MOVEMENT OF ATLANTIC COD (*GADUS MORHUA*) IN AND AMONG THE WESTERN GULF OF MAINE ROLLING CLOSURES AS DETERMINED THROUGH MARK AND RECAPTURE

BY

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ABSTRACT

In response to the increased pressure to lower fishing effort on Atlantic cod (*Gadus morhua*) in the northwest Atlantic, rolling time/area closures were created in the western Gulf of Maine. These closures are intended to protect fish by closing specific fishing grounds at times when fish abundance is particularly high. However, fisheries dependent data for rolling/time area closures is lacking and little is known about their effectiveness.

To determine the effectiveness of the western gulf of Maine rolling time/area closures as a management tool, movement patterns and catch per unit effort of Atlantic cod were investigated via mark and recapture. Tagging was conducted in cooperation with the commercial fishing industry. In 91 sampling trips, a total of 17,860 Atlantic cod were tagged, with 1,148 having been recaptured by October 2002. Information gathered was used to determine if the movement of Atlantic cod mirrored the timings of the rolling closures.

Overall, movement of Atlantic cod in the western gulf of Maine appears to be associated with spawning. In the spring, cod were observed to move from offshore areas and aggregate inshore (area 133) to spawn. Post-spawning movements began in June and were characterized as a general dispersion offshore away from the spawning grounds. Cod were again observed to move inshore for spawning in December-January, suggesting the possibility of two distinct spawning groups. These spawning events were each associated with movements in and out of area 133. When average length was compared,

it was determined that the spring spawning cod were significantly larger than the winter spawning cod.

Movement of Atlantic cod was observed to correlate with the closing of areas 133, 132, 139, and 140 between April and June, as fish were observed migrating into these areas. However, as the southern closures (areas 124 and 125) reopened, there was evidence of movement into these spaces as well. While this may appear to be an obvious disadvantage in protection, we feel that the rolling closures still offer adequate protection by displacing fishing effort from areas with a high biomass of cod, to areas with a lower biomass of cod.

INTRODUCTION

Atlantic cod, *Gadus morhua*, is a species commonly found in the Northwest Atlantic Ocean from Cape Hatteras, North Carolina to Greenland (Bigelow and Schroeder 2002; Fahay et al. 1999). The species ranges in depth from the surface to 450m, but is typically found within 2m of the bottom, on rocky or broken substrates (Bigelow and Schroeder 2002; Fahay et al. 1999). This association with the ocean bottom is what categorizes cod as a groundfish species. Adults of the species feed primarily on fish, crustaceans, and mollusks. Spawning in the Gulf of Maine occurs in the early winter and early spring in dense concentration (>1 fish/m^3) (Fahay et al. 1999; personal observation). A large female is capable of producing between 3 and 9 million eggs per spawning event (Bigelow and Schroeder 2002; Fahay et al. 1999). Median age of maturity for males and females is 2.3 and 2.1 years, respectively. Cod enter the fishery between 2 and 5 years of age (Fahay et al. 1999).

The Northwest Atlantic Ocean has supported a major cod fishery since the 17th century (Mayo et al. 2002). Fishing was originally conducted using hook and line, but is now primarily conducted by long lines, gill nets, and otter trawls (Bigelow and Schroeder 2002). Prior to 1977, the fishery was an open access fishery to any nation that had the means to reach the fishing grounds of the northwest Atlantic. Management of the fisheries in US waters at this time was conducted through an international treaty. With the creation of the Magnuson Fishery Conservation and Management Act, all waters off the coast of the United States up to 200 miles off shore became known as an exclusive

economic zone (EEZ). This zone made all fishing grounds off limits to foreign fishing fleets. Management of all the newly created U.S. fisheries was now the responsibility of the National Marine Fisheries Service (NMFS). In turn, they delegated local management of fisheries to regional fisheries council's, whose responsibility was generating fishery management plans in their respective areas. In the Gulf of Maine, fisheries management is the responsibility of the New England Fishery Management Council (NEFMC) (Mayo et al. 2002).

In its first few years of existence, the NEFMC primarily utilized total allowable catch (TAC) quotas to manage the Atlantic groundfish stocks, including Atlantic cod. In 1982 the NEFMC developed an interim plan that did away with TAC quotas and instead implemented minimum mesh sizes and minimum landing size regulations (Mayo et al. 2002). To further manage groundfish stocks, the NEFMC drafted the Northeast Multispecies Fishery Management Plan (NMFMP) in 1985. This plan, and its first four amendments, had essentially the same management strategy as the interim plan, however in 1994, the drafting of Amendment 5 saw a change in the way the stocks were managed. With Amendment 5, the focus of the NMFMP was on reducing overall fishing mortality for the five key stocks (Georges Bank cod, Georges Bank haddock, Georges Bank yellowtail, Southern New England yellowtail, and Gulf of Maine cod by reducing the allowable days at sea (DAS) (Mayo et al. 2002; Framework 33).

The current management plan, Amendment 7, became effective on May 1st, 1996. In addition to regulating DAS, minimum mesh size, and minimum landing size, it utilized area closures and reestablished TAC quotas as a way to further reduce fishing mortality

rates (Framework 33). Once implemented, the plan was to be reviewed annually with the necessary changes, called frameworks, being made to better meet the goals of the plan.

The current framework, framework 33, became effective in May of 2002 (Framework 33). The principal action of this framework was to keep fishing mortality rates of the five major stocks at or below the target rates that were set by Amendment 7. To achieve this, the NEFMC established the Multi-Species Monitoring Committee (MSMC) to annually set TAC quotas for each of the five stocks. For the 2000 fishing season the MSMC set the TAC for the five stocks as follows: GB cod = 4,145mt, GB haddock = 6,252mt, GB yellowtail flounder = 4,618mt, SNE yellow tail flounder = 951mt, and GOM cod = 1,918mt (Framework 33).

While three of the stocks are currently below their respective target rates, fishing mortality on two of the stocks, GB cod and GOM cod needed to be further reduced by 36% and 56% respectively (Framework 33). To reduce fishing mortality on GOM cod, Amendment 7 utilized several area closures (Fig 1.). These consisted of one year round closure on Jeffery's Ledge (Area 156) and six rolling closures in the western portion of the Gulf of Maine (Areas 140, 139, 133, 132, 125, and 124). These rolling closures are areas (30x30 minute blocks) where fishing is restricted during certain times of the year, often at time where cod biomass is especially high (e.g. spawning) (Framework 33). With framework 33 the rolling closures were as follows: Areas 125 and 124 were closed February through April and October through November; Areas 133 and 132 were closed April through May; and Areas 140 and 139 were closed May through June.

These rolling closures are in a sense, temporary marine protected areas. While they are only meant to offer protection during specific times, they function in much the same way as permanent marine protected areas. Marine protected areas (MPA's) can help overexploited stocks by reducing over fishing, protection of habitat, protecting against uncertainty, acting as a buffer to management errors, and conserving genetic diversity (Conover et al. 2000; Lauck et al. 1998; Guenette et el. 2000; Koenig et al. 2000; Roberts 1998; Trexler and Travis 2000). MPA's have been hypothesized to rebuild fisheries in two ways. The first is known as the biomass-overflow hypothesis and states that if you lower fishing mortality in a protected area, then the density of fish within the reserve will increase and cause density-dependent emigration into adjacent non-reserve areas. The second is known as the larval-export hypothesis. This states that the increased spawning stock biomass within a reserve will lead to an increase in egg and larval production, which will then be transported by larval drift out of the reserve (Crowder et al. 2000; Dayton et al. 2000; Roberts 1998; Russ and Alcala 1996).

MPA's can differ in type and function depending on what their management goals are. Temporally there are two types of MPA's; permanent closures (Murawski et al. 2000) and seasonal closures (Beets and Friedlander 1998; Halliday 1998). A permanent closure is closed year round, while a seasonal closure (e.g. rolling closures) is only closed at certain times of the year, often corresponding to some life history event. MPA's can also differ in their level of protection. They can either be 100% protected by being off limits to any exploitation, or they can be off limits to a particular fishing gear type.

Placement and size are also important aspects to consider when planning a marine protected area. When considering placement as a factor, source-sink dynamics and habitat quality of the potential protected area must be taken into account. An area is considered a source site if it supplies a significant amount of individuals to a population. Conversely, if an area does not supply a significant amount to the population, it is considered a sink site. In theory, a MPA placed in a source site will have a greater effect on increasing the overall population than a reserve placed in a sink site (Roberts 1998). Two possible source sites could be spawning aggregations, which would supply eggs to a population (larval export) or a nursery site, which would supply future adult to a population (biomass-overflow) (Roberts 1998; Horwood 1998).

In addition to source-sink dynamics, habitat quality must be taken into account. Placing a MPA on unproductive habitat could cause increased fishing pressure on productive habitats and thus negate any benefit to the protected area (Crowder et al. 2000). The size of an area can also impact its effectiveness in rebuilding a stock. Opinion on the minimum size needed to have a positive effect varies among researchers. Guenette et al. (2000) suggested that areas encompassing 80% of the total stock range would cause an increase in abundance by decreasing the catch rate by half. Another study conducted by Lauck et al. (1998) suggested that an area encompassing 50% of the total population range was needed to safeguard against over fishing.

In the Gulf of Maine, the decline in groundfish stocks has been a major concern to fisheries managers (Framework 33). One example in which management used marine protected areas to manage groundfish is the three closed areas on Georges Bank. In

December of 1994, three areas totaling 17,000 km^2 were closed years round to all groundfish gear. These areas were seen as important spawning grounds for many groundfish species (Murawski et al. 2000). In the next five years, fishing effort was significantly reduced on not only groundfish stocks, but on the scallop stocks, which were also heavily fished. Following the closure, researchers saw a 14 fold increase in scallop biomass on Georges Bank (Murawski et al. 2000). They concluded that with the reduction in fishing effort as a result of the year round closure, "stock status in the Georges Bank area improved substantially, despite only modest recruitment" (Murawski et al. 2000).

Several factors can influence the effectiveness of MPA's. The first is the degree of movement in and out of the MPA (Appeldoorn 1997; Zeller and Russ 1998). It has been shown that for species that exhibit only small localized movements, such as red snapper, greater amberjack, and gray triggerfish, no-take marine protected areas may lead to an increase in biomass (Ingram and Patterson 2001). However, it has been suggested that MPA protection will not be sufficient if movement rates are high relative to MPA size (Appeldoorn 1997). The timing and placement of a MPA may also be complicated by the life histories and migratory rates of the species within it. If migratory rates are high, accurate placement becomes more important (Roberts 2000). In many MPA's, like the Georges Bank reserve, none of the important fishery species complete their entire life cycle within the boundaries of the MPA (Murawski et al. 2000; St Mary et al. 2000). So while a MPA may protect a species at one point in their lives, they may be vulnerable to exploitation at another point, negating the overall effectiveness of the MPA as a

management tool. This point is further supported by an earlier study that examined the spatial and temporal distribution of Atlantic cod. This study was conducted in response to the severe decline in the Atlantic coast cod fishery. The aim of the study was to determine the movement patterns of juvenile cod. From this, it was suggested that for a management plan to be effective, knowledge of fish movement is necessary (Wigley and Serchuk 1992).

A second factor that influences the effectiveness of marine protected areas is that, by definition, there is a lack of fisheries dependent data. Fisheries managers have relied on both fishery-dependent and fishery-independent data to make their management decisions. Fishery-dependent data is obtained from the landing records of commercial fishermen. With marine protected areas, with no commercial fishing effort, there is a complete absence of fishery-dependent data. Due of this, fishery managers have no data to tell if the marine reserves are working. Fishery-independent data is obtained from research survey trips conducted by the National Marine Fisheries Service (NMFS) (Mayo et al. 2002). The problem with this data is the scale at which it is collected. Most surveys are done over a large area (1000's of square miles). Within this area, only a few stations are sampled, e.g. 1 trawl for every 300 square miles (Pierce and Hughes 1979). While this method is good for providing information about large areas such as the entire Gulf of Maine, it does not provide adequate information for much smaller areas (100's square miles), as is the case for the western Gulf of Maine rolling closures.

One way to examine the movement of fish in and out of MPA's is by conducting a fishery-independent mark and recapture study (Martell et al. 2000; Stobo et al. 1988;

Boje 2001; Patterson et al. 2001; Cappo et al. 2000; Lawson and Rose 2000). Mark and recapture studies involve marking an individual in such a way that it can be identified at a later date and location. From this, information on population statistics such as abundance estimates, growth rates, stock structure, as well as exploitation and survival rates can be obtained (Cappo et al. 2000; Gazey and Staley 1986; Hunt and Neilson 1993; Murphy and Willis 1996). There are several ways in which an individual fish can be marked that vary in their complexity. The simplest way involves a process known as fin clipping. This involves removing a portion of a fin in such a way that it does not alter the mobility of the animal. This method can be utilized to mark a large number of individual of fish in a short amount to time. This method could be useful for example, in distinguishing between hatchery reared fish and wild fish, but would not be useful in distinguishing between specific individuals. A more complex method of marking involves the attachment, either internally or externally, of an identifying mark. These marks, known better as tags, come in many types, such as Petersen disk tags, spaghetti tags, dart tags, and anchor tags (Murphy and Willis 1996). These tags differ in the location of their placement as well as the actual shape of the tag, but all allow for individual recognition of fish. From this, data on specific movement rates can be obtained. The third type of tags are the electronic tags, which are capable of gathering environmental data (such as depth and water temperature), physiological data (such as body temp), and location data (such as GPS position). They include data storage tags, hydrostatic tags, satellite tags, and passive integrated responder tags. These tags can be attached either internally or externally depending on the type.

For a mark and recapture to be successful, getting the highest possible recovery rate is necessary. To obtain a high recovery rate, it is important to first ensure that the marks are highly visible by making them brightly colored. Second, you can also increase the recovery rate by publicizing the study. The more people that are aware of the study, the greater the chance marks will be noticed (Murphy and Willis 1996). There are also factors concerning the actual release of the fish that have an influence on the recovery rate. Fowler and Stobo (1999) complied a list of groundfish mark and recapture studies conducted in the Northwest Atlantic. They used this list to examine what influence different release parameters had on the recovery rate. They determined that different release factors such as length of fish, depth of capture, year of release, and catch size all had an influence of the recovery rate (Fowler and Stobo 1999).

Tagging studies also have several assumptions that must be met in order to ensure that accurate and reliable information is obtained. The first assumption is that once a fish is tagged and released, it mixes randomly with un-tagged fish, and that both tagged and untagged fish have the same chance of being recaptured. The second assumption is that a tagged fish can be recognized upon recapture. The third assumption is that tags are not lost at any point during the study. The fourth assumption is that tagging does not affect mortality of the fish, and does not make them more conspicuous to predators. The fifth assumption is that tagging does not alter the behavior of the animal (Jennings et al. 2001; Gazey and Staley 1986; Murphy and Willis 1996).

Mark and recapture studies have been utilized for studying the movement patterns of a wide variety of fish, and for a wide variety of reasons. For example, a study on red

snapper, *Lutjanus campechanus*, used mark and recapture techniques to examine stock structure in the Northern Gulf of Mexico (Patterson et al. 2001). From 519 recaptures, researchers calculated mean distance traveled and mean time at liberty and from this, concluded that movement of red snapper might be great enough to facilitate stock mixing (Patterson et al. 2001). This study is a good example of examining movement on a small scale. The mean distance moved was only 29.6 km with the furthest recapture traveling only 352 km (Patterson et al. 2001). This is relevant to the current study in that examining migration on a small scale (hundreds of miles), as opposed to migration on a large scale (thousands of miles), is important in understanding the effectiveness of a rolling closure. Fish may only travel a few miles but still cross into a different area. Thus even small movements can be significant if the fish are traveling from an open area to a closed area, or visa versa.

Mark and recapture studies can also be used to examine the seasonal movements of fish. For example, Shimada and Kimura (1994) conducted a mark and recapture study on Pacific cod, *Gadus macrocephalus*, in the eastern Bering Sea. They used the information obtained from 373 recaptures to determine what influences the seasonal movements of Pacific cod. Researchers determined that there was a strong relationship between location and season of release and location and season of recapture. They attributed these movements to migratory shifts between summer feeding areas and winter breeding areas (Shimada and Kimura 1994). Atlantic cod are thought to make similar movements in the Gulf of Maine (Hunt 1999).

The degree of movement of fish in and out of reserves can also be determined through mark and recapture studies. A study examining Lingcod, *Ophiodon elongates*, movement showed through tagging that fish seasonally move in and out of the protected area (Martell at al. 2000). Appeldoorn (1997) also suggested that mark and recapture experiments are an effective way to estimate movement rates in and out of protected areas. Both studies suggested that understanding the small-scale movements of fish is important in determining the overall success of a marine protected area (Appeldoorn 1997; Martell et al. 2000).

With Atlantic cod, mark and recapture studies have been used to study migration in the northwest Atlantic as early as 1897 (Wise 1963). Wise (1963) summarized Atlantic cod tagging studies done in the northwest Atlantic between 1897 and 1959. Within the Gulf of Maine specifically, more than 6,000 cod were tagged by the U.S. Bureau of Fisheries between 1923 and 1932. Tagging was primarily done around Mount Desert Island and Platts Bank. Findings from tagging in the Gulf of Maine, as well as other locations in the northwest Atlantic, suggested that there was little intermingling between the southern populations of cod and cod from the Gulf of Maine. Fish tagged around Mt. Desert Island were mostly recaptured in the same area, with a few moving eastward (Wise 1963).

Between 1955 and 1959, 436 cod were tagged at various locations in the Gulf of Maine, with 27 cod being recaptured. Results showed that fish tagged on Cashes Ledge were recaptured near the Massachusetts coast, Georges Bank, and off Provincetown, MA. Fish tagged on Jeffery's Ledge were recaptured both on Jeffery's Ledge and off Rhode

Island. Fish tagged on the Grand Manan Banks, were recaptured in the same area, Georges Bank, and Browns Bank (Wise 1963).

In a 1953 study, 1,804 cod were tagged off Lockeport, Nova Scotia, with 757 being recaptured. Results showed that most returns came from the tagging region. Tag returns from areas other than the tagging region included other neighboring inshore areas and Georges Bank. This study suggested that there was no pronounced seasonal movement, although cod were caught in deeper water in the winter than in the summer (McCracken 1956).

McKenzie (1956) published a study on Atlantic cod tagging off the southern Atlantic Canadian mainland. In this study, approximately 25,000 cod were tagged between 1924 and 1940. Data from the tag returns suggested that cod tagged inshore in the Bay of Fundy in the summer remained stationary, with only slight mixing with adjacent areas. An annual migration was detected from cod being located offshore in the winter off the eastern banks, and moving inshore in the summer in the Gulf of St. Lawrence (McKenzie 1956).

More recently, a mark and recapture study was used to study the seasonal movement of cod in Placentia Bay, Newfoundland. In this study, 5,235 cod were tagged with 471 being recaptured. Results showed that 87% of the recaptured fish came from within Placentia Bay. The remaining recaptures were located in Fortune Bay as well as on the offshore banks (Lawson and Rose 2000).

There has only been one recent tagging study in the Gulf of Maine which examined the movement patterns of adult cod. This study was conducted from 1979 to

1997 in North Atlantic Fisheries Organization (NAFO) division's 4X, 5Z, and 5Y. Specific tagging locations were chosen in areas with high catch rates, as determined from research vessel surveys. Results demonstrated that there was both immigration and emigration occurring at the NAFO division level. Recapture information showed movement of cod from area 5Z east to 4X. Results also showed that cod released on Georges Bank moved onto Browns Bank, and cod released on Browns Bank moved inshore off Nova Scotia and onto Georges Bank (Hunt et al. 1999).

Data from studies like those described previously, has provided fisheries managers with information to devise conservation management plans that take into account the life histories of the fish. In the case of the Atlantic cod fishery, and more specifically, the Gulf of Maine cod stock, the NEFMC generated the following regulations: 1) A reduction in daily trip limit to 400 lbs/day; 2) Creation of a year round closure on Jeffery's ledge; and 3) Creation of 6 inshore rolling closures in the western Gulf of Maine. The rational for creating these rolling closures was to protect the masses of fish that use these areas for spawning at certain times of the year. However, not known is precisely when these fish arrive in a given area and when they leave, how long they stay, and whether or not biomass is increasing in these areas.

To answer these questions as well as evaluate the effectiveness of the rolling closures as a management tool, a yearlong Atlantic cod mark and recapture experiment was conducted in the western Gulf of Maine. It was hypothesized that for the rolling closures to achieve maximum effectiveness, they must meet two criteria: 1) They must be accurate with respect to the timings of cod movements. The areas should be closed once

fish arrive in an area and reopened once fish disperse from an area, and 2) They must be accurate with respect to seasonal changes in biomass in an area. Areas should be closed when biomass is especially high (e.g. spawning) and reopened when biomass levels decrease (e.g. post-spawning). To test these two hypotheses, vector velocities, mean angle of travel, and dispersion coefficients were calculated. In addition, directionality for each group of recaptured fish was also tested. Catch-per-unit-effort (CPUE) was also calculated for each area for each month sampled. This information will be used to test whether biomass is higher in a closed area than in an open area, and if cod are moving into closed areas and moving out of open areas.

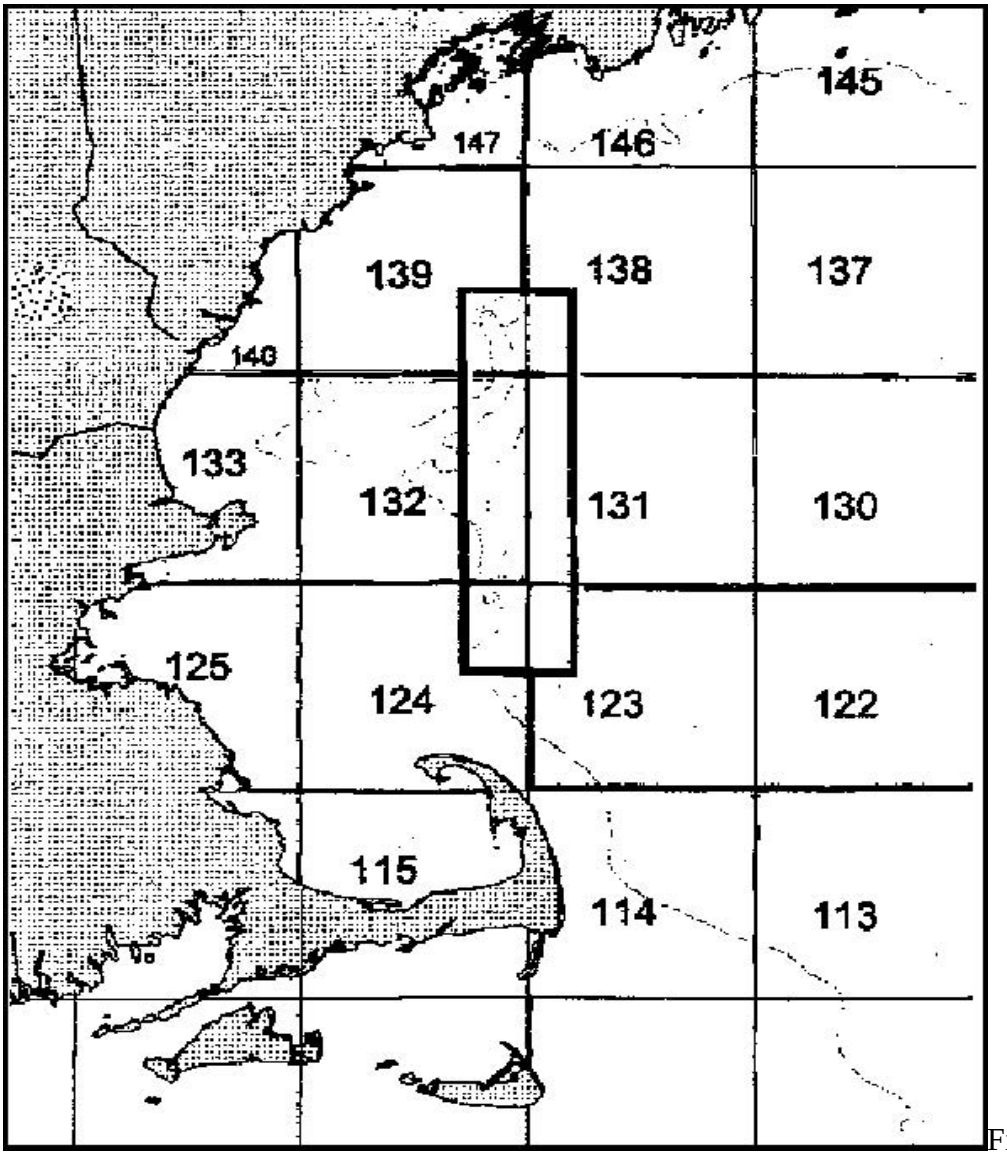


Figure 1. Map of 30x30 minute blocks in the western Gulf of Maine.
Areas: 140, 139, 133, 132, 125, and 124 represent the rolling closure areas.
The unnumbered rectangle represents the western Gulf of Maine year-round closure.

MATERIALS AND METHODS

Site and Vessel Selection

To examine Atlantic cod, *Gadus morhua*, movement in and among the western Gulf of Maine rolling closures, six areas were chosen to direct tagging effort (Areas: 140, 139, 133, 132, 125, and 124). These six areas are 30x30 minute blocks that lie of the coasts of Maine, New Hampshire, and Massachusetts ranging from 43° 30'N to 42° 00'N and 71° 00'W to 70° 00'W (Fig. 1). These areas were selected not only because they represent the six western Gulf of Maine rolling closures, but also because they represent the major fishing grounds of the New England inshore groundfish fleet and are prime spawning grounds for many groundfish stocks (Bigelow and Schroeder 2002; Colton et. al. 1979). Initially, tagging was to be conducted in all six blocks. However, two of the blocks, areas 140 and 125 were omitted because the substrate in these areas was not accessible to mobile fishing gear.

Sampling rolling closures presents a problem when an area becomes closed in that, by definition, there now exists a lack of fisheries dependent data. Because of this, a sampling regime was generated to ensure that an area would be sampled both when it was closed to fishing and when it was open. This sampling regime is shown in Table 1.

This study was conducted in cooperation with the New England commercial fishing industry. Five fishermen were contracted to take part in this study for the use of their vessels and fishing knowledge to aid in locating and tagging fish. The five vessels

were the *F/V North Star* out of Portland, Maine, the *F/V Ellen Diane* and *F/V Stormy Weather* out of Hampton, New Hampshire, the *F/V Lisa Ann* out of Newburyport, Massachusetts, and the *F/V Captain Dutch* out of Gloucester, Massachusetts. All vessels are small (<20m) inshore trawlers.

Capture and Tagging Methods

Tagging was performed aboard commercial fishing boats. Each boat was equipped with an otter trawl using standard 15.24cm (6 inch) mesh netting. Fishermen utilized their experience and knowledge of the fishing grounds to locate fish. Once located, fish were collected by making short tows (15-30 minutes) with the otter trawl in as shallow water as possible (30-100m or 15-50 fathoms). Upon completion of a tow, gear was retrieved as slowly as possible from the bottom. Conducting short tows in shallow water and retrieving the gear slowly was done to minimize stress and ultimately the mortality rate of the fish.

Once aboard, fish that were to be tagged were placed into a tank with re-circulating seawater. All other species were returned to the sea as quickly as possible. The primary species to be tagged was Atlantic cod (*Gadus morhua*), but also included haddock (*Melanogrammus aeglefinus*), pollock (*Pollachius virens*), plaice (*Hippoglossoides platessoides*), yellowtail flounder (*Limanda ferruginea*), and wolffish (*Anarhichas lupus*). Fish were placed on a measuring board and measured to the nearest centimeter. A 7 cm Floy T-bar tag was inserted with a tagging gun, into the musculature at the base of the first dorsal fin. The tag was bright yellow in color and included a tag

identification number and a telephone number to call when the fish was recaptured. Once tagged, the fish was placed headfirst back into the water. The time it took to tag a fish and return it to the ocean was less than 30 seconds.

The coordinates of the tows were recorded using Loran C bearings. The date of the trip, as well as the start time, stop time, area, and depth of the tow were also recorded. Data on the size of the fish, tag number, and reproductive condition were recorded on waterproof paper for future analyses.

For these data to be accurate and reliable, several assumptions must be met. The first assumption is that once a fish is tagged and released it mixes randomly with untagged fish, and that both tagged and untagged fish have the same chance of being captured. In this study there were several instances in which fish that were recently tagged were recaptured with untagged fish in successive tows within the same day. This observation suggests that tagged fish mix back into the population and have an equal chance of being recaptured with un-tagged fish. The second assumption is that a tagged fish can be recognized upon recapture. The tags we used were bright yellow in color and were placed in the same spot on the fish each time. While some fishermen have said the yellow tags blended into the yellowness of the fish, we feel that bright yellow color of the tag would still be recognized the majority of the time.

The third assumption is that tags are not lost at any point during the study. The tags used in the study were Floy™ T-bar anchor tags. While tag retention rates were not examined in this study, several other studies have addressed the issue of tag retention.

Muoneke (1992) evaluated tag retention using a double-tagging method, with Floy™ anchor tags, on white bass and found there to be a 75% retention rate for fish at liberty up to 560 days. Bulak (1983) found that Floy™ anchor tags had a retention rate of 99% on blueback herring. Tagging with Floy™ anchor tags on lake whitefish gave a retention rate of 81% for fish at large three years (Ebener and Copes 1982). With Atlantic cod, tag retention of anchor tags was estimated to be around 90% for fish at large for one year (Ottera et al. 1998).

The fourth assumption is that tagging does not affect mortality of the fish and does not make them more conspicuous to predators. While the mortality rate was not examined in this study, observation of post-tagging behavior of cod suggested that mortality was minimal. The majority of the fish that were tagged swam straight for the bottom as soon as they were released back into the water. Other times, fish that appeared more sluggish after tagging, swam on the surface for a short time (5-15 minutes) before swimming towards the bottom. Occasionally, fish were observed either swimming on their side, or floating motionless. These fish were considered to be deceased, however this occurrence was very rare. Based on observation alone, mortality was estimated to be less than 10%. The final assumption is that tagging does not alter the behavior of the animal. During the course of the study, tagged fish were recaptured with untagged fish. This suggests that cod assume normal behavior after being tagged.

Industry Awareness

In order to ensure a high rate of tag return, several steps were taken to make the commercial and recreational fishing industries aware of the project. The first was the creation of a cod-tagging website (http://marine.unh.edu/codtagging), which gave background information on the project, instructions on what to report when a tag was recaptured, and also displayed updates on the status of the project. The main function of the website was to report the recapture information back to the industry. Once a tag was called in, information on the release location and length at release was posted on the website so that fisherman could see when the fish was originally tagged.

Other steps to increase industry awareness came with the creation of a codtagging poster that contained a picture of a tagged cod, a brief description of the project, and information on where to report a tag return. The poster was distributed at fishermen's co-ops in Maine, New Hampshire, and Massachusetts. Finally, an advertisement was run in "Commercial Fisheries News" which is a monthly publication distributed to the commercial fishing industry.

General Tagging Statistics

Tag returns were anticipated to come from a variety of groups including commercial and recreational fishermen. Because of this, the quality of the data from the tag returns was also expected to vary. When a tag return was reported, the tag number,

date of capture, and the position of recapture were requested. This information varied from exact locations with complete coordinates, using such systems as Latitude/Longitude and Loran C, to approximate locations such as, “30 miles east of Portsmouth, NH”. Finally any additional information such as length of fish at recapture, depth of recapture, reproductive condition, and substrate type was recorded when available. Release information about the fish was given to the person who called in a tag return if such information was desired.

Data from the release information and tag returns were then complied into a Microsoft Excel™ worksheet. From this, information on total number of fish tagged and total number recaptured was obtained. Information on the number of research trips conducted per month in each area was also obtained. A histogram of days at large was created and linear regressions were run to examine the relationships between days at large, distance traveled, and total length of the fish.

Migration Statistics

Migration patterns were analyzed using only the most complete tag return data available, which included complete position data and accurate date of recapture. The first step in analyzing tag returns was to make sure all position data used the same coordinate system. This was achieved by using a program known as POSAID2™ to convert all positions into Latitude and Longitude coordinates. Straight-line distance traveled and bearing, measured as degrees from true north, was then obtained by plotting the release

and recapture position into a Maptech® digital Chartkit 2001 software program. With this information, velocity, mean-vector angle, and dispersion rates were calculated.

Velocity

North/South and East/West velocity was calculated using the equations from Saila and Flowers (1968). Velocity measures the rate and direction of travel over time.

North/South Velocity (km/day)

$$V = \frac{\sum rCos\theta}{\sum t}$$

East/West Velocity

$$V' = \frac{\sum rSin\theta}{\sum t}$$

V = North/South velocity
V' = East/West velocity
r = Straight line distance
Cosθ = Cosine of the direction (radians) of travel
Sinθ =Sine of the direction (radians) of travel
t = time (days)

Mean Angle of Travel (Zar 1999)

Mean angle of travel is calculated by a series of equations which take into account all the individual vector angles in the population. From this information, a mean direction of travel is calculated for the population. It is not measured by simply taking the mean of all the angles.

$$X = \frac{\sum Cos\theta}{n} \qquad Y = \frac{\sum Sin\theta}{n}$$

$$R = \sqrt{X^2 + Y^2}$$

$$\cos\bar{\theta} = \frac{X}{R} \qquad \sin\bar{\theta} = \frac{Y}{R}$$

Cosθ = Cosine of the direction (radians) of travel
Sinθ =Sine of the direction (radians) of travel
n = sample size (number of individual angles)

Angular Deviation (Zar 1999)

Angular deviation is a measure of how much variation there is in the population from the calculated mean angle of travel. A high angular deviation suggests the population is highly dispersed around the mean angle. A low angular deviation suggests that the population is concentrated around the mean angle of travel.

$$s = \frac{180}{\pi} \times \sqrt{2(1-r)}$$

s = Angular deviation
r = Straight line distance

Dispersion (Saila and Flowers 1968)

Dispersion takes into account the total area traveled away from the release site per day. It is measured as area traveled (km^2) per day.

$$a^2 = \frac{1}{n}\left[\sum \frac{r^2}{t} - \frac{\left(\sum r\cos\theta\right)^2}{\sum t}\right]$$

a^2 = km^2/day
n= sample size (number of recaptures)
t = time (days)
r = Straight line distance
rCosθ = Distance X Cosine of the direction (radians) of travel

Rayleigh Test (Saila and Flowers 1968)

Rayleigh's test is a test for directionally within a set of vectors. The test calculates a z-statistic which if significant, suggests that the movement patterns observed is non-random (directional). If the z-statistic is insignificant, then movement is random in nature.

$$R = \sqrt{\left(\sum Sin\theta\right)^2 + \left(\sum Cos\theta\right)^2}$$

$$\text{Z-statistic } z = \frac{R^2}{n}$$

Cosθ = Cosine of the direction (radians) of travel
Sinθ =Sine of the direction (radians) of travel
n = sample size

Mapping

Tag returns were grouped by month and area of release and mapped using ArcView 3.2.

Catch per Unit Effort Statistics

To determine changes in the abundance of Atlantic cod in the western Gulf of Maine over time, catch per unit effort was calculated for each tow conducted. Catch per unit effort was calculated by dividing the total weight of cod caught (kilograms) by the total fishing effort (hours of trawl). Since fish were not weighed, weight had to be estimated from length-weight relationship using the following equation (SAW 33):

$$\ln Weight(kg) = -11.7231 + 3.0521 \times \ln Length(cm)$$

Catch per unit effort values were plotted for each area over time and for each month over all the areas sampled. To look for significant differences in catch per unit effort, normality was first tested using a one-sample Kolmogorov-Smirnov test. If data were found to be nonparametric, it was rank transformed (Conover and Iman 1981). Next, analyses of variance were conducted on the transformed data. If a significant p-value was obtained ($p < 0.05$), then a Tukey's test was preformed to determine where the differences were.

Evaluation of the western Gulf of Maine rolling closures

To evaluate the effectiveness of the western Gulf of Maine rolling closures as a management tool, migration data and CPUE. data were combined. The timings of the individual rolling closure areas were compared to movement of Atlantic cod in and out of that area as well as the change in CPUE. for that area in a given month. For the rolling closures to be effective, the following hypotheses were proposed: 1) They must be accurate with respect to the timings of cod movements. The areas should be closed once fish arrive in an area and reopened once fish disperse from an area, and 2) They must be accurate with respect to seasonal changes in biomass in an area. Areas should be closed when biomass is especially high (e.g. spawning) and reopened when biomass levels decrease (e.g. post-spawning).

Length Statistics

In order to examine changes in fish length over time and between areas, length-frequency histograms were generated. Since the sex of the fish was not determined, with the exception of when they were spawning, length frequencies represented both males and females. Length-frequency histograms were created for each area sampled each month using Microsoft Excel™.

Data were first analyzed by area, by examining changes in mean length over all the months sampled. First normality was tested using a one-sample Kolmogorov-

Smirnov test. If the data were normally distributed, analyses of variance tests were conducted to determine if a significant difference existed between all months sampled. If a significant difference existed ($p < 0.05$), then a Tukey's test was preformed to determine specifically where these differences were. Data were also analyzed for between area differences within a given month using the same techniques.

