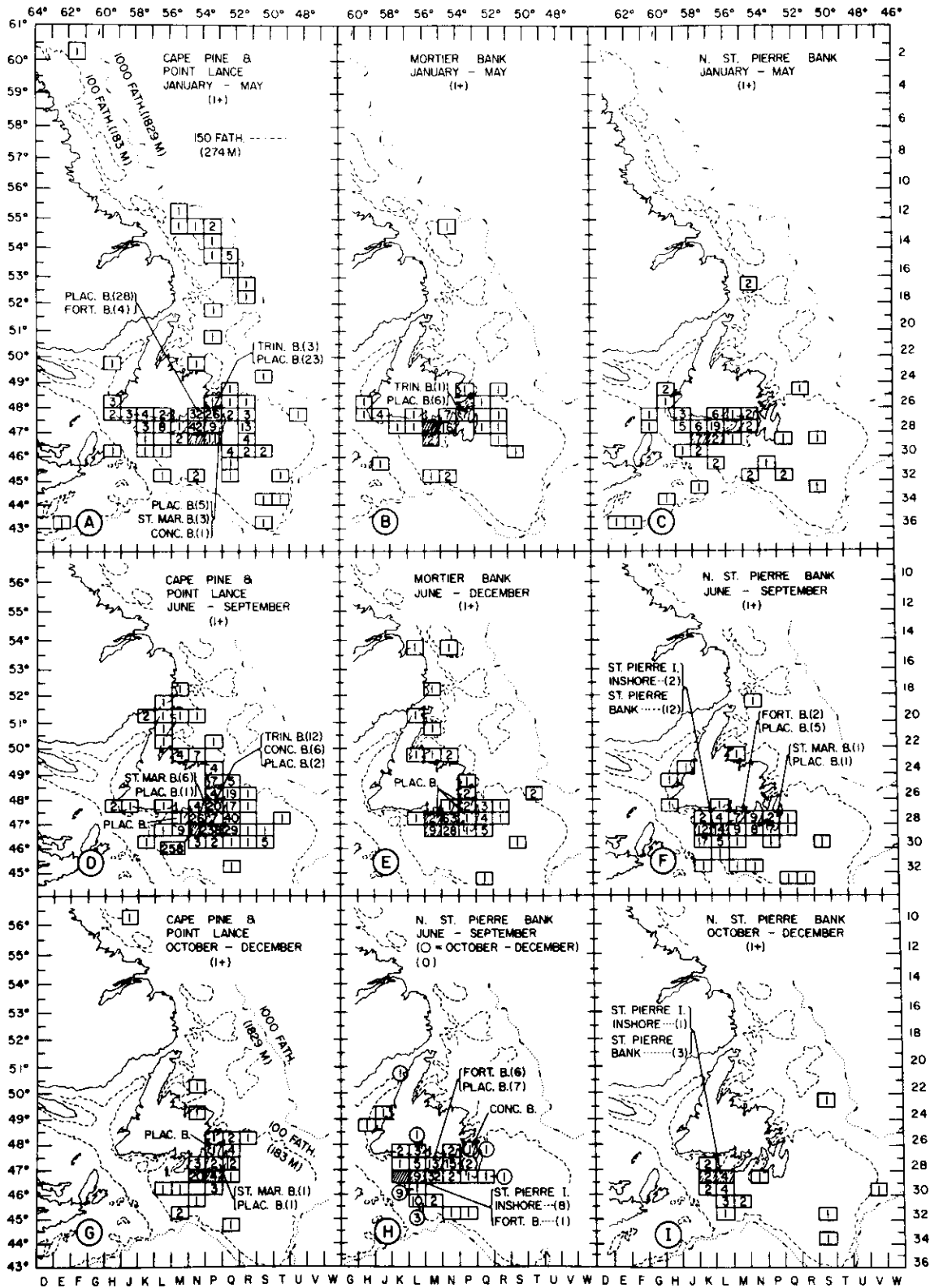
Fig. 14.   Location of returns in various monthly periods from cod tagged off southwestern Newfoundland, 1963-65: off
Cape Pine and Point Lance (A, D, G); Mortier Bank (B, E); northwestern St. Pierre Bank (C, F, H, I). (See
Appendix for details of tagging.)

Newfoundland stock on the northern and northeastern Grand Bank; and the southern Grand Bank stock on the northern, northeastern, and southern Grand Bank. In summer the fish tagged at the Virgin Rocks mainly homed to the Virgin Rocks area and to a gradually lesser degree migrated to the Avalon Peninsula and to the southern Grand Bank. Cod with the low vertebral numbers typical of the southern Grand Bank stock are found over the surface of the Grand Bank in summer (Templeman, 1962b), and thus many of the cod tagged at the Virgin Rocks and migrating into Div. 3N and 3O were probably fish of the southern Grand Bank stock.

*Western Grand Bank.* The cod tagged on the western slopes of the Grand Bank at Woolfall Bank and off Cape Race during 28 April–13 May were mainly related in January–May of ensuing years (Fig. 13B) to the Avalon Channel and Peninsula. The main relationship in June–December (Fig. 13EG) was with the Avalon Peninsula, especially the southern part. Some of the tagged fish carried out feeding migrations to the Grand Bank at this time.

*Halibut Channel.* The cod tagged in the Halibut Channel during 16–25 January could be expected to be in large part a southern St. Pierre Bank–Green Bank stock. In June–September (Fig. 13FI) they were mainly located around the Avalon Peninsula. In October–December (Fig. 13F), they were chiefly part of the southern St. Pierre Bank stock and of the population in the Halibut and Haddock channels. In January–May (Fig. 13CH), they intermingled throughout most of the area of the Avalon stock complex, including St. Pierre Bank, Avalon Channel and Placentia Bay, but the greatest concentrations were in the Halibut and Haddock channels and along the southwestern Grand Bank, mainly in the western part of Div. 3O.

*Cape Pine and Point Lance.* Inshore cod tagging was carried out off Cape Pine and Point Lance (near Cape St. Mary's) on the southern part of the Avalon Peninsula during 6 November–12 December and 14–20 September. This is part of the main area of summer intermingling for the Avalon stock complex. In January–May (Fig. 14A), most recaptures were in Placentia Bay, indicating a winter abode in the deep water of Placentia Bay for many fish of the local populations more closely related to the mouth of Placentia Bay and to the southern coast of the Avalon Peninsula. There was a smaller winter migration westward to the coastal slopes and banks northwest of St. Pierre Bank, where they intermingled with the northern Gulf–western South Coast stock complex, and eastward to the western slopes of the Grand Bank and the Avalon Channel. Offshore tagging in spring off southern Labrador and on the Northeast Newfoundland Shelf (Fig. 3, 4) showed that some of the

Labrador–East Newfoundland stock migrated after spawning season to feeding areas as far south and west as the Avalon Peninsula. The small numbers recaptured off Labrador and on the Northeast Newfoundland Shelf in January–May from the taggings off Cape Pine and Point Lance (Fig. 14) were presumably Labrador–East Newfoundland stock.

Although the tagging locations were only about 24 nautical miles apart, there were apparent differences in migration of fish from the tagging in the two localities. In January–May, relatively more cod from the more easterly Cape Pine tagging (44%) and less (17%) from the more westerly Point Lance tagging were recaptured eastward of the Cape Pine tagging Rectangle P29 (in the Avalon Channel, on the western fringes of the Grand Bank and northward to off southern Labrador), and relatively less (24% compared with 65% for the Point Lance tagging) in and at the mouth of Placentia Bay westward of the Cape Pine tagging rectangle. Tagging off Cape Pine was more than 1½ months later than that off Point Lance and the migrations easterly and westerly to the wintering areas may have begun by the time (November–December) that the Cape Pine tagging occurred.

Recaptures in June–September in years after the tagging year (Fig. 14D) were mainly concentrated in coastal areas of the Avalon Peninsula, especially in and near the tagging rectangles at the southern part of the Peninsula. There was a definite homing to the tagging area. From the Cape Pine tagging, there were 182 recaptures in tagging Rectangle P29 off Cape Pine and 102 in the adjacent N29 off Point Lance, whereas from the Point Lance tagging there were 156 recaptures in tagging Rectangle N29 off Point Lance and 56 recaptures in the adjacent P29 off Cape Pine.

Cod tagged on northern St. Pierre Bank and migrating to the Avalon–Burin region (Fig. 14CFHI) had mainly returned to St. Pierre Bank by October–December, but those tagged off Cape Pine and Point Lance were still almost all related to the Avalon Peninsula in these months (Fig. 14G), with only a few on St. Pierre Bank as there were in January–May (Fig. 14A).

*Mortier Bank.* Recaptures in January–May from tagging on Mortier Bank (Fig. 14B) were mainly in Placentia Bay, with some dispersion to the Avalon Channel and its southern branches, the western part of the south coast of Newfoundland and Cabot Strait.

In June–December (Fig. 14E), recaptures were predominantly in Placentia Bay within the tagging rectangles, with a relatively small dispersion northward along the east coast of Newfoundland and southern Labrador. All 15 recaptures in

October–December were taken within the rectangles associated with the Avalon and Burin peninsulas.

*St. Pierre Bank.* Cod tagged on the northwestern fringe of St. Pierre Bank in 59–102 m during 3–24 May 1963 (Fig. 14C) appeared to be mainly western South Coast stock which were visiting the northwestern slope of St. Pierre Bank at the time of tagging. However, cod tagged on northern St. Pierre Bank, only about 10 nautical miles farther south in one of the same rectangles (L29) in 49–51 m during 20 May–2 June 1954 (Templeman, 1974), were chiefly related in January–May of ensuing years with northern St. Pierre Bank and showed relatively little relationship with the western South Coast stock. Also, because the June–September relationships were with northern St. Pierre Bank and coastally mainly with the Avalon Peninsula and the southern and eastern sides of the Burin Peninsula, the cod were included with the Avalon stock complex.

*Northern local populations.* The more northern local populations, already discussed under the Labrador-East Newfoundland stock, will be briefly considered in relation to the Avalon stock complex. The cod tagged off Fermeuse and Cape Spear intermingled very greatly coastally around the Avalon Peninsula in June–September (Fig. 6FE) with cod of the more western stocks, but with a more easterly and northerly displacement along the Avalon Peninsula. In January–May (Fig. 6CB), many of these cod were part of the wintering and spawning stock or stocks on the slopes of western and northern Grand Bank. Also, in January–May, it is evident that many of these Fermeuse-Cape Spear cod belonged to the Labrador-East Newfoundland stock and were found off Labrador and on the Northeast Newfoundland Shelf. Cod, tagged in five inshore localities of the east coast of Newfoundland, from Baccalieu Island northward to Quirpon (Fig. 6ADG, 5), had a gradually decreasing involvement with the Avalon Peninsula, the Grand Bank, and the Avalon stock complex, and a correspondingly increasing percentage belonged to the Labrador-East Newfoundland stock.

*Trans-Laurentian Channel movements.* In years after the tagging year, the following percentages of total recaptures from the various taggings were taken south of the Laurentian Channel: eastern Grand Bank, 3 (1 fish); Virgin Rocks, 1; western Grand Bank, 0; Cape Pine–Point Lance, 0.2; Halibut Channel 3; Mortier Bank, l. Additionally for the Halibut Channel tagging, 1% of the recaptures in the tagging year were taken across the Laurentian Channel. All trans-Channel recaptures were on the Scotian Shelf, indicating that the crossings occurred mainly across that part of the Channel from Cabot Strait to St. Pierre Bank. Of the

9 recaptured trans-Channel migrants, 7 were taken in January–May and 2 in October–December.

*Discussion and conclusions.* From the location of the winter-spring recaptures (Fig. 14C), the cod of the northwestern slope (59–102 m) of St. Pierre Bank tagged in May 1963 belonged mainly to the western South Coast stock. Cod tagged on the northwestern slope of St. Pierre Bank in February 1961, were mainly recaptured in summer in Placentia Bay (Sidorenko and Postolaky, MS 1963). The results of earlier tagging in 1954 (Templeman, 1974) on St. Pierre Bank, only 10 nautical miles south of the 1963 tagging but in shallower water (50 m) and 2 weeks later, showed that these cod were located in winter-spring mainly on St. Pierre Bank and were St. Pierre Bank stock of the Avalon stock complex. From cod tagging in July 1935, centrally on St. Pierre Bank (Thompson, 1943), in years after the tagging year there were three recaptures in January–May off the southwest coast of Newfoundland and three on St. Pierre Bank (in May). The lack of recaptures from St. Pierre Bank in winter was apparently due to tne absence of a winter fishery on the bank. The cod, however, probably spawned mainly on St. Pierre Bank because in June–September after the tagging year there were 15 recaptures on St. Pierre Bank, 2 in coastal areas immediately north of the bank, 2 in coastal areas south of the Avalon Peninsula and 2–5 (probably 5) on the Grand Bank. Small numbers of cod tagged on the southern part of St. Pierre Bank (Templeman and Fleming, 1962) indicated some migration in March–April to the Halibut Channel and in summer to the Avalon Peninsula. From the distribution of recaptures, the Halibut Channel cod, as part of the St. Pierre Bank-Green Bank-western Grand Bank stock or stocks, form part of the Avalon stock complex (Fig. 13).

The taggings in 1954 off Cape Pine, Cape St. Mary's, and off Fermeuse in the main summering area of the Avalon stock complex (Templeman, 1974), produced a much larger proportion of January–May recaptures on St. Pierre Bank, in the Halibut and Haddock channels, and on the southern Grand Bank than the more recent taggings in 1963–65 in the same areas. This may be attributed to the much greater amount of haddock fishing in these areas in the years immediately following the 1954 tagging than in the later period.

Where spawning times and locations are uncertain it is assumed that spawning and best stock definition occur where the stock is located in January–May. The summering and feeding areas, where most of the cod of the area were tagged, contain local populations, which may be a mixture of stocks. Under the above definition, stocks included in the Avalon stock

complex are: the St. Pierre Bank and Halibut Channel stock or stocks; the Placentia Bay stock; a small St. Mary's Bay stock, related in winter to the deep water of St. Mary's Bay; the stock or stocks on the northwestern slope of the Grand Bank and in the adjacent Avalon Channel, and tentatively the Haddock Channel as an extension of the Avalon Channel. The whole of this area is within the flow of the western branch of the Labrador Current and in or adjacent to the Avalon and St. Pierre channels or their branches.

Recaptures from tagging of various parts of the stock complex have shown enough homing in the summer–autumn feeding season to outline at this season the following local populations, some of which are mixtures of portions of the component stocks of the Avalon stock complex and of other stocks: the Placentia Bay, Point Lance and Cape St. Mary's local populations individually and collectively; northern St. Pierre Bank (Templeman, 1974); southern St. Pierre Bank (Templeman and Fleming, 1962); east coast of the Avalon Peninsula, especially the southern half related to the Fermeuse area; and Virgin Rocks.

It is apparent that the more easterly portions of the western South Coast stock, tagged in spring on Burgeo Bank (Fig. 10BE) and especially off Penguin Islands (Fig. 11EFI) and off Fortune (Fig. 11DG), have many migrants located in summer–autumn on coastal banks and shelves east of the Burin Peninsula among the Avalon stocks, but that by January–May most of these migrants have returned to the western south coast. Some of these eastwardly feeding migrants, which have returned to rejoin the western South Coast stock in its wintering and spawning area, are evident in the western south coast and Gulf recaptures in January–May from the Cape Pine, Point Lance and Mortier Bay taggings (Fig. 14AB).

## Distant Recaptures

Of 15,500 cod recaptured from the 1962–66 taggings, 27 were reported (Fig. 15) from beyond Subareas 2–4. Of these distant recaptures, only 1 was southward in Subarea 5 (on Georges Bank), 18 were from West Greenland, 3 from East Greenland, 3 from
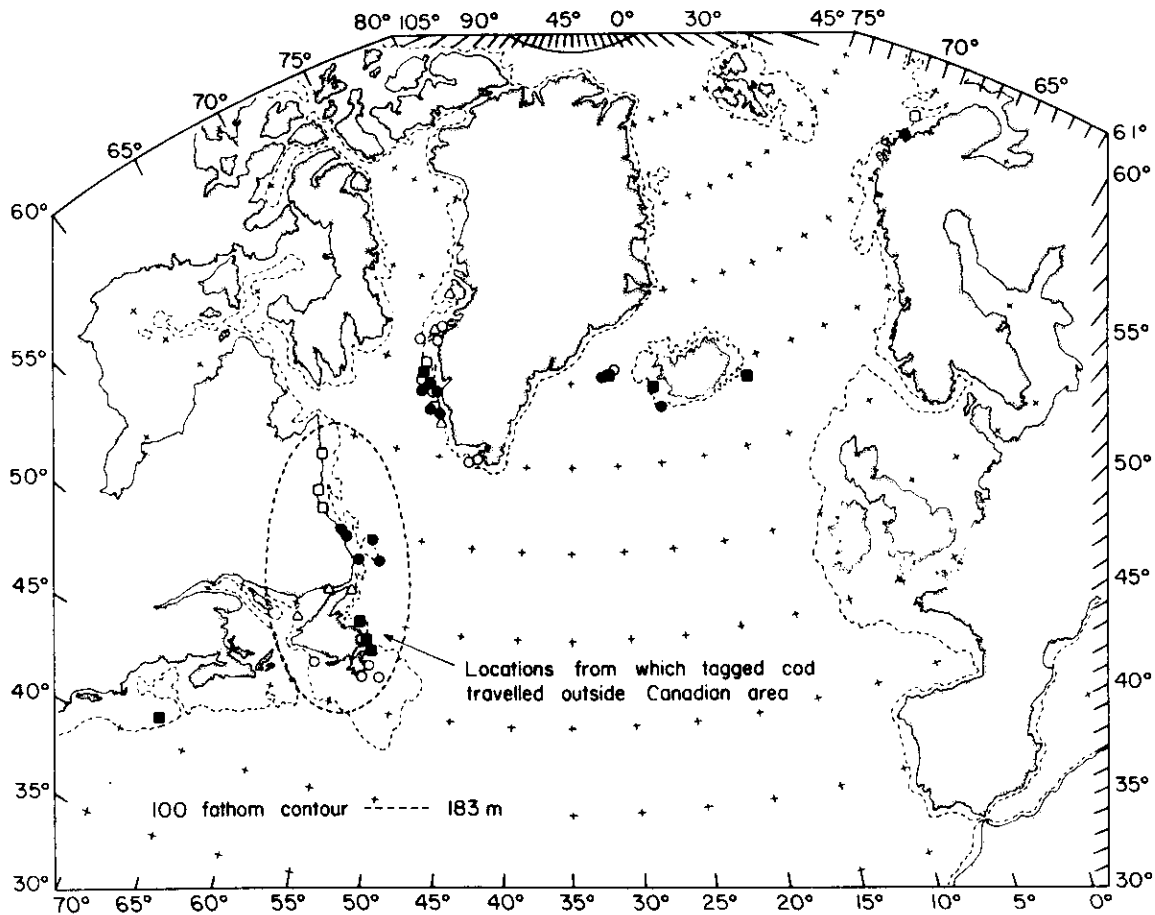


Fig. 15. Records of distant recaptures from the 1962-66 tagging of cod in the Newfoundland and adjacent waters.

Iceland and 2 from the Barents Sea. Eleven of the distant recaptures were tagged off Labrador and 2 others close to Labrador. The average number of days from tagging to recapture was 567 for the 11 recaptures at distances of 415-985 (average 650) nautical miles and 600 for the 11 recaptures at distances of 1,065-1,350 (average 1,230) nautical miles.

Only rarely are transatlantic crossings by cod completely authenticated. However, only apparently authentic records have been used for Fig. 15. Three other reported recaptures in West Greenland were not included from lack of detailed information. None were recaptured in the tagging year, months of recapture were provided for 26 and days for 23 returns. Latitudes and longitudes of recapture were reported for 16 returns, a latitude for another, a bank or similarly definite location or an ICNAF division for 8 others, and southwest coast of Iceland for another. Only 1 fish, reported from West Greenland, lacked a fairly precise location. Reasonable fish lengths at recapture were reported for 18 and weights for 11 including 2 without recapture lengths. Otoliths were returned from 10 of these recaptures. Depths of recapture were reported for 7 cod.

Most of the distant tags were returned by Government fisheries research organizations: Belgium (1), England (1), German Democratic Republic (2), Federal Republic of Germany (10), France (1), Faroe Islands (1) and USSR (4). Two were returned by the Portuguese Fisheries Department. Additionally, 3 were returned from France (2 directly from trawler personnel and 1 from an individual correspondent), 1 directly from a British and two Austrian fishermen fishing by net off southwest Iceland, and 1 from a Norwegian fish plant. The fish recaptured at southwest Iceland was 295 days between tagging and recapture with a minimum travel speed of 4.1 nautical miles per day.

Distant recaptures of Atlantic cod were reviewed by Templeman (1974). (In addition, see Hansen, 1956; Danke, 1967.) The 9 distant recaptures from the 1954-55 Newfoundland taggings represented 0.18% of the total recaptures, compared with 0.17% for the 1962-66 taggings.

## Depths of Recapture

Depths of recapture by month were available for 8,275 tagged cod recaptured in years after the tagging year. The data were combined by five areas showing similar patterns of depth distribution of fish tagged in the area. The pattern for cod tagged off Labrador (Fig. 16A) gave coastal recaptures, mainly in shallow water of 37 m or less, in June-August. There were few recaptures at any season from 74 to 183 m, as the coastal fishing did not as a rule extend to these depths covered by cold water below 0° C for much of the year. The offshore winter-spring fishery in deeper water was mainly betwen 257 and 402 m. (See also Templeman and May, 1965.) There were few deepwater recaptures from June to December, presumably due to the low level of offshore fishing in the area. In December-March, only one fish was recaptured at less than 147 m and in April none shallower than 111 m.

From the coastal tagging off northeastern Newfoundland (Fig. 16B), recaptures in June-August were most numerous in shallow coastal water of 37 m or less and secondarily in 38-73 m, and in September-October were predominantly from the latter depth range. There were few recaptures in any season between 111 and 183 m where a cold water layer (<0° C) existed over most of the year. Deeper water recaptures were mainly from 184-329 m with most from 257-293 m. These were chiefly from offshore trawling in winter-spring and gillnetting and longlining on the slopes of the coastal shelf during the remainder of the year. In December-April, there was only one recapture shallower than 111 m.

For the southern part of the east coast and the northern Grand Bank tagging (Fig. 16C), recaptures in June-August were mainly from shallow water of 37 m or less in the coastal area and around the Virgin Rocks, with smaller numbers from 38-73 m. In September-November, the greatest numbers were from the latter depth. Most of the remaining recaptures were from 74 to 293 m. In January-February, there were no recaptures shallower than 111 m and in March none shallower than 74 m.

From taggings off the eastern part of the south coast (Fig. 16D), most recaptures were from coastal waters during June-September in 37 m or less, and secondarily during May-October in 38-73 m, also mainly coastal but some on the shallower parts of St. Pierre Bank. Winter recaptures were almost all between 74 and 183 m.

Recaptures from tagging in the Gulf of St. Lawrence and off southwestern Newfoundland (Fig. 16E) were mainly from the shallow coastal water of 37 m or less in June-July and from 38 to 73 m in August-October. There were also many recaptures from 74 to 110 m, particularly during May to August. Winter-spring recaptures, predominantly on the southwest coast of Newfoundland near Cabot Strait, were chiefly from 111 to 183 m (147-183 m in March).

Only a few recaptures from any area were reported from deeper than 439 m. It is apparent that, in all areas,

DEPTHS OF RECAPTURE (FATHOMS)

DEPTHS OF RECAPTURE (METRES)

Months: JAN. FEB. MARCH APRIL MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. | JAN. FEB. MARCH APRIL MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.

Fathom depths (left): 0 - 20, 41 - 60, 81 - 100, 121 - 140, 161 - 180, 201 - 220, 241 - 260, 281 - 300

Metre depths (right): 0 - 37, 74 - 110, 147 - 183, 221 - 256, 294 - 329, 367 - 402, 440 - 476, 513 - 549

A. LABRADOR INSHORE and OFFSHORE + FUNK ISLAND BANK

B. BELLE ISLE BANK COASTAL SHELF and INSHORE QUIRPON – BONAVISTA

C. BACCALIEU ISLAND – FERMEUSE INSHORE and GRAND BANK EXCEPT OFF CAPE RACE

D. CAPE PINE – FORTUNE INSHORE + OFF CAPE RACE, ST. PIERRE BANK and HALIBUT CHANNEL

E. SOUTHWEST COAST NEWFOUNDLAND FROM PENGUIN ISLANDS WEST, BURGEO BANK, GULF ST. LAWRENCE

NUMBER OF COD
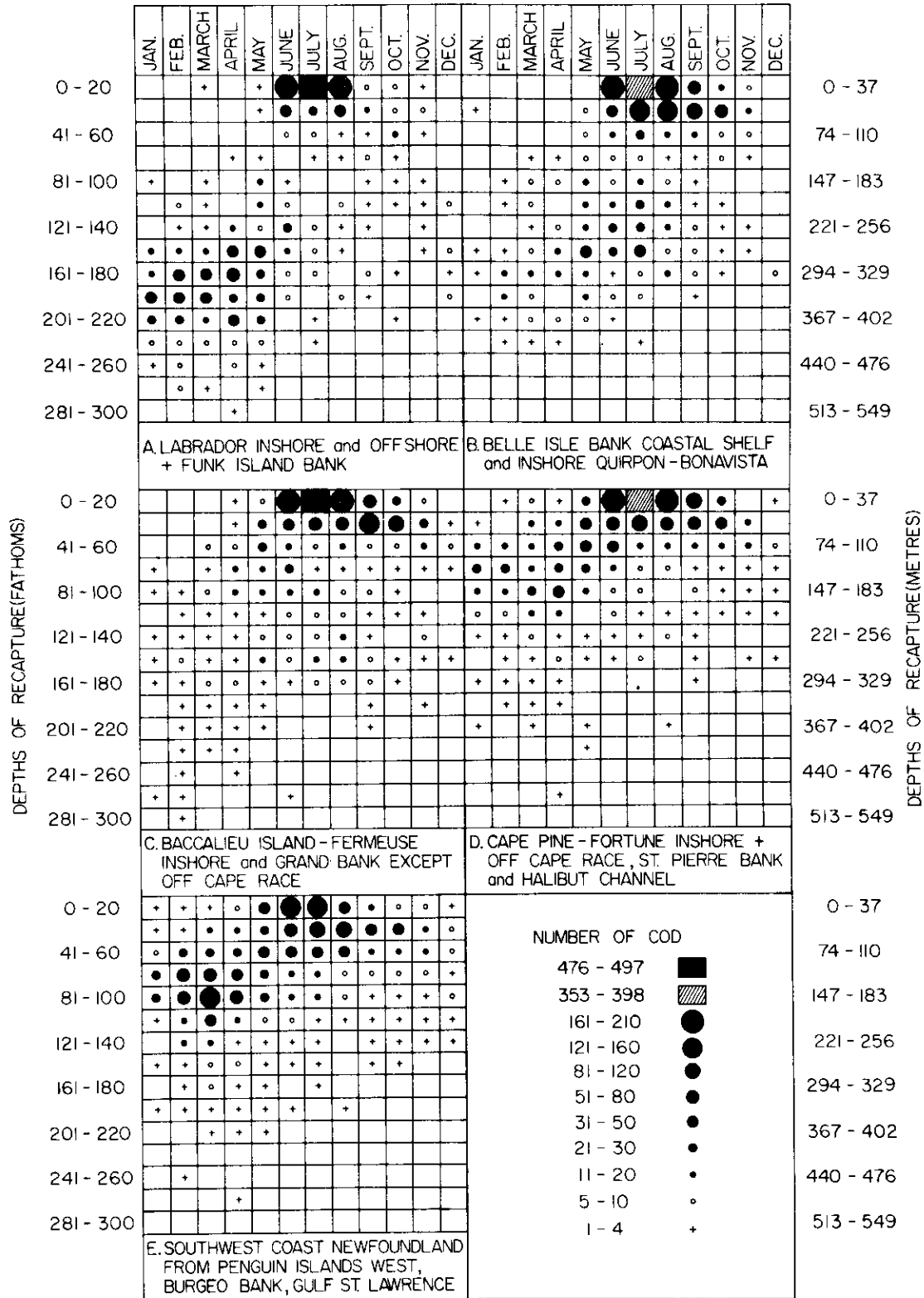| 476 - 497 | ■ |
| 353 - 398 | ▨ |
| 161 - 210 | ● |
| 121 - 160 | ● |
| 81 - 120 | ● |
| 51 - 80 | ● |
| 31 - 50 | ● |
| 21 - 30 | • |
| 11 - 20 | • |
| 5 - 10 | ○ |
| 1 - 4 | + |

Fig. 16. Distribution by month and depth of recapture of cod tagged in Newfoundland and adjacent waters in 1962-66. (Recaptures in the calendar year of tagging are omitted.)

large numbers of cod come to the coastal shallow water areas in summer and that there are relatively fewer cod in shallow waters in August in the warmer water areas (southwest coast of Newfoundland and Gulf of St. Lawrence) than in more northern colder water areas. The northern cod lie at great depths in winter, with those off Labrador lying deeper than those off Northeast Newfoundland. The cod of the south coast of Newfoundland and of the Gulf of St. Lawrence are considerably shallower in winter. Most of the northern Gulf of St. Lawrence stock are in the southern part of Div. 4R and on the southwest coast of Newfoundland in winter-early spring, and the depths at which cod are found in numbers in these areas are directly related to the relative depths of the upper cold water layer. The cod, living deeper in winter-spring in the north, spawn earlier than those living shallower in the south, the former spawning largely in March-April and the latter a month or more later. The Flemish Cap cod, which spawn mainly in March, also reside in winter and early spring and spawn mostly at depths exceeding 300 m (Noskov *et al.*, 1963) and exceeding 350 m (Mankevich and Prokhorov, 1962), although near-bottom temperatures on Flemish Cap are suitable for cod at any depth (Templeman, 1975, 1976).

## Distances Between Tagging and Recapture Positions

### By season in years after tagging year

There was great variation between seasons and between tagging areas in the average distances between places of tagging and recapture (minimal distances travelled; Table 4). For fish tagged relatively close to the coast of Labrador and eastern Newfoundland, mainly in summer and autumn (Table 4ABEG), the January-May tagging-recapture distances were greater than those of June-December. The greatest distances in January-May were by fish tagged in northern Labrador (Saglek-Hopedale), partly because of the relative lack of offshore fishing in Div. 2G and 2H compared with that in Div. 2J which is farther from the tagging locations. Similarly, average distances in summer-autumn were greater for Labrador taggings than for the other coastal taggings of the above group. Distances between tagging and recapture positions from tagging on the east and southeast coasts of Newfoundland were comparatively short (only one-third of the winter-spring distances) in June-September (Table 4EG). This was due to the relatively good homing toward the tagging locations in these areas and the large amount of coastal fishing near the tagging locations.

Most of the offshore tagging on Hamilton Bank and on banks from Hawke Channel to the Grand Bank (Table 4CD) was done in April-May before the offshore spawning concentrations had dispersed to the coast, and some of the Hamilton Bank tagging close to the coastal shelf was done in September when many of the Labrador fish had left the coast. The summer-autumn distances were therefore large and comparable to the January-May distances for the coastally-tagged fish of this area, as most of the offshore-tagged cod returned in summer to their feeding areas near the coast. The January-May distances for these off-shore tagged cod

TABLE 4. Average distances (nautical miles) in different seasons between places of tagging and recapture for cod tagged in the Newfoundland area and vicinity in 1962–66. (Distances measured by the most direct route of possible travel. Adjacent areas with similar patterns of travel distances combined. Recaptures off West Greenland and at more distant localities and in the calendar year of tagging omitted.)

| Recapture periods | Average distances in naut. miles by years free after tagging year (number of fish in parentheses) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 1–11 | | 1–11 | |
| **A. Northern Labrador (inshore, Saglek Bay – Hopedale, Fig. 2)** | | | | | | | | |
| Jan–May | 278 | (73) | 247 | (81) | 258 | (50) | 261 | (204) |
| Jun–Aug | 226 | (135) | 194 | (38) | 137 | (32) | 206 | (205) |
| Sep–Dec | — | | — | | — | | 201 | (10) |
| **B. Southern Labrador (inshore, Cape Harrison–Domino, Fig. 2)** | | | | | | | | |
| Jan–May | 177 | (132) | 151 | (62) | 195 | (57) | 175 | (251) |
| Jun–Aug | 115 | (208) | 115 | (63) | 126 | (86) | 118 | (357) |
| Sep–Dec | — | | — | | — | | 169 | (39) |
| **C. Hamilton Bank (offshore, Fig. 3)** | | | | | | | | |
| Jan–May | 108 | (88) | 127 | (40) | 125 | (28) | 116 | (156) |
| Jun–Aug | 155 | (100) | 155 | (42) | 160 | (25) | 156 | (167) |
| Sep–Dec | — | | — | | — | | 155 | (38) |

TABLE 4. (continued).

| Recapture periods | Average distances in naut. miles by years free after tagging year (number of fish in parentheses) | | | |
|---|---|---|---|---|
| | 1 | 2 | 1–11 | 1–11 |

**D. South side of Hawke Channel, Funk I. Bank, North Cape and eastern Grand Bank (offshore, Fig. 4, 12)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May | 200 | (54) | 241 | (16) | 167 | (21) | 200 | (91) |
| Jun–Sep | 179 | (45) | 160 | (22) | 184 | (23) | 176 | (90) |
| Oct–Dec | — | | — | | — | | 243 | (12) |

**E. Belle Isle Bank, Newfoundland East Coast (Quirpon–Fermeuse) and Virgin Rocks (Fig. 4–6, 13)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May | 166 | (369) | 210 | (184) | 189 | (192) | 183 | (745) |
| Jun–Sep | 57 | (1803) | 71 | (593) | 73 | (556) | 63 | (2952) |
| Oct–Dec | — | | — | | — | | 53 | (331) |

**F. Woolfall Bank, western Grand Bank off Cape Race and Halibut Channel (offshore, Fig. 13)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May | 97 | (41) | 94 | (15) | — | | 108 | (66) |
| Jun–Sep | 122 | (46) | 124 | (16) | 109 | (21) | 119 | (83) |
| Oct–Dec | — | | — | | — | | 90 | (23) |

**G. Cape Pine and Point Lance (inshore, Fig. 14)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May | 96 | (158) | 182 | (39) | 183 | (28) | 121 | (225) |
| Jun–Sep | 43 | (471) | 53 | (148) | 45 | (114) | 45 | (733) |
| Oct–Dec | 73 | (32) | 67 | (19) | 59 | (12) | 69 | (63) |

**H. Mortier Bank, N St. Pierre Bank and Fortune (Fig. 11, 14)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May | 75 | (119) | 133 | (52) | 132 | (31) | 98 | (202) |
| Jun–Sep | 58 | (193) | 68 | (81) | 123 | (44) | 69 | (318) |
| Oct–Dec | 74 | (30) | 50 | (5) | 56 | (12) | 67 | (47) |

**I. Penguin Islands (Fig. 11)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May | 59 | (98) | 77 | (40) | 99 | (31) | 71 | (169) |
| Jun–Sep | 169 | (49) | 169 | (26) | 212 | (24) | 179 | (99) |
| Oct–Dec | — | | — | | — | | 133 | (18) |

**J. Burgeo Bank, Port aux Basques and Rose Blanche (Fig. 10)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May | 51 | (265) | 40 | (116) | 46 | (83) | 47 | (464) |
| Jun–Sep | 180 | (160) | 195 | (55) | 208 | (49) | 188 | (264) |
| Oct–Dec | 152 | (19) | 120 | (13) | 156 | (18) | 145 | (50) |

**K. Gulf of St. Lawrence (Lark Harbour, Fig. 8)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May | 124 | (104) | 116 | (27) | 127 | (32) | 123 | (163) |
| Jun–Sep | 34 | (96) | 28 | (49) | 79 | (28) | 40 | (173) |
| Oct–Dec | 41 | (22) | 20 | (25) | 52 | (14) | 35 | (61) |

**L. Gulf of St. Lawrence (Port au Choix, Centre Bank, Bonne Esperance, and La Tabatiere, Fig. 8, 9)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May | 228 | (372) | 239 | (156) | 219 | (135) | 229 | (663) |
| Jun–Sep | 66 | (302) | 84 | (161) | 59 | (226) | 68 | (689) |
| Oct–Dec | 123 | (30) | 124 | (10) | 96 | (29) | 112 | (69) |

**M. North Shore of Gulf (Cape Whittle Bank, Baie Johan Beetz, Havre St. Pierre, and Seven Islands, Fig. 9)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jan–May [a] | 239 | (168) | 229 | (74) | 232 | (83) | 235 | (325) |
| Jun–Sep [a] | 114 | (137) | 165 | (71) | 137 | (98) | 133 | (306) |
| Oct–Dec | 66 | (31) | 130 | (12) | 107 | (21) | 92 | (64) |

[a] Jan–Apr and May–Sep for Seven Islands

were also large, and larger for the southern than for the northern areas, as many of the fish tagged had evidently come from spawning farther northward and were often caught north of the tagging rectangles in subsequent winter-spring periods.

