

## **A Review of Tagging Information for Stock Identification of Cod off New England**

Jon Loehrke and Steve Cadrin  
NOAA/UMass CMER Program  
School for Marine Science & Technology

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### **Abstract**

Recent observations of cod movement across stock boundaries are generally consistent with historical tagging data as well as information from other stock identification approaches. This working paper provides a historical context in which to consider recent tagging data for spatial delineation of cod stock assessments (TOR C).

### **Introduction**

The objective of this report is to review the literature available for stock identification of cod off New England. The review is focused on tagging studies, but also refers to relevant information from other approaches to determine spatial population structure, though not comprehensively. The organization is initially chronological, to illustrate the historical development of perspectives on cod stock structure, but conclusions are based on multidisciplinary synthesis of information pertaining to movement across current stock boundaries.

### **Review of Previous Research**

#### Pre-1900 – late 1930s

Goode (1884) consolidated the earliest information regarding the fisheries of the New England area. This work catalogued the cod fishing grounds, cod fishing methods, and predominant cod fishing ports through a series of fisherman interviews. Goode's (1884) documentation established a baseline for which cod catch statistics were gathered by identifying the key ports within the region. Annual reporting of catches initiated in 1893 (Serchuk and Wigley 1992). The reporting was temporally consistent, although occasionally ports were missed during any year. Goode (1884) delineated fishing grounds in his earliest work, however apparent inconsistencies between captains required a redefinition of fishing grounds by the late 1920s (Rich 1930).

During the early 1900's tagging studies were conducted in association with cod hatcheries. Hatchery experiments began in Gloucester, MA in 1884 (Tarr 1884), and by the 1900's a permanent hatchery had been established in Woods Hole, MA (Smith 1902). Smith (1902) conducted the first exploratory tagging experiment at the Woods Hole hatchery. Cod that had been collected on Nantucket Shoals for brood stock were tagged and released of Woods Hole, MA after they spawned. Recaptures from this experiment

indicated that many cod returned to Nantucket Shoals, and some moved southward to the middle Atlantic Bight (Smith 1902).

A second tagging investigation was initiated in 1923 (Rich 1925) and continued annually through 1932 when funding diminished (Higgins 1934). The initial scope of this project was to repeat Smith's (1902) experiment tagging and releasing cod at Woods Hole and also to carrying out tagging on Nantucket Shoals (Rich 1925; Schroeder 1930). Reports of this work were filed annually with the U.S. Commissioner of Fisheries fiscal reports (Rich 1925; 1926; Higgins 1927; Schroeder 1927, 1930; Higgins 1928, 1929, 1930, 1931, 1932, 1933, 1934) and at meetings of the North Atlantic Commission of Fisheries Investigations (NACFI 1932, 1935, 1939). These reports provide precise reporting of the dates, location, and number of tagged cod, but the conclusions are often generalized and lack specific details. By 1928 a general perception of cod stock structure had been formed (Higgins 1929):

- A seasonally migrating group between the grounds of southern Massachusetts and North Carolina.
- A Nantucket Shoals group with components that move westward and eastward in the summer.
- Massachusetts Bay fish that tend to migrate to the south
- Relatively sedentary groups ranging from northern Massachusetts Bay to eastern Maine.
- In the middle of the Gulf of Maine some banks had stationary stocks while other individuals appeared to migrate randomly out of the area in all directions.
- The offshore banks of Georges and Browns Banks appeared connected.

Schroeder (1930) provided extensive analysis of the cod tagging that occurred primarily along the southern shore and specifically at Nantucket Shoals. Furthermore, Schroeder conducted an investigation in growth patterns through scale ageing and length frequencies collection. Schroeder (1930) provided a view of New England cod stock structure, stating:

*“The stock of cod living on Nantucket shoals, consisting chiefly of young adult and nearly adult fish, is for the most part distinct from that living to the north and east of Southern Massachusetts, for there is no general intermingling of the fish belonging to these regions...only a very small percentage of the Nantucket cod stray to the north and east annually, and, conversely, only a few cod tagged to the north and east stray to Nantucket Shoals”*

*“A large part of the Nantucket Shoals cod population make a fall migration into the Rhode Island-North Carolina region, where most of them remain until the spring. These fish are joined by others from the North and east of Cape Cod; but that southern New England cod form the bulk of the fish which occupy these wintering grounds is indicated by the paucity of recaptures there of fish tagged to the northward and eastward of Cape Cod and by the general similarities in length frequencies between the population in this wintering region and the summer cod on Nantucket Shoals. In the spring the fish return eastward, the majority of them stopping to summer on Nantucket Shoals, but others, chiefly the larger*

*fish, most of which probably came from the north and east of Cape Cod, continue on to deeper water.”*

*“Part of the cod living on Nantucket Shoals emigrate eastward to the Chatham-South Channel region during certain summers...the size of the fish but temperature, too, appears to influence this emigration...fewer cod took part in the summer eastward emigration than in the fall westward migrations.”*

Preceding the investigation on Nantucket Shoals, Schroeder switched focus to the coastal Maine and offshore bank stocks. Unfortunately, detailed analysis from these investigations was never published. What results have been published include:

Browns Bank: Major pathway of movement was North and Northeast with a little to the south and West (Higgins 1931).

Georges Bank: Most fish stayed on the Bank with movement to Browns Bank and slightly less to Nantucket Shoals and Southward (Higgins 1931).

Maine Coast: Most returns local, those fish that did migrate tended to move East (Higgins 1933). The Maine coast stock was not thought to be a feeder to the offshore banks (Higgins 1934).

This early series of tagging investigations provided the first information on movement patterns of cod off New England, but they were not quantitative. Documentation is incomplete, and conclusions are somewhat subjective. Furthermore, much resolution in data may have been forgone due to an estimated 60-70% tag loss (Schroeder 1927, Higgins 1929)

#### 1930-late 1950s.

Haddock had become increasingly important by the late 1920's (Higgins 1928; Serchuk and Wigley 1992), and cod catches along Southern New England had declined severely by 1934 (Higgins 1935). These fluctuations in landings prompted efforts to improve fishery monitoring and control factors affecting the fishery (Rounsefell 1948). A system of geographically defined statistical reporting units was developed based upon the European system. Units in the Gulf of Maine region were designed to encompass historically important banks while in the Great South Channel and Georges Bank they were designed around the apparent natural effort distributions of the offshore fishery (Rounsefell 1948; Figure 1). Catch statistics and later trawl survey data became tabulated by statistical areas (Rounsefell 1948; Halliday and Pinhorn 1990; Serchuk and Wigley 1992). Although no investigations into New England cod occurred during this time period, a tagging study was conducted in Nova Scotian waters (McKenzie 1956).