Reproductive Statistics

Spawning Atlantic cod were encountered in the spring of 2001 and 2002 and winter 2001/2002. During these times it was possible to determine the sex of the fish by observing if they spawned eggs or milt when slight pressure was applied to the abdomen. This information combined with the length data, made it was possible to examine differences in the sizes of male and female cod during the spawning seasons. To analyze differences in length, an analysis of variance and Tukey's test were once again used. First, the three spawning seasons, spring 2001, winter 2001/2002, and spring 2002 were compared to each other for males and females, as well as both sexes combined. Next, male mean length was compared to female mean length for each of the three spawning seasons. Finally length-frequency histograms were generated for each sex for each spawning season.

RESULTS

General Tagging Statistics

A total of 20,128 fish were tagged on 91 dedicated tagging trips conducted between February 2001 and June 2002 in the western Gulf of Maine. Of these, 17,860 were the targeted species, Atlantic cod. The remaining fish were of species that were opportunistically caught and tagged as time permitted. These included such species as haddock, pollock, wolffish, American plaice, and yellowtail flounder. There were a total of 1,148 tag recaptures obtained between March 2001 and October 2002. Of the Atlantic cod tagged, 1,086 (6.08%) were recaptured in this time period. Table 1 illustrates the research trips conducted, number of Atlantic cod tagged, and the number of Atlantic cod recaptured per month and area sampled. Table 2 provides the number tagged and number recaptured for all the non-target species encountered.

Since Atlantic cod were the primary focus of this study and provided the most recaptures, only data from the analyses of cod returns will be presented. A histogram of days at large for Atlantic cod recaptured was generated (Fig. 2) to show the change days at large over time. The histogram demonstrates that days at large decreases exponentially over time, with the majority of the recaptures coming within the first month after initial release. There is however, a small spike in recaptures occurring 1-year after release.

Next, the relationship between distance traveled and days at large, and length of fish and days at large was examined. Figure 3 provides the linear regression plot of

distance traveled vs. days at large. A p-value of 0.00 suggests that there is a significant relationship between the two. However, an R^2 value of 0.06 suggests that there is not a strong relationship between distance traveled and days at large. Figure 4 provides the linear regression plot of length of fish vs. days at large. A p-value of 0.00 suggests that there is a significant relationship between the two. However, an R^2 value of 0.03 suggests that there is not a strong relationship between the length of the fish and days at large. Finally a linear regression of the relationship between the length of the fish and distance traveled was performed (Fig. 5). A p-value of 0.41 suggests that there is not a significant relationship between the two.

Month	Research Trips Conducted				Total # Atlantic cod Tagged				Total # Atlantic cod Recaptured			
	Area				Area				Area			
	124	132	133	139	124	132	133	139	124	132	133	139
Feb-01	1	0	0	0	212	0	0	0	11	0	0	0
Mar-01	0	2	1	1	0	82	6	2	0	5	1	0
Apr-01	1	1	4	1	636	72	2277	0	54	9	177	0
May-01	2	5	7	2	569	831	4572	233	45	69	449	8
Jun-01	1	3	3	3	14	399	257	189	0	52	22	5
Jul-01	1	1	2	2	183	105	39	19	5	5	1	0
Aug-01	0	1	1	2	0	116	8	4	0	7	0	0
Sep-01	0	1	0	0	0	73	0	0	0	1	0	0
Oct-01	0	1	1	2	0	440	11	6	0	8	0	0
Nov-01	1	1	1	0	365	350	178	0	4	7	15	0
Dec-01	0	0	1	1	0	0	305	7	0	0	9	0
Jan-02	0	1	2	0	0	136	482	0	0	9	22	0
Feb-02	0	1	1	0	0	52	160	0	0	0	4	0
Mar-02	0	1	1	1	0	12	59	2	0	1	3	0
Apr-02	0	2	2	2	0	589	556	17	0	12	13	0
May-02	1	5	5	3	288	492	1700	379	5	8	29	3
Jun-02	0	1	1	3	0	104	110	162	0	0	4	4
Total	**8**	**27**	**33**	**23**	**2267**	**3853**	**10720**	**1020**	**124**	**193**	**749**	**20**

Table 1. Total number of research trips conducted, Atlantic cod tagged, and Atlantic cod recaptured for each month and area sampled. Areas represent 30 X 30 minute blocks in the western Gulf of Maine.

Species	# Tagged	# Recaptured	% Recaptured
American Plaice			
Hippoglossoides platessoides	840	30	3.57
Grey Sole			
Glyptocephalus cynoglossus	7	0	0.00
Haddock			
Melanogrammus aeglefinus	1138	8	0.70
Pollock			
Pollachius virens	79	7	8.86
Winter Flounder			
Pseudopleuronectes americanus	12	0	0.00
Wolffish			
Anarhichas lupus	41	6	14.63
Yellowtail Flounder			
Limanda ferruginea	28	3	10.71

Table 2. Number tagged, recaptured, and percent recaptured for the major non-target species encountered in this study.

Figure 2. Histogram of Atlantic cod days at large for fish tagged in the western Gulf of Maine rolling closures

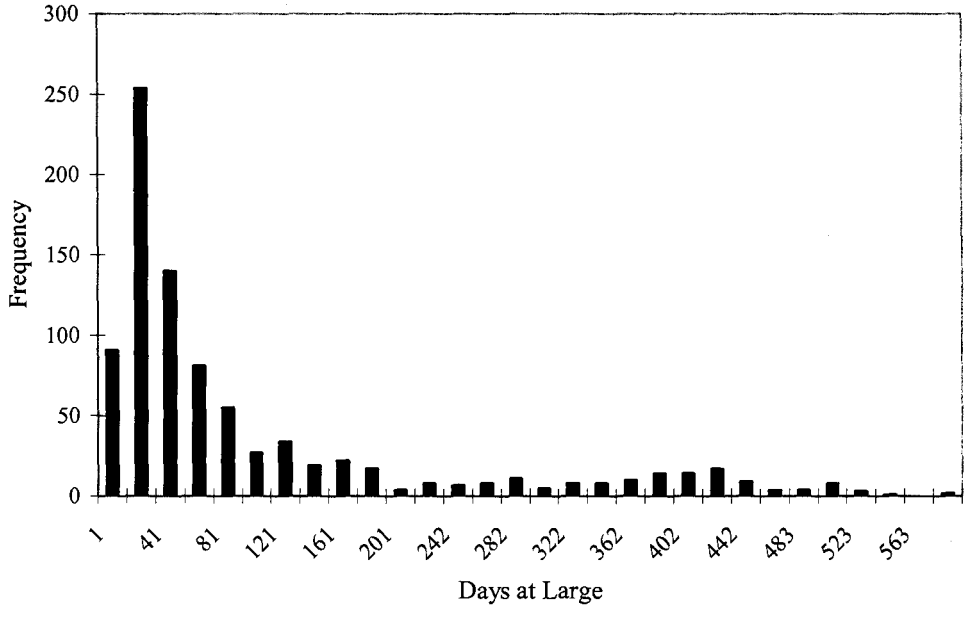


Figure 3. Days at large vs. distance traveled of Atlantic cod tagged in the western Gulf of Maine

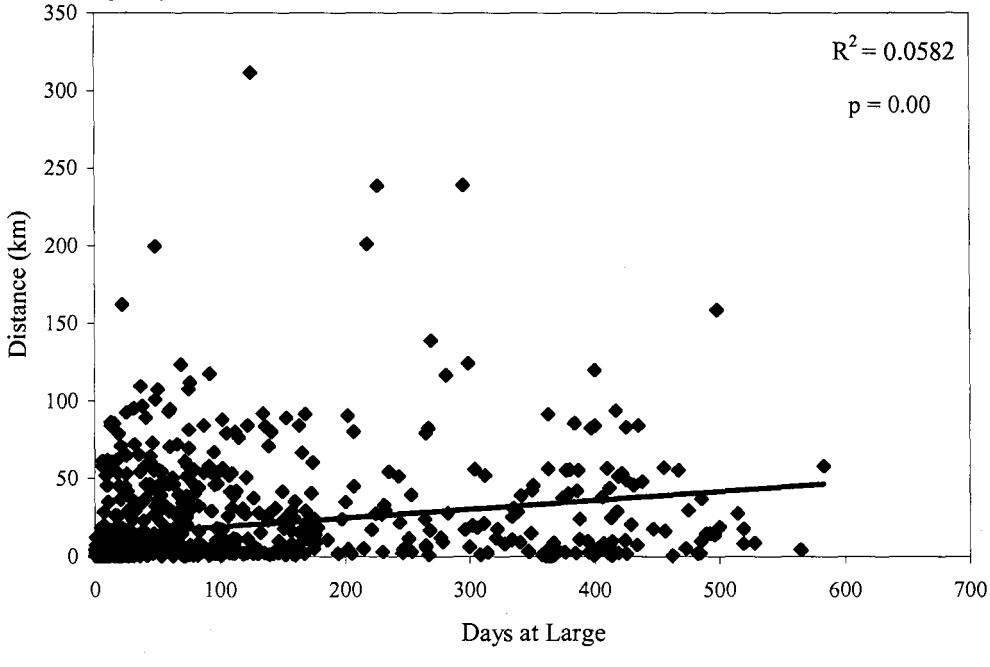


Figure 4. Days at large vs. total length for Atlantic cod tagged in the western Gulf of Maine

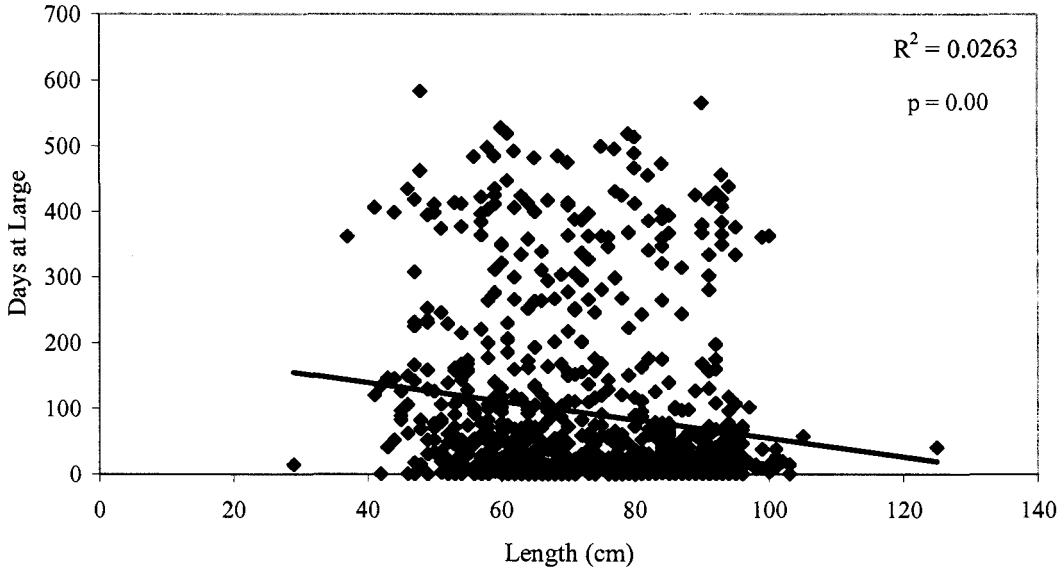
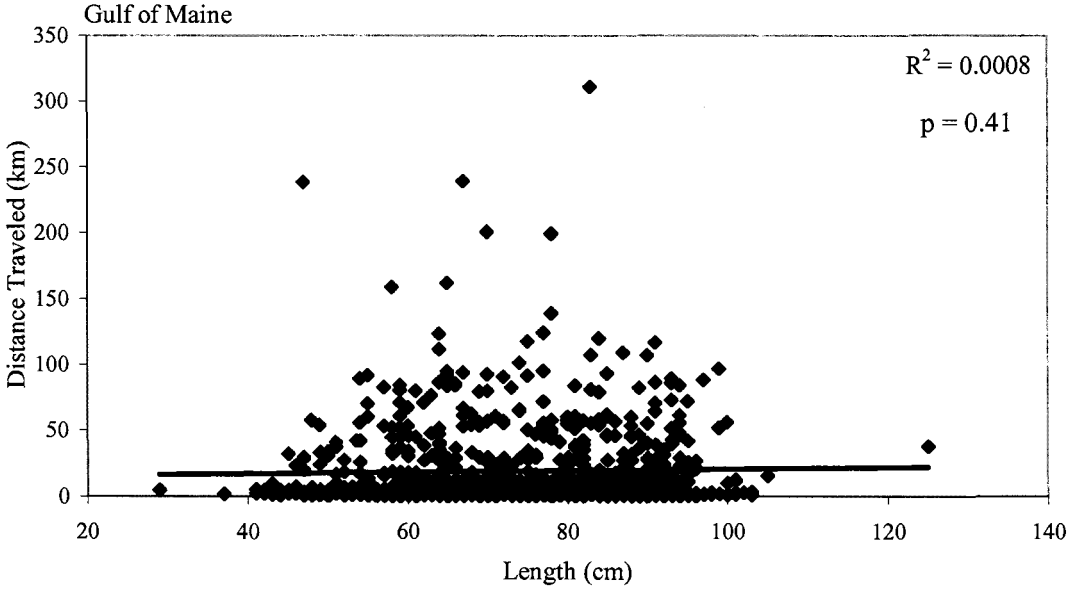


Figure 5. Distance traveled vs. total length of Atlantic cod tagged in the western Gulf of Maine



Migration Statistics

To examine the movement patterns of Atlantic cod in and among the western Gulf of Maine rolling closures, tag returns were grouped and analyzed by month and area of release. Groups with fewer than 5 recaptures were not included in the analyses, but in some cases, groups with 3-4 recaptures were plotted to provide anecdotal information on cod movement. Tag returns were first analyzed on a large scale, e.g. all tag returns from a release group were included in the analyses regardless of month of recapture. In cases where a release group included a large number of tag returns (40+), analyses were then conducted on a smaller scale, e.g. analyzed by grouping all the returns from a release group into smaller sub-groups based on month of recapture.

Overall Migration Statistics

Area 124

Monthly migration statistics for Atlantic cod tagged in area 124 are provided in Table 3. Some months were omitted from the analyses due to low numbers of returns. Overall, 2,267 cod were tagged in area 124 with 93 (4.10%) being recaptured. Tagging within five of the months sampled provided at least the minimum number of tag returns to perform the analyses. The mark and recapture data for February 2001 and April 2001

(Figures 6a and 6b) suggest that there is primarily a southeastern movement of fish from the point of release. The majority of the tag returns came from areas 124 and 125, with a small number of recaptures coming from areas 132 and 133.

Figures 7a and 7b show the recapture locations for cod tagged in May 2001 and July 2001, respectively. Recaptures from tagging in these two months were mostly obtained south of their point of release in area 124. In May 2001, recaptures were located southeast of their release point, where as in July 2001, recaptures were located southwest of their release point. There was also a small group of tag returns from May 2001 that moved northeast into area 132.

Fish tagged in November 2001 did not produce enough returns to perform the various migration analyses, however, enough returns were obtained to generate a map of recapture locations. Cod tagged in this month moved in a southeastern direction (Fig 8). Finally in May 2002 (Fig 9), all cod were recaptured close to their point of release.

	Month Released				
	Feb-01	Apr-01	May-01	Jul-01	May-02
Number Released	212	636	569	183	288
Number Recaptured	7	37	34	5	5
% Recaptured	3.30	5.82	5.98	2.73	1.74
Average Days at Large	259 ± 211	92 ± 140	122 ± 175	220 ± 117	26 ± 26
Average Distance Traveled (km)	37.5 ± 15	19 ± 42	12 ± 27	12 ± 7	3.6 ± 1
North/South Velocity (km/day)	0.02 S	0.03 S	0.02 S	0.01 N	0.06 N
East/West Velocity (km/day)	0.01 E	0.09 E	0.04 E	0.02 W	0.06 W
Mean Angle	192°	273°	34°	278°	308°
Angular Deviation	72°	70°	74°	62°	52°
Dispersion (km^2/day)	10.2	15.2	17.7	1.2	0.94
Rayleigh Test Z(calculated)*	0.14	2.41	0.87	0.85	1.76

Table 3. Migration statistics for Atlantic cod tagged in area 124. Some months were omitted due to low numbers of returns. Average days at large and average distance traveled include standard deviation. *Rayleigh Test denoted with an asterisks represent a significant value ($p < 0.05$).

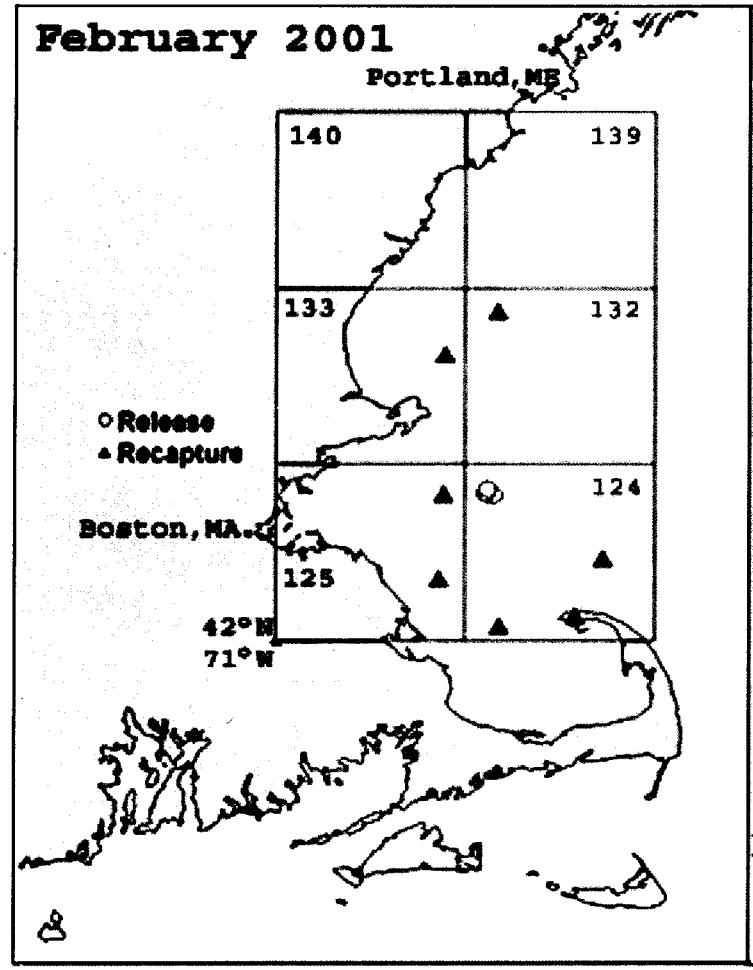


Figure 6a. Map of release and recapture locations for Atlantic cod tagged February 2001 in area 124.

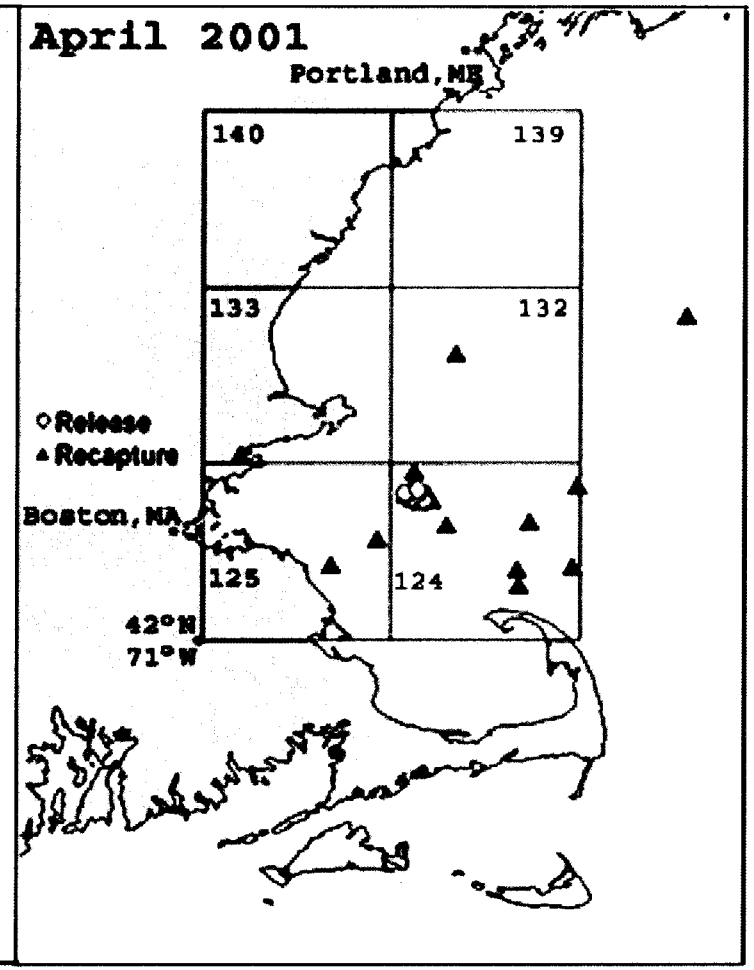


Figure 6b. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 124.

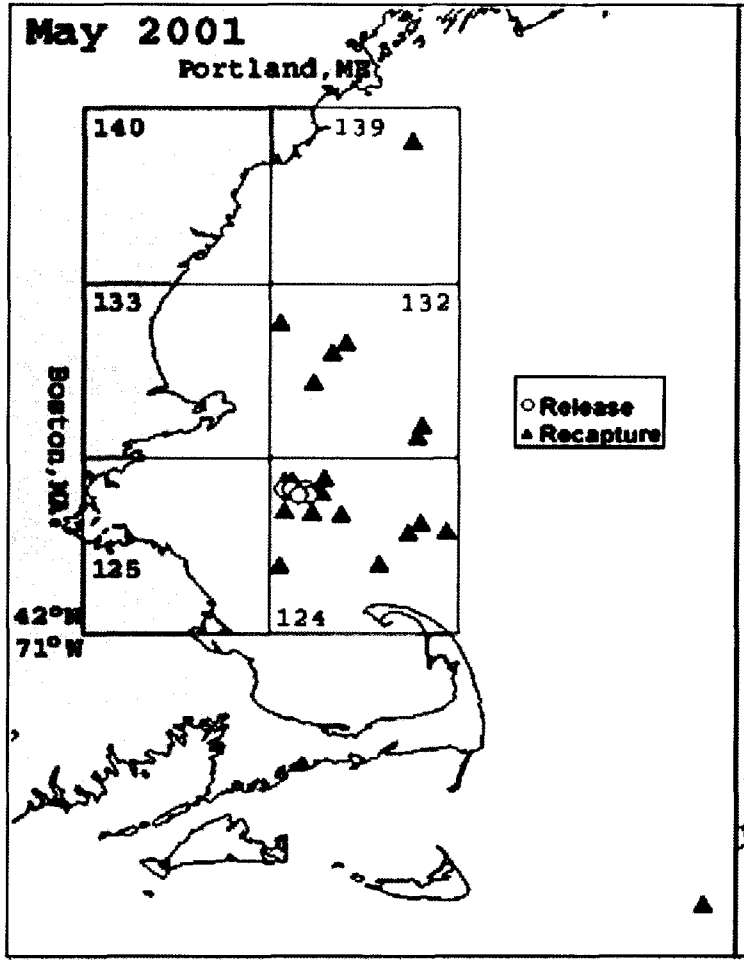


Figure 7a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 124.

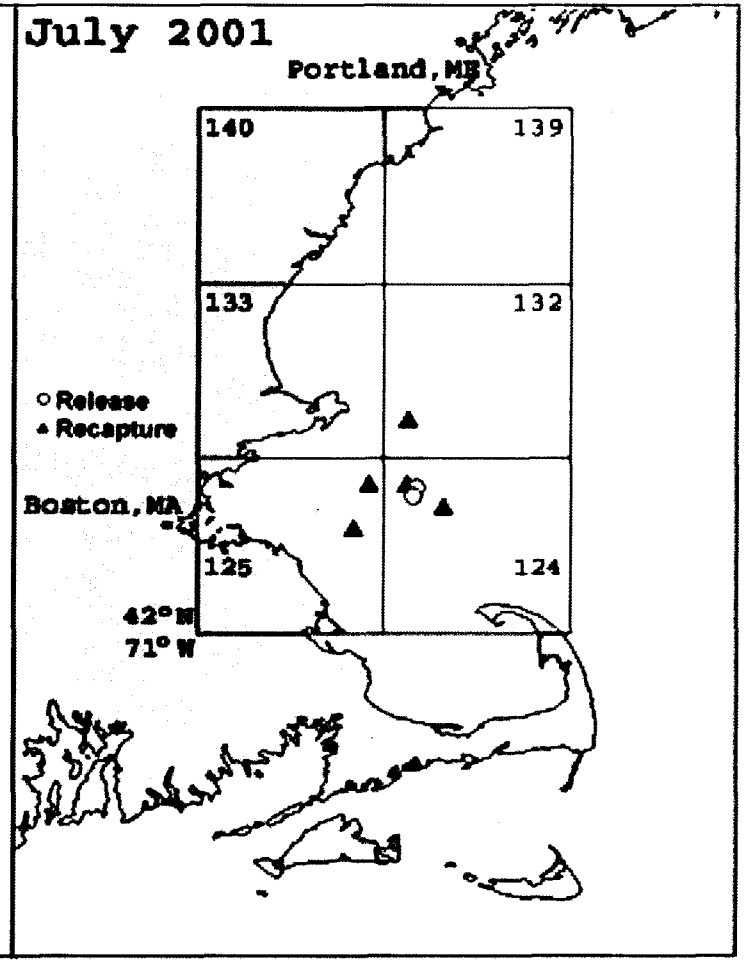


Figure 7b. Map of release and recapture locations for Atlantic cod tagged July 2001 in area 124.

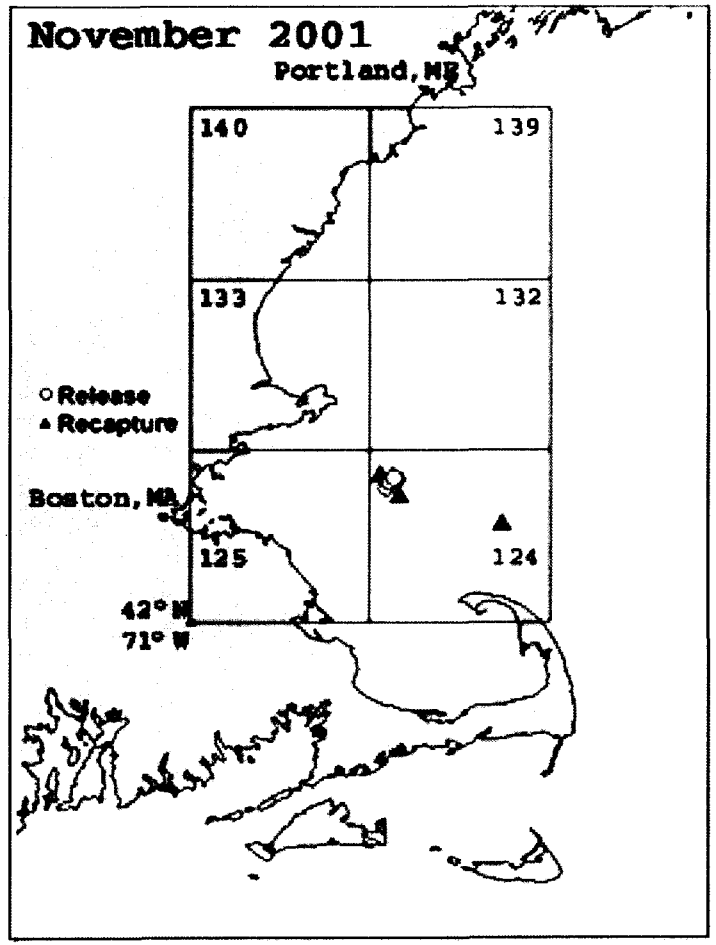


Figure 8. Map of release and recapture locations for Atlantic cod tagged November 2001 in area 124.

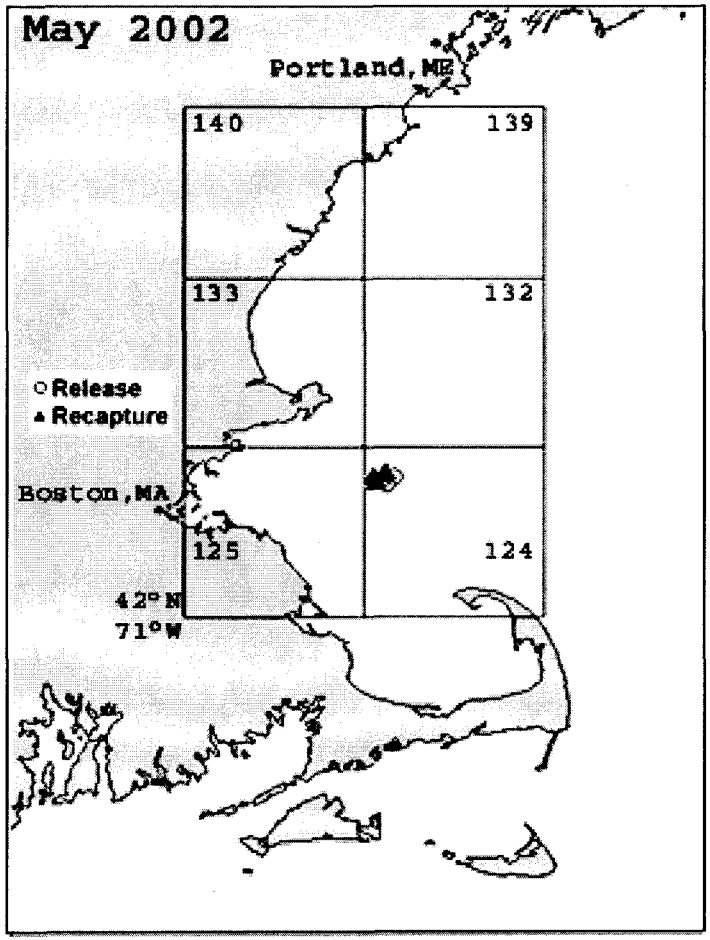


Figure 9. Map of release and recapture locations for Atlantic cod tagged May 2002 in area 124.

Area 132

Monthly migration statistics for area 132 are provided in Table 4. Overall, 3,853 Atlantic cod were tagged with 193 (5.0%) being recaptured. Some months were omitted from analyses due to low numbers of returns. Nine of the months sampled provided enough recaptures to perform the various migration analyses. Tagging in March 2001 did not net enough returns to perform the analyses, however, enough returns were obtained to generate a map (Fig. 10a), which shows that moved in a generally westerly (inshore) direction. In April 2001 (Fig. 10b) there appears to be two groups of recaptures of Atlantic cod. One group moved west (inshore) into area 133. The other group moved northeast towards area 139.

Recaptures from May 2001 tagged fish (Fig. 11a), formed three patterns of movement. One group of fish moved west (inshore) into area 133. Another group moved southeast (offshore), but stayed in area 132. The final group moved south into area 124. In June 2001 (Fig. 11b), cod recaptures displayed a westerly movement into area 133. There were also several recaptures located close to their point of release.

Atlantic cod tagged in July 2001 (Fig. 12a) were recaptured both north of their release site, but still in area 132, and south in area 124 and 125. Fish tagged in August 2001 (Fig. 12b) were recaptured west of their release site in both areas 132 and 133. In October 2001 (Fig. 13), recaptures were obtained southeast of their release location, but no tags were recaptured outside of area 132. In January 2002 (Fig. 14), recaptures were

located mostly west of their release point in area 132. One fish was recaptured east, remaining in area 132.

Returns from tagging in April 2002 (Fig. 15a) were mostly located close to their point of release. There is a small movement towards area 133. Recaptured were also located south in area 124. In May 2002 (Fig. 15b), all recaptures were located close to their release site.

	Month Released								
	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Oct-01	Jan-02	Apr-02	May-02
Number Released	72	831	399	105	116	440	136	589	492
Number Recaptured	6	64	41	5	9	5	8	17	8
% Recaptured	8.33	7.70	10.28	4.76	7.76	1.14	5.88	2.89	1.63
Average Days at Large	191 ± 187	127± 133	120 ± 117	239 ± 117	202 ± 157	149 ± 70	110 ± 106	88 ± 63	73 ± 55
Average Distance Traveled(km)	17.8 ± 14	9.4 ± 15	10.2 ± 23	22.7 ± 18	6.3 ± 9	9.8 ± 9	7.7 ± 3	7.7 ± 14	2.8 ± 4
North/South Velocity (km/day)	0.031 N	0.035 S	0.045 S	0.008 S	0.006 S	0.056 S	0.007 N	0.049 S	0.009 N
East/West Velocity (km/day)	0.13 E	0.015 W	0.006 E	0.03 W	0.022 W	0.007 W	0.034 W	0.001 W	0.101 W
Mean Angle	343°	247°	162°	317°	222°	215°	276°	201°	325°
Angular Deviation	71°	73°	58°	52°	50°	53°	51°	62°	79°
Dispersion (km^2/day)	4.01	4.2	4.6	3	0.80	0.69	4	6	0.21
Rayleigh Test Z(calc)	0.356	2.28	9.87*	1.69	3.38*	1.66	2.87	2.88	0.02

Table 4. Migration statistics for Atlantic cod tagged in area 132. Some months were omitted due to low numbers of returns. Average days at large and average distance traveled include standard deviation. *Rayleigh Test denoted with an asterisks represent a significant value.

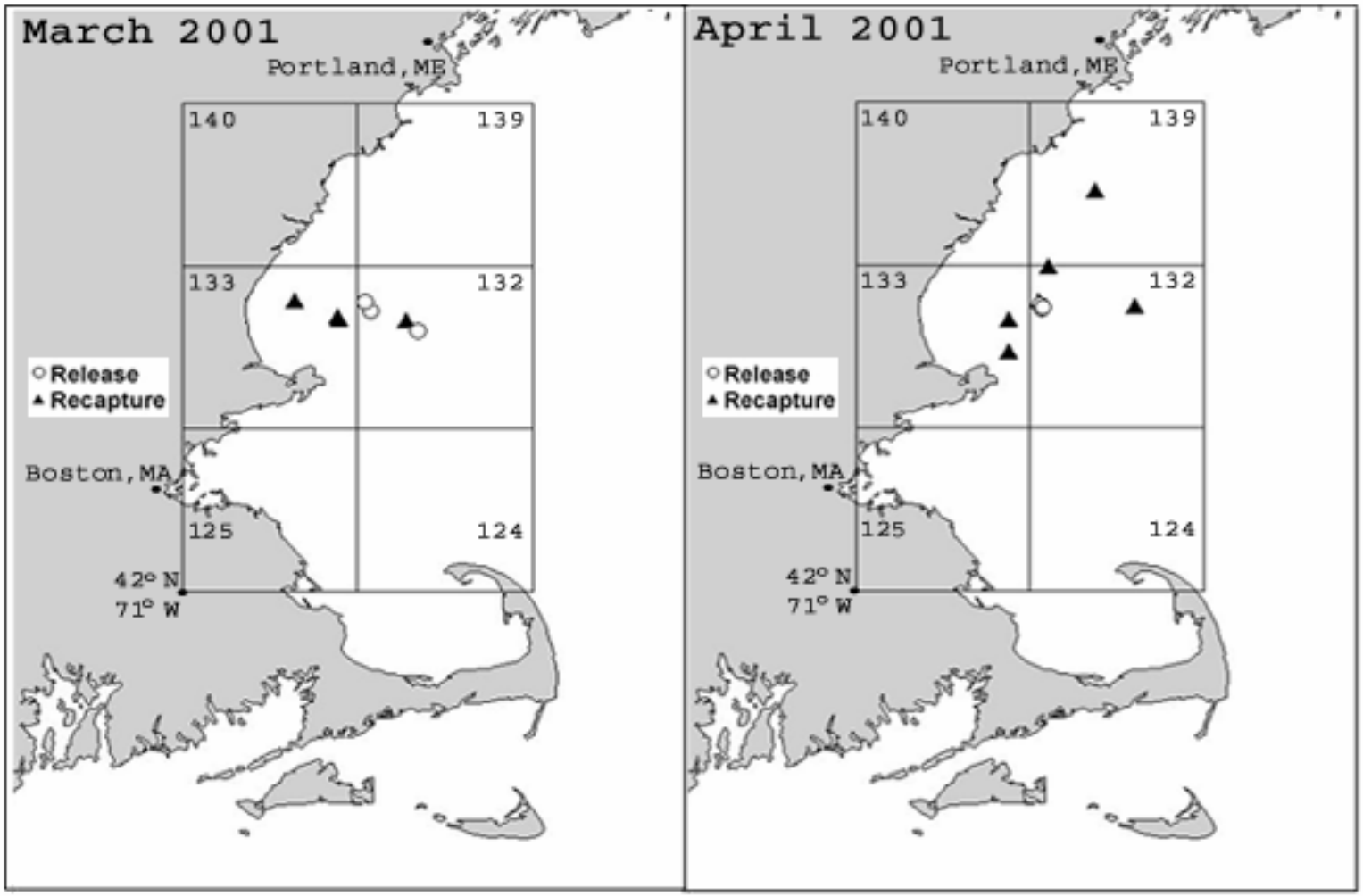


Figure 10a. Map of release and recapture locations for Atlantic cod tagged March 2001 in area 132.

