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# Bank-Scale Migration Patterns in Northern Cod

by

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## Introduction

Proper resolution of population structure in northern cod is necessary not only for the interpretation of temporal and spatial variations in the biology of the species, but also for successful management (Angel et al. 1994). These issues are exemplified by the seriously depleted northern cod stock complex (Northwest Atlantic Fisheries Organization (NAFO) Divisions 2J, 3K, and 3L).

Although the distribution and migration patterns of northern cod are recognized as complex, it is generally understood, at least historically, that most mature northern cod overwinter along the margin of the continental shelf where spawning occurs over a 3-4 month period from winter through early summer (Myers et al. 1993). It is also known that some northern cod remain inshore all winter, relying on serum antifreeze proteins to survive in cold (< 0 °C) coastal water (Goddard et al. 1994), and that these fish appear genetically dissimilar form those fish overwintering offshore (Ruzzante et al. 1996). In general, cod that have overwintered and spawned offshore migrate inshore in the spring to coastal feeding grounds and then return offshore in late autumn and early winter (Templeman 1966).

Bentzen et al. (1996) have briefly reviewed the biological and genetic basis of population structure within the northern cod complex which are equivocal in their implications. On the one hand, geographic surveys (Hutchings et al. 1993), vertebral data (Templeman 1981, Lear and Wells 1984) and tag recovery data (Templeman 1974, 1979; Lear 1984; reviewed in Lear and Green 1984 and in Taggart et al. 1995) all suggest that northern cod are divided into several distinct offshore spawning units. In particular, cod-tagging studies have provided evidence of population fidelity to particular overwintering/spawning areas on offshore banks and in some inshore bays, as well as evidence of vagrant movements among these areas (Lear 1984; Taggart et al. 1995; Wroblewski et al. 1996). Thus far, however, evidence of population structure gained from genetic studies of northern and other western Atlantic cod has been mixed, and subjected to various interpretations (see Bentzen et al. 1996). However, in that same paper, Bentzen et al. (1966) have reported on polymorphism at six microsatellite loci in northern cod sampled from offshore overwintering/spawning locations spanning their range from the northern Grand Bank northwest to Hamilton Bank off Labrador and they describe evidence that northern cod may comprise more than one population. In particular they show that within the northern cod complex, two pooled samples, NORTH (i.e. Hamilton, Funk and Belle Isle Banks) and SOUTH (i.e. northern Grand Bank area including the North Cape region) were distinguishable from each other using a variety of genetic measures applied to the microsatellite data.

In this paper, cod tagging data from Taggart et al. (1995) are employed to assess migrational patterns in northern cod and to compare those patterns to the population structure described in Bentzen et al. (1996). This is achieved using a compilation of tagging experiments conducted over the last 3 decades in the Hamilton Bank and Belle Isle Bank regions (equivalent to NORTH) and in the North Cape region of the Grand Bank (equivalent to SOUTH).

## METHODS

Cod tagging data were extracted from the tagging data base described in Taggart et al. (1995). Only those tagging experiments that occurred offshore during winter (February to May) were used for the analyses in this paper and are described as follows in Table 1:

TABLE 1.

| Exp. Number | Year tagged | Location | latitude dec. deg. | longitude dec. deg. | Number tagged | Number reported | % reported |
|---|---|---|---|---|---|---|---|
| 6404 | 1964 | Hamilton Bank | 53.5 | 53.3 | 1152 | 186 | 16.1 |
| 6601 | 1966 | Hamilton Bank | 54.9 | 54.9 | 1120 | 300 | 26.8 |
| 8103, 8104 | 1981 | Hamilton Bank | 54.7, 53.4 | 54.0, 53.2 | 3766 | 450 | 11.9 |
| 8202, 8203 | 1982 | Hamilton Bank | 54.7, 53.2 | 53.7, 52.4 | 3160 | 761 | 24.1 |
|  |  | *Hamilton Bank* | *54.1* | *53.6* | *9198* | *1697* | *18.4* |
| 7801 | 1978 | Belle Isle Bank | 52.1 | 51.8 | 4456 | 843 | 18.9 |
| 8303 | 1983 | Belle Isle Bank | 52.1 | 52.5 | 3142 | 562 | 17.9 |
|  |  | *Belle Isle Bank* | *52.1* | *52.2* | *7598* | *1405* | *18.5* |