#### 1950-1960

Towards the end of the 1950's there was a renewed interest in cod stock structure. Wise (1958) conducted a repeat of Smith's (1902) and Schroeder's (1930) investigation of the cod along the southern New England Mid Atlantic Bite region. This group had already been identified as exhibiting a unique seasonal migration between Nantucket Shoals and the Mid Atlantic region. Wise (1958) conducted his tagging along the southern New Jersey shore, finding the same seasonal pattern describe by Schroeder (1930) and in the Commissioner of Fisheries reports. Based upon the presence of

spawning individuals along the New Jersey coast, he concluded that these cod spawn in the south during the winter and migrate northward to feed during the summer, however.

This period was punctuated by a significant effort to consolidate the information on stock structure along the Western Atlantic coast (Halliday and Pinhorn 1990; Serchuk and Wigley 1992). Wise and Jensen (1960) performed a preliminary investigation on cod stock structure finding that in New England:

*“While cod is the subject of the major fishery in the Convention Areas and yearly landings of cod usually surpass those of all other species combined in Subareas 1, 2, 3, and 4, they are of subordinate importance in Subarea 5. In addition, about one-half or two-thirds of the cod landing in Subarea 5 are incidental to the haddock fishery. These facts have functioned to de-emphasize cod research in the Subarea: for about twenty-five years following 1930 there was no research in progress.”*

*“...the most important single population is that of eastern Georges Bank, which apparently mixes little with the more westerly and northerly groups although some of the large and older fish do appear to wander off to join the populations of western Nova Scotia (Subarea 4).*

*West of the shoals of Georges Bank (about 68°W.) there is another population which summers in the great South Channel (about 69°W.), particularly on the western side, and which spends the better part of the rest of the year inshore in the Nantucket Shoals-Chatham region. North of this group of fish are those of the Gulf of Maine, one or more sedentary stocks.”*

*“Joining the Nantucket Shoals-Chatham fish in the summer are fish whose winter habitat is outside the Convention Area. They migrate along the Rhode Island, Long Island and New Jersey shores in the autumn, some years reaching as far as North Carolina (about 35°N.), then return in spring to summer in southern New England waters again.”*

Templeman (1962) summarized this report and others to delineate Western Atlantic cod stocks (Figures 2). Some boundaries of the statistical reporting areas were readjusted following these reports to more suitably encompass the stocks in question (Halliday and Pinhorn 1990).

Sherman and Wise (1961) used of parasites as biological tags to determine stock structure of cod. Their one-year study found that the prevalence of the gill parasite increased in the shore fish as latitude increased. Prevalence was relatively low in all offshore samples. They concluded that there are probably three stocks in the New England area consisting of the Gulf of Maine where parasitism was higher, Georges Bank where parasitism was relatively low, and Southern New England where no parasitism was found. Their stock boundaries coincided with the statistical areas defined earlier by Rousenfell (1948).

Wise (1963) completed a broad scale, four-year tagging investigation to study New England cod stock structure (Figures 3-5). Through a synthesis of tagging results, commercial length frequency data, the earlier parasitic investigation, and a meristic study, Wise (1963) concluded on New England Cod stock structure that:

1. “The cod of the offshore banks (Georges and Browns) are closely related to the fish of the southwestern Nova Scotia coast.”

2. “The cod of the Gulf of Maine, probably divided into many subgroups, and receiving considerable recruitment from the south.”
3. “The cod of southern New England and the South Channel.”
4. “The New Jersey coastal cod, which spend part of the year mingled to a greater or lesser degree with the southern New England fish.”

Furthermore, Wise (1963) went on to describe how the bathymetry and hydrography of the region shape the structure of cod stocks. Northern stocks seemed to be defined by bathymetry; on Georges Bank they are divided by western shoals of the Bank, at about 68°W, while the South Channel was divided from the Gulf of Maine by the constriction at the North end of Cape Cod. Hydrography played a roll in defining the NJ coastal cod and the growth differences between Gulf of Maine fish and those to the South (Wise 1958).

### 1960-1980

The history of cod management on Georges Bank during this period is documented by Serchuk and Wigley (1992). There was a major shift from international management through ICNAF to internal management starting in the early 1970s. ICNAF division 5 was subdivided into area 5Y (Gulf of Maine) and 5Z (Georges Bank) in 1972 (Serchuk and Wigley 1992). An initiative to advance stock assessments of New England cod resources led to a multidisciplinary review of information on spatial population structure to define operational management units with similar demographic parameters for population modeling.

Pentilla and Gifford (1976) compared cod growth and mortality rates between the Gulf of Maine, Southern New England and the South Channel region (Nauset), and on Georges Bank. They found “highly significant differences between areas ( $P < 0.01$ ), except for the age 3 autumn comparison between Georges Bank and the South and Nauset areas ( $P > 0.05$ ). For age 4 and older cod the mean lengths at age from these two areas are very similar” (Pentilla and Gilford 1976). Similarities in growth rates eventually led to the consolidation of the Georges Bank stock with the South Channel and SNE stock into an operational stock. The principal spawning times and locations for cod were described by Colton et al. (1979).

Serchuk and Wood (1979) document the evidence for a consolidation of previously recognized stocks, including information on historical fisheries trends, management structure, distributional data, trends in trawl survey data, mortality estimates, growth investigations, commercial indices of catch-per-unit-effort and commercial catch composition. They also demonstrated the management implications of different life histories and fishery patterns through yield-per-recruit analyses, illustrating different population dynamics and productivity of the newly delineated stocks. Serchuk and Wood (1979) concluded that the similar trends in growth rates, trawl survey indices, and commercial catch compositions between George Bank and more southern areas, as well as the apparent absence of juvenile cod from the Mid-Atlantic region justified a common approach to assessment and management for both areas. They state:

*“The question of biological stock identity of the southerly cod populations may be moot relative to management concerns. If the similarities between the Southern New England-Middle Atlantic and Georges Bank cod populations result from similar biotic and environmental factors, management measures applied to the two groupings as a unit should*

*produce similar responses within each group. Contrariwise, if the similarities between the groups reflect the movement of Georges Bank fish southward, then only one biological stock exists and management measures applied similarly in both regions should produce a uniform impact”*

This operational stock definition has been applied to New England cod resources since the late 1970s.