Figure 10b. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 132.

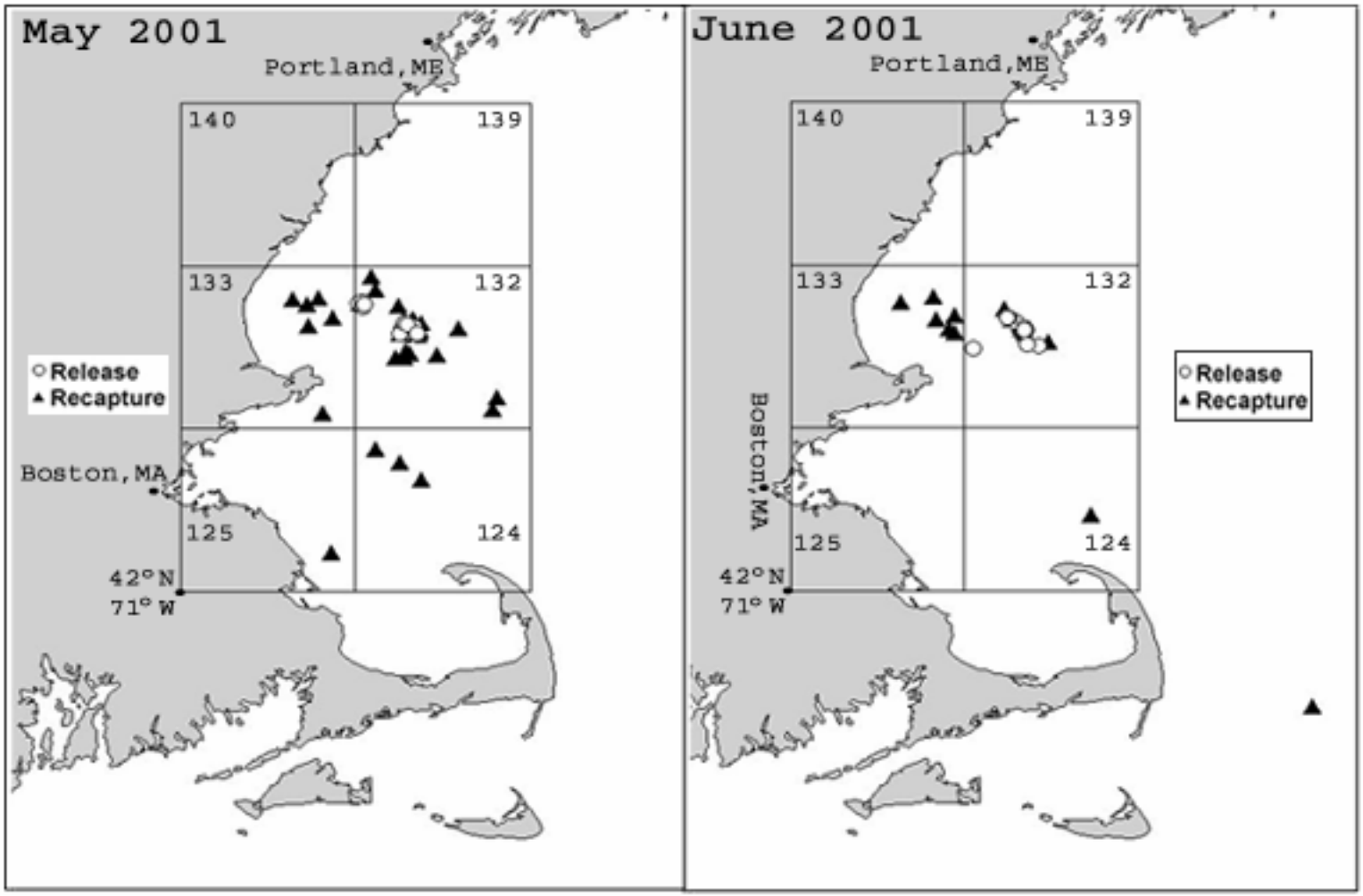


Figure 11a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 132.

Figure 11b. Map of release and recapture locations for Atlantic cod tagged June 2001 in area 132.

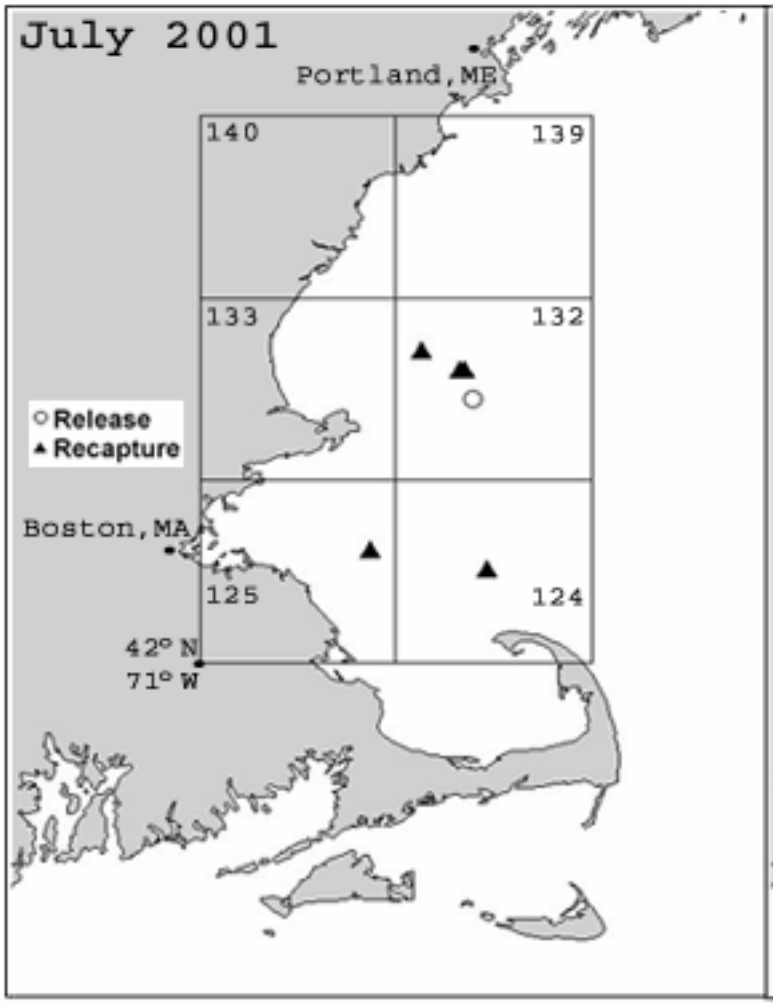


Figure 12a. Map of release and recapture locations for Atlantic cod tagged July 2001 in area 132.

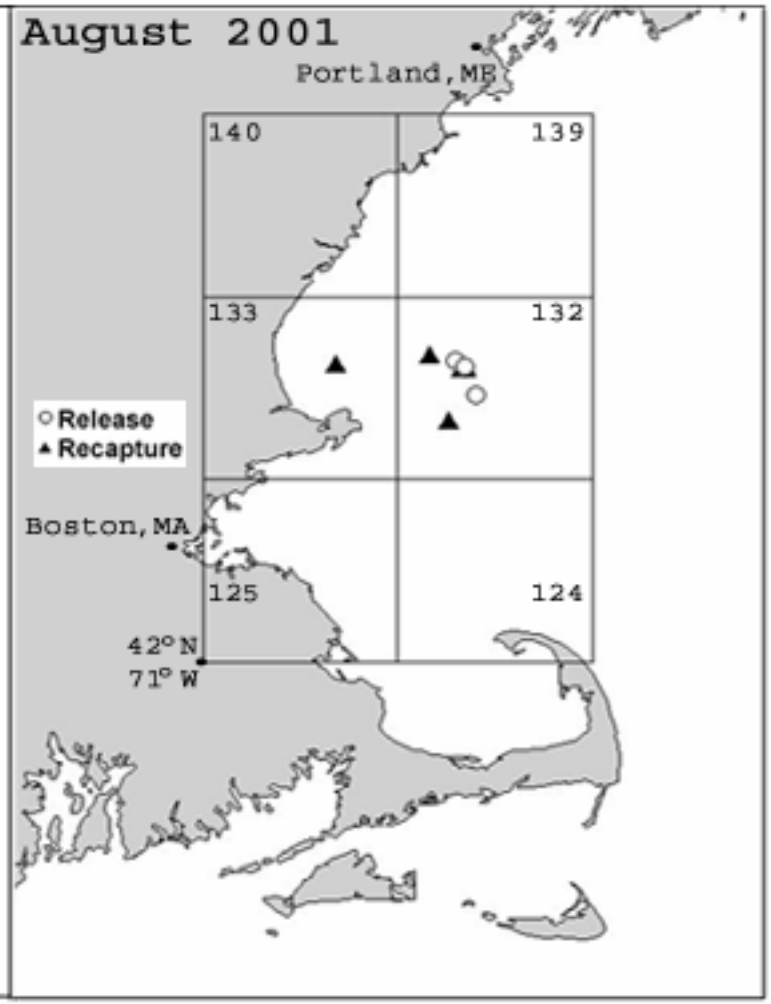


Figure 12b. Map of release and recapture locations for Atlantic cod tagged August 2001 in area 132.

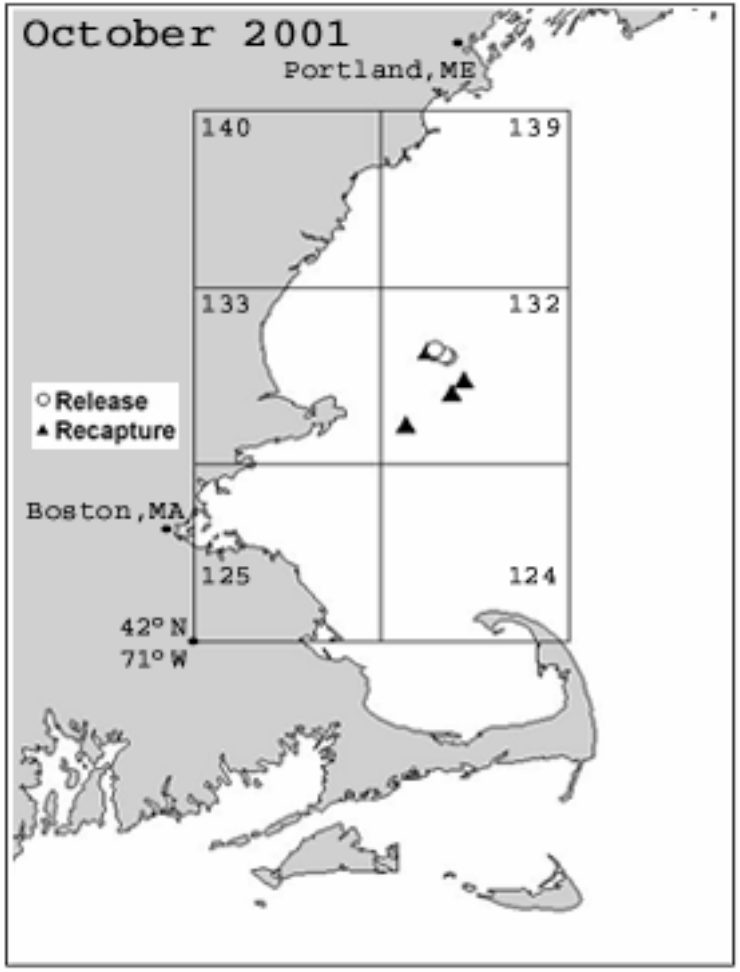


Figure 13. Map of release and recapture locations for Atlantic cod tagged October 2001 in area 132.

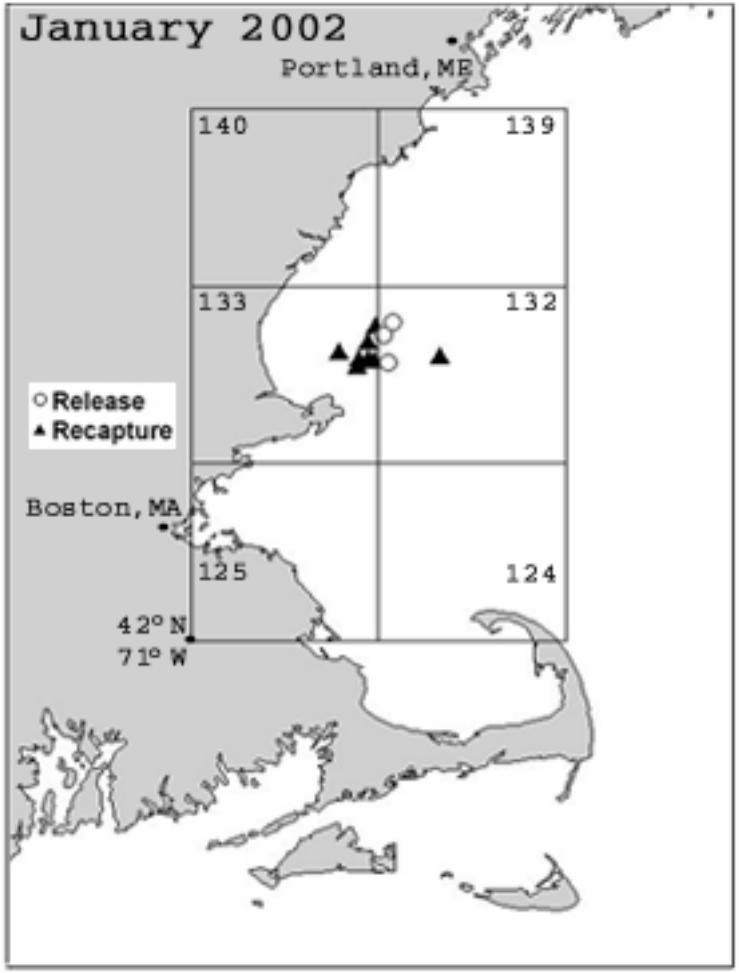


Figure 14. Map of release and recapture locations for Atlantic cod tagged January 2002 in area 132.

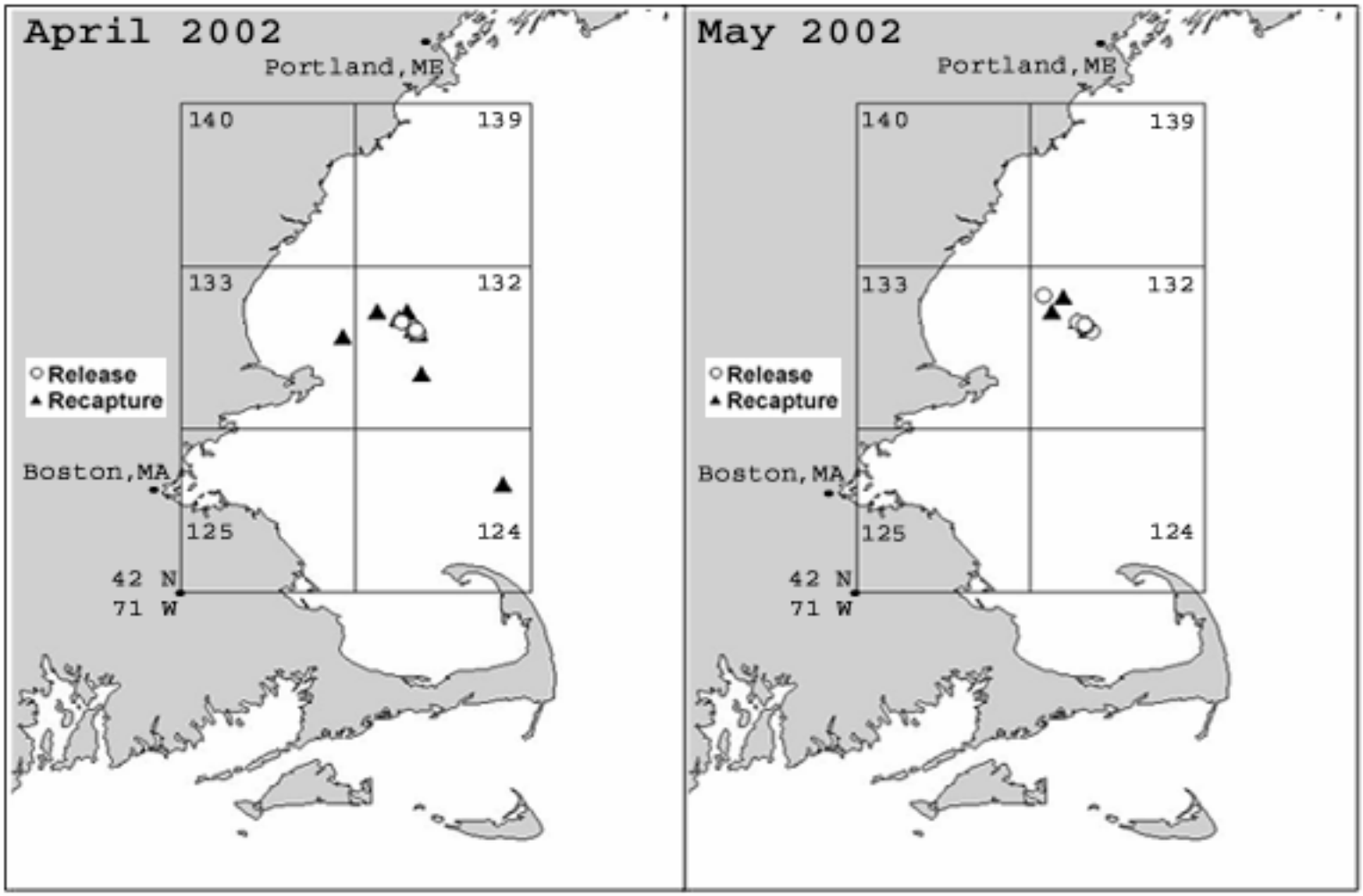


Figure 15a. Map of release and recapture locations for Atlantic cod tagged April 2002 in area 132.

Figure 15b. Map of release and recapture locations for Atlantic cod tagged May 2002 in area 132.

Area 133

Monthly migration statistics for area 133 are provided in Table 5. Overall 10,720 Atlantic cod were tagged with 749 (7%) being recaptured. Some months were omitted from analyses due to low numbers of returns. Nine of the months sampled provided sufficient tag returns to perform the various migration analyses. April 2001 and May 2001 provided the most tag returns per month/area with complete data (138 and 368 respectively). In April 2001 (Fig. 16a) there appeared to be four groups of tag returns. One group was located to the west, further inshore in area 133. Another group was located east of the release site in area 132. There was a group of fish that moved southeast, with recaptures coming from areas 124 and 125. Finally, there was a small group of recaptures located to the northeast in, and beyond, area 139. In May 2001 (Fig. 16b) we saw that the patterns of recaptures were similar to three of the patterns from April. Fish appeared to be moving east (offshore), northeast, and southeast. Also, several tag returns were located far offshore, beyond the rolling closure areas.

In June 2001, the number of tag returns decreased to 10. The net direction of movement, described in Fig. 17, was southeast, with some recaptures located close to their release location and a small group of recaptures located in area 132. The number of tag returns further decreased in the summer of 2001, to a point where very few tags were returned from July-October 2001. In November 2001, enough tag returns were once again obtained in order to properly analyze the movement data. Movement during this month was again in the southeasterly direction (Fig. 18) with the majority being recaptured in area 124.

Starting in December 2001, fish were captured closer to their release site. Fish tagged at this time (Fig 19a) were recaptured to the east in areas 132 and 133, and to the south in area 124. In January 2002 (Fig. 19b), most fish were recaptured either close to their release site in area 133, or just to the east in area 132. A couple of tag returns were located offshore to the northeast. In February 2002 (Fig. 20) tag recaptures were located offshore to the east in area 132, and to the northeast in area 139.

In April 2002 (Fig. 21a), returns were mostly located inshore, close to their release site. One fish was recaptured northeast of its release site just beyond area 139. In May 2002 (Fig. 21b), we saw that returns were located both close to their release site as well as east of their release site in area 132. Two recaptures were located to the south in area 124 and 125.

	Month Recaptured								
	Apr-01	May-01	Jun-01	Nov-01	Dec-01	Jan-02	Feb-02	Apr-02	May-02
Number Released	2277	4572	257	178	305	482	160	556	1700
Number Recaptured	138	368	10	7	9	19	5	12	27
% Recaptured	6.06	8.05	3.89	3.93	2.95	3.94	3.13	2.16	1.59
Average Days at Large	105 ±146	69 ± 122	87 ± 148	112 ± 93	130 ± 100	63 ± 92	156 ± 101	21 ± 51	48 ± 51
Average Distance Traveled (km)	20 ± 23	19.7 ± 33	13.6 ± 21	53.6 ± 40	49.7 ± 63	17.7 ± 27	24.5 ± 28	11.5 ± 27	13.7 ± 19
North/South Velocity (km/day)	0.02 S	0.11 S	0.08 S	0.41 S	0.28 S	0.01 N	0.04 N	0.35 N	0.14 S
East/West Velocity (km/day)	0.05 E	0.17 E	0.10 E	0.22 E	0.21 E	0.22 E	0.09 E	0.14 E	0.20 E
Mean Angle	164°	125°	132°	166°	131°	101°	117°	248°	112°
Angular Deviation	78°	63°	69°	42°	42°	46°	47°	49°	43°
Dispersion (km^2/day)	17.8	33.6	36.6	9.0	21.5	16.3	30.2	27.2	5.4
Rayleigh Test Z(calc)	0.98	57.3999*	0.818	3.7996*	4.842*	8.714*	2.17	4.78*	13.97*

Table 5. Migration statistics for Atlantic cod tagged in area 133. Some months were omitted due to low numbers of returns Average days at large and average distance traveled includes standard deviation. *Rayleigh Test denoted with an asterisks represent a significant value.

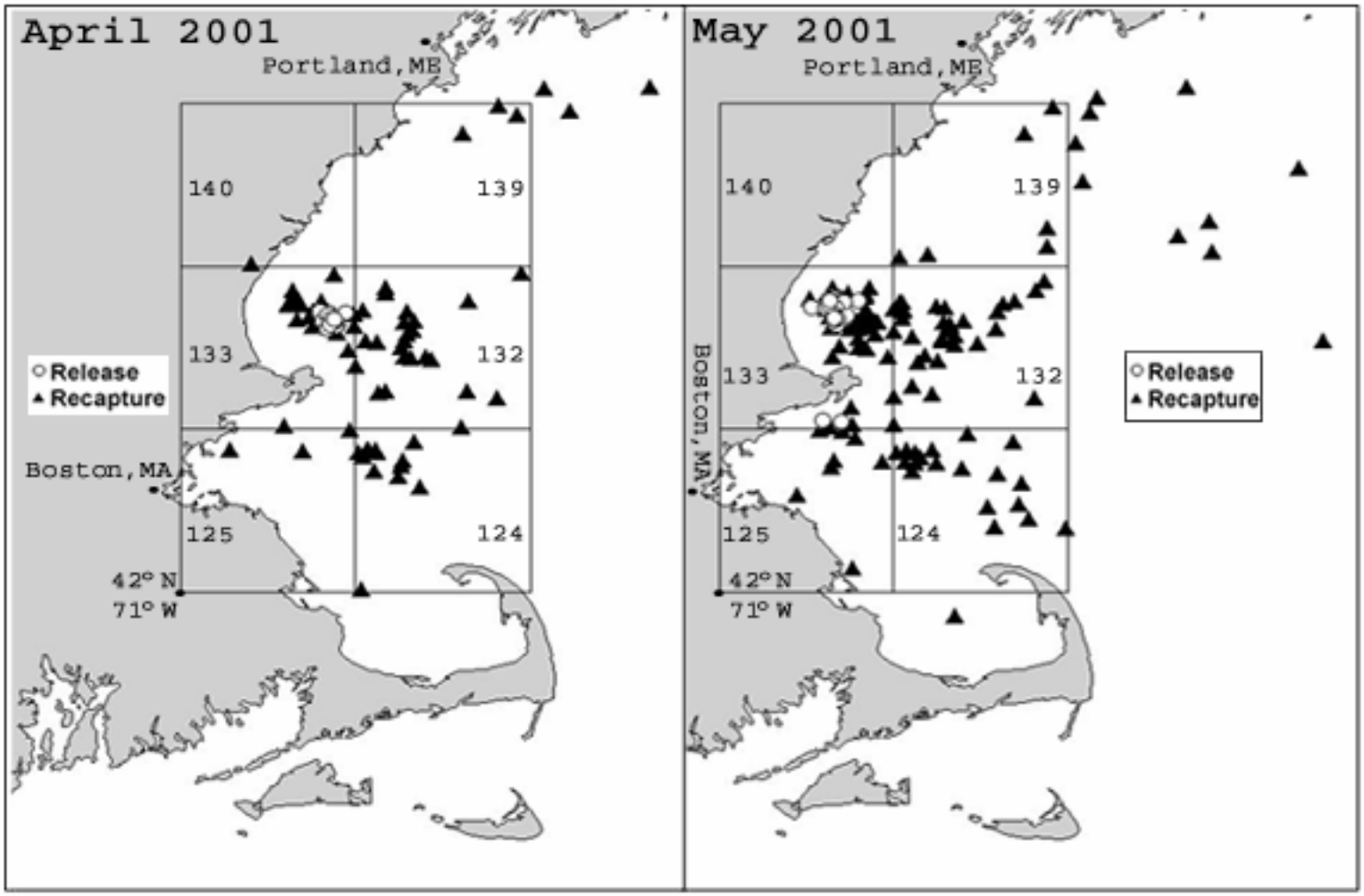


Figure 16a. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 133.

Figure 16b. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133.

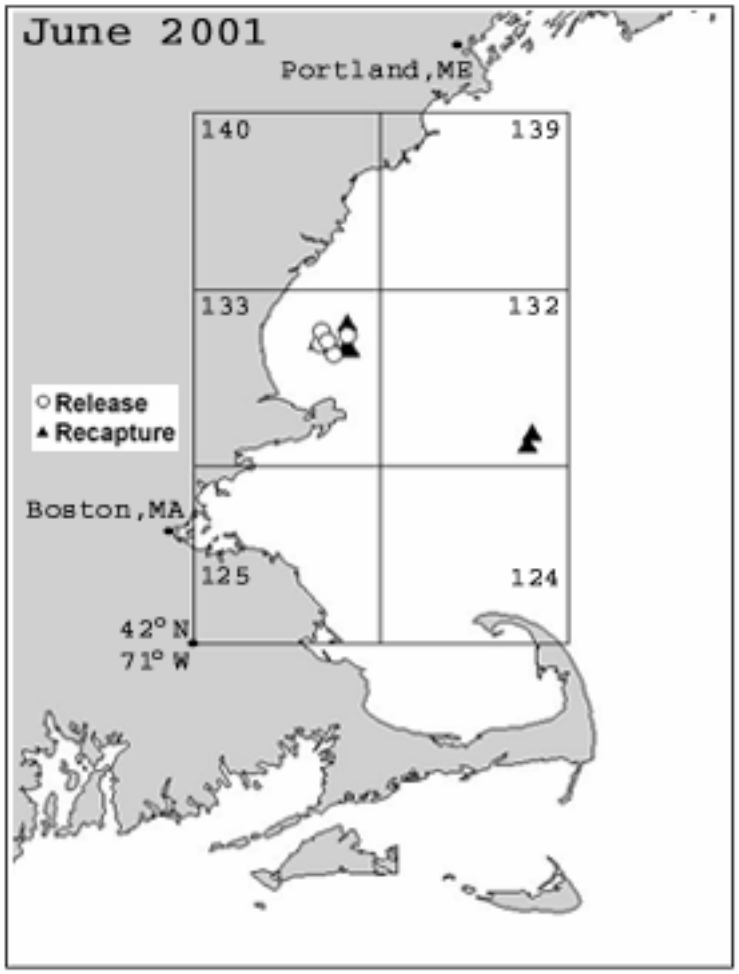


Figure 17. Map of release and recapture locations for Atlantic cod tagged June 2001 in area 133.

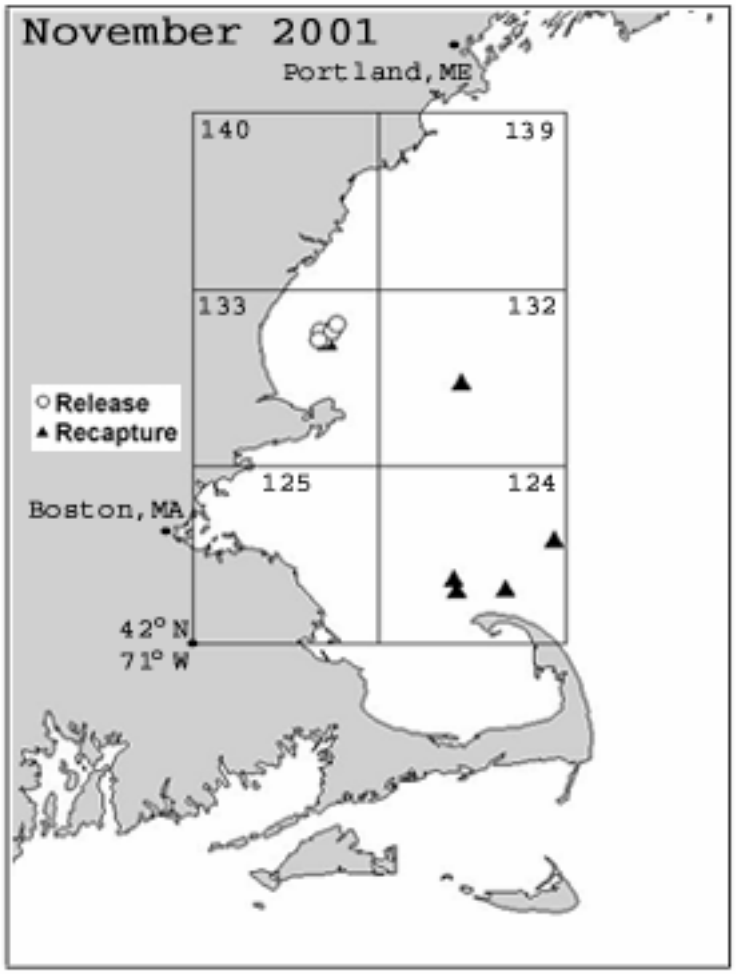


Figure 18. Map of release and recapture locations for Atlantic cod tagged November 2001 in area 133.

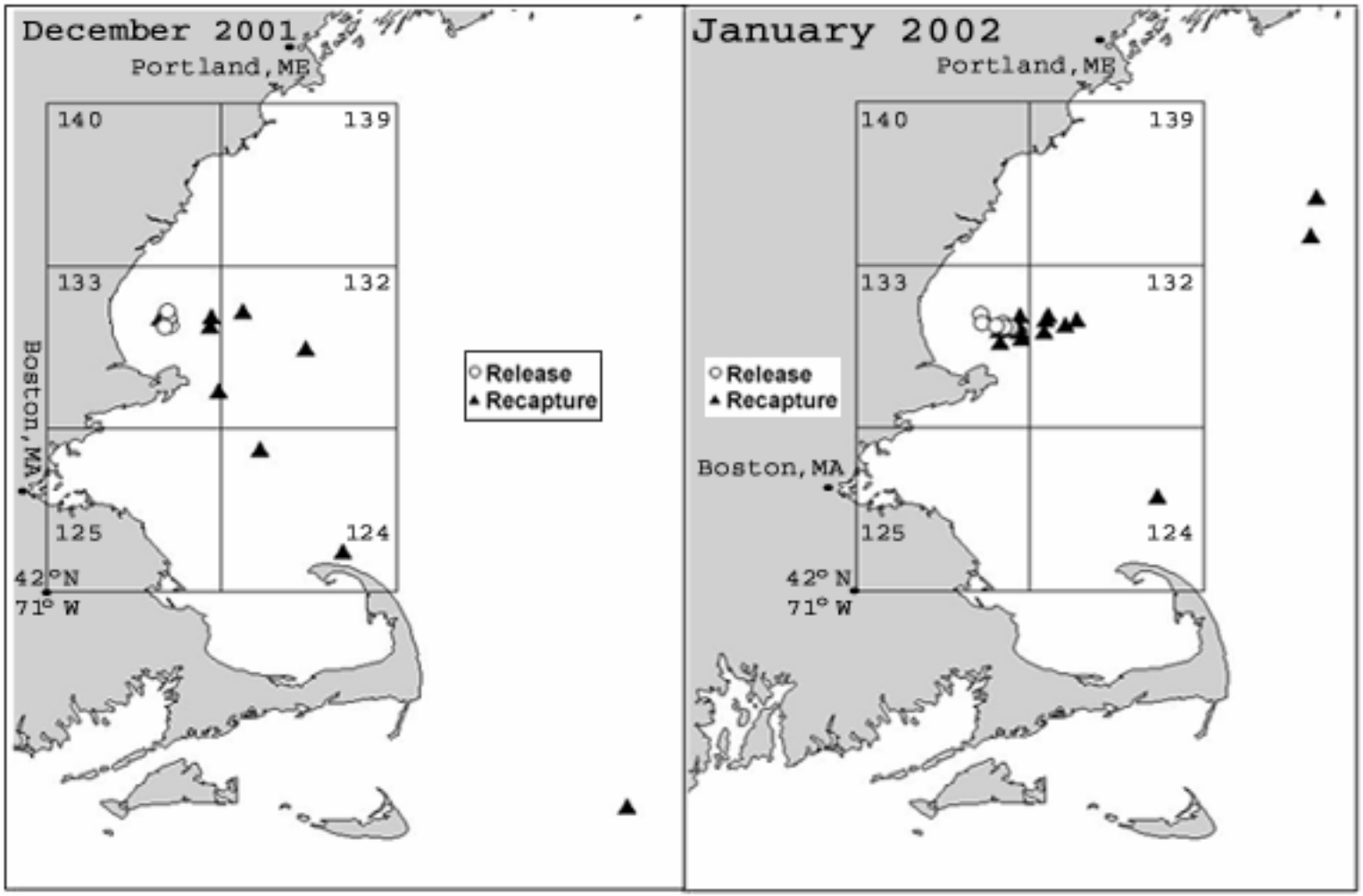


Figure 19a. Map of release and recapture locations for Atlantic cod tagged December 2001 in area 133.

Figure 19b. Map of release and recapture locations for Atlantic cod tagged January 2002 in area 133.

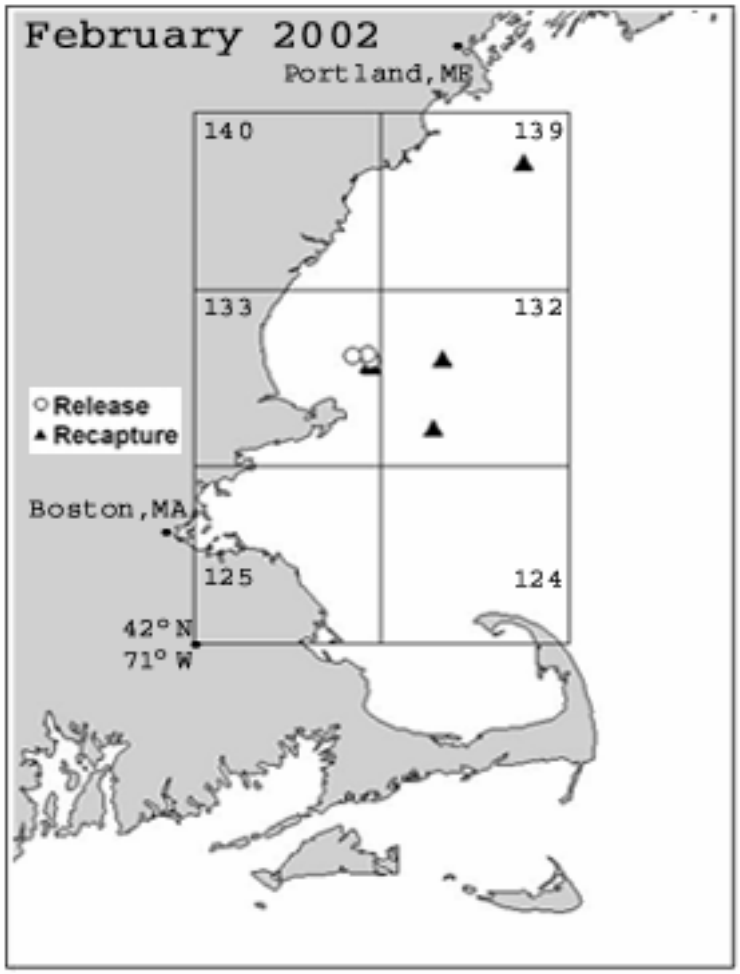


Figure 20. Map of release and recapture locations for Atlantic cod tagged February 2002 in area 133.