**TABLE 1.** (continued)

| Exp. Number | Year tagged | Location | latitude dec. deg. | longitude dec. deg. | Number tagged | Number reported | % reported |
|---|---|---|---|---|---|---|---|
| 8003 | 1980 | North Cape | 49.1 | 50.2 | 1994 | 225 | 11.3 |
| 8206 | 1982 | North Cape | 49.2 | 50.6 | 492 | 33 | 6.7 |
| 8301, 8304 | 1983 | North Cape | 48.5 | 49.9 | 3031 | 99 | 3.3 |
| 9001 | 1990 | North Cape | 49.2 | 50.1 | 2447 | 115 | 4.7 |
| 9102 | 1991 | North Cape | 49.0 | 50.1 | 3466 | 158 | 4.6 |
| | | *North Cape* | *48.9* | *50.1* | *11430* | *630* | *5.5* |

For each region/experiment the latitude and longitude of the marking location and the reported recapture times and locations were used to assess the migration pattern relative to the marking location for each of the three regions. These data were ordered sequentially with respect to the recapture date, from earliest to latest, and then the dates and recapture latitudes and longitudes were "smoothed" using a 15-point, uniformly weighted, moving average to calculate the mean position of the tagged population at the average date of recapture. The standard error around the moving average was calculated in the same manner. These data were then employed for each region/experiment to assess the frequency and amplitude of migrations relative to the tagging location.

To estimate the overall annual mean pattern of migration ("the normal") for each of the three major region of tagging, each of the experiments within a region, and regardless of year of tagging, were pooled together and sorted according to the day of the year (1 to 365) of reported recapture and the 15 point moving average was used to estimated the mean location and the standard error around the mean throughout the "normal" year. As the number of recaptures range from ~600 (North Cape) to ~1500 (Hamilton and Belle Isle Banks), there are, on average, ~2 to ~5 recaptures for each day of the year for these regions respectively (Table 1).

Differential reporting of tags, and differential fishing effort, within or among tagging experiments, has not been incorporated into these analyses. However, as there is considerable overlap among the years of tagging and among the subsequent years of reported recapture among the three geographic regions (Table 2), particularly in the 1980's, differential fishing effort among regions is assumed to be minimal, at least as it relates to a first approximation for the interpretation of the results presented here.

**TABLE 2.**
Year of tagging (start) among regions (location) followed by a 5 year period of expected and realized reporting of recapture (see Taggart et al. 1995) to illustrate periods of overlap in reporting among experiments (North Cape in the 1990 omitted).

| year location | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hamilton** | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | | | | | | | | | | | | |
| **Hamilton** | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | | | | | | | | | | |
| **Hamilton** | | | | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | |
| **Hamilton** | | | | | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | |
| **Belle Isle** | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | |
| **Belle Isle** | | | | | | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| **North Cape** | | | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | |
| **North Cape** | | | | | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | |
| **North Cape** | | | | | | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |

## RESULTS.

### Relative Locations of Tagging Experiments

The average tagging location in the North Cape region is approximately 360 nm SSE of the average tagging location on Hamilton Bank, and approximately 190 nm SSE of Belle Isle Bank, which is itself approximately 175 nm SSE of Hamilton Bank (Table 1).

### Hamilton Bank

The overall (combined) annual along-shelf (N-S) pattern of migration is variable through the year (Fig. 1a). In general, during the April through June period (days 90-180), the fish are moving southward at the same time as moving landward (Fig. 1b). This is followed by a generally northward but oscillatory movement once the fish have reached the coast; i.e. during this summer period inshore (July through September) there is variable northward and southward movement along the coast before the fish begin a slow northward progression as they move offshore in September (Fig. 1b).

The overall (combined) annual pattern of cross-shelf migration (E-W) inferred from tag reporting shows the majority of fish located offshore in the vicinity of the tagging location during the winter period of January through April (days 0-120; Fig. 1b). Landward migration appears to begin near the end of April (day 120; Fig. 1b) and last approximately two months through to the end of June (day 180). The fish remain inshore through to the end of day 270 (September; Fig. 1b) at which time there is a slow (relative to the landward migration in spring) seaward progression back toward the Bank.

During the winter period the across-shelf mean distribution is of the order 50 nm (Fig. 1c). In contrast, the along shelf mean distribution is of the order 175 nm (Fig. 1c) which just extends to the vicinity of Belle Isle Bank. The greater variation in the along-shelf distribution is shown be the larger standard errors relative to the mean which is of the order ± 100 nm compared to ± 25 nm in the across-shelf distribution (Figs. 1a,b).

