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Migrations and Stock Relationships of East and Southeast Newfoundland Herring (*Clupea harengus*) as shown by Tagging Studies

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Abstract

From the tagging of Atlantic herring in different seasons at 23 localities along the east and southeast coasts of Newfoundland during 1974-81, the tag recoveries indicated substantial intermingling of the local populations of the different bays. This intermingling is mainly due to northward feeding migrations in summer and southward migrations in autumn to over-wintering areas. Movement to spawning grounds occurs in the spring, at which time the populations of the various bays tend to be very discrete. However, the relationships of the populations outside the spawning season are dynamic, with the degree of intermixing being partially dependent on population size. It is concluded that the fisheries for herring along the east and southeast coasts of Newfoundland outside the spawning season could conveniently be managed as four stock complexes in the following areas: White Bay-Notre Dame Bay, Bonavista Bay-Trinity Bay, Conception Bay-Southeast Avalon, and St. Mary's Bay-Placentia Bay.

Introduction

Traditionally, catches of Atlantic herring along the east and southeast coasts of Newfoundland have been low and tended to reflect variations in market demand rather than changes in abundance (Pinhorn, 1976). Even during the post-war period (1945-50) when the demand for herring was high, catches in eastern Newfoundland waters did not exceed 7,500 tons annually. From less than 1,000 tons annually during the 1960's, catches increased substantially during the 1970's to a peak of 28,400 tons in 1979 from NAFO Div. 3K and 3L, mainly the result of increased fishing effort due to conversion of many small vessels from traditional longlining and gillnetting operations for groundfish species to purse-seining. These increased catches emphasized the need for biological advice on optimum exploitation levels of the herring populations in coastal waters of eastern Newfoundland. As part of the research required to provide this advice, series of tagging experiments were conducted during 1974-81 to determine migratory patterns and stock relationships of herring populations along the east and southeast coasts of Newfoundland.

Earlier research on the Newfoundland herring stocks was based mainly on indirect methods of stock discrimination with rather inconclusive results. Tibbo (1956) suggested that herring found off the Labrador coast in summer and autumn represented migrants from the Notre Dame Bay population. This view was based on similarities in mean vertebral counts, growth rates and scale diameters. Parsons and Hodder (1971), from a study of the incidence of larval nematodes in spring-spawning herring, suggested that herring in Notre Dame Bay constituted a relatively discrete stock which intermingled with populations to the north in White Bay and to the south in Bonavista Bay. Parsons (1973, 1975), from studies of meristic and morphometric characters respectively, concluded that herring in Newfoundland waters consisted of a number of discrete units or local stocks which intermingle to a limited extent, but a clear distinction between the stocks could not be determined.

Wheeler and Winters (1984) have examined the homing behavior of herring along eastern Newfoundland during the spring-spawning season. This paper deals with the migratory patterns of these herring populations during other seasons of the year to determine general stock areas and the degree of intermixing.

Materials and Methods

During 1974-81, about 117,000 herring were tagged at 23 localities along the east and southeast coasts of Newfoundland (Fig. 1). The tagging experiments were designed to include as many areas and as many months of the year as possible during the fishing season, which was generally limited by environmental conditions and behavioral characteristics of the herring. Ice conditions along the east coast prevented fishing operations during January-March, and the dispersal of herring for feeding in summer reduced availability during July-August in most areas. The fishery, and hence the tagging, was restricted mainly to the