Recaptures from the tagging along the western part of the south coast of Newfoundland (Table 4IJ) in March-April gave short travel distances in January-May, as the fish returned to their tagging places near the Cabot Strait entrance to the Gulf of St. Lawrence. The fish at Penguin Islands, being farthest east of the group, spread more along the south coast and gave somewhat greater January-May travel distances. Many of the fish, tagged on the western part of the south coast, were of the northern Gulf stock and others were very likely western South Coast stock which grew up as immature fish in the Gulf. Consequently, their migrations back to their summer feeding areas gave long June-December tagging-recapture distances.

From tagging in the Gulf during September-October (Table 4KLM), travel distances were relatively long in January-May, as the fish migrated mainly to Cabot Strait and vicinity and to some extent through the Strait of Belle Isle to deepwater spawning grounds on the slopes off Labrador and Newfoundland. January-May distances were considerably less for the Lark Harbour tagging which was closer to Cabot Strait. June-September travel distances from these Gulf taggings were much less than those of winter-spring, because of the homing of these fish in summer to their feeding abodes near the tagging areas. The homing was stronger (or relatively less fish were caught in the migration movement) for the Lark Harbour-La Tabatiere taggings (Table 4KL) than for taggings on the North Shore of the Gulf from Cape Whittle Bank to Seven Islands (Table 4M).

**By length range and season in years after the tagging year**

Several patterns of tagging-recapture distances emerge from the comparisons of these travel distances for cod of various length ranges (Table 5). For the Labrador inshore and offshore tagging (Table 5ABC), most of the tagged fish were small, few migrated to the Grand Bank, and differences between minimum distances travelled by larger and smaller tagged fish were variable and usually insignificant. From tagging along the east coast of Newfoundland (including the Virgin Rocks and the Belle Isle Bank coastal shelf, Table 5E) and to a lesser degree at Cape Pine and Point Lance (Table 5G), the usual pattern was that the smaller fish travelled considerably farther than the larger sizes in January-May. In June-September and

October-December, the smaller fish, being farthest removed from the tagging area in winter-spring, were also slightly farther away than the larger fish from their tagging locations. Having travelled farther, they were more likely to come to shore farther away and, even if homing to the tagging area, be caught in June-December at greater distances from the tagging location than fish which had travelled less. As will be discussed in more detail later, mature cod of the Labrador-East Newfoundland stock are smaller than those related to the Grand Bank. The distances northward to the Labrador spawning grounds from the southern part of the east coast of Newfoundland are considerably greater than to the spawning grounds on the northern and western Grand Bank. Hence the smaller fish moving northward toward spawning grounds off Labrador and on the Northeast Newfoundland Shelf travel farther than larger fish which tend to migrate toward the Grand Bank for spawning.

For the long migrations in the area where cod were associated with the Gulf of St. Lawrence (June-September for those tagged in spring along the western part of the south coast of Newfoundland, Table 5IJ, and January-May for the fish tagged in autumn in the Gulf, Table 5KLM), the situation was opposite to that on the east coast in that travel distances in these months increased from the smallest to the larger size ranges of cod. The shorter travel distances in January-May for the first group (Table 5IJ) and in June-September for the second group (Table 5KLM) were, however, similar to those of the east coast, in that travel distances were usually greater for the smaller than for the larger fish. In the Gulf and its southwestern Newfoundland approaches, a large proportion of the smaller cod tagged were immature (Fleming, 1960). Trout (1957) showed that the immature cod of the Arcto-Norwegian stock undertook a dummy run of lesser distance than mature cod toward the winter spawning grounds. The smaller cod of the southern Gulf stock did not migrate as far toward and through Cabot Strait in winter as the larger ones (Jean, 1964). Smaller immature cod tagged in Greenland did not migrate the considerable distance to their spawning grounds at Iceland until later years after tagging compared with larger mature fish (Tåning, 1937). Apparently, there was a similar reduction in travel distances for immature northern Gulf cod in their winter migration toward Cabot Strait and, having moved away from the tagging area, a lesser homing tendency back to the tagging area by these smaller cod.

The displacement distances in the first year after the tagging year were usually lower than in the second year at all length ranges.

TABLE 5. Average distances (nautical miles) between places of tagging and recapture for size groups of cod tagged in the Newfoundland area and vicinity in 1962–66 and recaptured in years after the calendar year of tagging.

| Index of area[a] | Recapture periods | Years free | Average distances travelled by size groups (no. of fish in parentheses) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 55–64 cm | | 65–74 cm | | 75–90 cm | |
| A. | Jan–May | 1–11 | 261 | (179) | 257 | (25)[b] | — | |
| | Jun–Aug | 1–11 | 203 | (183) | 228 | (22)[b] | — | |
| B. | Jan–May | 1–11 | 178 | (162) | 167 | (71) | 180 | (18) |
| | Jun–Aug | 1–11 | 124 | (210) | 117 | (112) | 84 | (35) |
| C. | Jan–May | 1–11 | 117 | (133) | 112 | (23)[b] | — | |
| | Jun–Aug | 1–11 | 154 | (115) | 160 | (52)[c] | — | |
| D. | Jan–May | 1–11 | 222 | (66) | 146 | (24)[d] | — | |
| | Jun–Sep | 1–11 | 160 | (55) | 200 | (35)[c] | — | |
| E. | Jan–May | 1 | 181 | (183) | 156 | (118) | 145 | (68) |
| | | 2 | 235 | (87) | 227 | (60) | 125 | (37) |
| | | 3–11 | 218 | (91) | 171 | (65) | 149 | (36) |
| | | 1–11 | 204 | (361) | 178 | (243) | 141 | (141) |
| | Jun–Sep | 1 | 58 | (855) | 59 | (577) | 50 | (371) |
| | | 2 | 79 | (238) | 73 | (196) | 57 | (159) |
| | | 3–11 | 88 | (167) | 76 | (189) | 57 | (200) |
| | | 1–11 | 66 | (1260) | 65 | (962) | 54 | (730) |
| | Oct–Dec | 1–11 | 71 | (123) | 45 | (108) | 39 | (100) |
| G. | Jan–May | 1–11 | 123 | (102) | 128 | (77) | 107 | (46) |
| | Jun–Sep | 1 | 53 | (163) | 41 | (166) | 33 | (142) |
| | | 2 | 59 | (46) | 64 | (53) | 35 | (49) |
| | | 3–11 | 68 | (19) | 42 | (51) | 39 | (44) |
| | | 1–11 | 56 | (228) | 46 | (270) | 35 | (235) |
| H. | Jan–May | 1–11 | 90 | (109) | 104 | (57) | 116 | (36) |
| | Jun–Sep | 1–11 | 71 | (154) | 65 | (95) | 72 | (69) |
| I. | Jan–May | 1–11 | 84 | (74) | 65 | (60) | 52 | (35) |
| | Jun–Sep | 1–11 | 159 | (43) | 174 | (31) | 221 | (25) |
| J. | Jan–May | 1–11 | 47 | (321) | 47 | (143)[e] | — | |
| | Jun–Sep | 1–11 | 182 | (161) | 184 | (81) | 244 | (22) |
| K. | Jan–May | 1–11 | 112 | (95) | 134 | (43) | 146 | (25) |
| | Jun–Sep | 1–11 | 43 | (116) | 35 | (57)[e] | — | |
| L. | Jan–May | 1 | 219 | (187) | 235 | (116) | 242 | (69) |
| | | 2 | 231 | (68) | 245 | (55) | 243 | (33) |
| | | 3–11 | 202 | (37) | 233 | (63) | 214 | (35) |
| | | 1–11 | 219 | (292) | 237 | (234) | 235 | (137) |
| | Jun–Sep | 1 | 77 | (122) | 58 | (98) | 60 | (82) |
| | | 2 | 98 | (53) | 86 | (59) | 66 | (49) |
| | | 3–11 | 82 | (74) | 48 | (77) | 48 | (75) |
| | | 1–11 | 83 | (249) | 62 | (234) | 57 | (206) |
| M. | Jan–May[f] | 1–11 | 224 | (182) | 245 | (108) | 260 | (35) |
| | Jun–Sep[f] | 1–11 | 145 | (158) | 128 | (97) | 108 | (51) |

[a] Index letters A to M refer to areas in Table 4. [b] 65–75 cm. [c] 65–85 cm. [d] 65–80 cm. [e] 65–90 cm. [f] Jan–Apr and May–Sep for Seven Islands area.

## Percentage Recaptures by Length Group of Cod in January–May of Years After the Tagging Year

As demonstrated in Fig. 2, 5 and 6, the local populations of cod tagged in coastal areas of Labrador and the east coast of Newfoundland often diverged quite widely in their winter-spring locations. Some of these divergences correspond with differences in fish length at the time of tagging (Table 6).

From the most northern coastal tagging at Saglek Bay, the range of fish sizes was too small and too few migrated out of the Labrador area in January–May to compare differences by size group.

From the more southern coastal Labrador taggings (Nain to Domino), there was some indication of selective migration of the largest length group from Subarea 2 to Div. 3K and 3L but numbers were small. The coastal taggings on the east coast of Newfoundland from Belle Isle Bank (coastal) and Quirpon to Cape Fogo were all in Div. 3K. From these taggings there was a definite tendency for the recapture in January–May of smaller fish in Subarea 2 off Labrador and larger fish in the more southern divisions (3K and 3L).

TABLE 6.    Percentages of cod, of different length groups when tagged in 1962–66 in various localities of Labrador and eastern Newfoundland, recaptured in various ICNAF divisions in January–May of years after the tagging year.

| ICNAF Div. | Length group (cm) | Percentages of cod recaptured in ICNAF divisions | | | | | No. of recaptures |
|---|---|---|---|---|---|---|---|
| | | 2GHJ | 3K | 3L | 3NO | 3P+4R | |
| 2G[a] | 55–64 | 97 | 2 | 1 | — | — | 87 |
| | 65–74 | 100 | — | — | — | — | 9 |
| 2HJ[b] | 55–64 | 82 | 13 | 2 | — | 2 | 268 |
| | 65–74 | 83 | 12 | 2 | — | 2 | 89 |
| | 75–90 | 68 | 27 | 5 | — | — | 22 |
| 3K[c] | 55–64 | 57 | 20 | 18 | — | 5 | 87 |
| | 65–74 | 39 | 28 | 26 | 1 | 6 | 109 |
| | 75–90 | 28 | 35 | 33 | — | 4 | 72 |
| 3L[d] | 55–64 | 49 | 13 | 31 | 3 | 4 | 121 |
| | 65–74 | 35 | 6 | 50 | 4 | 4 | 68 |
| | 75–90 | 21 | 4 | 65 | 4 | 6 | 48 |
| 3L[e] | 55–64 | 22 | 10 | 62 | 2 | 3 | 126 |
| | 65–74 | 18 | 5 | 66 | 5 | 7 | 62 |
| | 75–90 | — | 6 | 72 | 6 | 17 | 18 |

[a] Inshore Labrador, Saglek Bay.

[b] Inshore Labrador, Nain to Domino.

[c] Belle Isle Bank (coastal shelf) and inshore NE Newfoundland Quirpon to Cape Fogo.

[d] Inshore E Newfoundland, Cape Bonavista and Baccalieu Island.

[e] Inshore SE Newfoundland, Cape Spear and Fermeuse.

From coastal taggings on the southern part of the east coast of Newfoundland (Cape Bonavista to Fermeuse), all in Div. 3L (Fig. 5G, 6ABC), the January–May recaptures in Subarea 2 and Div. 3K (mainly in the northern half) were predominantly of smaller fish. A much higher proportion of the larger fish migrated within Div. 3L, especially to the northern Grand Bank and the Avalon Channel, and to southern and western divisions, rather than to more northern divisions (Table 6). From the Cape Spear and Fermeuse taggings in January–May, 67% of the recaptures at the smallest length range and 95% at the largest were taken in the southern divisions (3L, 3N, 3O and 3P).

In Div. 3L north of St. John's, at St. John's (Cape Spear), on northern Grand Bank, and in a more limited way in Div. 3L south of St. John's (from unpublished data), the smaller fish are mainly of the Labrador-East Newfoundland stock with high vertebral numbers, and the larger fish are more typically of the southern Grand Bank stock or Avalon stock complex with lower vertebral numbers. It is apparent (Table 6) that, from the east coast tagging localities, relatively more small than large cod move to more northern spawning areas off Labrador in Subarea 2, and relatively more large cod migrate to the northern Grand Bank and Avalon Channel in Div. 3L and adjacent southern divisions. Some small and some large fish, however, move to each area to spend the winter-spring or part of it, and some will be caught in other divisons when proceeding to or returning from their actual wintering areas. The smaller number of larger cod from the taggings on the Newfoundland east coast, moving northward to spawning grounds in Subarea 2 and Div. 3K, also belong to the Labrador-East Newfoundland stock.

The Labrador cod become sexually mature at an earlier age and a smaller size than those of the Newfoundland inshore and offshore areas to the south and particularly those of the southern Grand Bank. Maturing earlier, they grow more slowly, and hence the typical adult Labrador fish are small, the mature fish of the southern Grand Bank large and those of the east coast of Newfoundland and the northeast Grand Bank intermediate between them in size (Fleming, 1960).

At first glance, the evidence for a higher proportion of smaller fish than larger moving northward from the Newfoundland east coast local areas toward the Labrador spawning grounds, and for a higher proportion of larger fish than of smaller fish migrating toward spawning grounds on the northwestern and western Grand Bank, does not entirely agree with the other evidence that is best explained by local populations growing up in a nursery area, migrating to spawn in another area and then

returning in the feeding season to the local area. One would think that, unless the immature components of the two stocks have hereditary differences in age at maturity, the fish of both stocks should grow similarly except in the period of absence from the local area. Observations in the spring (presumably also in winter) indicate that there is excellent feeding on capelin on the slopes of the northern and western Grand Bank, where both cod and capelin live at this time just below the cold layer, whereas off Labrador and on the Northeast Newfoundland Shelf at this time the spawning cod lie more deeply and food is very scarce. Spent cod returning to the southeast coast of Newfoundland (St. John's area) in June have fat livers and have recovered from spawning, whereas spent cod upon reaching the coast of Labrador in June or July are reported to have very lean livers. Cod spawning on the Grand Bank also have a relatively short distance to travel from and to the southeast coast of Newfoundland, whereas the distances to the Labrador spawning grounds from these coastal areas are considerably greater. The loss of energy is therefore much greater for the Labrador migrants. It would be expected therefore that, once migration toward their spawning grounds begins, the fish of the Labrador-Newfoundland stock will grow less than those of the northern and western Grand Bank. It is also evident from the migration studies that, apart from cod which grew up in a local area and return to it (for example near the Avalon Peninsula) many cod tagged off Labrador in summer were found in east coast Newfoundland localities in summer-autumn of ensuing years, presumably often migrating there in early summer from offshore areas as part of local schools and in pursuit of capelin (Fig. 2GHI). Similarly, some cod tagged in summer at the Virgin Rocks on the northern Grand Bank moved in ensuing summers (Fig. 13D) into the neighboring coastal areas of southeastern Newfoundland, very likely in pursuit of capelin. These wanderings of fish, which had lived much of their lives in the areas from which they came and to which they should return at spawning time, are responsible for some of the size differences in cod recaptured in these areas.

## Summary of the Migrations and Stock Relationships

### Labrador-East Newfoundland stock

The Labrador-East Newfoundland stock possesses the highest average vertebral numbers of any cod stock in the Northwest Atlantic. This stock spawns offshore mainly in March-May, principally in March-April, in the deep water on the outer part of the continental shelf off Labrador (Subarea 2) and the Northeast Newfoundland Shelf (Div. 3K). There is also some May-July spawning by this stock on the coastal shelves. Although this stock extends southward to the northern slopes of the Grand Bank (Div. 3L), there is no evidence as yet of large-scale spawning by this stock on the Grand Bank or its slopes. The eggs, larvae and fry from the spawning of this stock drift long distances southward with the Labrador Current. Because of the early spawning and the consequent slow embryonic development in cold water, the vertebral averages are high. The fry from the northern spawning settle in areas extending from southern Labrador to the northern Grand Bank and especially, because of the shoreward trend of the Labrador Current, in the bays, harbours and coves along the east coast of Newfoundland in gradually decreasing numbers from the northeast coast to around the Avalon Peninsula. (See also Serebryakov, 1967; Bulatova, 1962.) In and near these areas they grow to sexual maturity, pursuing limited migrations to shallow water in summer and to deeper water in winter. As they approach sexual maturity they move offshore and northward with other mature fish of the Labrador-East Newfoundland stock against the Labrador Current in late autumn and/or early winter to the vicinity of the spawning areas from which they were derived. The northern components of the stock usually spawn farther northward than the southern components, but there is considerable overlapping in the spawning or at least the wintering areas. It is strongly indicated, from the winter-spring returns after the tagging year from offshore taggings on the Labrador and Northeast Newfoundland shelves, and from the rapid southward migrations after spawning off northern Labrador (Postolaky, 1966; Danke, 1967), that the actual spawning areas of many of the recaptured fish are farther north than they appear to be from their winter-spring recapture locations. The USSR egg-collection data (Serebryakov, 1967) indicate that the greatest spawning of the Labrador-East Newfoundland stock is off northern Labrador (Div. 2G).

After spawning, the cod of the Labrador-East Newfoundland stock move southward and westward with the Labrador Current, homing especially but with considerable straying, toward the feeding areas where they grew up as immature fish, especially to the Labrador coast, the northeast coast of Newfoundland and in gradually declining numbers along the east coast of Newfoundland to and around the Avalon Peninsula. Similar patterns of migration in relation to spawning and feeding occur in other large cod stocks: the Icelandic stock in relation to West Greenland (Tåning, 1937; Hansen, 1949), and the Arcto-Norwegian stock (Trout, 1957). As the surface water becomes warmer, many of the cod, especially the smaller, migrate to the shallow coastal and bank areas and others, especially the larger, to the fringes of the coastal shelves below the cold-water layer

(Templeman and Fleming, 1956, 1963b). The main coastward migration in June coincides with the spawning migration of the capelin to shallow water. Coastward cod migrations, over bottom water often below -1°C, appear to be pelagic as are the capelin migrations. Within the shallow coastal areas, the cod often pursue the capelin into very shallow water (Templeman, 1948, 1965a). Some cod, especially from localities in and near the Strait of Belle Isle, leave the Gulf of St. Lawrence in autumn through this strait, spawn with the Labrador-East Newfoundland stock in spring, and return in early summer to the Gulf. These are Labrador-East Newfoundland stock, presumably in part developing as immature fish in the Gulf from eggs larvae and fry of this stock entering the Gulf mainly on its northern side where the current is predominantly inward. Also, some of the Labrador-East Newfoundland stock presumably wander into the Gulf through the Strait of Belle Isle in search of food or pursue capelin into the Gulf in June. There is evidence of the occurrence of high-vertebral-count cod of the Labrador-East Newfoundland type on the southern side of the Strait of Belle Isle and adjacent localities in the Gulf.

### The northern Gulf-western South Coast stock complex

The northern Gulf stock spawns in the Gulf of St. Lawrence north of the Laurentian Channel. In winter, this stock migrates toward Cabot Strait and some fish move through the strait and along the south coast of Newfoundland, a small percentage migrating as far east as Fortune Bay and the northwestern slope of St. Pierre Bank but not usually beyond these areas. Return to the Gulf through Cabot Strait is mainly accomplished by the end of April, and spawning occurs in the Gulf in March–September but principally in May–early June. The relative quantities spawning in different places in the northern Gulf are not known, as catches in the northern Gulf are usually very low in April and May. Beginning in June, there are large concentrations of cod of this stock in and near the Strait of Belle Isle. The northern Gulf stock evidently retains a sufficient proportion of its eggs and larvae in the northern Gulf to maintain the stock, and the water-current eddies in the northern Gulf are presumably responsible for this egg and larval retention. As was indicated for the Labrador-East Newfoundland stock, there is considerable homing of the local populations of the northern Gulf stock to their summer-autumn feeding areas.

There are also cod which, from April to June but principally in May, spawn in relatively small numbers, compared with those spawning in the northern Gulf, on the coastal banks and slopes off southwestern Newfoundland. These cod are therefore western South Coast stock, and, because they intermingle in winter

with northern Gulf cod emerging from the Gulf and in summer with northern Gulf stock during feeding migrations, they constitute a part of the northern Gulf-western South Coast stock complex. The western South Coast stock extends as far east as Penguin Islands and Fortune Bay as a spawning stock and part of it moves eastward along the south coast of Newfoundland in summer feeding migrations. From west to east, an increasing proportion of the cod tagged in spring off the western part of the south coast of Newfoundland remained in summer off the south coast, with fewer and later migrants to the Gulf.

The cod remaining on the western part of the south coast in summer (e.g. near Penguin Islands) presumably settled there as young from spawning of the western South Coast stock. Other eggs and larvae from spawning of this stock must flow with the prevailing current into the northern Gulf of St. Lawrence. As for the Labrador-East Newfoundland stock and other well-documented large cod stocks (e.g. Arcto-Norwegian and Iceland-West Greenland), it is to be expected that the young would grow to maturity in the general vicinity of their settling areas and then return to spawn off southwestern Newfoundland. After spawning they would be expected to home back in the feeding season to the areas of the Gulf where they grew up. The larval drift and the migration patterns of adults to spawning and feeding grounds, partly factual and partly hypothesized, are similar to those for large cod stocks generally, as mentioned earlier.

Why do cod of the northern Gulf stock move to or through Cabot Strait in winter? The migration is not for spawning, because by definition and by observation this stock spawns in the northern Gulf, but rather a retreat in advance of the ice which first forms in the western and northern Gulf areas and eventually covers most of the Gulf. Usually the northern part of Cabot Strait and the western part of the south coast of Newfoundland remain ice free. The mature cod of the southern Gulf stock also move toward or through Cabot Strait on the southern side of the Laurentian Channel in winter, the mature and maturing fish moving farther eastward than the immatures, and return to the southern Gulf in spring and spawn (Jean, 1964; Martin and Jean, 1964). Similarly, large quantities of mainly mature herring of the southern Gulf spend the winter in the fjords along southwest Newfoundland and return in spring to the southern Gulf where they spawn (Hodder and Winters, MS 1970; Winters, MS 1971; Beckett, MS 1971; Winters and Hodder, 1975). Templeman and Fleming (1962) concluded that the Gulf cod in their migrations to and from Cabot Strait are responding to hereditary patterns which over the period of development of these stocks have been advantageous for their survival and

that the same is presumably true for the migrations of all major fish stocks. All of the migrations from the Gulf in winter occur in advance of surface ice formation. Outside the Gulf, the fish live and feed in relatively shallower water and generally under better light conditions than if they had remained in the Gulf in winter. Baggerman (1957) found in the three-spined stickleback (*Gasterosteus aculeatus*) that, under light intensities of 15 and 25–30 foot candles, the fish matured more rapidly under the higher light intensity. The favorable effect for cod in advancing the time of maturity may be that the peak spawning period coincides more frequently with the period of plankton blooms and hence, on the average, allows more favorable survival. On the other hand, the mature cod of the Labrador and Flemish Cap areas live deeper in winter and spawn earlier than those of the northern Grand Bank.

Minet (MS 1976), in the winter of 1975, found larger amounts of food, especially capelin, in the stomachs of cod on Rose Blanche and Burgeo banks (Subdiv. 3Pn and 3Ps) than in those of Div. 4R and suggested that the migration from the Gulf may be related to feeding. It is possible that capelin also move southward toward Cabot Strait in winter and that cod may follow them.

## The Flemish Cap stock

The cod stock on Flemish Cap, being isolated from those of the Grand Bank by the deep Flemish Channel, spawn in deep water on the southwestern part of the bank in March to May, but mainly in March. When water current conditions are favorable, eggs and larvae are retained by a clockwise eddy circling the bank (Serebryakov 1967; Templeman, 1976). Usually the colder part of the Labrador current flows southward along the eastern slope of the Grand Bank and does not affect the Flemish Cap, but in certain years (such as 1972) cold Labrador Current water reaches the Cap and must take with it some cod larvae from the northeastern Grand Bank (Templeman, 1975). Although most spawning of Flemish Cap cod is in March–April, coincident with the spawning of the Labrador-East Newfoundland stock, temperatures over the Cap at this time are considerably higher than on the Labrador and Northeast Newfoundland shelves. Consequently, Flemish Cap cod have lower vertebral numbers than those of the Labrador-East Newfoundland stock.

## The Avalon stock complex

Cod of the Avalon stock complex are delimited by their spawning places on St. Pierre Bank, including the Halibut and Haddock channels, on the northwestern and western slopes of the Grand Bank, including the Avalon Channel, and presumably in Placentia and St. Mary's bays. These stocks partly intermingle in summer-autumn on the coastal banks and shelves of the Avalon and St. Pierre channels, especially around the Avalon Peninsula where they mix with the feeding schools of the southern part of the Labrador-East Newfoundland stock. There is also some intermingling at this time and area with eastwardly migrating cod of the western South Coast stock and with westward migrants from the southern Grand Bank stock. Some cod of the Avalon stock complex migrate in summer to the neighboring shallow-water parts of the Grand Bank, especially the Virgin Rocks, while others remain on St. Pierre Bank or the western Grand Bank.

Most of the tagged cod, related to the east coast of Newfoundland during the summer-autumn feeding season and migrating in significant numbers to spend the winter-spring period and presumably spawn on the northern slopes of the Grand Bank (Fig. 5, 6), were usually located west of the North Cape of the Grand Bank in May and June. Eggs and larvae from these cod, spawning later than the Labrador-East Newfoundland stock and in more southern areas such as Grand Bank and St. Pierre Bank, will develop more rapidly at higher temperatures and have a much shorter pelagic period than those from the earlier spawning off Labrador. Eggs and larvae from cod spawning on the western and northwestern slopes of the Grand Bank in April–June will usually drift southwestward with the coastal branch of the Labrador Current allowing the fry to settle on the coastal shelves and banks around the Avalon Peninsula. Settling may also occur from the slow southward current over the western shallow area of the Grand Bank and some fry may reach St. Pierre Bank. They will grow up in these nursery areas and, when mature, move toward the spawning areas from which they originated on the northwestern Grand Bank, homing back to their feeding areas after spawning. The winter migration to the northwestern and northern Grand Bank occurs mainly from coastal waters between Cape Fogo and Fermeuse (Fig. 5, 6), from the Virgin Rocks (Fig. 13) and from the southern Avalon Peninsula area (Fig. l4).

Larvae of cod spawning on St. Pierre Bank, the southern slope of Green Bank and in the channels between these banks may be retained in these areas by slow circular currents, but this has yet to be demonstrated. However, larvae and fry of St. Pierre Bank haddock, spawning a little later than the cod of the area, are retained on the bank in large numbers in favorable years (Templeman and Bishop, 1979a, 1979b), and similarly cod eggs, larvae and fry from spawning on St. Pierre Bank should be retained. Judging by the success of the fishery for cod on the bank and their year-class success, cod are more successful than haddock in populating the bank with

young fish (Pinhorn, 1971). The prevailing south-westerly winds should cause some St. Pierre Bank larvae to settle as fry on the coastal banks and westward slopes of the Avalon Channel (see also Serebryakov, 1967). Also, some larvae from St. Pierre Bank and the Avalon Channel should move westward toward Cabot Strait with the prevailing current.

## The southern Grand Bank stock

The southern Grand Bank stock, described by Templeman (1962b) as having low average vertebral numbers in contrast with high vertebral numbers of the Labrador-East Newfoundland stock, has its main base in Div. 3N and 3O. The portion least diluted by other stocks occurs toward the tail of the Grand Bank, most distant from the coast and from the northern and western parts of the bank. In the northern and western parts of Div. 3O, there is some intermingling with stocks of the Avalon Stock complex. Cod with low vertebral numbers characteristic of this stock are found over the surface of the Grand Bank in Div. 3LNO in summer, and are found at all seasons in the vicinity of schools of the high-vertebral-count Labrador-East Newfoundland stock on the northeastern Grand Bank in Div. 3L, where separate schools of cod have been noted with strongly contrasting average vertebral numbers at different depths. In this paper, taggings on the eastern Grand Bank (Fig. 12), near the Virgin Rocks, on the western Grand Bank, and in Halibut Channel (Fig. 13) showed the greatest relationship with the southern Grand Bank stock. The taggings on the southern Grand Bank (Div. 3N and 3O) (Thompson, 1943; Templeman and Fleming, 1962; Templeman, 1974; and Fig. 12BEH) show that cod of the southeastern Grand Bank (Div. 3N) are mainly related to the Grand Bank itself. Small numbers migrate from the southeastern Grand Bank to the coast, mainly around the Avalon Peninsula, and to St. Pierre Bank. It is also evident from the cod taggings by Thompson (1943) and Templeman and Fleming (1962) that the cod in Div. 3O have a greater relationship with the neighboring coastal waters of Newfoundland than cod in the more distant Div. 3N. This is also demonstrated by the strong relationship with the coast as well as with the Grand Bank in summer-autumn of cod tagged on the western Grand Bank immediately north of Div. 3O (Fig. 13EG). It is also indicated strongly by the distribution of cod infected with adult *Lernaeocera branchialis* (Templeman *et al.*, 1976) that cod in the northern and western parts of Div. 3O have a much greater relationship with the coast than cod living farther to the southeast on the Grand Bank.

The southern Grand Bank stock in Div. 3N and 3O and the portions of this stock on the northeastern Grand Bank spawn mainly in April–June, and usually from the latter half of April to early June. Egg-development in warmer surface water, from the later spawning and more southern location, produces lower vertebral numbers in the cod of the southern Grand Bank stock than in those of the more northward and earlier spawning Labrador-East Newfoundland stock.

Eggs and larvae from cod spawning on the northeastern and eastern slopes of the Grand Bank should drift southward around the bank and move more slowly over the bank in the eastern branch of the Labrador Current. Many of these larvae, and those produced by spawning on the southern and southwestern Grand Bank, in favorable years should be retained on this bank for the relatively shorter pelagic period than the more northern Labrador-East Newfoundland stock, and by the slow current speed. (Also, see Serebryakov, 1967). Larvae and fry of haddock, which spawn on the southern Grand Bank a little later than the cod of the area, are retained in large numbers on the southern part of the bank in favorable years (Templeman *et al.*, 1978a, 1978b). Cod larvae and fry from spawning on the southern part of the Grand Bank should be similarly retained. Cod and haddock year-class success on the southern Grand Bank usually occurred in the same years (May, 1965).

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# APPENDIX

APPENDIX. TABLE 1. Tagging localities, rectangles, positions, dates, depths, and numbers of cod tagged, related to sections of Fig. 2–14.

| Tagging localities and (rectangles) | Positions | | Dates of tagging | Depths where fish caught (m) | Number of fish tagged | Figure references |
|---|---|---|---|---|---|---|
| | Lat. N | Long. W | | | | |
| Saglek Bay (E6) | 58°30′ | 62°45′ | 5–6 Aug 1964 | 6–18 | 1,152 | 2A,E |
| Off Nain (F9) | 56°32′ | 61°39′ | 4–24 Aug 1962, 1963 | 7–46 | 1,472 | 2B,F |
| Off Hopedale (G l2) | 55°27′ | 60°12′ | 2–19 Aug 1962, 1963 | 15–46 | 1,120 | |
| Off Cape Harrison (K13) | 54°55′ | 57°55′ | 12–14 Aug 1963 | 18–37 | 1,152 | 2C,G,I |
| Off Smokey (Kl4) | 54°26′ | 57°14′ | 22–25 Jul 1964 | | 1,152 | |
| Domino (M16) | 53°29′ | 55°47′ | 28–30 Jul 1962 5–9 Aug 1963 | 6–29 | 1,536 | 2D,H,I |
| W Hamilton Bank (M15) | 53°51′ 53°58′ | 55°15′ 55°25′ | 12–21 Sep 1962 | 139–194 | 1,088 | 3A,D,G |
| NE Hamilton Bank (N13) | 54°49′ 54°53′ | 54°48′ 55°00′ | 20–22 Apr 1966 | 165–210 | 1,120 | 3B,C,E,F,H,I |
| SE Hamilton Bank (P15) | 53°30′ 53°35′ | 53°11′ 53°20′ | 10–14 May 1964 | 194–210 | 1,152 | 3C,E,F,H,I |
| S of Hawke Channel (P17, P18) | 52°29′ 52°39′ | 53°15′ 53°20′ | 15–16 May 1964 | 183–241 | 768 | 4A,C,F |
| Belle Isle Bank (N18) | 52°01′ 52°05′ | 54°26′ 54°35′ | 23–26 Sep 1962 | 161–183 | 736 | 4D,G |
| Funk I. Bank (R20, S20) | 51°21′ 51°24′ | 51°00′ 51°06′ | 17–18 May 1964 | 216–236 | 384 | 4B,E,H |
| Off Quirpon (M19) | 51°36′ 51°39′ | 55°21′ 55°25′ | 11–23 Aug 1962 | 62–88 | 768 | 5A,D |
| Off Grey I. (M20, M21) | 50°56′ 51°10′ | 55°30′ 55°40′ | 8–19 Nov 1963 | 33–119 | 1,152 | 5B,E |
| Off Cape Fogo (P23) | 49°42′ 49°47′ | 53°54′ 53°59′ | 25 Oct–2 Nov 1963 | 22–66 | 1,152 | 5C,F |
| Off Cape Bonavista (Q25) (P25) | 48°40′ 48°46′ | 52°57′ 53°05′ | 1–13 Oct 1962 14 Oct–2 Nov 1964 | 59–81 37–106 | 384 1,152 | 5G,H,I |
| Off Baccalieu I. (Q26) | 48°11′ 48°13′ | 52°47′ 52°48′ | 3–25 Nov 1962, 1964 | 26–113 | 1,920 | 6A,D,G |
| Off Cape Spear (Q28) | 47°27′ 47°30′ | 52°37′ 52°38′ | 22 Nov –18 Dec 1965 | 37–146 | 1,152 | 6B,E,H |
| Off Fermeuse (Q29) | 46°44′ 46°52′ | 52°50′ 52°54′ | 5–25 Oct 1963 | 18–110 | 2,304 | 6C,F,I |
| Gulf Area A (J23, J24) | 49°23′ 50°00′ | 58°10′ 58°39′ | 20–21 Jan 1962 | 73–137 | 768 | 7A,D,G,J |
| Gulf Area B (H24) | 49°05′ | 59°06′ | 22 Jan 1962 | 106–112 | 384 | 7B,E,H,K |
| Gulf Area C (H26) | 48°23′ | 59°26′ | 23 Jan 1962 | 110–125 | 448 | 7C,F,I,L |

APPENDIX TABLE 1. (continued)

| Tagging localities and (rectangles) | Positions | | Dates of tagging | Depths where fish caught (m) | Number of fish tagged | Figure references |
|---|---|---|---|---|---|---|
| | Lat. N | Long. W | | | | |
| Off Lark Harbour (J24) | 49°07'<br>49°13' | 58°20'<br>58°34' | 8-19 Nov 1964 | 37-88 | 768 | 8A,B,C |
| Off Port au Choix (K21) | 50°50' | 57°20' | 31 Aug-23 Sep 1964 | 46-106 | 768 | 8D,E,F |
| Centre Bank (L19) | 51°30'<br>51°37' | 56°25'<br>56°36' | 27 Sep-1 Oct 1962 | 51-59 | 768 | 8G,H,I |
| Off Bonne Esperance (K20) | 51°22'<br>51°26' | 57°27'<br>57°37' | 27 Sep-3 Oct 1963 | 37-102 | 1,152 | 8J,K,L |
| Off La Tabatiere (J21) | 50°45' | 58°45' | 17-25 Sep 1963 | 18-91 | 1,152 | 9A,B,C |
| Cape Whittle Bank (G23) | 49°47'<br>49°50' | 60°06'<br>60°08' | 23-26 Oct 1962 | 86-88 | 768 | 9D,E,F |
| Off Baie Johan Beetz (D22)<br>Havre St. Pierre (E22) | 50°00'<br>50°07' | 63°00'<br>63°36' | 11-14 Sep 1963<br>29 Sep-5 Oct 1964 | 51-77<br>66-102 | 384<br>384 | 9G,H,I |
| Off Seven Islands (A22) | 50°06' | 66°28' | 8-13 Oct 1964 | 44-104 | 1,152 | 9J,K,L |
| Burgeo Bank (K28) | 47°11' | 52°44' | 30 Mar-7 Apr 1963 | 66-117 | 1,152 | 10A,B,C,D,E,F |
| Port aux Basques (H27)<br>Rose Blanche (J27) | 47°33'<br>47°34' | 59°11'<br>58°44' | 14-26 Mar 1963<br>20-25 Mar 1963 | 102-139<br>91-155 | 1,536<br>768 | 10G,H,I,J,K,L |
| Off Fortune (M28) | 47°04' | 55°54' | 23 Oct-11 Nov 1965 | 46-110 | 384 | 11A,D,G |
| Off Penguin Islands (L28) | 47°22' | 57°02' | 30 Mar-13 Apr 1963 | 59-165 | 1,152 | 11B,C,E,F,H,I |
| Flemish Cap (Y29) | 46°44'<br>47°00' | 44°40'<br>45°00' | 30 May -3 Jun 1962<br>5-11 Jul 1964 | 124-179 | 774 | 12A,D,G |
| E Grand Bank (U31) | 45°40'<br>45°46' | 48°21'<br>48°28' | 25-27 Apr 1964 | 161-214 | 768 | 12B,E,H |
| N Grand Bank (S26) | 48°15'<br>48°26' | 50°03'<br>50°16' | 18-20 Apr 1964<br>20-21 May 1964 | 177-192 | 1,536 | 12C,F,I |
| Virgin Rocks (S30) | 46°28' | 50°49' | 6-8 Jul 1963 | 27-55 | 1,152 | 13A,D |
| Woolfall Bank (R28)<br>Off Cape Race (Q29, Q30) | 47°07'<br>46°03'<br>46°35' | 51°39'<br>52°14'<br>52°36' | 28-30 Apr 1964<br>4-13 May 1965 | 102-126<br>70-155 | 1,152<br>768 | 13B,E,G |
| Halibut Channel (M32) | 45°17'<br>45°25' | 55°04'<br>55°12' | 16-20 Jan 1963<br>22-25 Jan 1965 | 128-157 | 863 | 13C,F,H,I |
| Off Cape Pine (P29)<br>Off Point Lance (N29) | 46°31'<br>46°45' | 53°33'<br>54°03' | 6 Nov-12 Dec 1963<br>14-20 Sep 1965 | 49-88<br>37-60 | 1,152<br>1,152 | 14A,D,G |
| Mortier Bank<br>(N28, M28, M 29) | 47°00'<br>47°03' | 54°58'<br>55°01' | 21 Sep-5 Oct 1965 | 15-117 | 384 | 14B,E |
| NW St. Pierre Bank<br>(L29, K29) | 46°41'<br>46°47' | 56°57'<br>57°09' | 3-24 May 1963 | 59-102 | 1,152 | 14C,F,H,I |

# Mesh Selection of Silver Hake, *Merluccius bilinearis*, in Otter Trawls on the Scotian Shelf with Reference to Selection of Squid, *Illex illecebrosus*

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## Abstract

Mesh selection studies on silver hake, *Merluccius bilinearis*, and the short-finned squid, *Illex illecebrosus*, were carried out on the Scotian Shelf in 1977 during joint Canada-Cuba and Canada-USSR research vessel cruises. The 50% retention lengths of silver hake were 185, 216 and 260 mm for codend mesh sizes of 40, 60 and 90 mm respectively for the Canada-Cuba study, and were 226, 210 and 410 mm for codend mesh sizes of 60, 70 and 120 mm respectively for the Canada-USSR study. Yield-per-recruit analyses of available data indicated that a 30% increase in fishing effort would be required to maintain current catch levels if the mesh size is increased from 60 to 90 mm and that approximately 100% more effort would be required if the mesh size was increased from 60 to 120 mm. In the first case, the long-term yield may increase depending on the natural mortality and partial recruitment factors used, whereas in the second case the long-term yield would likely decrease.