**Belle Isle Bank**

Data from the two Belle Isle Bank tagging studies reveal an annual migrational pattern very similar to that seen for Hamilton Bank. During winter (days 0-120; Fig. 2b) most fish are found in the vicinity of the offshore tagging location and begin landward migration in early May (day 120; Fig. 2a). The fish appear to remain inshore during June through October (days 150-300) after which they begin a seaward migration (Fig. 2b). As seen for Hamilton Bank, the along-shelf variation (Fig. 2a) is greater than the across-shelf variation, and as well, the landward migration is accompanied by a generally southward migration. Again, as seen with the Hamilton Bank study, after arriving at the coast there is a general northward migration along the coast before the fish move offshore again for the winter (Fig. 2a). The greater variation in the along-shelf distribution is shown by the larger standard errors relative to the mean compared to the across-shelf distribution.

It appears that these distributional patterns, particularly in winter and early spring, are not overly influenced by the tags that were reported during the first three months immediately subsequent to tagging and release. When the above analyses were repeated after removing the first three months of reported returns in each experiment, the same annual pattern of migration was revealed, although the standard errors were somewhat reduced (Fig. 3).

During the winter period the across-shelf mean distribution is of the order 50 nm (Fig. 2c). In contrast, the along shelf mean distribution is of the order 125 nm (Fig. 2c), but does not extend northward to the vicinity of Hamilton Bank, nor southward to the vicinity of the North Cape. However, as shown above, the offshore winter distribution of Hamilton Bank fish does extend to the Belle Isle Bank region.

The well defined across-shelf annual cyclic pattern described in Figures 2 and 3 results from it being repeated among years within an experiment, as well as among experiments (Fig.4) where there is a clear tendency for a wintertime return to the general vicinity of the tagging location. In general, there is little evidence to suggest that fish are found more than 100 miles north of their original tagging location on Belle Isle Bank, though they appeared further toward the shelf-break during the winter.

**North Cape of the Grand Bank**

The overall annual pattern of cross-shelf migration inferred from tag reporting from cod tagged in the north Cape region shows the majority of fish located offshore in the vicinity of the tagging location during the winter period of January through April (days 0-120; Fig. 5) as seen for other tagged populations above. Landward migration appears to begin near the end of April (day 120; Fig. 5b) and lasts, with some apparent oscillations, for approximately two months through to the end of June (day 180). The fish remain inshore through to the end of day 270 (September; Fig. 5b) at which time there is a slow seaward progression back toward the shelf-break.

The along-shelf pattern of migration is much more variable through the year (Fig. 5a). However, in general, during the April through June period (days 90-180), when the fish are moving landward, they are also moving southward, to be followed by a generally northward, but oscillatory movement along the coasts and bays of eastern Newfoundland before they move offshore in September (days 270).

During the winter period the across-shelf mean distribution is of the order 50 nm and the along shelf mean distribution is of the order 75 nm (Fig.5c) which clearly does not extend northward to overlap the range of fish tagged on either of Belle Isle Bank or Hamilton Bank (see above Figs. 1 and 2).

**DISCUSSION**

It appears from the results presented above that fish tagged in the vicinity of Hamilton Bank can overlap in their offshore winter distribution with those tagged on Belle Isle Bank, and thus the populations can intermingle during the offshore spawning period. This is consistent with the inability to resolve genetic differences between these bank-specific populations (Bentzen et al. 1996). However, the same cannot be said for the fish tagged in the North Cape, for which their mean distributions during winter offshore does not overlap with those fish tagged on either Hamilton or Belle Isle Bank. This is also consistent with the genetic results in Bentzen et al. (1996) which showed that cod sampled from the North Cape region in 1992 and 1993 were genetically distinguishable from more northern populations sampled on Hamilton, Belle Isle and Funk Island Banks. These results are also consistent with those of Lear (1984) who argued bank-scale population structure and also those of Cross and Payne (1978) who were able to resolve genetic differences among these same populations.

**Inshore and Offshore Aggregations of Northern Cod in Recent Years: An Hypothesis**

Cod tagged in the winter period in the North Cape region show a pattern of fish moving from a relatively aggregated distribution offshore in the winter to the inshore region in summer followed by an offshore return to the same location (Fig. 5). The persistence of an offshore winter aggregation in this region is consistent with the offshore aggregations regularly observed over the short period covered by the annual research survey in the late autumn and early winter in that region, at least up until 1993 (cf. Fig 13 in Shelton et. al. 1996 and Figs. 5 & 6 in Taggart et al. 1994). However, the autumn surveys of 1994 and 1995 failed to reveal these offshore aggregations in the North Cape region (Shelton et al. 1996). Is it simply coincidence that it was precisely in the following April and May periods of those years when large aggregations of cod were located in the Random Island region of Trinity Bay (Taggart, unpublished data, Brattey 1996)?