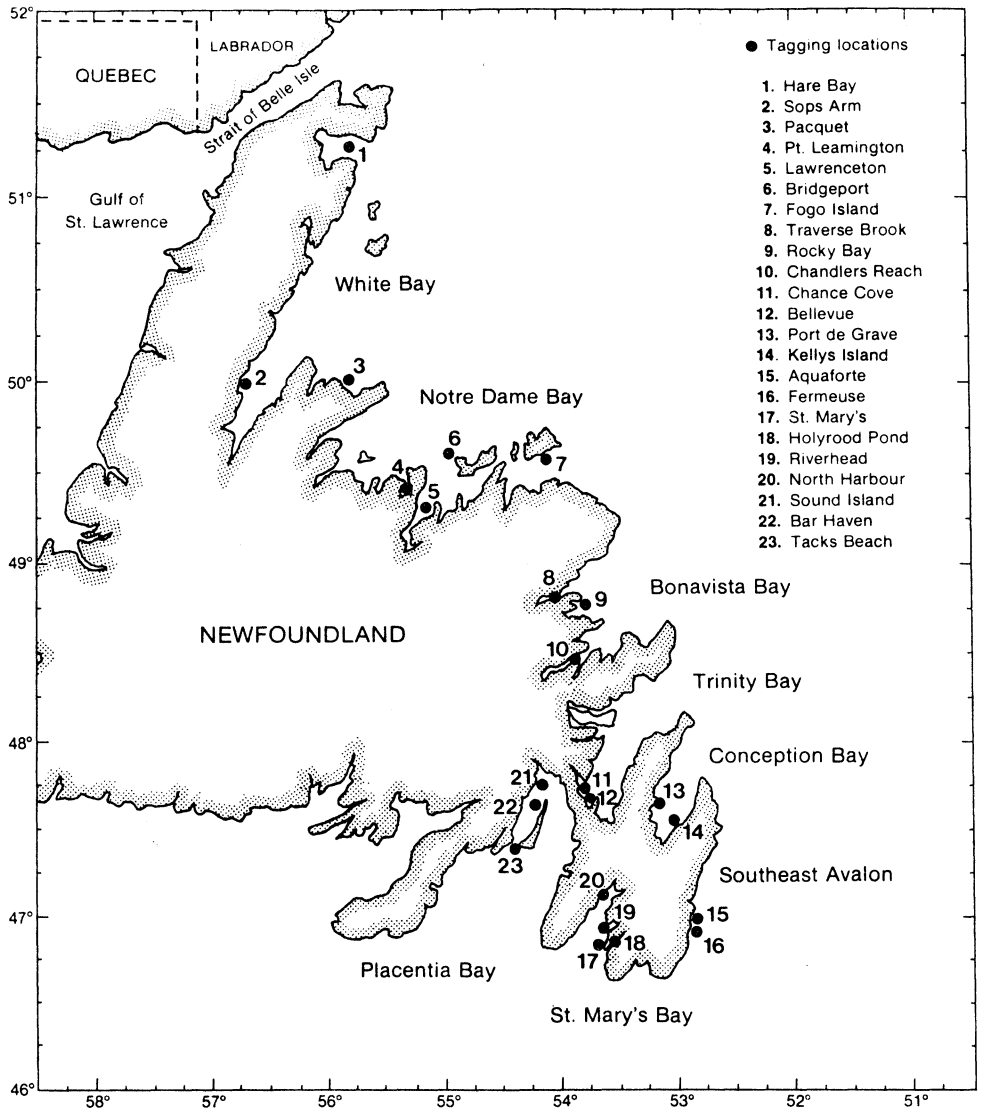

Fig. 1. Locations where tagging experiments were conducted in east and southeast Newfoundland coastal waters.

spawning season in May–June and to the autumn months of October and November, except in Placentia Bay where tagging was conducted in winter. The herring were obtained from purse seines, bar seines and poundnets which were operated by commercial fishermen, and the months of tagging (see Table 1) generally reflect the peak fishing periods in the various areas. Tagging procedures were the same as those used by Moores and Winters (1984).

Five types of external tags were used in the experiments: anchor (Floy FD-68), short anchor (Floy FD-68D), dart (Floy FD-2), streamer (Floy FTSL-73), Petersen disc, and dangler tags. More than 80% of the tags applied were of the anchor type, which has been shown to optimize tagging efficiency (B. Nakashima, Northwest Atlantic Fisheries Centre, St. John's, Newfoundland, pers. comm., 1984). Tags were yellow or orange in color, and each bore a unique number and the address of the Fisheries Centre. Initially, a reward of $3.00 (Can.) was offered for each tag returned with information on date, location and method of capture. In 1981, the reward was increased to $5.00 as an additional incentive for fishermen to return the tags. Tags were returned by both individual fishermen and workers in fish-processing plants, but those from fishermen usually were accompanied by better information, particularly about the location of recapture. In cases of missing or inadequate recapture data, contact with the person who returned the tag often resulted in more complete information than was initially provided. No distinction among tag types and colors was made for this study of migration patterns. All tag recoveries to the end of 1983 have been considered.

In all analyses, both the actual numbers of tag recoveries and the numbers adjusted for catch are included. The adjustments were necessary because the number of tagged herring recaptured in an area is dependent not only on the ratio of marked to unmarked fish in the sampled population but also on the exploitation rate. In the absence of comparative fishing effort data and assuming that a unit of catch required the same fishing effort in each area, the adjustments involved expressing the quarterly and annual recapture data in terms of number per 1,000 tons of catch in each area.

Normally, a random sample of 50 herring were collected during each tagging experiment. Examination of these fish included total length, weight, sex and maturity. Ages were determined from otoliths, and spawning type was assigned on the basis of the 8-point maturity scale, which was adopted for herring research in the Northwest Atlantic (ICNAF, 1964).

Results

General tagging results

The tagging of 117,149 herring at 23 localities distributed among eight geographical areas of eastern and southeastern Newfoundland (Fig. 1) during various months of 1974–81 have yielded 4,437 tag recoveries to the end of 1983, representing an overall return rate of 3.8% (Table 1). Most recaptures occurred within the year of tagging (3,348, 73%), and 1,933 of these occurred within 1 month of the tagging dates. Tag recoveries declined rapidly in subsequent years to 932 (21%), 161 (3.6%), 34 (0.8%) and 17 (0.4%) in the first, second, third and fourth years after the tagging year respectively.