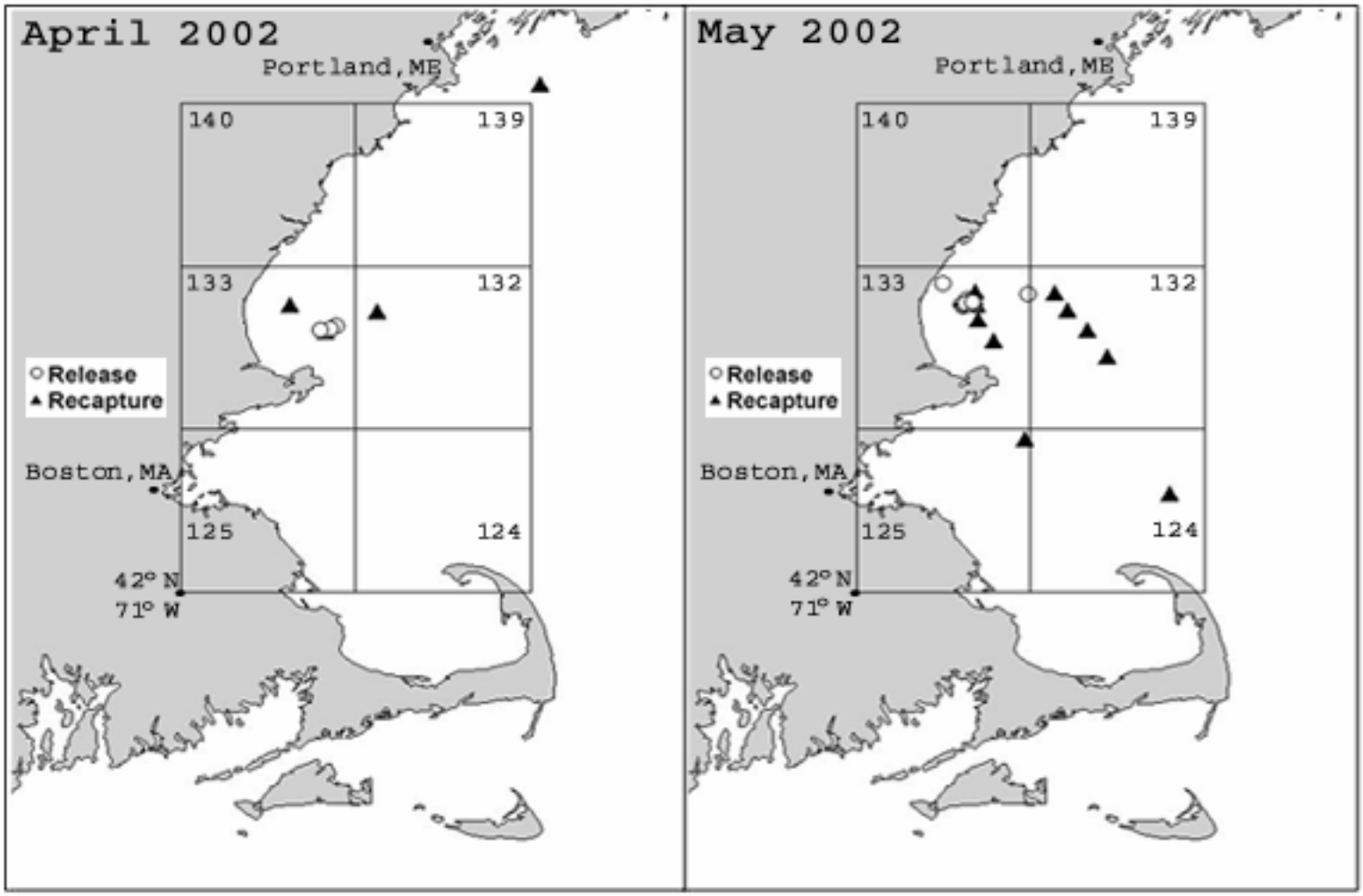


Figure 21a. Map of release and recapture locations for Atlantic cod tagged April 2002 in area 133.

Figure 21b. Map of release and recapture locations for Atlantic cod tagged May 2002 in area 133.

Area 139

Table 6 provides the migration statistics from May 2001, which was the only month of tagging which provided enough recaptures for analysis. However, maps were generated for May and June 2001 (Figs. 22a and 22b) and May and June 2002 (Figs. 23a and 23b). All four months displayed a similar pattern of recaptures. All recaptures were located south of their release site in areas 124, 132, and 133. One recapture was located south of area 139, but outside of the six rolling closure blocks.

	Month Released
	May-01
Number Released	233
Number Recaptured	5
% Recaptured	2.1
Average Days at Large	150 ± 110
Average Distance Traveled	94 ± 30
North/South Velocity (km/day)	0.6 S
East/West Velocity (km/day)	0.04 E
Mean Angle	177°
Angular Deviation	24°
Dispersion (km^2/day)	51.7
Rayleigh Test Z (calc)	4.2*

Table 6. Migration statistics for Atlantic cod tagged in area 139. Average days at large and average distance traveled include standard deviation. *Rayleigh Test denoted with an asterisks represent a significant value.

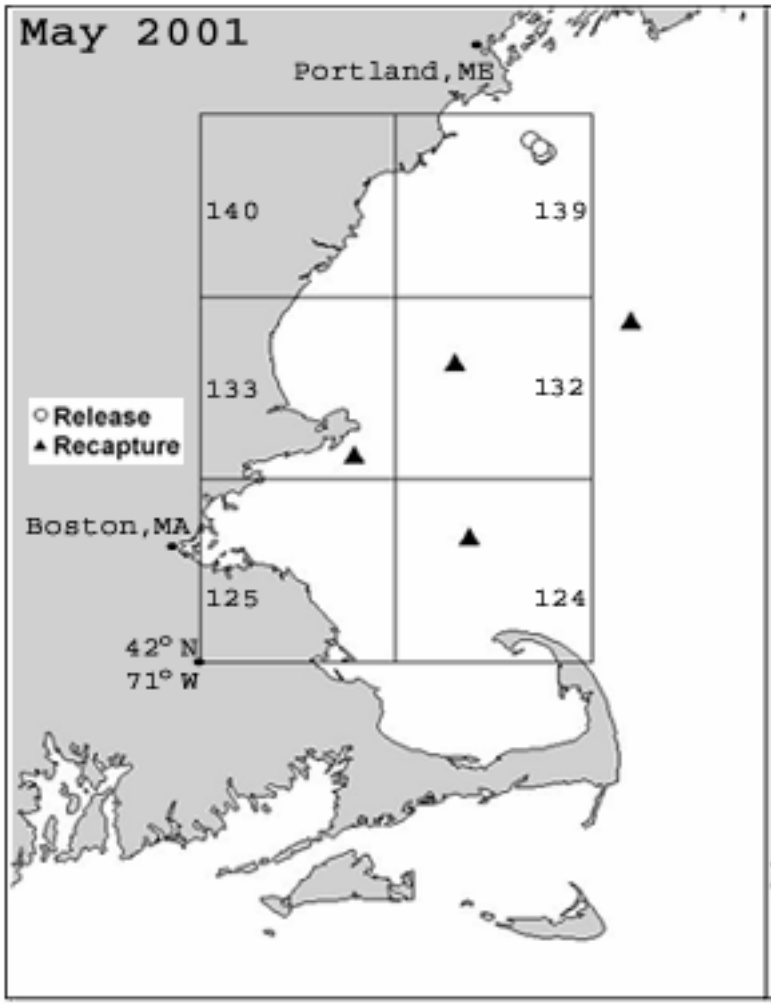


Figure 22a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 139.

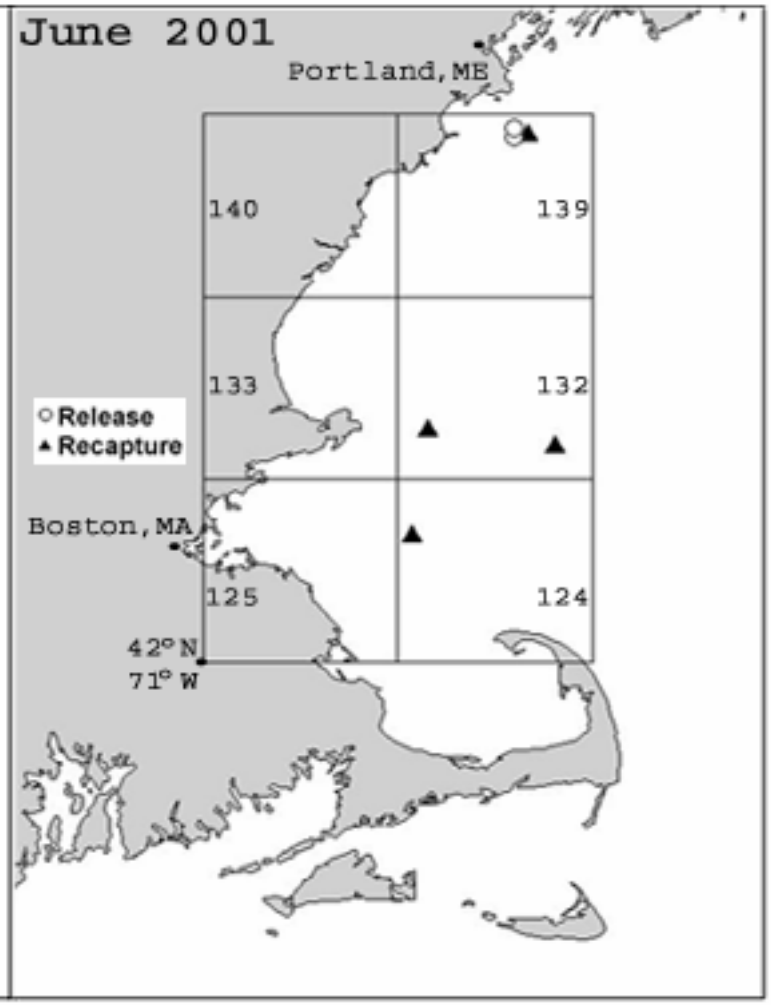


Figure 22b. Map of release and recapture locations for Atlantic cod tagged June 2001 in area 139.

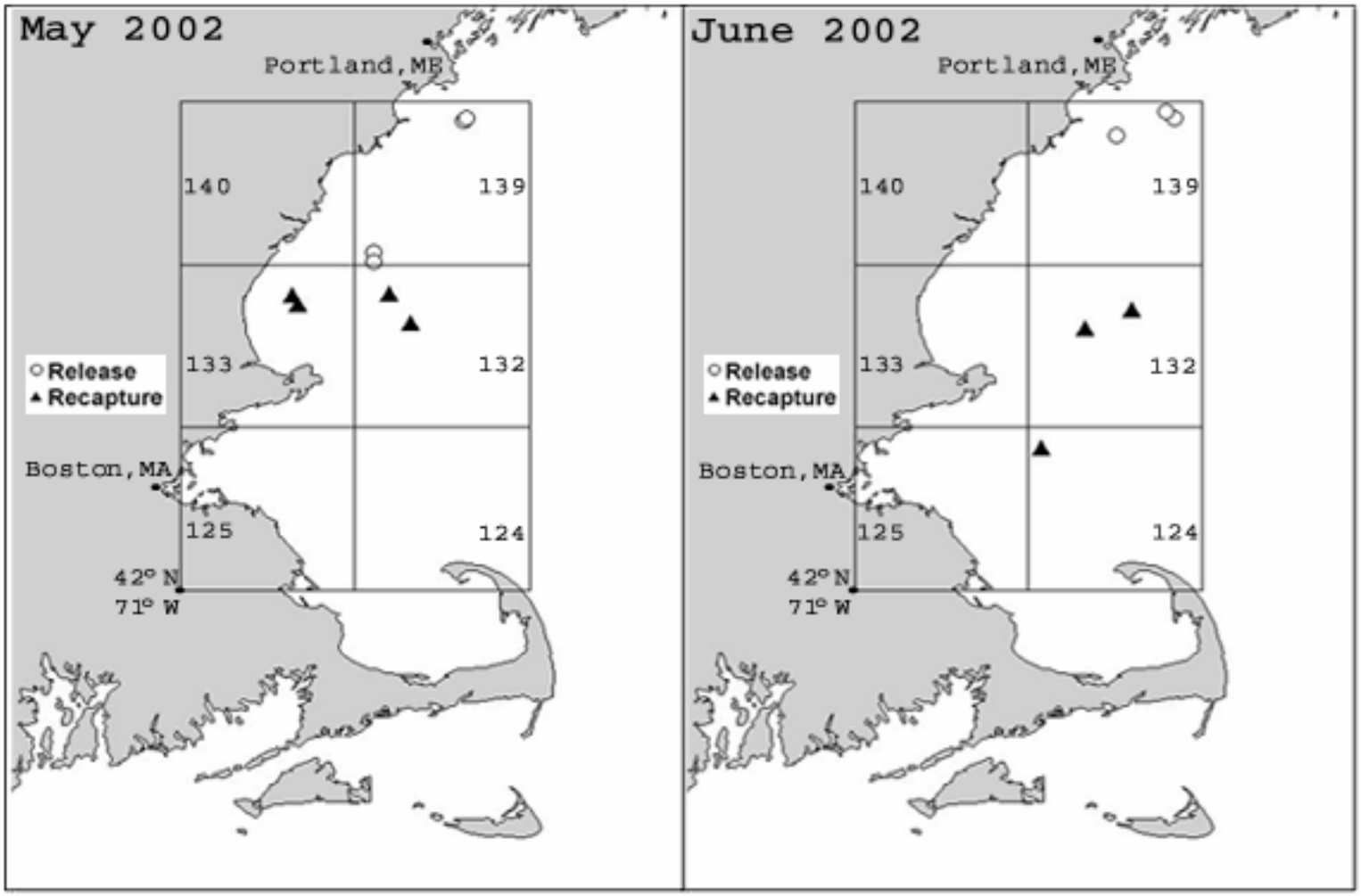


Figure 23a. Map of release and recapture locations for Atlantic cod tagged May 2002 in area 139.

Figure 23b. Map of release and recapture locations for Atlantic cod tagged June 2002 in area 139.

Fine Scale Migration Analyses

Area 132

When the number of recaptures was large enough, cod movement was analyzed on a seasonal basis. For area 132, May 2001 and June 2001 both provided ample recaptures to perform these analyses. Returns were grouped into spring (April-June), summer (July-September), and fall (October-December). Sufficient recaptures were not obtained in the winter (January-March) for either month of release. Migration statistics for both months are provided in Table 7.

Examining the maps generated from cod tagged in May 2001 provides a picture of their seasonal movements. In the spring of 2001 (Fig. 24a), some cod were recaptured westerly (inshore) towards area 133 while a few returns were located south of their release location. In the summer of 2001 (Fig. 24b) the majority of recaptures were located in area 132, slightly southeast of their release location. One recapture was located due south of its release location in area 124. In the fall of 2001 (Fig. 25), most cod were recaptured just west of their point of release. One fish was recaptured southwest of its release location, in area 125. In the spring 2002 (Fig. 26a), most cod tagged in May 2001, in area 132, were recaptured back in area 132 near their original point of release. One fish was recaptured south of its location of release, in area 125. In the summer of 2002 (Fig. 26b), cod were recaptured both south and west of their release location.

Recaptures from fish tagged in June 2001 were analyzed for both the summer and fall of 2001. In the summer of 2001 (Fig. 27a), most cod were recaptured close to their location of release. One fish was recaptured west of its release location, inshore in area 133. In the fall of 2001 (Fig. 27b), cod were recaptured again close to their location of release, with one fish being recaptured south in area 124.

	Month Recaptured						
	Spring01	Summer01	Fall01	Spring02	Summer02	Summer01	Fall01
Month released	May-01	May-01	May-01	May-01	May-01	Jun-01	Jun-01
Total Number Released	831	831	831	831	831	399	399
Number recaptured by area	15	27	12	5	5	26	6
Average distance traveled (km)	9.96 ± 12	5.64± 11	13.95± 23	10.22 ±17	16.15± 18	3.99± 3	12.29± 24
North/South Velocity (km/day)	0.14 S	0.04 S	0.05 S	0.02 S	0.02 S	0.04 S	0.08 S
East/West Velocity (km/day)	0.18 W	0.02 E	0.03 W	0.01 W	0.01 W	0.02 E	0.02 E
Mean Angle	248°	349°	236°	287°	206°	148°	164°
Angular Deviation	66°	78°	67°	70°	44°	44°	44°
Dispersion (km^2/day)	11.7	1.6	3.0	0.8	1.1	0.4	2.6
Rayleigh's Test Z(calc)	1.68	0.17	1.28	0.35	2.45	13.09*	3.01*

Table 7. Migration statistics separated into season of recapture for Atlantic cod tagged in area 132. Average days at large and average distance traveled include standard deviation. *Rayleigh Test denoted with an asterisks represent a significant value.

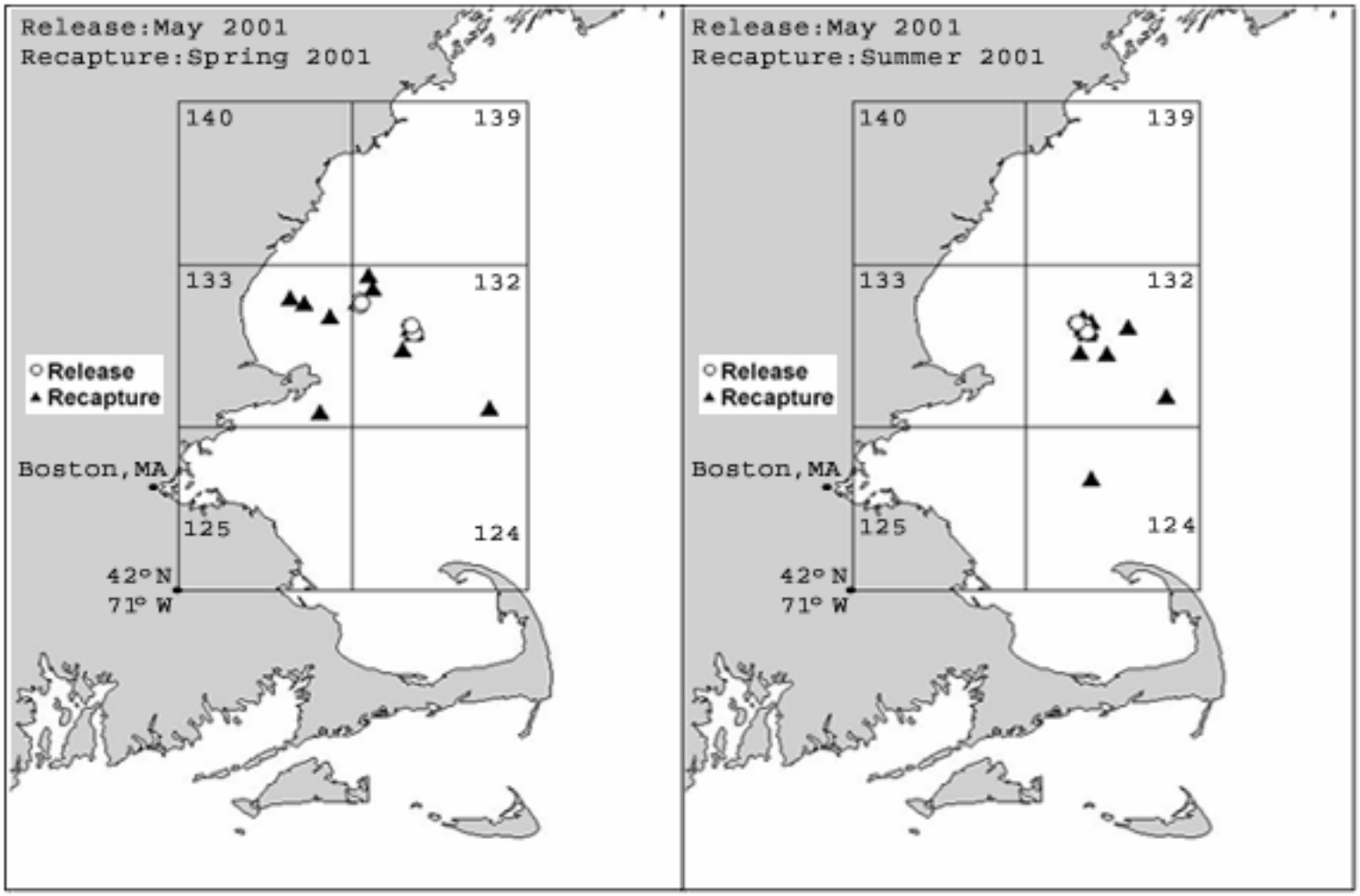


Figure 24a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 132 and recaptured in spring 2001.

Figure 24b. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 132 and recaptured in summer 2001.

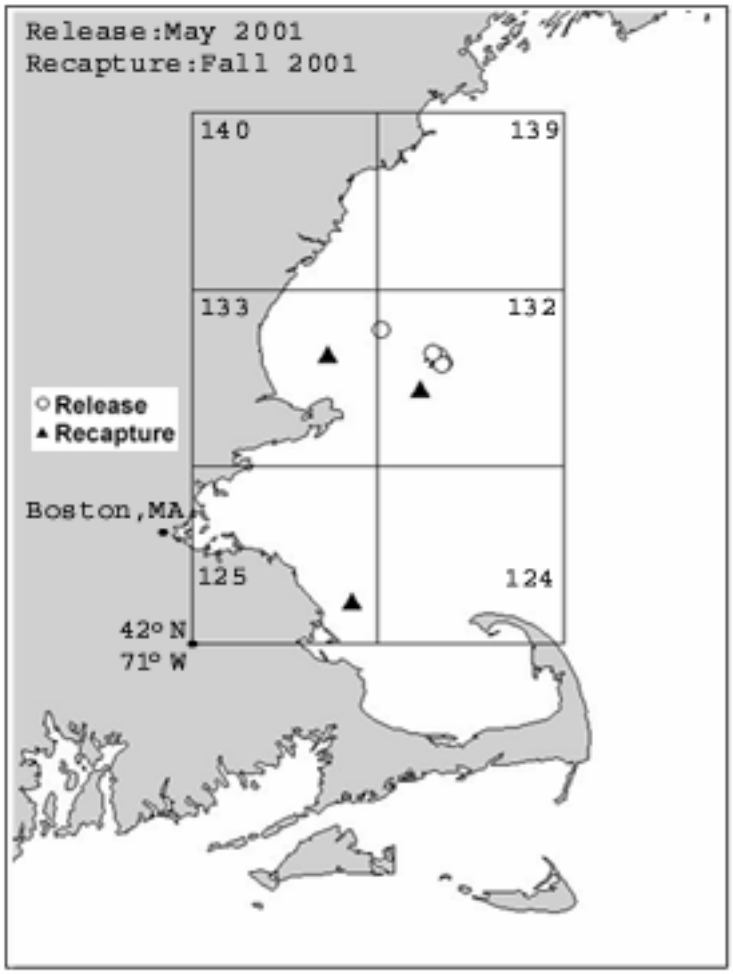


Figure 25. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 132 and recaptured in fall 2001.

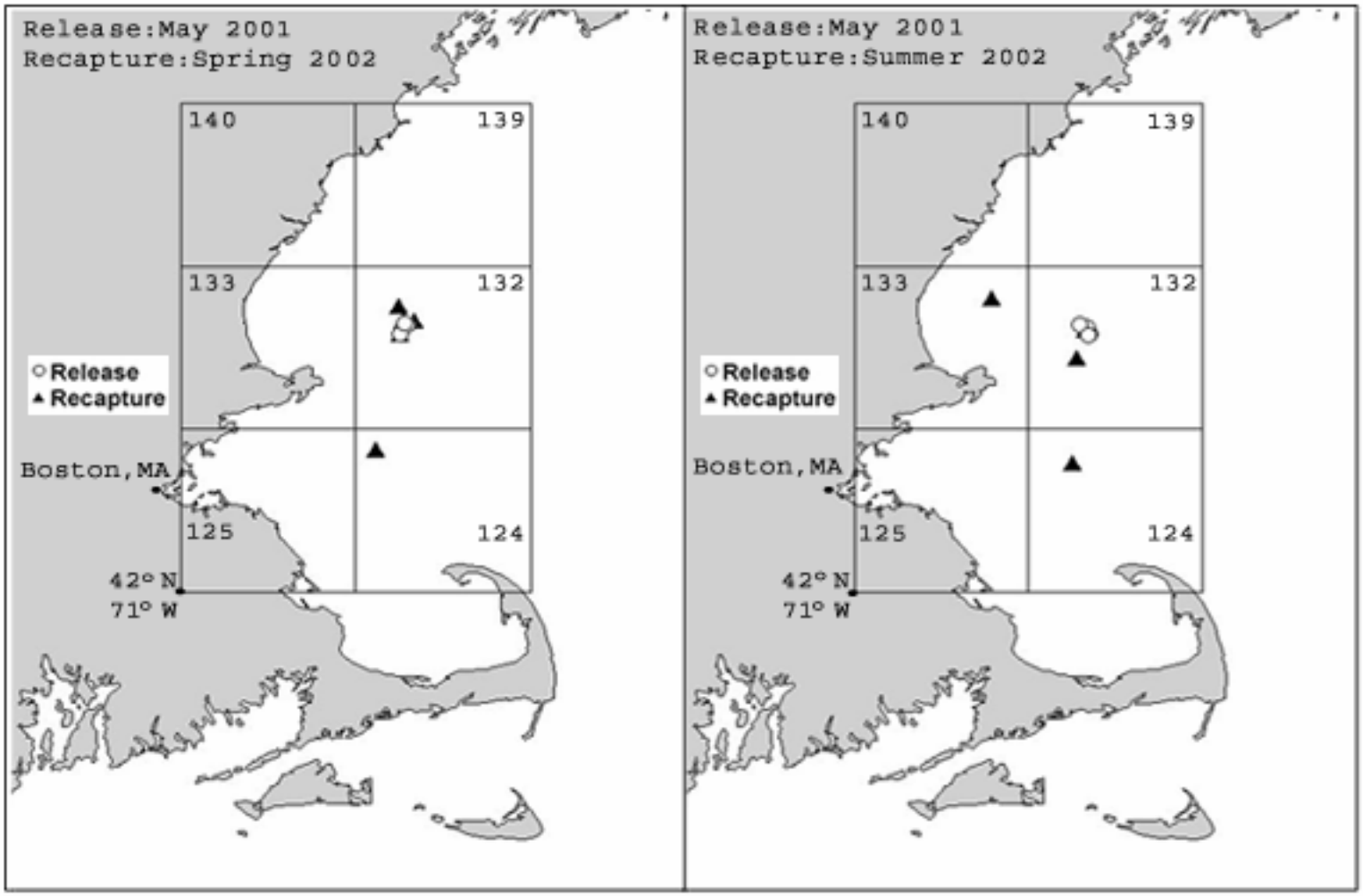


Figure 26a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 132 and recaptured in spring 2002.

Figure 26b. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 132 and recaptured in summer 2002.

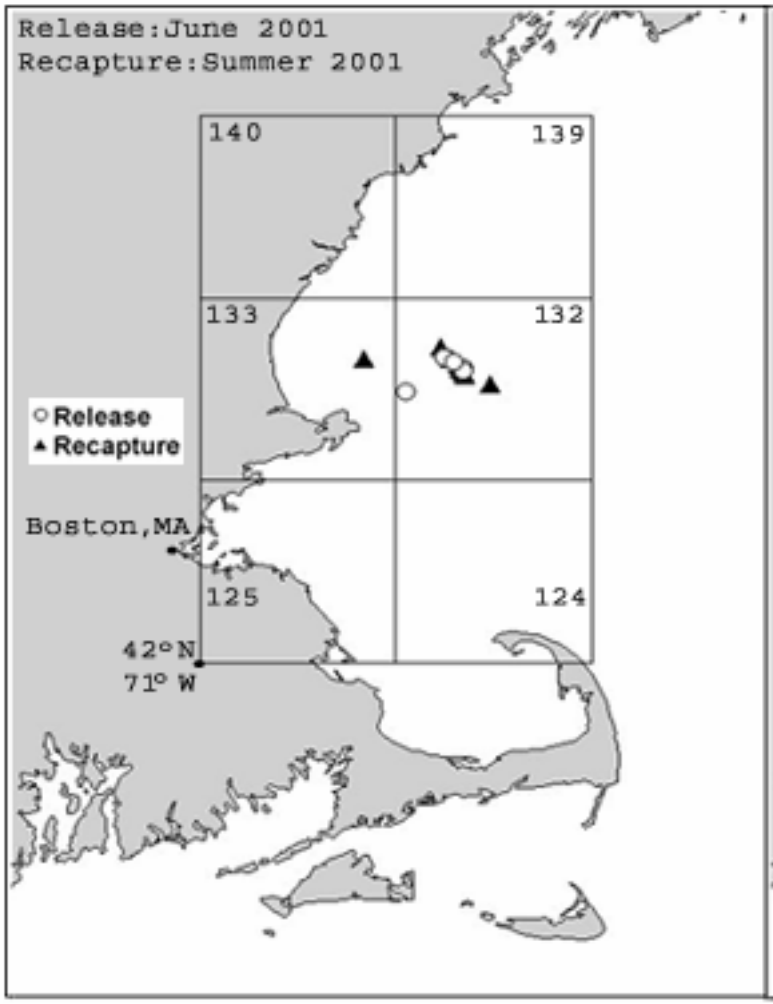


Figure 27a. Map of release and recapture locations for Atlantic cod tagged June 2001 in area 132 and recaptured in summer 2001.

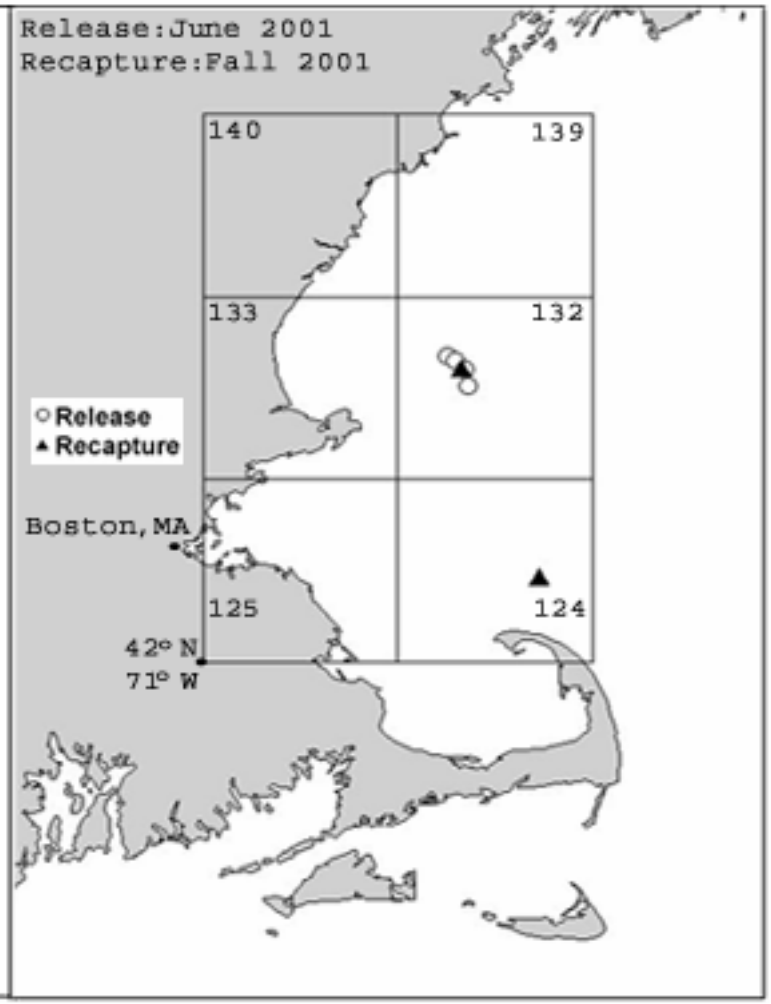


Figure 27b. Map of release and recapture locations for Atlantic cod tagged June 2001 in area 132 and recaptured in fall 2001.

Area 133

April 2001 and May 2001 provided the most tag returns for Atlantic cod tagged in area 133. Due to this, recaptures could be grouped into smaller subunits to examine cod movement on a month-by-month basis. Recaptures were grouped in single month blocks when the number of recaptured permitted it. If there was not sufficient recaptured for a particular month, consecutive months were grouped together in a way that made the best biological sense for Atlantic cod. Migration statistics for Atlantic cod tagged in April 2001 are provided in Table 8, while statistics for cod tagged in May 2001 are provided in Table 9.

For cod tagged in April 2001, recaptures from the same month (Fig. 28a) were located close to their release location. Most of these recaptures consisted of fish that were recaptured the same day they were released. In May 2001 (Fig. 28b), most cod were recaptured in the same area, but moved further inshore. Another group of cod was recaptured in area 125, southeast of their release location. One fish was recaptured northeast in area 139.

Recaptures from June 2001 (Fig. 29a) were widely dispersed from their release location. One group of recaptures came from fish that moved inshore from their release location, while another group of fished moved due east off shore into area 132. A large group of recaptures were located south of the release location in area 124 and 125. Finally, a small group of fish was recaptured northeast of their release point. In July 2001 (Fig. 29b) cod recaptures were from fish that moved offshore into area 133, from fish that moved northeast into area 139, and from fish that moved southeast into area 124.

Atlantic cod that were recaptured between August 2001 and October 2001 (Fig. 30a) moved offshore, with recaptures being obtained from both areas 133 and 132. Fish that were recaptured between December 2001 and March 2002 (Fig. 30b) represented the winter offshore movements of cod. Most recaptures were located southeast of their release location in area 132. One fish was located inshore in area 125.

Fish that were recaptured between April 2002 and May 2002 (Fig. 31a) represented cod that were caught one year after their release. Recaptures were located close to their release positions. This suggests that Atlantic cod may migrate back to the same locations each year. Cod recaptured between June 2002 and July 2002 (Fig. 31b) were located east in area 132, southeast in area 124, and northeast in area 139. While the number of recaptures decreased from June and July 2001, the movement patterns are similar suggesting that make the same movements each year.

The last group of cod movements examined on a fine scale were from fish tagged in May 2001 in area 133. Same month recaptures (Fig. 32a) were primarily located close to their points of release. There were however, two fish that moved southeast to area 124. In June 2001 (Fig. 32b) recaptures were highly dispersed, with the majority of recaptures offshore in area 132, and southeast in area 124. There was also a small group of recaptures northeast of the release location.

Recaptures from July 2001 (Fig. 33a) followed a pattern similar to June 2001, with the majority of fish being recaptured offshore in area 132. There was also a group of recaptures southeast in area 124 and northeast in area 139. Most cod recaptured in August 2001 (Fig. 33b) were caught east of their release location in areas 133 and 132.

Cod recaptured in September 2001 (Fig. 34a) and between October 2001 and February 2002 (Fig. 34b), displayed a similar pattern to recaptures from August 2001. The difference between these months was that cod recaptured in September 2001 and between October 2001 and February 2002 were recaptured further offshore.

Cod recaptured between March 2002 and April 2002 (Fig. 35a) were caught closer inshore than in the previous month, with fish appearing to head back into 133. Cod recaptured one year later in May 2002 (Fig. 35b), were located both close to their original point of release as well as northeast beyond area 139, east in area 132, and southwest in area 125. This movement pattern is similar to the movement patterns of May 2001 and June 2001.

In June 2002 (Fig. 36a), recaptures again displayed the offshore dispersal of cod. Recaptures were primarily located offshore in area 132, southeast in area 124, and northeast of area 139. Recaptures from July 2002 (Fig. 36b) also showed this offshore movement, but several recaptures were close to their release point. Finally, cod recaptured between August 2002 and October 2002 (Fig. 37) were located east of the release location on the outer boundaries of areas 132 and 139.

	Month Recaptured							
	Apr-01	May-01	Jun-01	Jul-01	Aug01-Oct01	Dec01-March02	Apr02-May02	Jun02-Jul02
Total Number Released April 2001	2277	2277	2277	2277	2277	2277	2277	2277
Number recaptured by area	30	35	29	10	9	7	7	7
Average distance traveled (km)	1.60 ± 1	18.68 ± 19	32.13 ± 30	38.37 ± 29	24.68 ± 18	28.01 ± 13	6.86 ± 3	38.53 ± 27
North/South Velocity (km/day)	0.16 S	0.02 N	0.01 S	0.02 N	0.09 S	0.07 S	0.01 N	0.02 S
East/West Velocity (km/day)	0.21 E	0.11 W	0.22 E	0.24 E	0.14 E	0.02 E	0.02 W	0.03 E
Mean Angle	143°	303°	99°	84°	121°	147°	275°	131°
Angular Deviation	56°	48°	79°	74°	32°	33°	38°	50°
Dispersion (km^2/day)	4.72	24.34	36.07	28.42	7.30	1.66	0.14	4.69
Rayleigh's Test Z(calc)	7.95*	14.61*	0.07	0.30	6.48*	4.90*	4.31*	2.72

Table 8. Migration statistics separated into months of recapture for Atlantic cod tagged April 2001 in area 133. Average days at large and average distance traveled include standard deviation. *Rayleigh Test denoted with an asterisks represent a significant value.