Although inshore populations of cod have been known to overwinter in the Trinity Bay region, and they have been show to be genetically different from offshore overwintering populations (Ruzzante et al. 1996), no large aggregations such as those in the spring of 1995 and 1996 have been reported even though there have been regular surveys conducted there during the spring period of 1991, 1992, 1993, and 1994 (Taggart unpublished data), and prior to those years (Lear, unpublished data). Interestingly, Brattey (1996) showed that the large and main aggregation of fish (say POP-1) in that region (NW-Arm and Smith Sound) had relatively low levels of *Lemaeocera branchialis* infection (consistent with what is normally observed for offshore populations) while the other less aggregated cod sampled in the SW-Arm area of the region (say POP-2) had relatively high levels of infection (consistent with what is normally observed for inshore populations). Ruzzante et al. (1996) have show that inshore overwintering populations from the Random region are genetically distinguishable from offshore overwintering fish, but those inshore overwintering populations sampled were not from large dense aggregations as seen in recent years (POP-1), but from smaller more dispersed aggregations (POP-2). Brattey (1996) has also shown that the here-defined POP-2 (inshore population) were not in spawning condition as would be expected (see Wroblewski et al. 1996) while the large aggregation (POP-1) was in spawning condition (as would be expected for a normally offshore spawning group). It has also been shown (above Fig. 5) that fish tagged in the North Cape region habitually migrate from the North Cape region to the bays and coasts of eastern Newfoundland, including Trinity Bay.

Taken together, these observations imply that it is reasonable to hypothesize that the large aggregations of cod observed in recent years in the Random Island region of Trinity Bay (POP-1) may be those fish that would normally aggregate offshore in the North Cape region, but for some reason have ceased their normal migration pattern to offshore for winter.

It should be possible to genetically test this hypothesis using tissue samples drawn from the large aggregation (POP-1) and comparing their genetic structure to the inshore (POP-2) and offshore (POP-1?) populations documented in Ruzzante et al. (1996). This hypothesis would be rejected if these fish were not genetically different from the inshore population. On the other hand, the hypothesis would not be rejected if the aggregation was not distinct from offshore fish sampled in winter 1992 and 1993 (Ruzzante et al. 1996). If the hypothesis was not rejected, then it is not unreasonable to consider the possibility of other populations or aggregations of fish overwintering in inshore regions that would normally overwinter offshore where virtually none have been observed recently.

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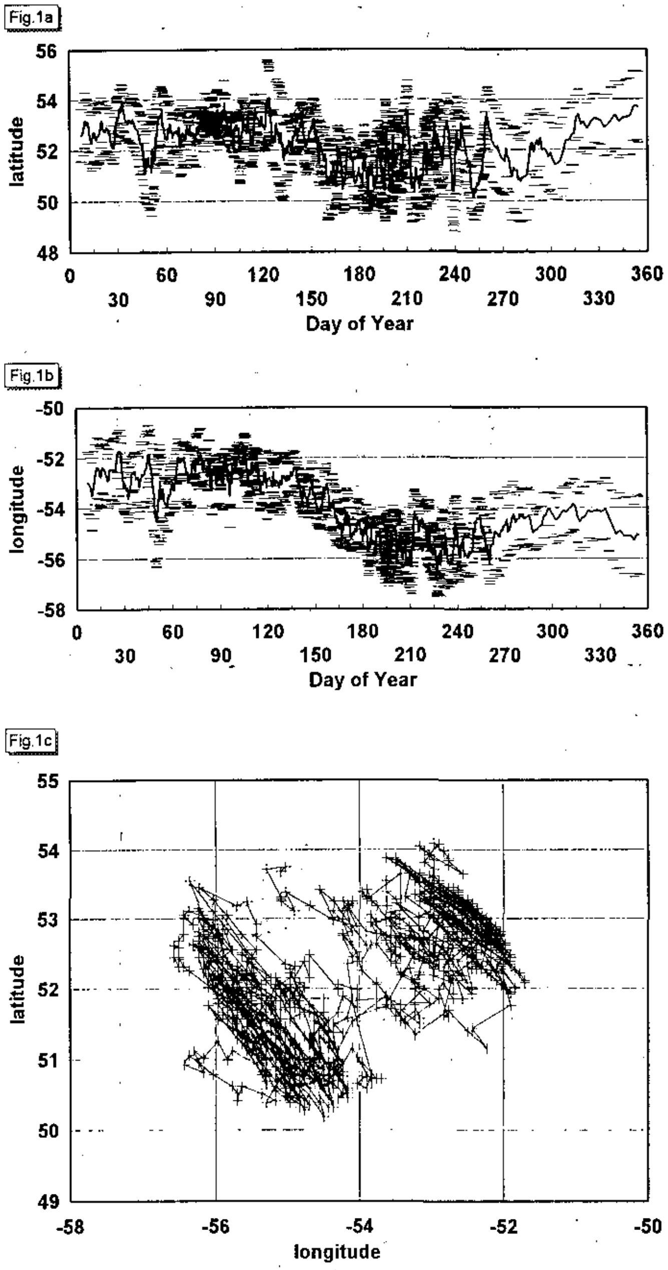