The 50% retention lengths for squid were 140, 180 and 240 mm for codend mesh sizes of 60, 70 and 120 mm. However, due to squid morphology and rapid seasonal growth, the escapement of squid may best be analyzed in terms of percentage escapement by weight at frequent intervals during the season. Escapement would be high in June and July, declining to about 30% or less from August to November. The use of 90-mm mesh codends would consequently result in relatively low catch rates during the early part of the season with increased yields later in the year as the squid grow to maximum size.

A major consideration relating to the codend mesh size appropriate for the silver hake and squid fisheries is its effect on by-catches of other commercially-important species (i.e. cod, haddock, etc.), which are currently protected by a 130-mm mesh regulation. The use of 90-mm mesh codends is suggested as an interim measure for the silver hake and squid fisheries to provide the opportunity to test population response not only in these species but also in other commercially-important groundfish species.

## Introduction

Selection experiments to design 'savings gear' were begun nearly a century ago (Fulton, 1893). Many original studies were attempts to design fishing gear to reduce the destruction of immature fish and although some of these were effective modifications (Ridderstad, 1915; Pettersson, 1925; Buchanan-Wollaston, 1929) they were generally too cumbersome for commercial use because of their rigid frames. Cassie (1955) pointed out that an ordinary trawl with no further modifications than an increased mesh size in the codend can act as an effective 'savings gear'. For this reason the present studies concentrated on comparing the selection characteristics of various mesh sizes of codends made of kapron, a polyamide material used extensively by the USSR and Cuban fleets in the silver hake and squid fisheries.

Selection studies are important for two reasons: first and foremost, they can be used as management tools to reduce the destruction of undersized fish; secondly, such studies allow biologists, who can rarely study a fish population directly, to use fisheries data in the evaluation of assessment techniques and thus provide a better understanding of the population dynamics of a species.

Life history studies in the New England and Nova Scotia areas show that silver hake grow rapidly during the first year of life (Hunt, 1978; ICNAF, MS 1976). Spawning occurs between April-May and October-November with the peak occurring in June-July (Sauskan, MS 1964; Sarnitts and Sauskan, 1977). The larvae hatch from pelagic eggs and do not move to the bottom until they are approximately 4 cm in length (Nichy, 1969). Approximately 10% of the male population become mature in the first year (about 20 cm in length) and 98% in the second year, while 3% and 80% of the females become mature in the first and second years respectively (Doubleday and Halliday, 1976).

During the period from March to October, a large silver hake fishery, conducted primarily by USSR stern trawlers (>2000 gross registered tons), takes place on the Scotian Shelf. Catches have been variable but have averaged slightly less than 100,000 metric tons per

annum over the last decade. In recent years, other countries, most notably Cuba, have also participated in the silver hake fishery. In addition, some exploratory fishing by Canadian vessels has been carried out. Historically, the USSR fishing fleet used 40 mm mesh codends (Anon., MS 1976), often with 40-mm liners. The modal length of the commercial catch of silver hake, according to USSR statistics in ICNAF Sampling Yearbooks, ranged from 28 to 30 cm (ICNAF, 1962-72). This modal length range represents fish of approximately 2 to 3 years of age. The small-meshed codends (40 mm) used prior to 1977 retained most fish greater than 15 cm (age 1+). Because the numbers of 2- and 3-year-olds in the catch were greater than the number of 1-year-olds (Doubleday and Hunt, MS 1977), there must be some selection in the fishery as a result of availability of juveniles.

A conservation measure agreed upon in December 1976 (ICNAF, 1977) limited fishing landward of the 'small mesh gear line' shown in Fig. 1 to midwater trawls with a minimum mesh size of 60 mm and to bottom trawls with a minimum mesh size of 130 mm. The aims of the measure were to reduce any undesirable bycatch of juveniles of other commercially important species (particularly cod) and, if possible, to increase the maximum sustainable yield of the silver hake fishery. The regulation was based upon selectivity data available only from studies conducted in ICNAF Subarea 5 by Clark (1963) and Jensen and Hennemuth (1966), using codend materials different from those currently used in Subarea 4. The purpose of the two joint mesh selection studies undertake in 1977 by Canada and Cuba (August) and by Canada and USSR (October-November) was to quantify the effects of this new measure upon the silver hake fishery.
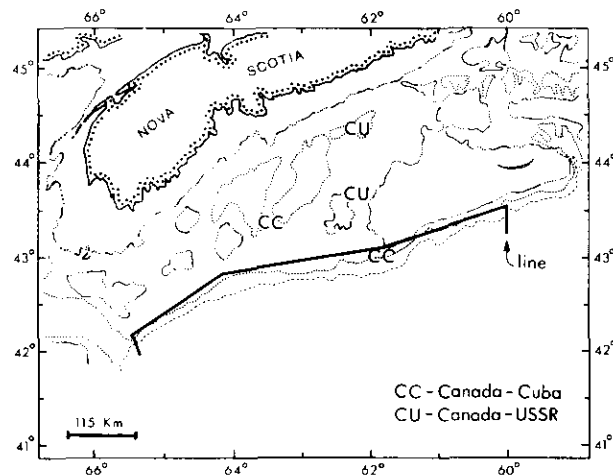


Fig. 1. Map showing the "small mesh gear line" and the approximate locations of the joint Canada–Cuba and Canada–USSR mesh selection studies in 1977.

## Methods

Specifications of the vessels and gears used are presented in Table 1, and a comparison of the commercial mesh sizes (manufacturers' specifications) and the average measured mesh sizes for both the cover and codends used in the studies are given in Table 2. The codend mesh sizes referred to throughout the text are those of the manufacturers' specifications. Figure 1 indicates the approximate locations of the two study areas in ICNAF Division 4W in relation to the 'small mesh gear line'.

On the USSR vessel, R/V *Foton*, the topside cover was fitted to the codend according to ICES specifications (ICES, 1964). The general construction and dimensions of this gear are shown in Fig. 2. On the Cuban vessel, R/V *Isla de la Juventud*, exact details of the attachment of the cover are not available in the cruise reports (Anon., MS 1977; Hare, MS 1977) although Hare (pers. comm.) has recalled that the cover was attached close to the codend. This problem

TABLE 1. Specifications of research vessels and gears used in the joint mesh selection studies in 1977.

| | Cuba | USSR |
|---|---|---|
| | R/V *Isla de la Juventud* | R/V *Foton* |
| Overall length (m) | 70.3 | 54.6 |
| Beam (m) | 12.5 | ..... |
| Displacement — net (tons) | 1,556 | 660 |
| — gross (tons) | 2,200 | 987 |
| Engine power (HP) | 2,400 | 800 |
| Speed (knots) | 14.5 | 10 |
| Type of vessel | Stern trawler (freezer) | Side trawler |
| Type of trawl | Bottom trawl[a] | Bottom trawl |
| Footrope length (m) | 57.9 | 31.4 |
| Headrope length (m) | 41.6 | 28.0 |
| Headrope height (m) | 6.0 | 5.0 |
| Wing spread (m) | unknown | 11.0 |
| Length of bridles (m) | 113 | 50 |
| Type of doors | oval | oval steel |
| Weight of door (kg) | 1,500 | 650 |
| Area of door (m²) | 5.5 | (2.75 × 1.80) |
| Mesh size of wings (mm) | 204 | 200 |
| Mesh size — square (mm) | 200 | |
| — middle (mm) | 150 | 160 |
| — end (mm) | 123 | |
| Mesh size of codend (mm) | (1) 40.1[b] | (1) 39.6 |
| | (2) 66.1[b] | (2) 59.8 |
| | (3) 90.2[b] | (3) 69.7 |
| | | (4) 124.1 |
| Liner in codend | yes[c] | no |
| Cover on codend | yes | yes |
| Mesh size of cover (mm) | 20 | 34.5 |
| Chafing gear fitted | yes | no |
| Rollers on footrope | no | yes[d] |
| Codend material | kapron | kapron |
| Codend twine | unknown | 93.5 tex × 18[e] |
| Cover material | kapron | kapron |
| Cover twine | unknown | 93.5 tex × 12 |

[a] Spanish type.

[b] Same measurements for wet and dry codends.

[c] Liner covering the codend knot.

[d] Steel rollers, 145 mm diameter, were connected through their centers with a heavy cable, and the entire apparatus was connected to the footrope by chains 18 cm long.

[e] Twine assumed to be 93.5 tex × 12 for 124.1 mm codend

TABLE 2. Results of mesh measurements of codends and covers used on Cuban and USSR reseach vessels during joint mesh selection studies on the Scotian Shelf in 1977.

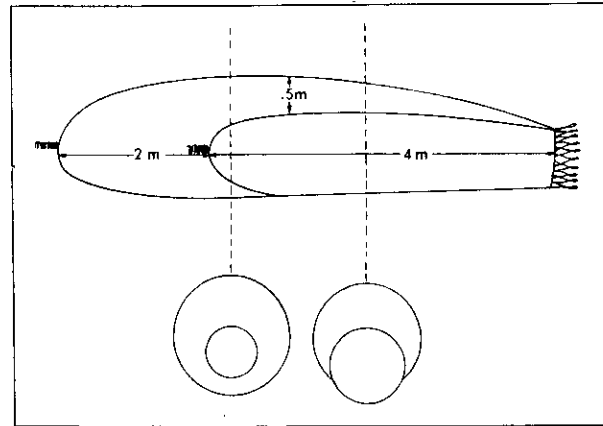| Commercial rated mesh size (mm) | Measured wet | | Measured dry | |
|---|---|---|---|---|
| | No. of meshes | Mean ± SD (mm) | No. of meshes | Mean ± SD (mm) |
| R/V *Isla de la Juventud* (Cuba) | | | | |
| 20[a] | | 20.1 | | 20.0 |
| 50 | | 40.1 | | 40.1 |
| 60 | | 66.1 | | 66.1 |
| 90 | | 90.2 | | 90.0 |
| R/V *Foton* (USSR) | | | | |
| 30[a] | 10 | 34.5 ± 1.5 | 10 | 32.6 ± 1.3 |
| 40 | 10 | 39.6 ± 1.5 | 10 | 33.4 ± 1.5 |
| 60 | 30 | 59.8 ± 1.5 | 10 | 56.4 ± 1.3 |
| 70 | 30 | 69.7 ± 1.7 | 10 | 65.8 ± 2.1 |
| 120 | 20 | 124.1 + 3.1 | — | — — |

[a] Measurements small-meshed cover.



Fig. 2. Schematic diagram and dimensions of the topside covered codend used by the USSR R/V *Foton* during the joint Canada-USSR mesh selection study in 1977.

of cover attachment may have affected the selectivity of the codend.

The sizes of the codend meshes were measured with an ICNAF gauge at 4 kg pressure. During the Canada-USSR study three series of measurements were taken on 10 random meshes for each mesh size. During the Canada-Cuba study fewer measurements were taken. These data are summarized in Table 2.

All length measurements of silver hake made during both the Canada-Cuba and the Canada-USSR study were total lengths to the nearest 1 cm. All weights are expressed in kilograms to the nearest 0.1 kg. The selection data, collected during these series of covered codend mesh selection trials were analyzed according to Pope *et al.* (1964). Recent reviews of analysis of selection data by Pope *et al.* (1975) and Holden (1971) have also been consulted. These authors concluded that fitting the selection ogive by the maximum likelihood method is the most accurate way of deriving the curve. However, the tedious calculations associated with this method are not often warranted, and it has been found that fitting the curve by eye gives unbiased estimates (Pope *et al.*, 1975) which are very close (often within 1% of those obtained by the maximum likelihood method (Holden, 1971). Another problem with using the maximum likelihood method is that the 'entire curve' must be fitted (Pope *et al.*, 1975), and, in the case of the Canada-Cuba data where this was not possible (Mari, pers. comm.) biased results can be obtained (Mari, MS 1978). The 50% retention length was calculated for this study by a moving average of 3 points and compared to the curve fitted by eye. Although this method gives unbiased estimates of the 50% point, it should not be used for other points

(Pope *et al.*, 1964). As a check of technique, the 50% retention length was also found by a linear regression (by the method of least squares) carried out on data between the 25 and 75% retention lengths.

In order to obtain a 'commercial average' (i.e. a mean selection ogive that approximates the average for the fleet as a whole with all variation included), the satisfactory hauls (those completed according to plan and without damage to gear) from one area and one codend mesh size were combined to produce a single selection ogive. To estimate the variability of the data, the 50% retention length of each satisfactory haul was determined and the mean and standard deviation calculated according to the method given in ICES (1964).

As a check on the calculated selection factor, a series of 93 length-girth measurements were taken. These were collected from a stratified sample of fish between 15 and 57 cm in length. The unconstricted maximum girth was measured by a loop of non-stretchable synthetic twine.

The study areas for the Canada-Cuba survey were determined by a searching program which attempted to find commercial-sized silver hake concentrations. The percentage of silver hake in the catch ranged from 9% in the first two study areas to 67% in the third area (a total of only 15 complete covered codend tows were made). In order to avoid extensive searching and thus allow more fishing time for the Canada-USSR study, the author chose three areas of likely silver hake concentrations in depths less than 150 m. Fishing continued at each location, whatever the species make-up, in order to provide as large a number of

individual hauls as possible. The percentage of silver hake in the catches ranged from 30 to over 60% (103 covered codend tows were made). USSR scientists wished to carry out a feeding survey on Sable Island Bank and thus one additional area was studied. However, the percentage of silver hake was very low (9%) in the few tows made in this latter area.

Definitions of some expressions used in this paper (from Pope et al, 1975) are as follows: (i) length selection ogive or curve means the proportions of fish at each length interval entering the codend that are retained by the net; (ii) 50% retention length (or 50% escapement length) is the length or point on the selection ogive where 50% of the fish are retained; (iii) selection range is the range of length between the 25 and 75% retention lengths; (iv) selection factor is the ratio of the 50% retention length to the mesh size of the codend (both parameters expressed in the same unit of measurement).

## Results and Discussion

The major purpose of the two cruises was to obtain trawl selectivity data for silver hake. Therefore, length and girth measurements were collected on the Canada-USSR cruise from a stratified sample of fish between 15 and 57 cm in length. The resulting relationship (Fig. 3) is

$$G = 0.48\ TL - 1.99 \quad (n = 93, r^2 = 0.97)$$
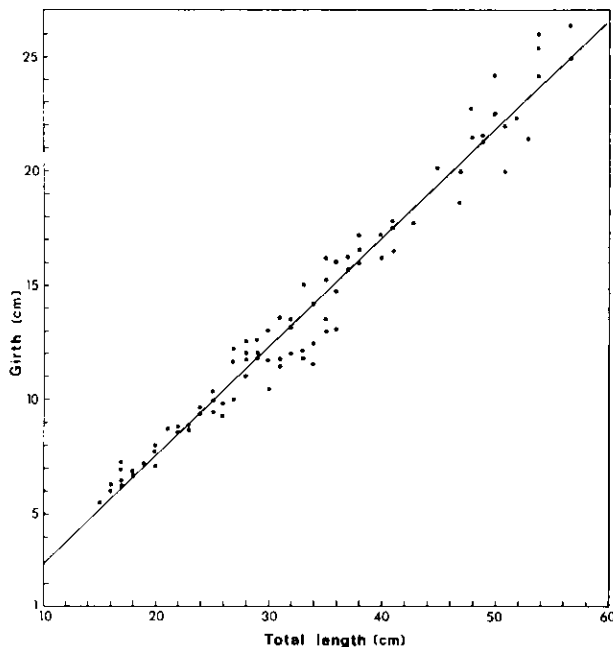
Fig. 3.   Total length-girth relationship for silver hake in Div. 4W in October 1977. (Girth (cm) = TL(cm) - 1.99, r² = 0.97, n = 93.)

where G is the girth in cm and TL is the total length of fish in cm. This is nearly identical to that calculated by Hennemuth (MS 1964) for silver hake in ICNAF Subarea 5. Margetts (1954 and 1957) showed how girth measurements can provide a preliminary estimate of selectivity and a means of validating the results.

### Canada-Cuba study

The selection ogives fitted by eye indicate 50% retention length of 17.5, 21.5, and 26.0 cm for mesh sizes of 40, 60, and 90 mm respectively (Fig. 4, Table 3). Figure 5 shows the length frequency of the population sampled and the location of the 50% retention length.
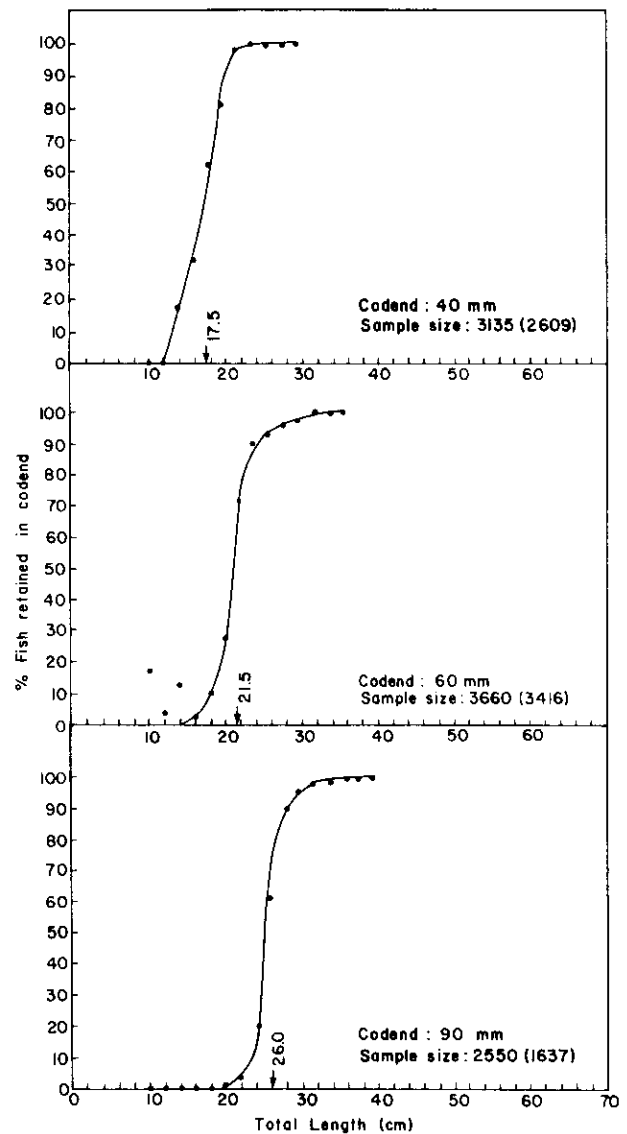
Fig. 4.   Selection ogives for silver hake in Div. 4W based on data from Canada-Cuba study in August 1977. (The sample size is the number of fish in codend and cover, with the number in codend in parentheses. The 50% retention lengths are indicated by arrows.)

TABLE 3. Silver hake on the Scotian Shelf: 50% retention lengths, selection ranges and selection factors for kapron codends used in the Canada-Cuba (CC) and Canada-USSR (CU) studies in 1977.

| Codend mesh size (mm) | 50% retention lengths (mm) | | | 25-75% selection range (cm) | Selection factor |
|---|---|---|---|---|---|
| | Fitted by eye | Moving average | Linear regression | | |
| 40 CC | 175 | 177 | — | 6.3 | 4.4 |
| 60 CU[a] | 225 | 229 | 224 | 13.2 | 3.8 |
| 60 CC | 216 | 216 | — | 1.7 | 3.6 |
| 70 CU[a] | 205 | 219 | 200 | 15.4 | 2.9 |
| 90 CC | 260 | 259 | — | 1.9 | 2.9 |
| 120 CU | 411 | 402 | 417 | 17.9 | 3.4 |

[a] For the pooled Canada-USSR data, the 50% retention length for the 60-mm mesh is greater than that for the 70-mm mesh; more realistic values are given in Table 4 based on the means of individual tows.

Due to an acute lack of data from this study, no attempt was made to calculate variations in the data or the effect on the 50% retention length of different sizes of catch. Although the reports of the Canada-Cuba cruise indicated a masking effect of the cover, the data were considered inadequate to attempt any such estimate (only 15 usuable covered codend tows for three mesh sizes). Since Pope et al. (1975) indicated that between haul variation was normally very large, it is advisable to make as many hauls as possible in the experimental area. In a detailed study of such variation, Gulland (1964) found that the variation was mainly due to 'a real difference between sets or hauls', caused either by the fish (e.g. feeding) or by the gear (e.g. towing speed).

The mean selection factor found in the Canada-Cuba study was 3.6 (Table 3), which lies between the 3.1 average recorded by Clark (1963) and the value of 4.1 obtained by Gulland (1956) for hakes using codends made of cotton, manila and nylon. The selection range generally tends to increase as the mesh size increases (Clark, 1963; Jensen and Hennemuth, 1966). In this study, the selection range decreased as the mesh size increased (Table 3). Clay (MS 1978) suggested that this could be due to variation in netting material. Boerema (1956) has shown differences in selection between various materials, and kapron is known to have an elongation factor almost 50% greater than nylon (Holden, 1971). Information obtained from the observer on the cruise indicated some possible problems with the attachment of the cover. If the cover is too closely attached, it is conceivable that the escape of large fish (i.e. fish at or over the 50% retention length) would be inhibited. This would depress the 50% retention length and such an effect would become progressively greater as the mesh size and thus the size of escaping fish increases. The 50% retention length and the length of fish whose grith equals the circumference of the mesh size are plotted against the stretched mesh size in Fig. 6. For most fish, a crude approximation of the 50% retention length can be estimated from the girth-length relationship. Figure 6 indicates that the 50% retention lengths found for the

60-mm and especially the 90-mm codends during the Canada-Cuba study were depressed by some factor, the most probable of which being the incorrect attachment of the cover to the codend.
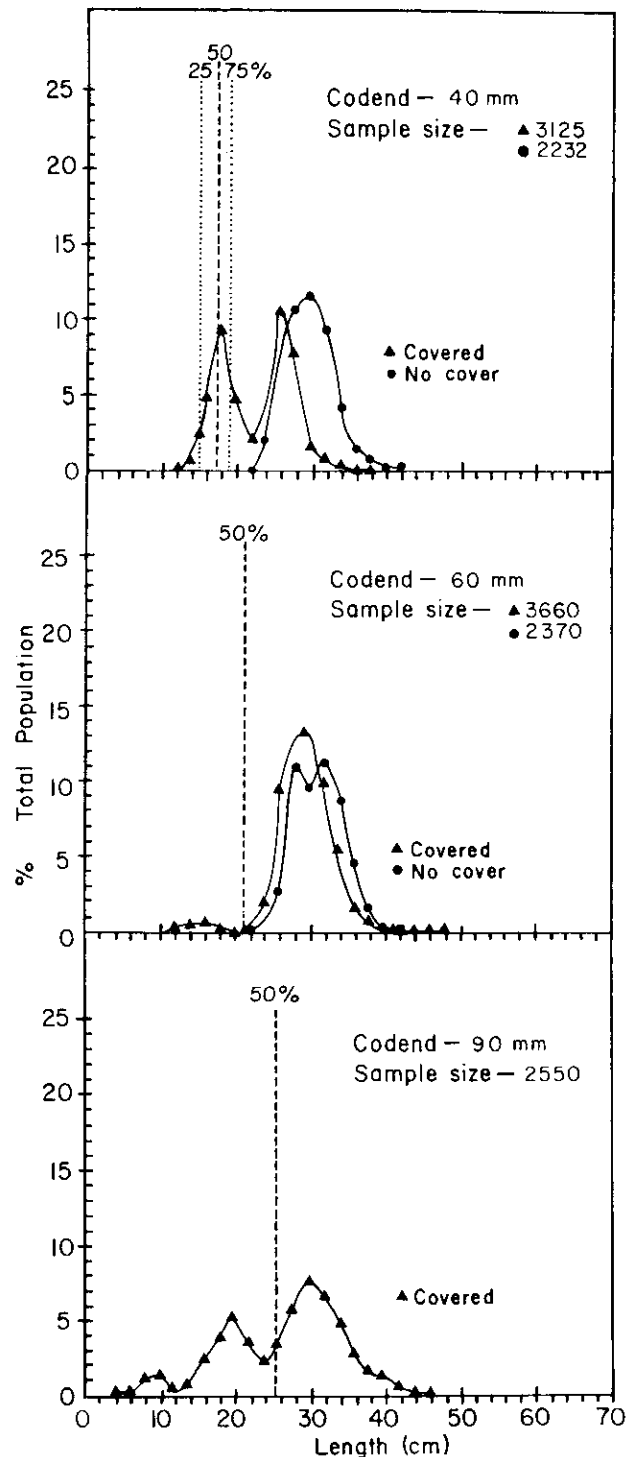


Fig. 5. Length frequencies of catches of silver hake in Div. 4W based on data from the Canada-Cuba study in August 1977 for codends with and without cover. (The 50% retention lengths are indicated for all three data sets and the 25-75% selection range for the smallest codend mesh size.)
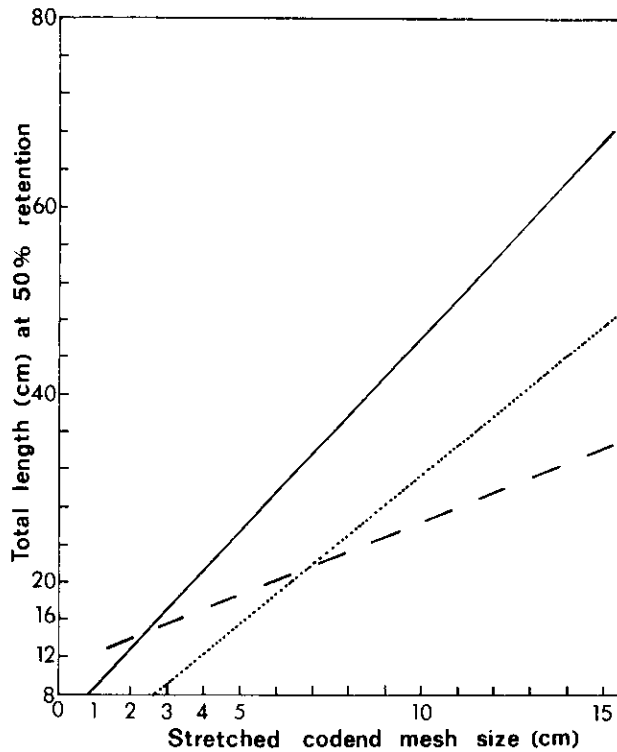
Fig. 6.  Relationship between 50% retention length and codend mesh
size for silver hake on the Scotian Shelf in 1977, based on the
Canada-Cuba study (broken line) and on the Canada-USSR
study (dotted line). (The solid line represents the girth-length
relationship where the girth is expressed in terms of the mesh
circumference.)

## Canada-USSR study

During the Canada-USSR study, greater amounts
of data were collected than on the earlier Canada-
Cuba cruise, providing the possibility of obtaining
more realistic selection ogives to represent the average
for the commercial fishery. The mean selection factor
of 3.3 (Table 3) is within the historical bounds for hake
(Gulland, 1956; Clark, 1963). The selection ogives (Fig.
7) shows 50% retention lengths of 22.6, 21.0, and 41.0
cm for codend mesh sizes of 60, 70, and 120 mm
respectively. Figure 8 shows the length frequencies of
the sampled population and the location of the 50%
retention lengths. Appendix Table 1 gives numerical
selection ogives for silver hake (expressed as
percentages released relative to total lengths of fish),
and Appendix Table 2 gives the 1977 selection-at-age
values, determined by three methods of estimation as
defined in the heading to this Table. Although some
differences were noted, it was considered that the
method of applying the selection ogive to the length
distribution of age-groups in the population and
summing the results is the best technique.

Previous selection experiments (Clark, 1963;
Gulland, 1956; Bohl et al., 1971) tended to show an
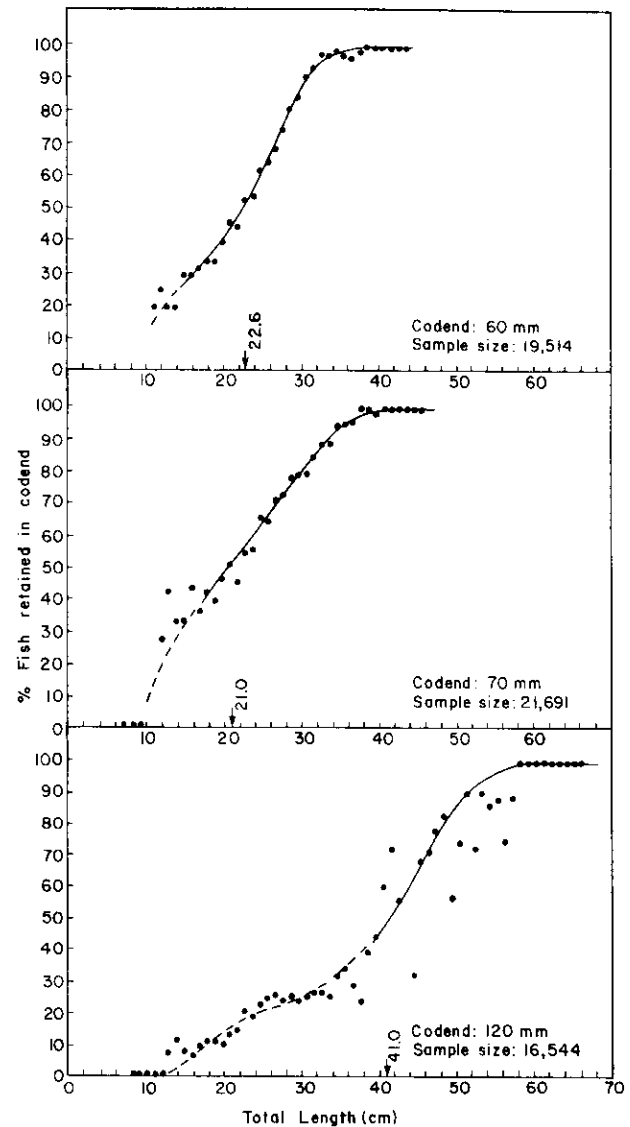


Fig. 7.  Selection ogives for silver hake in Div. 4W based on data from
the Canada-USSR study in October-November 1977. (The
50% retention lengths are indicated by arrows.)

increasing selection range with greater codend mesh
size. This was not found in the Canada-Cuba study but
was observed in the Canada-USSR data (Table 3).

Where reliable data were available, the selection
factor was plotted against the weight of the total catch
of individual 60-mm and 70-mm hauls. Individual 50%
retention lengths and selection factors are shown in
Table 4 and the catch weight is plotted against
selection factor in Fig. 9. Although the trend lines are
shown to be positive, the correlation coefficients were
very close to zero, indicating no significant trend.
However, for such species as haddock and cod
(Beverton, 1964; Clark, 1963; Hodder and May, 1964)
and the Cape hake (Bohl et al., 1971), much better
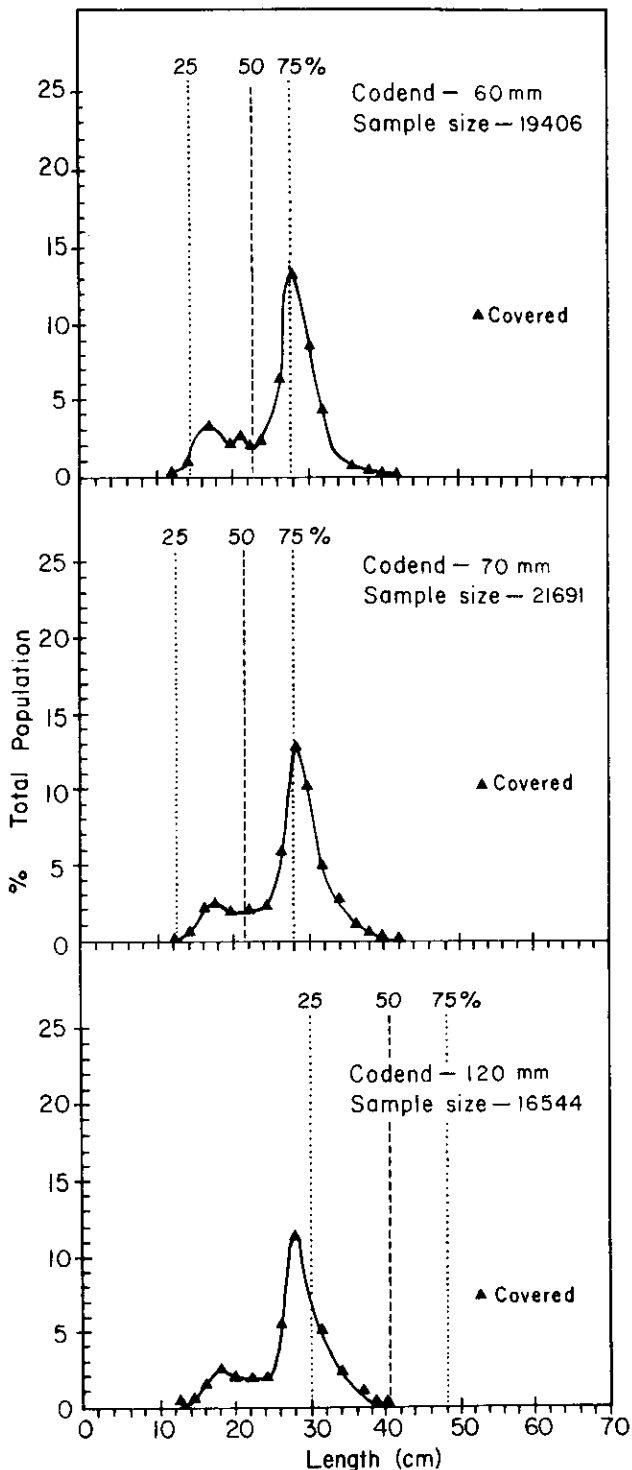correlations were found which were all negative. Bohl

Fig. 8. Length frequencies of catches of silver hake in Div. 4W based on data from the Canada-USSR study in October-November 1977. (The 50% retention lengths and the 25-75% selection ranges are indicated by vertical lines.)