### 1980-2000

The information described above was reviewed for the international boundary decision (Bowen 1987), and the reviews concluded that

*“Cod in 5Y appear to be relatively isolated from those in 4X and on Georges bank, although they probably mix with cod along the coast to the north and south. Indeed, there is reason to believe that cod are homogeneously distributed along the coastline, with few apparent discontinuities north of Cape Cod. Such firm conclusions cannot yet be made for the 4X and Georges bank fish. Despite the evidence of exchange between Georges Bank, Browns bank, and the Bay of Fundy, enough segregation apparently occurs to maintain some group-specific characteristics of morphology and population dynamics.”*

Serchuk and Wigley (1992) outline the major changes to cod management occurring on the Georges Bank stock following the renewed internal US management. Assessment and management of the Gulf of Maine stock:

*“Due to pronounced demographic similarities between Georges-Bank and Southern New England-Middle Atlantic cod, the two groups have been treated as a single ‘Georges Bank’ stock unit (Div. 5Z and Subarea 6) by the USA since 1977. From 1983 through 1988, Canada similarly considered the ‘Georges Bank’ stock as encompassing the cod in Div. 5Z and Subarea 6 (Bowen, MS 1987; Hunt, MS 1988). In 1989, Canada re-examined the definitions of management units for groundfish species on Georges Bank (in light of the separate USA and Canadian management systems and the delimitation in 1984 of a maritime boundary between the USA and Canada in the Gulf of Maine/Georges Bank area), and concluded that the ‘Georges Bank’ cod stock could be partitioned in to two management units: (1) eastern Georges Bank cod (unit areas 5Zj and 5Zm) remainder of Div. 5Z and Subarea 6) (Hunt, MS 1989). As such, from 1989 onwards, Canada has treated the cod on Georges Bank as being comprised of two separate units (CAFSAC, MS 1989; Halliday and Pinhorn, 1990).”*

Hunt et al. (1999) summarized several years of tagging investigations on inshore Nova Scotian waters, the Bay of Fundy, and offshore banks (Figure 6 and 7). Several conclusions for coastal Nova Scotian stocks were produced. Some work was additionally conducted on Eastern Georges Bank and many tags had been recaptured in U.S. waters.

Connectivity between all areas in the Gulf of Maine was found, although the rate of movement was very small.

Ruzzante et al. (1999) published a study investigating genetic variation between the Bay of Fundy, Georges Bank, and Browns Bank cod. Utilizing polymorphic microsatellites they found distinct variation between each of the three regions. The authors concluded that the unique oceanographic and bathymetric features at each of the three sites provided sufficient barriers to facilitate speciation and promote unique population demographics (Ruzzante et al. 1999).

Finally, Begg et al. (1999) conducted an exploratory analysis on survey demographic data (Figures 8 and 9). Based on survey data of eggs, larvae, and adults, they hypothesized, that there is continuity between the Gulf of Maine and Georges Bank groups along Cape Cod and based upon the autumn trawl survey that there is a break between eastern and western Georges Bank. Analyzing growth data they found that the growth rates differed between both Georges Bank vs. Gulf of Maine and eastern vs. western Georges Bank, although the magnitude and consistency of the variation was greatest between Georges Bank and the Gulf of Maine. Total mortality estimates did not differ greatly between stocks. Maturity rates differed between Georges Bank and the Gulf of Maine and varied between eastern and western Georges Bank (Begg et al. 1999).

#### 2000-2007

O'Brien et al. (2005) reviewed historic data, ichthyoplankton, and adult cod sexual maturity from surveys and found considerable structuring of spawning groups throughout the region. Spawning occurs on eastern and western Georges Bank, Nantucket shoals, Massachusetts Bay, in Ipswich Bay (with separate spawning events in winter and spring), and small distinct zones along the central Maine coast (Ames 2004). Spawning has been noted along the Mid-Atlantic coast (Schroeder 1930; Colton et al. 1979), however very few fish have been collected there recently (Serchuk and Wigley 1992). Clark (2005) concluded that similar structuring of localized coastal groups and more diffusive bank groups exists for cod within the Scotian Shelf stock. Furthermore, surveys of cod spawning condition indicated unique spawning locations on Nantucket Shoals, Coxes Ledge, Stellwagen Bank, and Massachusetts Bay (SMAS-UNH-NYU tagging and genetic project, in process).

Lage et al. (2004) explored the genetic relationship between Nantucket Shoals, Georges Bank, and Browns Bank spawning grounds finding more heterogeneity between Nantucket Shoals and Georges Bank than between Browns Bank and Georges Bank. Wirgin et al. (2007) concluded that significant genetic heterogeneity exists both between stock management areas (Georges Bank vs. Gulf of Maine) and within stock management areas. Samples were collected from a number of sources in the initial phase of the project including larvae and adults. Later stages of the project purified samples to individuals in spawning condition collected on assumed spawning aggregations. The Ipswich spring spawning group was found to exhibit the most genetic variance, primarily expressed by a single genetic marker (*Gmo 132*), with a maximum significant variance ratio of 0.0221 with the Chatham group. The genetic structure of the New England area is far from resolved and further investigation is needed.

## Conclusions

### Movement across the Georges Bank-Gulf of Maine stock boundary

Recent tagging investigations report adult movement from Georges Bank to the Gulf of Maine (Northward; Tallack 2006) and from Gulf of Maine to Georges Bank units (Southward; Tallack 2006; Gröger et al. 2007). These results are equivalent to reports and conclusions from previous region wide tagging investigations. Rich (1926) reported a low percentage of recaptures south of Provincetown MA from cod tagged along the Maine coast between Portland and Mount Desert Island, on Platts Bank, and on Stellwagen Bank. Schroeder (1927,) noted that although Massachusetts Bay fish migrate eastward and southward, the cod east of Cape Ann, MA do not migrate south towards Cape Cod. Higgins (1929) concluded of the ongoing tagging investigations that the primary migratory pathway from Massachusetts Bay was south rather than North. Schroeder (1930) suspected that the intermingling of these North and South groups was low based upon the lack of clear migrations, like those noted in the Southern New England groups. Those fish that did make movements around Cape Cod were thought of as ‘stragglers’, or individual fish that had randomly strayed from their greater contingent of fish (Fig. 10). Wise (1963) also reported both northward and southward movements concluding that the southward movements were rare while the northward movements from Southern New England into the Gulf of Maine constituted probable ‘one way trips’ of larger individuals.

