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Old and Older Perceptions of the Migrations and Distribution of Haddock, *Melanogrammus aeglefinus*, in Northwest Atlantic Waters from Tagging Conducted in the Bay of Fundy, Georges Bank, Scotian Shelf, and the Southern Gulf of St Lawrence.

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Abstract

An overview of tagging studies on haddock conducted since the 1920s demonstrates an erosion of population components, partially mirrored by progressive changes in perceived commercial fishery stock structure through time. In Canadian waters our fisheries likely started with five or more discrete populations, of which only two populations remain clearly discernible. The two survivors are highly migratory populations that spend the winter offshore, only coming inshore in warmer months. It is indeterminate if any non-migratory inshore haddock populations still exist.

Keywords: haddock, *Melanogrammus aeglefinus,* tagging, migrations, distribution, Gulf of St. Lawrence, Bay of Fundy, Georges Bank, Scotia Shelf

Introduction

Most of our perceptions of the discreteness, seasonal movements, and dispersal of haddock populations from the Gulf of Maine to the Gulf of St. Lawrence are based on tagging studies carried out by Canada and the US in the 1920s (Needler, 1930; Schroeder, 1942) and scientists of the Fisheries Research Board of Canada during the 1950s. Subsequent tagging studies have been conducted and some likely used in an ad hoc fashion to refine these views, but without formal analysis or publication of results. Thus the stock delineations currently applied by assessors and managers of haddock fisheries are largely based on the earlier work. Some of the unpublished work was quickly or informally examined to provide timely answers in support of fisheries management, knowledge being lost to expediency.

Also over the course of the many decades that have passed since the baseline tagging studies were conducted, the various population components of haddock throughout the northwest Atlantic have experienced many changes as a result of fishing pressure. Previously dominant components of haddock populations that supported major fisheries have diminished to commercial irrelevance. We sometimes even forget the existence of earlier haddock stocks, currently active fisheries overwhelming our purview of the distribution and abundance of haddock populations. This might lead us to disregard some long-term potentials of recovery strategies, perhaps focusing too much of our attention on those haddock supporting fisheries at the present time.

In this paper all the available data from tagging studies conducted on haddock throughout Canadian waters west of Newfoundland between 1953 and 1985 are examined. This provides a composite of previously unpublished tagging results from the 1980s with the data from a number of separately published studies for the 1950s tagging. Fresh insights from the 1980s tagging, the wider scope of several studies, and new approaches to analysis of tagging data, may enhance our understanding of haddock populations.

Methods

Areas of interest in the context of haddock movements and fisheries are variously discussed in terms of common place names (a bay, basin, bank, channel, etc.) or the

ICNAF Unit Areas familiar to those involved in fishery resource assessments. Whichever location descriptors seem to work best for a given situation are used, so Fig. 1 is provided as a general map of the regions of interest, with both common and NAFO/ICNAF identifiers, and hopefully sufficient depth contouring to discern major features without too much clutter.

The many tagging studies discussed in this paper are depicted in Figs. 2–5 and summarized in Table 1. A detailed tabular representation of releases and associated recoveries is provided in an Appendix. Further background information on these studies is provided by Stobo and Fowler (2006). Other, minor, tagging events for which no recoveries were obtained are not shown. A few studies, for which the recoveries were considered too few to interpret, are labelled in italics in Figs. 2–5 and noted as 'Not Examined' in the Appendix.

Some of the historical tagging studies of the 1950s and 1960s were characterized by one or more of four features that subsequent tagging research has demonstrated can

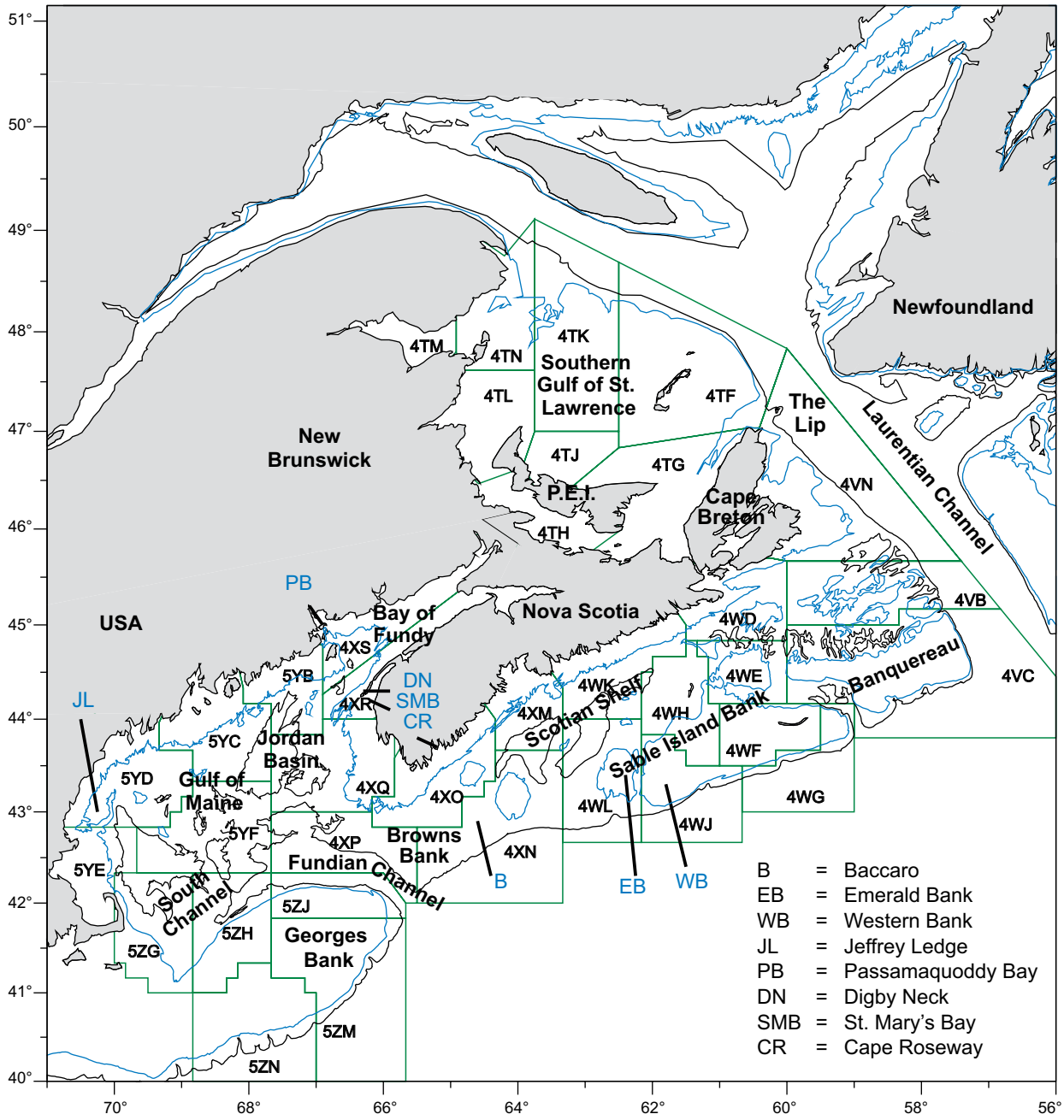

Fig. 1. Map of the area relevant to haddock tagging studies in this paper. Common names of geographic features and the boundaries of DFO Statistical Unit Areas mentioned in the text are provided. The 100-meter (blue) and 200-meter (black) contour lines are used to distinguish major depth breaks.

Table 1. Summary of haddock tagging activities depicted in Figures 2–6

Year	Month	NAFO Area	Number Released	Number Recovered	Percent Recovered	Historical References
1953	May	4XO	117	40	34.2	Martin, 1961; McCracken, 1958
1953	Jun	4XO	55	22	40.0	Martin, 1961; McCracken, 1958
1953	Jul	4XO	223	60	26.9	Martin, 1961; McCracken, 1958
1953	Aug	4XO	126	38	30.2	Martin, 1961; McCracken, 1958
1953	Sep	4XO	34	9	26.5	Martin, 1961; McCracken, 1958
1953	Oct	4XO	25	5	20.0	Martin, 1961; McCracken, 1958
1954	Jun	4VN	3	3	100.0	
1954	Jul	4WK	25	4	16	
1954	Jul	4XO	1	0	0	
1954	Aug	4WD	11	1	9.1	
1956	Sep	4TG	281	33	11.7	McCracken, 1954
1956	Sep	4TH	352	61	17.3	McCracken, 1954
1956	Oct	4TG	223	34	15.2	McCracken, 1954
1956	Oct	4TH	143	47	32.9	McCracken, 1954
1957	Mar	4XN	336	22	6.5	Martin, 1959
1957	Mar	4XO	56	3	5.4	Martin, 1959
1957	Mar	4XP	98	5	5.1	Martin, 1959
1957	Apr	4XN	634	43	6.8	Martin, 1959
1957	Oct	4XS	112	18	16.1	McCracken, 1953
1957	Nov	4XS	706	197	27.9	McCracken, 1953
1957	Dec	4XO	268	66	24.6	McCracken, 1963
1958	Apr	4XS	31	0	0	
1959	Mar	4WJ	258	15	5.8	
1959	Mar	4WL	224	11	4.9	
1959	Mar	4XN	29	2	6.9	
1959	Sep	4WF	147	0	0	
1959	Sep	4WH	64	0	0	
1959	Sep	4WL	4	0	0	
1960	Mar	4WH	600	15	2.5	Martin, 1960
1963	Nov	4XR	661	93	14.1	Halliday & McCracken, 1970
1966	Oct	4XR	107	14	13.1	Halliday & McCracken, 1970
1966	Oct	4XS	212	46	21.7	Halliday & McCracken, 1970
1969	Jun	4XN	5	0	0	
1969	Jun	4XO	12	1	8.3	
1969	Jun	4XP	234	9	3.8	
1970	Mar	4XP	22	0	0	
1971	Mar	4XP	900	15	1.7	
1972	Apr	4XO	47	2	4.3	
1973	Jun	4XR	121	8	6.6	
1973	Jun	4XS	119	6	5	
1978	Nov	4WJ	28	0	0	
1978	Nov	4WL	110	3	2.7	
1979	Jan	4WK	10	0	0	
1980	Feb	4WK	67	0	0	
1980	Feb	4XM	74	0	0	
1982	Jun	4XR	2 973	429	14.4	
1983	Mar	4XP	297	17	5.7	
1983	Apr	4XN	2 831	192	6.8	
1983	Apr	4XP	419	11	2.6	
1984	Feb	4XP	1 999	13	0.7	
1984	Feb	5ZJ	236	0	0	
1984	Mar	4XN	4 733	76	1.6	
1984	Mar	4XP	4 220	150	3.6	
1984	Mar	5ZM	2 953	49	1.7	
1984	Aug	4XS	3	0	0	
1985	Mar	4XN	2 874	9	0.3	
1985	Mar	4XP	5 994	69	1.2	
1985	Mar	5ZJ	2 944	43	1.5	
1985	Apr	4XN	2 925	19	0.7	
1985	Apr	4XP	200	0	0	
1985	Jul	4XR	134	1	0.7	
1985	Jul	4XS	50	0	0	
1985	Jul	5YB	299	1	0.3	

confound interpretations of tag return data. These four features comprise:

Not considering the higher likelihoods of recovery with proximity in time to the tagging event. Treating immediate recoveries as equal in import to later recoveries can exaggerate the perception of recoveries from the tagging area.

Terminating consideration of recoveries after a couple of years. Sometimes a pattern of movement is not apparent, or may appear as marginal dispersal, if recoveries are interpreted too soon after tagging. Such movements can become more pronounced with annual redundancy over a longer time period. As well, some movements may not be initiated until an animal attains a certain size or age that does not occur until a few years post-tagging. And finally, receipt of hoarded tags post-analysis can change the picture, especially if well-documented by a fisherman (*e.g.* the hobby of collecting and taping tags to a sheet with annotations like locations, size, etc.).