Figure 1. Combined average (± 2 SE) latitudinal (a) and longitudinal (b) and progressive vector diagram (c) of reported cod-tag returns as a function of day of the year from tagging experiments conducted on Hamilton Bank during the winter periods of 1964, 1966, 1981, and 1982. Data from Taggart et al (1995).

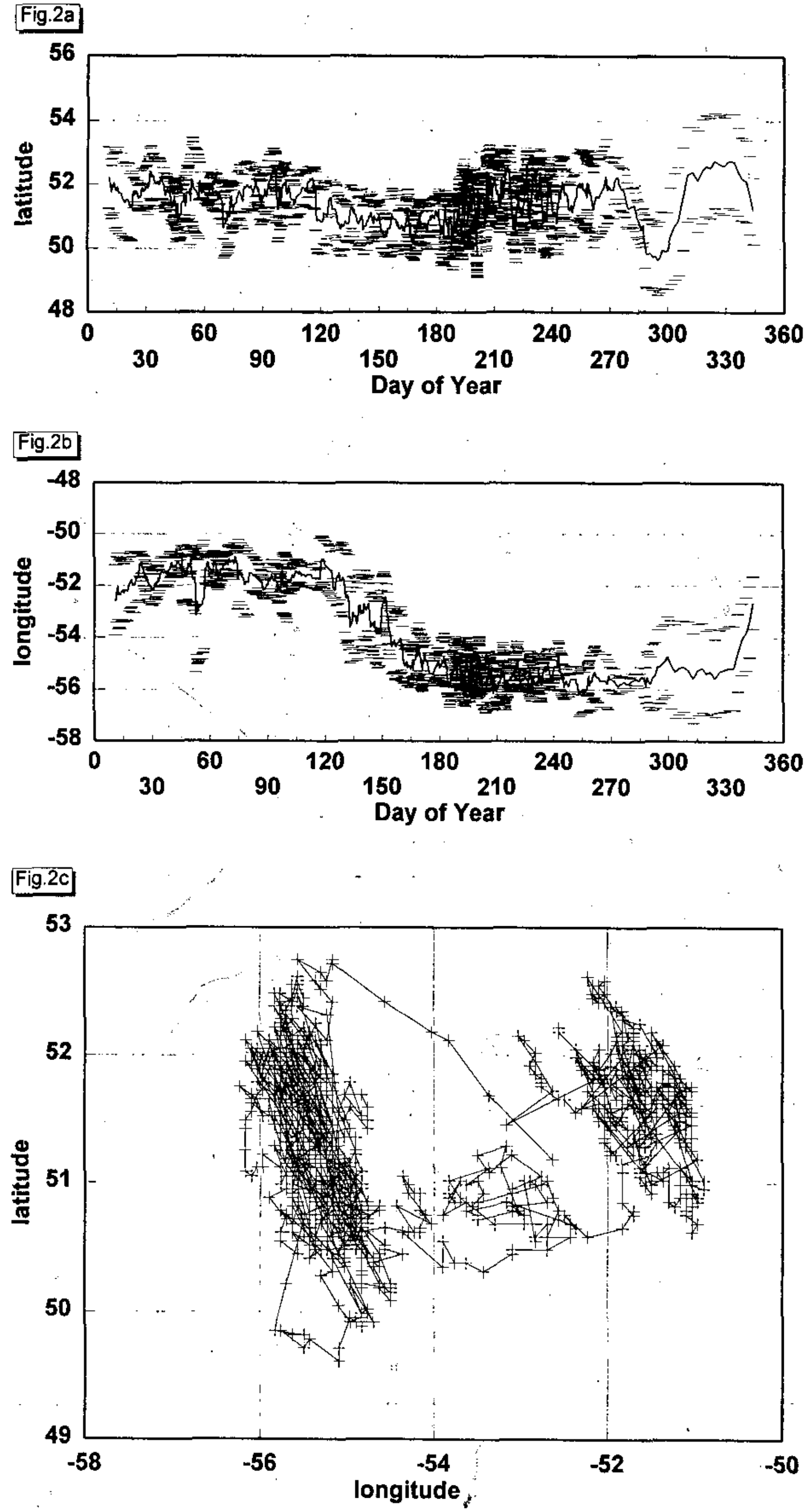

Figure 2. Combined average (± 2 SE) latitudinal (a) and longitudinal (b) and progressive vector diagram (c) of reported cod-tag returns as a function of day of the year from tagging experiments conducted on Belle Isle Bank during the winter periods of 1978 and 1983. Data from Taggart et al (1995).