The earliest conclusions are somewhat uncertain. Schroeder (1927) was certain that the individual fishing grounds contained unique stocks of fish but could not explain where the shore spawning aggregations came from:

*“Each cod ground affording a differing physical conditions has its own peculiar stock of fish, and there appears to be no general intermingling of fish from the various banks. It is true that large numbers of spawning cod collect in the shore waters of New England throughout the winter, but I am not prepared to say at this time where they come from or where they go after spawning.”*

### Summary:

- The New Jersey coastal group is uniquely migratory (Smith 1902; Schroeder 1930; Wise 1958; Wise 1963)
- The coastal Maine stocks are uniquely sedentary (Higgins 1929; 1933).
- The Nantucket Shoals cod are associated with those in the Great South Channel
- The northern extent of the range of cod on Nantucket Shoals fish was disputed (Schroeder 1930; Wise 1963).
- Schroeder (1927; 1930) and Higgins (1929) thought the Channel fish were associated with groups no further north than Massachusetts Bay and no further east than western Georges Bank.
- Wise (1963) delineated the range of south channel cod as the northern tip of Cape Cod, despite noticeable recaptures north of the Cape. Wise seemed more rigid in his interpretation that these were one-way trips than earlier authors.
- Templeman (1962) in his review of the cod stocks of the Western Atlantic considered the range of the south channel stock to encompass Stellwagen Bank,

- while the Maine coastal stock extended south to Ipswich bay. Templeman based his stock boundaries on the contemporary literature and personal communication with researchers along the coast.
- Wise's (1963) affirmation that the south channel fish did not move northward around the Cape may have been more of a practical consideration. The statistical area (521) was typically fished as a part of trips to Georges Bank, and the complications of a mixed stock statistical unit may have been too great considering the apparent distributions of fishing effort (Rousenfell 1948).

#### Movement across the Georges Bank-Scotian Shelf stock boundary

The first tagging on northeast GB was 1926 (Higgins 1927) followed by a second cruise the following year (Higgins 1928). By 1927 recaptures had been reported locally, on southeast Georges Bank, Browns Bank, and near Block Island as well as one on La Have Bank. This suggested that the Georges Bank cod migrate in all directions (Higgins 1928). By 1930 it was concluded that most of the eastern Georges Bank fish remain on the bank with movements to Browns Bank and some to Nantucket Shoals and southward (Higgins 1931). Wise (1963), in his investigations (1955-1959) reported a low recapture rate for the tagging on Eastern Georges Bank. The majority of the recaptures coming locally with some from Browns Bank and inshore Nova Scotian waters. Some fish tagged at Grand Manan were recaptured on Eastern Georges Bank (Wise 1963). Wise's (1963) overall conclusion on cod stocks of the offshore banks was that they are separate stocks with a low exchange with the inshore areas but considerable within group movement. Hunt et al. (1999) provided the first reporting of tagging experiments whose recapture rates were standardized by effort. They also showed localization and a stronger affinity to Browns Bank and the Scotian shelf than to western Georges Bank and the inshore Gulf of Maine. The interpretation of results concluded:

*“Results of the present study support the occurrence of seasonal movement but also indicate that it is not a closed system. There is evidence of immigration and emigration and an apparent net loss from the Georges Bank area to the Browns Bank and division 4X area.”*

Tagging also occurred on Browns Bank in 1927 (Higgins 1928). Of the Browns Bank tagging, recaptures were reported on Georges Bank and at the Rhode Island coast in low numbers (Higgins 1929). Most of the movement appeared to be to the North and northeast (Higgins 1931). McKenzie (1956) conducted investigations primarily on inshore groups of cod finding some small movement to the offshore banks. Wise (1963) conducted some tagging on Browns Bank receiving recaptures locally, inshore Nova Scotian waters to both the north and east and on Eastern Georges Bank. Hunt et al. (1999) conducted more extensive tagging experiments on Browns Bank and inshore Nova Scotian waters than Georges Bank. Although some fish moved west they found less connectivity between Browns Bank and Eastern Georges than between Browns Bank and the Bay of Fundy (Hunt et al. 1999).

## Discussion

Previous tagging literature documents similar pathways of movement between stock areas, but the frequency of residence and movement are different among studies. Most cod tagging was not designed to evaluate movement rates, and the proportional recaptures may not reflect changes in movement rates. Current stock boundaries for cod off New England are primarily based on an operational definition (e.g., demographic patterns) and practical limitations of monitoring fisheries (e.g., mixed-stock fishing trips). However, advancement of methods for exploring spatial population structure (genetics, otolith microstructure and chemistry, electronic tags, spatial analysis) as well as greater spatial resolution in fishery data suggest that investigation of stock structure should continue toward the objective of improving stock definitions for population modeling and stock assessment.