Disregarding unplottable recoveries. Disregarding unplottable recoveries (no latitude/longitude) in favour of recoveries lending themselves conveniently to plotting. Very often an unplottable recovery will still be known to the precision of unit area. And in some cases the likelihood of a plottable location being provided was systematically biased according to the types of fisheries involved, and these in turn were sometimes associated with non-overlapping geographic areas.

Over-aggregating the seasonal scale of recoveries. A discrete but rapid movement may be masked if recoveries are summarized over periods of several months.

The tagging data, inclusive of recoveries made subsequently to earlier interpretations or publications for studies conducted between 1953 and 1973, were assessed in the form of monthly recovery plots and tabular summaries. The monthly plots were aggregated over years, and recoveries within 3 months of tagging (termed immediate recaptures) were not plotted. The tables detail the recoveries by year, month and ICNAF Unit Area if possible (NAFO Subarea or Division if nothing more precise), and included immediate and unplottable recaptures not represented by the figures. Lengths of fish when tagged (and sometimes when recovered) were also considered, and instances of tagging of immature fish were noted.

Seasonal spawning closures (typically March–May, sometimes including February) of critical portions of Browns Bank, Georges Bank, and the South Channel were implemented in 1970 (Halliday and Pinhorn, 1996), and are still in effect today. These are depicted on recovery plots for appropriate months by grey borders. Although they only inhibited recoveries with respect to the tagging in the 1980s, the closed areas are also identified in plots of historical recoveries to facilitate comparison between time periods. Another, permanent, closure referred to as the Haddock Box was implemented in Div. 4W (encompassing Western and Emerald Banks) in 1987, and is also still in effect today. This closure, initiated 2 years after the last tagging study in 1985, has not been identified in plots but should be borne in mind for the later years of recoveries from Browns Bank tagging.

An aspect of recapture probabilities, rarely encountered with open fisheries in Canadian Atlantic waters for the last few decades, is that the post-war Canadian fishery was relatively small, and not as cognizant of the locations of fish as they are today. Relative fishing effort among areas plays a crucial role in likelihoods of tag recoveries. Unfortunately the documentation of fishing effort in the earliest years of interest to us, the 1950s and early 1960s, lacks the geographic detail available today. To build as coherent a picture as possible, the ICNAF Statistical Bulletins for 1953–1959 (ICNAF, 1953, 1954, 1955, 1956, 1958, 1959) were coupled with anecdotal information gleaned from Canadian Research Reports for 1958–1962 (Martin, 1958, 1959, 1960, 1961, 1962), both annual series during the period. The Statistical Bulletins only documented catches by what we call today NAFO Division and Subarea, not the finer-scale ICNAF Unit Areas that were later determined necessary to interpret fishing trends. The catch reporting system was also focused on large international fisheries, such that important details of the smaller Canadian fishery are absent, especially with respect to inshore gears. Landings in later years were derived from Van Eeckhaute and Brodziak (2005) for Div. 5Zj and 5Zm, Hurley *et al.,* (1998) and O'Boyle *et al.,* (1982) for 4X, and Frank *et al.,* (MS 1997) for Div. 4TVW. The combined landings information for both periods (Table 2) was used subjectively, not quantitatively. The earlier years could not be considered for weighting by effort, as catch data was only documented to the geographic precision of Division and Subarea (Unit Area is essential for weighting haddock recoveries). By the 1980s all areas where haddock occurred were intensively fished unless closed, and no improvement in our ability to decipher tag returns by weighting for effort could be discerned.

Initially, an attempt is made to portray the results of tagging studies from the 1950s and 1960s in the context in which they were perceived at the time. Then previously unpublished results of the tagging studies conducted in the 1980s are summarized. Finally the earlier tagging studies are revisited, adjusting interpretations where appropriate for post-publication recoveries, biases due to immediate

recoveries, disregarded (unplottable) recoveries, disaggregated months of recovery, and insights provided by the subsequent 1980s tagging.

Results and Discussion

Review of Historical Tagging

The earliest tagging studies in the 1920s, conducted by both US and Canadian scientists, were mostly dealt with by Needler (1930), with a followup by Schroeder (1942) with more focus on US tagging. These studies generally portrayed 3 major migratory populations of relevance to waters between Laurentian and Fundian Channels, and an indeterminate number of non-migratory inshore haddock populations along the coast of Nova Scotia from Digby to west of Cape Breton. Digby Neck and Shelbourne posed discernable candidates of inshore haddock populations, but there was limited tagging elsewhere along the coast. The three migratory populations comprised the Div. 5Y, 4X, and 4TVW stocks that are still perceived today. The Div. 5Y population was considered to be primarily resident in the Gulf of Maine but with a northerly summer migration that could introduce small numbers of haddock into the Bay of Fundy on the New Brunswick side (4Xs). The Div. 4X population summered in the Bay of Fundy area and wintered offshore on the western Scotian Shelf. The Div. 4TVW population summered in the Gulf of St. Lawrence and wintered offshore on the eastern Scotian Shelf.

Based on returns from haddock tagged near Cape Roseway (close inshore near Lockeport in DFO Unit Area Div. 4Xo) in the summer of 1953 (Fig. 2), McCracken (1956) purported a single, seasonally migrating, southwest Nova Scotia haddock population that supported both the summer inshore and winter offshore fisheries. There were

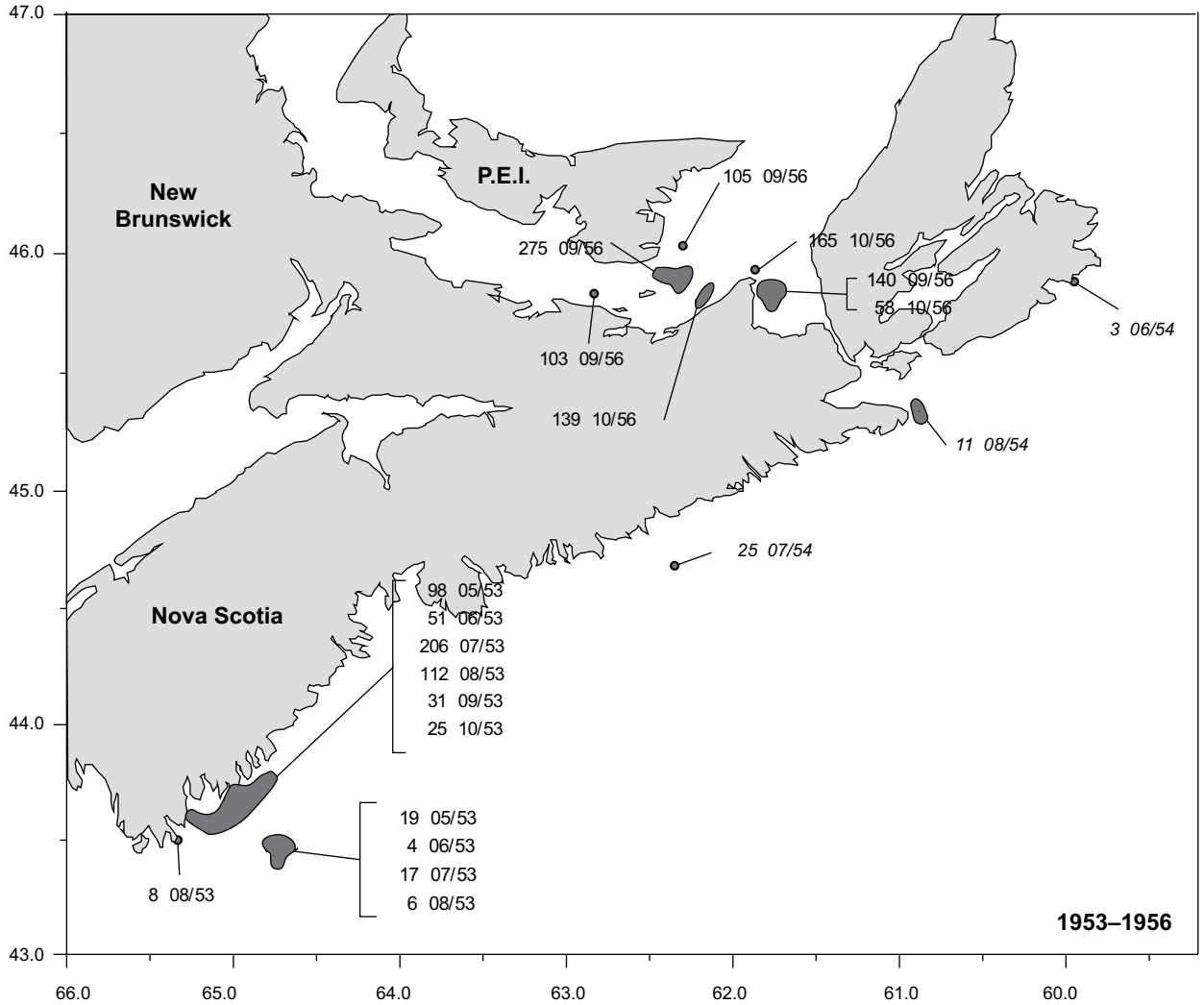

Fig. 2. Locations of tagging releases of haddock in NAFO Subarea 4 between 1953 and 1956. The numbers of fish tagged and the month and year of release are given for each release location. In many cases several discrete releases of close geographic proximity and/or size range of fish were combined for this composite map. Numbers in italics denote releases for which recoveries were too few to include in analyses.

very few returns from the Bay of Fundy, and none of these were summer recaptures, thus no suggestion of a link between summer inshore DFO Unit area 4Xo haddock and Bay of Fundy haddock. Northeasterly movements as far as Cape Breton were reported, but numbers were felt low enough to consider the DFO Unit area 4Xo haddock distinct from eastern Shelf haddock.

Tagging of haddock in Passamaquoddy Bay, in the north portion of the mouth of the Bay of Fundy in DFO Unit area 4Xs, in the winter of 1957 (Fig. 3) indicated that most of the haddock from the New Brunswick side of the Bay of Fundy overwintered in New England waters (primarily Jeffrey Ledge and South Channel in the western Gulf of Maine), returning to Passamaquoddy Bay in