Overall recovery rates of tags varied considerably both within and among the eight areas (Table 1), with the percentages ranging from a low of 0.7% for the September 1980 experiment in Notre Dame Bay to a high of 12.4% for the October 1976 experiment in Bonavista Bay. Relative to the total numbers of herring tagged by area, the percentage recoveries ranged from 1.9% for the Notre Dame Bay and Placentia Bay experiments to 8.6% for the Southeast Avalon area, where the recovery rate was consistently high from spring taggings in each of the 4 years.

Tag recoveries within 1 month of the tagging dates (Table 1) varied greatly both within and among areas, the percentages ranging from 19.8% for the Conception Bay taggings to 63.3% for those in Bonavista Bay. To allow sufficient time for the tagged fish to intermix with the herring populations in each area, tag recoveries within 1 month of tagging were not used in the analysis of migration patterns. With these tags excluded, the "effective" recovery rates by area varied from 1.2% for the Notre Dame Bay taggings to 4.2% for the Southeast Avalon taggings, the rate for all areas combined being 2.2%.

The age compositions of samples collected during the tagging operations indicated the dominance of the 1968 year-class at most tagging localities except those in Placentia Bay (Fig. 2). These observations are consistent with information derived from sampling the commercial fishery along the east coast of Newfoundland (Wheeler and Winters, MS 1981). Except for two samples from the Southeast Avalon area in 1977 and 1979, spring-spawners dominated at all tagging sites. As most of the herring tagged were adults (age 4+), no comparisons were made to determine the effect of maturity stage on migration patterns.

Spatial pattern of tag recoveries

The results of the experiments in White Bay and Notre Dame Bay indicated considerable intermixing of herring in the two areas (Table 2). About 30% of the adjusted recoveries from the White Bay taggings occurred in Notre Dame Bay, and 42% of those from the Notre Dame Bay taggings were from White Bay. The degree of intermixing of these northern populations with herring in Bonavista Bay was evidently small. However, three tags applied in White Bay, were recovered on the west coast of Newfoundland, the only recoveries in that area from any of the tagging experiments.

From the Bonavista Bay taggings, nearly half (46% of the adjusted recoveries) occurred in Trinity Bay, but such intermixing was not evident from the Trinity Bay taggings, from which only 8% of the recoveries occurred in Bonavista Bay. There was no evidence of substantial northward movement of herring to Notre Dame Bay from Trinity Bay and Bonavista Bay, but considerable southward movement was indicated by the occurrence in Conception Bay of 32% of the adjusted recoveries from the Trinity Bay taggings.

Adjusted recoveries from the taggings in Conception Bay and the Southeast Avalon area showed little affinity to the northern populations, with the occurrence in Trinity Bay and Bonavista Bay of only 7.5% of the recoveries from the Conception Bay taggings and 1.2% of the recoveries from the Southeast Avalon taggings. About 25% of the adjusted recoveries from the Conception Bay taggings were from this Southeast Avalon area, but only 5% of the recoveries from the Southeast Avalon taggings occurred in Conception Bay. A southerly movement was clearly evident from the recovery in St. Mary's Bay and Placentia Bay of tags applied in the Conception Bay and Southeast Avalon areas.

From the St. Mary's Bay taggings, adjusted recoveries were higher from the Southeast Avalon area (45%) than from the tagging area (37%), indicating a

TABLE 1. Summary of herring tagging experiments at various locations in eight areas of eastern and southeastern Newfoundland, 1974–81.