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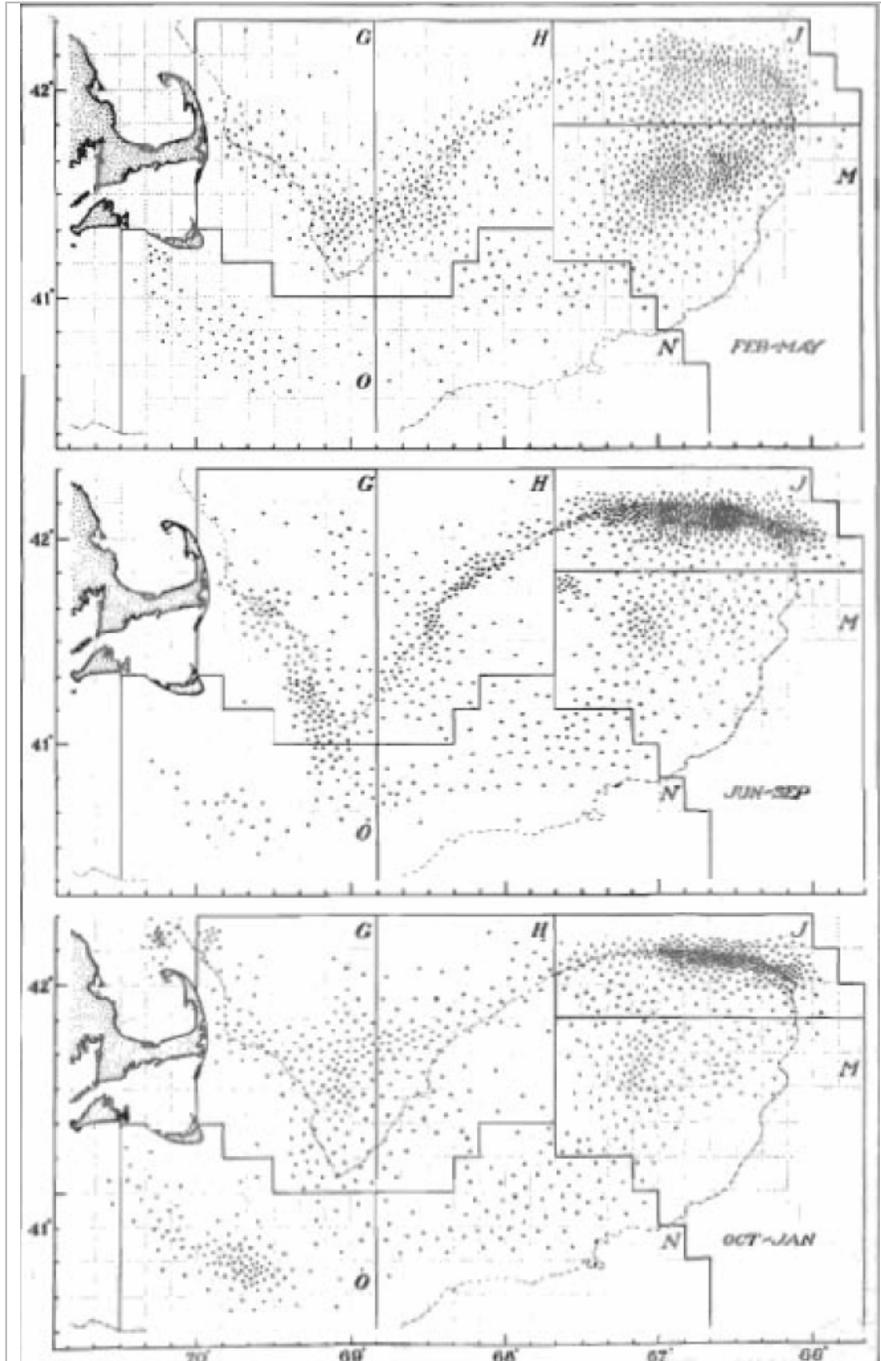


Figure 1. Distribution of Boston based trawl fleet effort where each dot is 10 day's fishing effort. Statistical areas drawn around apparent natural divisions of fishing activity. From Rounsefell 1948.

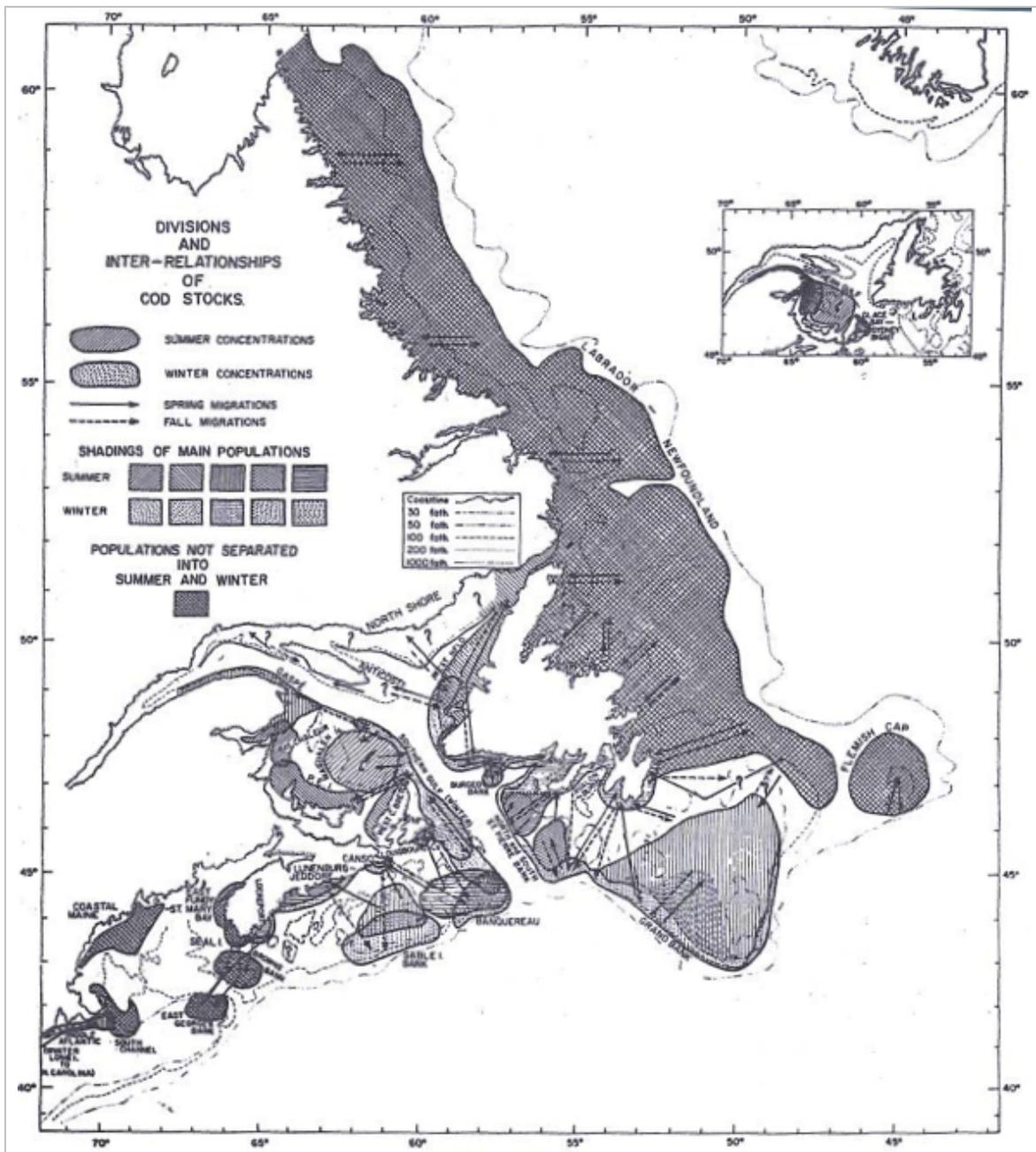


Figure 2. Cod stocks from ICNAF Subareas 2-5 and southward. From Templman 1962.