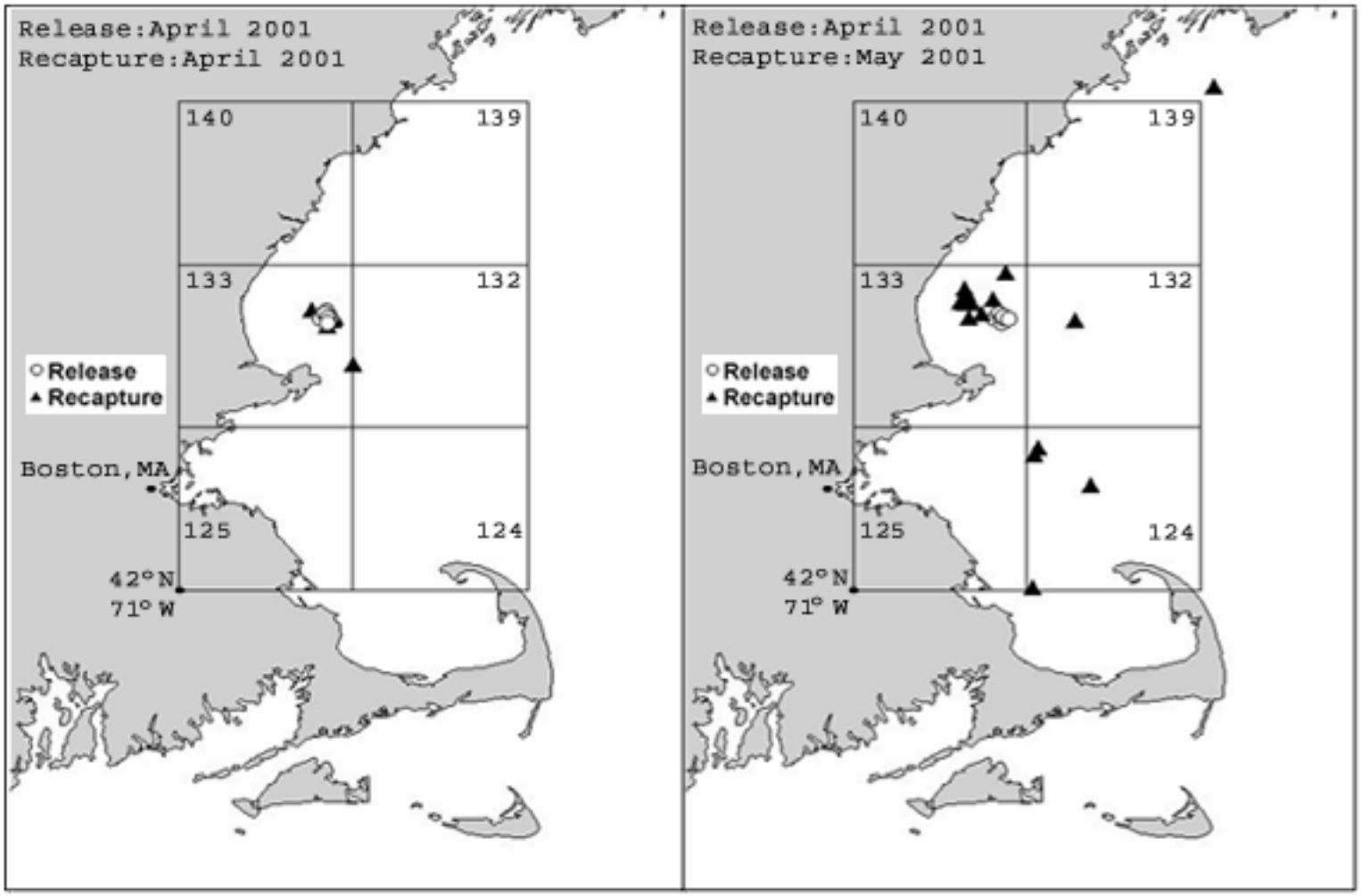


Figure 28a. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 133 and recaptured in April 2001.

Figure 28b. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 133 and recaptured in May 2001

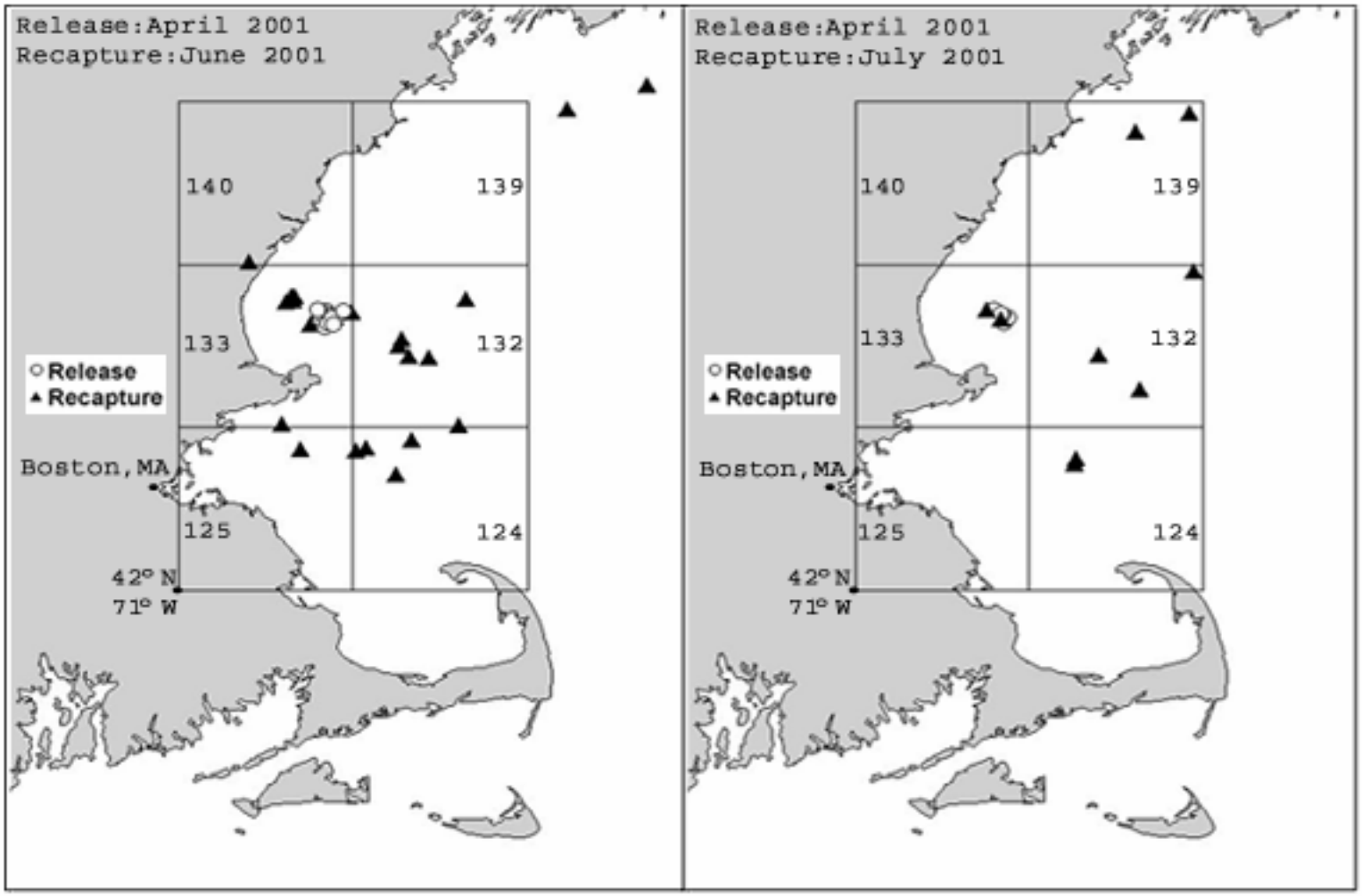


Figure 29a. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 133 and recaptured in June 2001.

Figure 29b. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 133 and recaptured in July 2001.

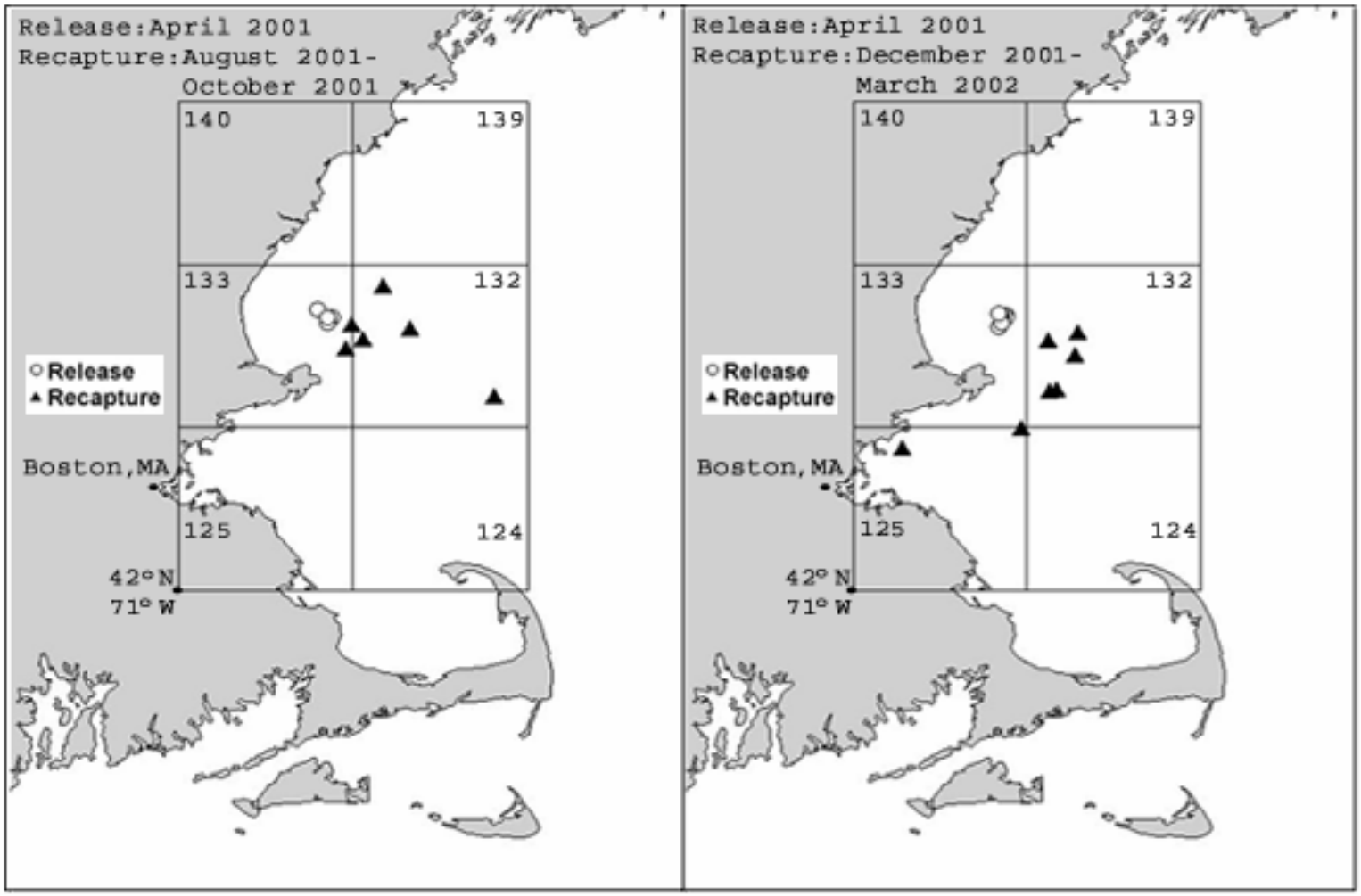


Figure 30a. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 133 and recaptured between August and October 2001.

Figure 30b. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 133 and recaptured between December 2001 and March 2002.

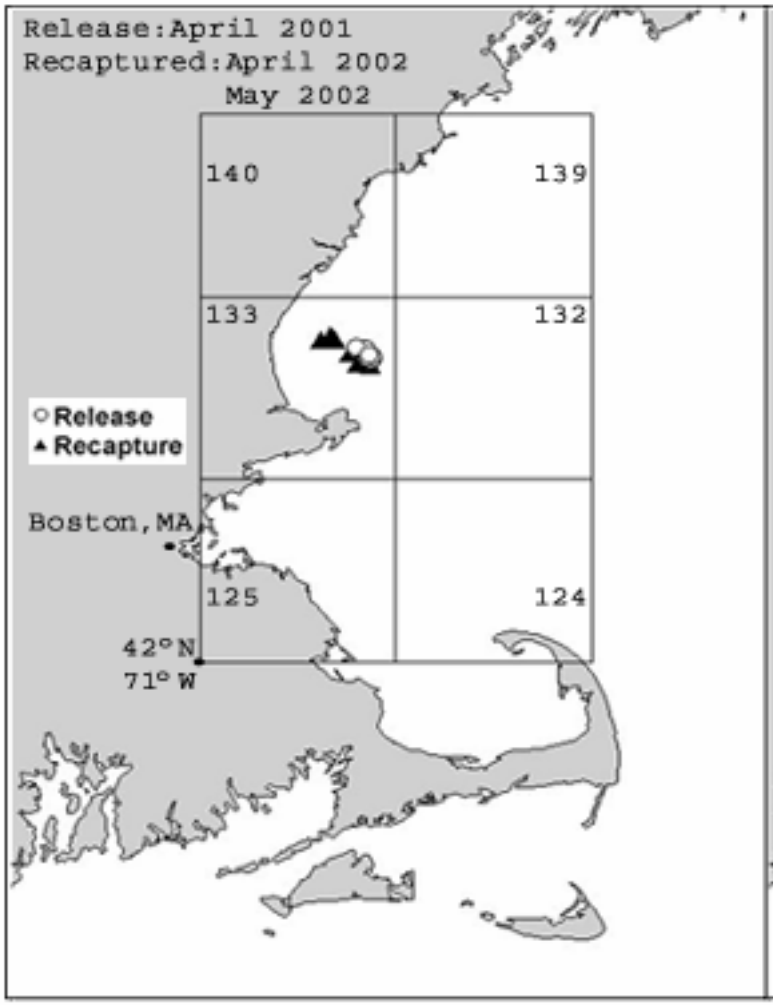


Figure 31a. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 133 and recaptured between April and May 2002.

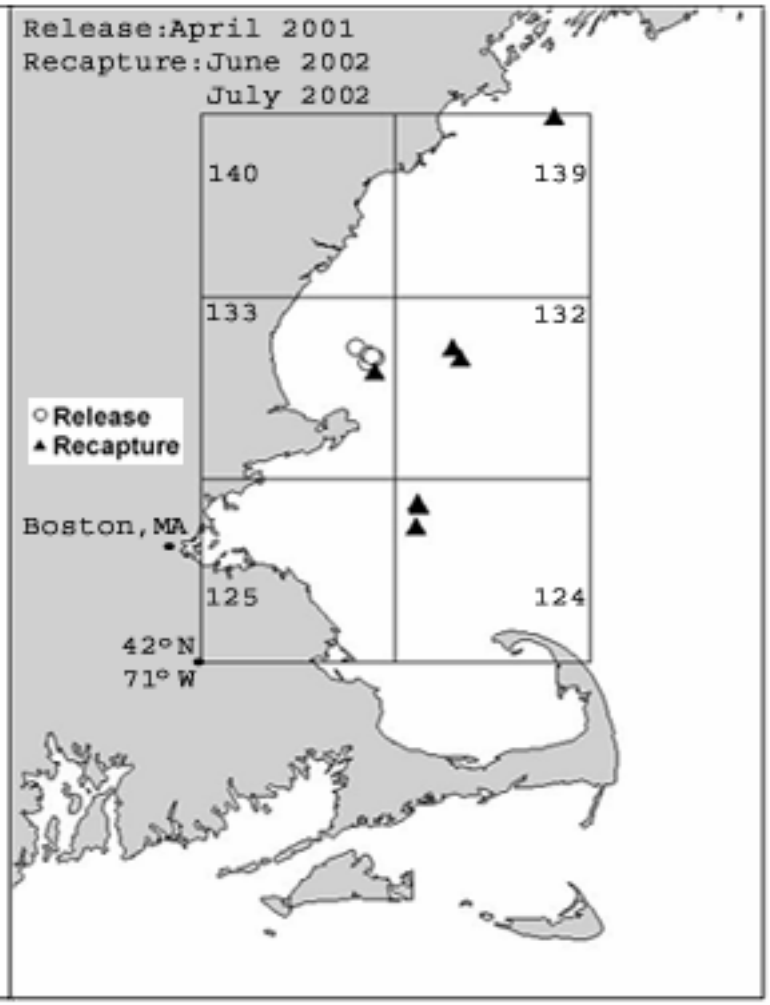


Figure 31b. Map of release and recapture locations for Atlantic cod tagged April 2001 in area 133 and recaptured between June and July 2002.

	Month Recaptured										
	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Oct01-Feb02	Mar02-Apr02	May-02	Jun-02	Jul-02	Aug02-Oct02
Total Number Released May 2001	4572	4572	4572	4572	4572	4572	4572	4572	4572	4572	4572
Number recaptured by area	61	208	28	14	9	6	6	12	9	8	7
Average distance traveled (km)	4.4 ± 13	12.2 ± 22	31.8 ± 26	51.1 ± 28	86.8 ± 88	47.5 ± 34	61.02 ± 89	18.31 ± 30	64.4 ± 28	38.83 ± 35	38.91 ± 15
North/South Velocity (km/day)	0.70 S	0.35 S	0.19 S	0.37 S	0.11 S	0.09 S	0.08 S	0.01 S	0.01 S	0.04 S	0.02 S
East/West Velocity (km/day)	0.26 E	0.35 E	0.42 E	0.35 E	0.61 E	0.20 E	0.16 E	0.02 E	0.10 E	0.05 E	0.06 E
Mean Angle	258°	125°	118°	132°	112°	122°	117°	110°	114°	126°	108°
Angular Deviation	75°	65°	28°	31°	32°	18°	32°	68°	50°	41°	30°
Dispersion (km^2/day)	26.27	36.11	27.60	32.23	116.23	11.40	32.78	3.13	12.30	5.50	3.49
Rayleigh's Test Z(calc)	1.12	27.72*	21.76*	10.13*	6.42*	5.42*	4.29*	0.98	3.48*	4.50*	5.24*

Table 9. Migration statistics separated into months of recapture for Atlantic cod tagged May 2001 in area 133. Average days at large and average distance traveled include standard deviation. *Rayleigh Test denoted with an asterisks represent a significant value.

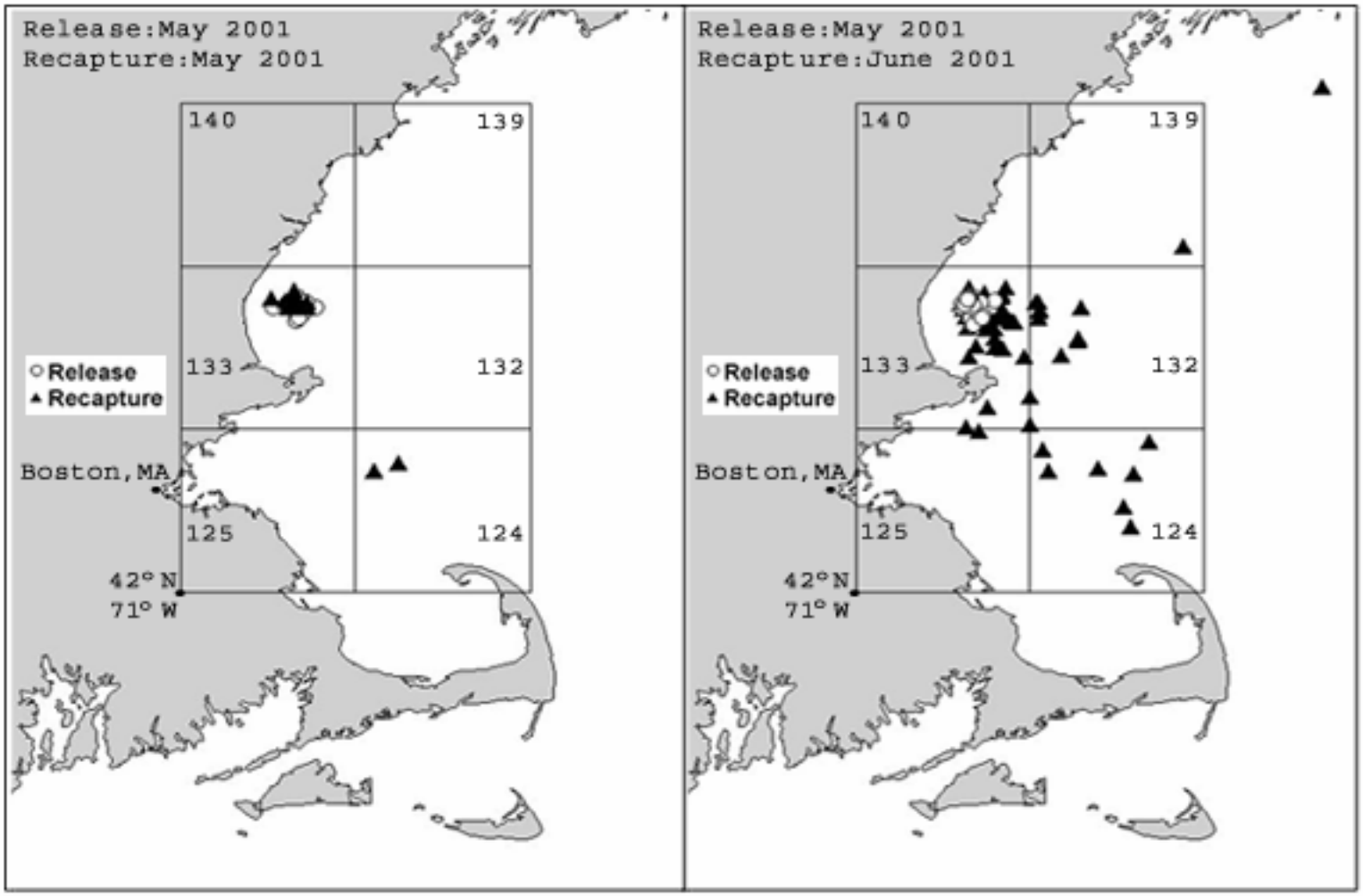


Figure 32a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured in May 2001.

Figure 32b. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured in June 2001

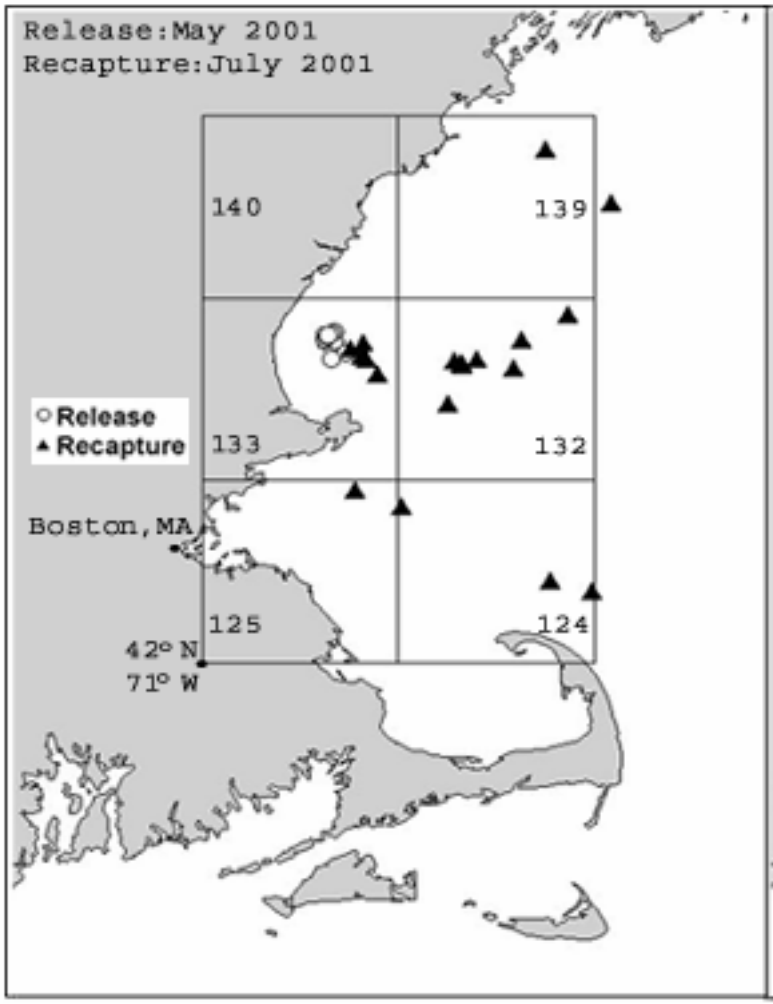


Figure 33a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured in July 2001.

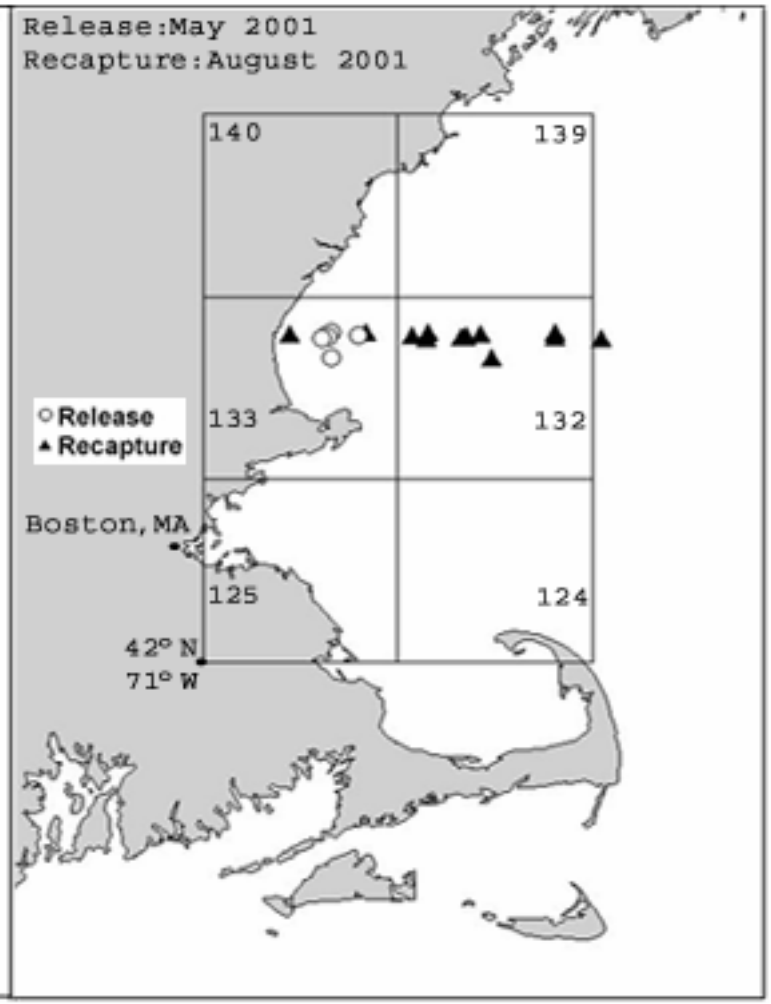


Figure 33b. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured in August 2001.

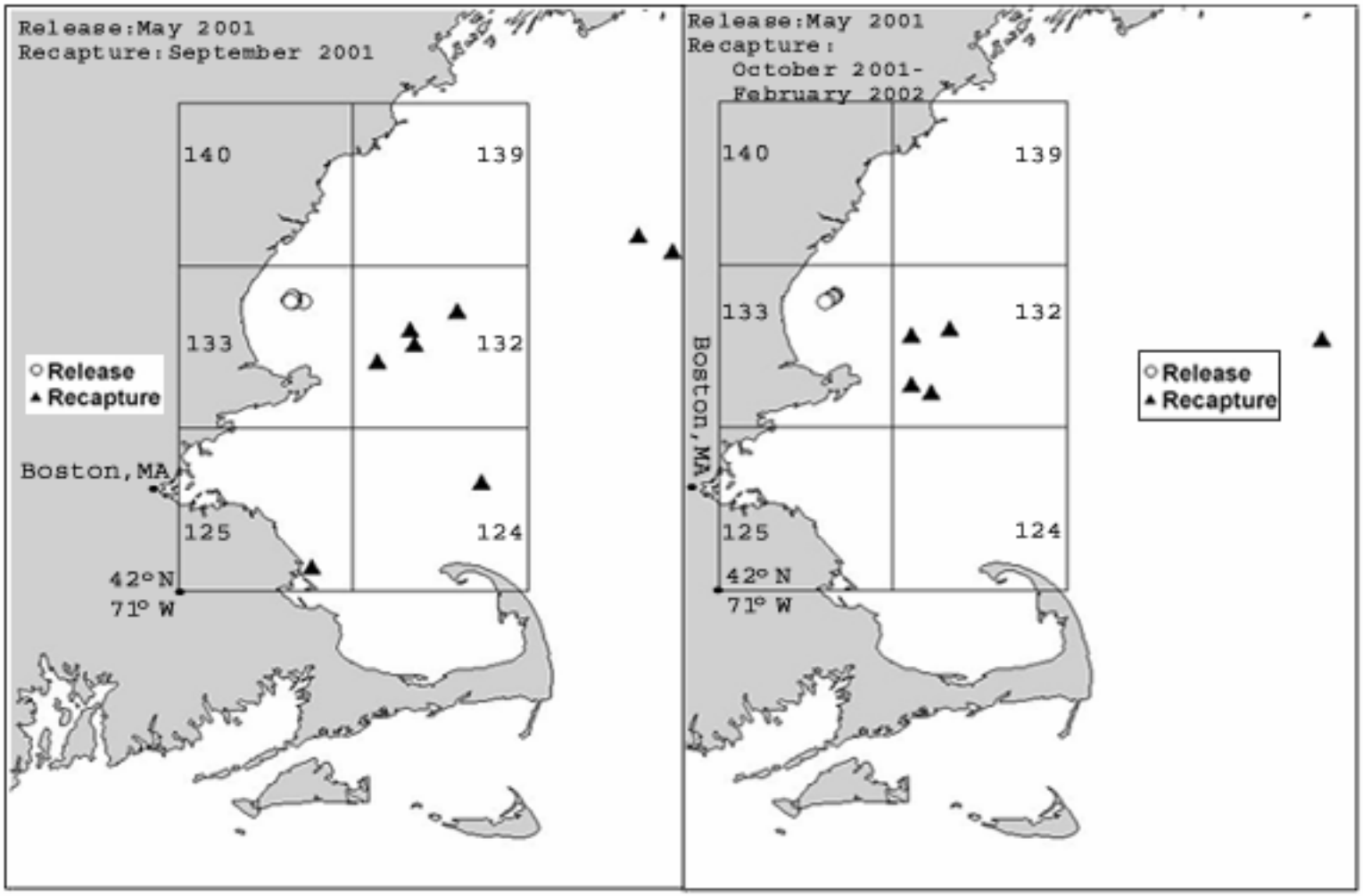


Figure 34a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured in September 2001.

Figure 34b. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured between October 2001 and February 2002.

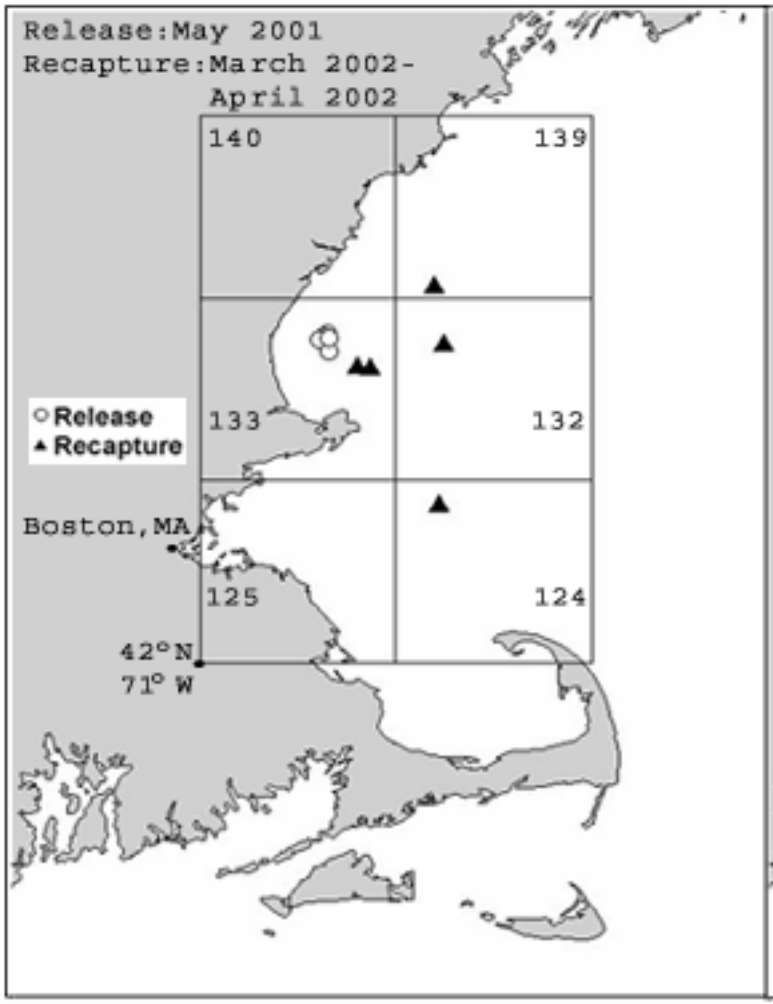


Figure 35a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured between March and April 2002.

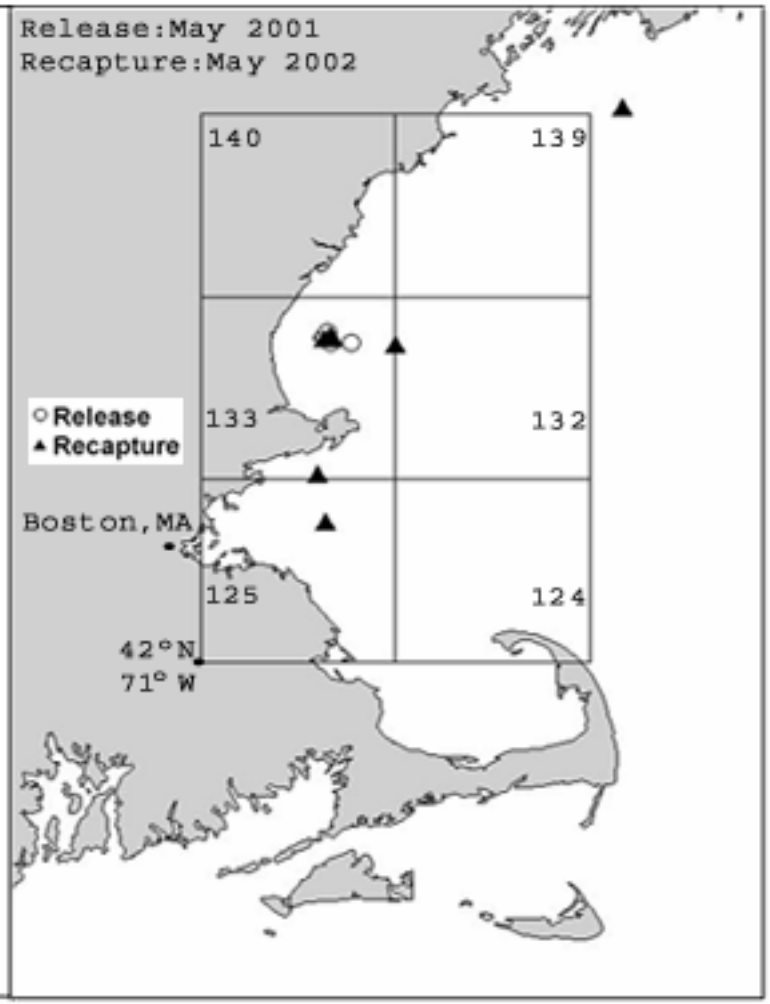


Figure 35b. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured in May 2002.

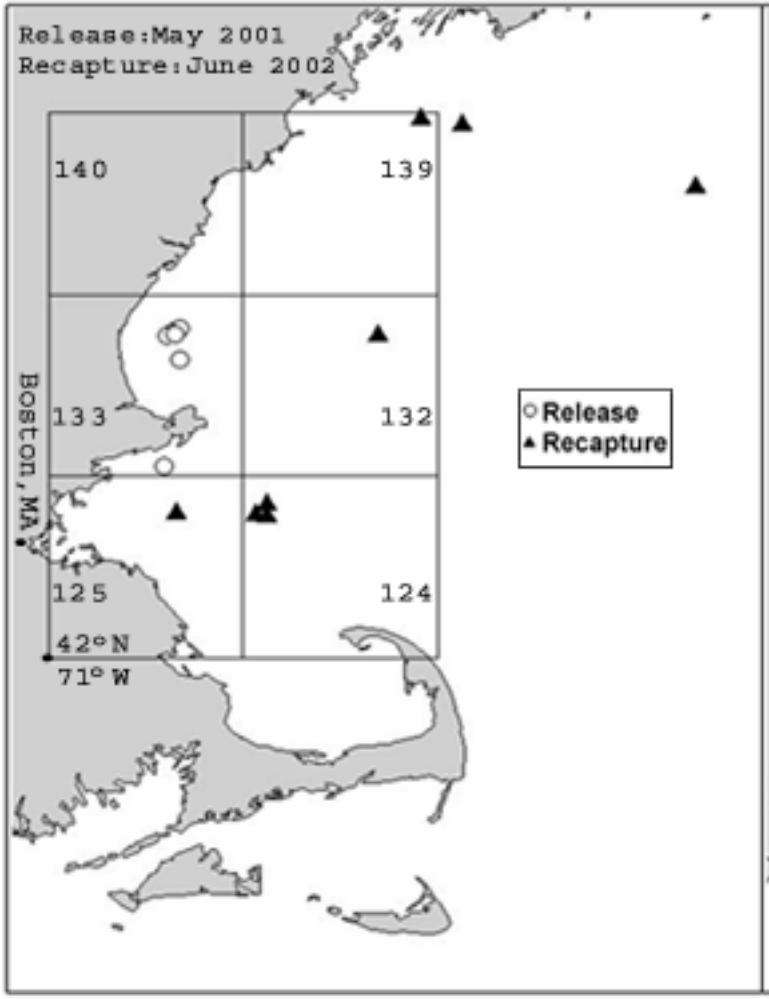


Figure 36a. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured in June 2002.