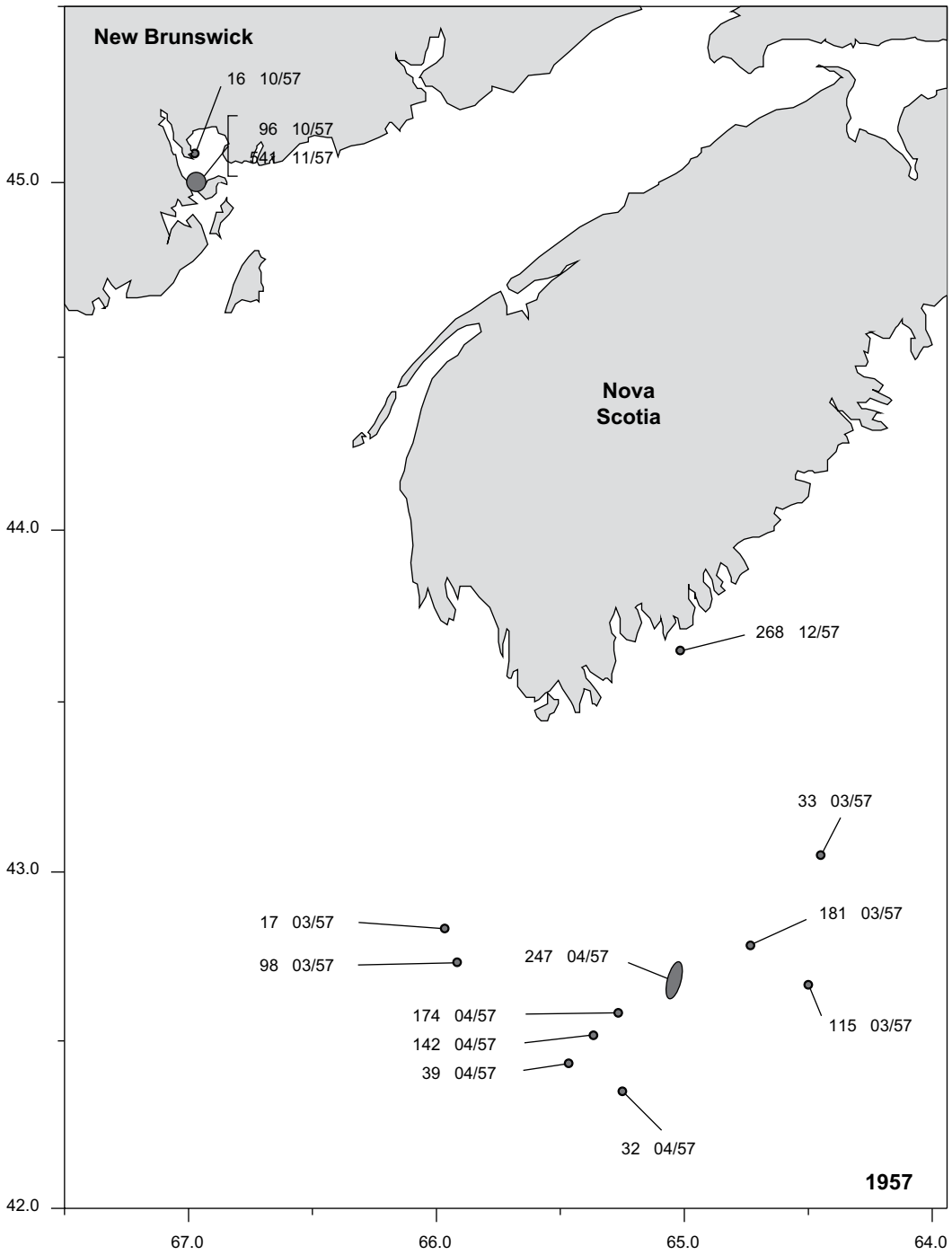

Fig. 3. Locations of tagging releases of haddock in NAFO Subarea 4 in 1957. The numbers of fish tagged and the month and year of release are given for each release location. In many cases several discrete releases of close geographic proximity and/or size range of fish were combined for this composite map. Numbers in italics denote releases for which recoveries were too few to include in analyses.

the summer (McCracken, 1960). As well about 15% of these haddock were recaptured from the Digby Neck and Browns Bank fisheries during the winter (December–May) of 1957–58, and this proportion increased to 40% over the following winter.

Interpretation of recoveries by McCracken (1963) of haddock tagged in the southern Gulf of St Lawrence (DFO Unit Areas 4Tfg) during the autumn of 1956 (Fig. 2) confirmed hypotheses that they represented a migratory population that over-wintered on the Scotian Shelf (Needler,1930), mostly in the vicinity of Sable Island Bank and Emerald Bank. The recovery rate was high enough to distinguish the timing and route of migration around Cape Breton, demonstrating that these fish supported the spring trap and autumn otter trawl haddock fisheries in the Cape Breton area.

The last major tagging studies on Scotia/Fundy haddock to be conducted and formally published prior to the 1980s focused on the autumn (November, 1963 and October, 1966) inhabitants of the Bay of Fundy in the vicinity of Digby Neck (the Nova Scotian side of the Bay, see Fig. 4). Returns indicated that many of these haddock overwintered offshore (mostly Browns Bank) while other mature haddock remained local, giving the impression of two stocks in the area over the summer. The haddock remaining inshore were confirmed as mature. Summer mixing was apparent with Passamaquoddy Bay haddock, but few recoveries extended into the Gulf of Maine (Halliday and McCracken, 1970).

Haddock were also tagged offshore on and around Browns Bank in the spring of 1957 (Fig. 3), on offshore banks of Div. 4W (Emerald, Western and Sable Island Banks) in March of 1959 and 1960 (Fig. 4), again off Digby Neck in June of 1973 (Fig. 4), and possibly again inshore near Cape Roseway in December of 1957 (Fig. 3). Results of these studies do not seem to have been formally published, however all but the 1973 Digby Neck tagging appear to have been reviewed, as documented by Martin (1960;1961;1962) in the Canadian Research Reports for 1959–1961. Very low and localized returns characterized the Scotian Shelf tagging. It was suggested that the poor recovery rate was due to high tagging mortality, a consequence of targeting spawning fish, with some

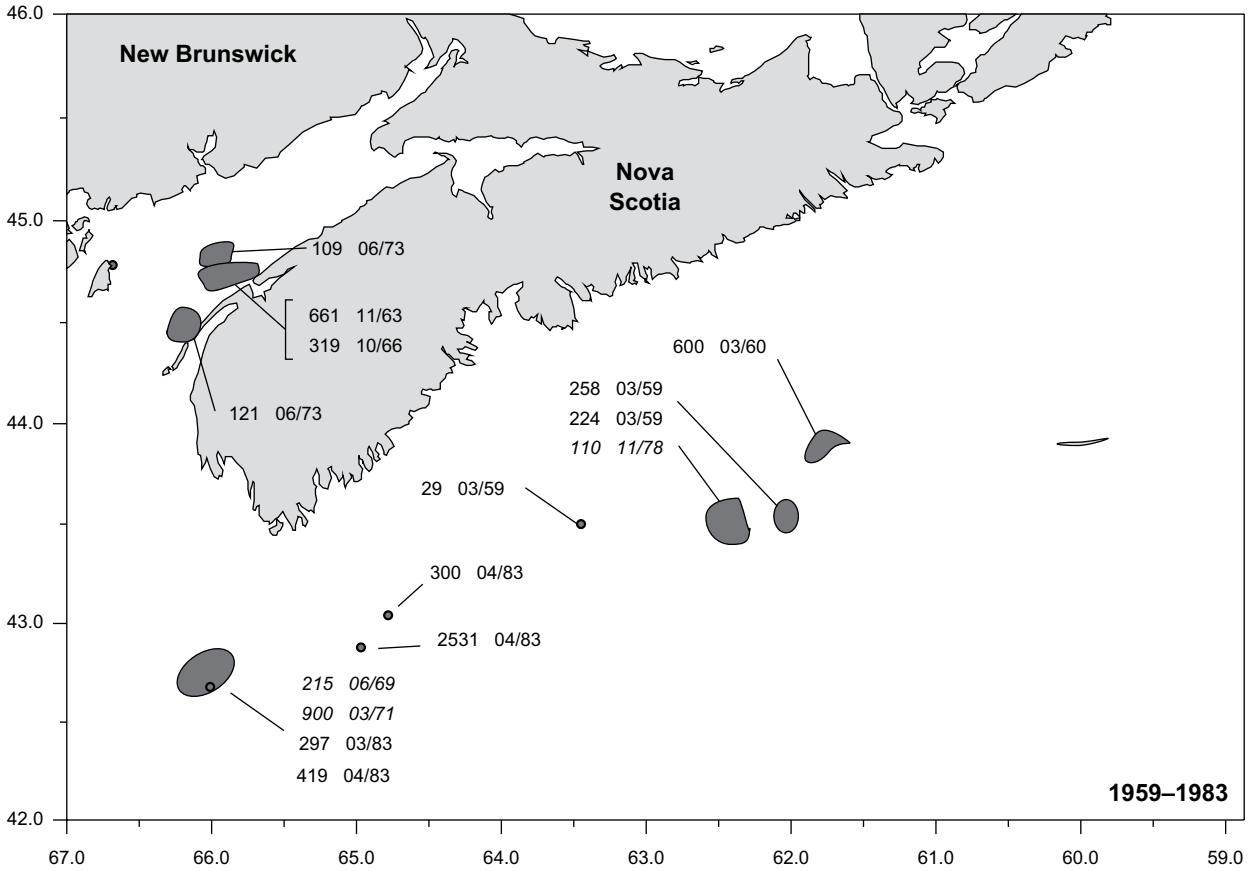

Fig. 4. Locations of tagging releases of haddock in NAFO Subarea 4 between 1959 and 1973. The numbers of fish tagged and the month and year of release are given for each release location. In many cases several discrete releases of close geographic proximity and/or size range of fish were combined for this composite map. Numbers in italics denote releases for which recoveries were too few to include in analyses.

further speculation of low fishing mortality. Although not explicitly stated, it is possible that the researchers of the time did not feel the Shelf tagging depicted haddock movements adequately to warrant a formal paper. The same reasoning may apply to the 1973 Digby tagging, which provided very few recoveries and added nothing to the earlier work.

The possible second Cape Roseway tagging, in 1957, is not mentioned in its own right. It may be that the alleged Cape Roseway tagging was mistaken logging of latitude and longitude, such that these were actually Passamaquoddy Bay haddock, although typical errors like shifting or crossing a degree digit is not involved. If indeed Cape Roseway tagging, then it was confused with the Passamaquoddy Bay tagging, as the number of Passamaquoddy Bay haddock quoted as tagged in both the 1957 and 1958 Canadian Research Reports (Martin, 1958; Martin, 1959) exceeds that of the recorded data by the same amount as the number of haddock recorded as tagged off Cape Roseway. The confirmed Passamaquoddy Bay haddock were tagged during October–November of 1957, and the dubious Cape Roseway haddock were tagged in December of 1957, the tag series a continuum over time. Inferring from the tag numbers and timing, all this tagging was likely conducted by the same vessel. A December Cape Roseway tagging is a possibility, and could have been accomplished as an unplanned afterthought on the way home to port, and as such may have been poorly documented. As recovery patterns were compatible with the confirmed Passamaquoddy Bay tagging, there is no concern that interpretations of the movements of Passamaquoddy Bay haddock might have been compromised. It is only unfortunate, if the tagging really was off Cape Roseway, as these haddock can be identified by their movements as the Passamaquoddy Bay population. This would have greatly improved our understanding of the possible migration routes taken by the Passamaquoddy Bay haddock that go to Browns Bank to overwinter rather than the Gulf of Maine, which remain highly speculative.

Martin (1962) provided a useful snapshot of perceptions of stock identities in the early 1960s. Summarizing interpretations of past tagging and biological studies, it was concluded that at least three and perhaps four major haddock stocks resided in NAFO Subarea 4. The northwest Div. 4Xs (Passamaquoddy Bay) haddock were considered a migratory component of the NAFO Subarea 5 (Gulf of Maine) haddock stock. Browns Bank haddock were perceived as a discrete stock that mixed with Bay of Fundy haddock in the summer. And eastern Scotian Shelf (NAFO Divisions 4W, 4V) haddock were regarded as a partially separate stock that might be further subdivided into resident inshore stocks and a migratory offshore component that moved into NAFO Divisions 4T (southern Gulf of St Lawrence) in the summer. A local (non-migratory) Div. 4Xr population, distinct from the migratory Passamaquoddy Bay/Gulf of Maine and Browns Bank/Bay of Fundy haddock populations, was the possible 4th major stock.

The Passamaquoddy Bay and Digby Neck tagging studies provided much of the basis for treating Div. 4Xs haddock as part of the Gulf of Maine population, discrete from southwest Nova Scotia haddock, a stock definition that was used until 1998, when Div. 4Xs was treated as part of the southwest Nova Scotia haddock stock (Hurley *et al.*, 1998). The summer residents of Div. 4Xr were included with the migratory Browns Bank/Bay of Fundy haddock throughout, so Canada treated Div. 4X haddock as comprised of two populations until 1998, and one population since that time. The southern Gulf of St Lawrence tagging provided much of the basis for the Div. 4TVW haddock stock definition, which is still in use.