Fig.3a

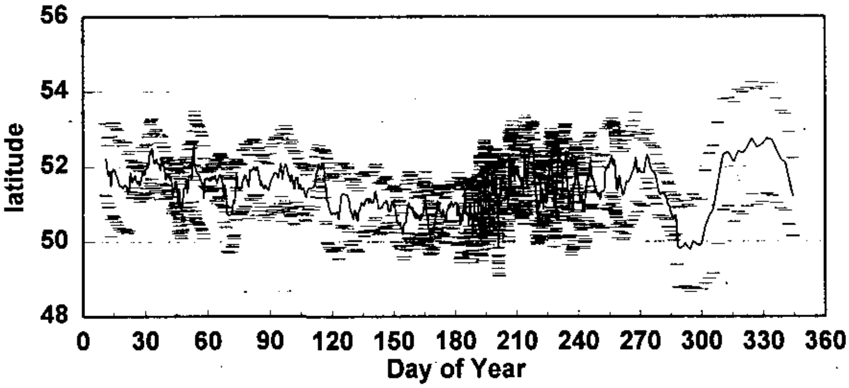

Fig.3b

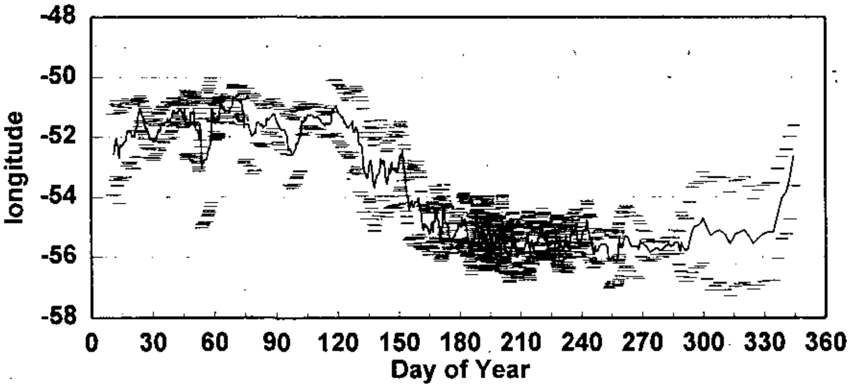

Fig.3c

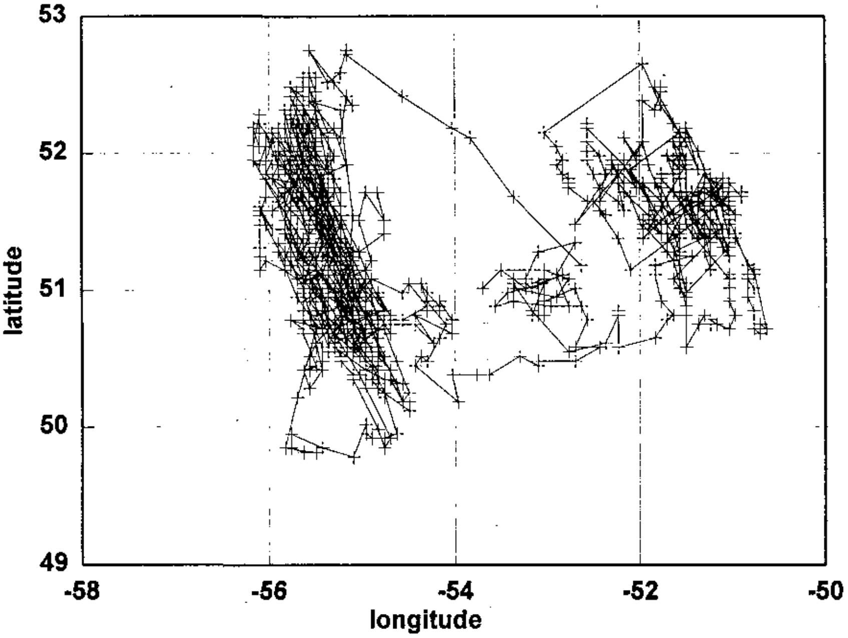

Figure 3. Combined average (± 2 SE) latitudinal (a) and longitudinal (b) and progressive vector diagram (c) of reported cod-tag returns as a function of day of the year from tagging experiments conducted on Belle Isle Bank during the winter periods of 1978 and 1983. Data from reported returns during the first three months immediately following tagging are not included. Data from Taggart et al (1995).