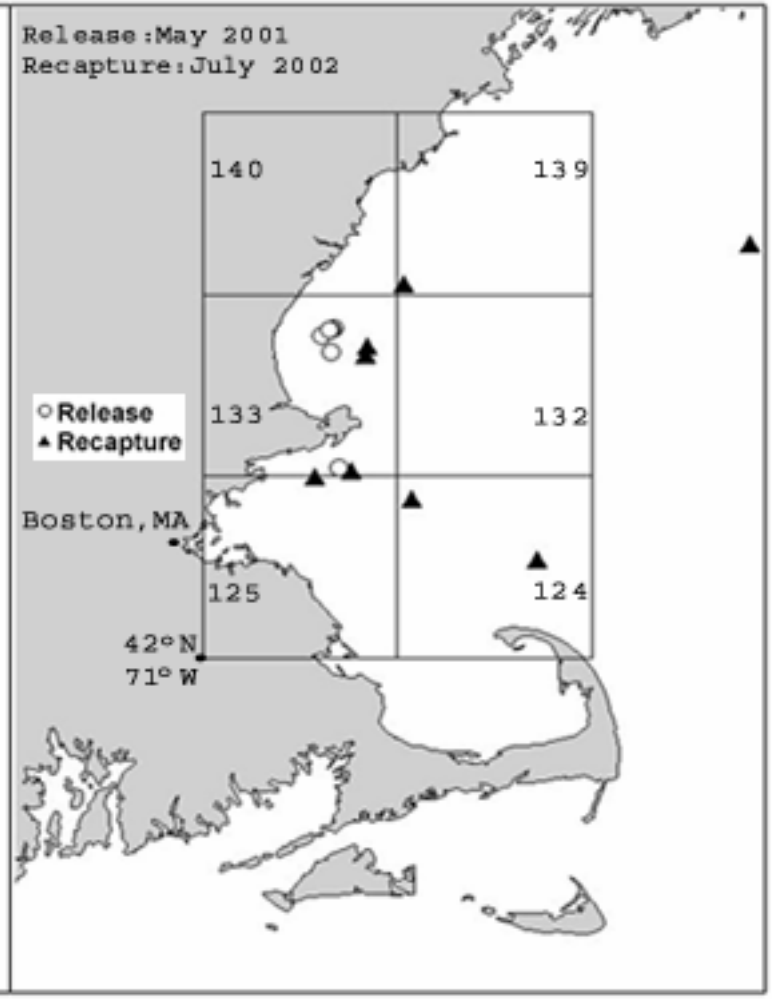


Figure 36b. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured in July 2002.

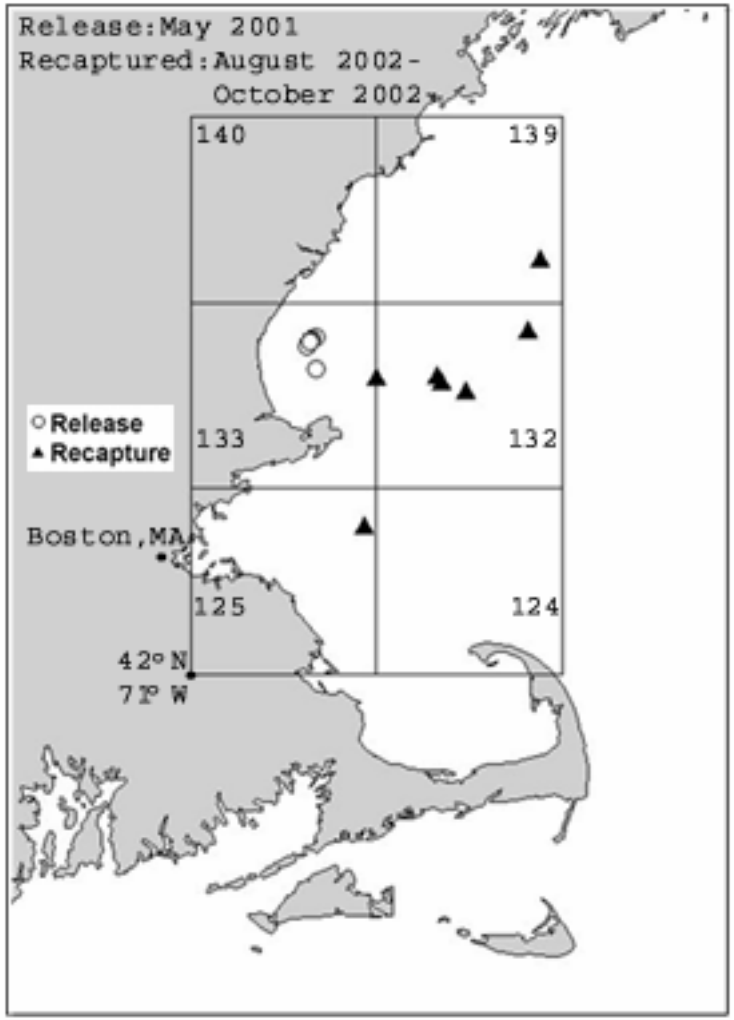


Figure 37. Map of release and recapture locations for Atlantic cod tagged May 2001 in area 133 and recaptured between August and October 2002.

Miscellaneous migration analyses

In addition to examining where Atlantic cod traveled to, recaptures were grouped to examine where cod recaptured in a particular area came from. Table 10 groups all the recaptures into separate areas and months and reports areas the cod were originally released. Table 10 also provides the average net distance traveled and average days at large for cod recaptured in a given area/month.

Most of the recaptures in this study were from cod recaptured in or adjacent to the six western Gulf of Maine rolling closures. There were however, several recaptures that were located a large distance (> 100km) from their point of release. A table of these recaptures along with their distance traveled, direction, and days at large is provided in Table 11.

Month of Recapture	Area of Recapture	N	% Came from 124	132	133	139	Average Distance Traveled (km)	Average Days at Large
Apr-01	124	16	100	0	0	0	2.4 ± 1	2 ± 2
May-01	124	24	83.3	0	16.7	0	11.6 ± 18	9 ± 14
Jun-01	124	22	18.2	13.6	68.2	0	37.2 ± 36	29 ± 22
Jul-01	124	5	20	40	40	0	31.6 ± 42	51 ± 11
Aug-01	124	5	20	0	80	0	38.7 ± 24	98 ± 9
Jan-02	124	9	0	22.2	66.7	11.1	22.0 ± 28	112 ± 113
Mar-02	124	9	11.1	22.2	66.7	0	31.1 ± 14	245 ±89
Jun-02	124	20	60	5	35	0	21.0 ± 23	292 ± 160
Jul-02	124	7	0	14.3	71.4	14.3	35.9 ± 18	214 ± 194
Oct-02	124	5	0	40	60	0	11.5 ± 5	265 ± 158
May-01	132	12	33.3	50	16.7	0	16.0 ± 20	30 ± 31
Jun-01	132	26	7.7	11.5	80.8	0	43.4 ± 27	33 ± 20
Jul-01	132	36	2.8	50	44.4	2.8	21.3 ± 24	55 ± 19
Aug-01	132	40	2.5	62.5	30	5	23.4 ± 31	71 ± 19
Sep-01	132	17	0	70.6	29.4	0	19.7 ± 23	113 ± 28
Oct-01	132	11	0	90.9	9.1	0	5.9 ± 9	133 ± 24
Nov-01	132	5	20	60	20	0	16.0 ± 20	165 ± 27
Feb-02	132	5	0	40	60	0	23.8 ± 12	75 ± 44
Apr-02	132	10	10	60	30	0	31.2 ± 38	165 ± 136
May-02	132	7	0	85.7	14.3	0	21.3 ± 36	180 ± 164
Jun-02	132	7	42.9	28.6	28.6	0	11.9 ± 15	341 ± 143
Jul-02	132	21	14.3	47.6	28.6	9.5	18.6 ± 25	209 ± 147
Aug-02	132	5	0	40	40	20	35.0 ± 36	228 ± 194
Sep-02	132	14	0	57.1	42.9	0	14.1 ± 15	251 ± 172
Oct-02	132	7	0	71.4	14.3	14.3	13.0 ± 12	302 ± 177
Apr-01	133	33	0	9.1	90.9	0	2.2 ± 2	4 ± 9
May-01	133	88	0	1.1	98.9	0	5.3 ± 7	11 ± 13
Jun-01	133	198	0	3.0	7.0	0	5.9 ± 7	19 ± 12
Jul-01	133	23	0	4.4	91.3	4.4	11.2 ± 20	44 ± 21
Oct-01	133	5	20	40	40	0	20.7 ± 14	167 ± 12
Jan-02	133	12	8.3	16.7	75	0	9.7 ± 12	61 ± 109
Feb-02	133	6	0	50	50	0	7.0 ± 6	69 ± 124
Apr-02	133	14	0	7.1	92.9	0	5.0 ± 6	116 ± 161
May-02	133	32	0	6.3	93.8	0	5.7 ± 9	192 ± 181
Jul-02	133	13	0	15.4	76.9	7.7	11.1 ± 8	207 ± 192
Oct-02	133	9	0	33.3	66.7	0	8.4 ± 6	326 ± 156
Jul-01	139	5	40	0	60	0	50.7 ± 18	69 ± 12

Table 10. Areas of original release, expressed as a percentage, for Atlantic cod recaptured in a given month and area. Average days at large and average distance traveled are means and standard deviation.

Date of Release	Tag Number	Length at Release	Area of Release	Date of Recapture	Area of Recapture	Days at Large	Direction (degrees)	Distance (km)
04/20/01	1313	47	124	12/02/01	110	226	113°	238.7
05/10/01	3762	58	124	9/20/02	98	498	145°	158.78
06/20/01	11291	78	132	03/16/02	113	269	152°	139.13
11/13/01	13285	78	132	12/31/01	101	48	183°	199.68
04/27/01	2033	77	133	08/07/01	76	102	125°	408.9
05/11/01	4217	83	133	09/13/01	Canada	125	82°	311.1
05/11/01	4391	91	133	02/16/02	130	281	96°	117.03
05/26/01	8654	67	133	03/17/02	111	295	114°	239.17
12/12/01	14290	70	133	7/18/02	98	218	147°	200.99
05/30/01	8945	77	139	03/25/02	130	299	136°	124.3

Table 11. Tag recaptures obtained from far beyond the western

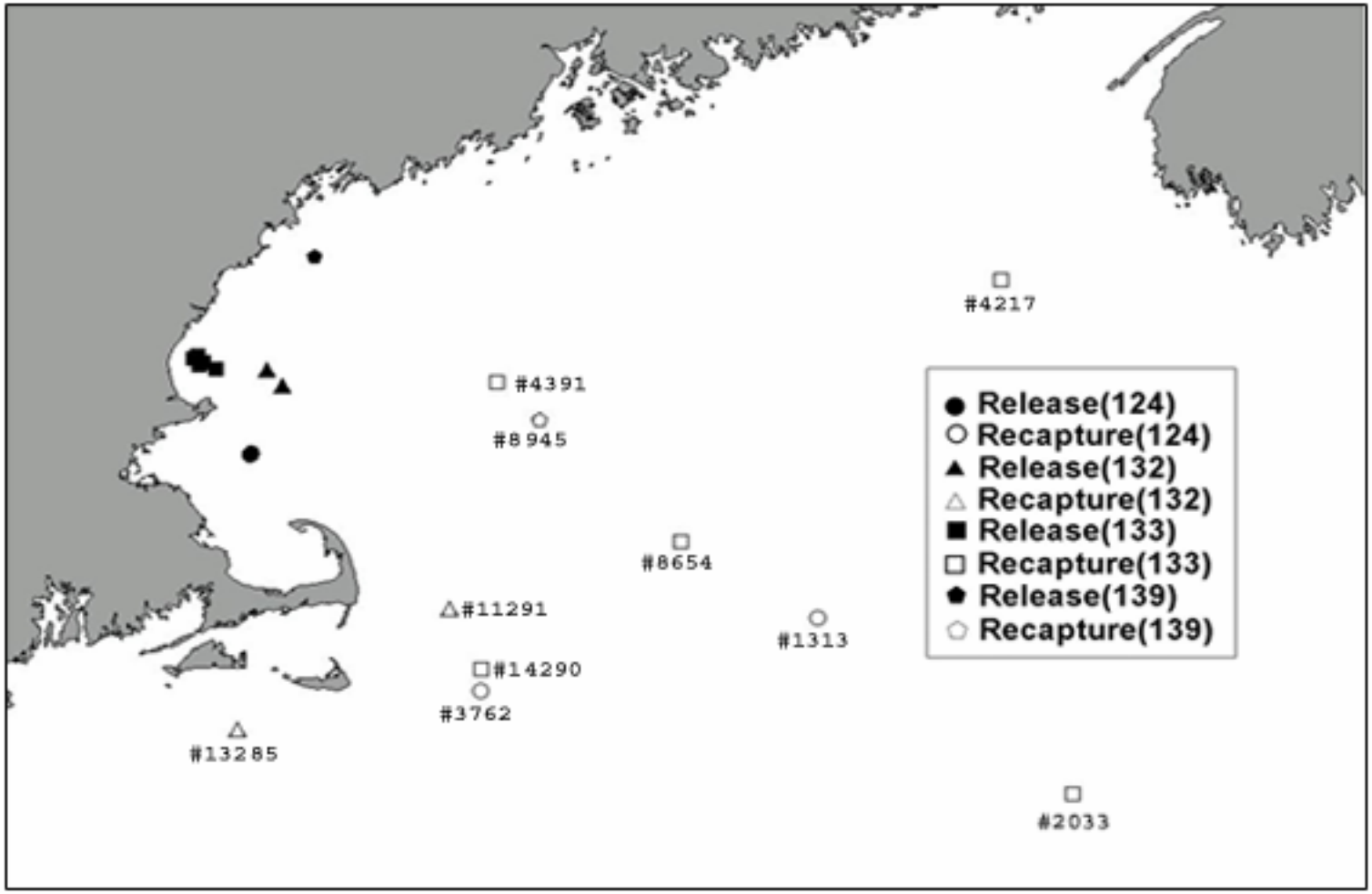


Figure 38. Tag recaptures obtained from far beyond the western Gulf of Maine rolling closures.

Catch Per Unit Effort

Analyses by Area

A one-sample Kolmogorov-Smirnov test was used to determine if catch-per-unit effort was normally distributed. Analyses proved that data were not normally distributed so a rank transformation was preformed. When completed, an analysis of variance (ANOVA) was used to test for significant differences in the catch per unit effort (CPUE) of Atlantic cod both within an area over time, and between areas in a given month. If a significant difference was found (p-value <0.05), then a Tukey's test was preformed to determine which pair wise comparisons were significant. First, catch per unit effort was analyzed within an area to examine seasonal trends in CPUE over time.

Table 12 describes the means and standard deviation for CPUE levels for each month/area sampled. Results of the ANOVA and Tukey's tests are provided in tables 12-16. For area 124, there was a significant difference (p= 0.04) in CPUE over all months sampled. This difference was observed between April and June 2001, which have the highest and lowest CPUE levels respectively (Table 13).

For area 132, there was a significant difference (p= 0.00) in CPUE over time. The largest of these significant increases in CPUE were observed in October and November (Tables 12 and 14). In area 133, significant differences (p= 0.00) in CPUE were observed over all months sampled. CPUE was observed to increase in April and May, decreased to 7 kg/hr in August, and increased again in December and January (Table 15). In area 139, there was a significant change in CPUE over time (p= 0.00). Table 16,

describes an increase in abundance in the Months of May and June for both 2001 and 2001, with the greatest significant increase coming in May 2002.

The graphs of CPUE for each area are shown in figures 39 - 42.

Month	Area 124	132	133	139
Feb-01	217 ± 224			
Mar-01		33 ± 30	5 ± 9	1 ± 2
Apr-01	289 ± 197	105 ± 115	970 ± 1354	0 ± 0
May-01	138 ± 127	99 ± 86	2228 ± 2443	259 ± 235
Jun-01	8 ± 12	146 ± 104	99 ± 107	100 ± 135
Jul-01	160 ± 191	49 ± 48	18 ± 24	13 ± 15
Aug-01		62 ± 68	7 ± 60	4 ± 10
Sep-01		31 ± 25		
Oct-01		847 ± 436	10 ± 12	2 ± 3
Nov-01	262 ± 122	862 ± 390	124 ± 134	
Dec-01			424 ± 329	7 ± 8
Jan-02		90 ± 82	259 ± 359	
Feb-02		17 ± 30	112 ± 116	
Mar-02		13 ± 15	71 ± 79	3 ± 4
Apr-02		272 ± 396	396 ± 720	8 ± 16
May-02	246 ± 70	104 ± 104	584 ± 577	302 ± 419
Jun-02		155 ± 1	190 ± 253	142 ± 301

Table 12. Mean and standard deviations of catch per unit effort (kg/hr) for individual areas over all the months sampled.

	Feb-01	Apr-01	May-01	Jun-01	Jul-01	Nov-01	May-02
Feb-01	NS						
Apr-01	NS	NS					
May-01	NS	NS	NS				
Jun-01	NS	*	NS	NS			
Jul-01	NS	NS	NS	NS	NS		
Nov-01	NS	NS	NS	NS	NS	NS	
May-02	NS	NS	NS	NS	NS	NS	NS

Table 13. Results of Tukey's pair wise comparisons of catch-per-unit-effort for each month sampled in area 124.

NS= Not significant ($p > 0.05$)
* = $p < 0.05$

	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sept-01	Oct-01	Nov-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02
Mar-01	NS														
Apr-01	NS	NS													
May-01	NS	NS	NS												
Jun-01	*	NS	NS	NS											
Jul-01	NS	NS	NS	NS	NS										
Aug-01	NS	NS	NS	NS	NS	NS									
Sept-01	NS	NS	NS	NS	NS	NS	NS								
Oct-01	***	NS	NS	NS	*	*	**	NS							
Nov-01	***	NS	*	NS	*	*	**	NS	NS						
Jan-02	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS					
Feb-02	NS	NS	NS	**	NS	NS	NS	***	***	NS	NS				
Mar-02	NS	NS	*	**	NS	NS	NS	***	***	NS	NS	NS			
Apr-02	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
May-02	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	
Jun-02	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 14. Results of Tukey's pair wise comparisons of catch-per-unit-effort for each month sampled in area 132.

NS= Not s
** = p<0.01ignificant (p >0.05)
* = p <0.05

	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Oct-01	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02
Mar-01	NS														
Apr-01	***	NS													
May-01	***	*	NS												
Jun-01	NS	***	***	NS											
Jul-01	NS	***	***	NS	NS										
Aug-01	NS	***	***	NS	NS	NS									
Oct-01	NS	***	***	NS	NS	NS	NS								
Nov-01	*	NS	***	NS	NS	NS	NS	NS							
Dec-01	***	NS	NS	NS	**	*	*	NS	NS						
Jan-02	**	NS	***	NS	*	NS	NS	NS	NS	NS					
Feb-02	NS	NS	***	NS	NS	NS	NS	NS	NS	NS	NS				
Mar-02	NS	NS	***	NS	NS	NS	NS	NS	NS	NS	NS	NS			
Apr-02	**	NS	***	NS	*	NS	NS	NS	NS	NS	NS	NS	NS		
May-02	***	NS	NS	***	***	***	***	NS	NS	NS	NS	NS	NS	NS	
Jun-02	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 15. Results of Tukey's pair wise comparisons of catch-per-unit-effort for each month sampled in area 133.

NS= Not significant ($p > 0.05$)
* = $p < 0.05$
** = $p < 0.01$
*** = $p < 0.001$

	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Oct-01	Dec-01	Mar-02	Apr-02	May-02	Jun-02
Mar-01	NS											
Apr-01	NS	NS										
May-01	***	***	NS									
Jun-01	***	***	NS	NS								
Jul-01	NS	NS	***	*	NS							
Aug-01	NS	NS	***	***	NS	NS						
Oct-01	NS	NS	***	***	NS	NS	NS					
Dec-01	NS	NS	***	NS	NS	NS	NS	NS				
Mar-02	NS	NS	***	*	NS	NS	NS	NS	NS			
Apr-02	NS	NS	***	***	NS	NS	NS	NS	NS	NS		
May-02	***	***	NS	*	***	***	***	***	***	***	NS	
Jun-02	**	***	NS	NS	*	***	***	*	*	***	NS	NS

Table 16. Results of Tukey's pair wise comparisons of catch-per-unit-effort for each month sampled in area 139.

NS= Not significant ($p > 0.05$)
* = $p < 0.05$
** = $p < 0.01$
*** = $p < 0.001$

Figure 39. Catch Per Unit Effort (CPUE) of Atlantic cod in Area 124

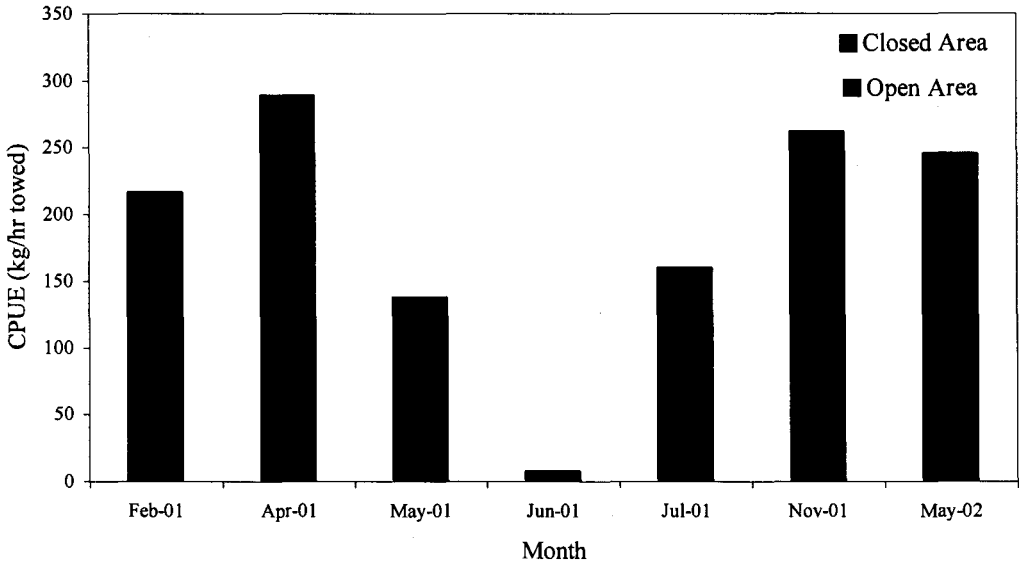


Figure 40. Catch Per Unit Effort (CPUE) of Atlantic Cod in Area 132

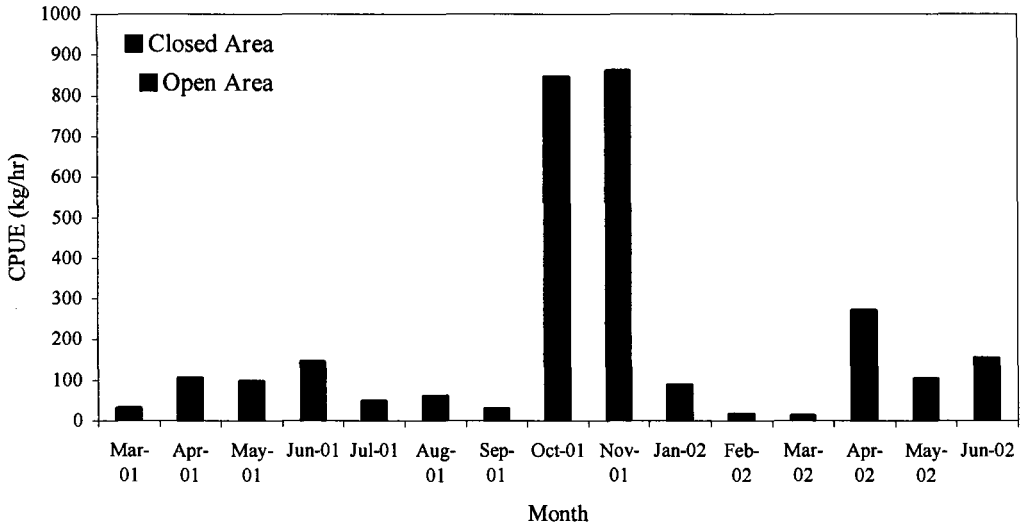


Figure 41. Catch Per Unit Effort (CPUE) of Atlantic Cod in Area 133

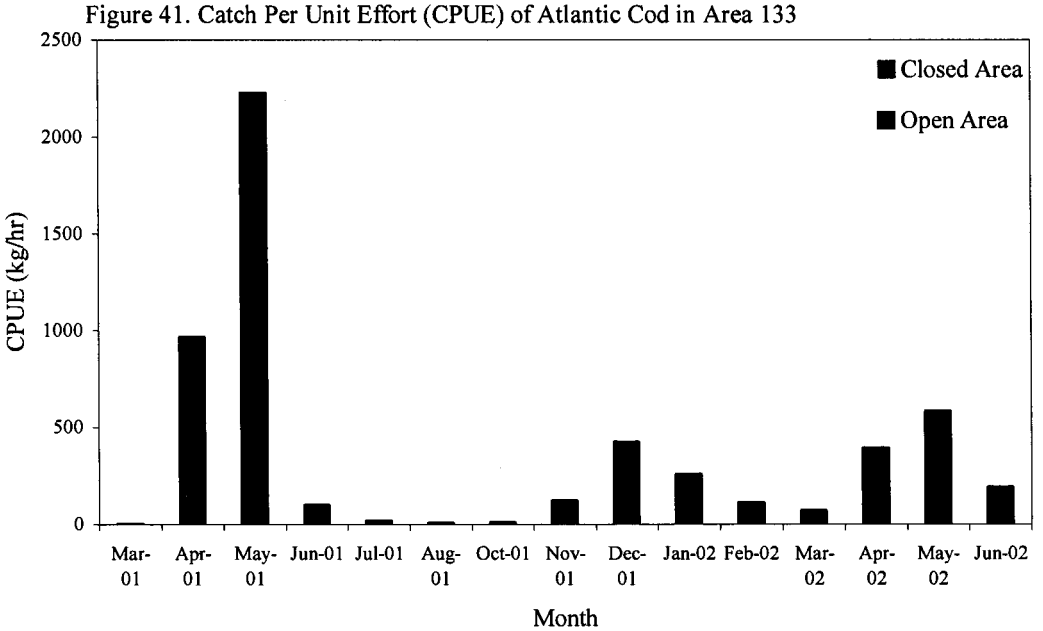
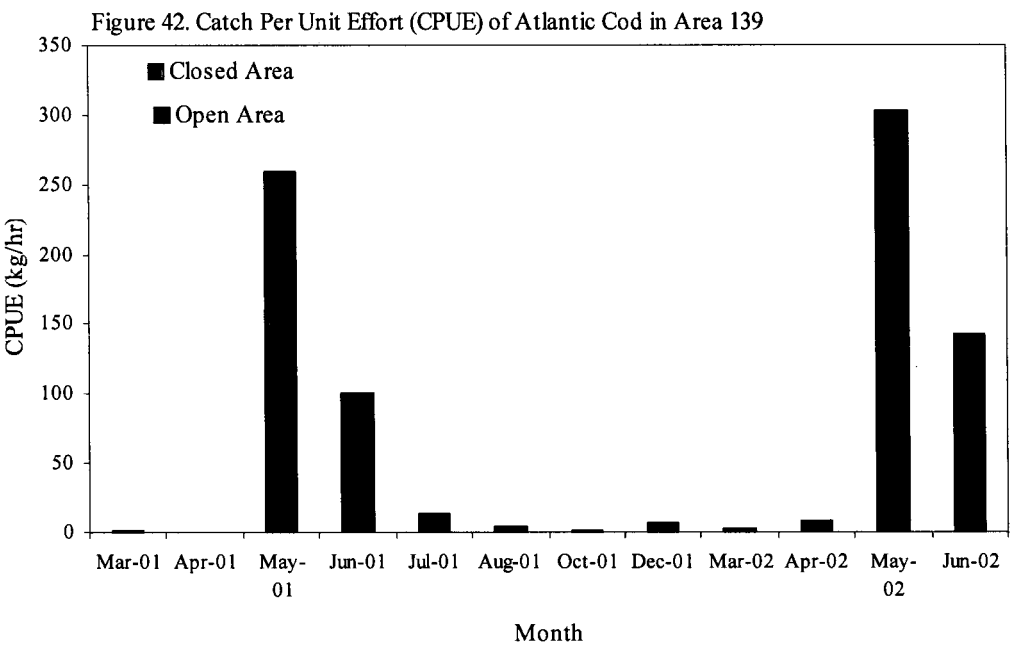


Figure 42. Catch Per Unit Effort (CPUE) of Atlantic Cod in Area 139



Analyses by Month

In addition to analyzing CPUE by area, I examined changes in CPUE between areas in a given month. Theses analyses were conducted in order to determine if there existed regional differences in Atlantic cod abundance throughout the year. Table 17 provides the mean and standard deviations of CPUE for all area/months sampled. Results of the analysis of variance and the pair wise comparisons are found on the CPUE graphs (figures 43-57). Values with like superscripts are not significantly different from each other while values with different superscripts are significantly different from one another.

In March 2001, area 132 had a significantly higher CPUE than areas 133 and 139. In April 2001, there was an increase in the CPUE for area 133 however, over all the areas, CPUE was not significantly different. In May 2001, there was an increase in CPUE for area 133, which was significantly different than areas 124, 132, and 139. In June 2001, the CPUE for area 132 was significantly different from area 124, with area 133 and 139 not being significantly different from both 132 and 124.

In July 2001, the CPUE was not significantly different between areas. In August, October, and November 2001, CPUE was highest in area 132 (62, 847, and 862 kg/hr respectively). In all three months, these relationships are significant. In December 2001, CPUE was significantly higher in area 133 than in area 139.

In January, there was no significant difference in CPUE between the two areas sampled. In February and March 2002, CPUE was significantly highest in area 133. CPUE for April 2002 was highest in areas 132 and 133, and lowest in area 139. In May 2002, as 2001, there was an increase in CPUE in area 133. However, CPUE was not

significantly different in area 133 than in areas 124 and 139. Area 132 had the lowest CPUE levels for this month. Finally, in June of 2002, there was no significant change in CPUE between the areas sampled.

Month	Area 124	132	133	139
Mar-01		33 ± 30	5 ± 9	1 ± 2
Apr-01	289 ± 197	105 ± 115	970 ± 1354	0 ± 0
May-01	138 ± 127	99 ± 86	2228 ± 2443	259 ± 235
Jun-01	8 ± 12	146 ± 104	99 ± 107	100 ± 135
Jul-01	160 ± 191	49 ± 48	18 ± 24	13 ± 15
Aug-01		62 ± 68	7 ± 60	4 ± 10
Oct-01		847 ± 436	10 ± 12	2 ± 3
Nov-01	262 ± 122	862 ± 390	124 ± 134	
Dec-01			424 ± 329	7 ± 8
Jan-02		90 ± 82	259 ± 359	
Feb-02		17 ± 30	112 ± 116	
Mar-02		13 ± 15	71 ± 79	3 ± 4
Apr-02		272 ± 396	396 ± 720	8 ± 16
May-02	246 ± 70	104 ± 104	584 ± 577	302 ± 419
Jun-02		155 ± 1	190 ± 253	142 ± 301

Table 17. Mean and standard deviations of catch per unit effort (kg/hr) for individual months over all the areas sampled.