TABLE 4. Silver hake on the Scotian Shelf: 50% retention lengths and selection factors for the 60-mm and 70-mm codends used in the Canada-USSR study for individual sets in which the catches were adequate to provide a unique result (see Fig. 9).

| Set no. | Codend catch (kg) | 50% retention lengths (cm) and selection factors for | |
|---|---|---|---|
| | | 60 mm | 70 mm |
| 5 | 1,839 | 20.16(3.4) | |
| 8 | 762 | 19.62(3.3) | |
| 9 | 872 | 20.27(3.4) | |
| 10 | 1,047 | | 28.43(4.1) |
| 11 | 1,610 | | 29.93(4.1) |
| 13 | 1,833 | | 30.31(4.3) |
| 23 | 3,083 | | 27.26(3.9) |
| 24 | 329 | | 18.26(2.6) |
| 26 | 248 | 18.42(3.1) | |
| 27 | 93 | 21.75(3.6) | |
| 32 | 200 | 18.51(3.1) | |
| 34 | 805 | 23.57(3.9) | |
| 37 | 590 | 19.73(3.3) | |
| 38 | 306 | 22.85(3.8) | |
| 42 | 394 | | 14.95(2.1) |
| 43 | 215 | | 22.18(3.2) |
| 44 | 183 | | 23.47(3.4) |
| 45 | 244 | | 21.61(3.1) |
| 47 | 623 | | 21.77(3.1) |
| 48 | 580 | | 21.94(3.1) |
| 88 | 420 | 25.76(4.3) | |
| 89 | 409 | 23.84(4.0) | |
| 90 | 1,161 | 25.55(4.3) | |
| 91 | 1,577 | 26.04(4.3) | |
| 93 | 574 | | 22.59(3.2) |
| 94 | 569 | | 24.33(3.5) |
| 95 | 305 | | 23.40(3.3) |
| 96 | 364 | | 25.61(3.7) |
| 97 | 605 | | 25.10(3.6) |
| 98 | 533 | | 24.75(3.5) |
| 101 | 419 | 27.07(4.5) | |
| 102 | 761 | 27.70(4.6) | |
| Mean 50% retention length | | 22.72±3.19 | 23.82±3.82 |
| Mean selection factor | | 3.79±0.52 | 3.40±0.55 |

et al. (1971) also found the variation to be great, but the range of catch size in their study was much greater than that found in this study on silver hake. For the Cape hake (Bohl et al., 1971) the selection factor decreased by 0.18 per ton increase in weight of catch. The decrease in selection factor with increasing catch for other species is reported to range from 0.05 per ton increase in catch for haddock to 0.3 for a change in catch from 10 to 15 kg in the dab and plaice (Bohl, 1964). However, as noted earlier, no conclusion can be drawn about the effect of catch size on selection factor from the current study on silver hake, due possibly to the relatively small range of catch size.
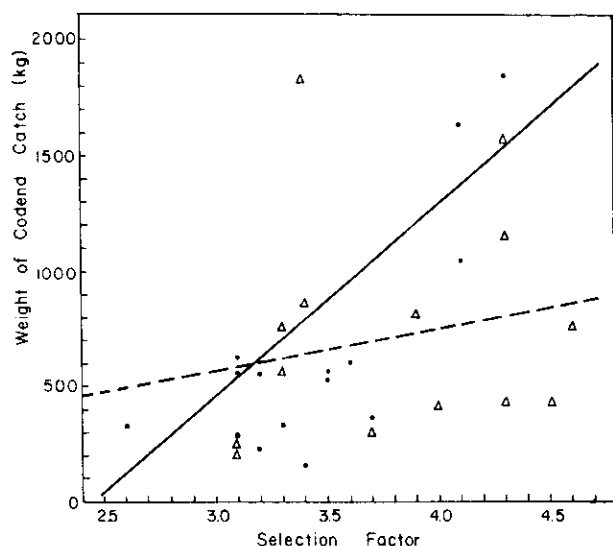
Fig. 9.  Plot of selection factors for individual tows against weight of the codend catch for the 60-mm mesh (dots and broken line) and the 70-mm mesh (triangles, solid line) codends, from data in Table 4. (Regression for 60-mm codend is $y = 164.76 \times + 72.53$, $r^2 = 0.03$, $n = 15$, and for 70-mm codend is $y = 818.38 \times - 2012.44$, $r^2 = 0.36$, $n = 16$. The point representing the catch of 3,083 kg is omitted from the graph.)

### General comments

Current studies on silver hake indicate that selection is different from that for the European or Cape hakes. However, two problems that may affect such a conclusion involve the type of cover material and the cover mesh size. ICES (1964) suggested that the cover material should be made of a buoyant material such as polyethylene (e. g. Courlene). In the present studies, non-floating kapron covers were used. ICES (1964) also recommended that the mesh size of the cover should not be less than one-third to one-half of the codend mesh size to reduce masking effects. However, such effects were likely to have been present in both the Canada-Cuba and the Canada-USSR studies with the large-sized codend, as a 20-mm mesh cover was used on a 90-mm mesh codend in the first case and a 30-mm mesh cover on a 120-mm mesh codend in the second case. Masking is described by Davis (1934) as an 'elusive factor' of the flow effect of

the cover. Masking tends to reduce the flow of water through the codend meshes, thus reducing the 50% retention length and decreasing the selection factor. In both the Canada-Cuba and the Canada-USSR studies (Table 3) the selection factor decreases as the codend mesh size increases (e. g. 4.4 to 2.9 and 3.8 to 3.4). Thus if the results of the 40-mm mesh codend in the Canada-Cuba study and of the 60-mm mesh codend in the Canada-USSR study are considered as being the least affected by masking, the average selection factor is 4.1, a value which implies that silver hake may have essentially the same selection characteristics as the European and Cape hakes. Such an assumption is further borne out by the similarity of the girth-length relationships for the three hakes (Table 5).

A selection factor of 4.0 was accepted as a provisional working figure for the European hake for cotton and hemp trawls (ICES, 1957). Bohl et al. (1971) found similar selection factors for the Cape hake and assumed that 'as the selectivities of cotton/hemp and polyamide are known to be the same' there was no difference in escapement for Cape hake and European hake. The evidence now available indicates that the silver hake also appears to have the same selection characteristics as these other members of the genus Merluccius. Consequently, Clay (1979) calculated a 'general selection pattern' for the hake family as:

50% Retention length = 4.04 (mesh size) - 26.12

where both parameters are expressed in mm.

### Application to the silver hake fishery

The first application of selection data to a trawl fishery is the investigation of the immediate effects of various mesh sizes on catches. Two approaches are possible: the first assuming that fishing effort remains constant and the mesh size changes, and the second assuming that fishing effort is altered to generate some 'optimal' value of fishing mortality (e. g. $F_{0.1}$ ) as the mesh size changes.

The first approach is to study the effects of applying codend selection ogives to the length distribution of a known population of fish. For this

TABLE 5. Comparison of girth-length relationships for silver hake, European hake, and Cape hake (modified after Bohl et al. 1971). (G = girth, TL = total length and FL = fork length, all in cm units.)

| Species | Source | Relationship | % girth relative to silver hake girth for 2 different fish lengths | |
| --- | --- | --- | --- | --- |
| | | | 30 cm | 50 cm |
| Silver hake | Present study | G = 0.48 TL - 1.99 | 100.0 | 100.0 |
| " | Hennemuth, 1964 | G = 0.44 FL - 0.31 | 105.5 | 100.5 |
| European hake | Gulland, 1956 | G = 0.47 TL - 1.10 | 104.8 | 101.7 |
| Cape hake | Bohl et al., 1971 | G = 0.49 TL - 2.44[a] | 98.7 | 100.2 |
| " | Bohl et al., 1971 | G = 0.46 TL - 1.45[b] | 99.5 | 97.9 |

[a] Cape grounds                    [b] Luderitz grounds

TABLE 6. Simulation of the effects of fishing silver hake in two areas of the Scotian Shelf using 90-mm and 120-mm mesh codends relative to the 60-mm mesh codend generally in use for the silver hake fishery. Area A refers to the more northerly and Area B to the more southerly of the two areas labelled "CU" in Fig. 1.

| Parameters | Area A | | | Area B | |
|---|---|---|---|---|---|
| | No. of fish | Weight (kg) | Av. wt. (g) | No. of fish | Weight (kg) |
| Total population | 16,544 | 2,411 | 146 | 19,406 | 2,556 |
| Catch (60 mm codend) | 11,883 | 2,001 | 168 | 13,265 | 2,062 |
| Catch (90 mm codend) | 8,122 | 1,396 | 172 | 9,549 | 1,494 |
| Catch (120 mm codend) | 3,810 | 715 | 188 | 4,262 | 731 |
| Change from 60 to 90 mm (%) | -32 | -30 | +2 | -28 | -28 |
| Change from 60 to 120 mm (%) | -68 | -64 | +12 | -66 | -65 |

purpose, the combined length frequencies of the catches (both cover and codend) in two of the Canada-USSR study areas were used to simulate silver hake populations in these areas. The length compositions consisted of 16,544 fish in one case and 19,406 fish in the other (Table 6). Application of the selection ogive for the 60-mm mesh (Appendix Table 1) to the length compositions of the two populations indicated that an average of 70% by number and 82% by weight would be caught, and the average weight would increase from 146 g in the total population to 168 g (the average weights for Area B were essentially the same as those listed in Table 6 for Area A). An increase in mesh size from 60 mm to 90 mm would result in immediate losses of 32% by number and 30% by weight for Area A and 28% by number and by weight for Area B, and the average weight would increase slightly to 172 g. An increase in mesh size from 60 mm to 120 mm would result in more than doubling the immediate losses (64-68%) both in number and weight, and the average weight would increase by 12% to 188 g. The resultant size compositions of the population in Area A before and after applying the 60-mm and 120-mm selection ogives are shown in Fig. 10.

The second approach, a more realistic way of studying the change in yield, assumes that fishing effort will be regulated at the F0.1 level, taking into account appropriate partial recruitment factors for each age-group in the population. As a starting point, the partial recruitment factors for the 40-mm mesh codend, estimated from historical data prior to the imposition of area and gear restrictions, were averaged and then smoothed from the fishing mortality tables of Doubleday and Hunt (MS 1977) and Doubleday and Halliday (1976), resulting in values of 0.08, 1.00, 0.97, 0.54, 0.63 and 0.27 for age-groups 1 to 6+ respectively. Initially the technique to estimate change in yield, as proposed by Allen (1967), was tried. This method assumes knife-edge selection at the 50% retention length and was therefore considered unsuitable with partial recruitment factors such as those for silver hake. The yield per recruit (to the fishery) method of Thompson and Bell (Ricker, 1975) was chosen in an

attempt to predict an equilibrium yield. The input data for this method are the weights at age, as taken from the latest assessment by Halliday et al. (MS 1978), and the partial recruitments for each different mesh size. The partial recruitments listed above for the 40 mm mesh codend contain factors for both the selectivity of the codend and the general availability (or distribution) of the fish at each age-group. Partial recruitments for the 60-, 90-, and 120-mm codends were calculated, assuming no alteration of fishing patterns, by multiplying the selection at age for each mesh size (Appendix Table 3) by the availability factors derived from the selectivity and partial recruitments of the 40-mm mesh codend. These calculations are presented in Appendix Table 4. When calculating the fishing mortalities for each age group, the $F_{0.1}$ is usually
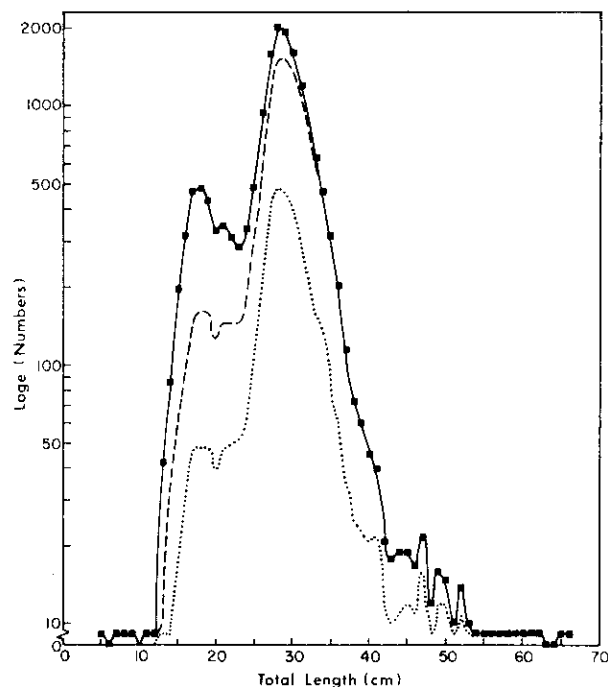


Fig. 10. Length frequency of silver hake catches in codend + cover (solid line), and the length frequencies of the retained catches if fishing with a 60-mm mesh codend (broken line) and a 120-mm mesh codend (dotted line).

multiplied by the normalized (to 1) partial recruitments. In order to make the fishing mortalities (and thus fishing effort) comparable for all mesh sizes, the partial recruitments for this exercise are based on the 40 mm net where age 2 is normalized to 1.0. As an example of this, the fishing mortalities (from Fig. 11) by age have been calculated for a natural mortality (M) of 0.4 (Appendix Table 5). Figure 11 gives the yield-per-recruit (age-groups 1 to 6+) for natural mortalities from 0.2 to 0.5. The yield-per-recruit (Y) tends to decrease with increases in mesh size for M = 0.5 but increases progressively as M decreases from 0.4 to 0.2.

The degree of increase in yield-per-recruit shown in Fig. 11 is the minimum that could be expected for
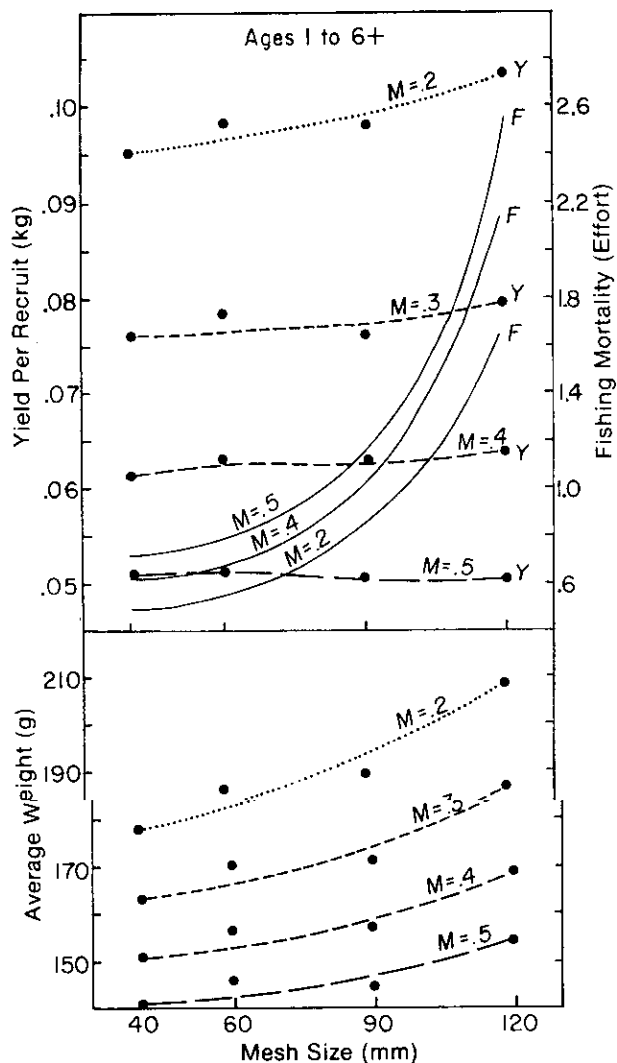


Fig. 11. Plots of yield-per-recruit, fishing mortality and average weight of silver hake (age groups 1 to 6) against mesh size for different values of natural mortality (M). [The F-curves are $F_{0.1}$ values calculated for partial recruitments taken from Appendix I (Tables 4 and 5) normalized for the 40-mm mesh size to 1. This makes the F (related to effort) comparable within the graph for each mesh size but not comparable to the F-values of Fig. 12 and 13. The F-values can be considered an index of effort.]

two reasons. In the first case, since M was assumed to be 0.4 or higher, previous analyses have been based on the grouping of all fish greater than age 6 into an age-group categorized as age 6+, and consequently increases in yield-per-recruit, resulting from a shift in population structure toward the older age-groups for lower values of M, have not been taken into full account. Thus for all values of M < 0.4, the increases in yield would be greater than those shown in Fig. 11. The second factor which depresses the projected yields is the partial recruitment values which decrease with age. In the past, fishing effort has generally been concentrated on the largest concentrations which consist mainly of 2- and 3-year-old fish. As these fish become less available to the commercial catches due to the use of larger meshed trawls, the age structure of the population as well as that of the commercial catches will change. There is no way of knowing precisely how much this pattern will change, but it can be assumed that there would be an increase in the abundance of the older age-groups. To investigate the extreme limits of the change in yield, two additional series of yield-per-recruit calculations were carried out. The first series used partial recruitment values of 0.08, 1, 1, 1, 1 and 1 for ages 1 to 6+ respectively (Fig. 12). The increase in yield for M = 0.2 is much greater in this case than in Fig. 11 and the average weight of fish caught increases by about 30%. The second series is based on using mean weight-at-age data for fish aged 6 to 12 years, the resulting values being 600, 730, 890, 1000, 1120, 1280 and 1370 g respectively, as derived from the growth equation ($L_\infty$ = 74.65, K = 0.116, $t_o$ = - 1.976) and the length-weight relationship (with coefficients 3.317 and 0.00206) given by Halliday et al. (MS 1978). The resulting yield-per-recruit curves (Fig. 13), calculated for ages 1 to 12, indicated that at a maximum age of 12 years the increases in yield were greater than the initial estimates for values of M < 0.4. However, at M = 0.4 the yield-per-recruit decreases with increases in mesh size from 60 to 120 mm, an indication that growth cannot compensate for natural mortality at the higher values of M.

For all three analyses (Fig. 11-13), it appears that an increase in mesh size from 60 to 90 mm would produce the same or a slight increase in long-term yield with an increase in the average size of fish. From an economic viewpoint, best indicated by the fishing mortality (F) which is directly related to fishing effort, there is an exponential rise in effort as mesh size increases (Fig. 11-13). The exponential increase indicates that the increased fishing effort required to achieve the same yield when changing from 60- to 90-mm mesh nets is in the range of 10 to 30% and that required when changing from 90- to 120-mm mesh nets is in the range of 30 to 100%. Such large increases in effort required if the mesh size is increased to 120 mm could not be justified until better quantitative estimates of yield are available.
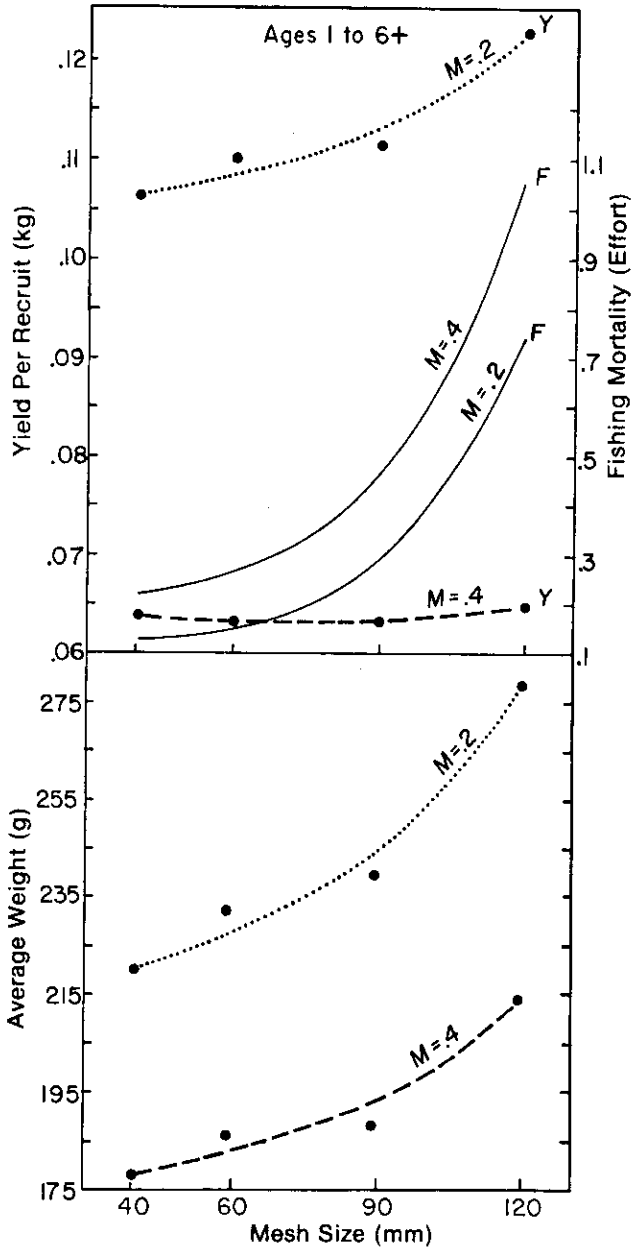
Fig. 12. Similar to Fig. 11, except that calculations based on only two levels of M and partial recruitment altered to assume full recruitment after age 2 (see text for values).
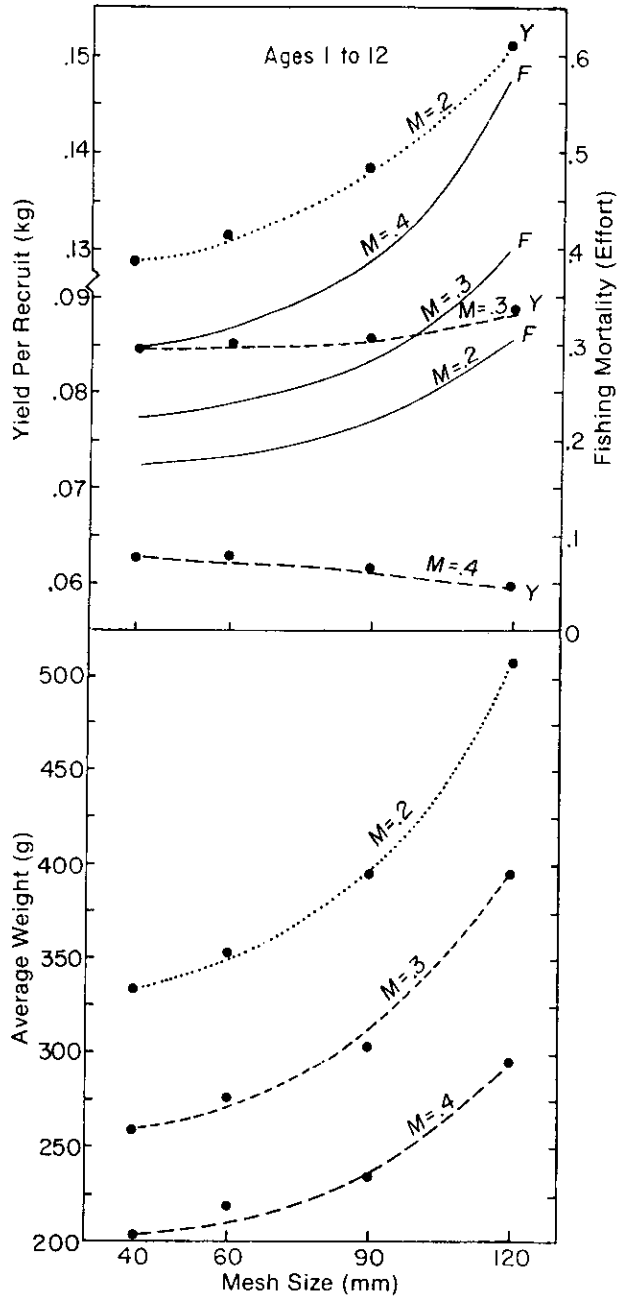


Fig. 13. Similar to Fig. 12, except that age structure includes ages 1 to 12 instead of ages 1 to 6 (see text for values).

Since the historical partial recruitment of age 1 fish is 0.08 (for 40 mm mesh), increasing the codend mesh size from 40 to 60 mm would make little if any difference to the catch, because codends with both mesh sizes would retain age 1 fish if they were available, or would not retain them if they were not available in the fishing areas. Therefore, to allow the escapement of age 1 and some age 2 fish, it is necessary to increase the mesh size beyond 60 mm to perhaps 90 mm.

Doubleday and Halliday (1976) suggested that yield-per-recruit would be greatest if the mean length of recruitment was increased to 25.5 cm. These authors studied the sexual maturity of silver hake from Canadian research vessel data and found that males were mostly mature in their second year while all of the females were mature in their third year. Since most fish in a population should be allowed to spawn at least once prior to exploitation, it therefore follows that

cropping of the silver hake stock should not begin until they reach their third year ( i. e. at 30-32 cm in length). From these hypotheses, the 90-mm mesh codend would seem the most likely choice of an interim mesh size while detailed monitoring is being carried out to investigate the effects of such an increase on the population.

## Application to the squid fishery

During the Canada-Cuba and the Canada-USSR studies, large percentages of squid occurred in the catches, the composition of which were similar to those of the commercial catches in 1977. Thus any masking effect of squid on the retention of silver hake in large commercial catches will be at least partially accounted for in the present studies. The larger commercial catches will tend to depress the selection factor (reduce the escapement) although no estimate of this can be made from the current study. However, the results of Bohl et al. (1971) for Cape hakes indicate that the selection factor may decrease by as much as 5-6% per ton increase in catch. Thus the selection factor applicable to the commercial fishery (with larger catches) may be somewhat lower than those obtained from the current experimental study. One factor which could depress the selection factor even further is any 'strengthening' that may be carried out on commercial-size codends(e. g. use of double twine), such alterations being common but not necessarily uniform throughout a fishing fleet.

Since both the Cuban and USSR fisheries on the Scotian Shelf in recent years are essentially mixed fisheries for silver hake and squid, and as squid have appeared in increasing abundance since 1970 (Scott, 1978), the effect on the squid catches of increasing the codend mesh size to 90 mm is also considered. Squid, due to their morphology and narrow size range, cannot be studied for mesh selection as readily as can most finfish species. The tentacles on squid can cause great variation in selection making the 50% retention length difficult to measure, in much the same way as teeth and spines complicate selection ogives of gillnets. Selection ogives give 50% retention lengths of approximately 14.0, 18.0 and 24.0 cm for codends with mesh sizes of 60, 70 and 120 mm respectively (Fig. 14). Monthly length compositions of squid on the Scotian Shelf from April to August 1977 are shown in Fig. 15. Because of the rapidly changing size composition as the season progresses, it was decided to study the percentage by weight of escapement through the codend meshes rather than use the 50% retention lengths. Figure 16 and Table 7 show the percent by weight of squid passing through codends of different mesh sizes. Twenty-five to 30% of the squid encountered by the gear in late summer and early autumn will escape a 90-mm research-type trawl.
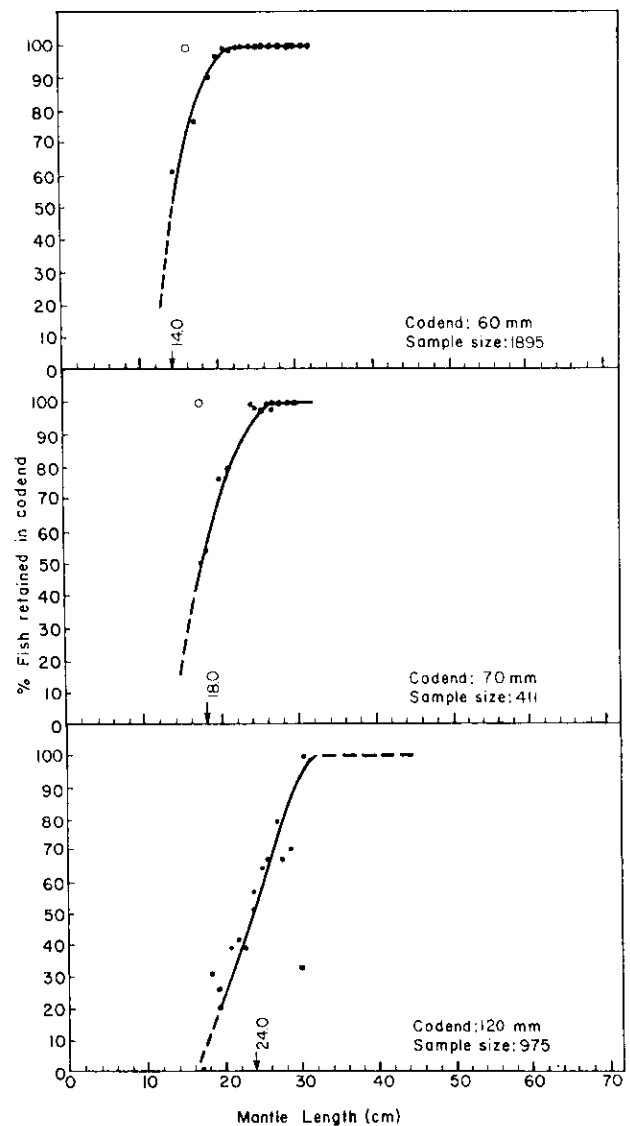


Fig. 14. Selection ogives for squid, *Illex illecebrosus*, in Div. 4W, based on data from the Canada-USSR study in October 1977. (The 50% retention lengths are indicated by arrows.)
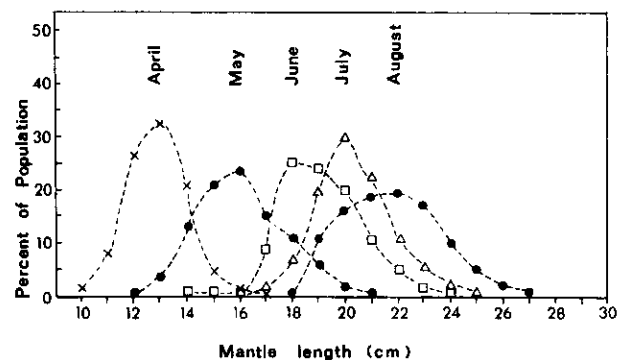


Fig. 15. Monthly length composition of the commercial squid catch on the Scotian Shelf for April-August 1977, based on data from the International Observer Program.
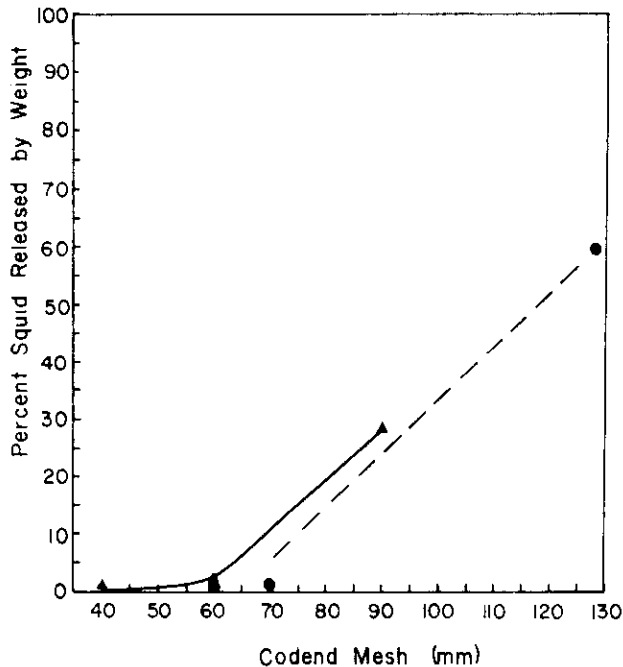
Fig 16  Percentages of the weight of squid released by codends of various mesh sizes in the Canada-Cuba study (solid line) in August and the Canada-USSR study (dashed line) in October-November 1977.
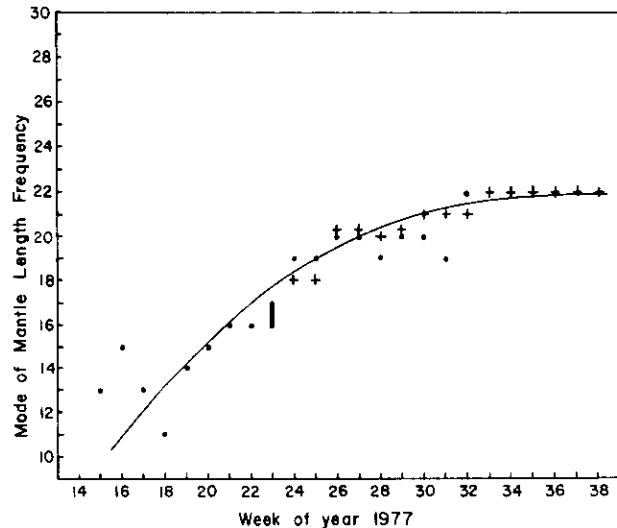


Fig. 17.  Seasonal growth of squid on the Scotian Shelf in 1977, as indicated by the weekly progression of length frequency modes for samples of the Cuban commercial catches (dots) and USSR commercial catches (crosses) based on data from the 1977 International Observer Program. (The vertical bar represents a week when the mode was spread over two centimeter groups.)

These escapees will tend to be smaller squid which may increase the yield-per-recruit, but, more importantly, the 90-mm mesh codends will allow otherwise discarded juvenile finfish the chance to escape. These research studies were conducted in August and October-November, times when the modal length of the squid population ranged from 20 to 22 cm (Fig. 15 and 17). The percentage of squid released by the 90-mm codend (Fig. 16) decreases somewhat between August and October-November due to growth in size. However, the growth rate is greatest in the period from April to June (Fig. 17). The use of 90-mm mesh codends would allow the cropping of the

larger sizes of squid in July with about 75% of the population growing to catchable size by August. These data suggest that a 90-mm mesh regulation applied to the squid fishery would not prevent catch allocations from being taken, although it would substantially reduce catch rates in June and July. However, there would be little effect during the remainder of the season (according to 1977 sample data). Precise calculations of the effect on yield-per-recruit and on fishing effort by increasing the mesh size to 90 mm require more data than are presently available.

## Conclusions

A 90-mm mesh codend regulation would appear suitable for silver hake as an experimental level to test population response and changes in the fishery due to changes in mesh size. While the long-term benefits that would accrue by increasing the codend mesh size to 90 mm cannot be firmly established, it has been shown that long-term losses will not occur over the wide range of parameters considered here. It appears that such a regulation would not have a severely adverse effect on the squid fishery. There is the additional factor of by-catches to be considered in establishing such mesh regulations. Fish caught as by-catch are in part juveniles of species whose fisheries are regulated by 130-mm minimum mesh sizes, and reduction of such by-catches would result in an increase in yield of these fisheries.

TABLE 7.  Percentages of squid in the catches and released from codends of various mesh sizes used in the Canada-Cuba (CC) and Canada-USSR (CU) studies on the Scotian Shelf in 1977

| Mesh size (mm) | % by weight of squid in catch | % by weight of squid released |
|---|---|---|
| 40 CC | 29.5 [1] | 0.0 |
| 60 CU | 28.0 | 0.5 |
| 60 CC | 83.0 [a] | 1.8 |
| 70 CU | 21.0 | 0.5 |
| 90 CC | 66.0 [a] | 28.0 |
| 120 CU | 26.0 | 59.8 |

[a]  The Canada-Cuba study was conducted over a large area, and the great variation in the quantities of squid in the catches cannot be attributed to mesh size

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# APPENDIX

TABLE 1. Selection ogives for silver hake based on the Canada-USSR mesh selection study in October-November 1977. (Values smoothed by running average of five.)

| Total length (cm) | % released from various codends | | | | |
|---|---|---|---|---|---|
| | 40 mm[a] | 60 mm | 70 mm | 90 mm[a] | 120 mm |
| 15 | 59 | 73 | 62 | 77 | 91 |
| 16 | 56 | 71 | 62 | 76 | 90 |
| 17 | 53 | 68 | 61 | 74 | 90 |
| 18 | 51 | 66 | 58 | 73 | 90 |
| 19 | 46 | 63 | 57 | 71 | 89 |
| 20 | 41 | 61 | 55 | 68 | 88 |
| 21 | 37 | 57 | 53 | 66 | 86 |
| 22 | 33 | 53 | 49 | 64 | 84 |
| 23 | 30 | 48 | 45 | 62 | 82 |
| 24 | 27 | 45 | 42 | 60 | 80 |
| 25 | 21 | 40 | 38 | 56 | 78 |
| 26 | 17 | 35 | 34 | 52 | 77 |
| 27 | 11 | 30 | 30 | 48 | 78 |
| 28 | 8 | 25 | 27 | 46 | 76 |
| 29 | 3 | 20 | 22 | 44 | 76 |
| 30 | 1 | 15 | 18 | 42 | 75 |
| 31 | — | 11 | 17 | 40 | 75 |
| 32 | — | 8 | 14 | 38 | 74 |
| 33 | — | 5 | 14 | 37 | 73 |
| 34 | — | 4 | 11 | 35 | 71 |
| 35 | — | 4 | 9 | 33 | 71 |
| 36 | — | 4 | 8 | 31 | 71 |
| 37 | — | 3 | 5 | 30 | 69 |
| 38 | — | 3 | 3 | 28 | 66 |
| 39 | — | 2 | 3 | 27 | 61 |
| 40 | — | 1 | 2 | 26 | 53 |
| 41 | — | — | 2 | 25 | 46 |
| 42 | — | — | 2 | 24 | 45 |
| 43 | — | — | 1 | 23 | 43 |
| 44 | — | — | 1 | 22 | 40 |
| 45 | — | — | 1 | 20 | 39 |
| 46 | — | — | 1 | 19 | 34 |
| 47 | — | — | — | 14 | 29 |
| 48 | — | — | — | 10 | 28 |
| 49 | — | — | — | 7 | 25 |
| 50 | — | — | — | 2 | 22 |
| 51 | — | — | — | 1 | 19 |
| 52 | — | — | — | — | 18 |
| 53 | — | — | — | — | 15 |
| 54 | — | — | — | — | 15 |
| 55 | — | — | — | — | 15 |
| 56 | — | — | — | — | 13 |
| 57 | — | — | — | — | 10 |
| 58 | — | — | — | — | 7 |
| 59 | — | — | — | — | 2 |

[a] Estimated values using linear interpolation of results of 60, 70 and 120 mm codends and taking in account data for the 40-mm mesh from the Canada-Cuba study.