Tagging area	Tagging location (Fig. 1)	Month and year of tagging	Number tagged	Total recoveries		Recoveries in 1 month	
				No.	%	No.	%
White Bay	2	Jun 1976	5,650	411	7.3	206	50.1
	1	Oct 1976	5,000	230	4.6	71	30.9
	2	Jun 1977	5,000	169	3.4	57	33.7
	1	Sep 1977	1,600	32	2.0	18	56.3
	3	Oct 1977	1,700	24	1.4	6	25.0
		Total	18,950	866	4.6	358	41.3
Notre Dame Bay	5	Jun 1975	5,200	95	1.8	29	30.5
	6	Jul 1975	950	56	5.9	47	83.9
	4,5	Jun 1976	4,911	113	2.3	22	19.5
	5	Jun 1977	5,000	91	1.8	43	47.3
	5	Jun 1978	225	7	3.1	4	57.1
	7	Sep 1980	5,000	36	0.7	0	—
		Total	21,286	398	1.9	145	36.4
Bonavista Bay	10	Nov 1975	3,750	63	1.7	26	41.3
	10	Oct 1976	4,125	513	12.4	429	83.6
	10	Oct 1977	1,225	63	5.1	46	73.0
	8,9	May 1981	8,000	152	1.9	0	—
		Total	17,100	791	4.6	501	63.3
Trinity Bay	11	May 1975	3,725	124	3.3	30	24.2
	11	Apr 1976	5,000	218	4.4	2	0.9
	12	May 1977	5,000	221	4.4	75	33.9
	12	May 1978	4,200	65	1.5	44	67.7
		Total	17,925	628	3.5	151	24.0
Conception Bay	13,14	Aug 1975	3,100	50	1.6	13	26.0
	14	Dec 1975	2,350	106	4.5	17	16.0
	14	Jun 1976	4,000	61	1.5	13	21.3
		Total	9,450	217	2.3	43	19.8
Southeast Avalon	16	May 1975	2,000	87	4.4	3	3.4
	15,16	May 1976	4,225	379	9.0	303	79.9
	15	Apr 1977	2,400	215	9.0	79	36.7
	15	May 1978	2,900	307	10.6	129	42.0
		Total	11,525	988	8.6	514	52.0
St. Mary's Bay	20	Jun 1974	6,888	270	3.9	205	75.9
	18	Jun 1975	600	29	4.8	8	27.6
	17	Apr 1976	3,825	88	2.3	2	2.3
	19	May 1977	3,000	36	1.2	0	—
		Total	14,313	423	3.0	215	50.8
Placentia Bay	23	Dec 1975	2,100	37	1.8	3	8.1
	22	Jan 1977	1,457	23	1.6	2	8.7
	21	Mar 1977	3,043	66	2.2	1	1.5
		Total	6,600	126	1.9	6	4.8
	All areas		117,149	4,437	3.8	1,933	43.6

strong northward movement. However, the majority of these Southeast Avalon recaptures were from a single tagging experiment in April 1976 at Point La Haye on the eastern side of St. Mary's Bay. There was also some evidence of movement farther northward to Conception Bay and Bonavista Bay (10% of adjusted recoveries) and westward movement to Placentia Bay (7%). Herring tagged in Placentia Bay exhibited some movement eastward to St. Mary's Bay (18%), but most of the recoveries (82%) were from the tagging area.