Figure 43. Catch Per Unit Effort (CPUE) of Atlantic Cod in March 2001

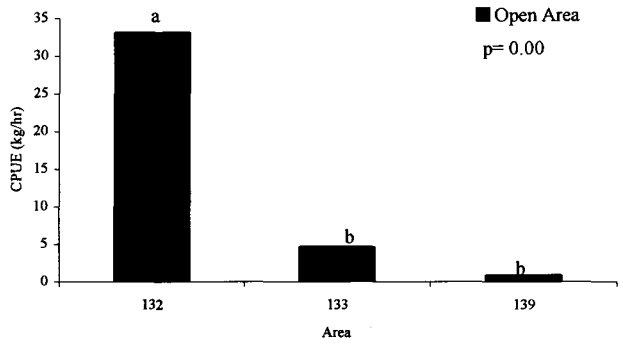


Figure 44. Catch Per Unit Effort (CPUE) of Atlantic Cod in April 2001

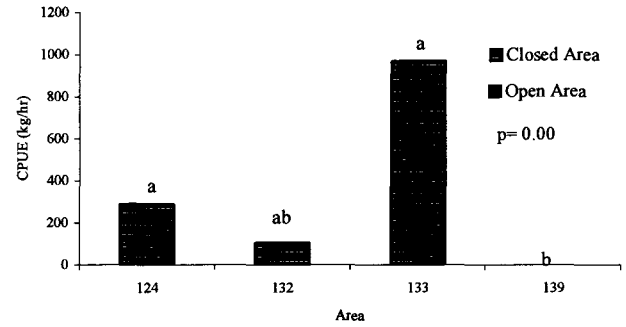


Figure 45. Catch Per Unit Effort (CPUE) of Atlantic Cod in May 2001

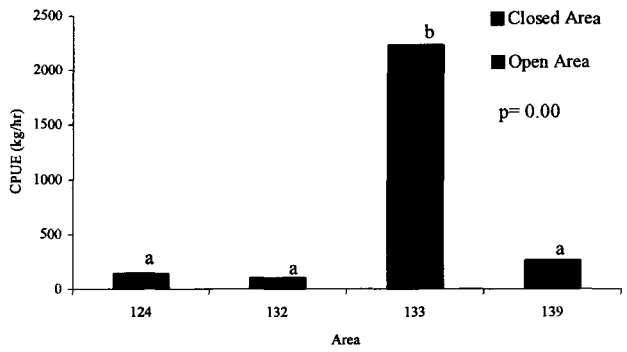


Figure 46. Catch Per Unit Effort (CPUE) of Atlantic Cod in June 2001

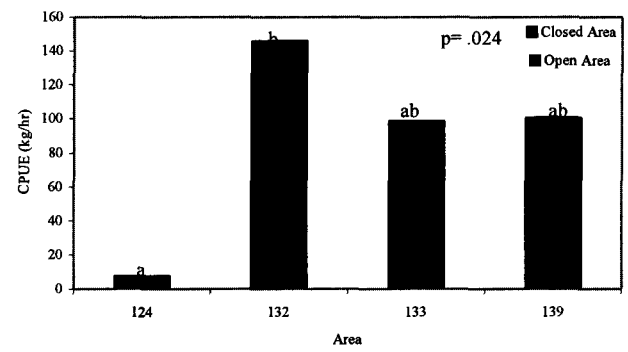


Figure 47. Catch Per Unit Effort (CPUE) of Atlantic Cod in July 2001

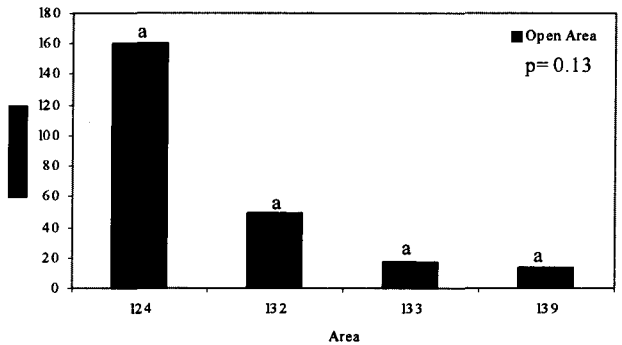


Figure 48. Catch Per Unit Effort (CPUE) of Atlantic Cod in August 2001

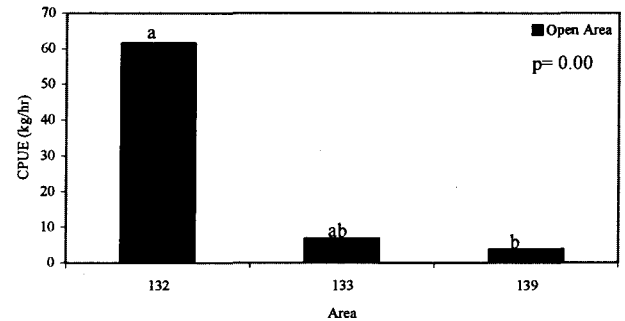


Figure 49. Catch Per Unit Effort (CPUE) of Atlantic Cod in October 2001

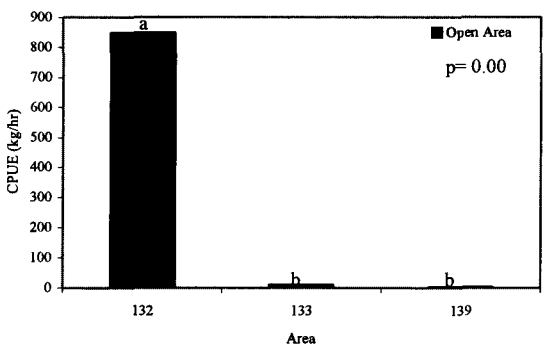


Figure 50. Catch Per Unit Effort (CPUE) of Atlantic Cod in November 2001

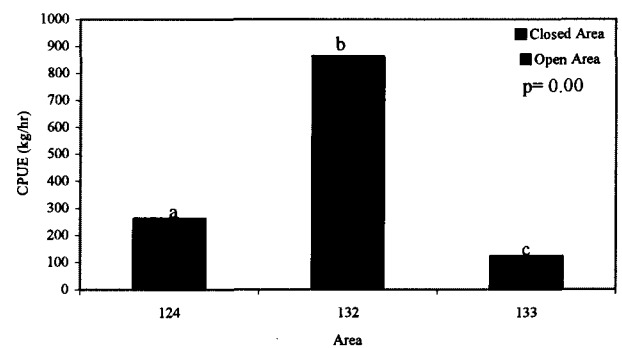


Figure 51.Catch Per Unit Effort (CPUE) of Atlantic Cod in December 2001

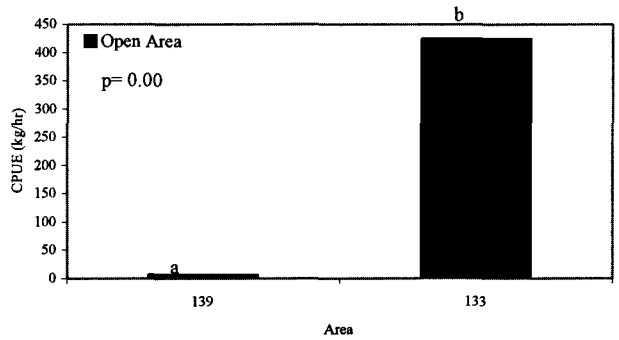


Figure 52. Catch Per Unit Effort (CPUE) of Atlantic Cod in January 2002

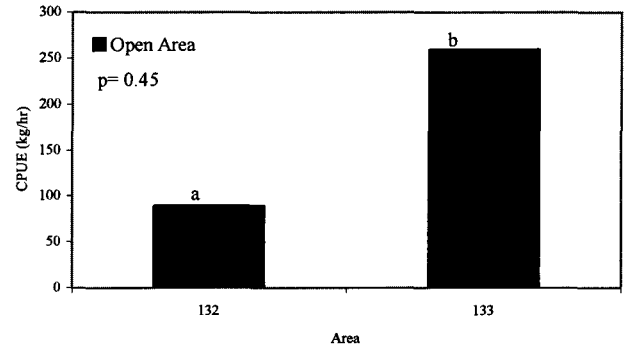


Figure 53. Catch Per Unit Effort (CPUE) of Atlantic Cod in February 2002

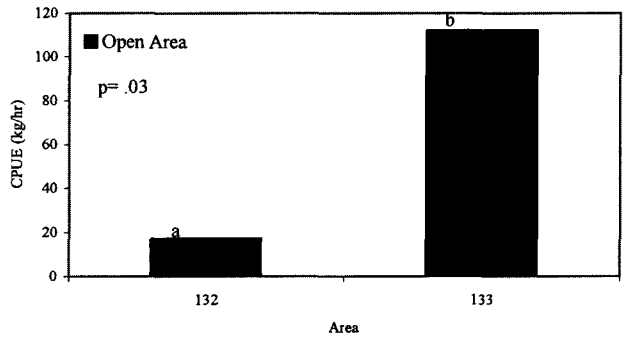


Figure 54. Catch Per Unit Effort (CPUE) of Atlantic Cod in March 2002

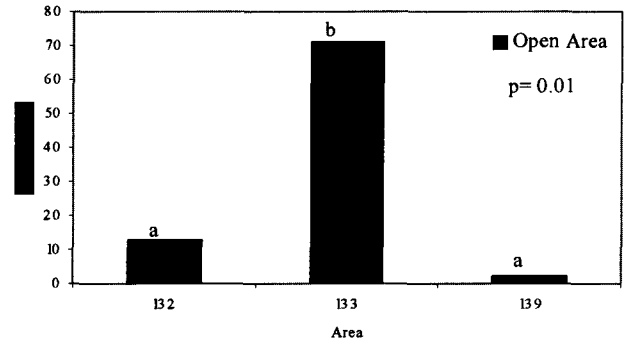


Figure 55. Catch Per Unit Effort (CPUE) of Atlantic Cod in April 2002

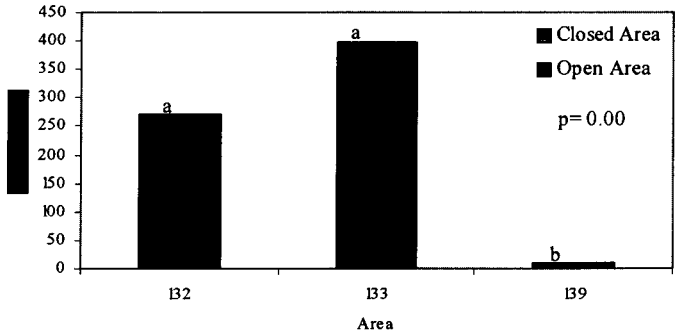


Figure 56. Catch Per Unit Effort (CPUE) of Atlantic Cod in May 2002

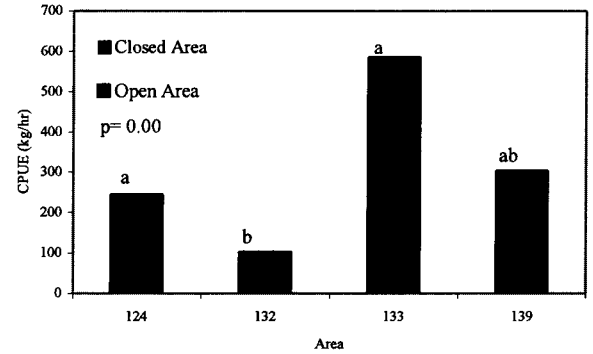
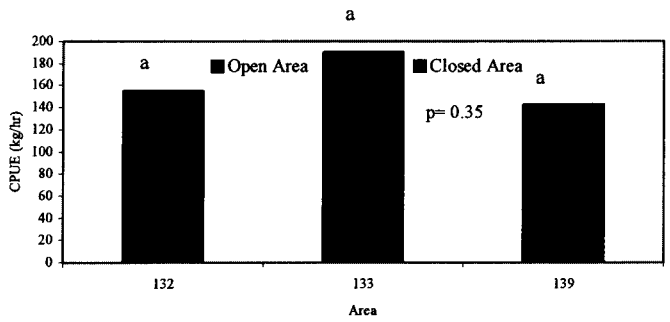


Figure 57. Catch Per Unit Effort (CPUE) of Atlantic Cod in June 2002



Length Statistics

Analyses by Area

Length-frequency histograms were generated for cod tagged in each area over all the months sampled (Figures 58-104). These histograms combined lengths from both males and females, as sex was not determined unless cod were spawning. An analysis of variance test was used to examine if there was a significant difference in the mean lengths of fish in a given area over all the months sampled. If a significant p-value was obtained ($p < 0.05$), then a Tukey's test was used to determine which months were significantly different from each other.

Table 18 provides the mean lengths and standard deviations for cod tagged in each area over all months sampled. Data are arranged in columns and analyzed separately according to area. Mean lengths are compared consecutively descending down a column. Values that are significantly different from each other are connected by bracketed arrows.

Beginning with area 124, there was a decrease in mean length from 59.2cm in February 2001 to 52.7cm in April 2001. Over the next three months sampled, there was no significant change in mean length. There was a significant increase in mean length from 48cm in June 2001 to 74.5cm in July 2001. The mean length then decreased significantly to 56.5cm in November 2001. Finally in May 2002, the mean length increased significantly to 60.8cm.

In area 132, there was no significant change in mean length from March 2001 to April 2001. In May 2001, mean length decreased significantly from 75.6cm the previous

month to 59.4cm. Over the next four months sampled, there was no significant change in mean length. In October 2001, mean length increased significantly to 65cm, from 52.3cm the previous month. There was no further change in mean length until February 2002, where mean length decreased to 46cm from 66cm in January 2002. Mean length then increased to 67.3cm in March 2002 with no further changes for the remainder of the study.

In area 133, mean length of cod in the first month of sampling (March 2001) was 70.1cm. There was no significant change in mean length between March 2001 and December 2001, although mean length decreased slightly to 66.5cm in November and December. In January 2002, mean length increased significantly, from the previous months, to 71cm. Mean length again increased in March 2002 to 81.9cm. Between April 2002 and May 2002, there was a significant decrease in mean length from 85cm to 78.2cm. Finally, mean length increased significantly to 87.7cm in June 2002.

Area 139 provides the least change in mean length over time. In May 2001, the mean length was 75cm. The mean lengths of fish did decrease slightly, although not significantly in the winter months. The only significant change is between April 2002 and May 2002, where mean length increased from 68.8cm to 78.9cm.

	124	132	133	139
Feb-01	59.2 ± 10.8			
Mar-01		70.6 ± 15.3	70.1 ± 14.1	
Apr-01	52.7 ± 6.8	75.6 ± 12.6	79.4 ± 12.8	
May-01	53 ± 6.3	59.4 ± 13.5	79.7 ± 12.8	75 ± 13.5
Jun-01	48 ± 11.6	58.8 ± 12.2	77.6 ± 16.1	78.6 ± 12.8
Jul-01	74.5 ± 8.7	54.9 ± 7.8	73.3 ± 15.9	78 ± 16.8
Aug-01		50.3 ± 10.9	78.8 ± 11.6	82.3 ± 18.2
Sep-01		52.3 ± 11.8		
Oct-01		65 ± 8.0	72 ± 9.7	64.3 ± 4.3
Nov-01	56.5 ± 10.2	66.9 ± 3.9	66.5 ± 7.8	
Dec-01			66.5 ± 8.3	70.4 ± 8.6
Jan-02		66 ± 10.0	71 ± 9.8	
Feb-02		46 ± 4.7	70 ± 8.8	
Mar-02		67.3 ± 8.3	81.9 ± 7.5	
Apr-02		65.6 ± 10.9	85 ± 9.9	68.8 ± 13.0
May-02	60.8 ± 9.9	65.3 ± 13.8	78.2 ± 14.5	78.9 ± 12.7
Jun-02		64.9 ± 11.8	87.7 ± 8.9	82.2 ± 10.8

Table 18. Mean length (cm) and standard deviation, of Atlantic cod tagged for each area and month sampled. Values analyzed within area over all months sampled and are read consecutively down a column. Values connected with an arrow are significantly different from each other.

Analysis by Month

Mean length was also analyzed over all areas sampled within a given month. Table 19 gives the means length and standard deviations for all cod tagged in each area over all the months sampled. Data is arranged in rows and analyzed separately by month. Values with like superscripts are not significantly different from each other while values with different superscripts are significantly different from each other.

There was no significant difference in the mean lengths for fish tagged in March 2001. In April 2001, all three areas sampled were significantly different in mean length with area 133 having the highest mean length of 79.4cm and area 124 having the smallest mean length of 52.7cm. For the months of May 2001 and June 2001, areas 133 and 139 had the highest mean length values. In both of these months, area 124 had the smallest mean length values (53cm and 48cm). In July 2001, the highest mean length values were found in areas 124, 133, and 139. None of these months were significantly different from each other. In August 2001, the largest fish were once again found in areas 133 and 139. From January 2002 through April 2002, the largest fish were found in area 133. In May 2002 and June 2002, the largest fish were found in areas 133 and 139. The smallest fish for the month of May 2002 were found in area 124 (60.8cm). The findings for May 2002 and June 2002 were consistent with the findings from May 2001 and June 2001, and suggest that there is little inter-annual variation on where the larger fish are located.

	124	132	133	139
Mar-01		70.6 ± 15.3^{a}	70.1 ± 14.1^{a}	
Apr-01	52.7 ± 6.8^{a}	75.6 ± 12.6^{b}	79.4 ± 12.8^{c}	
May-01	53 ± 6.3^{a}	59.4 ± 13.5^{b}	79.7 ± 12.8^{c}	75 ± 13.5^{d}
Jun-01	48 ± 11.6^{a}	58.8 ± 12.2^{b}	77.6 ± 16.1^{c}	78.6 ± 12.8^{c}
Jul-01	74.5 ± 8.7^{a}	54.9 ± 7.8^{b}	73.3 ± 15.9^{a}	78 ± 16.8^{a}
Aug-01		50.3 ± 10.9^{a}	78.8 ± 11.6^{b}	82.3 ± 18.2^{b}
Oct-01		65 ± 8.0^{a}	72 ± 9.7^{b}	64.3 ± 4.3^{ab}
Nov-01	56.5 ± 10.2^{a}	66.9 ± 3.9^{b}	66.5 ± 7.8^{b}	
Dec-01			66.5 ± 8.3^{a}	70.4 ± 8.6^{a}
Jan-02		66 ± 10.0^{a}	71 ± 9.8^{b}	
Feb-02		46 ± 4.7^{a}	70 ± 8.8^{b}	
Mar-02		67.3 ± 8.3^{a}	81.9 ± 7.5^{b}	
Apr-02		65.6 ± 10.9^{a}	85 ± 9.9^{b}	68.8 ± 13.0^{a}
May-02	60.8 ± 9.9^{a}	65.3 ± 13.8^{b}	78.2 ± 14.5^{c}	78.9 ± 12.7^{c}
Jun-02		64.9 ± 11.8^{a}	87.7 ± 8.9^{b}	82.2 ± 10.8^{c}

Table 19. Mean length (cm) and standard deviation, of Atlantic cod tagged for each area and month sampled. Values analyzed within months over all areas sampled and are read across a row. Values with like superscripts are not significantly different from each other. Values with different superscripts are significantly different from each other.

Figure 58. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged February 2001 in Area 124

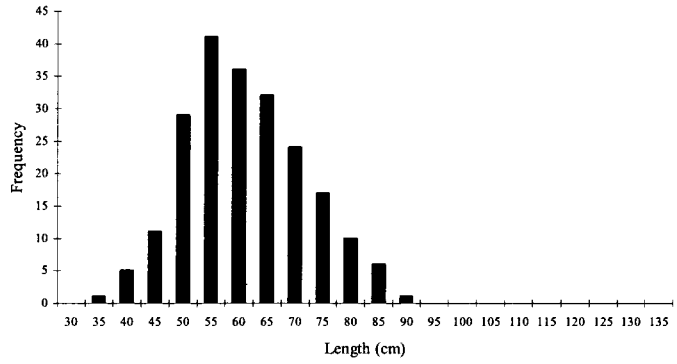


Figure 59. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged April 2001 in Area 124

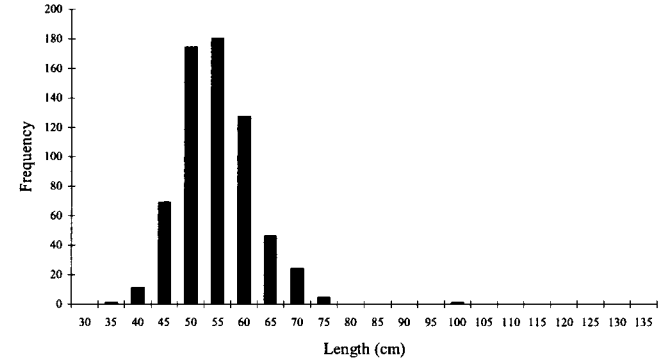


Figure 60. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged May 2001 in Area 124

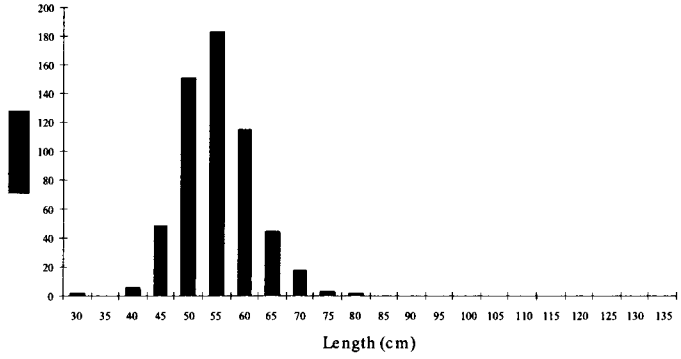


Figure 61. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged June 2001 in Area 124

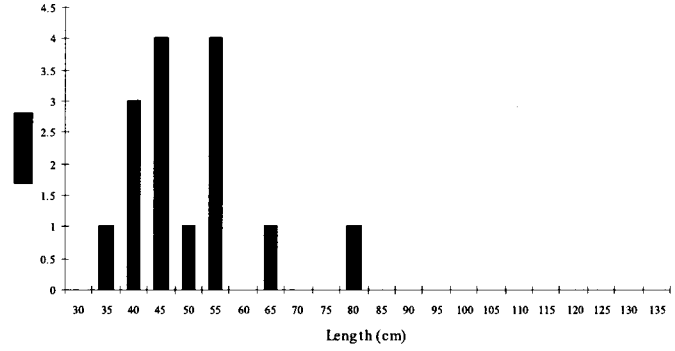


Figure 62. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged July 2001 in Area 124

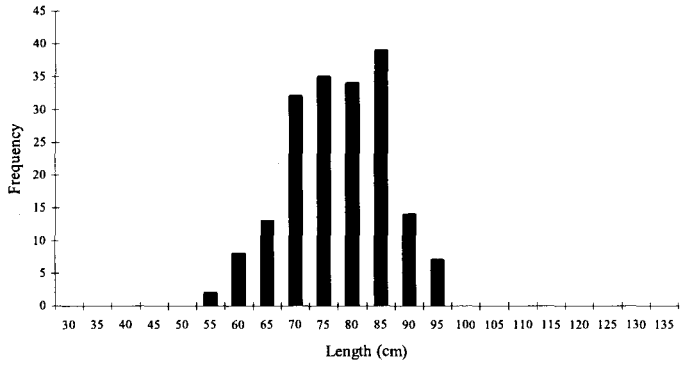


Figure 63. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged November 2001 in Area 124

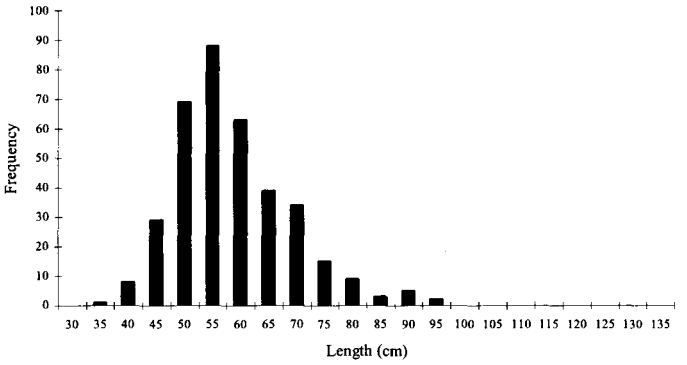


Figure 64. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged May 2002 in Area 124

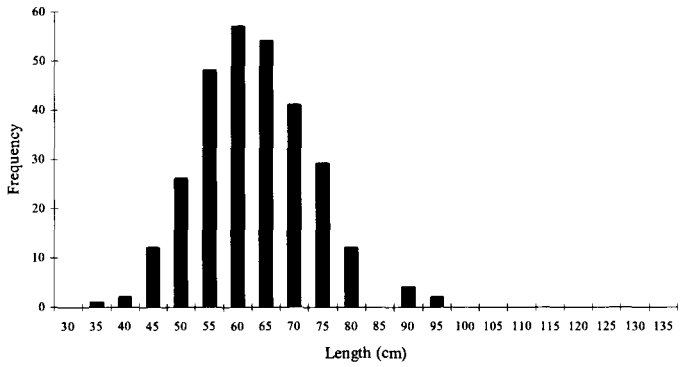


Figure 65. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged March 2001 in Area 132

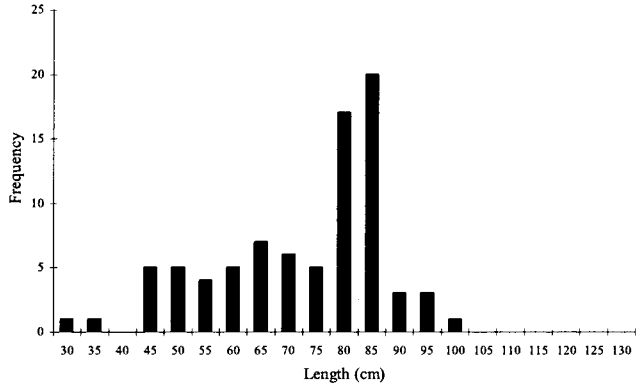


Figure 66. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged April 2001 in Area 132

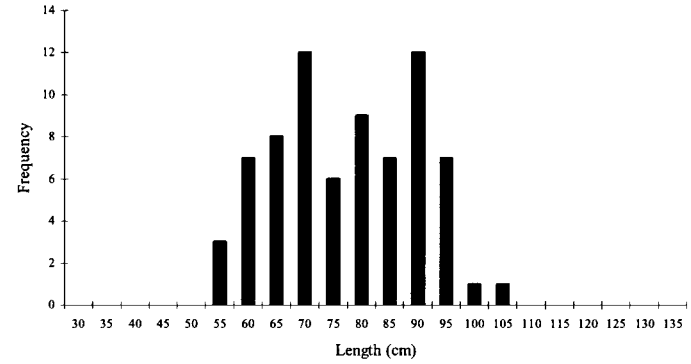


Figure 67. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged May 2001 in Area 132

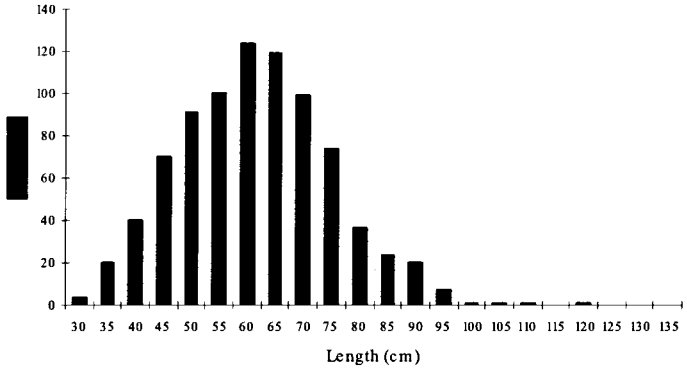


Figure 68. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged June 2001 in Area 132

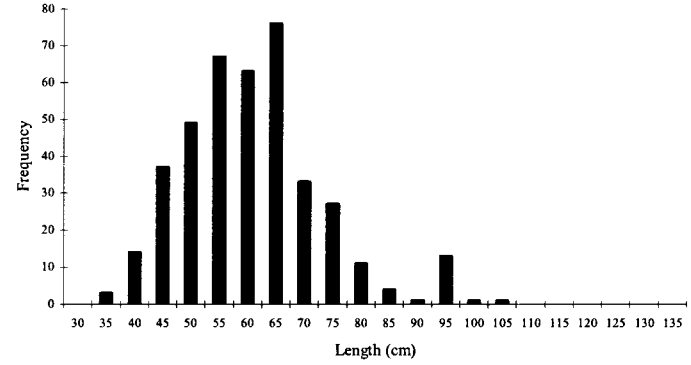


Figure 69. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged July 2001 in Area 132

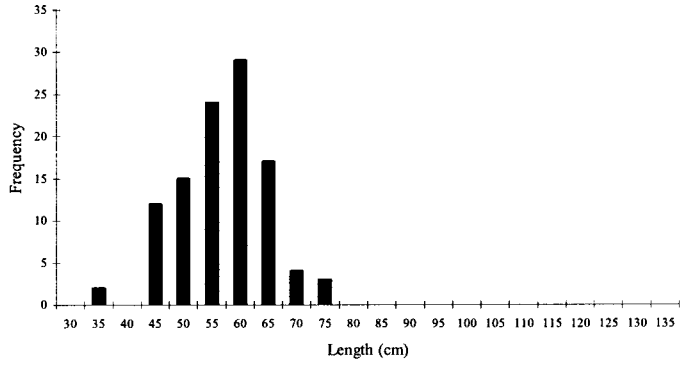


Figure 70. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged August 2001 in Area 132

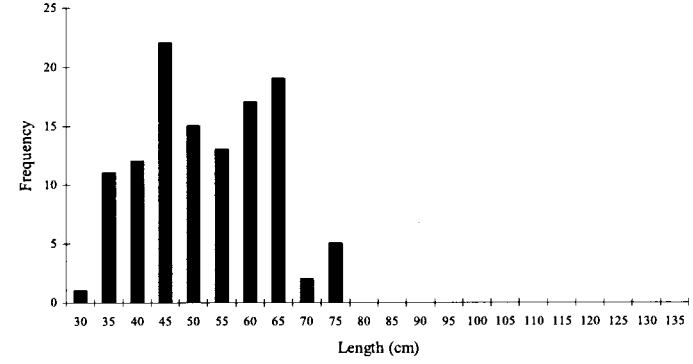


Figure 71. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged September 2001 in Area 132

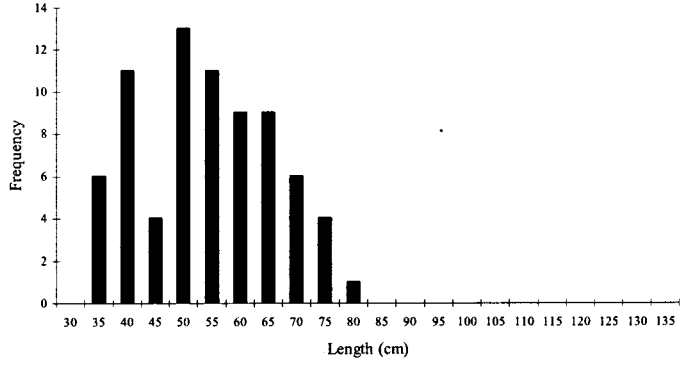


Figure 72. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged October 2001 in Area 132

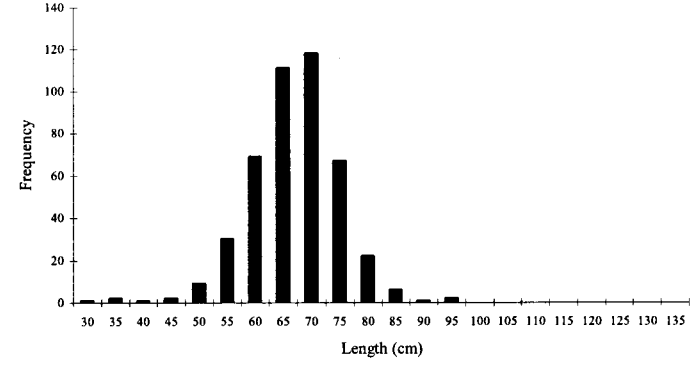


Figure 73. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged November 2001 in Area 132

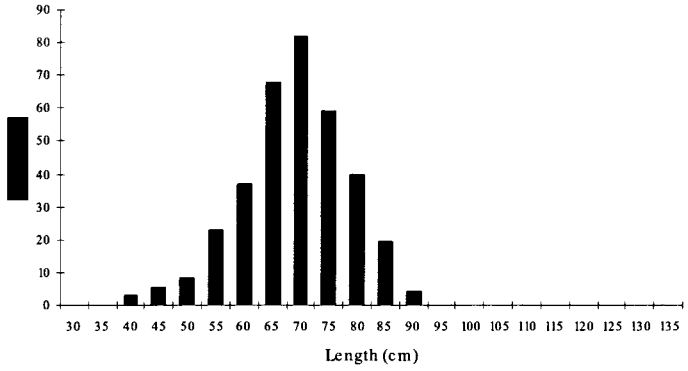


Figure 74. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged January 2002 in Area 132

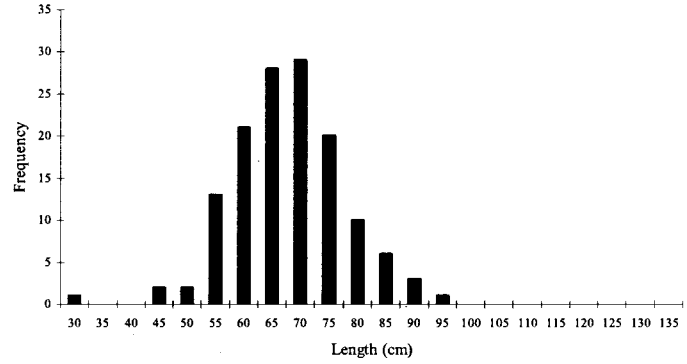


Figure 75. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged February 2002 in Area 132

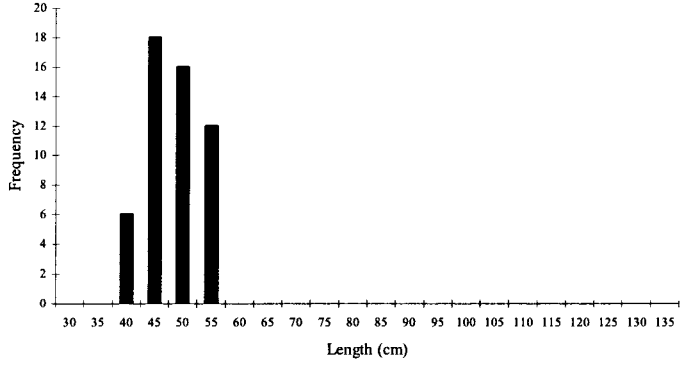


Figure 76. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged March 2002 in Area 132

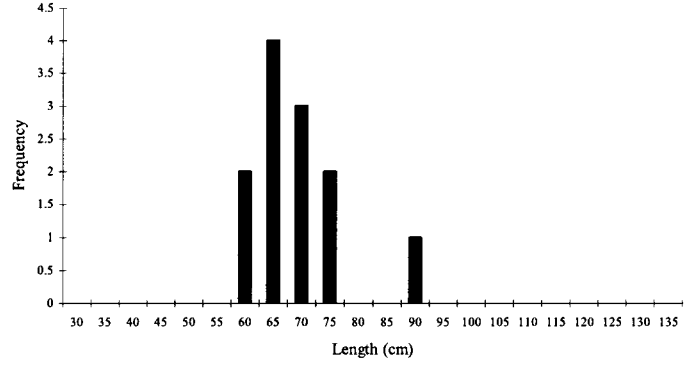


Figure 77. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged April 2002 in Area 132

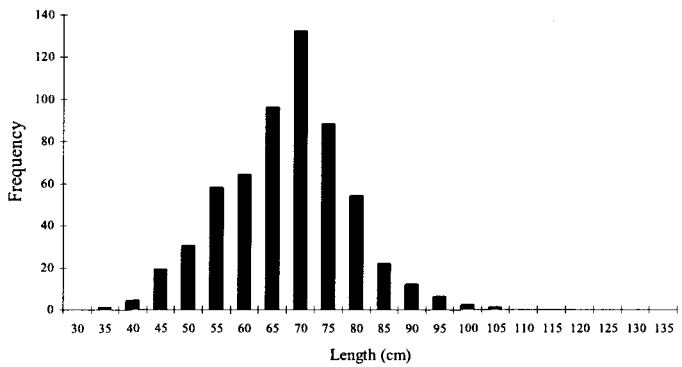


Figure 78. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged May 2002 in Area 132

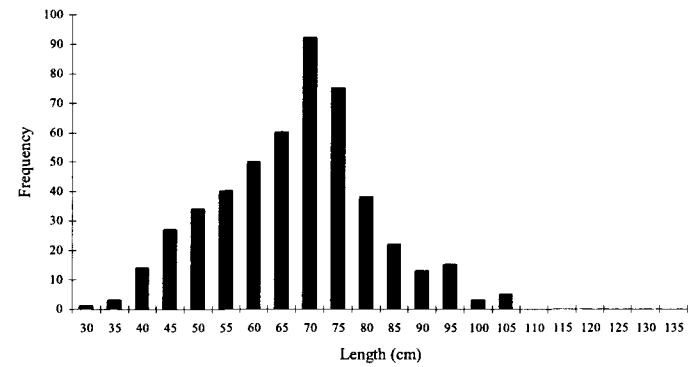


Figure 79. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged June 2002 in Area 132

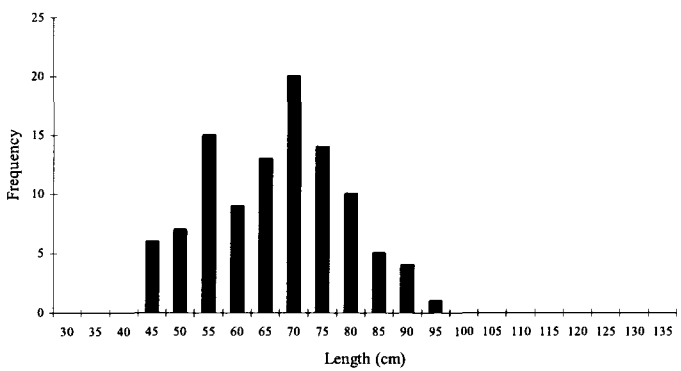


Figure 80. Length-Frequency Histogram for Atlantic cod (Gadus morhua)
Tagged March 2001 in Area 133

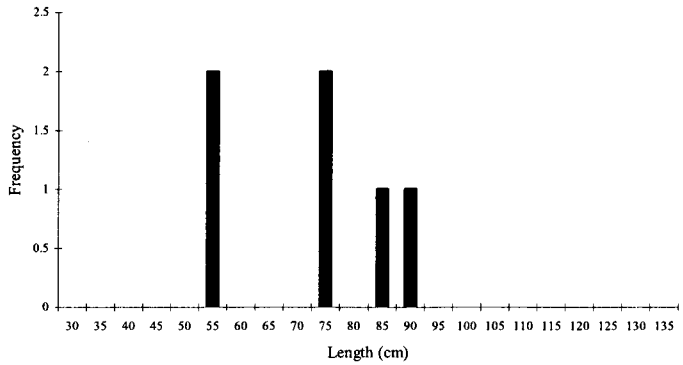


Figure 81. Length-Frequency Histogram for Atlantic cod (Gadus morhua)
Tagged April 2001 in Area 133

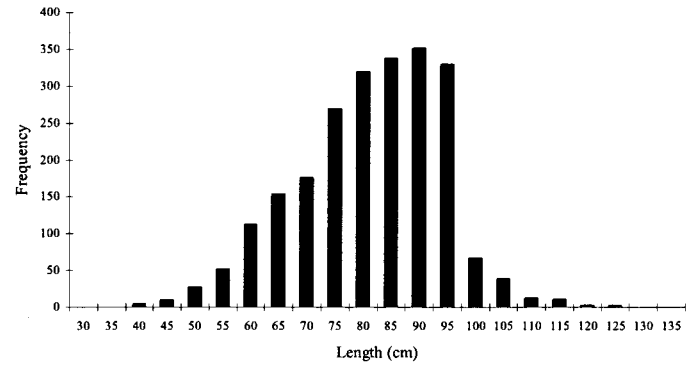


Figure 82. Length-Frequency Histogram for Atlantic cod (Gadus morhua)
Tagged May 2001 in Area 133

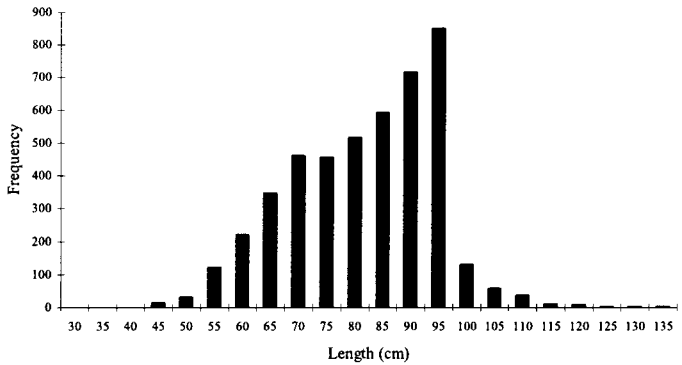


Figure 83. Length-Frequency Histogram for Atlantic cod (Gadus morhua)
Tagged June 2001 in Area 133

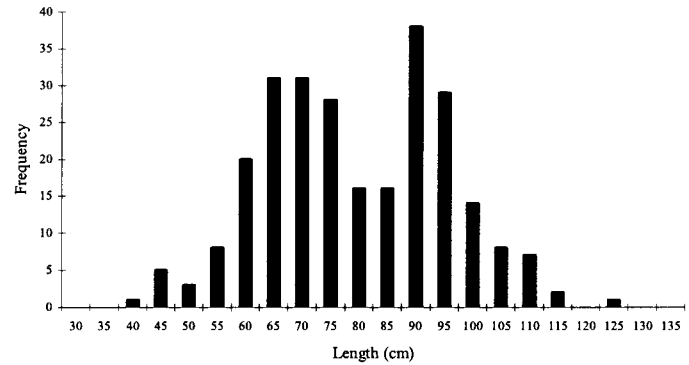


Figure 84. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged July 2001 in Area 133