TABLE 2. Percentage of silver hake retained by age and sex for the 60-mm mesh by 3 methods: the first method is based on applying the 60-mm selection ogive of Appendix Table 1 to sample population length frequencies, and the other 2 methods are based on the values from the selection ogive lengths at age.

| Age-group | Sex | Sample fishing | Modal length | Mean length |
|---|---|---|---|---|
| 1 | M | 41 | 37 | 38 |
|   | F | 40 | 39 | 38 |
| 2 | M | 72 | 75 | 68 |
|   | F | 78 | 80 | 74 |
| 3 | M | 83 | 89 | 87 |
|   | F | 91 | 95 | 94 |
| 4 | M | 91 | 95 | 95 |
|   | F | 95 | 96 | 95 |
| 5 | M | 91 | 89 | 96 |
|   | F | 97 | 97 | 99 |
| 6 | M | 100 | 98 | 100 |
|   | F | 99 | 100 | 100 |

TABLE 3. Percentage of silver hake (sexes combined) retained in various codend mesh sizes by age-group based on applying the selection ogives of Table 1 to sample populations (see text and Appendix Table 2).

| Age-group | % retained in various codends | | | |
|---|---|---|---|---|
|  | 40 mm | 60 mm | 90 mm | 120 mm |
| 1 | 59 | 40 | 34 | 11 |
| 2 | 93 | 74 | 52 | 21 |
| 3 | 99 | 87 | 59 | 25 |
| 4 | 100 | 95 | 64 | 27 |
| 5 | 100 | 97 | 69 | 34 |
| 6 | 100 | 99 | 83 | 64 |

TABLE 4. Calculated partial recruitment (PR) of silver hake for the 60, 90 and 120 mm mesh codends from the partial recruitment in the historic fishery (40 mm mesh) using the relationship PR = Selectivity × Availability.

| Age-group | Partial recruitment (40 mm) | Selection (40 mm) | Availability factors | Calculated partial recruitments | | |
|---|---|---|---|---|---|---|
|  |  |  |  | 60 mm[a] | 90 mm[a] | 120 mm[a] |
| 1 | 0.08 | 0.59 | 0.14 | 0.06 | 0.05 | 0.02 |
| 2 | 1.00 | 0.93 | 1.08 | 0.80 | 0.56 | 0.23 |
| 3 | 0.97 | 0.99 | 0.98 | 0.85 | 0.58 | 0.25 |
| 4 | 0.54 | 1.00 | 0.54 | 0.51 | 0.35 | 0.15 |
| 5 | 0.63 | 1.00 | 0.63 | 0.61 | 0.43 | 0.21 |
| 6+ | 0.27 | 1.00 | 0.27 | 0.27 | 0.22 | 0.17 |

(columns related by: Partial recruitment = Selection × Availability factors)

[a] Selectivity from Appendix Table 3.

TABLE 5. Calculation of fishing mortalities by age for silver hake in the 40 and 120 mm mesh codends at M = 0.40, using the partial recruitment values of Appendix Table 4 to distribute the F0.1 of Fig. 11 over the age-groups. Similar calculations yield fishing mortalities for the intermediate mesh sizes.

| Age-group | 40 mm | | | 120 mm | | |
|---|---|---|---|---|---|---|
|  | Partial recruitment | $F_{0.1}$ (Fig. 11) | Fishing mortality | Partial recruitment | $F_{0.1}$ (Fig. 11) | Fishing mortality |
| 1 | 0.08 |  | 0.05 | 0.02 |  | 0.04 |
| 2 | 1.00 |  | 0.60 | 0.23 |  | 0.51 |
| 3 | 0.97 | × 0.6 = | 0.58 | 0.25 | × 2.2 = | 0.55 |
| 4 | 0.54 |  | 0.32 | 0.15 |  | 0.33 |
| 5 | 0.63 |  | 0.38 | 0.21 |  | 0.46 |
| 6+ | 0.27 |  | 0.16 | 0.17 |  | 0.37 |
|  |  |  | F = 0.35 |  |  | F = 0.38 |

# Maturation Index and Fecundity for Female Squid, *Illex illecebrosus* (LeSueur, 1821)

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## Abstract

The maturation continuum in female *Illex illecebrosus* has been divided into five discrete stages based on the development of the nidamental gland. Analysis of laboratory and field data shows that development of the nidamental gland is well correlated with ovarian development. The maturity stages are expressed quantitatively in terms of the ratio of nidamental gland length to mantle length. Numerical values for the maturation stages (m) are as follows: Stage I, $m \leqslant 0.09$; Stage II, $0.05 < m \leqslant 0.125$; Stage III, $0.125 < m \leqslant 0.20$; Stage IV, $0.20 < m \leqslant 0.35$; and Stage V, $0.35 < m$. This index is convenient and accurate in determining the maturity condition of female squid both in the field and in the laboratory. Ovarian weight is shown to be dependent on the total weight of the female. The total egg mass produced is approximately 23% of total body weight. The average fecundity of six mature females is estimated at 400,000 ova. The number of eggs produced by a population can be predicted from the number and size of females in the population late in the autumn.

## Introduction

The life cycle of the short-finned squid, *Illex illecebrosus*, is largely a matter of conjecture (Mesnil, 1977; Lu, MS 1973; Squires, 1967) because the females upon becoming mature disappear from the areas where they are normally fished. Further information on the maturation processes in this species is required for proper management of the fishery since maturation patterns of both sexes control fecundity and behaviour and may be a key to ascertaining the time and location of spawning. There is an adequate description of sexual development in males as their onset of maturation occurs relatively early during their seasonal occurrence in coastal waters (Mercer, MS 1973), but information on maturation in females is scant as few mature females have been observed in the wild population (Mercer, MS 1973; Squires, 1957, 1967).

Advanced stages of maturity have been observed in female *Illex illecebrosus* maintained in captivity in the Aquatron Laboratory at Dalhousie University, Halifax, Nova Scotia (O'Dor *et al.*, 1977). Data obtained from these squid and also from samples taken in the field are used in this paper to examine the maturation process in females, and an estimate of fecundity based on egg counts of females maintained in captivity is made.

Several methods have been used to describe the maturation stages in cephalopods. In most cases, maturity is determined by the size (length and weight) and coloration of the gonad and accessory organs (Mercer, MS 1973; Vovk, 1972a; Hayaski, 1970; Tinbergen and Verwey, 1945), or by histological examination of the ovary (Takahashi and Yahata, 1973). Although histological examination is perhaps the most reliable indicator of maturity, the procedure is tedious and often impossible in the field. In this study, it is noted that the development of the nidamental glands (accessory sex organs) correlates well with ovarian development, and when related to mantle length can be used as a maturity index. The ratio of nidamental gland length to mantle length is simply

obtained and is practical for both field and laboratory studies. The method eliminates the subjective variability of visual assessment of the gonad condition.

## Materials and Methods

The majority of the specimens used for this analysis were taken in a floating box trap in inshore waters less than 20 m deep off Herring Cove, near the mouth of Halifax Harbour, Nova Scotia. Individual catches ranged from a few to several hundred squid, most of which were female (>90%). A random sample of at least 25 specimens was examined from each catch. These data were supplemented by samples from trawl catches made offshore on the Scotian Shelf (ICNAF Div. 4W) during the autumn of 1976.

More than 150 squid were maintained for periods up to 12 weeks in a 15-m diameter pool in the Aquatron Laboratory at Dalhousie University. They remained in excellent condition and grew at rates comparable to the wild population. All females were approaching advanced stages of maturity within 40 - 60 days after being placed in the pool (O'Dor et al., 1977).

Data collected from all captive females and from about 400 females in field samples included total body weight (BW), dorsal mantle length (ML), nidamental gland length (NGL) and ovary weight (OW). After weighing, the ovaries from fresh specimens were fixed in Bouin's solution and routinely processed for microscopic examination. The developmental stage of an ovum was defined from the stages of oogenesis proposed by Selman and Arnold (1977) for Loligo pealei. The diameters of 30 of the largest ova in each stage were measured.

Fecundity in Illex illecebrosus was estimated using the gonads from six fully mature pre-spawning females which survived in captivity. The total number of eggs present in the females was estimated from an exact count of eggs in four 250 mg samples of mature eggs from the oviducts. The counting and measuring was carried out with a binocular dissecting microscope equipped with an ocular micrometer.

As a test of the proposed index, the maturity condition of late-season females in a sample from the offshore population, collected during 15-23 November 1977 with bottom trawl in depths of 50-450 m on the Scotian Shelf (Amaratunga et al MS 1978), was compared with that of samples from the inshore population taken in October just before their disappearance from the inshore area.

## Results

The gonads of the six mature females examined contained an average of 96 ± 9 g (mean and standard deviation) of mature ova in the oviducts. The ovaries were typically empty of mature ova and made up less than 5% of the total gonad weight. The mature ova weighed an average of 240±20 $\mu$g and were 0.90 mm × 0.63 mm (oblate spheroids). The average fecundity was estimated to be 400,000 ± 40,000 ova for these females whose body weight averaged 443 ± 13 g. Although these were the only females to reach full maturity in captivity, eight other specimens had some mature ova in the oviducts at death. All of the mature ova were in the same size range as those of the fully mature animals. The data of Vovk (1972b) for Loligo pealei and Fields (1965) for Loligo opalescens indicate that the size of the mature ova varies very little and that the number of ova ultimately produced depends on the size of the animal.

The maturation process is actually a continuum, but for certain studies it is convenient to divide it into discrete stages. Indices such as OW/BW and NGL/ML vary continuously, but oogenesis proceeds in distinct developmental stages during maturation (Arnold and Williams-Arnold, 1977). Since the total weight of mature ova produced by an individual appears to be fixed proportion of body weight (approximately 23%) and the weight of a mature ovum varies very little, stages based on artificial limits of gonad weight can be calculated from the maximum size of the ova in a particular developmental stage (Table 1) and from the total number of ova expected for a female of a particular weight. For example, a female weighing 440 g would have an ovary weighing l.20 g if all 400,000 ova were at the maximum size in Stage 1 (no proliferation follicle cells), and the OW/BW ratio would be 0.0026. If all of the ova were at the maximum size in Stage II (proliferation of follicle cells starting), the OW would be 2.45 g and the OW/BW ratio would be 0.0051. Similarly, the OW/BW ratios would be 0.015, 0.09 and 0.22 for females with ova at the maximum size in Stage III (proliferation of follicle cells completed), Stage IV (vitellogenesis), and Stage V (mature) respectively (Table 1). The process of maturation in females can thus be divided into five stages using the OW/BW index based on the development of the ova.

The most obvious structures of the female reproductive system are the nidamental glands. These glands increase in length and weight during maturation (Rowe and Mangold, 1975). The logarithmic relationship between the length of the nidamental gland and the weight of the ovary is

TABLE 1. Characteristics of the maturation stages in female *Illex illecebrosus*.

| Maturity stage | Range of NGL/ML | Range of NG (mm) | Range of OW/BW | Range of OW (g) | Stage[a] | Follicle Size[b] ($\mu$g) | Follicle Dimension[c] (mm) | Distinguishing morphological feature |
|---|---|---|---|---|---|---|---|---|
| I | m $\leqslant$ 0.09 | 11-25 | m $\leqslant$ 0.0026 | 0.14-0.90 | 1 | 2.90 | 0.20 $\times$ 0.14 | NG thin and transparent |
| II | 0.09 < m $\leqslant$ 0.125 | 25-35 | 0.0026 < m $\leqslant$ 0.0051 | 0.68-1.60 | 2 | 5.66 | 0.26 $\times$ 0.16 | NG transparent to translucent, ovary granular |
| III | 0.125 < m $\leqslant$ 0.20 | 25-60 | 0.0051 < m $\leqslant$ 0.015 | 1.10-5.42 | 3 | 16.04 | 0.35 $\times$ 0.25 | NG translucent to opaque |
| IV | 0.20 < m $\leqslant$ 0.35 | 55-90 | 0.015 < m $\leqslant$ 0.09 | 6.0-30.0 | 4 | — | — | NG white, oviducts forming |
| V | 0.35 < m | 110-120 | 0.09 < m | 50.0-104.0 | 5 | 240.0 | 0.90 $\times$ 0.63 | Eggs in oviducts |

[a] As defined by Selman and Arnold (1977).
[b] Calculated using formula 4/3 $\pi a^2 b$, where a and b are the major and minor semi-axes respectively.
[c] Dimensions refer to major and minor axes; measurements of follicles fixed in Bouin's solution.
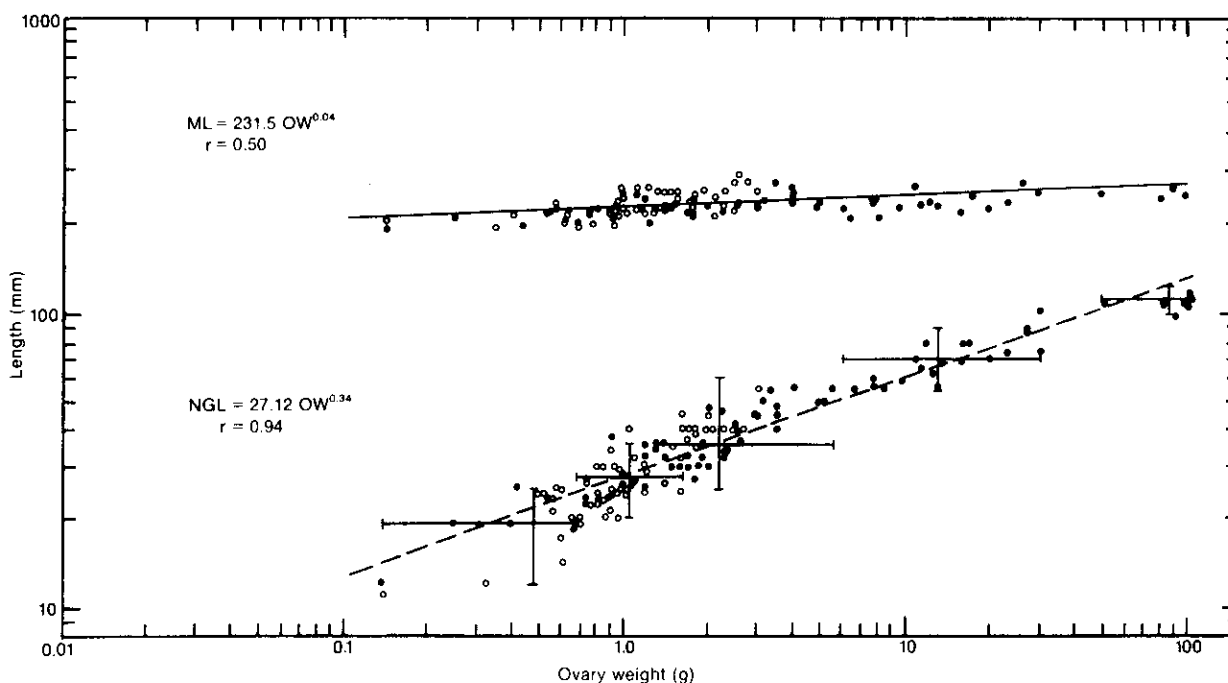


Fig. 1. Relationships of nidamental gland length and mantle length to ovary weight for *Illex illecebrosus* from data obtained during 1976 and 1977. (Open circles refer to females taken in field studies and solid circles refer to females kept in captivity; the horizontal and vertical bars indicate the mean and range of NGL and OW for the stages of maturity defined in Fig. 2.

illustrated in Fig. 1, the correlation coefficient (r) being 0.94. This correlation does not result simply from normal animal growth, as a similar plot of mantle length against ovary weight gave a much lower slope and a poorer correlation (0.50).

The relationship between nidamental gland length and mantle length is shown in Fig. 2 for females classified by maturity stages according to the specified ranges of OW/BW ratios. For the later stages of maturation (III, IV and V), the females can be separated by the NGL/ML index into the same stages as indicated

by the OW/BW index. For the earlier stages (I and II), however, the correspondence between the indices is rather poor, an analysis of variance indicating a significant difference at $p = 0.01$. The variation in body weight probably accounts for much of the difference between the OW/BW and NGL/ML indices at these early stages. In Fig. 1, the horizontal and vertical bars indicate the mean and range of OW and NGL for the maturity stages which are based on the NGL/ML index defined in Fig. 2, indicating a division of the maturation into five discrete stages based on ovarian development. Table 1 summarizes the limits of the NGL/ML
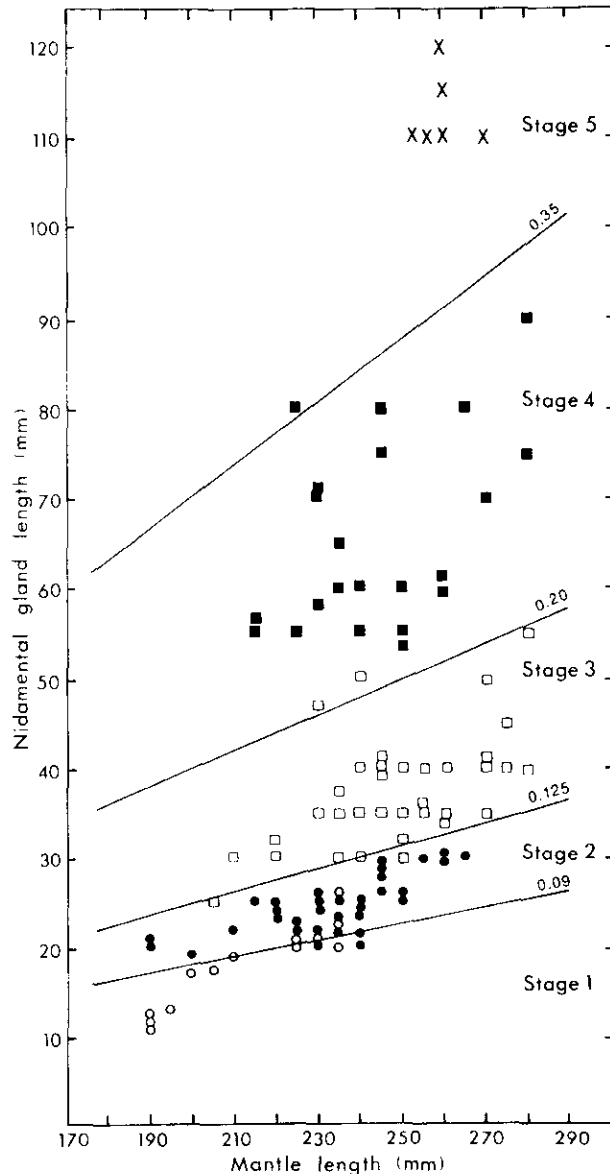
Fig. 2.    Relationship between nidamental gland length and mantle length for female *Illex illecebrosus* classified by ratios of OW to BW as defined in the fourth column of Table 1 for the various maturity stages. (The solid lines represent the limits for the NGL/ML ratios corresponding to the OW/BW classes and define the maturity stages proposed).

index corresponding to distinguishable stages of ova development and relates them to other grossly apparent parameters. Representative specimens in Stages I, II, III and V are illustrated in Fig. 3.

The majority of females in the inshore samples during October 1977 were in Stage II. Those in offshore samples taken about 1 month later were mainly in Stage III with some entering Stage IV. This suggests that the follicle cells proliferate rapidly in the autumn. The data plotted in Fig. 1 indicate that the rate of

maturation in females taken in coastal waters is similar to that observed in females maintained in captivity, at least through Stages I to III.

## Discussion

Mantle length is a standard field measurement for squid, and the nidamental gland, the most obvious structure of the female reproductive system, is now used for determining the sex of squid and as a qualitative indicator of maturity (Vovk, 1972a). Accurate measurements of the nidamental gland length can be made very quickly in the field, and the NGL/ML ratios can be calculated to provide a good indicator of the maturity condition.

Although measurements on fresh specimens are always preferred, the length-based index is better than a weight-based index for frozen samples, as the loss of accuracy in length measurements is much less than that which results from fluid loss when frozen ovaries are removed for weighing.

The nidamental gland develops relative to the ovary throughout maturation, and mantle length increases as the animal grows. Events such as fasting or a recent meal can cause short-term fluctuations in body weight, but the mantle length appears to be a consistent indicator of growth throughout the life cycle. Therefore, the use of the length-based index (NGL/ML) avoids the variability associated with body weight when used as a parameter.

This index may be applicable to a variety of squid species. A similar relationship exists between NGL/ML ratios and the stage of ovarian development in *Loligo pealei*, even to the extent that the numerical values of the index correspond to particular stages (W. R. Macy, personal comm.). If this relationship holds for other species, it could provide a universal maturity index for squid. A simple index based on nidamental gland length and mantle length could eliminate or significantly diminish errors which occur when inexperienced observers try to estimate maturity from gross examination of the gonads or from complex multifactorial indices.

The pattern of hormonal regulation of the maturation process (Wells and Wells, 1959) probably accounts for the improved relationship between the NGL/ML and OW/BW indices in the later stages. The initial development of the reproductive organs (Stages I and II) is not regulated by the gonadotropic hormone and is nearly allometric with overall growth (Buckley, MS 1976), but, because of fluctuation in the body weight, there is high variation in the OW/BW ratios.
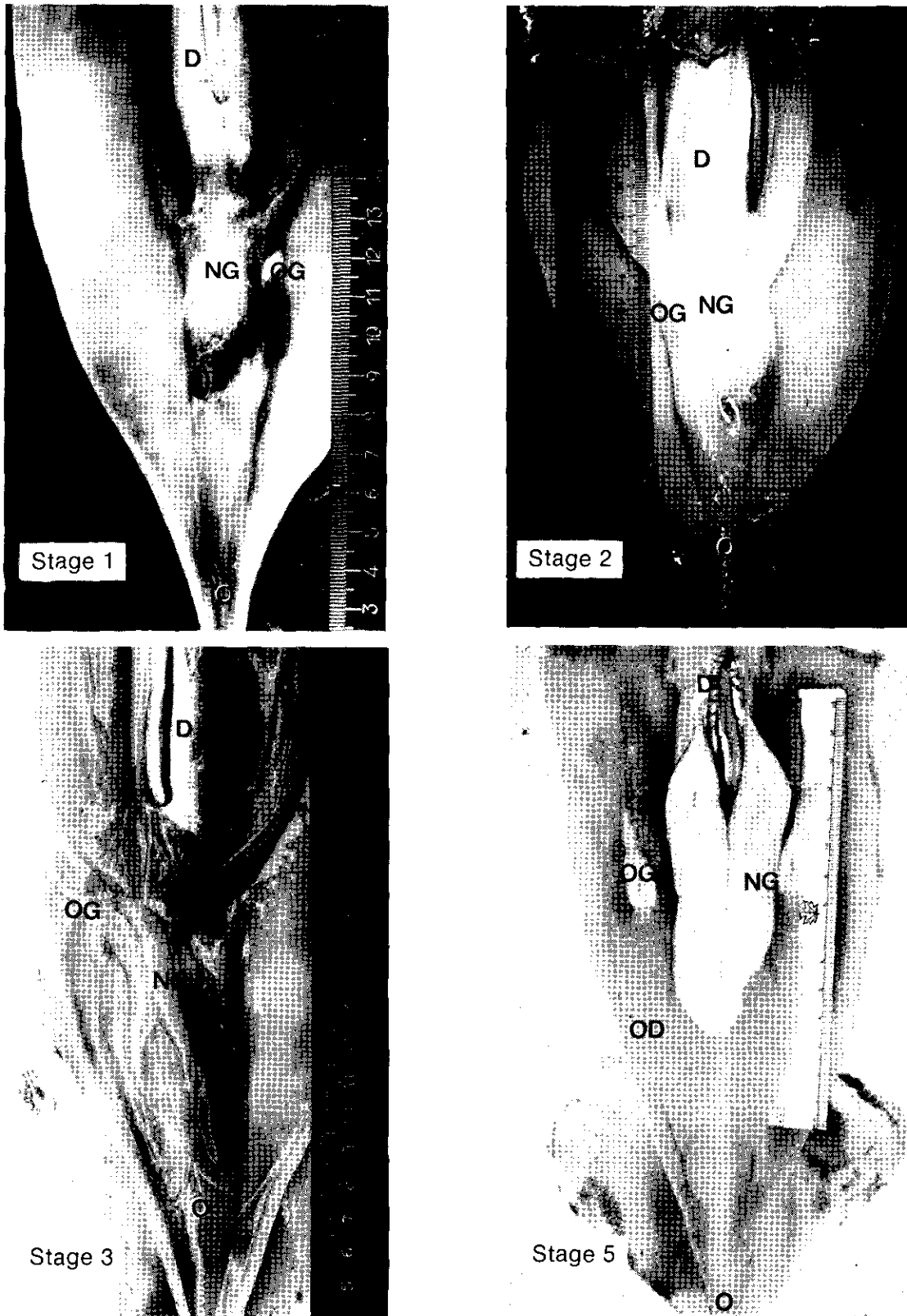
Fig. 3.   Typical specimens of female *Illex illecebrosus* in late spring (Stage 1), summer (Stage 2), late autumn (Stage 3), and the most advanced condition (Stage 5). Reproductive organs represent one-third of the total body weight. (D = digestive gland, NG = nidamental gland, OG = oviducal gland, OD = oviduct, and O = ovary.)

During the lengthy period of development (June–October) through Stage I and II, the ova increase in size slowly. Once the hormonal system is 'turned on' [probably by a photoperiodic cue (O'Dor et al., 1977; Richard, 1967)], the entire reproductive system seems to develop in a 'programmed' manner so that the gonad weight is a fixed proportion of the body weight. In most cephalopods, the later stages of maturation are associated with reduced feeding activity and growth (Wodinsky, 1977), and much of the protein in the yolk is actually made from muscle protein degraded during this period (O'Dor and Wells, 1978). This may account for the apparent fixed relationship between OW and BW in the late stages.

The relationship between OW and BW during the later stages allows the estimation of the spawning potential of a population before full maturity is reached, the egg production being predictable from data on the number and size of females in the population in late November when the females have developed to Stage III and their maturation is controlled by the gonadotropic hormone. For example, if the total biomass of squid at the time were 10,000 tons and the sex ratio 50:50, the estimated egg mass would be about 1,150 tons (23%) or about $4.8 \times 10^{12}$ eggs. Clearly, allowance must be made for mating success and embryo and larval survivorship in predicting future recruitment. Although no data are available at present, further studies on captive populations could provide valuable insights to these critical phases of the life cycle.

The proposed maturation index for females is based on data collected under artificial conditions, but the laboratory data do not conflict with observations on samples taken in the field. It is therefore suggested that the index can be effectively used to analyze the life cycle of female squid. Correlation between the life cycles of both sexes will provide insight to the reproductive patterns of Illex illecebrosus and possibly lead to improved predictions of recruitment.

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# Diurnal Variation in Availability of Witch Flounder, *Glyptocephalus cynoglossus*, and its Effect Upon Estimates of Biomass

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## Abstract

Diurnal variation in the catchability of witch flounder, *Glyptocephalus cynoglossus*, was investigated in three different areas using a different approach for each investigation. All studies indicated that generally larger catches of witch flounder were experienced during periods of darkness but little diurnal variation was found in the size composition of catches. Statistically, however, there appeared to be no reason for segregation of day and night catches for estimates of biomass.

## Introduction

In recent years, greater attention has been given to the stratified-random survey design as a method for determining the relative abundance of demersal fish stocks in the Northwest Atlantic region (Pinhorn, MS 1972). One of the biases connected with these estimates of abundance is the availability of the fish to the fishing gear, which is both a function of the efficiency of the fishing gear itself and the behaviour of the fish species in question. Changes in availability of different fish species have been the subject of many investigations; one of the most widespread is that associated with the diurnal changes in catchability. Sandeman (1969) and Parsons and Parsons (1976) investigated the diurnal variability of beaked redfish and found highly significant differences between day and night catches as well as changes in size composition. Pitt (1967) found that American plaice were more abundant in daytime catches than in those at night. Bagenal (1958) investigated several species and found all to vary in abundance from day to night catches. The purpose of this paper is to determine if there are diurnal variations in the availability of witch flounder, the size composition of fish in the catch, and how they affect estimates of trawlable biomass.

## Materials and Methods

The information presented here is the result of three different surveys designed to investigate diel variations in abundance of redfish. Since witch flounder occupy the same depth and temperature range as redfish (Bowering, 1976), the results of the same surveys are used to determine if diurnal variability in catches of witch occurs and to what extent. The three surveys were carried out in different areas using a different approach for each:

a) **St. Pierre Bank.** This survey was undertaken during a June 1974 cruise of the R/V *A. T. Cameron* with comparative day-night fishing at depths ranging from 101 to 400 fath (1 fath = 1.83 m). The stratification scheme of Pinhorn (MS 1972) was modified to include 101–150, 151–200, 201–300 and 301–400 fath depth contours (Parsons and Parsons, 1976). In 11 of the strata fished, a minimum of 2 randomly selected stations were fished during both day and night. Day sets were made during the period from 1 hr after sunrise to 1 hour before sunset. All sets were made with the No. 41-5 otter trawl with a 6 to 35 mm nylon liner in the codend and were of 30 min duration.

b) **Hermitage Bay, Newfoundland.** This survey was carried out in February 1978 at four fixed stations in depths of 120–160 fath. These stations were fished randomly for a total of 45 sets. However, no station was fished more than once per 12-hour period. The ship, gear and sampling methods were the same as noted for St. Pierre Bank above.

c) **Northeast Grand Bank.** This investigation was conducted in April 1978 with the R/V *Gadus Atlantica*. The gear used was an Engels high-rise otter trawl with a 6-mm nylon mesh liner throughout the codend. A total of 140 fixed stations were fished randomly, 70 stations at

120-180 fath and 70 at 180-240 fath depth. The stations were chosen as a rectangle matrix of stations such that each station was at a radius of 10 miles to its nearest four surrounding stations. Each fishing day was broken down into 10 equal time intervals and each station was fished at the beginning of each interval. This sequence in the fishing pattern was set at the beginning of the survey and was continued to the end. If a station had to be deleted for any reason, the time interval was also omitted and the ship waited for the next time interval to fish the next station. All tows were in the same direction and of 30 min duration, and no station was fished more than once.

All witch flounder catches were weighed, counted, sexed and length measurements taken. Length measurements (total length to the nearest cm) were generally taken of the entire catch or of a representative portion when catches were large.

## Results

### Comparison of day and night catches

For the St. Pierre Bank survey (Table 1), more than twice as many witch flounder per set were caught at night then during the day for both depth ranges (101-300 fath and 301-400 fath). The night-time catches in the Hermitage Bay area were also greater than during the day, although the differences were not as great as in the St. Pierre Bank survey. For the Northeast Grand Bank survey, the average catch at
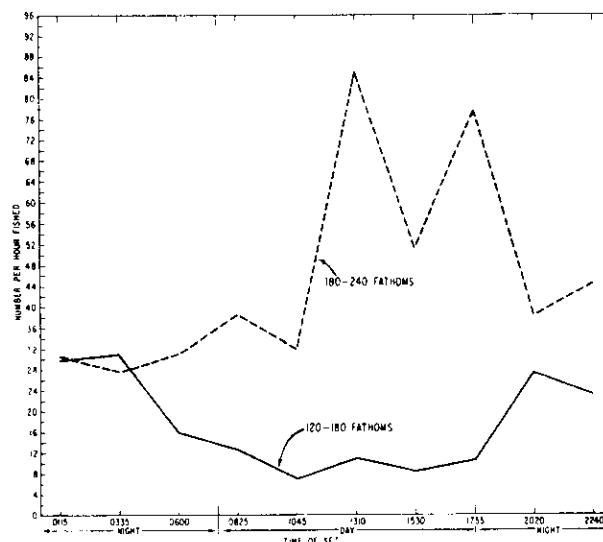


Fig. 1.   Average number of witch flounder caught per hour fished at specified time intervals (Newfoundland Standard Time) over a 24-hr period in two depth ranges on Northeast Grand Bank in April 1978.

night was more than twice as large as during the day for the 120-180 fath depth range. Since the Northeast Grand Bank survey was carried out at specified times during a 24-hr period, it was possible to follow the trends in catch during the day-night period (Fig.1). For the 120-180 fath depth range, catches were higher during darkness, became lower during the daytime and increased again as darkness approached. For the 180-240 fath depth range, on the other hand, catches were on the average much higher during the daytime but fluctuated greatly.

TABLE 1. Mean catch (numbers) per standard set and the relevant statistics for the three surveys used to study diurnal variation in catches of witch flounder in the Newfoundland area.

| Depth | | Mean catch | Variance | Coefficient of variation | 95% confidence limits | |
|---|---|---|---|---|---|---|
| | | | | | Upper | Lower |
| **St. Pierre Bank** | | | | | | |
| 100-300 fath | Day | 9.02 | 114.933 | 1.19 | 31.14 | -13.11 |
| | Night | 20.89 | 734.616 | 1.30 | 79.03 | -37.24 |
| 301-400 fath | Day | 9.16 | 123.417 | 1.26 | 32.50 | -14.18 |
| | Night | 19.23 | 740.183 | 4.42 | 79.11 | -40.65 |
| **Hermitage Bay** | | | | | | |
| | Day | 48.96 | 2940.286 | 1.11 | 167.11 | -69.20 |
| | Night | 57.36 | 2942.400 | 0.95 | 174.53 | -59.80 |
| **Northeast Grand Bank** | | | | | | |
| 120-180 fath | Day | 3.46 | 7.962 | 0.82 | 9.17 | -2.25 |
| | Night | 8.00 | 51.333 | 0.90 | 22.79 | -6.79 |
| 180-240 fath | Day | 13.63 | 347.616 | 1.42 | 52.80 | -25.55 |
| | Night | 9.52 | 61.784 | 0.83 | 25.65 | -6.61 |

## Size composition of day and night catches

In the St. Pierre Bank survey (Fig. 2), there was little difference in the size composition of the day and night catches for both of the depth ranges studied, but slightly more larger fish were caught in the 101–300

fath depth range. In the Hermitage Bay survey (Fig. 3), the size composition of the day and night catches were practically identical, although smaller females (<30 cm) seemed to be slightly more vulnerable to the gear during the night. In the Northeast Grand Bank Survey (Fig. 4), no real difference was apparent in the size
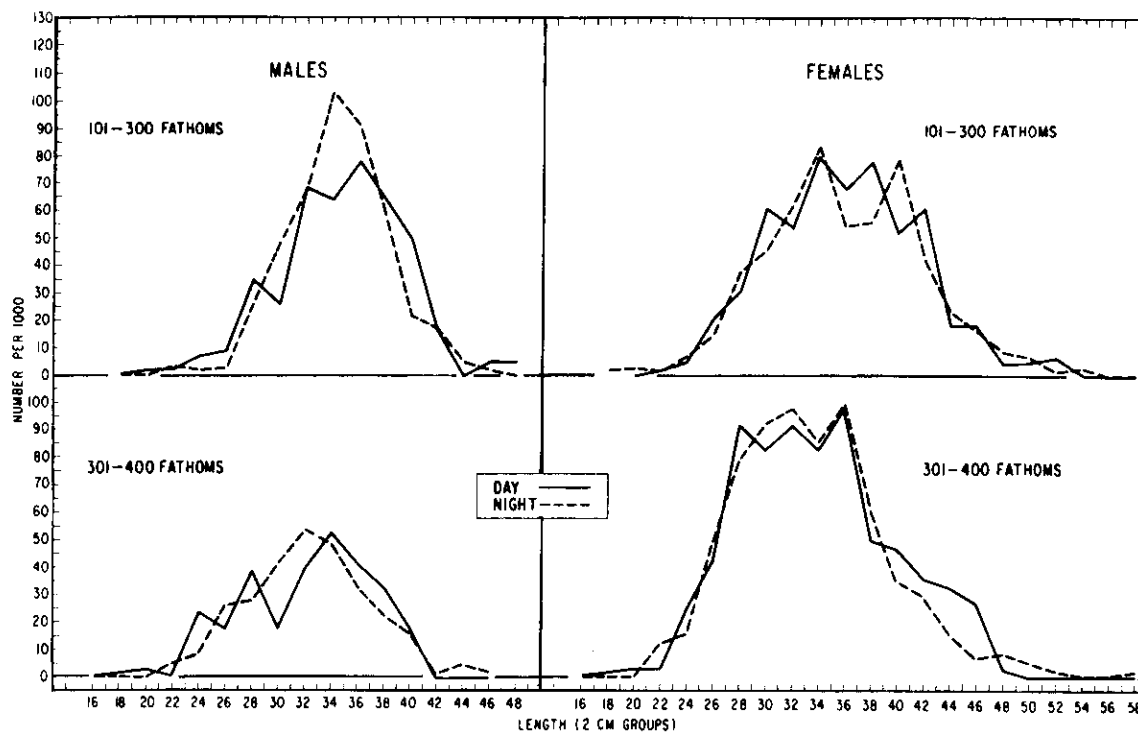


Fig. 2.    Length composition of male and female witch flounder by depth range and time of day on St. Pierre Bank in June 1974.
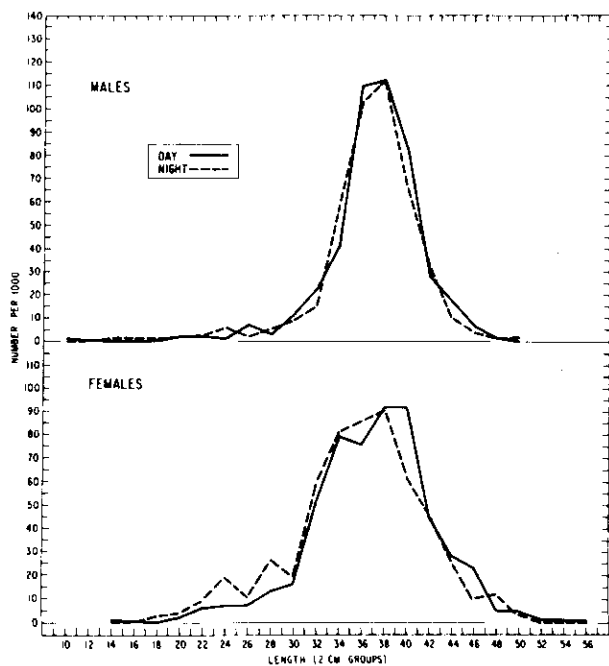


Fig. 3.    Size composition of male and female witch flounder by depth range and time of day in Hermitage Bay in January 1978.
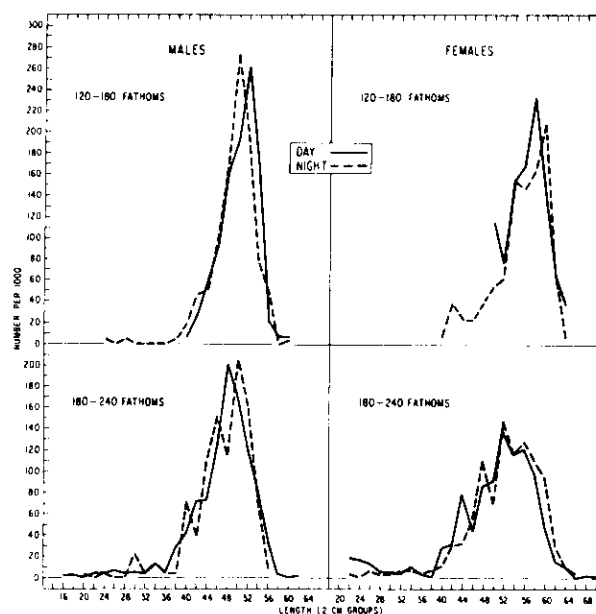


Fig. 4.    Size composition of male and female witch flounder by depth range and time of day on the Northeast Grand Bank in April 1978.

composition of day and night catches at 180-240 fath, but the difference was noticeable at 120-180 fath, in that no males less than 40 cm and no females less than 50 cm in length were taken during day-time fishing. However, within the size ranges common to both day and night catches, the differences in the size composition were insignificant.