Tagging in the 1980s

In 1982–1985 a new haddock tagging program was conducted by DFO in NAFO Subareas 4X and 5Z (Figs. 4 and 5), largely to answer questions related to potential transboundary issues involving Gulf of Maine, Georges Bank, Browns Bank, and Bay of Fundy haddock. The National Marine Fisheries Service (NMFS) also tagged haddock in the US portions of Div. 5Y and 5Z to complete the picture. Canadian tagging efforts concentrated on spawning haddock during the spring (February–April) on Browns and Georges Banks, and on young summer (June) residents of St. Mary's Bay. This could distinguish the migratory Div. 4X population from adjacent Gulf of Maine and inshore Digby Neck populations. Results of these studies were discussed informally at the time, but not published.

During 1982–1987, the core period for recoveries from the 1980s tagging, haddock recaptures would have been thwarted by March-May spawning area closures to otter trawls that covered Browns Bank, the tip of Georges Bank, and an area between Cape Cod and Georges Bank called the South Channel. Thus we see very few recoveries in closed areas during the spawning months, with the numbers suddenly increasing in the months immediately prior and subsequent to the closures. These closed areas are depicted on all recovery plots for March, April and May. So long as we keep these closures in mind, it is fairly straightforward to reason out the transition between February and June. As well, summer inshore movements remain visible in all months, as all the closures involve offshore banks. In this light the Browns Bank (Fig. 6) and St. Mary's Bay (Fig. 7) tagging told the same general story.

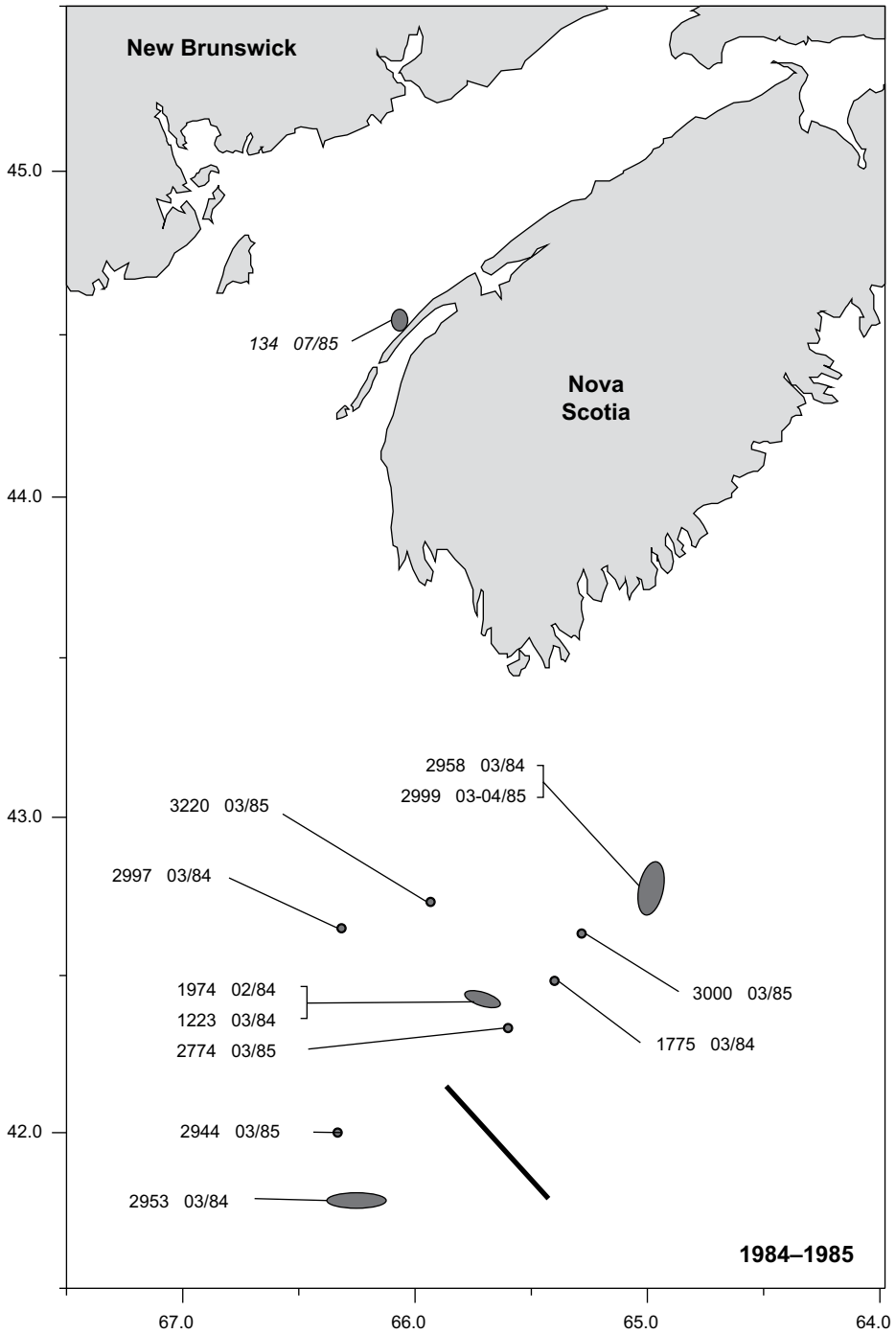

Fig. 5. Locations of tagging releases of haddock in NAFO Divisions 4X, 5Y and 5Z between 1984 and 1985 (the heavy line marks the Fundian Channel separating Divisions 4X and 5Z). The numbers of fish tagged and the month and year of release are given for each release location. In many cases several discrete releases of close geographic proximity and/or size range of fish were combined for this composite map. Numbers in italics denote releases for which recoveries were too few to include in analyses.

The Browns Bank (western Shelf) and St. Mary's Bay haddock demonstrated a spring/summer/autumn affinity for inshore areas off southwest Nova Scotia and the Nova Scotian side of the Bay of Fundy. In winter an offshore emphasis on Browns Bank was apparent. The Browns Bank haddock appeared more inclined to undertake easterly movements along the Nova Scotia coast during the summer/autumn (July–November) than the St. Mary's

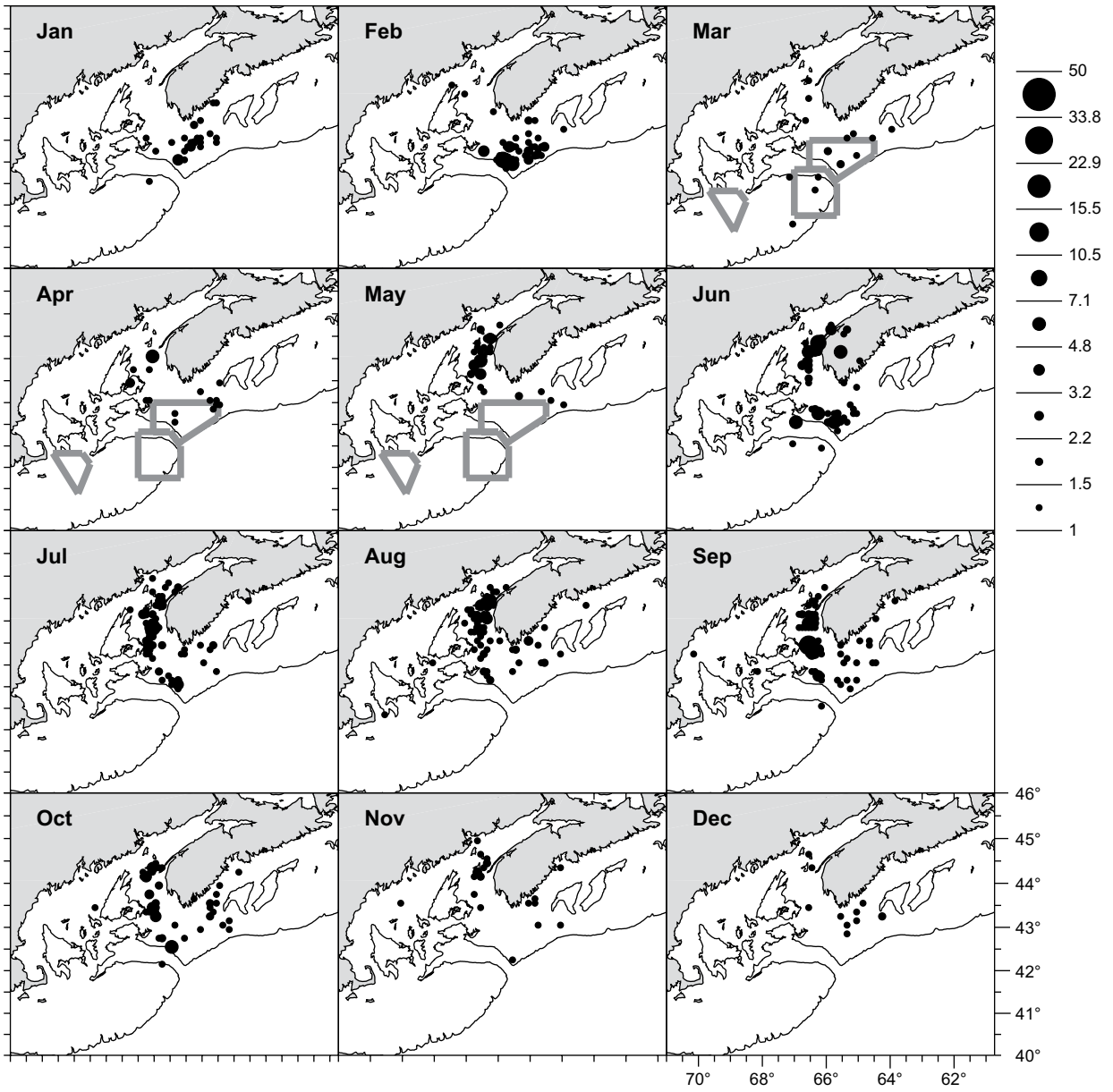

Fig. 6. Recoveries from haddock tagged on Browns Bank, Scotian Shelf, Springs of 1983–1985. Recoveries are aggregated over years and five minute squares, and plotted separately for each month. Recoveries within three months of release are not plotted. Grey boundaries delineate seasonal spawning area closures to fisheries.

Bay haddock, although recoveries should be interpreted in light of the larger number of haddock recovered from offshore tagging, and the focus of the inshore tagging on younger (immature) fish. Common lengths at tagging were 48–55 cm offshore versus 33–34 cm inshore, and common recapture lengths were 51–58 cm for offshore haddock and 43–45 cm for inshore haddock. If the eastward movements are characteristic of larger or more mature fish, there may have been few inshore haddock achieving such status prior to recapture. In which case the St. Mary's Bay haddock would be indistinguishable from the migratory Div. 4X haddock, providing no proof of the survival of an inshore Digby Neck population.