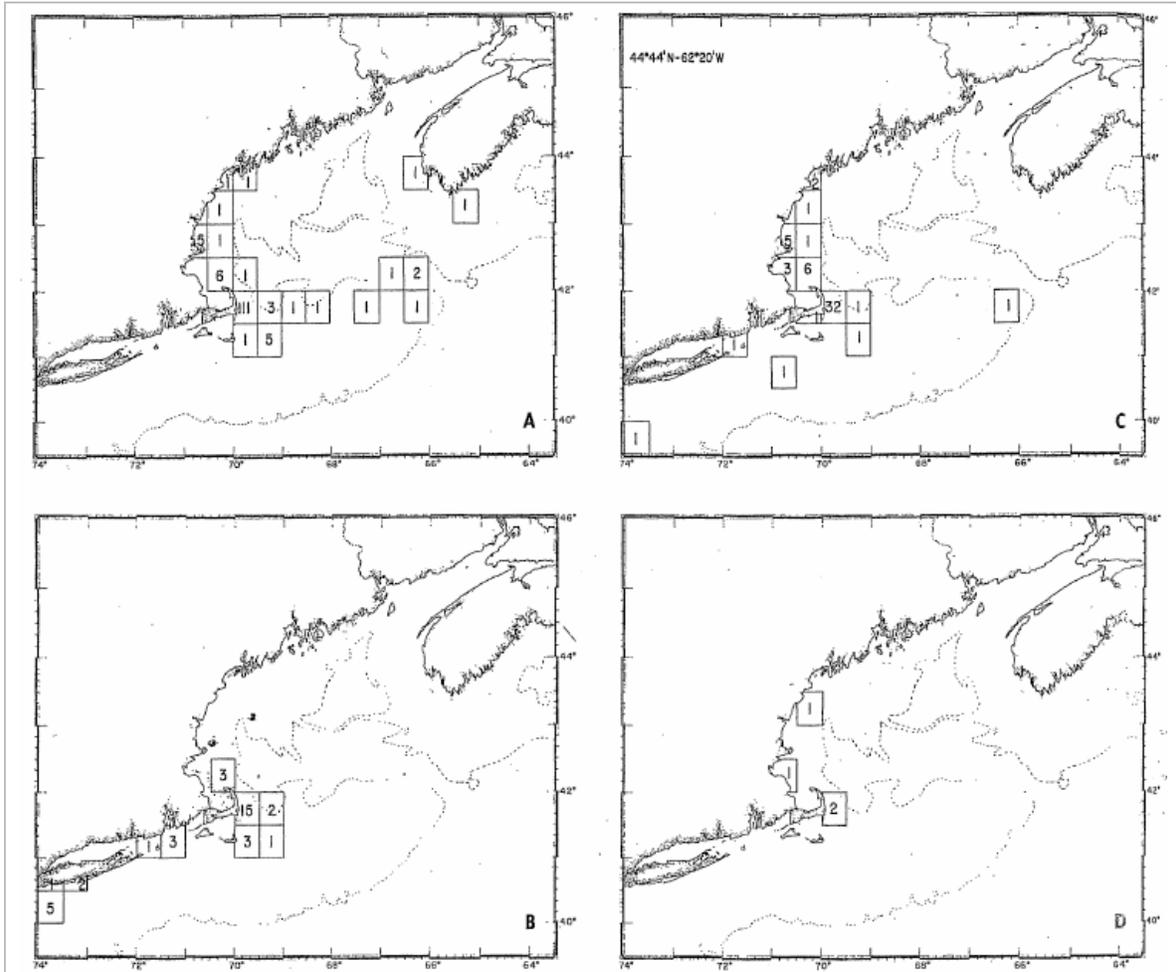


Figure 3. Recaptures of cod tagged off Chatham Massachusetts Feb-March 1957. A) Within 26 weeks, b) 27-52 weeks, c) 53 to 78 weeks, d) 79 to 119 weeks. From Wise 1963.