## Discussion

Diurnal variation in fish catches has been well documented, but many contradictory findings have been reported for the flatfishes. Pitt (1967) found that American plaice were more plentiful during daylight hours as did Woodhead (1960), whereas Parrish, Blaxter and Hall (1964) reported better catches at night. Both Bagenal (1958) and Beamish (1966) found witch flounder catches to be larger at night as did this study.

One of the important assumptions made in a study such as this is that the survey is being carried out within a closed system and that the only fish being removed are by the fishing operation itself. It is difficult to conceive of no immigration into or emigration from the system or that the species is evenly distributed throughout the system. In particular, the Hermitage Bay survey was probably strongly influenced by emigration as repeated fishing at the same positions would have caused continuous disturbance. The Northeast Grand Bank survey, on the other hand, may have been strongly affected by the patchiness in the distribution of fish throughout the area, thus explaining most of the variation around the mean numbers caught (Table 1) as well as the fluctuation in catches in the 180-240 fath depth range over the 24-hr period.

Although there was a tendency for night catches to be larger than day catches in most cases, the coefficients of variation are consistently high and the 95% confidence limits of all mean day and night catches overlap (Table 1). This could be attributed to inadequate sampling, although the sampling was extensive relative to the cost and the time consumed. It is unlikely that sampling in random stratified biomass surveys could be more extensive than in these experiments, with the consequence that variances would generally be expected to be large. Statistically, there appears to be no difference between day and night catches of witch flounder in the areas surveyed and therefore no reason to apply conversion factors to adjust for the apparent differences within depth strata.

## Acknowledgements

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# Sexual Maturity and Spawning in Haddock, *Melanogrammus aeglefinus*, of St. Pierre Bank

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## Abstract

Investigations on sexual maturity and spawning in haddock, *Melanogrammus aeglefinus*, of St. Pierre Bank (ICNAF Subdiv. 3Ps) were carried out from 1947 to 1975. Mean lengths at 50% maturity ($L_{50}$) were lowest in the 1952–58 period when the stock was dominated by the very large but slow-growing 1949 year-class, with $L_{50}$ values averaging about 8 cm less for males than for females. Mean ages at 50% maturity ($A_{50}$) were low in 1952–58 when there was heavy fishing on the 1949 year-class, and following an increase in 1959–64, they continued to decline during 1965–75 to levels more than a year less than the average for 1948–64. These recent declines coincided with decreasing numbers in the population and increasing growth rates. In each of the periods considered, the $A_{50}$ for males was at least a year less than for females. Males were rarely mature at age 2 and females at age 3. Maturation in males occurred mainly from ages 4 to 6 during 1948–64 and from ages 3 to 5 during 1965–75, and in females mainly from ages 5 to 8 during 1948–64 and from ages 4 to 6 during 1965–75. Faster growing fish of an age-group matured at an earlier age than the slower-growing fish. Spawning extended from March–April to August–early September, with most spawning probably from mid-June to mid-July. Average weights of testes in mature males were greatest in April and average weights of ovaries of mature females were greatest in late May–early June in the early part of the spawning period.

## Introduction

Data on haddock catches in Div. 3P, mainly St. Pierre Bank, are available from ICNAF statistics since 1953. Before this time catches were probably quite small, but they increased rapidly to a peak of 58,000 metric tons in 1955 as a result of the exceptionally successful 1949 year-class which was dominant in the increased catches during 1954–56. The haddock catch declined rapidly to 6,000 tons in 1957 and then gradually to 450 tons in 1976 and 820 tons in 1977 (Templeman and Bishop, 1979).

In the 1947–75 period, research vessels of the Newfoundland Biological Station usually carried out annual surveys of the haddock population on St. Pierre Bank, collecting data related to sexual maturity which are presented and analyzed in this paper. Shestov (1967) and Serebryakov (1971) also carried out studies related to haddock spawning on this bank.

## Materials and Methods

The research vessels *Investigator II* in 1947–65 and the *A. T. Cameron* in 1960–75 used bottom otter trawls in surveys for haddock on St. Pierre Bank and its slopes to depths of 275–300 m, as described by Templeman and Bishop (1979). Maturity stages were determined by the authors or under the supervision of the authors by experienced technicians and scientists. The maturity stages and the measuring and weighing methods are described in detail by Templeman *et al.* (1978b), the trawl details by Templeman and Bishop (1979), and the ageing methods by Templeman *et al.* (1978a) and Templeman and Bishop (1979). [In Templeman *et al.* (1978b), table 1, under "Female", "Spent P Mat N" should be "Spent P Mat A–N".]

Although some data on maturity stages and gonad weights were obtained at other times, most of the data were collected in February–June close to or during the spawning season, in order to facilitate the separation of mature and immature fish and to minimize the differences due to plus growth in the year of capture.

For each survey year, random length frequencies of the research catches in February–June were combined and the total length frequency converted to numbers at length per mille, from which an age, length, maturity table was calculated by applying the appropriate age-length key for each sex. After the

combination of the per mille data for periods of years, the period frequencies were weighted by the numbers of haddock sampled in the relevant periods.

The analyses of the maturity data for length ($L_{50}$) and age ($A_{50}$) at 50% maturity were carried out by the probit method (Mather, 1946; Fisher and Yates, 1953; Fleming, 1960; Templeman *et al.*, 1978b). The variances, from which the standard errors (SE) of the $L_{50}$ and $A_{50}$ values were derived, were calculated by the large sample formula given by Fisher and Yates (1953). To justify the use of that formula, the goodness of fit of the transformed probit values was determined by $x^2$. In the few cases where the calculated $x^2$ exceeded $x^2$ for $P = 0.05$, the standard errors of the $L_{50}$ and $A_{50}$ values were multiplied by $\sqrt{x^2/n}$, as suggested by Fisher and Yates (1953).

## Results

### Sexual maturity and fish length

The length frequencies by sex for immature and mature haddock in the various time periods (Fig. 1) indicate that males first mature at a smaller size than females. Although the smallest mature males were 4-10 cm smaller than the smallest mature females, occasional males up to 66-67 cm in length were

TABLE 1. Mean length (cm) at 50% maturity ($L_{50}$) and standard error (SE) of $L_{50}$ for male and female haddock from St. Pierre Bank in February–June 1948-75. (See Fig. 1 for numbers of fish examined.)

| Years | Male | | Female | |
|---|---|---|---|---|
| | $L_{50}$ | $SE(L_{50})$ | $L_{50}$ | $SE(L_{50})$ |
| 1948–51 | 42.75 | 0.717 | 50.35 | 0.577 |
| 1952–58 | 36.64 | 0.425 | 44.79 | 0.368 |
| 1959–64 | 41.55 | 0.368 | 48.43 | 0.401 |
| 1965–68 | 42.94 | 0.531 | 50.05 | 0.894 |
| 1969–75 | 40.14 | 0.451 | 50.12 | 0.531 |

assigned to the immature group, but no immature females were recorded at lengths greater than 58-59 cm.

The length at which 50% of the haddock were sexually mature was about 7-10 cm smaller for males than for females (Table 1, Fig. 2) the difference being significant for each of the periods considered ($P<0.001$). The low $L_{50}$ values in 1952-58 for both males and females are significantly different ($P<0.001$) from the higher values for each of the other four periods. Also, for males, the $L_{50}$ values in 1948-51, 1959-64 and 1965-68 are significantly higher than the value for 1969-75 ($P<0.005$, $<0.02$ and $<0.001$ respectively), and the $L_{50}$ value for 1965-68 is significantly higher than that for 1959-64 ($P<0.05$), but the $L_{50}$ value for 1948-51 is not significantly different (at $P = 0.05$) from those for 1959-64 and 1965-68. For
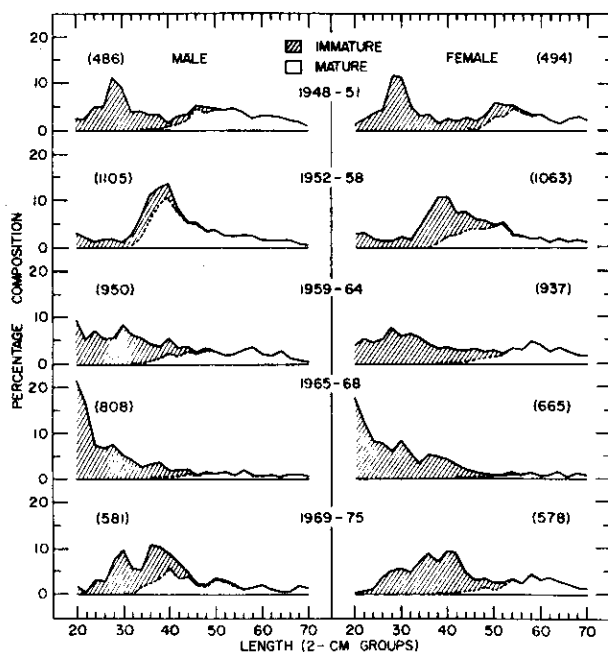


Fig. 1.   Percentage frequencies of immature and mature haddock of St. Pierre Bank by sex and 2-cm length groups (20-21 cm, etc.), February–June 1948-75. (The numbers examined for sexual maturity are given in parentheses. Fish below 20 and above 71 cm in length are omitted.)
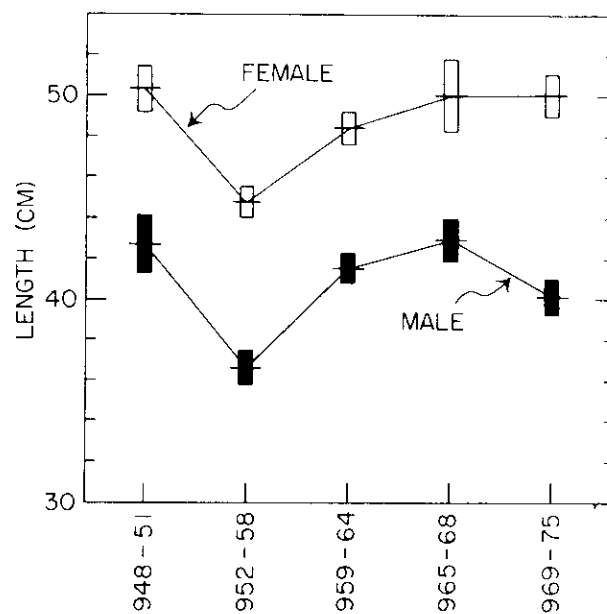


Fig. 2.   Trends in mean length at 50% sexual maturity for male and female haddock of St. Pierre Bank, February–June 1948-75. (The vertical bars represent the 95% confidence limits, i. e. $L_{50}$ $\pm 2$ standard errors. See Fig. 1 for numbers of fish examined.)

females, the $L_{50}$ values for 1948-51 and 1969-75 are significantly higher than the value for 1959-64 (P<0.01 and <0.02). The $L_{50}$ value for 1965-68 is not significantly different from that of 1959-64, and the values for 1948-51, 1965-68 and 1969-75 are not significantly different from one another.

## Variation in age at sexual maturity

The sexual maturity data are compared in periods of 4-7 years (Table 2). Although it would have been desirable to use approximately equal periods of years, as was done in similar studies on Grand Bank haddock (Templeman et al., 1978b), the very abundant 1949 year-class so dominated the maturity data for St. Pierre Bank in 1952-58 that it was necessary to treat the whole period as a unit. It was also necessary to combine data for the 1969-75 period because of the small numbers of haddock older than age 5 for males and age 6 for females in the samples taken during the whole period.

No female and only one male haddock was recorded as being mature at age 1 in 619 male and 415 female specimens examined. The male specimen called mature was 20 cm long. The observation was made at sea by a technician and not checked by a scientist. Since 54 males of 22-27 cm and 53 of 28-35 cm from the same cruise in 1965 were all classified as immature, it is highly probable that the 20-cm specimen was recorded as mature in error. The only males classed as sexually mature at age 2 were 1% of the samples in 1969-75 (Table 2). No females were mature at age 2 and only 1% at age 3 in 1969-75. In general, sexual maturity began at age 3 for males and in smaller percentages at age 4 for females.

In the maturing age range, the percentages mature at the same age tended to increase from the 1948-64 periods to the 1965-75 periods (Table 2). However, in the 1952-58 period, considerably higher percentages of males were mature at ages 4 and 5 and females at age 6 than in either of the adjacent periods. For comparisons of significance of the various percentages mature, chi-square values were calculated from 2 × 2 contingency tables as in section 8.10 of Snedecor and Cochran (1967), with Yates' correction for continuity. The values used for each set of data compared were the numbers mature and the numbers immature.

For males, the maturity value at age 3 for 1965-75 (Table 2) is significantly greater than that for each of the other four periods (P<0.001), and the value for 1965-68 is significantly greater than that for 1959-64 (P<0.05). At age 4, the maturity value for 1969-75 is significantly greater than that for each of the three periods between 1948 and 1964 (P<0.01), the value for 1965-68 is greater than those for 1959-64 (P<0.001) and 1948-51 (P<0.05), and the value for 1952-58 is greater than that for 1959-64 (P<0.001). At age 5, the maturity values for 1965-68 and 1969-75 are significantly greater than those for 1959-64 (P<0.001) and 1948-51 (P<0.05), and the value for 1952-58 is greater than that for 1959-64 (P<0.001). Other differences in maturity values between periods for each of ages 3, 4 and 5, and all differences for each of ages 6-9 are not significant at the 0.05 level.

For females, the maturity value at age 4 for 1969-75 (Table 2) is significantly greater than those for 1952-58 and 1959-64 (P<0.001) and 1948-51 (P<0.05), and the

TABLE 2. Percentages of sexually mature haddock by age and sex on St. Pierre Bank in February-June 1948-75. (Numbers of specimens examined in parentheses).

| Age (yr) | 1948-51 | 1952-58 | 1959-64[a] | 1965-68[b] | 1969-75[c] |
|---|---|---|---|---|---|
| | | | **Male** | | |
| 2 | 0 (158) | 0 (84) | 0 (258) | 0 (274) | 1 (153) |
| 3 | 5 (51) | 5 (104) | 3 (130) | 11 (122) | 35 (264) |
| 4 | 37 (14) | 54 (212) | 30 (98) | 77 (25) | 80 (49) |
| 5 | 63 (11) | 87 (239) | 66 (84) | 98 (33) | 93 (57) |
| 6 | 94 (36) | 98 (177) | 93 (47) | 98 (22) | 100 (24) |
| 7 | 97 (50) | 92 (94) | 100 (36) | 100 (18) | 100 (12) |
| 8 | 100 (6) | 97 (47) | 100 (30) | 100 (12) | 100 (7) |
| 9 | 100 (6) | 94 (41) | 100 (9) | 100 (9) | 100 (3) |
| | | | **Female** | | |
| 2 | 0 (174) | 0 (96) | 0 (254) | 0 (231) | 0 (103) |
| 3 | 0 (49) | 0 (113) | 0 (139) | 0 (164) | 1 (269) |
| 4 | 0 (19) | 0 (188) | 1 (75) | 22 (23) | 28 (58) |
| 5 | 30 (20) | 25 (183) | 27 (79) | 56 (19) | 88 (68) |
| 6 | 28 (24) | 78 (161) | 53 (38) | 100 (17) | 100 (53) |
| 7 | 96 (66) | 81 (132) | 84 (34) | 100 (12) | 100 (17) |
| 8 | 82 (12) | 98 (61) | 100 (32) | 100 (8) | 100 (14) |
| 9 | 100 (5) | 100 (34) | 100 (9) | 100 (15) | 100 (5) |

[a] No samples in 1961, and 1962 omitted because very few mature haddock were examined.
[b] No samples in 1966.
[c] No sexing in 1970, and no samples in 1971.

value for 1965-68 is greater than those for 1952-58 and 1959-64 (P<0.01). At age 5, the maturity value for 1969-75 is significantly greater than each of those for the four periods from 1948 to 1968 (P<0.01), and the value for 1965-68 is greater than those for 1952-58 and 1959-64 (P<0.001 and <0.05). At age 6, the maturity value for 1969-75 is significantly greater than each of those in the three periods from 1948 to 1964 (P<0.001), and each of the values for 1965-68 and 1952-58 is greater than those for 1948-51 and 1959-64 (P<0.01). Other differences in maturity values between periods for each of ages 4, 5, and 6, and all differences for each of ages 7 and 8 are not significant at the 0.05 level, except that the value for age 7 in 1948-51 is greater than that for 1952-58 (P<0.05).

It is evident that differences in maturity values are not generally significant at ages where nearly all fish in all periods are immature or almost all mature, but significant period differences between maturity values are apparent at ages 3-5 for males and ages 4-6 for females, during which a rapid transition occurs from immature to mature. At these ages for males and females respectively (Table 2), it is evident that haddock matured earlier in the 1965-68 and 1969-75 periods than in the three preceding periods. The transition to the mature condition for males occurred mainly over ages 4-6 in 1948-64 and over ages 3-5 in 1965-75. For females, the transition occurred mainly over ages 5-8 in 1948-64 and over ages 4-6 in 1965-75. Although males matured at a younger age than females, all female haddock aged 9 and older were mature of 385 specimens aged 9-20 examined, whereas one age 9 male at 68 cm, two age 10 at 61 cm and one age 11 at 58 cm were recorded as immature. All 141 males aged 12-20 were mature.

The ages of males and females at 50% maturity show a slight decline from the 1948-51 period to 1952-58, an increase in 1959-64 and a definite decline in the two most recent periods (Table 3, Fig. 3). On the average, males matured about 1.3 years earlier than females during the three periods spanning 1948-64
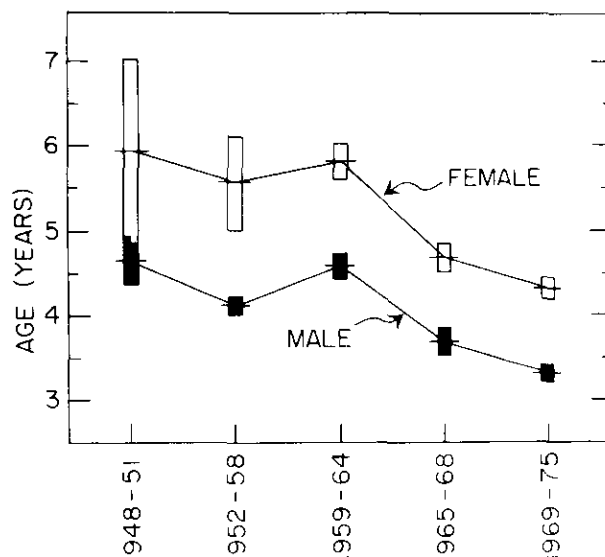


Fig. 3.   Trends in mean age at 50% sexual maturity for male and female haddock of St. Pierre Bank, February-June 1948-75. (The vertical bars represent the 95% confidence limits, i. e. $L_{50}$ ± 2 standard errors. See Table 2 for numbers of fish examined.)

and about 1.0 years earlier than females in the two most recent periods. The difference in age at 50% maturity between males and females is highly significant in each of the four periods from 1952 to 1975   (P<0.001) and significant also in the 1948-51 period   (P<0.025).

The $A_{50}$ values for the first three periods are significantly greater than those for the two later periods, with P<0.001 in all cases for males, and P<0.005 for females except between the first and fourth periods where P<0.025. Although the $A_{50}$ values for females in the first three periods were not significantly different from each other due to the high variance associated with the values in 1948-51 and 1952-58, that for males in 1952-58 was significantly lower than those for the two adjacent periods (P<0.001). The significance of the low $A_{50}$ value for males in 1952-58 implies that the decline for females in this period may also be real.

## Sexual maturity and growth

Only the 1949 year-class had enough maturing fish for use in assessing the effect of growth in length on age at maturity (Table 4). The variance test for homogeneity of a binomial distribution was used to test the null hypothesis that fish of different sizes in an age-group mature at the same rate (Snedecor and Cochran, 1967). In all age-groups considered, the larger fish had higher percentages mature than smaller fish of the same age. These differences within groups were significant or highly significant for all three age-groups of females.

TABLE 3.  Mean age (yr) at 50% maturity ($A_{50}$) and standard error (SE) of $A_{50}$ for male and female haddock from St. Pierre Bank in February-June 1948-75, based on data in Table 2.

| Years | Male | | Female | |
|---|---|---|---|---|
| | $A_{50}$ | SE ($A_{50}$) | $A_{50}$ | SE($A_{50}$) |
| 1948-51 | 4.65 | 0.138 | 5.94 | 0.542[a] |
| 1952-58 | 4.11 | 0.050 | 5.57 | 0.276[a] |
| 1959-64 | 4.58 | 0.076 | 5.82 | 0.108 |
| 1965-68 | 3.69 | 0.078 | 4.68 | 0.087 |
| 1969-75 | 3.32 | 0.053 | 4.32 | 0.065 |

[a] $x^2$ (as a measure of fit) exceeded $x^2$ for P = 0.05, and SE ($A_{50}$) multiplied by $\sqrt{x^2/n}$. (See Materials and Methods section for explanation.

TABLE 4. Relative proportions sexually mature at different length ranges for various ages in the 1949 year-class of male and female haddock from St. Pierre Bank in March–June 1953-56. (Data sets designated by * and ** indicate significance of the indicated relationship between sexual maturity and length range at probability levels of 0.025 and 0.005. Numbers of specimens in parentheses.)

| Male | | | | Female | | | | |
|---|---|---|---|---|---|---|---|---|
| Age 4 | | Age 5 | | Age 5 | | Age 6 | | Age 7 | |
| Length (cm) | % mature | Length (cm) | % mature | Length (cm) | % mature | Length (cm) | % (mature) | Length (cm) | % mature |
| 32–37 | 54 (98) | 34–39 | 88 (83) | 36–41 | 27 (75)** | 36–45 | 70 (70)** | 40–49 | 71 (63)* |
| 38–41 | 52 (86) | 40–43 | 87 (87) | 42–47 | 21 (66)** | 46–57 | 92 (66)** | 50–63 | 92 (38)* |
| 42–49 | 69 (16) | 44–55 | 95 (43) | 48–55 | 57 (23)** | | | | |

## Sexual maturity stage and spawning period

As indicated by Templeman et al. (1978b), maturity stages in relation to spawning can be determined more readily and precisely in females than in males, and hence the spawning season is best defined from the female spawning stages (Table 5). Spawning apparently begins in March or April. The relatively large percentage of females (12%), designated as Spent P in March, occurred in maturity determinations on shipboard, and, judging from the small percentage in Mat B-P and the lack of fish in the Mat C-P category, these haddock were probably mainly Spent L showing little or no recovery from the previous year's spawning. (Similarly for males, the Spent P Mat A-N fish in March and April were probably in the Spent L Mat P stage and should be in the Mat A-P column of Table 5.) With 89% of the females in the Mat A-P (opaque egg) stage in April, it is evident that little spawning occurred before or during April. Females in the Mat C-P stage and some in the late Mat B-P stage

were probably spawning (Templeman et al., 1978b), and thus at least 74% of the mature females (including 43% Spent P) were in or very near the spawning stage during 21 June–3 July. In September and October, all of the small number of females examined were spent. Recovery from spawning occurred in some males at least as early as June, whereas only 2-5% of the females were in the Mat A-N stage by September-October.

## Variation in gonad weight by maturity stage and season

The weight of the testes (including vasa deferentia and contents) of mature males in relation to the gutted and gilled weight of the fish was greatest in April at 2.4%, declining to 1.4% by late June–early July and to 0.5% in October when spawning was over (Table 6). The weight of the ovary of mature females, on the same basis as for males, was greatest at 11.4% in late May–early June near the peak of the spawning season,

TABLE 5. Percentages of maturing and mature male and female haddock from St. Pierre Bank in various stages of sexual maturity 1947-75. [See Templeman et al. (1978b) for explanation of maturity terms.]

| Month | Number of mature fish | Sp L | Mat A-P[a] | Mat B-P[a] | Mat C-P[a] | Partly Sp P | Sp P' | Sp P Mat A-N[a] | Mat A-N[a] | Maturing and spawning | Recovery after spawning |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Male** | | | | | | | | | | | |
| 12–28 Feb | 68 | 0 | 100 | — | — | 0 | 0 | 0 | 0 | 100 | 0 |
| 17–29 Mar | 205 | 0 | 85 | — | — | 4 | 10 | 1 | 0 | 89 | 11 |
| 1–30 Apr | 232 | 0 | 83 | — | — | 9 | 2 | 6 | 0 | 92 | 8 |
| 16–29 May | 39 | 0 | 84 | — | — | 13 | 0 | 3 | 0 | 97 | 3 |
| 1–19 Jun | 583 | 0 | 50 | — | — | 24 | 3 | 22 | 1 | 74 | 26 |
| 21 Jun–2 Jul | 473 | 0 | 25 | — | — | 23 | 19 | 31 | 2 | 48 | 52 |
| 17 Oct | 37 | 0 | 0 | — | — | 0 | 0 | 22 | 78 | 0 | 100 |
| 30 Nov–4 Dec | 10 | 0 | 0 | — | — | 0 | 0 | 50 | 50 | 0 | 100 |
| **Female** | | | | | | | | | | | |
| 12–13 Feb | 1 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 |
| 17–29 Mar | 117 | 0 | 83 | 5 | 0 | 0 | 12 | 0 | 0 | 88 | 12 |
| 1–30 Apr | 210 | 2[b] | 89 | 6 | 1 | 0 | 2 | 0 | 0 | 98[b] | 2 |
| 16–29 May | 49 | 0 | 43 | 29 | 10 | 0 | 18 | 0 | 0 | 82 | 18 |
| 1–19 Jun | 389 | 0 | 25 | 34 | 28 | 4 | 9 | 0 | 0 | 91 | 9 |
| 21 Jun–2 Jul | 419 | 0 | 7 | 19 | 23 | 8 | 43 | 0 | 0 | 57 | 43 |
| 5–30 Sep | 41 | 0 | 0 | 0 | 0 | 0 | 98 | 0 | 2 | 0 | 100 |
| 17 Oct | 41 | 0 | 0 | 0 | 0 | 0 | 95 | 5 | 0 | 0 | 100 |

[a] Mat B-P and Mat C-P not applicable to males, for which Mat A-P = Mat P and Mat A-N = Mat N.

[b] It is assumed that the two Spent L fish will spawn in the year of examination.

TABLE 6. Percentage gonad weight relative to gutted and gilled weight for sexual maturity stages of haddock from St. Pierre Bank in 1947–60. (Numbers of specimens in parentheses. Data used were from fish 32 cm or larger in length.)

| Maturity stage | Percentage gonad weight of gutted and gilled weight | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 13 Feb | | 9 Apr | | 24 May–10 Jun | | 24 Jun–2 Jul | | 17 Oct | |
| **Male** | | | | | | | | | | |
| Imm | — | | 0.1 | (6) | 0.1 | (60) | 0.1 | (28) | 0.1 | (2) |
| Mat P | 1.3 | (40) | 2.4 | (40) | 1.6 | (144) | 1.8 | (48) | — | |
| Partly Sp P | — | | — | | 2.2 | (62) | 1.5 | (69) | — | |
| Spent P | — | | — | | — | | 0.3 | (13) | — | |
| Sp. P, Mat N | — | | — | | — | | 0.9 | (39) | 0.7 | (8) |
| Mat N | — | | — | | — | | — | | 0.5 | (27) |
| Total mature | 1.3 | (40) | 2.4 | (40) | 1.8 | (206) | 1.4 | (169) | 0.5 | (35) |
| **Female** | | | | | | | | | | |
| Imm | 0.7 | (58) | 0.5 | (8) | 0.6 | (177) | 0.6 | (105) | 0.9 | (21) |
| Mat A-P | — | | 5.6 | (44) | 11.2 | (58) | 11.7 | (14) | — | |
| Mat B-P | — | | 9.1 | (1) | 13.3 | (62) | 14.6 | (44) | — | |
| Mat C-P | — | | — | | 14.2 | (47) | 16.4 | (23) | — | |
| Partly Sp P | — | | — | | 4.4 | (8) | 3.8 | (16) | — | |
| Spent P | — | | — | | 1.5 | (18) | 1.6 | (64) | 1.6 | (39) |
| Sp P, Mat A-N | — | | — | | — | | — | | 2.4 | (2) |
| Total mature | — | | 5.7 | (45) | 11.4 | (193) | 8.4 | (161) | 1.6 | (41) |

declined to 1.6% in October and subsequently increased upon recovery from spawning to 5.7% in April. Ovaries in the Mat C-P stage were heavier than those in the Mat B-P stage and the latter heavier than those in the Mat A-P stage.

## Discussion

### Length and age at sexual maturity

The low $L_{50}$ values in the 1952–58 period (Fig. 2) are associated with slow growth, due largely to the exceptionally large 1949 year-class which dominated the maturing haddock of the period. At the same time, the age at maturity was slightly lower than in the adjacent periods (Fig. 3). Similar reduction in length at maturity also occurred in Grand Bank haddock in periods of successful year-classes and slow growth (Templeman et al., 1978b). Other differences in $L_{50}$ between periods were due to the interaction between changes in age at maturity and the relative growth of haddock in the periods. Because males mature on the average at least a year earlier than females, the trend for females may be somewhat different from that for males. The greater $L_{50}$ values for female than for male fish are due to the greater age of females at sexual maturity and to their greater growth because of their later maturity (Templeman and Bishop, 1979). The relatively high $L_{50}$ values in the two most recent periods, in spite of the lower age at maturity, were due to the relatively high growth rate in these periods. The earlier age at maturity, related to faster growth, is associated with the usual occurrence that the faster-growing haddock of an age-group tend to have a higher percentage of mature individuals than the slower-growing fish (Table 4; and Templeman et al., 1978b).

The $L_{50}$ values for St. Pierre Bank haddock were usually higher than those for the Grand Bank. In the slowest-growing period for both areas, the $L_{50}$ values were higher for St. Pierre Bank, but, in the recent periods of fast growth on both banks (since 1965), the $L_{50}$ values were slightly lower for females and considerably lower for males on St. Pierre Bank than on Grand Bank (Table 1; and Templeman et al., 1978b), but at the same time the $A_{50}$ values were lower for St. Pierre Bank than for Grand Bank haddock. The usually higher $L_{50}$ value for St. Pierre Bank haddock is an indication of faster growth on this bank than on Grand Bank.

The lower $A_{50}$ values in 1952–58, compared with those for the adjacent periods (Fig. 3), occurred when the growth of the maturing age-groups was depressed considerably (Templeman and Bishop, 1979), apparently due to the abundant 1949 year-class which made up almost all of the maturing haddock during the period, and to lower temperatures. Also, the intensity of fishing increased greatly during 1953–56. Similarly, the $A_{50}$ values for Grand Bank haddock declined as successful year-classes appeared, the growth rate decreased, and the fishery became more intense (Templeman et al., 1978b).

The substantial decline in $A_{50}$ during the 1965–68 and 1969–75 periods for both male and female haddock

on St. Pierre Bank occurred as growth rapidly increased (Templeman and Bishop, 1979). Similarly, a decline in age at maturity with increasing growth rate occurred on the Grand Bank as haddock became scarce (Templeman et al., 1978b). However, the $A_{50}$ values for St. Pierre Bank in the two most recent periods were considerably lower than those for Grand Bank in the fast-growing 1963–66 period. Although the analysis of maturity data for Grand Bank haddock extended only to 1966, there was evidence that the $A_{50}$ for males was declining rapidly in 1968 under conditions of very fast growth (Templeman et al., 1978b), and presumably the $A_{50}$ for females would have declined in the following year or two.

For St. Pierre Bank, as for Grand Bank (Templeman et al., 1978b), although males matured on the average at least a year earlier than females, immature males were recorded at greater ages and larger sizes than females. Occasionally in haddock the condition of the gonad is such that the sex cannot be distinguished. It is possible therefore that the few large males of mature size, recorded as immature, should have been noted as undifferentiated without assignment of sex, and that this condition very likely applies to most or all males recorded as immature after age 7 from St. Pierre Bank.

## Sexual maturity and growth

For St. Pierre Bank haddock, it was evident (significantly so for females) that faster-growing fish matured at an earlier age than slower-growing fish. Similar results reported for other areas (Raitt, 1933; Clark, 1959; Sonina, 1969) and for Grand Bank are discussed by Templeman et al., (1978b).

## Sexual maturity stages and spawning period

Haddock spawning on St. Pierre Bank began in March or April and was probably at its peak in June and early July. Although data for August are lacking, it is apparent from the presence of Mat A-P females in late June–early July that some spawning continues until August. Shestov (1967) reported that the first ripe individuals on St. Pierre Bank appear toward the end of March, that the peak of spawning is in the latter part of June and early July, and that the end of spawning is at the beginning of September. Thus the spawning period presumably extends from late March to August or early September with most spawning probably occurring from mid-June to mid-July. The spawning period on St. Pierre Bank is therefore not greatly different from that on Grand Bank (Templeman et al., 1978b).

## Variation on gonad weight

Gonad weights relative to fish weights for St. Pierre Bank have the same pattern as for Grand Bank, but the ratios are higher for St. Pierre Bank in each of the three female maturity stages (Mat A-P, B-P and C-P), presumably due to the relatively larger sizes of mature females on St. Pierre Bank.