Most of the haddock recovered from tagging on the northeast (Canadian) portion of Georges Bank (Fig. 8) were taken from Georges Bank, regardless of season. This suggests a resident population on Georges Bank, discrete

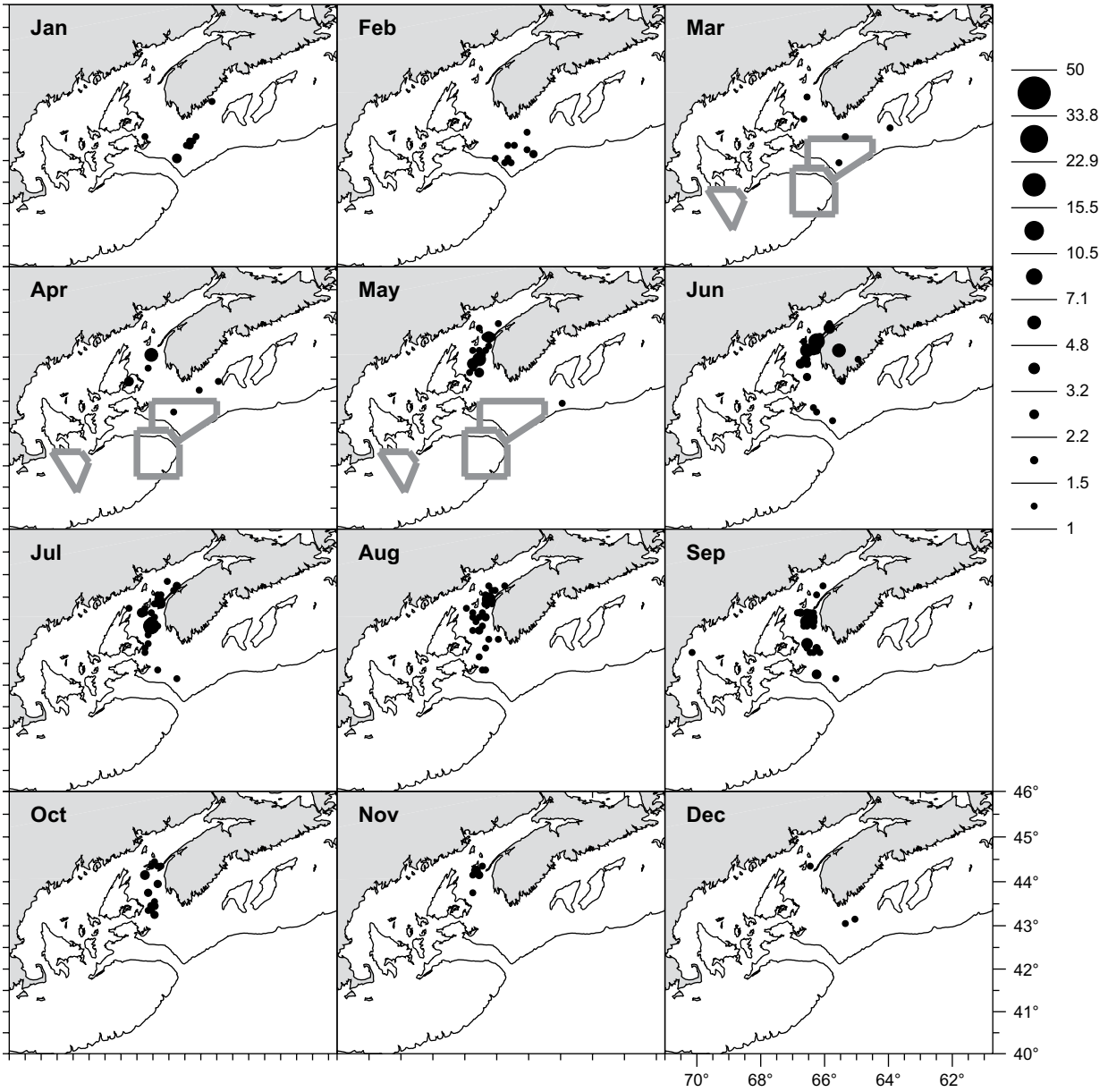

Fig. 7. Recoveries from haddock tagged in St. Mary's Bay, Nova Scotia, in June of 1982. Recoveries are aggregated over years and five minute squares, and plotted separately for each month. Recoveries within three months of release are not plotted. Grey boundaries delineate seasonal spawning area closures to fisheries.

from the haddock just across the Fundian Channel on Browns Bank. Only 5 of 88 recoveries came from Browns Bank. Single returns from Jeffrey Ledge, South Channel, and the Bay of Fundy might indicate some straying.

As is evident from Table 1, recovery rates from 1980s tagging studies were much lower than the recovery rates from 1950s tagging studies. This phenomenon is not exclusive to haddock, but occurs generally across species tagged during both periods, and has been investigated in earlier analyses (Stobo and Fowler, 2006; Fowler and Stobo, 1999) for several species, with particular emphasis on cod, haddock and plaice. Two primary causes of the difference are changes in tag reporting likelihoods and a general shift in tagging strategy in the later period to try to avoid active fisheries. Both are applicable to haddock, but the former cause appears the most relevant. The decline in reporting likelihood is probably a combined

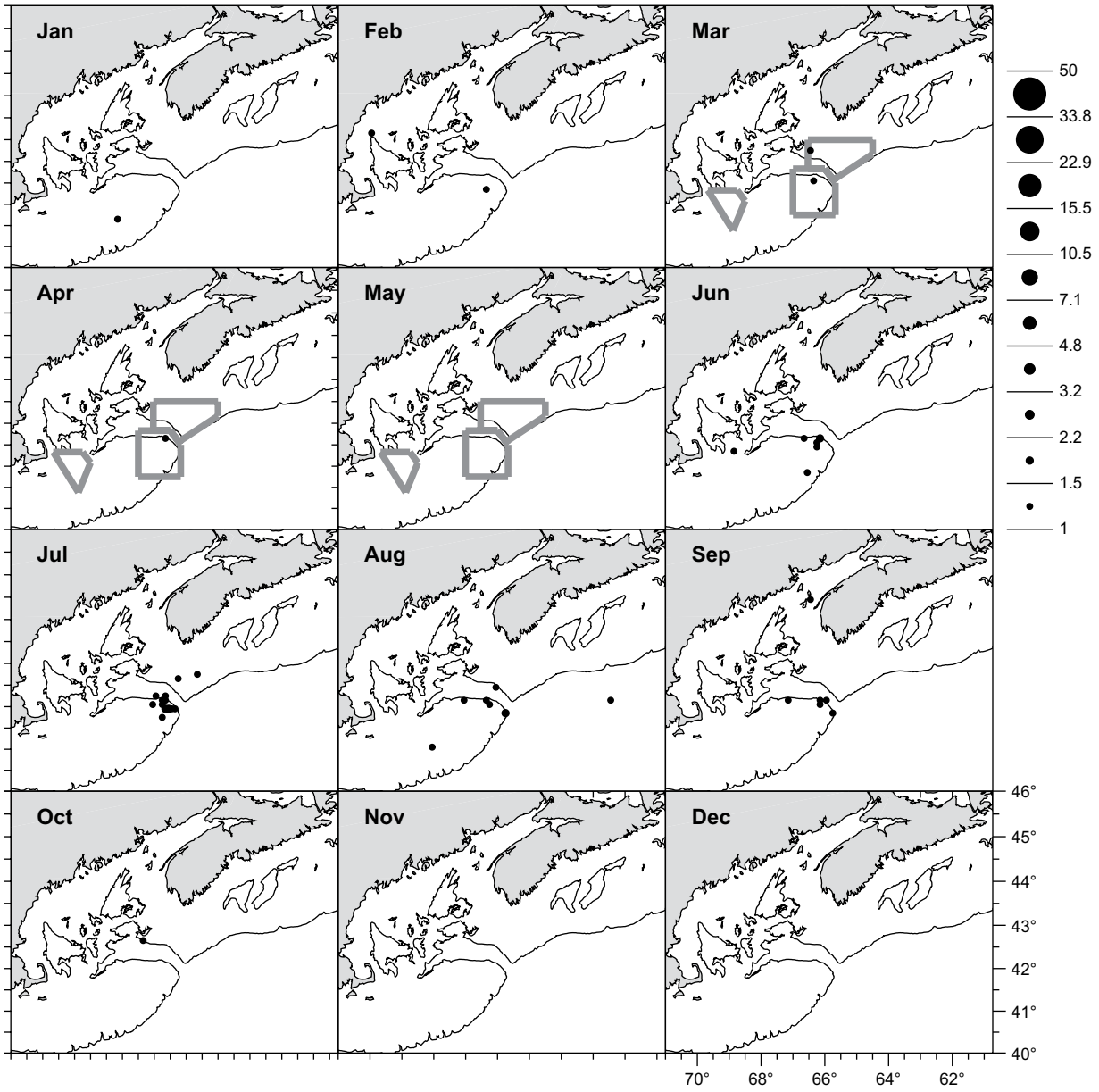

Fig. 8. Recoveries from haddock tagged on Georges Bank in the Springs of 1984–1985. Recoveries are aggregated over years and five minute squares, and plotted separately for each month. Recoveries within three months of release are not plotted. Grey boundaries delineate seasonal spawning area closures to fisheries.

result of increased automation in the fishery (less human interaction with the fish) and a depreciation in attitude towards fisheries science as fisheries management became a constraint on fishing activity. By the 1980s many industry components felt concerned that tagging studies in particular could have negative implications for catch allocations, such that returning a tag could be perceived as unwise. The decline in reporting likelihood is effectively offset by the increase in numbers tagged during the 1980s, and should not bias interpretations.

Revisiting the Early Tagging Studies

Overview of the Fishery. The haddock fishery in Scotia/Fundy waters (Div. 4XWV) during the 1950s was primarily Canadian (Table 2). Otter trawls made up almost half the fleet, with the rest predominantly handline (hook and line, distinguished from longliners). Handlining, being of relatively little import in the context of international fisheries, was included in the ICNAF Miscellaneous Gear category. But some textual background in the Statistical

Table 2. Commercial landings (metric tons) of haddock by year and area.

Source	ICNAF Statistical Bulletins					
Year/Area	US 4X	CAN 4X	CAN 4W	CAN 4V	CAN 4T	
1953	8 700	7 949	9 356	3 543		
1954	14 613	7 124	12 323	5 549	7 002	
1955	12 067	8 709	12 777	3 311	3 132	
1956	12 130	9 251	18 248	4 806	2 860	
1957	72 96	9 862	1 740			
1958	12 141	9 695	17 572	3 166	2 598	
1959	5 465	9 807	21 156	5 028	2 969	

Source	Van Eeckhaute & Brodziak (2005)	NAFO	Frank *et al.,* (1997)				1962–1969 (Peter Hurley, pers. comm.); Hurley *et al.,* (1998) 1970–1989
Year/Area	5Zjm	4X	4W	4Vs	4Vn	4T	4Xs alone
1960	a	16 261	21 244	5 132	1 420	2 041	–
1961	a	17 862	23 858	2 379	1 104	1 572	–
1962	a	17 925	21 408	2 311	1 105	1 142	2 046
1963	a	24 414	20 138	4 085	1 284	1 065	3 204
1964	a	35 979	19 016	2 747	1 069	462	2 786
1965	a	29 007	51 487	3 054	539	438	3 413
1966	a	42 224	20 199	2 443	857	150	5 132
1967	a	37 307	8 690	1 746	355	121	4 987
1968	39 816	32 482	10 057	2 966	203	148	1 859
1969	22 224	30 413	9 370	1 423	357	170	838
1970[b]	11 280	18 139	7 296	1 500	473	160	452
1971	10 727	17 600	10 378	2 258	682	151	340
1972	5 719	13 499	3 108	1 060	520	60	179
1973	5 302	13 103	3 192	673	526	23	101
1974	4 145	13 234	1 614	547	165	31	145
1975	5 400	18 250	1 587	159	86	37	68
1976	4 308	17 424	1 244	63	41	12	39
1977[c]	10 813	21 269	2 898	145	197	8	32
1978	22 281	26 672	5 279	482	122	18	103
1979	19 401	24 935	2 516	652	205	59	293
1980	27 502	29 006	12 688	1 841	230	81	389
1981	24 837	30 962	17 892	1 796	144	177	209
1982	17 508	24 450	12 600	2 373	206	47	349
1983	11 868	25 401	7 617	1 542	223	30	395
1984	10 264	19 909	4 393	3 198	310	120	227
1985	7 752	15 340	3 216	7 293	657	498	295
1986	6 740	15 331	6 667	8 802	921	531	212
1987[d]	6 858	13 797	1 355	1 587	497	438	84
1988	8 433	11 295	1 607	2 057	507	369	46
1989[e]	4 490	6 803	5 513	3 099	423	79	15

a Total 5Zjm catches were likely at record high levels around 60 000 mt during the early 1960s (Van Eeckhaute & Brodziak, 2005)
b Haddock nursery area closures instituted
c 200-mile limit goes into effect
d Haddock Box introduced
e Haddock fishery closed mid-season

Bulletins noted that gear code MISC[ellaneous] was mostly hook and line where Subarea 4 haddock were concerned.