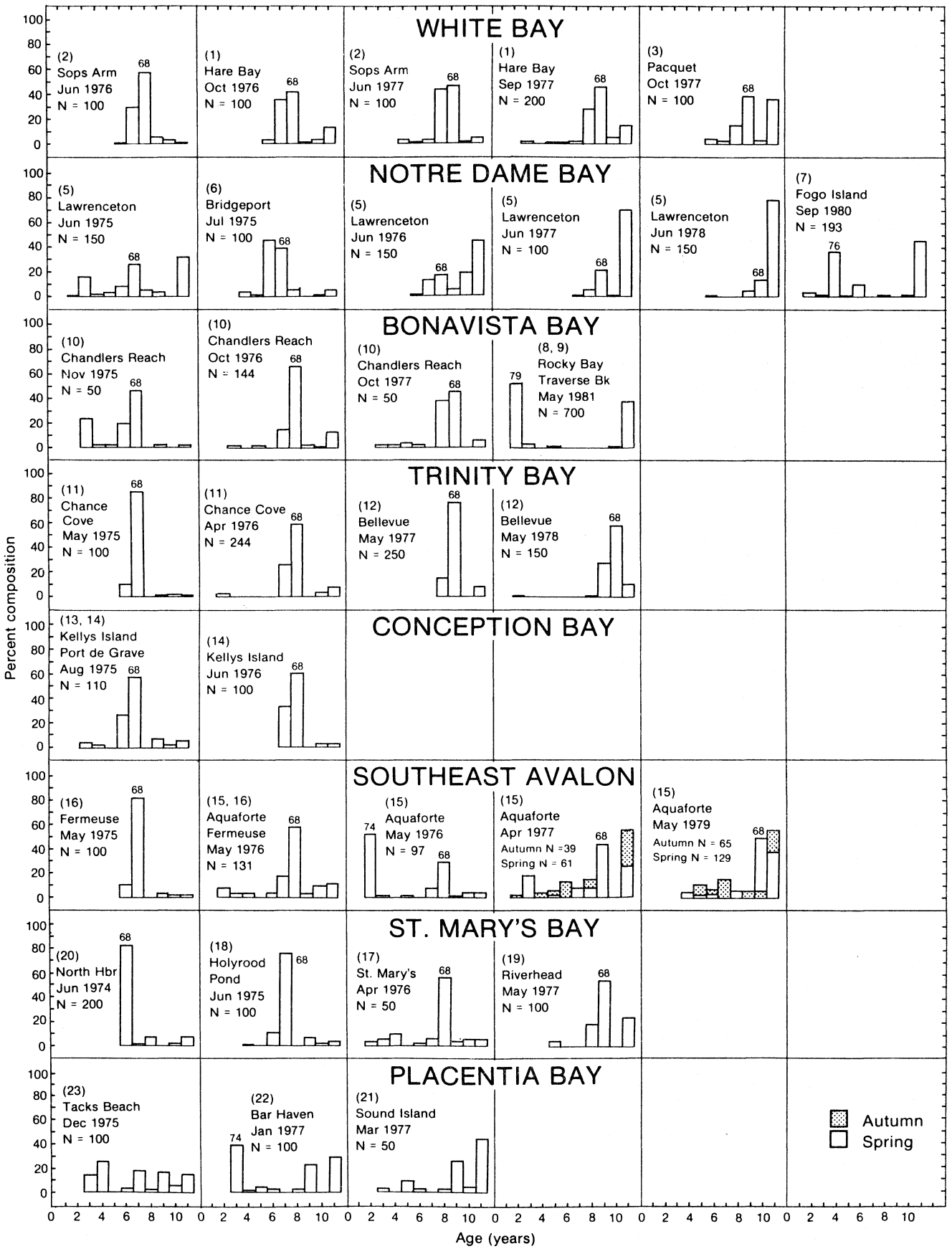

Fig. 2. Age and spawning group composition of herring sampled during the various tagging experiments.

TABLE 2. Effective and adjusted tag recoveries by season and area from herring tagged in coastal waters of eastern and southeastern Newfoundland during 1974–81. Adjusted values are effective numbers per 1,000 tons of herring caught in the relevant areas and seasons. (* No adjustments made for one tag recovery. ** No commercial catch from which to recover tags.)

Tagging area (No. of tags)	Recapture area	Effective tag recoveries by calendar quarter					Adjusted tag recoveries by calendar quarter					
		1	2	3	4	Total	1	2	3	4	Total	%
White Bay	W. Newfoundland	—	3	—	—	3	—	1.1	—	—	1.1	3.2
(18,950)	White Bay	—	41	83	63	187	**	17.3	25.2	20.9	21.6	63.3
	Notre Dame Bay	4	67	3	244	318	14.5	4.8	2.2	16.2	10.4	30.5
	Bonavista Bay	—	6	—	5	11	—	2.2	—	0.6	1.0	2.9
Notre Dame Bay	White Bay	—	2	19	11	32	**	2.6	7.9	2.6	4.3	42.1
(21,286)	Notre Dame Bay	4	80	26	76	186	14.3	3.6	14.3	5.2	4.7	46.1
	Bonavista Bay	—	10	—	8	18	—	9.7	—	0.6	1.2	11.8
	Trinity Bay	—	—	1	—	1	—	—	*	—	*	
Bonavista Bay	White Bay	—	—	—	1	1	**	—	—	*	*	
(17,100)	Notre Dame Bay	—	2	—	2	4	—	1.0	—	0.3	0.5	2.9
	Bonavista Bay	—	57	2	165	224	—	11.0	181.8	8.2	8.8	51.5
	Trinity Bay	—	39	1	4	44	—	17.6	*	1.5	7.8	45.6
	Conception Bay	—	1	—	—	1	—	*	—	—	*	
	Southeast Avalon	—	1	—	—	1	**	*	—	—	*	
Trinity Bay	Notre Dame Bay	—	—	—	2	2	—	—	—	0.2	0.2	0.4
(17,925)	Bonavista Bay	—	29	—	61	90	—	4.8	—	4.0	4.3	7.8
	Trinity Bay	18	170	38	117	343	59.2	25.6	17.5	20.1	23.0	41.8
	Conception Bay	1	1	3	4	9	*	*	19.9	20.2	17.8	32.3
	St. Mary's Bay	—	3	—	—	3	—	9.8	**	—	9.8	17.8
Conception Bay	Bonavista Bay	—	1	—	9	10	—	*	—	0.9	1.0	2.3
(9,450)	Trinity Bay	—	2	—	6	8	—	1.7	—	2.4	2.2	5.2
	Conception Bay	—	47	56	20	123	—	13.5	80.6	19.5	23.7	55.6
	Southeast Avalon	—	8	—	—	8	**	10.8	—	—	10.8	25.4
	St. Mary's Bay	—	12	—	—	12	**	4.9	—	—	4.9	11.5
	Placentia Bay	1	—	—	—	1	*	—	—	—	*	
Southeast Avalon	Bonavista Bay	—	—	—	5	5	—	—	—	0.7	0.7	0.3
(11,525)	Trinity Bay	—	5	1	5	11	—	5.9	*	1.7	2.3	0.9
	Conception Bay	2	30	60	12	104	95.2	7.1	24.1	11.0	13.3	5.2
	Southeast Avalon	—	359	7	—	366	**	233.7	218.8	—	229.0	89.8
	St. Mary's Bay	6	44	—	—	50	4.9	7.5	**	—	7.1	2.8
	Placentia Bay	4	1	—	—	5	3.4	*	—	—	2.7	1.1
St. Mary's Bay	Notre Dame Bay	—	—	—	1	1	—	—	—	*	*	
(14,313)	Bonavista Bay	—	—	—	13	13	—	—	—	0.8	0.8	2.5
	Trinity Bay	1	—	—	1	2	*	—	—	*	*	
	Conception Bay	—	2	3	2	7	—	1.4	2.6	9.4	2.5	7.9
	Southeast Avalon	—	18	—	—	18	**	14.3	—	—	14.3	45.3
	St. Mary's Bay	7	120	—	—	127	3.6	13.5	**	—	11.7	37.0
	Placentia Bay	6	4	—	—	10	1.7	4.7	—	—	2.3	7.3
Placentia Bay	Conception Bay	—	—	—	1	1	—	—	—	*	*	
(5,600)	Southeast Avalon	—	1	—	—	1	**	*	—	—	*	
	St. Mary's Bay	4	14	—	—	18	8.0	3.1	**	—	3.6	18.1
	Placentia Bay	86	16	—	3	105	16.0	15.3	—	500.0	16.3	81.9