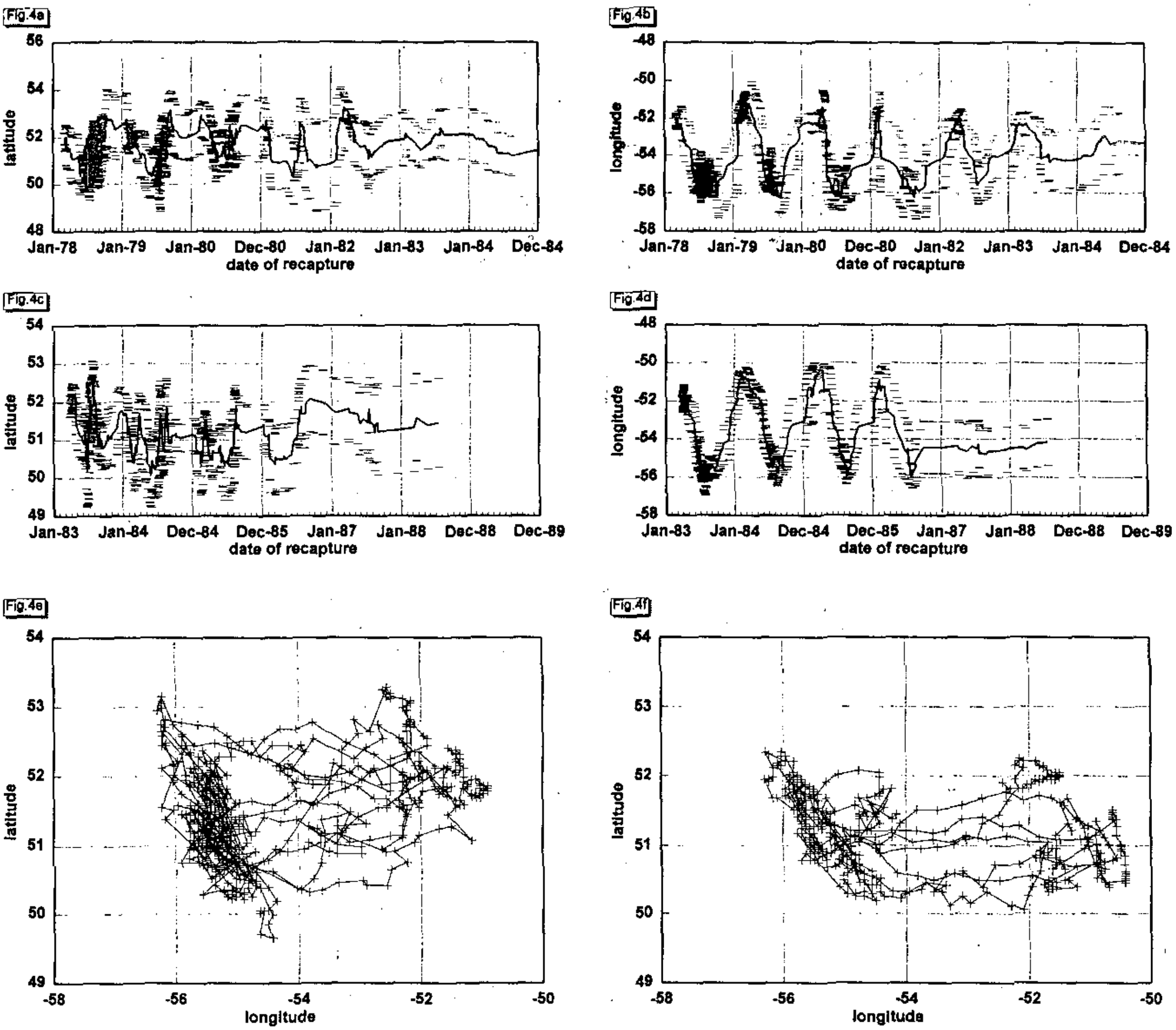

Figure 4. Average (± 2 SE) latitudinal (a,c) and longitudinal (b,d) and progressive vector diagram (e,f) of reported cod-tag returns as a function of date from tagging experiments conducted on Belle Isle Bank during the winter periods of 1978 (a, c, e) and 1983 (b, d, f). Data from Taggart et al (1995).