Unlike the recent years with which we are most familiar, the core of the Canadian haddock fishery during the 1950s and early 1960s was Div. 4W. During this period Div. 4W typically gave twice as much haddock landed in Canada as Div. 4X, and 3-4 times that of Div. 4V or 4T. Shift in effort to Div. 4X, the centre of the Canadian haddock fishery today, occurred in the 1960s as haddock became relatively more abundant in Div. 4X than 4W, with 1965 the last year that Div. 4W landings exceeded those of Div. 4X. The Div. 4W fishery was characterized by offshore otter trawling as opposed to the handlining which was common in Div. 4X. Probabilities of recovering tags inshore in Div. 4W may have been low, but we would expect to see recoveries if haddock ventured onto the offshore banks of Div. 4W. Similarly offshore effort in Div. 4X was high enough to expect recoveries from the banks, but we don't know how inshore (hook and line) fishing was distributed throughout the Bay of Fundy and southwest Nova Scotia.

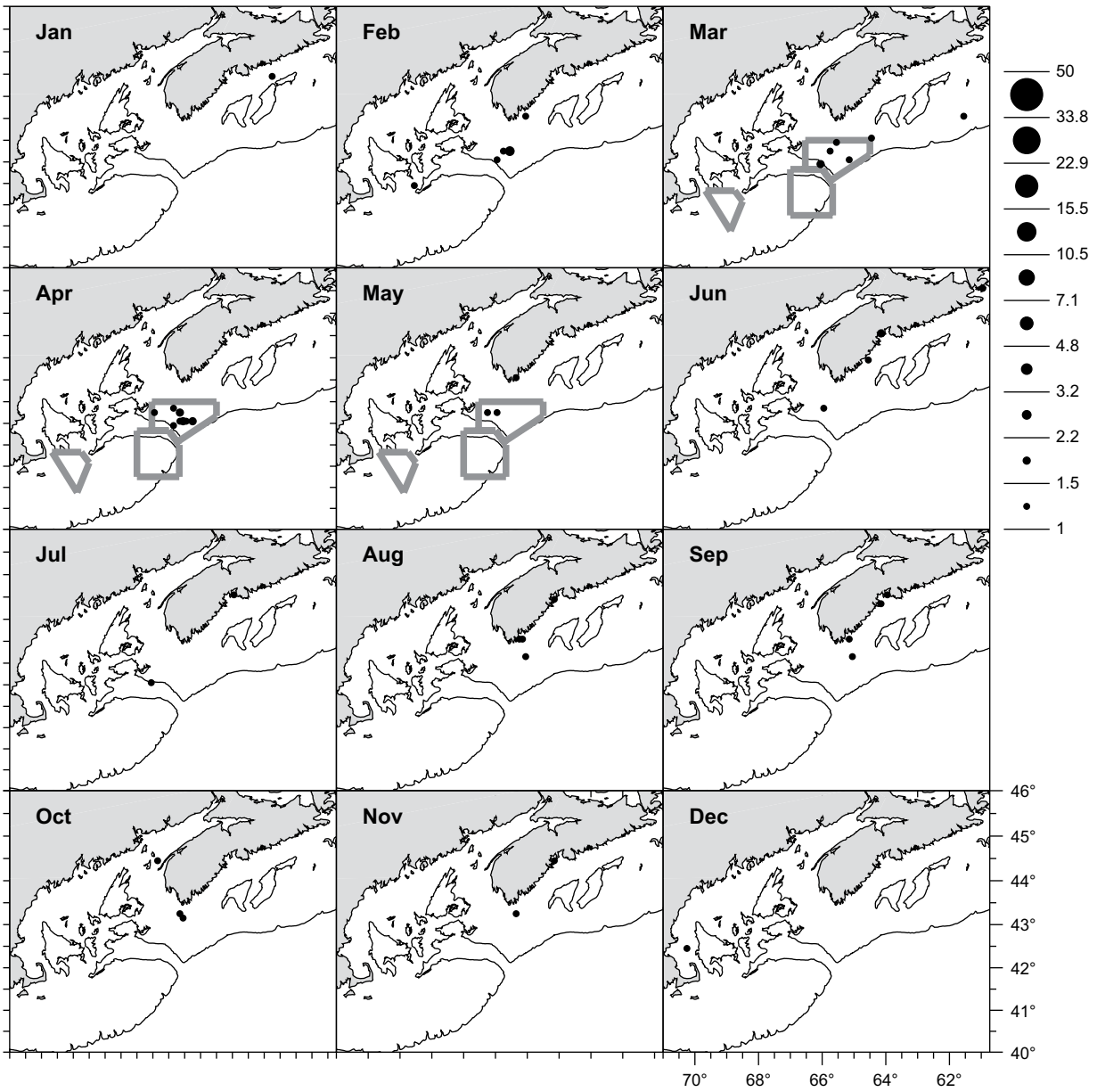

Fig. 9. Recoveries from haddock tagged on Browns Bank, Spring of 1957. Recoveries are aggregated over years and five minute squares, and plotted separately for each month. Recoveries within three months of release are not plotted. Grey boundaries delineate seasonal spawning area closures to fisheries.

Seasonal breakdowns of landings were initiated in 1954. The Div. 4W fishery generated significant landings throughout the year, with a peak during the winter (January–April). The Div. 4X otter trawl fishery was typified by a winter focus (February–April), while the Div. 4X handline fishery was most active during spring-summer-autumn. The small US fishery in the Gulf of Maine (Div. 5Y) was prosecuted throughout the year with a spring peak (May–April), while that on Georges Bank (Div. 5Z) was a very strong fishery all year. We would expect recoveries from haddock that visited Georges Bank, especially in light of the Div. 5Y recoveries from the much lesser effort relative to Div. 5Z.

Retrospective of the Historical Tagging Studies.

The unpublished historical tagging of haddock on Browns Bank in 1957 (Fig. 3) showed little movement except for some easterly coastal dispersion (Fig. 9). We did not see summer returns from the Bay of Fundy that featured so prominently with Browns Bank tagging in the 1980s (Fig. 6). The 1957 Passamaquoddy Bay tagging

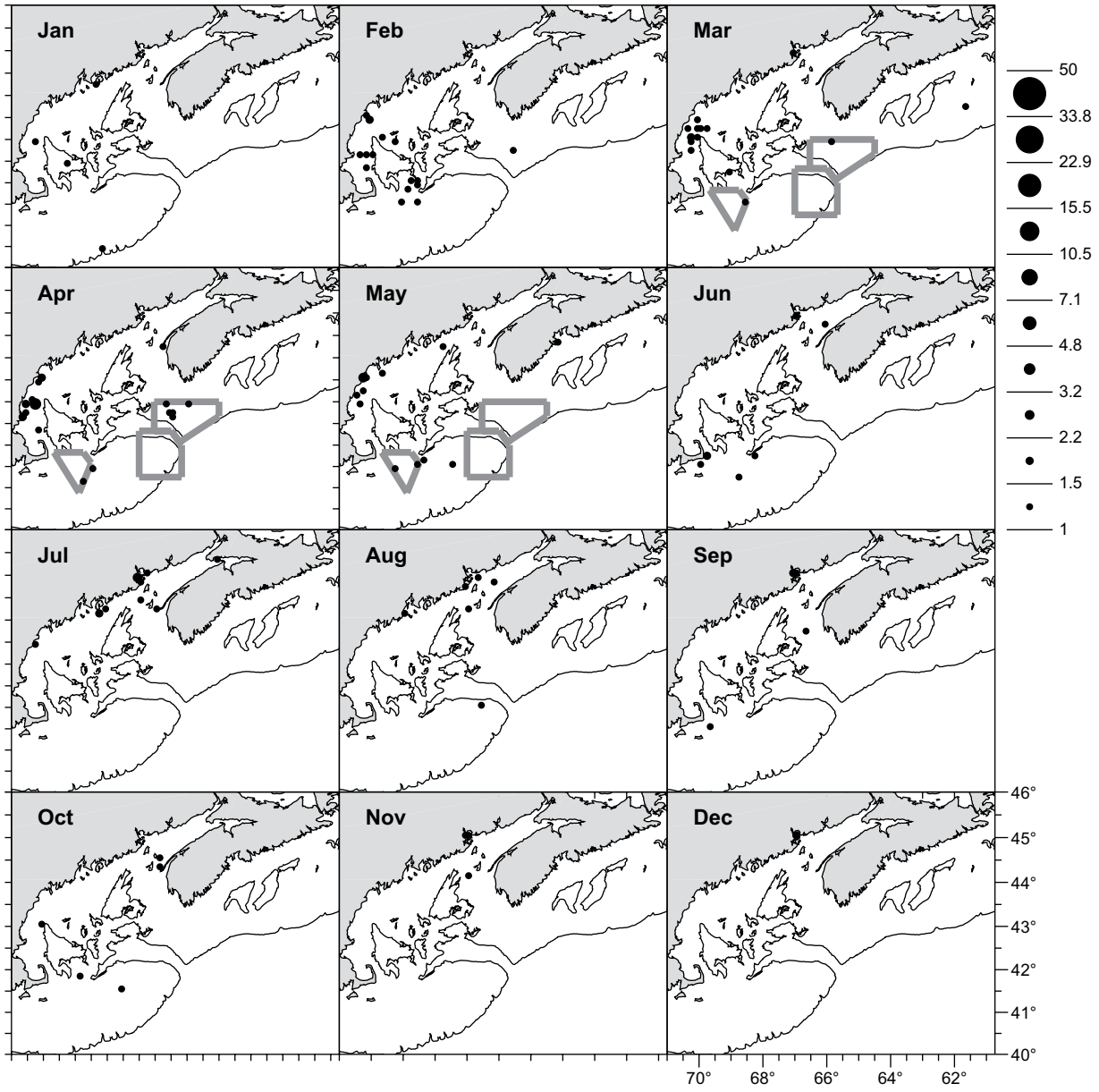

Fig. 10. Recoveries from haddock tagged in Passamaquoddy Bay, Autumn of 1957. Recoveries are aggregated over years and five minute squares, and plotted separately for each month. Recoveries within three months of release are not plotted. Grey boundaries delineate seasonal spawning area closures to fisheries.