Temporal pattern of tag recoveries

Adjusted tag recoveries from the White Bay taggings were mainly from the tagging area during spring and summer (Table 2), but significant southward movement to Notre Dame Bay was evident in autumn and also in winter, although the lack of fishing activity in White Bay during winter precludes estimation of the relative proportions of the herring population that overwinters in each of the two bays. Herring tagged in Notre Dame Bay exhibited northward movement to White Bay as indicated by the relatively high proportions of adjusted recaptures in spring, summer and autumn. Recoveries in Bonavista Bay occurred mainly in the spring and were primarily from a single tagging experiment in September 1980 off Fogo Island at the eastern extreme of Notre Dame Bay.

Adjusted recoveries from the Bonavista Bay taggings were considerably higher in Trinity Bay during the spring than in the tagging area, but the reverse situation was not evident from the Trinity Bay taggings. Rather, the relative proportions of adjusted recoveries from the Trinity Bay taggings were approximately the same in Conception Bay and Trinity Bay during the summer and autumn quarters. Winter recaptures outside of Trinity Bay were too sparse to allow inferences about migrations to be made.

Adjusted recoveries from the Conception Bay taggings occurred in the Southeast Avalon and St. Mary's Bay areas only in the spring, whereas recoveries from the Southeast Avalon taggings occurred in Conception Bay in all seasons of the year. However, during the spawning (spring) and post-spawning (summer) seasons, relatively high proportions of adjusted recoveries from the Southeast Avalon taggings were from the tagging area, with some northward movement to Conception Bay in summer. All autumn recoveries from the Southeast Avalon taggings occurred north of the tagging area in Conception Bay, Trinity Bay and Bonavista Bay. Many of these fish apparently overwintered in Conception Bay and also in St. Mary's Bay and Placentia Bay, but the lack of a winter fishery along the Southeast Avalon coast makes it impossible to estimate relative proportions of overwintering fish in each of these areas.

Adjusted recoveries from the St. Mary's Bay taggings showed a pattern of movement similar to that for the Southeast Avalon taggings. Winter recoveries were confined to Placentia Bay and St. Mary's Bay, but spring recoveries exhibited a northward movement to Southeast Avalon and Conception Bay. All recoveries in the summer and autumn occurred northward of the tagging sites in the region from Conception Bay to Notre Dame Bay. The absence of tag recoveries in the southern areas during summer and autumn reflects the lack of fishing activity due to unavailability of herring. Herring tagged in Placentia Bay exhibited some movement eastward to St. Mary's Bay but little indication of extensive movement northward along the east coast.

Tag recoveries by area and season

For the four tagging areas where herring were released in more than one calendar quarter, adjusted tag recoveries were grouped by area of recovery (Table 3). For three of these four areas, more than 70% of the recoveries from taggings in the spawning season (second quarter) were from the tagging area, the exception being Notre Dame Bay. For fish tagged and released in the third and fourth quarters in these areas, recaptures within the tagging areas varied from 12 to 66%.

Relation between tag density and stock biomass

Tag densities were determined for each area by examining experiments conducted during the spawning season. Adjusted tag recoveries from the tagging area during the spawning season (second quarter) in the first year after tagging were calculated and standardized in relation to the number of tags released in the second quarter of the preceding year (Table 4). Average biomass estimates for the stock complexes in the tag-recovery years were obtained from analytical assessments by Wheeler and Winters (MS 1981) and Moores *et al.* (MS 1981). Because these biomass estimates pertain to certain stock complexes, tag densities were calculated from combined data for White Bay and Notre Dame Bay, and for Conception Bay and Southeast Avalon. An inverse relationship between tag density and estimated biomass of herring (age 2 and older) is shown in Fig. 3.