Fig.5a

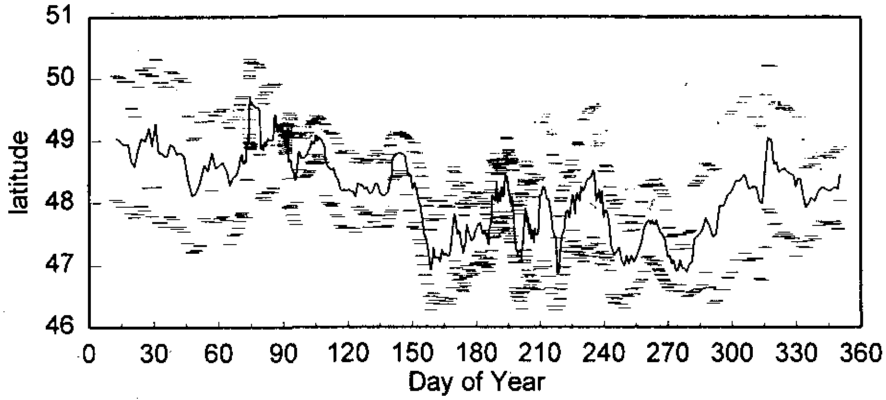

Fig.5b

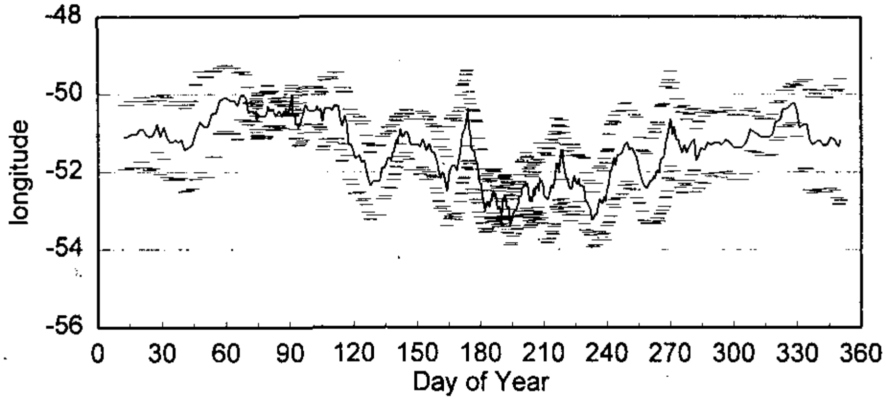

Fig.5c

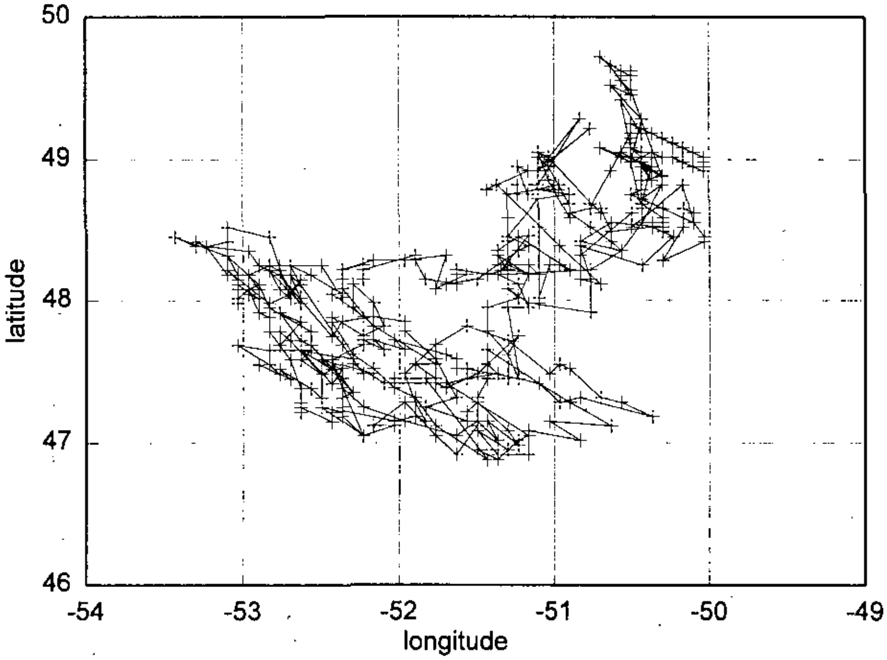

Figure 5. Combined average (± 2 SE) latitudinal (a) and longitudinal (b) and progressive vector diagram (c) of reported cod-tag returns as a function of day of the year from tagging experiments conducted in the North Cape region of the Grand Bank during the winter periods of 1980, 1982, 1983, 1990, and 1991. Data from Taggart et al (1995).