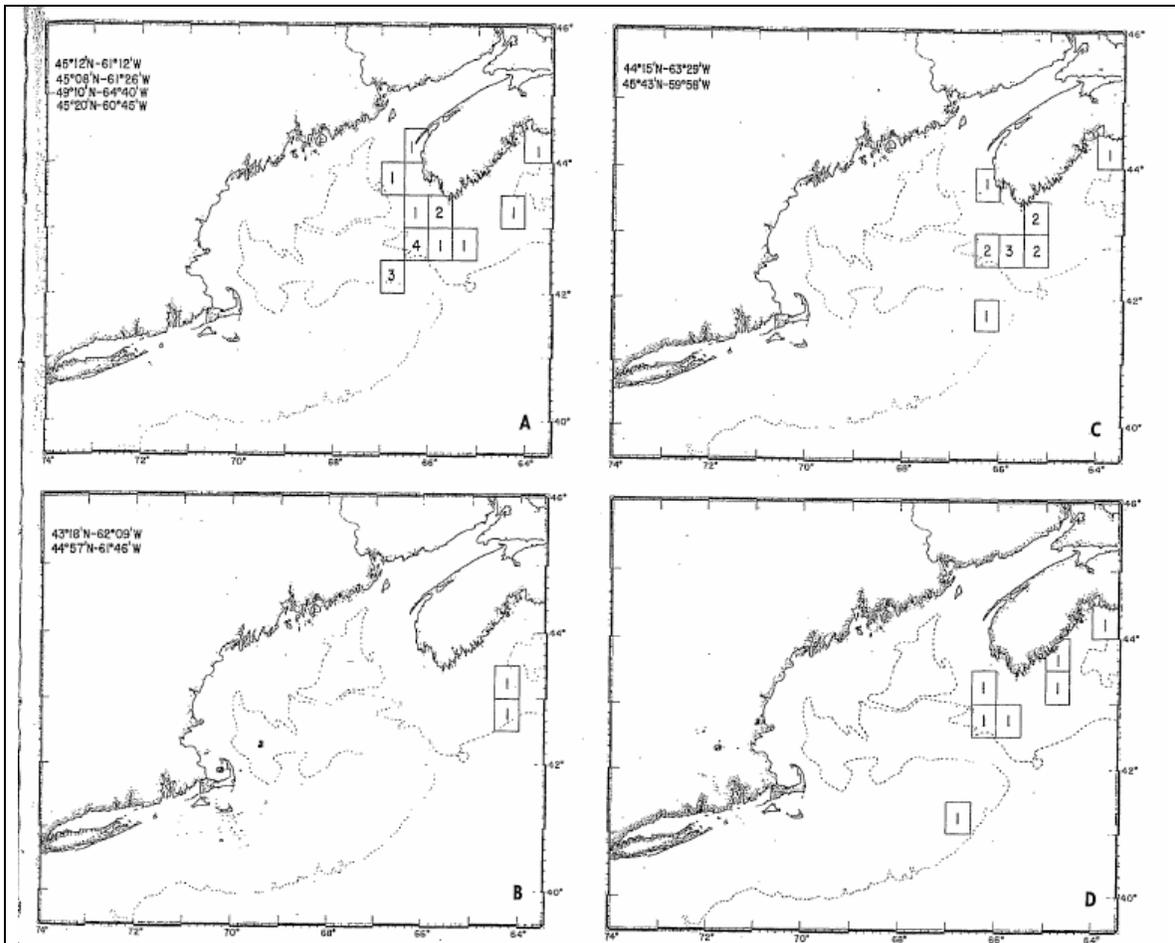
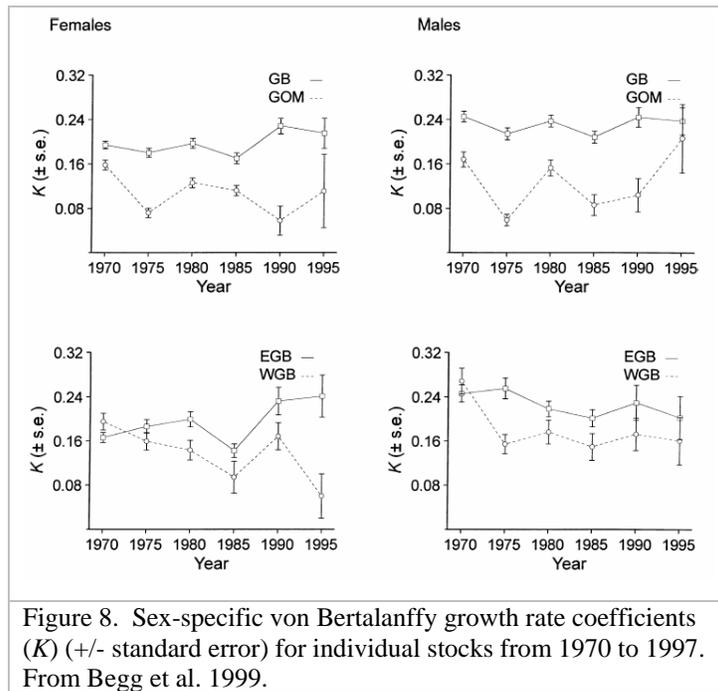
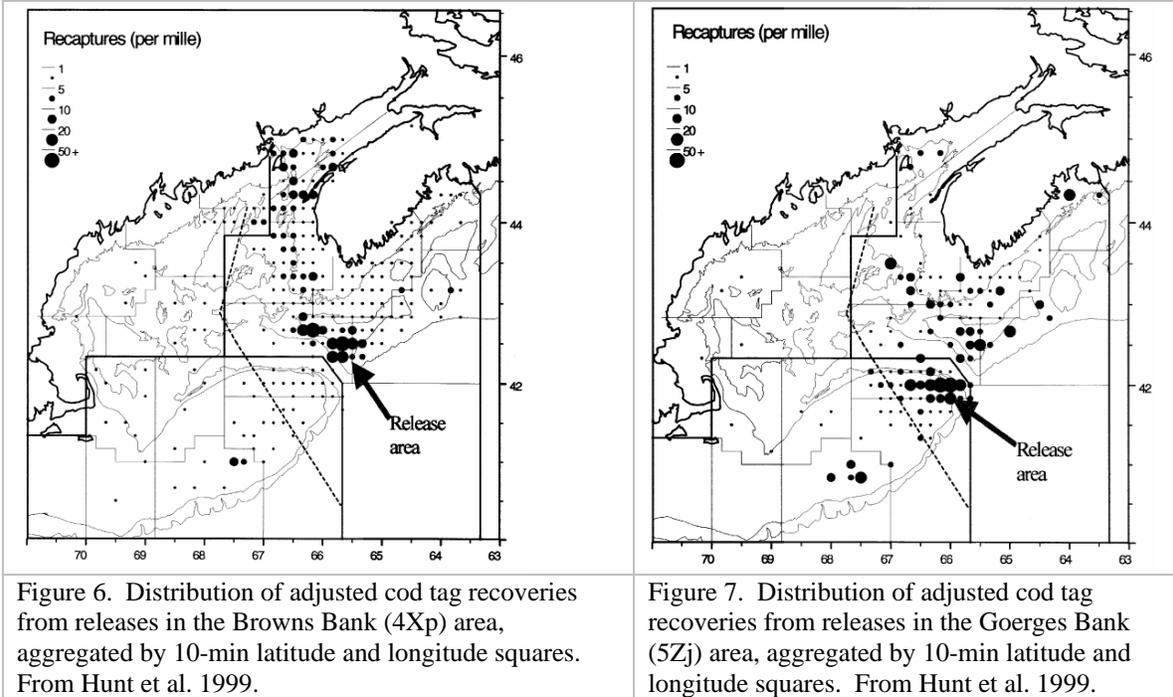


FIGURE 4.—Returns from tagging cod on Browns Bank, March 1957. (a) Within 26 weeks, (b) from 27 to 52 weeks (c) from 53 to 78 weeks, (d) from 79 to 163 weeks.