Discussion

The analyses of tagging data for herring of eastern and southeastern Newfoundland indicate that the coastal populations intermingle in varying degrees at different times of the year. For all areas, stocks are best defined during spawning in the spring when each bay contains its own discrete spawning groups which show consistent homing behavior (Wheeler and Winters, 1984). After spawning, the herring tend to move northward out of the bays in a pattern of sequential population replacement, and this results in an intermixture of the coastal populations. From this perspective, herring of the White Bay–Notre Dame Bay region may be considered as a large stock complex. During the summer, herring from Notre Dame Bay move northward and mix with White Bay herring to form feeding concentrations

TABLE 3. Adjusted tag recoveries by area and calendar quarter of release for areas in which tagging experiments were conducted during spring spawning and subsequent quarters of the year. (* indicates no adjustments for single recovery.)

Area of tagging	Calendar quarter of release	Adjusted tag recoveries by area								Percent recovered in area of release
		West Nfld.	White Bay	Notre Dame	Bonavista Bay	Trinity Bay	Conception Bay	Southeast Avalon	St. Mary's Bay	
White Bay	2	0.9	18.5	4.9	0.9	—	—	—	—	73.4
	3	—	2.7	2.3	—	—	—	—	—	54.0
	4	*	7.5	8.3	*	—	—	—	—	47.5
Notre Dame Bay	2	—	4.2	4.3	0.4	*	—	—	—	48.3
	3	—	*	7.5	3.8	—	—	—	—	66.4
Bonavista Bay	2	—	*	—	38.4	—	—	—	—	100.0
	4	—	—	0.5	4.9	7.8	*	*	—	37.1
Conception Bay	2	—	—	—	0.5	1.5	25.1	—	—	92.6
	3	—	—	—	1.0	—	6.9	42.6	5.0	12.4
	4	—	—	—	0.7	1.3	15.6	8.1	2.9	54.5

TABLE 4. Relationship between tag density and average biomass, where tag density is a function of the ratio of adjusted tag recoveries in the tagging area in the second quarter to the number tagged in the preceding second quarter.

Tagging area	Tag recovery years	Second quarter only		Tag Density	Average biomass[a] (tons)
		Number tagged	Adjusted recoveries		
White Bay	1977-78	10,650	25.4	2.38	—
Notre Dame Bay	1976-79	16,286	2.6	0.16	—
Total (WB + NDB)	1976-79	26,936	3.9	0.15	76,900
Bonavista Bay	1982	8,000	9.6	1.21	5,800
Trinity Bay	1976-79	17,925	12.1	0.68	16,500
Conception Bay	1977	4,000	2.1	0.52	—
Southeast Avalon	1976-79	11,525	30.3	2.63	—
Total (CB + SA)	1976-79	15,525	16.0	1.03	7,500
St. Mary's Bay	1975-78	14,313	9.9	0.69	25,200

[a]Values are averages for age 2 and older herring.

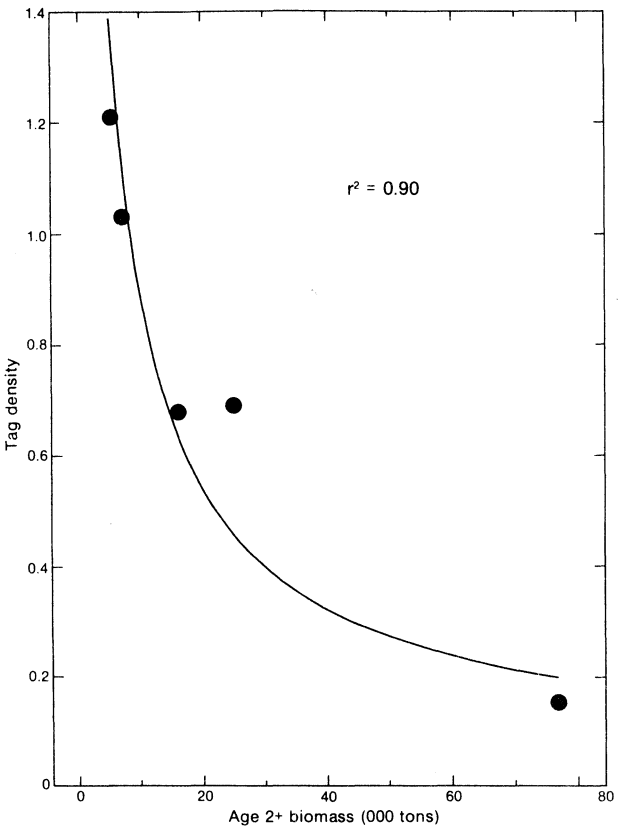

Fig. 3. Relationship between tag density per unit catch (standardized for number released) and estimated biomass from cohort analysis.