## Acknowledgements

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# Age, Growth, Year-class Strength, and Mortality of Haddock, *Melanogrammus aeglefinus*, on St. Pierre Bank in 1948-75 and their Relation to the Haddock Fishery of this Area

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## Abstract

Data on age, growth, year-class strength and mortality of haddock, *Melanogrammus aeglefinus*, from St. Pierre Bank, mainly obtained from research-vessel surveys in February-June of 1948-75, are considered in relation to the haddock fishery of the area. In the period 1953-77, for which statistics are available, the only large catches on St. Pierre Bank were in 1954-56. These were related to the exceptionally large 1949 year-class. From the peak of 58,000 metric tons in 1955, the catch declined, rapidly at first and then gradually, to 820 tons in 1977. Research-vessel catch per effort followed essentially the same pattern but the large numerical catches usually occurred several years earlier than large commercial catches. Only the 1949 year-class was great enough to produce large commercial catches, but the 1942, 1946-47 and 1955-58, 1962, 1964 and 1966 year-classes were relatively successful compared with year-classes other than that of 1949. After 1949 there were five successive years (1950-54) of almost complete year-class failure.

No consistent relationship was apparent between year-class success and the relative quantities of spawning females, iceberg number, or water temperature. After the fishery developed, negligible quantities of haddock survived to age 8 or older. The total mortality coefficient (Z) increased from 0.76 for the 1942 year-class in 1952-57 to 1.61 for the 1949 year-class in 1954-57, decreased to 0.83 for the 1961-62 year-classes in 1963-71 and rose to 1.66 for the 1966-67 year-classes in 1970-74.

The 1949 year-class grew more slowly than other year-classes from ages 4 to 11-13, although its growth rate did increase after age 7. Haddock grew more slowly when plentiful and faster when scarce. Haddock grew slowest during 1951-60 and fastest during 1969-75. Fastest growth occurred when haddock were least plentiful and when water temperatures were higher. After age 2, females grew faster than males. St. Pierre Bank haddock usually attained much greater lengths-at-age than Grand Bank haddock of the same time period.

## Introduction

Information on age, length and year-class strength of haddock on St. Pierre Bank (ICNAF Subdiv. 3Ps) was presented by Rojo (1959) from samples taken at sea by Spanish trawlers in 1955, by Hodder *et al.* (MS 1970) from the landings of Newfoundland commercial trawlers in 1953-56, and by Shestov (1967) from catches by USSR trawlers in 1954 and 1958-63.

The St. Pierre Bank population was one of two major populations of haddock in the Newfoundland area, the other being on the Grand Bank for which studies similar to those presented in this paper were reported by Templeman *et al.* (1978a). In that paper, evidence was presented for a considerable degree of separation between the Grand Bank and St. Pierre Bank haddock populations.

During the period of study covered by the research data presented in this paper (1948-75), catches were negligible until 1953, after which there was a rapid increase to nearly 60,000 tons in 1955 and just as rapid a decline to less than 1,000 tons by 1958. Since then, catches have been in the range of 200-4,500 tons.

## Materials and Methods

The materials and data were collected almost entirely during surveys by the Newfoundland Biological Station research vessels *Investigator II* and *A. T. Cameron* during February-June (actually, 14 February-2 July) of 1948-75. The data used were restricted to this period of each year in order to improve comparability by reducing the effects of growth in the years under consideration, although new

growth was usually evident in most of the immature and some of the younger mature fish by the end of June.

The research vessel survey pattern on St. Pierre Bank was generally as shown in Fig. 1 but varied somewhat from cruise to cruise by restraints of vessel operation, weather and the time available. The general survey pattern was established in 1952, but the patterns for 1948 and 1951 were somewhat similar and adequate. There was no cruise to St. Pierre Bank in 1949, and the survey in 1950 was very inadequate with only a few sets being made. From 1952 to 1955, there were only two lines of stations on the western slope, approximately lines 2 and 6 in 1952-54 and lines 2 and 8 in 1955. Lines 1, 2 and 6 on the western slope were used during 1956-63, and line 8 was added in 1964. The survey in 1962 was somewhat inadequate as only one line on the slope and two lines on the shallower plateaus of the bank were completed. The greatest depths fished were usually between 200 and 270 m before 1956, about 290 m during 1956-58, and at 275 m until 1970.
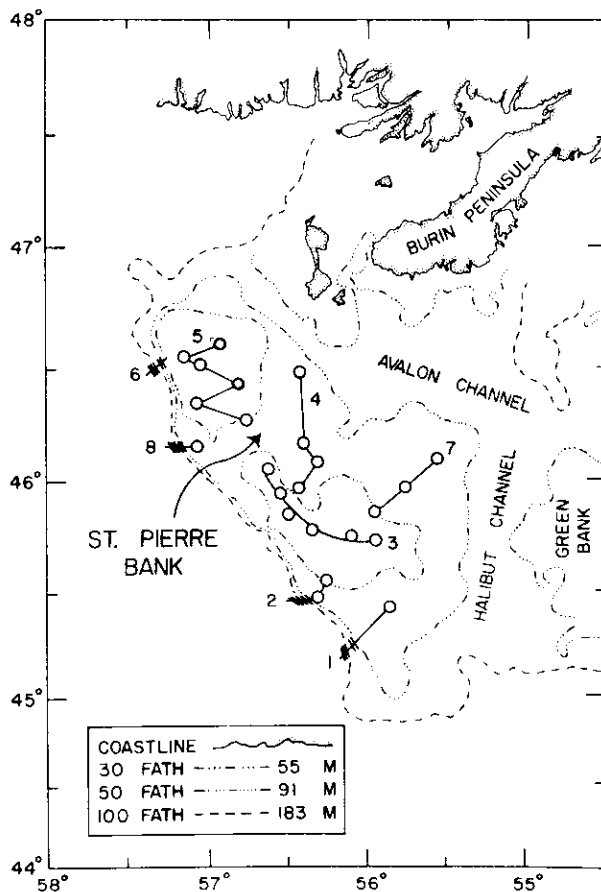


Fig. 1.   Research vessel fishing stations on St. Pierre Bank. Slope stations on sections 1, 2, 6 and 8, indicated by bars, are at 60 fath (110 m), 80 fath (146 m), 110 fath (201 m), 130 fath (238 m), and 150 fath (274 m).

In 1972-75, the survey pattern was changed to a stratified-random scheme applied to strata by area and depth ranges from 0-55 m to 195-366 m (Pinhorn, MS 1972; Pinhorn and Pitt, MS 1972). For comparison with the earlier survey results, the data used for 1972-75 excluded all stratified-survey data from depths greater than 302 m and data from all areas outside the boundary of St. Pierre Bank to the west, north and east (Fig. 1), except that data from Halibut Channel south of 45°40'N were included.

Surveys were carried out by the *Investigator II* in 1948-60, 1963 and 1965, using a No. 36 otter trawl, and by the *A. T. Cameron* in 1960, 1962, 1964, 1967-70 and 1972-75, using a No. 41-5 otter trawl. In 1967 and subsequently, a courlene 41-5 otter trawl was used instead of the manila trawls used previously. In 1948 and 1950, the codend mesh size was about 75-mm double manila. A. manila codend liner or cover of 44-mm mesh was used during 1951-57, and a nylon liner with mesh size of 19 mm was used in 1958, 29 mm in 1959-68, 6 mm in 1969, and 29-32 mm in 1970-75. All of the mesh sizes noted refer to the stretched mesh size of the material when new. In 1949, samples were taken at sea on a commercial trawler using a No. 41-5 otter trawl with codend mesh size of about 70 mm (internal, stretched, wet after use). No research samples were taken in 1961, 1966 and 1971.

Sampling of the research catches, fish length measurements, age reading, methods of checking ages from scales and otoliths of the 1948-64 samples, methods of obtaining representative length and age compositions by applying yearly age-length keys to the random survey length frequencies and of assembling the length and age data for period and year-class comparisons, calculation of total mortality coefficients, and any other relevant methods not described in this paper, were generally as described by Templeman et al. (1978a). Ages of the 1965-75 samples were determined by Bishop from otoliths and checked by scale readings in doubtful cases. These were read after considerable experience had been acquired in reading haddock scales and otoliths previously read by Templeman and V. M. Hodder. The von Bertalanffy growth parameters were calculated from unweighted mean length-at-age values (each based on five or more aged), using the least-squares method of Allen (1966).

For calculations involving research vessel catch per 30-min towing on bottom, the *A. T. Cameron* catch-per-unit-effort data for 1962-75 were converted to the *Investigator II* equivalent by multiplying by a factor of 0.5 [see Templeman et al. (1978a) for details of *A. T. Cameron* and *Investigator II* comparative fishing]. Although comparative fishing was conducted by both ships in 1960, the catch per set by *Investigator II* was used in the analysis. For Table 1 and Fig. 5 and 6 only, numbers per 30-min set were estimated for the four

years with no surveys and for 1950 from $\log_e N$ relationships with numbers in the same year-class in adjacent years from the survey data. This involved the calculation of numbers for two age-groups of the 1942 to 1944 year-classes for use in the 5-7 and 5-7+ columns of Table 1 and not more than for one age-group for any other year-class in the 2-7+ columns of this table.

The nominal catches of haddock in the commercial fishery were obtained from ICNAF (1952-77). All catches are reported in metric tons of round fresh fish.

The hydrographic stations on St. Pierre Bank from which the data of Fig. 6 originated are located as follows:

| Station | N. Latitude | W. Longitude | Depth (m) |
|---|---|---|---|
| 1 | 47°03' | 57°02' | 285 |
| 6 | 46°27' | 57°01'30" | 42 |
| 8 | 45°54' | 56°55' | 285 |
| 9 | 45°43'10" | 56°08'10" | 48 |
| 10 | 44°50'30" | 55°32' | 285 |

Stations 1, 8 and 10 are located on the northwestern, western and southern slopes and Stations 6 and 9 on the northern and southern plateaus respectively. No data for these stations were collected in 1966-68, but in the remaining years of the 1951-75 period the stations were occupied at some time during 12-27 August. For use in Fig. 6, average 25-m water column temperatures were obtained by averaging the upper and lower temperatures in each 25-m water column and then averaging for the number of such columns.

Iceberg numbers used in Fig. 6 are yearly numbers observed east of Newfoundland south of 43°N (Murray, 1969; International Ice Patrol Service, 1970-78). The value for 1960 is a correction as indicated in International Ice Patrol Service, 1971 (Bull. US Coast Guard No. 56, p. 2).

For use in Fig. 13, new von Bertalanffy growth parameters and curves were calculated for the 1956-60 and 1963-64 periods on the Grand Bank, using the same criteria as were used in calculating the St. Pierre Bank curves. These new parameters for Grand Bank haddock are:

1956-60   $L_\infty = 74.32$ cm   $K = 0.09$   $t_0 = -2.83$ yr
1963-64   $L_\infty = 74.77$ cm   $K = 0.10$   $t_0 = -3.60$ yr

The remaining von Bertalanffy growth curves for Grand Bank, as in Templeman *et al.* (1978a), were used in Fig. 13, as these would have been changed very little by the criteria used in the St. Pierre Bank analysis.

## Results

### Trends in catches

*St. Pierre Bank catches relative to those for Subarea 3.* Information on haddock catches in ICNAF Div. 3P (mainly St. Pierre Bank) is available only since 1953 (Fig. 2). As far as is known, most of the haddock landed by Newfoundland trawlers up to 1953 came from Grand Bank. Beginning in late autumn of 1953, Canadian trawlers increased fishing for haddock on St. Pierre Bank and 47% of the total Subarea 3 catch was taken in Div. 3P during 1954-56. In 1955, when a peak catch of about 104,000 tons was recorded for Subarea 3 as a whole, 58,000 tons (55%) were taken in Div. 3P. After 1956, the catch on St. Pierre Bank declined to 6,000 tons in 1957 and to 1,000 tons (only 2% of the Subarea 3 catch) in 1958. There was a slight increase in catch in Div. 3P during 1959-61 with a peak of 4,000 tons in 1960, which represented only 6% of the Subarea 3 catch in that year. In 1961 and 1962, when the catches in Subarea 3 as a whole were 80,000 and 35,000 tons respectively, only about 4% of the totals were taken in
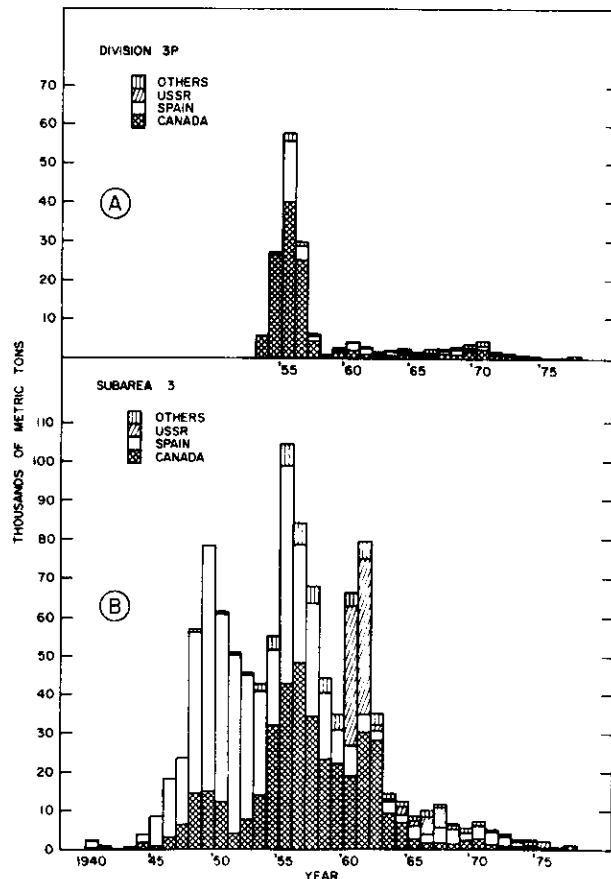


Fig. 2. Nominal catches (round fresh weight) of haddock from ICNAF Division 3P (including St. Pierre Bank) and from the whole of Subarea 3, 1940-77.

the St. Pierre Bank area. The Subarea 3 catch continued to decline after 1962, and the St. Pierre Bank catch, already at a low level since 1958, formed an increasing proportion of the Subarea 3 totals. In 1970, the St. Pierre Bank catch of 4,400 tons was 62% of the total Subarea 3 catch. After 1970, the St. Pierre Bank catch declined to only 200 tons in 1975 and 290 tons in 1976, and the Subarea 3 catch to 1,500 tons in 1975 and 450 tons in 1976. In 1977, the Subarea 3 catch was 960 tons, of which 820 tons were taken in Div. 3P (ICNAF, MS 1978).

The above amounts referred to as St. Pierre Bank catches are actually nominal catches from Div. 3P. In 1959, Div. 3P was subdivided into a small northwestern portion (Subdiv. 3Pn) and an eastern part (Subdiv. 3Ps) which includes St. Pierre Bank. In 1959-75, 94% of the total haddock catch in Div. 3P was taken in Subdiv. 3Ps. Only small quantities of haddock are taken on Burgeo Bank and those taken in the coastal waters of Subdiv. 3Ps are assumed to have migrated from St. Pierre Bank.

Some earlier catches have been recorded for St. Pierre Bank. McKenzie (1946) reported that the average yearly catch of Nova Scotian vessels was about 2,300 tons in 1939-40. Thompson (1939) found haddock abundant on the southern part of Grand Bank in the early 1930's but not on St. Pierre Bank. The best catches per 10-hr trawling by the research-trawler *Cape Agulhas* were 12,500 fish in 1932, 13,000 fish in 1933 and 35,000 fish in 1935 on the Grand Bank, but, in this period, no catches better than 1,300 fish per l0-hr trawling were obtained on St. Pierre Bank. It is apparent that only small quantities of haddock are normally present on St. Pierre Bank and that the great abundance as reflected by the large catches in 1954-56 was exceptional for this bank. Early catches of haddock in Subarea 3 generally are discussed by Templeman *et al.* (1978a).

*Discards.* As was the case for the early Grand Bank haddock fishery (Templeman *et al.*, 1978a), great quantities of small haddock were discarded in the early St. Pierre Bank fishery. These discards were particularly great in November–December 1953, when an intensive fishery began and 78% of the Newfoundland otter-trawl haddock catch for the year in Div. 3P was taken. Haddock discards from a Newfoundland commercial trawler fishing on St. Pierre Bank in April 1949, calculated from sea and shore length frequencies as described by Templeman *et al.* (1978a), were 33% by number and 10% by weight. In February 1953, when the large 1949 year-class was 4 years old but growing slowly, discards from a Newfoundland trawler, which obtained two-thirds of its catch on St. Pierre Bank, were 75% by number and

52% by weight. For the St. Pierre Bank part of the trip, the captain estimated that 80% (by weight) of the catch of about 82,000 kg was discarded. In 1954 and 1955, percentage discards presumably decreased as the 1949 year-class grew larger and haddock were landed in increasing proportions in the round condition, similar to what occurred on the Grand Bank (Templeman *et al.*, 1978a).

*Research vessel catch per effort.* Catches per 30-min set were high only in 1951-54, when almost all of the haddock belonged to the 1949 year-class (Fig. 3, 4). The abundance of this year-class was not detected in 1950 when no small-mesh liner was used in the codend and the survey was not representative. The largest commercial catches (weight) on St. Pierre Bank were in 1955 and consisted of almost all age 6 fish of the 1949 year-class (Fig. 2; and Hodder *et al.*, MS 1970). The largest research catches were in 1952 (1,858 fish per 30-min set), mainly age 3 fish of the 1949 year-class (Fig. 3, 4). Research vessel catches were also good in 1953 and 1954, but by 1955, although the catch by weight was still moderately high due to the increased weight of individual fish, the catch in numbers was quite low. Thus, the standing stock had fallen considerably by natural and fishing mortality from the peak in 1952 (actually the peak should be in 1950 as age 1 fish) to a relatively low level in 1955 (Fig. 3), which is surprising in view of the large commercial catches in 1955-56 (Fig. 2). The catch per 30-min set decreased to 57 haddock in 1958 and to 30 in 1960. Catches by the *A. T. Cameron* increased after 1960 to a small peak of 276 fish per 30-min set in 1967 and thereafter declined to 12 in 1972 and to 4 in 1974-75 (Fig. 3). To compare the catches by *A. T. Cameron* in 1962-75 with those of *Investigator II* in the earlier period, the former should be multiplied by 0.5. The 1950-54 year-classes were unsuccessful, and consequently in 1951-55, with very few young haddock appearing, the weight per 30-min
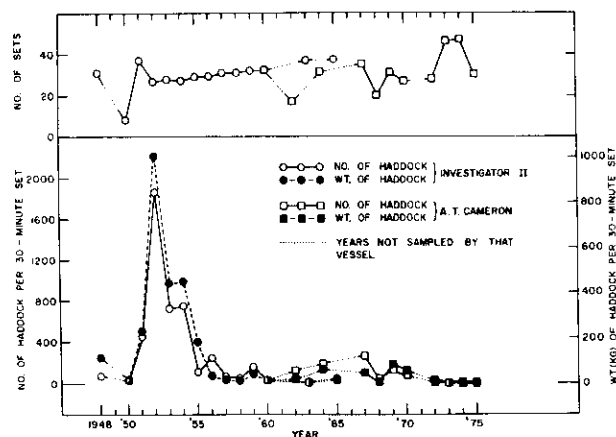


Fig. 3.　Haddock catch and effort by research vessels from surveys on St. Pierre Bank in February–June, 1948-75.

set gradually became greater relative to the number per set, as fish of the predominant 1949 year-class grew larger. After 1955, older haddock became relatively scarce and young fish from many small year-classes predominated. Thus, from 1956 to 1968, the number per 30-min set tended to be greater relative to weight per set than in the earlier period. As young haddock became scarcer and grew faster after 1968, weight per set increased again relative to number per set (Fig. 3).

## Age and length composition and variation in year-class success

*Random samples from annual research surveys.* The most successful year-classes on a percentage basis (i.e. unadjusted for fishing effort) were those of 1942, 1946, 1949, 1955-58, 1961, 1962, 1964, 1966, 1969, 1970 and 1972 (Fig. 4). There was also a very successful year-class in 1936 and good year-classes in 1933-35, shown in 1948 as age 12 and age 13+ fish respectively, and also in 1949 as age 13+ fish. In the samples for 1949, the 1935 year-class was the most numerous of the age 13+ fish which consisted mainly of the 1934-36 year-classes. There were no successful year-classes in 1937-41, 1943-45, 1948, and 1950-54. The 1947 year-class showed promise in 1948 and 1950 and the 1953 year-class in 1954, but these must have been chance catches, as their numbers were very low in subsequent years. The 1949 year-class was by far the most important, reducing all other year-classes to relative insignificance in 1951-55 and dominating fish of commercial size in 1953-58. Although some year-classes subsequent to 1955 are shown to dominate the research catches during two or more years, contrasts in abundance between year-classes are considerably less than during the 1933-54 period. Before 1951, ages 1 and 2 fish were not efficiently caught due to the lack of a small-meshed codend liner or cover and the percentages of older fish in the samples were higher than would be expected. Even allowing for this, there were relatively large numbers of haddock up to 70 cm long in the 1948 and 1949 catches, and relatively few above 60 cm after 1949 or above 50 cm after 1958. Larger fish again formed a higher percentage of research catches in 1970-75 but the number of haddock present was very low (Fig. 4). The successful year-classes can be followed in the younger fish both from the age and length frequency patterns, attesting to the validity of the age determinations.

*Research samples adjusted to relative numbers in survey catches.* Year-classes, as indicated by number per 30-min set, are illustrated in Fig. 5 and 6 in relation to some factors which could affect year-class success. Research catch per 30-min set varies in adequacy from year to year because of variations in gear and survey

patterns. Averaging of year-class numbers over 3 years reduces this variation. It is apparent that the 1949 year-class was exceedingly greater than the total of all other year-classes from 1942 to 1975. Other year-classes showing good to moderate success, if the 1949 year-class is not considered in comparison, were those of 1942, 1946-47, 1955-58, 1962, 1964 and 1966. There were five almost complete year-class failures from 1950 to 1954.

Considerable quantities of mature females were prevalent on St. Pierre Bank during 1948-55 and moderate quantities in 1956-58, 1964 and 1969 (Fig. 5C). The remarkably successful 1949 year-class was probably produced from a good supply of spawning females prevalent at the time. From the small fishing effort and from the apparent abundance of old fish in the 1948-49 research catches, spawning females were probably in good supply also for the production of the moderately successful 1942, 1946 and 1947 year-classes. However, the large quantities of spawning females present from 1951 to 1954 (and presumably 1950) produced year-class failures. The moderately successful (for its period) 1957 year-class was produced from a relatively small quantity of spawning females (5.4 kg per 30-min set). From 1954 to 1960, most of the spawning females on the bank belonged to the 1949 year-class (86-81% by weight in 1954-56, 68-73% by weight in 1957-59, 61% in 1960, 24-18% in 1962-63). By 1974-75, the quantity of spawning females on the bank was reduced to 1.3 kg per set in contrast to 50 kg per set when the only really successful year-class was produced in 1949.

There was similarly no consistent relationship between year-class success on St. Pierre Bank and iceberg numbers (Fig. 6), although there was a significant inverse relationship for Grand Bank haddock (Templeman *et al.*, 1978a). Usually the variation between year-classes was not great enough for useful comparison with iceberg numbers. The only very successful year-class of the 1942-75 period was that of 1949 which appeared in a year of low iceberg abundance. Prior to 1949, the good 1942 and 1946 year-classes were produced in years with low and moderate numbers of icebergs respectively. Extremely poor year-classes were produced in the low iceberg years of 1951-53. There was no great variation in the year-class strength during 1955-68, but the best year-classes of the period (1957, 1962 and 1966) appeared in years of high, low and zero iceberg numbers respectively. There was similarly no consistent agreement between year-class success and temperature or between iceberg number and temperature (Fig. 6).

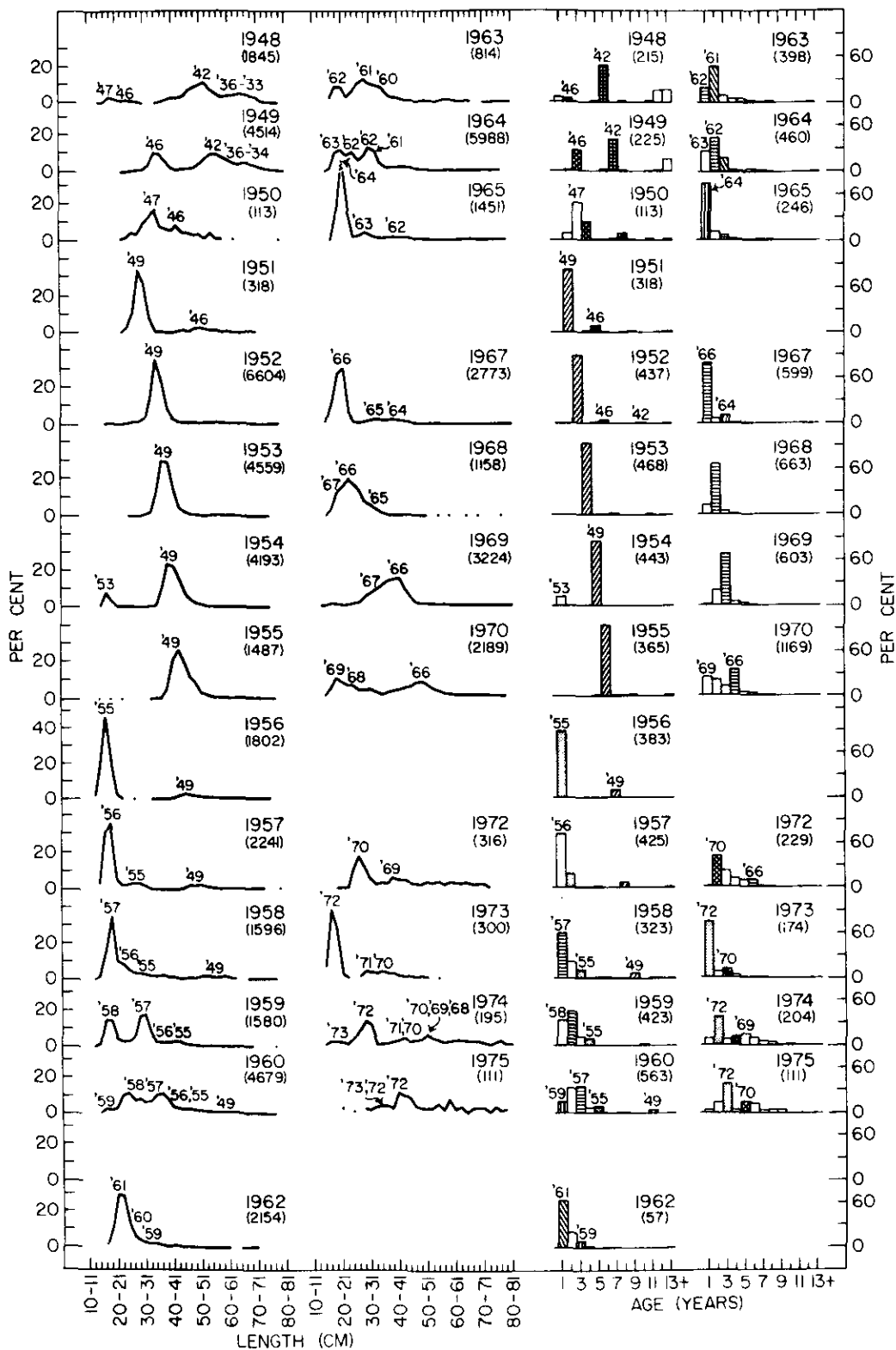The numbers of haddock in various age-groups of

Fig. 4.    Length and age composition of haddock from research vessel surveys with bottom otter trawl on St. Pierre Bank in February–June, 1948–75. (Numbers measured and aged are in parentheses, and the significant year-classes are noted.)
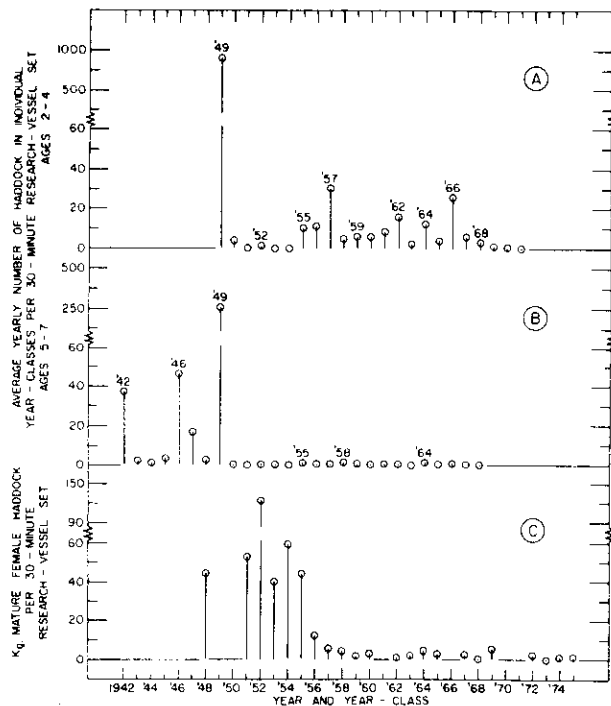
Fig. 5. Relation of year-class abundance of haddock on St. Pierre Bank to relative strength of the spawning stock. (See "Materials and Methods" for the further information.)
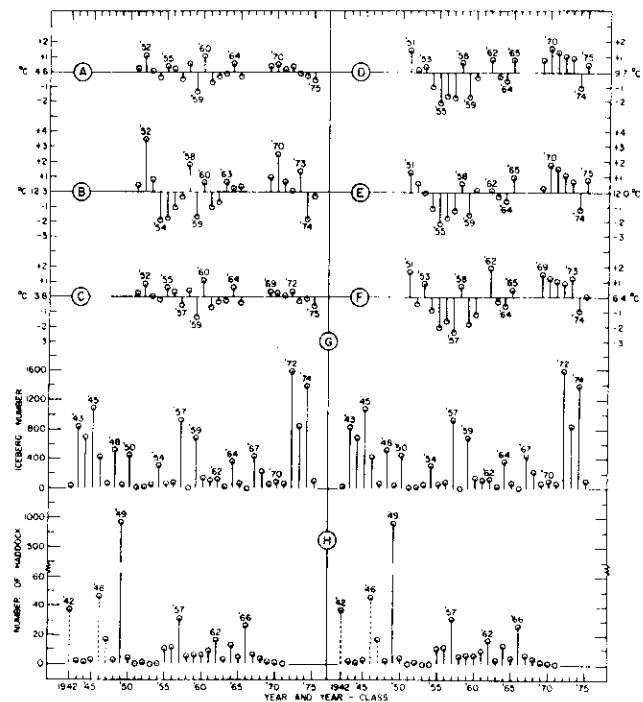


Fig. 6. Relation of temperature conditions (anomalies from averages of 25-m water-column temperatures) and iceberg numbers to year-class success of haddock on St. Pierre Bank. Temperatures for A, B and C are averages from three hydrographic stations on the southwest slope and for D, E and F from two stations on the plateau of the bank during 12–27 August. A, 0–275 m; B, 0–25 m; C, 25–275 m; D, 0–45 m; E, 0–25 m; F, 25–45 m; G, iceberg numbers south of 48°N; H, relative year-class success of haddock from Fig. 5 for ages 5–7 (1942–48) and ages 2–4 (1949–71). (See text table in "Materials and Methods" for further information.)

different year-classes per 30-min set and the survival from younger to older ages are shown in Table 1. In the early part of the survey period, age 1 and smaller ages 2–4 fish were not caught efficiently due to the lack of a small-meshed liner in the codend before 1951. Also, even after small-meshed liners or covers were used, the numbers of age 1 fish varied considerably from one year to another in comparison with older fish of the same year-class. Therefore, ages 2–4 have been used as the base for comparison with older fish. Numbers at ages 2–4 are not available for the 1942 and 1943 year-classes, but it is evident that relatively more survived beyond age 7 than in later year-classes. For the 1949–59 year-classes, the ratios of survival from ages 2–4 to ages 5–7 and to ages 5–7+ were moderately high, averaging 0.17 and 0.23 respectively (Table 1). For subsequent year-classes, 1960–68 (1960–67 for ages 5–7+), the corresponding survival ratios were usually low, averaging 0.06 and 0.07. Because the haddock fishery on St. Pierre Bank was not intensive before 1954, a relatively large percentage of fish of the 1942–43 year-classes survived beyond age 7. As the fishery developed, fish older than age 7 formed a smaller proportion of the research catches, and soon, even for the great 1949 year-class, the numbers surviving beyond age 7 were negligible.

## Total mortality

The unusually large numbers of the 1949 year-class on St. Pierre Bank, and the variability in the strength of year-classes generally, rendered comparison of numbers at successive ages unsuitable for estimation of mortality rates. However, the numbers at age per 30-min research set within successful year-classes were useful in deriving and comparing estimates of total mortality.

The total mortality coefficient (Z) was relatively low (0.76) for the 1942 year-class at ages 10–15, somewhat higher (1.12) for the 1946 year-class at ages 6–12, and considerably higher (1.61) for the 1949 year-class at ages 5–8 (Fig. 7). However, for the 1949 year-class at ages 8–15 (1957–64), Z decreased to 0.66. For the 1955–57 year-classes, Z was 0.97 at ages 2–6 and much lower (0.36) at ages 6–12. Z was 0.83 for the 1961–62 year-classes over ages 2–9 and was surprisingly high at 1.66 for the 1966–67 year-classes over ages 4–7. The apparent age at full recruitment declined from about ages 10 and 6 for the 1942 and 1946 year-classes (although data for the 1942 year-class are available only for age 6 and older) to age 5 for the 1949 year-class and to ages 1 and 2 for the 1955–57 and 1961–62 year-classes respectively, but increased to age 4 for the 1966–67 year-classes (Fig. 7).

TABLE 1. Relative numbers of haddock per 30-min research vessel set on St. Pierre Bank, February-June period of 1948-75.

| Year-class | Number per 30-min set | | | | Ratios | |
|---|---|---|---|---|---|---|
| | Ages 1-4 | Ages 2-4 | Ages 5-7 | Ages 5-7+ | $\dfrac{5\text{-}7}{2\text{-}4}$ | $\dfrac{5\text{-}7+}{2\text{-}4}$ |
| 1942 | — | — | 113.3 | 168.2 | — | — |
| 1943 | — | — | 6.8 | 9.7 | — | — |
| 1944 | — | — | 4.5 | 5.9 | — | — |
| 1945 | — | — | 10.0 | 10.5 | — | — |
| 1946 | — | — | 138.4 | 143.3 | — | — |
| 1947 | — | — | 50.7 | 51.9 | — | — |
| 1948 | — | — | 8.3 | 8.4 | — | — |
| 1949 | 2721.6 | 2721.6 | 779.1 | 791.1 | 0.29 | 0.29 |
| 1950 | 12.8 | 12.8 | 0.9 | 1.2 | | |
| 1951 | 15.4 | 0.9 | 0.1 | 0.4 | | |
| 1952 | 3.7 | 3.7 | 0.9 | 1.3 | 0.19 | 0.28 |
| 1953 | 93.1 | 0.1 | 0.8 | 1.1 | | |
| 1954 | 0.5 | 0.5 | 0.7 | 1.1 | | |
| 1955 | 253.7 | 32.4 | 4.0 | 5.1 | 0.12 | 0.16 |
| 1956 | 85.6 | 34.1 | 1.9 | 3.6 | 0.06 | 0.11 |
| 1957 | 126.7 | 92.9 | 2.3 | 3.1 | 0.02 | 0.03 |
| 1958 | 73.3 | 16.5 | 5.2 | 5.9 | 0.32 | 0.36 |
| 1959 | 22.9 | 18.5 | 2.5 | 2.8 | 0.14 | 0.15 |
| 1960[a] | ... | 18.1 | 1.0 | 1.2 | 0.06 | 0.07 |
| 1961 | 67.1 | 26.9 | 1.4 | 1.7 | 0.05 | 0.06 |
| 1962 | 53.0 | 49.0 | 1.8 | 2.2 | 0.04 | 0.04 |
| 1963 | 34.7 | 8.9 | 0.6 | 0.7 | 0.07 | 0.08 |
| 1964 | 75.5 | 38.8 | 4.0 | 4.1 | 0.10 | 0.11 |
| 1965[a] | ... | 13.5 | 2.0 | 2.0 | 0.15 | 0.15 |
| 1966 | 188.8 | 79.3 | 2.6 | 2.8 | 0.03 | 0.04 |
| 1967 | 27.9 | 19.8 | 0.7 | 0.8 | 0.04 | 0.04 |
| 1968 | 12.9 | 11.7 | 0.3 | — | 0.03 | — |
| 1969 | 14.8 | 5.0 | — | — | — | — |
| 1970[a] | ... | 3.1 | — | — | — | — |
| 1971 | 0.5 | 0.5 | — | — | — | — |

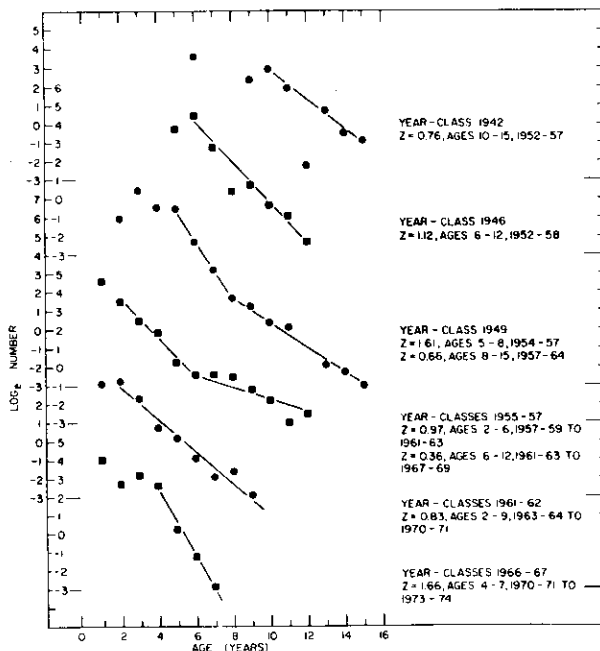[a] No data for age 1 due to no survey in the following year.