Figure 4. Recaptures of cod tagged on Browns Bank, March 1957. A) Within 26 weeks, b) 27-52 weeks, c) 53 to 78 weeks, d) 79 to 163 weeks. From Wise 1963.





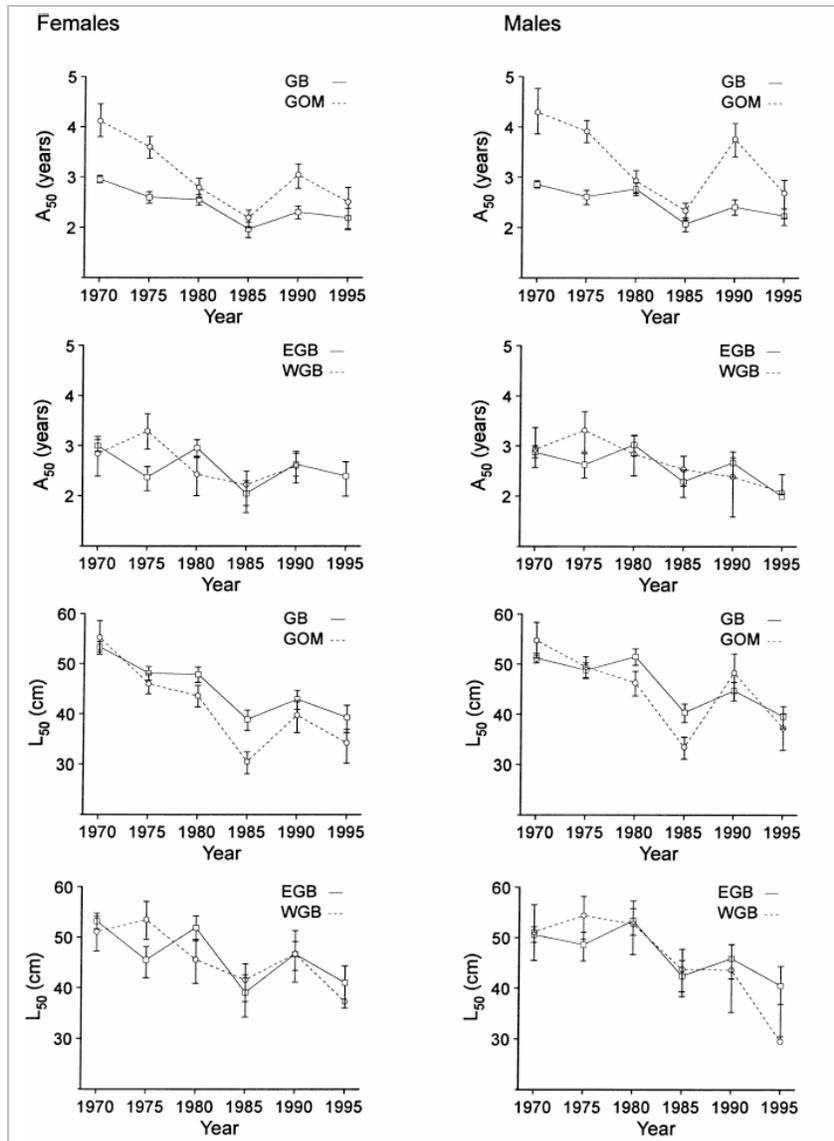


Figure 9. Sex-specific age and length at 50% maturity (+/- 95% confidence intervals) for individual stocks from 1970 to 1997. From Begg et al. 1999.

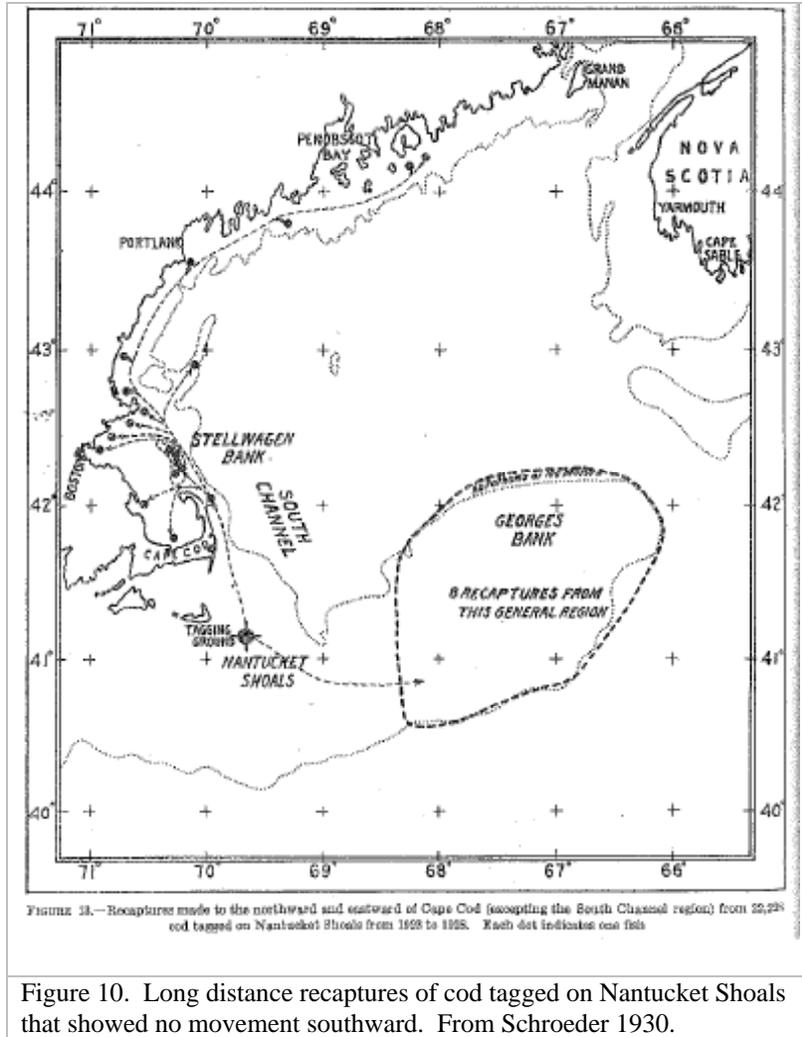


Figure 10. Long distance recaptures of cod tagged on Nantucket Shoals that showed no movement southward. From Schroeder 1930.