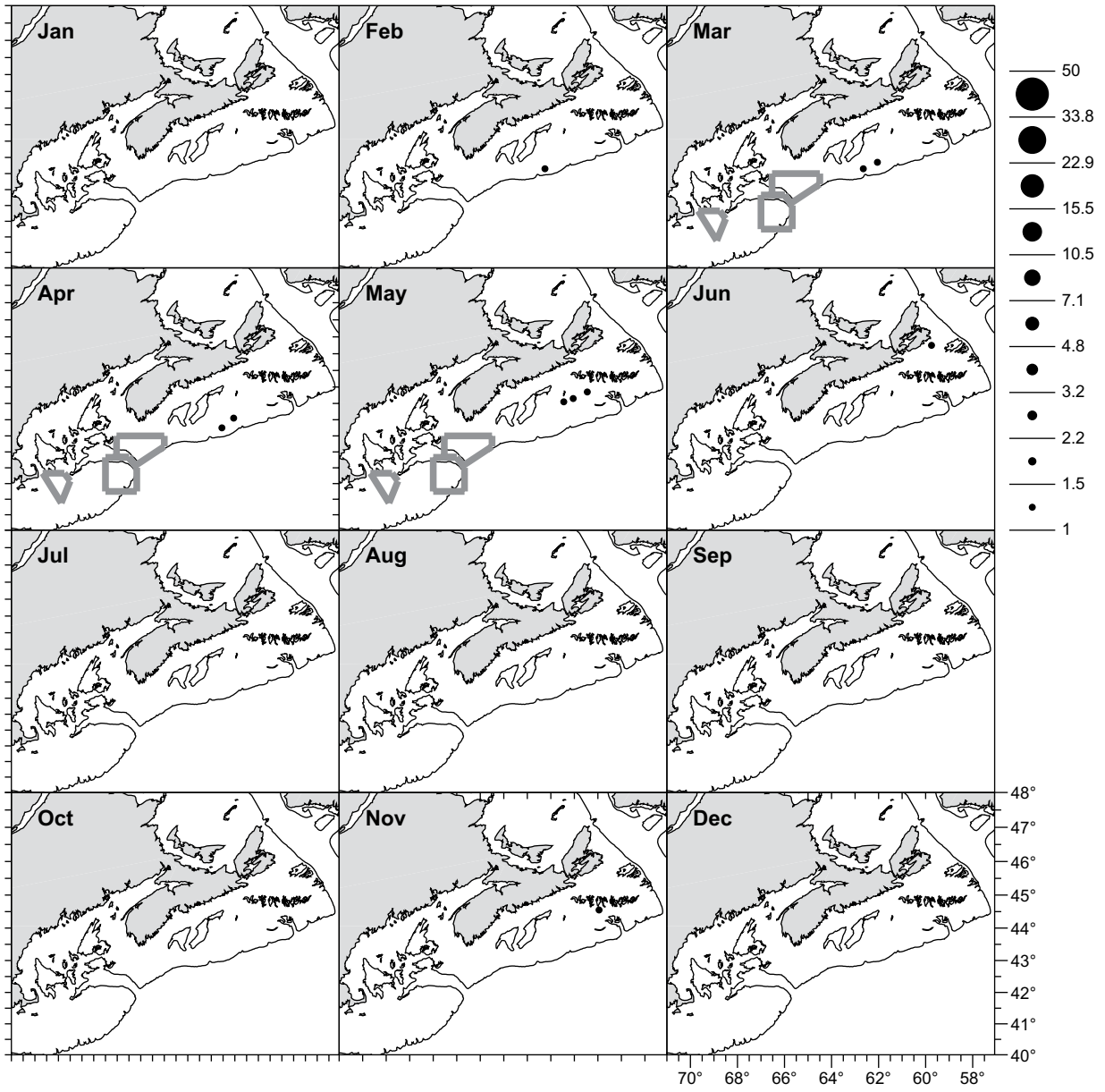

Fig. 11. Recoveries from haddock tagged on Sable Island and Western Banks, March of 1959 & 1960. Recoveries are aggregated over years and five minute squares, and plotted separately for each month. Recoveries within three months of release are not plotted. Grey boundaries delineate seasonal spawning area closures to fisheries.

saw numbers of summer returns from the Bay of Fundy (Fig. 10), however recoveries from Div. 4Xr (the Nova Scotia side of the Bay of Fundy) were quite sparse. We saw recoveries from the Gulf of Maine and Div. 4Xs (the New Brunswick side of the Bay of Fundy) emphasized, but we saw more recoveries from the distant Browns Bank area than any inshore areas between Div. 4Xs and Browns Bank. This raises a suspicion of possibly little effort in the general vicinity of Div. 4Xr in the 1950s, which would mitigate against recoveries of spring-tagged Browns Bank haddock, which the 1980s tagging indicated favour the Div. 4Xr side of the Bay of Fundy (Fig. 6). Unfortunately commercial fisheries data for the earlier time period was not reported by Unit Areas, which we need to determine relative effort within regions of Div. 4X. Researchers of the time would likely have known whether Div. 4Xr effort was suitable for recoveries to represent haddock movements, and possibly this was a factor in discouraging publication.

The unpublished 1959–1960 Sable/Emerald/Western Banks tagging (Fig. 4) gave primarily local recoveries, with little to suggest a link with Div. 4T (Fig. 11).

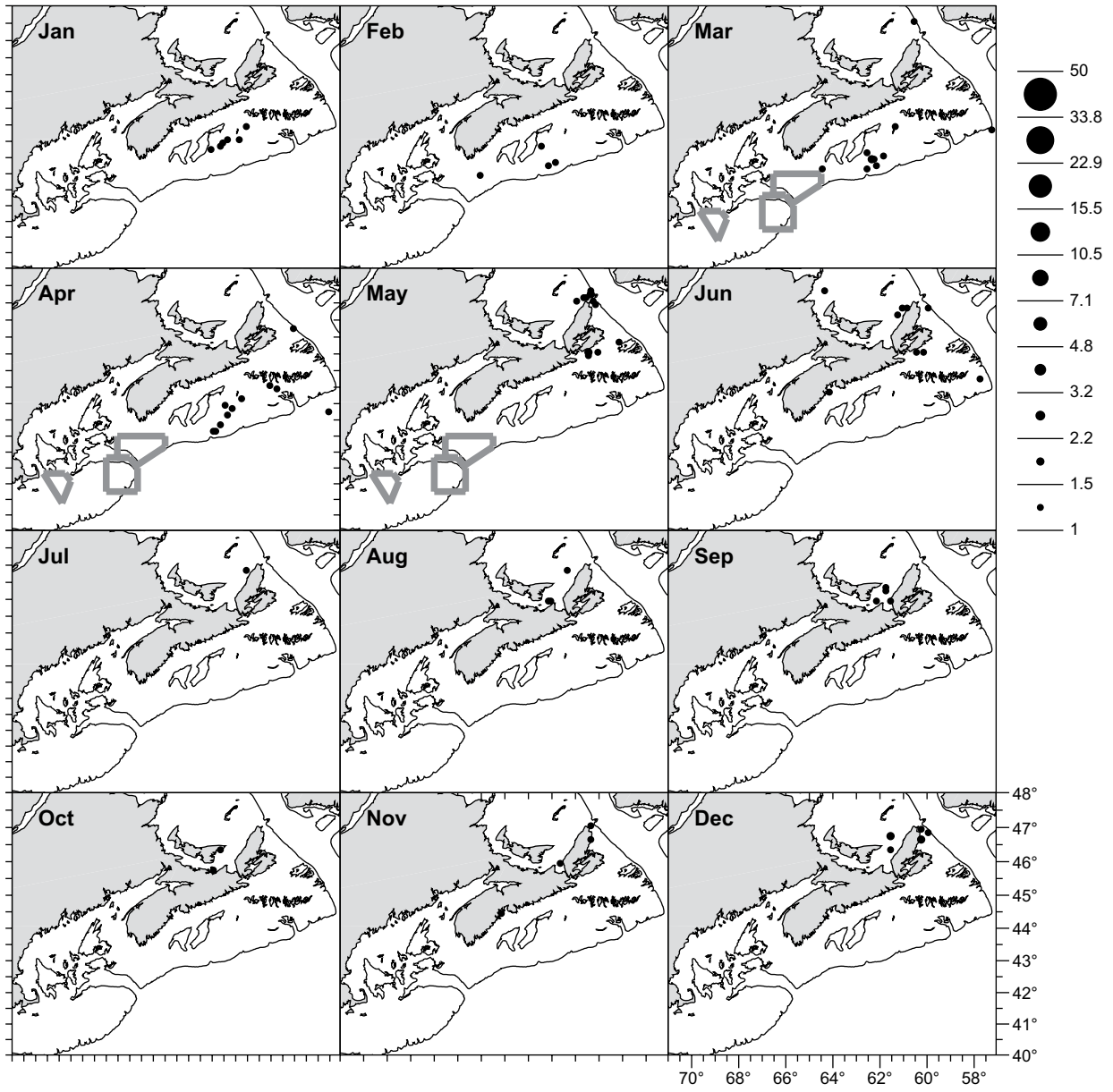

Fig. 12. Recoveries from haddock tagged between PEI and Cape Breton, Autumn of 1956. Recoveries are aggregated over years and five minute squares, and plotted separately for each month. Recoveries within three months of release are not plotted. Grey boundaries delineate seasonal spawning area closures to fisheries.

However only the March 1959/1960 tagging provided any recoveries (1959 28 recs, 23 plottable; 1960 15 recs, 10 plottable), while another 225 fish tagged in the same general area in September, 1959 (not shown in release plots) produced no returns at all. Gulf of St Lawrence and Sydney Bight fishing effort during potential recovery years for these fish was a small fraction that of Div. 4W (Table 2). Whether the tagging missed any Div. 4T migrants or lack of returns from Div. 4T was due to low fishing effort levels in Div. 4T, cannot be elucidated. Of the few recoveries from the Div. 4W tagging, all but one occurred in Div. 4W during November–May, while July–October are conspicuously devoid of any recaptures. A single June recovery near Scatarie (Div. 4Vn) is the only plottable non-4W recovery. As we would expect a Div. 4T association, if it existed, to be evidenced in the summer, the sheer absence of summer 4W recoveries seems quite relevant. Additionally, we have 10 unplottable recoveries (either no coordinates or no month), none of which came from Div. 4W (see Appendix). Of these 7 came from Div. 4X (4 April, 1 May, 1 September, 1 no month), 2 from Div. Div. 4V (in June and August), and 1 from Div. 4Tf (but no

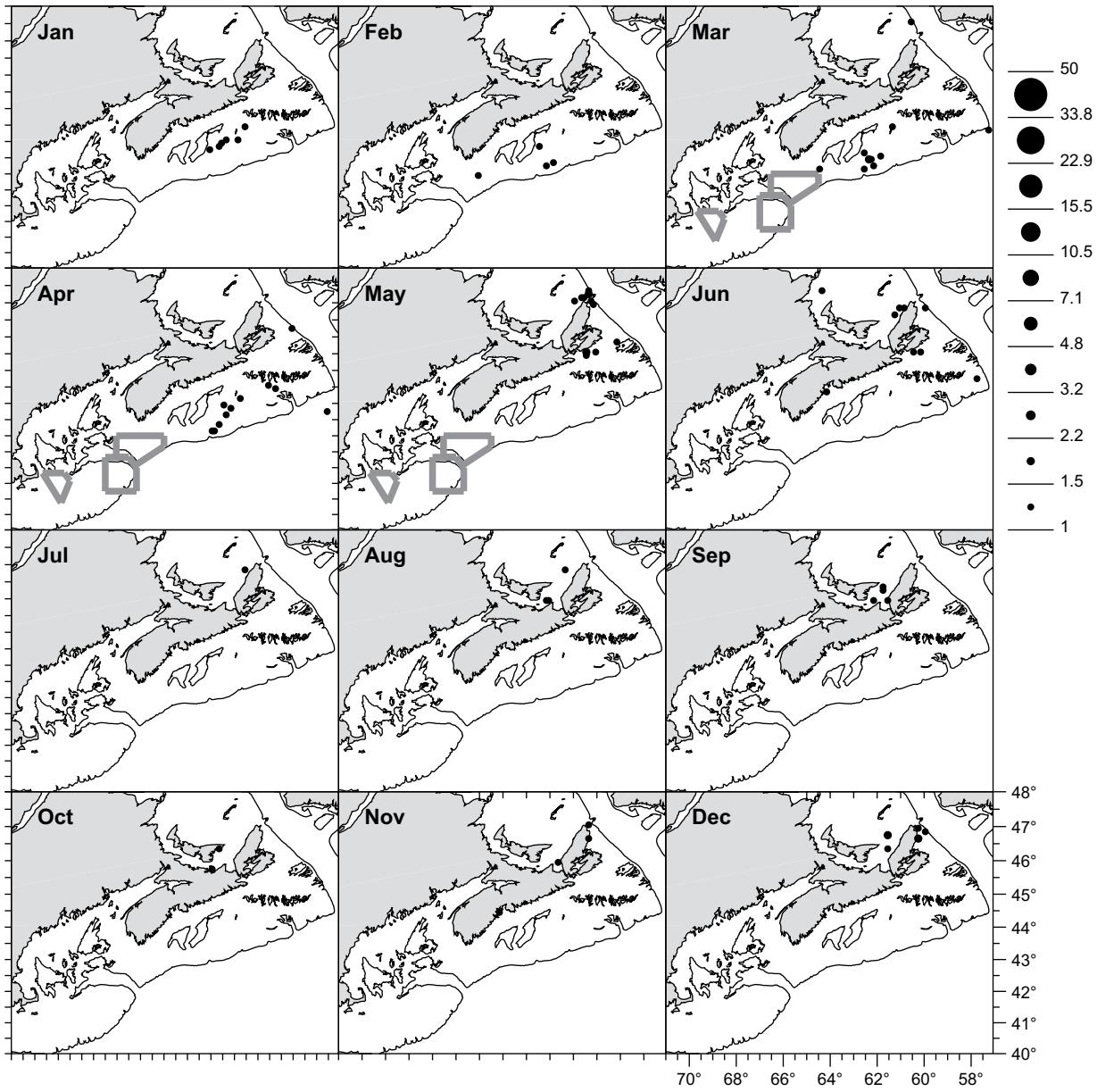

Fig. 13. Recoveries from haddock tagged inshore off Cape Roseway, May–October of 1953. Recoveries are aggregated over years and five minute squares, and plotted separately for each month. Recoveries within three months of release are not plotted. Grey boundaries delineate seasonal spawning area closures to fisheries.

month). We see from the Div. 4T tagging in the fall of 1956 (Fig. 12) that Div. 4T haddock were primarily resident in the Div. 4T tagging area during July–October, all null recovery months for the Div. 4W tagging, departing the Gulf during November–December (only 1 Div. 4T tagging recovery in November), entering the Gulf May–June (many recoveries around Cape Breton), and resident in Div. 4W January–April. Most of the Shelf recoveries came from the same vicinity as the later Sable Bank/Western Bank tagging. The pattern and timing of haddock movement around Cape Breton to go between the Gulf and the Shelf mirrors that described by Needler (1930), except for movements through the Strait of Canso (the strait was blocked by construction of a causeway in 1954).