Fig. 7.   Estimates of the instantaneous total mortality coefficient (Z) for relatively successful year-classes of haddock on St. Pierre Bank, 1942-67, from catch curves of number per 30-min set in the research vessel surveys.

## Growth

*Year to year trends in growth.* The most apparent and regular pattern was the low length-at-age of the 1949 year-class from ages 4 to 11 in the years 1953-60 (Fig. 8). Length at age was also low for ages 2 and 3 in 1962 and 1968, ages 4 and 5 in 1963, and ages 3 and 4 in 1973. Usually after 1962-63, there was a fairly continuous increase in length-at-age for fish of ages 2-11, with occasional declines in some years. By 1974-75, length-at-age was higher, and usually considerably higher, than in the previous period of fast growth before the appearance of the slow-growing 1949 year-class. The trend in mean length for age 1 was quite different, being highest during 1960-65.

Data for males and females are not shown separately in Fig. 8 because of the small numbers of fish aged at individual ages in many of the weaker year-classes. From Fig. 11, it is apparent that differences in length-at-age between the sexes would have little or no effect below age 3 and usually only a minor effect at higher ages. For ages 3, 6 and 9, the differences in mean length-at-age of females and males (averages and ranges from data used for Fig. 11) were 0.5 (0.0-1.2), 1.9 (0.8-3.0) and 2.9 (2.1-3.9) cm respectively. In Fig. 8, the differences between the
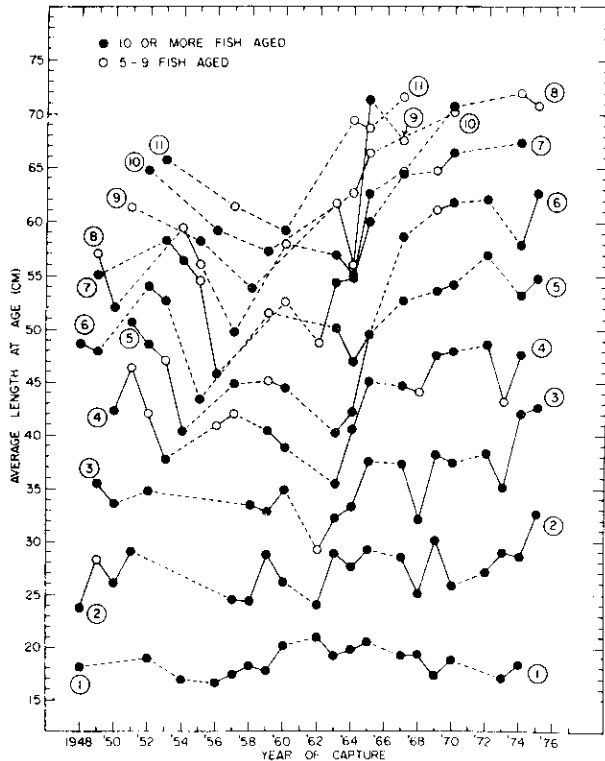
Fig. 8. Average lengths-at-age for age-groups 1 to 11 of haddock on St. Pierre Bank in February–June of individual years from 1948 to 1975. (Dashed lines are extrapolations across years in which fewer than five fish of an age-group were aged. See Fig. 4 for numbers aged and the relative abundance of age-groups.)



Fig. 9. Average length-at-age of successful or moderately successful year-classes of haddock on St. Pierre Bank in February–June, 1942–67, fitted with von Bertalanffy growth curves. (See Fig. 4 for numbers of fish aged.)

highest and the lowest mean length-at-age for ages 3, 6 and 9 are about 14, 19 and 17 cm respectively.

*Patterns of year-class growth.* The 1942 and 1946 year-classes showed a rapid decline in growth rate with increasing age and the smallest mean lengths at the greatest ages (Fig. 9, 12). The 1949 year-class grew relatively fast up to age 3, much more slowly at ages 4–7, and then entered a new stanza of more rapid growth, but did not reach a mean length-at-age equal to those of the 1942 and 1946 year-classes until after age 12. The growth of the 1949 year-class up to age 7 was so slow and its later growth so fast that $L_\infty$ computed for ages 2–15 had the exaggerated value of 191 cm.

In contrast to the 1946 year-class, the 1955–56 and 1957–58 year-classes, after slow growth at the early ages, grew faster and attained considerably greater lengths-at-age after age 7 than the 1942 and 1946 year-classes. The 1961–62 and 1966–67 year-classes grew faster at the younger ages than any of the preceding year-classes, and, although the lengths-at-age for the available ages were greater than those of earlier year-classes, there is an indication that the growth rate was
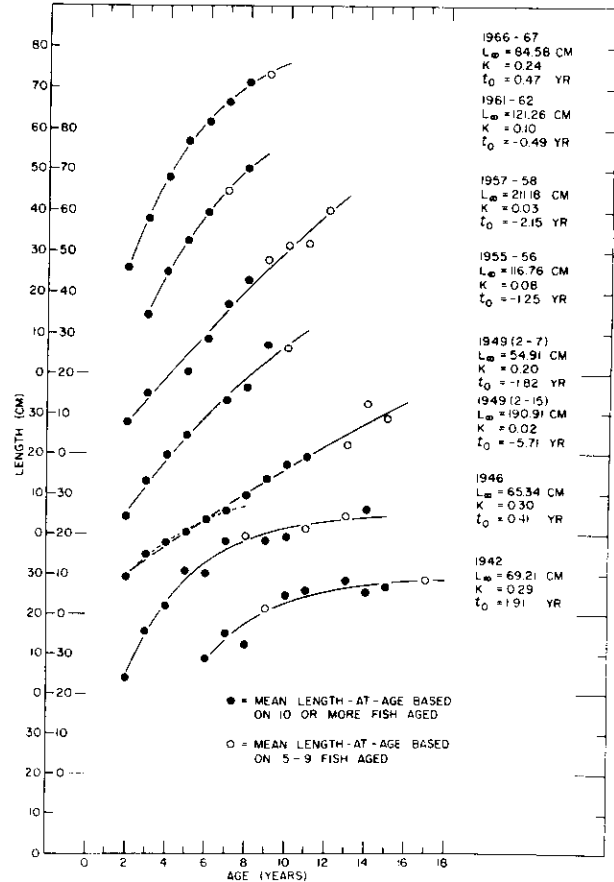
declining. However, the directions of the curves for the 1961–62 and 1966–67 year-classes beyond ages 8 and 9 respectively are somewhat uncertain due to lack of data points for older ages (Fig. 9, 12A).

*Period growth.* Year-classes were highly variable in numbers and yearly samples were small, so that the data for a single year were not suitable for the von Bertalanffy growth calculations. Also, the 1949 year-class so dominated the picture in 1951–60 that it was advantageous to combine the data for this whole period. The slowest-growing haddock occurred in the 1951–60 and 1948–50 periods (Fig. 10, 12B). Growth was somewhat faster in 1963–68, but the fastest growth occurred in the 1969–75 period. In the 1951–60 period, haddock grew more slowly as younger fish, and a little faster as older fish, than those in the 1948–50 period.

*Growth of males and females.* The mean length-at-age data over the range of ages considered tend to be irregular, in some cases because of small numbers of fish in the samples, and in others, as for the 1951–60 data, from the combination of the slow-growing 1949
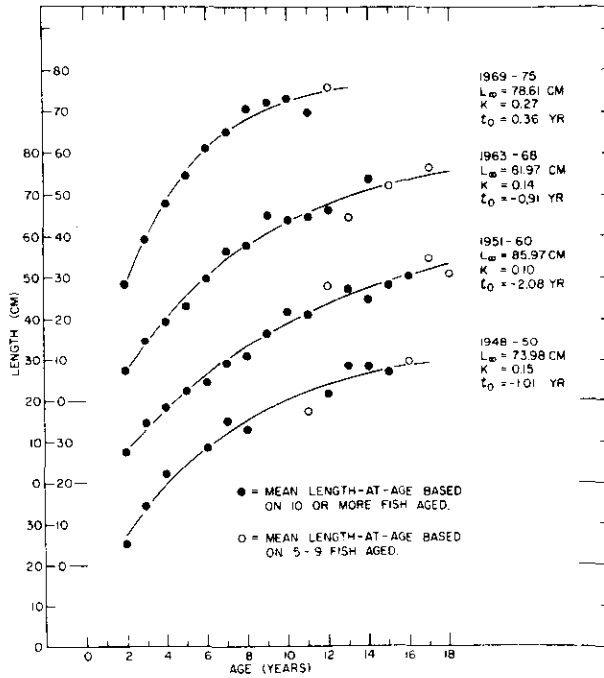
Fig. 10.  Average length-at-age of haddock on St. Pierre Bank in February–June of four periods from 1948 to 1975, fitted with von Bertalanffy growth curves. (See Fig. 4 for numbers of fish aged.)

year-class and other faster-growing year-classes (Fig. 11). However, usually after age 2, females grew faster than males, and the $L_\infty$'s for females are consistently higher than for males. These growth curves for males
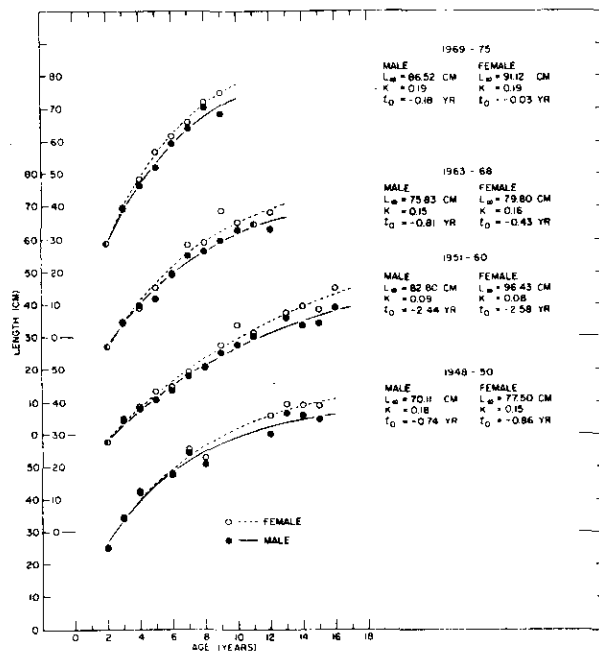


Fig. 11.  Average length-at-age of male and female haddock on St. Pierre Bank in February–June of four periods from 1948 and 1975, fitted with von Bertalanffy growth curves. (Average length for each sex and age-group based on five or more fish aged.)

and females show similar patterns to the corresponding curves for sexes combined (Fig. 12).

*Comparative growth of St. Pierre Bank and Grand Bank haddock.* Except for the youngest age-groups, the mean lengths-at-age for haddock on St. Pierre Bank were usually considerably greater than on Grand Bank for the same or similar year-classes and periods (Fig. 13). This was particularly true for the 1942, 1946 and 1949 year-classes (Fig. 13B) and also for the 1955–56 year-classes. Even after 1961, when the 1955 and 1956 year-classes on Grand Bank grew faster as haddock became scarcer, lengths-at-age for these year-classes remained much lower on Grand Bank than on St. Pierre Bank. However, the growth of the 1958 year-class (ages 2–7) on Grand Bank was similar to that of the 1957–58 year-classes over the same age range on St. Pierre Bank. In the 1946–60 period, average length-at-age on St. Pierre Bank was greater at
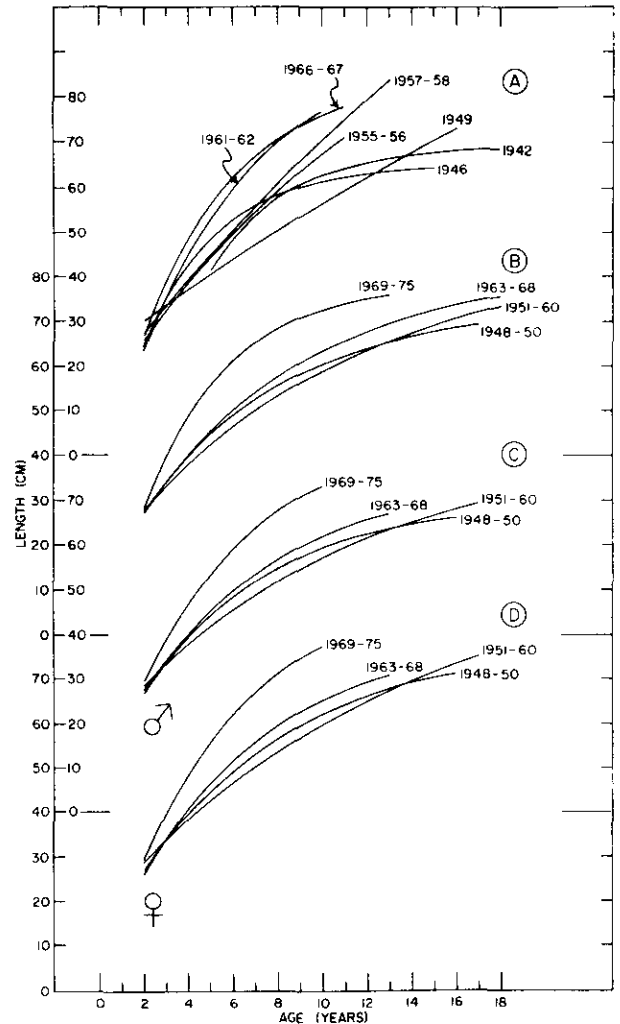


Fig. 12.  Comparison of von Bertalanffy growth curves for haddock on St. Pierre Bank: A, by year-classes from Fig. 9; B, by periods from Fig. 10; C and D, for males and females respectively from Fig. 11.
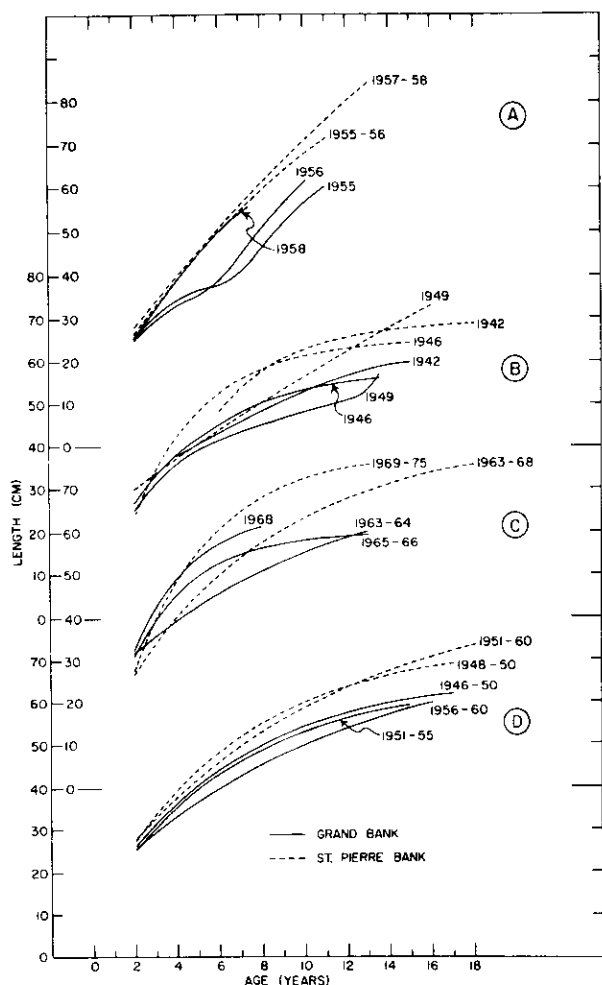
Fig. 13.  Comparison of von Bertalanffy growth curves for haddock on St. Pierre Bank and Grand Bank for various year-classes (A and B) and for various periods (C and D). (The growth curves for Grand Bank haddock are from Templeman *et al.* (1978a), except that curves for the 1956-60 and 1963-64 periods were recalculated using the same criteria as those for St. Pierre Bank.)

the younger ages and much greater at the older ages than on Grand Bank (Fig. 13D). In 1963-68, lengths-at-age were generally greater at the youngest ages on Grand Bank than on St. Pierre Bank but they were considerably greater at the older ages on St. Pierre Bank (Fig. 13C). The fastest growth of haddock on St. Pierre Bank occurred in the 1969-75 period for all ages up to 12 years (Fig. 12B, 13C). No growth data for Grand Bank haddock have been published for this period.

## Discussion

### Catches and year-class success

The successful year-classes of the 1934-36 period and of 1942 and 1946 were similarly successful on

Grand Bank. The only large catches of haddock on St. Pierre Bank, those of 1954-56 and smaller catches of 1953 and 1957, consisted almostly entirely of fish of the 1949 year-class which was larger than the total of all other year-classes in the period of investigation. After 1956, the fishing effort of almost the whole trawler fleet was once again directed to Grand Bank, where the 1952 and 1953 year-classes of haddock were moderately successful, although they were almost complete failures on St. Pierre Bank. The 1955 year-class was very successful and the 1956 year-class moderately successful on Grand Bank and both contributed significantly to the fishery in 1960-62, whereas on St. Pierre Bank these year-classes, although classed as moderately successful in comparison with year-classes other than that of 1949, yielded only small quantities to the commercial fishery. The 1962, 1964 and 1966 year-classes, relatively successful on St. Pierre Bank for their period but relatively small in commercial quantity, were similarly successful on Grand Bank but also of little commercial importance (Templeman *et al.*, 1978a).

### Year-class success

In Shestov's (1967) age readings of St. Pierre Bank haddock, from samples taken in 1962 and 1963, the 1955-58 year-classes were relatively successful, as in our investigations. Similarly in his 1962 sample, the 1949 year-class was greatest among the older year-classes, but the 1948, 1950 and 1951 year-classes were more significant in his age frequency than would be expected from our age readings of the younger fish. In ageing the older fish, it is to be expected that the accuracy of age determination diminishes so that some fish of a dominant year-class may be assigned to adjacent ages.

In Rojo's (1959) age estimates of haddock from St. Pierre Bank (March-April 1955), the most abundant year-classes were those of 1950, 1951 and 1952, the 1949 year-class being relatively small. Rojo's length frequency for this sample (allowing for more of the larger sizes of fish because of its commercial origin) is similar to ours, with a single mode at 44 cm corresponding to a mode in our research frequency at 42-43 cm. In our age data for 1955, the 1949 year-class constituted 94% of the total sample and was more than 55 times as abundant as either of the next most successful year-classes, 1942 and 1946. The 1949 year-class is clearly evident in each of our length frequencies from 1951 to 1955, with no evidence that the 1950-54 year-classes were of any significance. In fact, the 1949 year-class constituted 90, 94, 86 and 94% of our age frequencies in 1952-55 respectively. In our age reading of haddock samples taken in June 1951 on St. Pierre Bank, it was noted that there was a definite check in the summer growth of the first year in scales of

the smaller age 2 fish but rarely in the larger age 2 fish whose scales could be read without doubt, and it was concluded that this group of fish was uniformly 2 years of age.

Hodder et al. (MS 1970) found the 1949 year-class to dominate completely the haddock landings of Newfoundland trawlers from St. Pierre Bank in 1954-56, as 96, 97 and 96% of the fish in the commercial samples of these years belonged to the 1949 year-class.

It is apparent, from the material presented in this paper for St. Pierre Bank haddock, as also for Grand Bank (Templeman et al., 1978a), that the presence of large quantities of spawning females on the bank does not ensure year-class success. It is also apparent for both banks that the population of spawning females may be reduced so quickly by a commercial fishery that only very small year-classes are produced, even when other conditions for the production of good year-class are favorable.

For Grand Bank, there was a significant inverse relationship between year-class and iceberg number (Templeman et al., 1978a). No. such relationship is evident for St. Pierre Bank except that the only large year-class, that of 1949, was produced in a year of low iceberg numbers. The general pattern of iceberg drift in large numbers (Dinsmore, 1972) is related more to Grand Bank than to St. Pierre Bank, although the latter is affected by the Labrador Current passing through the Avalon Channel. Also there was no consistent relationship between temperature and year-class success on St. Pierre Bank. It is unfortunate that no temperature data are available for St. Pierre Bank in the early part of 1949 when the very successful year-class appeared. However, water temperatures in the upper layers at Station 27 near St. John's in July–August 1949 and air temperatures at St. John's Airport during May–August were not unusual for the period.

Templeman et al. (1978a) indicated that a period about 6-7 years after the appearance of a successful year-class on Grand Bank seemed to be favorable for the production of a new successful year-class, as most of the females of a successful year-class would be mature. Usually, after the production of one or two successful year-classes, there was a period of 2-4 years when year-classes were poor. On St. Pierre Bank, there was an even greater period of 5 years of year-class failure after the exceptionally large 1949 year-class, which occurred 7 years after the successful 1942 year-class. During the 1950-54 period of year-class failure on St. Pierre Bank, there were two successful year-classes (1952 and 1953) on Grand Bank. It appears possible that the great numbers of the

1949 year-class with its slow growth, indicating great pressure on the available food, acted as a depressant for the ensuing five year-classes. In the 1954-60 period, the 1949 year-class was calculated to provide respectively 86, 81, 86, 68, 72, 73 and 61% of the weight of mature females on St. Pierre Bank. The 1954 year-class was a failure in spite of a good spawning stock. During 1955-58, when the 1949 year-class was 6-9 years old and the females were achieving full maturity (74-77% mature at ages 6 and 7, 99% at age 8, and 100% at age 9), some moderate year-classes were produced, the best of these being that of 1957, which occurred when the 1949 year-class had begun to increase in growth due to the great reduction in its numbers. Thus in the period of great abundance of the 1949 year-class on St. Pierre Bank, the occasional moderately successful year-classes produced were relatively small, whereas the abundant 1949 year-class on Grand Bank was followed by successful year-classes in 1952 and 1955, the latter being exceptionally large.

May (1965) showed that, on the southern Grand Bank in 1946-55, successful year-classes of cod occurred in most years when there were successful year-classes of haddock. Pinhorn (1971) demonstrated that better than average year-classes of cod occurred on St. Pierre Bank in 1955, 1958, 1966, (especially good) and 1968, the first 3 years of which yielded successful (for the period) year-classes of haddock, that of 1966 being especially so. During the 1946-55 period, successful year-classes of cod on Georges Bank and on Grand Bank, and of haddock on Sable Island Bank, on Grand Bank and on St. Pierre Bank (except 1952-53) usually occurred in the same year (Templeman, 1972). In the latter paper and in Templeman (1965), relationships between year-class success of cod and haddock were demonstrated over much broader areas. These widespread relationships of year-class success lead to the probability of temperature effects, but, because of the lack of long time series of temperature data during the spawning period and for several months afterwards, such effects on year-class success cannot be demonstrated for haddock of the Newfoundland area. Hermann et al. (1965) correlated year-class success with temperature for cod in West Greenland waters.

## Total mortality

The only very intensive haddock fishery on St. Pierre Bank in the period studied was on the abundant 1949 year-class in 1954-56, resulting in high total mortality ($Z = 1.61$ for 1954-57). After 1949, no new successful year-classes appeared until 1955-57, and evidently these were fished more heavily as young fish in 1959-63 ($Z = 0.97$) than haddock of the 1949 year-class at ages 8-16 in 1957-64 ($Z = 0.66$). However, the

mortality indicated for the older age-groups of the 1955-57 year-classes was lower than that for similar age-groups of the 1949 year-class, but, as the age range decreased in later years, the change to a lower Z with increasing age was not noted in the 1961-62 and 1966-67 year-classes.

No satisfactory explanation is available for the high Z of 1.66 calculated over ages 4-7 of the 1966-67 year-classes in 1970-74. This value is similar to that of the 1949 year-class at ages 5-8 in the years of intense fishing. Haddock were growing faster in 1970-74 than in earlier periods and hence were more susceptible to capture at earlier ages. However, the total groundfish (especially cod and redfish) catch in Subdiv. 3Ps declined rapidly from 126,000 tons in 1970 to 77,000 tons in 1974, but, judging by the high mortality of haddock, the fishing effort for groundfish in this period must have been high.

The relatively high ages at full recruitment to the research gear, as indicated in Fig. 7 for the 1942 year-classes, can be attributed in part to the lack of a small-mesh liner in the codend during the early years of the surveys (1948-50) and the lack of sampling of the 1942 year-class prior to 1948. The 1955-57 year-classes, and especially the 1961-62 and 1966-67 year-classes were considerably faster growing after age 3 than the 1949 year-class and thus could have been more susceptible to capture at younger ages, but this is not so evident for the 1966-67 year-classes. It is possible that the lower rates of capture at ages 1-3 of the 1966-67 year-classes, relative to the number at age 4, than for the 1961-62 and 1955-57 year-classes were due to the use in 1967 and subsequently of a courlene trawl by the *A. T. Cameron* instead of the manila trawl used previously, and consequently to better escapement of young haddock from the anterior part of the trawl. Theoretically, if the youngest age-groups are fully available for capture, the greatest abundance of a year-class should be exhibited at age 1. However, small fish can readily escape through the larger meshes in the anterior parts of the trawl and thus not be fully recruited in spite of the small-mesh liner in the codend, although occasionally from chance captures there is the appearance of full recruitment at age 1, as in 1955-57. In the Grand Bank study, for which estimates of Z were available for both commercial and research sampling, ages at full recruitment for the good year-classes of the 1949-56 period were similar for the research and the commercial trawls (Templeman et al., 1978a).

### Relative numbers at ages 2-4 and 5-7

Because the haddock fishery in 1953-56, and especially in 1954-55, particularly on the highly successful 1949 year-class, was evidently more intensive than in other periods, it might have been expected that the numbers at ages 5-7 would show a greater decline relative to those at ages 2-4 for the 1949 year-class than for other year-classes. The lack of such a decline was because the age of full recruitment to the research catches for the 1949 year-class did not occur before age 5 and because the age 2 fish of this year-class were caught at not more than a fifth of their true number relative to their abundance at age 3. The decline in the ages 5-7/2-4 ratio from an average of 0.17 for the 1949-59 year-classes to 0.06 for the 1960-68 year-classes was probably due to faster growth in the latter period, making these age-groups progressively more susceptible to the fishery. An even greater decrease in this ratio was noted for Grand Bank haddock of the 1958-62 year-classes (Templeman et al., 1978a).

### Growth on St. Pierre Bank

The differences in growth pattern shown in the length-at-age curves by year-class and period (Fig. 9-13) must be considered in relation to growth in the years to which the curves apply. The growth curve of a year-class shows the growth year by year for the available ages. The growth curve for a period, however, is related to growth occurring within the period and also to growth which occurred before the period.

The 1949 year-class was many times larger than any other year-class in the period of study, and its slow growth must be attributed primarily to its great abundance. This is similar to what occurred in haddock on Grand Bank (Templeman et al., 1978a), where growth was reduced in periods of successful year-classes. The 1949 year-class on St. Pierre Bank was greatly reduced by intensive fishing during 1953-56. After age 7, with considerably fewer remaining and the number declining gradually year by year, haddock of the 1949 year-class began to grow faster, but their length-at-age remained relatively low because of the earlier slow growth. However, the increased growth after the earlier years of slow growth produced a curve which is almost linear, with a consequent change in $L_\infty$ from 55 cm for ages 2-7 to 191 cm for ages 2-15, the latter value being obviously unreal, as the largest haddock obtained from St. Pierre Bank during the whole period of study was 88 cm long. Length-at-age data for the 1949 year-class at ages greater than 15 were either lacking or too scarce to be included. The relatively slow growth of the 1942 year-class at ages 9-17 and of the 1946 year-class at ages 9-14 was undoubtedly due to the influence of the large 1949 year-class during the 1950's. The fast growth of the older fish of the 1955-58 year-classes occurred after the 1949 year-class and older haddock generally had been greatly reduced in number, and the faster growth of the 1961-62 and 1966-67 year-classes

occurred at a time when haddock of all ages were relatively scarce. The very high $L_\infty$ values for the 1955–58 and 1961–62 year-classes, ranging from 117 to 211 cm, are obviously unreal in terms of final haddock length, because of faster-than-usual growth at older ages and the lack of data for still older ages when the growth rate would have been expected to decline rapidly.

The slow growth of haddock in the 1951–60 period (Fig. 12 B, C, D) coincided with the dominance of the very numerous 1949 year-class. Haddock were only moderately abundant during the 1948–50 period but fish of the older age-group were relatively more abundant than in later years due to low fishing intensity. Consequently, while the older age-groups were rather slow-growing in this period, the younger fish grew a little faster than those of the 1951–60 period. The faster growth in 1963–68, and especially in 1969–75, occurred at a time of increasing scarcity of haddock on the bank. In contrast with the great variation in $L_\infty$ for the year-class growth curves (Fig. 9), those for the period growth curves (Fig. 10) were rather normal, rising from 74 cm for the 1948–50 period to 79–86 cm for the other periods.

The faster growth of females than males after sexual maturity is similar to that found for Grand Bank haddock (Templeman et al., 1978a). The transition to the mature condition for males occurred mainly from ages 4 to 6 in 1948–64 and ages 3 to 5 in 1965–75, and for females from ages 5 to 8 in 1948–64 and ages 4 to 6 in 1965–75 (Templeman and Bishop, 1979). As for haddock on Grand Bank (Templeman et al., 1978b), males on St. Pierre Bank spawned at least a year younger than females, and consequently growth slows sooner in males than in females.

### Effect of temperature on growth

Water temperatures on St. Pierre Bank in 1958 were above average, but, during most of the period dominated by the abundant 1949 year-class (1954–59), temperatures on the bank were mostly below average (Fig. 6), and some of the slow growth of that year-class can be attributed to lower temperatures. In the 1969–75 period, when haddock were scarce and the highest growth rates occurred, temperatures on the bank were generally above average (except in 1974), and some of the increased growth can therefore be attributed to higher temperatures.

### Comparative growth of St. Pierre Bank and Grand Bank haddock

The growth rate during 1946–50 (Fig. 13D), when the haddock populations on both St. Pierre Bank and Grand Bank were composed of a relatively wide range of age-groups and were least interfered with by the fishery, was presumably more representative of normal conditions than in more recent years. From 1951 to 1960, the large 1949 year-class on St. Pierre Bank and the lower temperatures on the shallow parts of the bank had the effect of reducing the length-at-age of the younger age-groups, whereas, after the population had been severely reduced in number by the fishery, there was an increase in growth of the older ages. Meanwhile, on Grand Bank, the large 1949, 1952 and 1955 year-classes and the moderate 1953 and 1956 year-classes had the effect of reducing the length-at-age for all age-groups (Templeman et al., 1978a). In 1951–55 and 1956–60, the average indices of abundance (number per 30-min set by Investigator II) were 781 and 117 respectively on St. Pierre Bank and 501 and 436 on Grand Bank. The faster growth on St. Pierre Bank was maintained in the 1951–60 period (Fig. 13D).

In the 1963–68 period (Fig. 13C), the average number per 30-min set was reduced to 66 on St. Pierre Bank and to 24 on Grand Bank. Although the length-at-age of the older haddock remained much greater on St. Pierre Bank than on Grand Bank, the youngest age-groups were slower-growing on St. Pierre Bank. During this period, the growth of haddock on Grand Bank was relatively low because of their abundance in the late 1950's up to 1961. By 1968, haddock were severely reduced in number on Grand Bank, the research vessel index being only 4 per 30-min set, and growth of the few remaining haddock was very rapid.

The research vessel indices for St. Pierre Bank (based on Investigator II data or equivalents) were further reduced to 54 and 3 haddock per 30-min set in 1969–70 and 1972–75 respectively, during which a considerable increase in growth occurred (Fig. 13C). The increased growth was also presumably enhanced by higher than normal water temperatures, especially over the shallow areas of the Bank.

The year-class growth curves (Fig. 13A, B) also show the pattern of faster growth for St. Pierre Bank than for Grand Bank haddock. The younger ages of the 1949 year-class on St. Pierre Bank (Fig. 13B) and the 1955 and 1956 year-classes on Grand Bank (Fig. 13A) were present in periods of great abundance and slow growth whereas the older ages of these year-classes were present in periods of low abundance and faster growth. However, because of the earlier slow growth, the increased growth of the 1955–56 year-classes on Grand Bank was not sufficient for them to attain the lengths-at-age of St. Pierre Bank haddock. The 1958 year-class on Grand Bank grew fast after age 2 because haddock of comparable ages were scarce and because haddock of all ages became progressively

scarcer after 1961.

Previous to the appearance of the 1949 year-class on St. Pierre Bank and during 1957-63, when this year-class was declining rapidly in abundance, haddock were apparently considerably less numerous on St. Pierre Bank than on Grand Bank and this may have been the major factor in producing the greater growth of haddock on St. Pierre Bank during those periods. However, environmental conditions may have been a contributing factor, in that summer temperatures in the shallow water areas of the haddock abode on St. Pierre Bank are usually higher than those on the Southeast Shoal where a large part of the Grand Bank population spends the summer (Andrews, MS 1954; Templeman, MS 1955, 1975; Templeman and Hodder, 1965a, 1965b; Templeman et al., 1978a). Also, because the coast is closer, many of the St. Pierre Bank haddock migrate to the coast more regularly than Grand Bank haddock, thus expanding their feeding range.

Over most of the period the faster-growing St. Pierre Bank haddock typically reach a greater length, but approximately the same age, at 50% maturity than Grand Bank haddock (Templeman et al., 1978b; Templeman and Bishop, 1979). Differences in age at sexual maturity were therefore not sufficient to account for the differences in growth.

## Acknowledgements

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## Text

a) Manuscript should be type-written, *double-spaced*, and on one side only of good quality white bond paper, size 8½ × 11 inches (220 × 280 mm).

b) Leave all margins 1 inch (25 mm) to 1½ inches (38 mm) for editorial marks and queries.

c) Prepare and submit the original and one copy of the text and two sets of illustrations.

d) Number all pages of the manuscript consecutively with Arabic numerals in the centre of the top margin space.

e) Start a new page for each of the following sections with appropriate headings and sub-headings: (1) title, name and address of author, list of contents (if applicable); (2) abstract of the paper; (3) text; (4) references to literature; (5) tables; (6) legends for figures and (7) figures.

f) Please *double-space everything* — Text, quotations, footnotes, tables and table headings, legends, references to literature, and use even greater spacing where helpful (particularly around equations and formulate).

g) Wherever practical the text should be subheaded into Abstract, Introduction, Materials and Methods, Results, Discussion and Acknowledgements. If authors wish to provide a summary of the conclusions, it should follow the Discussion.

h) All measurements, linear, weight, and time, should be given in numerals (not words) in the metric system. The Celsius scale should be used as a standard. When other units of measure are preferred, authors should include equivalents in metric units.

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j) Only those words to be printed in italics should be underlined.

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Each Manuscript should have an abstract not to exceed 3% of the length of the text or 200 words whichever is the smaller. For position of the abstract in the manuscript see (e) above. The abstract should summarize the contents and conclusions of the paper, point to new information in the paper and indicate the relevance of the work.

## Tables

a) Tables should be carefully constructed so that the data presented may be easily understood.

b) Tables should be set out on separate sheets following the references.

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d) Each table should be provided with a descriptive heading which, together with the column headings, makes the table intelligble without reference to the text.

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a) All illustrations, whether black-and-white drawings, graphs, photographs, or tone drawings, are to be considered as figures.

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[1] The following abbreviations *(in italics)* should be used when citing ICNAF publications and documents:

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*(ICNAF Stat. Bull.)* International Commission for the Northwest Atlantic Fisheries Statistical Bulletin
*(ICNAF Redbook)* International Commission for the Northwest Atlantic Fisheries Redbook
*(ICNAF Annu. Rept.)* International Commission for the Northwest Atlantic Fisheries Annual Report
*(ICNAF Samp. Yearb.)* International Commission for the Northwest Atlantic Fisheries Sampling Yearbook
*(ICNAF Spec. Publ.)* International Commission for the Northwest Atlantic Fisheries Special Publication
*(ICNAF Meet. Proc.)* International Commission for the Northwest Atlantic Fisheries Meeting Proceedings
*(ICNAF List Fish. Vessels)* International Commission for the Northwest Atlantic Fisheries List of Fishing Vessels
*(ICNAF Res. Doc.)* International Commission for the Northwest Atlantic Fisheries Research Document
*(ICNAF Sum. Doc.)* International Commission for the Northwest Atlantic Fisheries Summary Document
*(ICNAF Com. Doc.)* International Commission for the Northwest Atlantic Fisheries Commissioner Document