which extend northward to St. Anthony and even into the Strait of Belle Isle. These herring remain mixed during their southward migration through the White Bay area in the autumn and during the overwintering period in Notre Dame Bay. In early spring, there is a dispersal of herring to spawning areas in the north (Green Bay and White Bay) and in the south (Gander Bay to Cape Freels), at which time discrete groups are formed. Likewise, herring which spawn in Trinity Bay move northward into Bonavista Bay during the summer and form feeding concentrations which extend northward to the eastern part (Fogo Island) of Notre Dame Bay. These herring move southward in the autumn and apparently overwinter in Trinity Bay and Bonavista Bay. Similarly, Conception Bay appears to be a major summer-feeding area for herring from the Southeast Avalon area and to a lesser extent from St. Mary's Bay. These herring apparently move southward to overwinter in St. Mary's Bay. Placentia Bay herring exhibited the smallest degree of dispersion to other areas, but the area appears to be important as an overwintering ground for herring from St. Mary's Bay. Thus, the migration patterns of eastern and southeastern Newfoundland herring conform to the classic description of fish migrations, i.e. contranatant feeding migrations, denatant overwintering concentrations and contranatant spawning migrations (Harden-Jones, 1968). These findings imply that inferences about stock relationships may be as greatly influenced by the time of tagging as by the place of tagging. Fish tagged and released in the postspawning period when stocks are intermixed tend to be recaptured in the area of tagging to a lesser extent than fish tagged and released during the spawning season.

Management strategies for the herring stocks of eastern and southeastern Newfoundland are therefore dependent on the time of the year when the fisheries occur. Fisheries outside the spawning season are based mainly on mixed populations of herring. These fisheries could be managed in the context of four stock complexes: White Bay-Notre Dame Bay, Bonavista Bay-Trinity Bay, Conception Bay-Southeast Avalon, and St. Mary's Bay-Placentia Bay. Herring populations in these four regions could be assessed as stock complexes and an allowable catch allocated for each bay

on the basis of tag-recovery information. In the case of spring fisheries, it is necessary to consider the individual spawning populations in order to avoid depletion of localized components.

The tagging experiments were not designed to determine the number or relative contribution of these localized components within an area. However, the tag density (i.e. adjusted recoveries per unit catch, standardized for numbers released) appears to be inversely related to population size (Fig. 3). Only spawning season tag releases and recoveries were considered in this analysis, because it is during the spawning season that stocks are most discrete. From the estimated tag densities for the individual areas (Table 4), it is evident that Notre Dame Bay had a much larger population of herring in the late 1970's than White Bay, and that the Conception Bay component of the Conception Bay-Southeast Avalon stock complex was substantially larger than the Southeast Avalon component. Similarly, it appears that the White Bay-Notre Dame Bay stock complex was larger than either the Trinity Bay or St. Mary's Bay populations, which in turn were larger than the Conception Bay-Southeast Avalon stock complex.

The herring populations of eastern Newfoundland appear to be quite distinct from those of the west coast. Only 3 of 4,437 tag recoveries from the eastern and southeastern Newfoundland taggings were reported from western Newfoundland. Conversely, only 5 of 1,062 recoveries from 43,700 herring tagged along the west coast were reported from the White Bay-Notre Dame Bay region (Moores and Winters, 1984). The Strait of Belle Isle may be an area of mixing of the west and east coast populations during the summer-feeding season, but the very small catches of herring in that area during the summer does not favor the catching and reporting of many tagged fish.

The tagging experiments on herring in Newfoundland waters were conducted during a period of declining abundance when a single very strong year-class was passing through the fishery. Migratory patterns that are exhibited during periods of high abundance may not occur when stock sizes are smaller. During the 1960's, when the herring stock-complex in the southern Gulf of St. Lawrence was large, very large numbers migrated to southwestern Newfoundland in the autumn and overwintered there (Winters and Hodder, 1975; Winters and Beckett, 1978). These overwintering concentrations supported a large purse-seine fishery during the late 1960's until about 1971. As the stock-complex declined in the 1970's, this overwintering migration did not occur. Similar changes may have occurred along eastern Newfoundland. The most recent tagging experiments (since 1978) along eastern Newfoundland (Wheeler and Winters, MS 1984) indicate significant reductions in the range of migrations and the degree of intermingling relative to the results from the earlier experiments (i.e. those conducted in 1975). Such observations indicate that stock relationships are dynamic and that migratory patterns should be monitored when stock sizes are both large and small.

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