Both historical and recent tagging on Browns Bank showed the same relative Div. 4X cutoff in the nearshore dispersal up the coast of Nova Scotia, with very little penetration of the eastern Scotian Shelf (Figs. 6 and 9). Only the inshore Cape Roseway (Lockeport) tagging showed significant coastal dispersal into Div. 4VW (Fig. 13). Given the predominant Div. 4W haddock

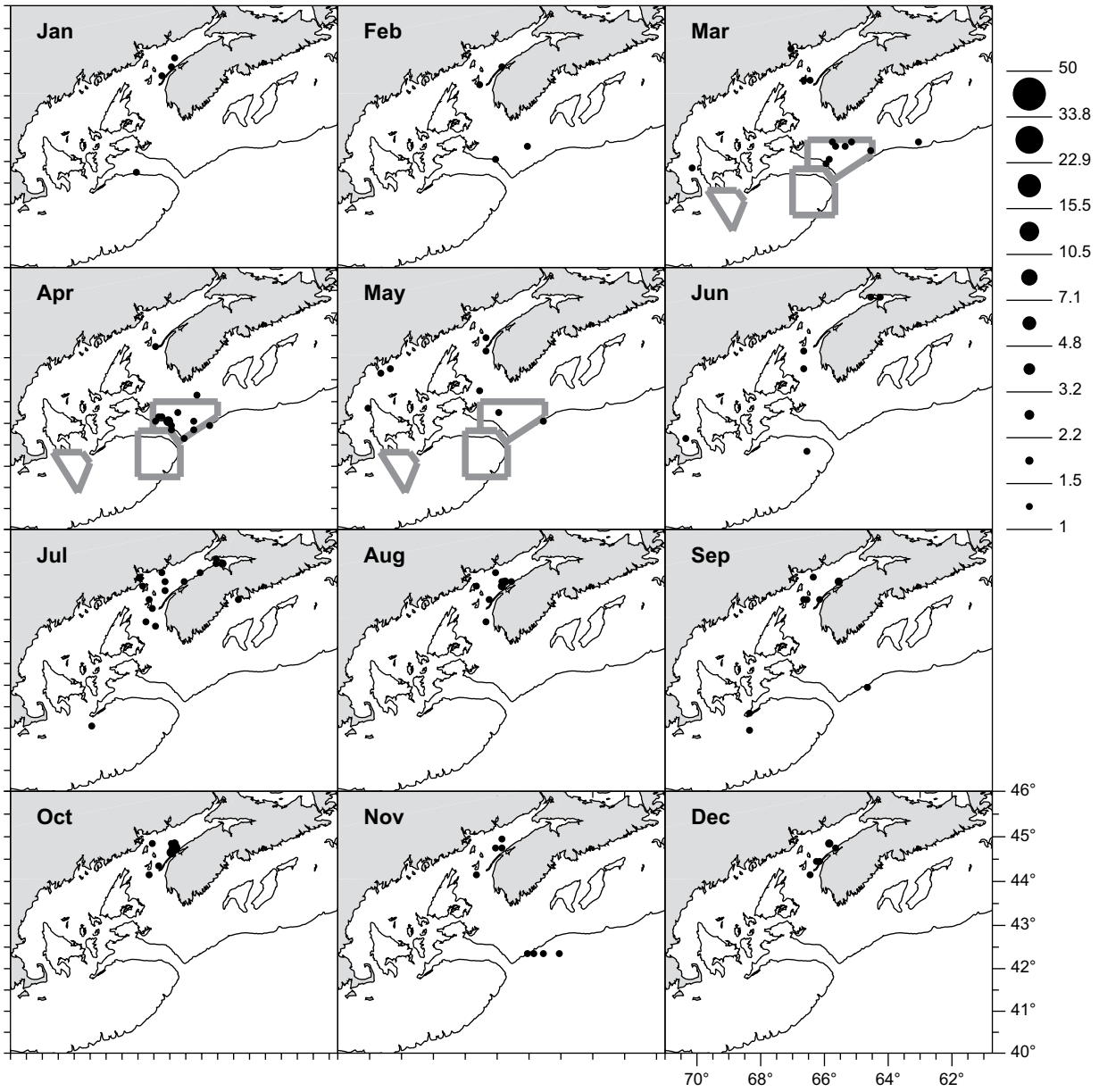

Fig. 14. Recoveries from haddock tagged near Digby, Autumn of 1963 & 1966. Recoveries are aggregated over years and five minute squares, and plotted separately for each month. Recoveries within three months of release are not plotted. Grey boundaries delineate seasonal spawning area closures to fisheries.

fishery on the offshore banks during the 1950s, if we did not see recoveries from Div. 4W, the haddock likely either did not go there or they stayed inshore (very little fishing inshore). The 1953 Cape Roseway tagging was dispersed over May–October (Fig. 2), but most were tagged May–August, and these represent the majority of recoveries. Little association with the Bay of Fundy or Gulf of Maine is evident from the recoveries, which favour Browns Bank February-April and the inshore tagging area in warmer months (Fig. 13). They also demonstrate easterly movements along the coast of Nova Scotia, being recovered as far east as Div. 4Vn, but few appear to mix with Div. 4W offshore banks haddock. These movements are characteristic of the haddock tagged on Browns Bank in the spring of 1957 (Fig. 9). Again, the possibility of low recovery probabilties from Div. 4Xr during the 1950s may have clouded the picture. It is indeterminate if these fish were the Shelbourne population, the Browns Bank/Bay of Fundy migrants, or a mix of both.

Recoveries from the Autumn Digby tagging (Fig. 14) look like a mix of the Autumn Passamaquoddy (Fig.10)

and spring 1983–1985 Browns Bank (Fig. 6) tagging. We see a summer Bay of Fundy and winter Browns Bank association as we see with Browns Bank tagging in the 1980s, but without the easterly coastal movement. However we also see a summer-autumn presence in the Passamaquoddy area and some spring-summer recoveries from the Gulf of Maine, more characteristic of the haddock tagged in Passamaquoddy Bay. This dual pattern is not specific to one of the tagging events, it is fully replicated for both years of tagging (the November 1963 and October 1966 tagging studies tell the same story). Breaking the releases up by specific tagging locations (unique pairs of latitude/longitude, unfortunately exact day of tagging not documented) distinguished at least 10 separate tagging events in 1963 and 2 in 1966. Of these, 7 of the groups (5 in 1963 and both in 1966) had recoveries from each of the three identifying areas (Div. 4Xs, Gulf of Maine, Browns). This suggests that the Passamaquoddy Bay and Browns Bank haddock may be well mixed in the Bay of Fundy in the autumn. We know from the Browns Bank and Passamaquoddy Bay tagging that both groups occupied the Digby Neck area in the autumn, but without the Digby tagging we might have speculated that they still remained spatially and temporally separate within the Digby area.

The unpublished June 1973 Digby tagging (Fig. 4) gave only local recoveries (not plotted), but only 12 locatable haddock were recovered, and all were caught between May and October. During these months the odds favour Bay of Fundy recaptures of Browns Bank haddock, so these recoveries don't necessarily discern a locally resident population.

The Passamaquoddy Bay tagging (Fig. 3) shows the winter Gulf of Maine association (Fig. 10), along with the summer return to the Passamaquoddy Bay area. The brief (mostly April) but notable recoveries from Browns Bank are interesting. The numbers are not trivial. Are we seeing a circular route around the Gulf of Maine for some of the haddock, crossing the Fundian Channel from Georges to Browns Bank before completing the summer return to the Bay of Fundy? The biggest gap in understanding is posed by the very large area around Jordan Basin that attracts very little fishing effort, as evidenced by aerial surveillance of vessel distributions (Halliday *et al.*, 1986). Survey distributions of this area show very few haddock (Halliday *et al*, 1986; Brodziak, 2005), but survey timing does not facilitate the perception of rapid seasonal movements. Thus brief migration windows (leaving or returning) through or around the edges of Jordan Basin may have very little potential of being exposed by either surveys or tag recoveries. Confusing the picture even further, we are not certain about the relationships between components of haddock in the Gulf of Maine. It is unclear if the Nantucket Shoals and Georges Bank haddock, the main concentrations, are separate populations, both with respect to each other as well as inshore Gulf of Maine haddock (Begg, 1998), much the same problem of discerning inshore populations as on the Scotian Shelf. They may have been so overfished (or some perhaps displaced by coastal development) prior to tagging studies that their remnants are too few to be distinguishable.

Conclusion

We have seen our perception of haddock populations essentially degrade over time as components have been either lost or diminished beyond our ability to confirm if they still exist. A focus on commercial fishery stocks may have facilitated a progressive dismissal of natural population structure in favour of commercially dominant components. Non-migratory nearshore populations that were thought to have existed before the 1950s may have been largely fished out prior to the 1950s and 1960s tagging studies. Unfortunately such populations could only be revealed by systematic inshore tagging while migratory populations were offshore, which rarely occurred. A localized Shelburne population was strongly evident in the 1920s, but could not be discerned by the 1950s. A localized Digby population suggested by the 1950s tagging was regarded as a remnant at the time. No inshore populations can be clearly discerned today. It seems likeliest that the post-war summer haddock fisheries in the Bay of Fundy were initially a mix of three populations, two of which have since diminished to the point that they may make little contribution to landings today. An inshore Div. 4Xr haddock population may have existed and remained viable into the 1960s, and Gulf of Maine migrants may have represented significant catches into the 1970s. Similarly the Gulf of Maine haddock fishery may have targeted a composite of resident coastal and migratory offshore populations that can no longer be discerned. No evidence for inshore populations along the eastern Scotian Shelf was provided by tagging studies since the studies discussed by Needler (1930), but any number of inshore populations to the east of Shelburne could have existed and disappeared prior to the 1950s.

From a historical perspective there may have been numerous reproductively discrete populations of haddock in the past. Today we can only easily discern two of the most migratory populations in Canadian waters — the Gulf of St Lawrence/eastern Scotian Shelf and Bay of Fundy/Browns Bank haddock. These are both characterized by occupying offshore banks in winter and only appearing inshore in any numbers during the summer. Greater variation in distribution due to this mobility may be the main reason they have survived, although the once-

dominant Div. 4TVW population has been drastically reduced to the point that it no longer supports directed fisheries.

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