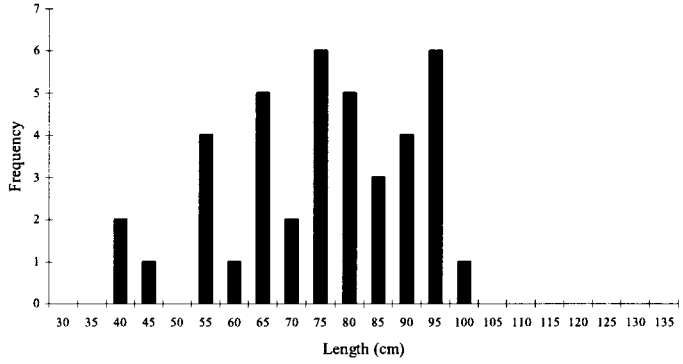


Figure 85. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged August 2001 in Area 133

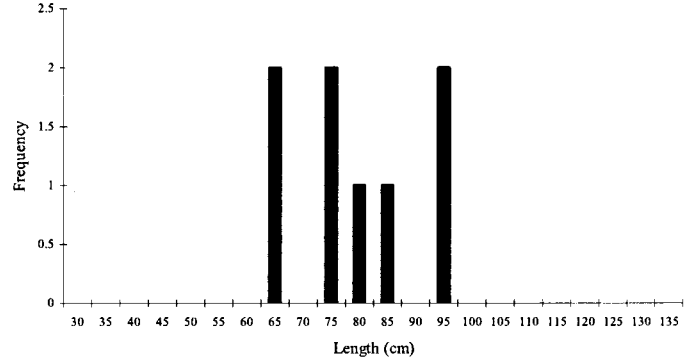


Figure 86. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged October 2001 in Area 133

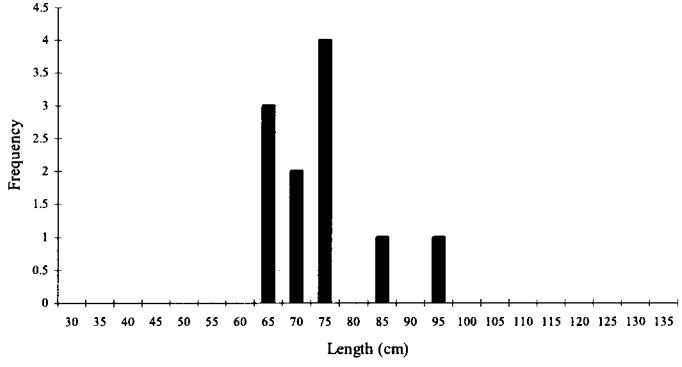


Figure 87. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged November 2001 in Area 133

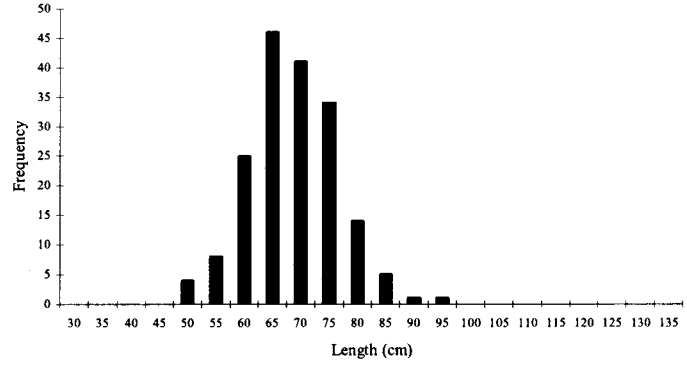


Figure 88. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged December 2001 in Area 133

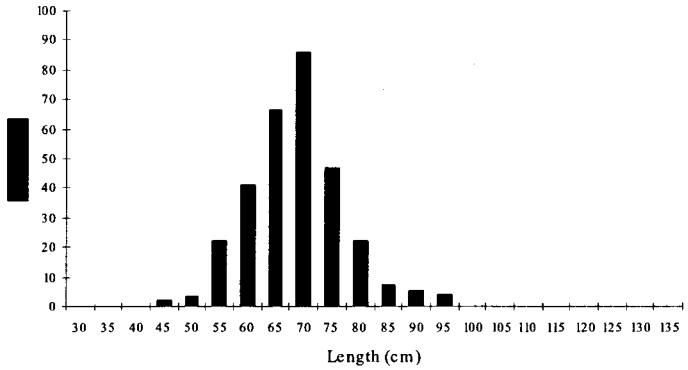


Figure 89. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged January 2002 in Area 133

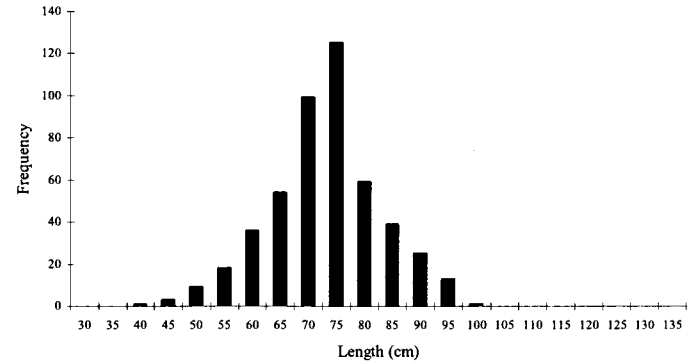


Figure 90. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged February 2002 in Area 133

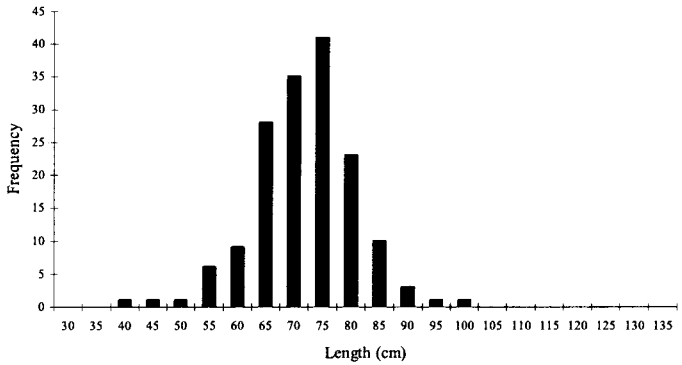


Figure 91. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged March 2002 in Area 133

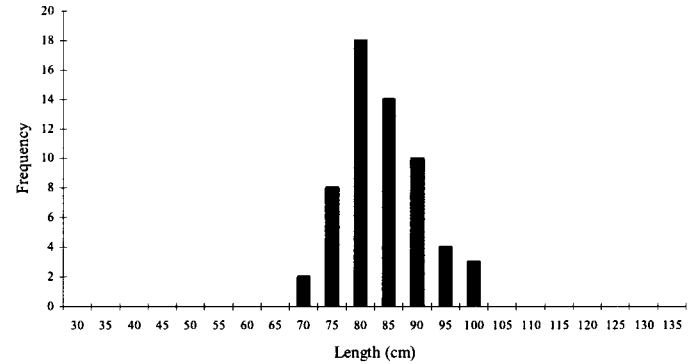


Figure 92. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged April 2002 in Area 133

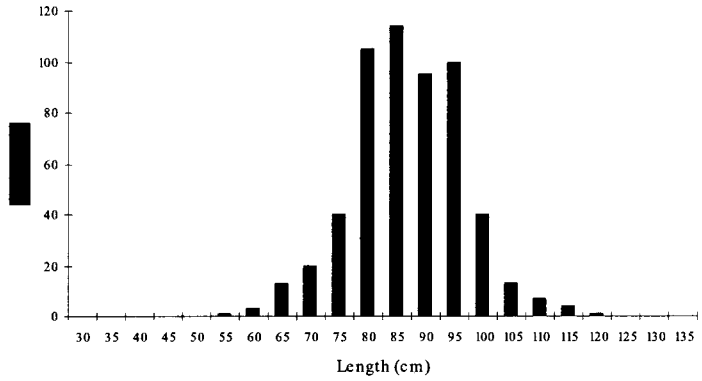


Figure 93. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged May 2002 in Area 133

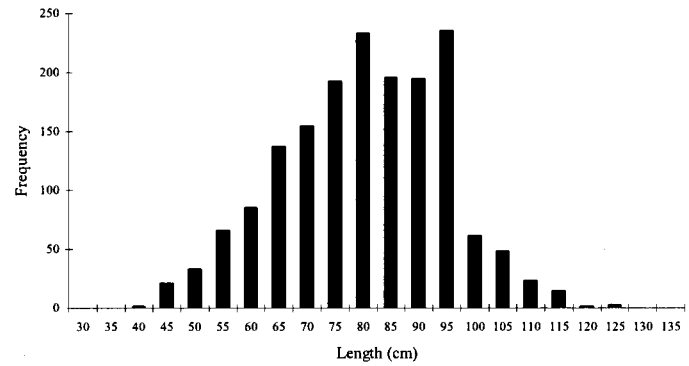


Figure 94. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged June 2002 in Area 133

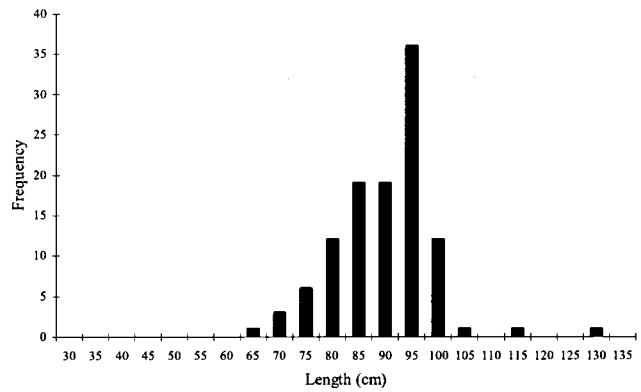


Figure 95. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged May 2001 in Area 139

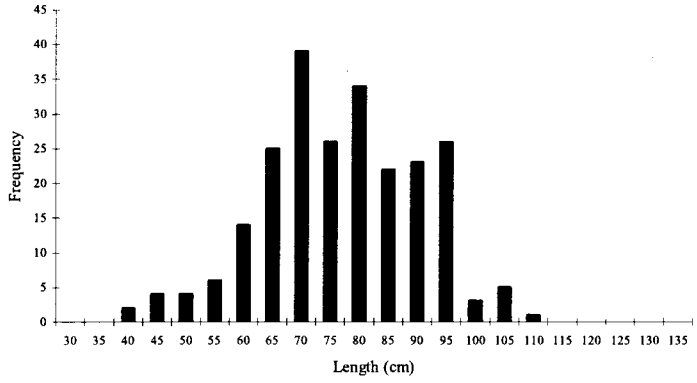


Figure 96. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged June 2001 in Area 139

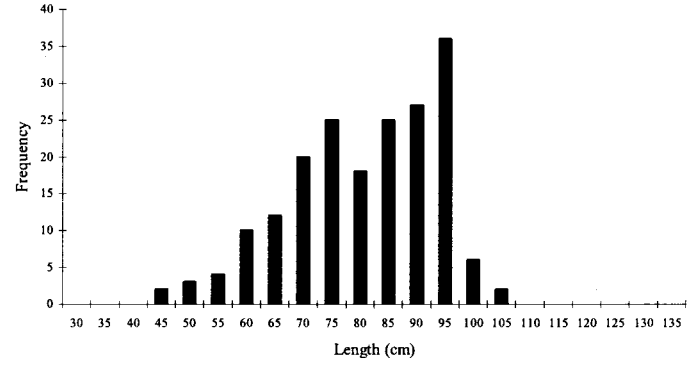


Figure 97. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged July 2001 in Area 139

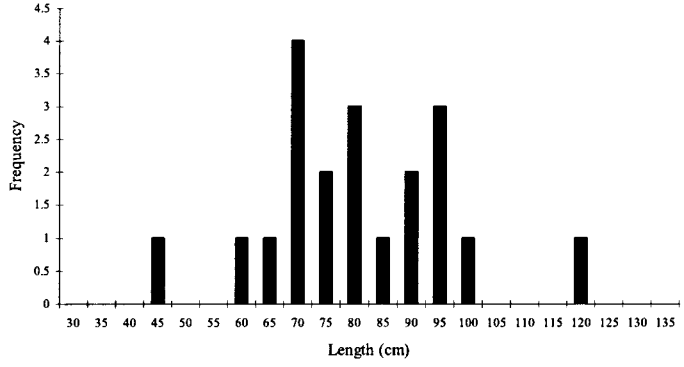


Figure 98. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged August 2001 in Area 139

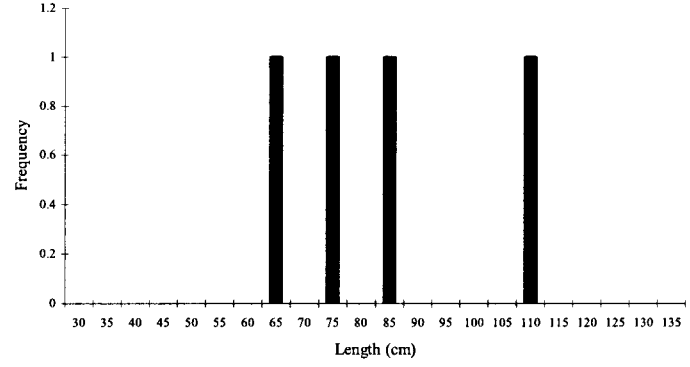


Figure 99. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged October 2001 in Area 139

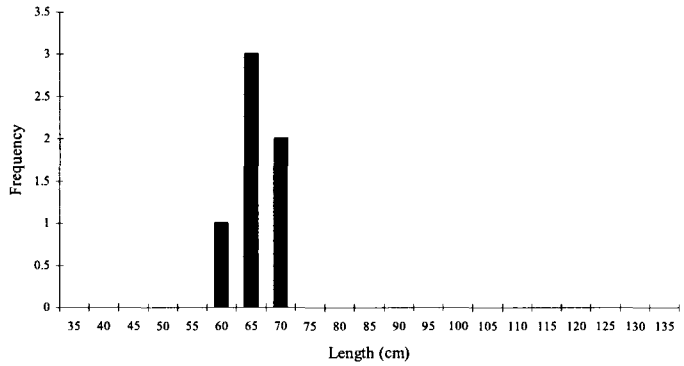


Figure 100. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged December 2001 in Area 139

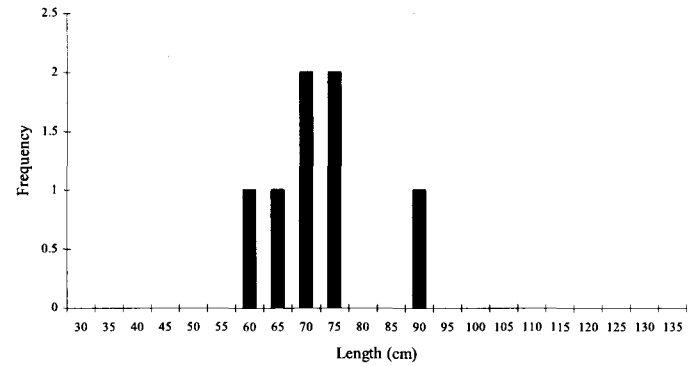


Figure 101. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged March 2002 in Area 139

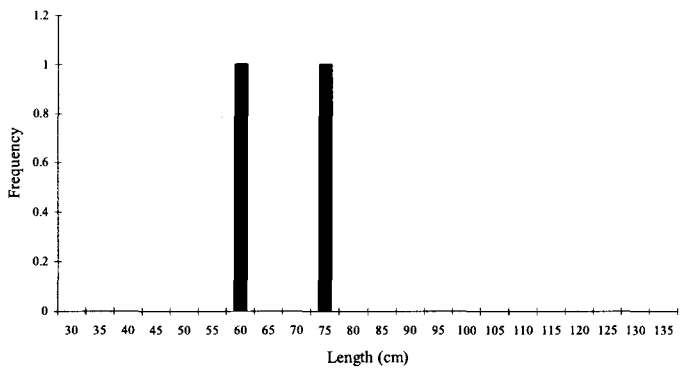


Figure 102. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged April 2002 in Area 139

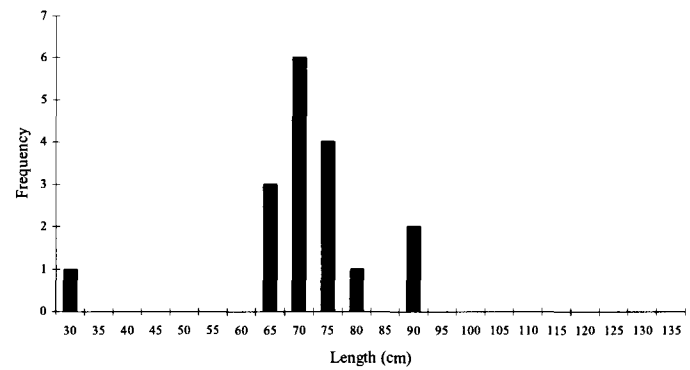


Figure 103. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged May 2002 in Area 139

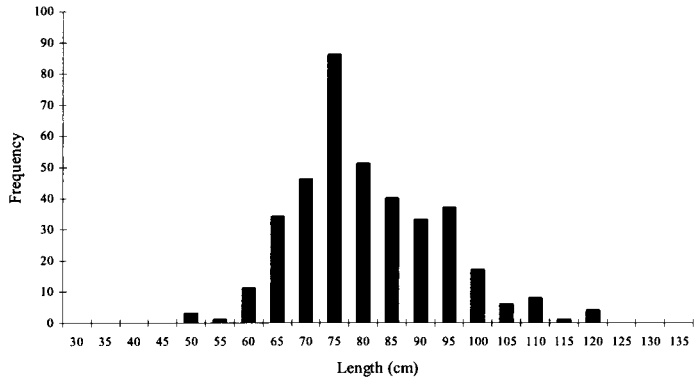
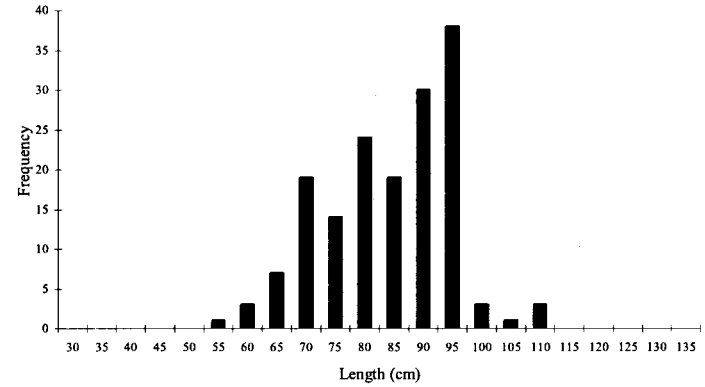


Figure 104. Length-Frequency Histogram for Atlantic cod (Gadus morhua) Tagged June 2002 in Area 139



Reproductive Length Statistics

Spawning cod were observed during three time periods in the course of the study. These spawning periods consisted of two spring spawning events (2001 and 2002) and one winter spawning event (2001). At each event, the number of male and female fish that were ripe was recoded as well as the length of each individual. An analysis of variance (ANOVA) was used to determine if the mean lengths varied between sexes and between spawning events. If a significant p-value was obtained with the ANOVA, a Tukey's test was used to determine which pair-wise mean lengths were significantly different from each other.

Ripe female fish were observed in the spring 2001 spawning event from April 27th and May 28th (Fig. 105) and had a mean length of 89.9 ± 15.0 cm. For the winter 2001-2002 spawning event, ripe female fish were observed from December 12th, 2001 to January 18th, 2002 (Fig. 106) and had a mean length of 75.4 ± 7.9 cm. For the spring 2002 spawning event, ripe female fish were observed from May 8th to May 22nd (Fig. 107) and had a mean of 90.5 ± 13.9 cm. Results of the ANOVA test suggested that there was a significant difference between the mean lengths for females ($p= 0.002$). Results of the Tukey's test suggested that females in both the spring 2001 and spring 2002 spawning events were significantly larger ($p= 0.003$ and $p=0.007$) than females in the winter 2001-2002 spawning event. However, there was no significant difference ($p= 0.99$) in the size of the ripe female cod between the spring 2001 and spring 2002 spawning event.

Ripe male fish were observed in the spring 2001 spawning event from April 3rd to

July 12th (Fig. 108) and had a mean length of 80.4 ± 11.5 cm. In the winter 2001-2002 spawning event, ripe male fish were observed from November 27th, 2001 to January 18th, 2002 (Fig. 109) and had a mean length of 75.05 ± 10.1 cm. For the spring 2002 spawning event, ripe male fish were observed from April 10th to June 29th (Fig. 110) and had a mean length of 81.2 ± 14.2 cm. Results of the ANOVA test showed that there was a significant difference ($p= 0.02$) among the mean lengths for males. The results of the Tukey's test showed that ripe males in the spring 2001 and spring 2002 spawning events were significantly larger ($p= 0.04 + 0.02$) than males in the winter 2001-2002 spawning event. Results also show that ripe males in the spring 2001 and spring 2002 spawning event were not significantly different ($p= 0.84$) in size from each other.

When the three spawning events were tested for seasonal variation in size of spawning fish with data from both sexes combined, results were consistent with the previous findings. The analysis of variance showed that there was a significant difference ($p= 0.001$) between the mean lengths for combined sexes for the three spawning events. The Tukey's test showed that Atlantic cod in both the 2001 and 2002 (Figs. 111 and 113 respectively) spring spawning events were significantly larger ($p< 0.002$) in their mean lengths than cod in the winter spawning group (Fig. 112). However, cod in both the spring spawning groups were not significantly ($p= 0.99$) different in size from each other.

Finally the mean lengths for males vs. females were tested for all three spawning events to determine if there were differences in size between the two sexes within a

spawning event. In the spring 2001 spawning event, the ANOVA showed that females (mean length 89.9 ± 15.0 cm) were significantly larger (p= 0.00) than males (mean length 80.4 ± 11.5 cm). For the winter 2001-2002 spawning event, the ANOVA showed that there was no difference (p= 0.90) between the mean length of females (75.4 ± 7.9 cm) and males (75.1 ± 10.1 cm). With the spring 2002 spawning event, the ANOVA showed that the mean length for females (90.5 ± 13.9 cm) was significantly larger (p= 0.01) than the mean length for males (81.2 ± 14.2 cm).

Figure 105. Length Frequency Histogram for Ripe Female Atlantic Cod Tagged Between April 27th, 2001 and May 28th, 2001

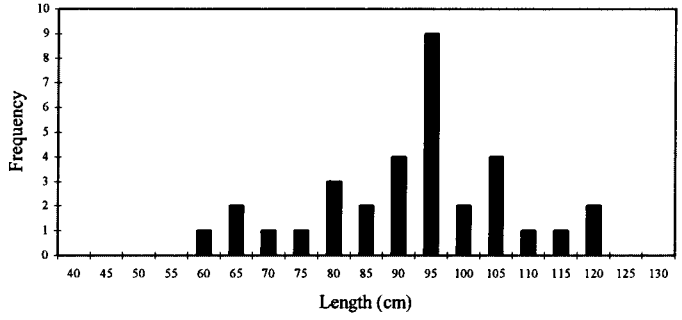


Figure 106. Length Frequency Histogram for Ripe Female Atlantic Cod Tagged Between December 12th, 2001 and January 18th, 2002

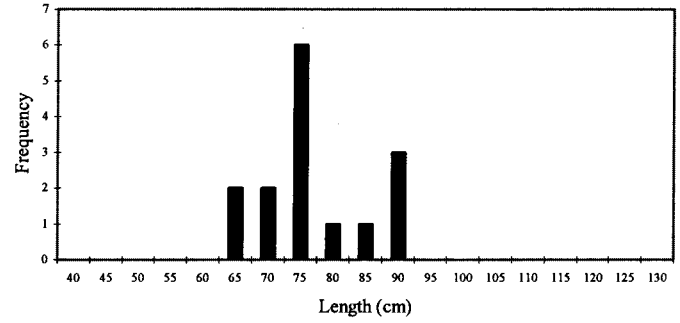


Figure 107. Length Frequency Histogram for Ripe Female Atlantic Cod Tagged Between May 8th, 2002 and May 22nd, 2002

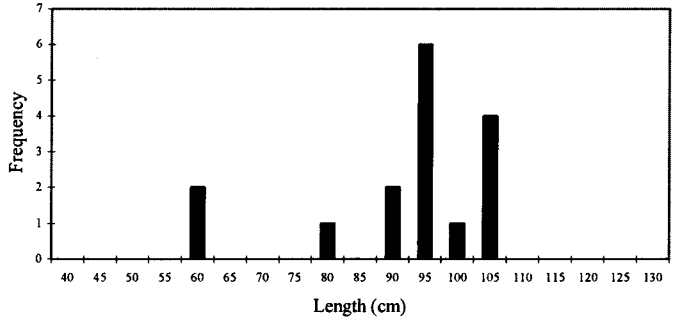


Figure 108. Length Frequency Histogram for Ripe Male Atlantic Cod Tagged Between April 3rd, 2001 and July 12th, 2001

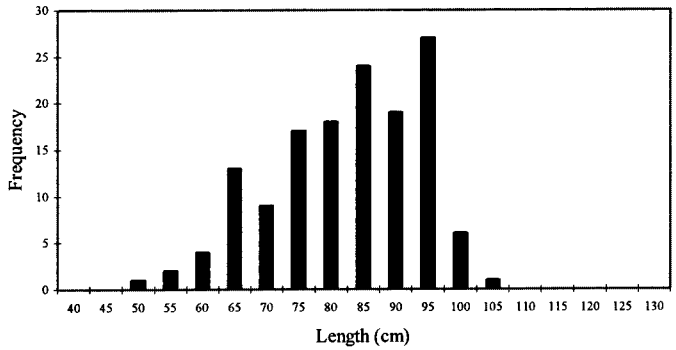


Figure 109. Length Frequency Histogram for Ripe Male Atlantic Cod Tagged Between November 27th, 2001 and January 18th, 2002

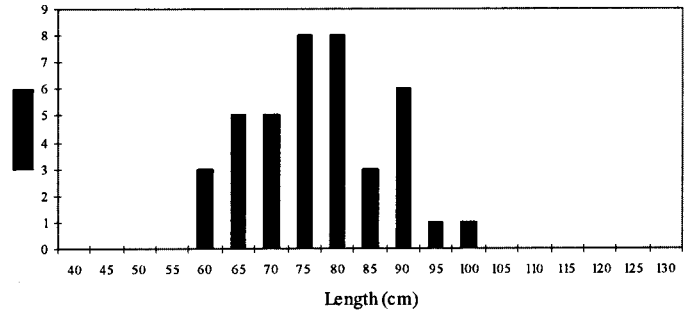


Figure 110. Length Frequency Histogram for Ripe Male Atlantic Cod Tagged Between April 10th, 2002 and June 29th, 2002

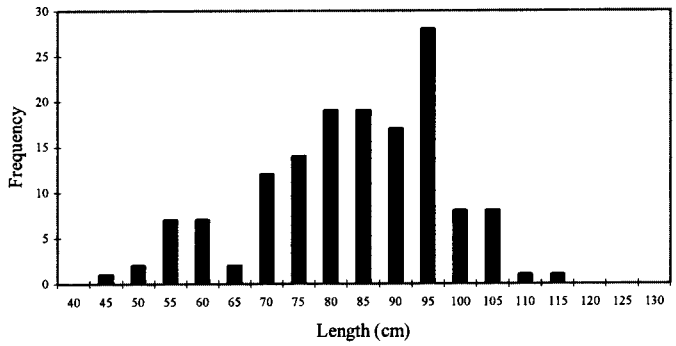


Figure 111. Length Frequency Histogram for Ripe Male and Female Atlantic Cod Tagged Between April 27th, 2001 and July 12th, 2001

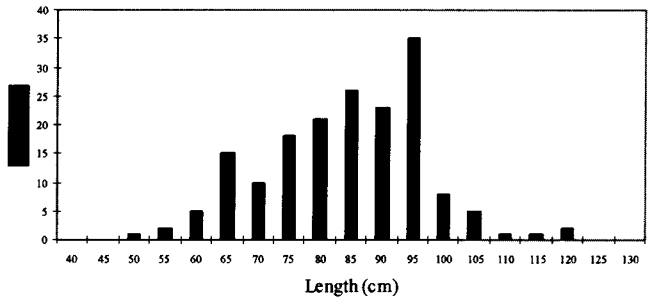


Figure 112. Length Frequency Histogram for Ripe Male and Female Atlantic Cod Tagged Between November 27th, 2001 and January 18th, 2002

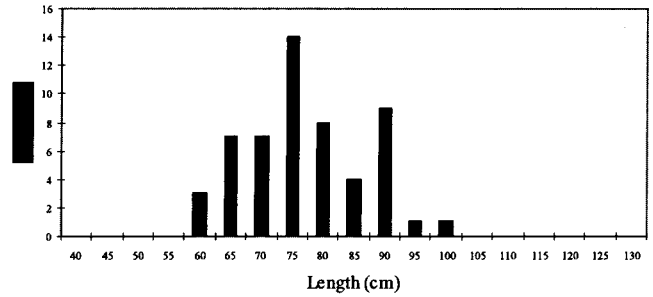
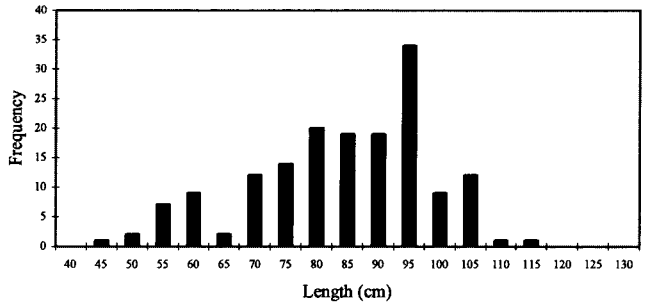


Figure 113. Length Frequency Histogram for Ripe Male and Female Atlantic Cod Tagged Between April 10th, 2002 and June 29th, 2002



DISCUSSION

Movement of Atlantic cod in the western Gulf of Maine

Fish movement can be categorized into three types: migratory, resident, and nomad (Attwood and Bennett 1995). Migratory movements involve directed, nonrandom movements to a specific location. Resident movements include localized movements within a species home range. Nomad movements consist of random, non-directional movements that are not correlated with any life history event (Attwood and Bennett 1995). Determining the type that best represents Atlantic cod movement in the western Gulf of Maine involved analyzing each individual component of movement to get an overall picture. With Atlantic cod, the components of movement examined were velocity, mean angle, and dispersion. Velocity and dispersion are both expected to be high with migratory movements due to directed movements away from an area. Conversely, these components are expected to be low with residential movements due to localized movement over time only, and variable with nomad (random) movements. Mean angle would be expected to be uniform within a population for migratory movement and random within a population for residential and nomad movement. Tracking via tagging is an effective way to determine which of the patterns best described the movement of fish, such as Atlantic cod, in the western Gulf of Maine. However, it should be noted that the tagging data represents patterns and trends in cod movement throughout the areas and does not give any specific movement rates. This is due to the

fact that the number of tag returns from an area is related to the level of fishing effort in that area (Hunt et al. 1999). This may create a bias in the number of tag returns if fishing effort differs between areas and over time.

Distribution of Atlantic cod in the northwest Atlantic differs based on age. Previous studies have shown that juvenile Atlantic cod may exhibit different distribution patterns than adults based on different feeding habits and habitat needs (Wigley and Serchuck 1992). In the present study, very few cod smaller than 40cm were caught, suggesting that all cod sampled were adults, as cod reach maturity between 32 and 41cm (Fahay et al. 1999). This suggests that all movement observed is representative of adult Atlantic cod.

A total of 1,086 Atlantic cod recaptures were obtained from March 2001 to October 2002. From this, 885 returns provided complete data including date, and exact location of recapture. The majority of these tag returns were obtained within two months of their release (Fig. 2). This pattern suggests that as fish disperse from an area the likelihood of recapture decreases. There was a small spike in the number of recaptures obtained between 362 and 442 days at large (Fig. 2). This is most likely due to the arrival of fish back inshore and the subsequent increase in fishing pressure, and suggests that cod return to the same locations each year, a concept suggested previously by Robichaud and Rose (2001).

Days at large, distance traveled, and length of fish were examined to determine if any of these factors were related. First, distance traveled and days at large were compared to determine if cod traveled further the longer they were at large. A significant

p-value suggested that there was a positive relationship between the two variables. However, the small R^2 value suggests that this relationship is not strong and the other factors may be affecting the overall distance traveled.

The relationship between total length of fish and days at large was examined to determine if larger fish remained at large longer than smaller fish, perhaps as a function of distance traveled. Results suggested that while there was a significant relationship between the two ($p < 0.05$), that relationship was not very strong ($R^2 = 0.03$). This suggests that factors other than size are affecting days at large. Finally, total length of fish was compared to distance traveled to examine if larger fish traveled further than smaller fish. Results of this linear regression suggested that there was no significant relationship between the two variables. Results of the three linear regressions suggest that both length and days at large are not significant factors in determining the distance traveled by cod. Analysis of movement patterns, via tagging, can better determine what factors affect distance traveled.

Based on the tagging results, movement of Atlantic cod in the western Gulf of Maine appears to be seasonal, and associated with spawning. Previous studies have also suggested cod movement to be seasonal in nature (Hunt et al. 1999 and Rose 1993). The seasonal patterns of pre-spawning, spawning, and post-spawning movement can be classified as a contraction (pre-spawning and spawning) and dispersion (post-spawning) of the stock.

Pre-spawning movements begin in the early spring, as cod move from areas offshore to a relatively localized area inshore in the western Gulf of Maine. Due to

limited tag returns outside of the western Gulf of Maine, it is not known how far offshore these cod come from. However limited data suggest that these fish come from areas to the northeast and east of Jeffery's Ledge. Pre-spawning movements are not likely made by fish tagged on Stellwagen Bank (area 124), as these fish either stayed in the area, or moved south (Figs 6a and 6b). Pre-spawning movements continue throughout the spring as cod aggregate first into area 132, and then move inshore into area 133. During this time, the biomass of cod continues to increase in area 133 as more cod move into this area.

Previous studies have identified cod spawning behavior as being concentrated in specific locations and during certain times of the year (Brander 1994; Rose 1993). The timing of spawning has been shown to be different depending on spawning location (Colton et al. 1979). Brander (1994) suggested that the timing and location of spawning may be linked to plankton production in order to ensure an adequate food source for juvenile fish Spawning movements in the western Gulf of Maine have been shown via tagging to occur in the spring and late fall. Spring spawning movements involve the continued inshore migration of the existing localized aggregation of cod in area 133 from May to June. In addition biomass, as shown through CPUE, also continues to increase in area 133 as more cod move into the area.

Post-spawning movements involved a generalized dispersion away from the spawning grounds beginning in the early summer. Based on tag returns, this dispersion is characterized by movement in a northeast, east, and southeast direction. The lack of evidence of any further inshore movement at this time may be due to the lack of fishing

effort in state waters (from the shore to 3 miles offshore). A similar patter was observed in Placentia Bay, Newfoundland. Tagging demonstrated that after spawning in the spring, cod dispersed east out of the bay. This was coupled with a decline in cod abundance inside the bay (Lawson and Rose 2000).

The same pattern of contraction and dispersion was again observed in the early winter in the western Gulf of Maine, although on a smaller scale when compared to the spring. In October and November, fish concentrated in area 132 then moved into area 133 in December and January to once again spawn. Upon spawning, fish again dispersed away from area 133, with recaptures coming mainly in area 132.

The overall movement pattern began again the following spring, suggesting that this may be a yearly cycle. The fact that cod which were tagged the previous year showed up in the same locations the following year suggests that Atlantic cod have the ability to home in on their spawning grounds. This was observed with fish tagged in Placentia Bay, Newfoundland. Cod were tagged during spawning season with long-term sonar transmitting tags that showed their ability to return to the same site the following year (Robichaud and Rose 2001). Lawson and Rose (2000) also showed that cod caught a year after being tagged in Placentia Bay, returned to the same spawning location.

Although Atlantic cod in the western Gulf of Maine are part of the same stock, two different movement patterns, migratory and residential, were observed based on the area and season of release. Cod tagged in areas 124 and 132 can be considered residential fish as they were found to remain primarily in the same area in which they were tagged. In addition, all but one of the months in the two areas (June 2001/Area 132)

had insignificant Rayleigh test values suggesting that movement was non-directional, or random in nature. The fact that movement was random within the same area and not random into other areas suggests that this is resident and not nomad movement. Also, both north/south and east/west velocities (Tables 3 and 4) were all low suggesting that fish are moving slowly within an area rather than moving rapidly through it. This pattern has been observed in other cod populations as well. McCracken (1956) observes that cod tagged inshore off of southwestern Nova Scotia remained inshore and did not mix with other populations.

Conversely, fish tagged as part of the spawning aggregation in area 133 displayed a more migratory movement. Upon spawning, movement was directed out of area 133 in a northeast, east, and southeast direction. In addition, the majority of significant Rayleigh test values were found in area 133, specifically around spawning and postspawning times (April-May and November-January). Also, for months with directed movement, higher north/south and east/west velocities (Table 5) were observed. This suggests that these movements out of area 133 are rapid movements that contain a significant directional component. The lack of fishing effort beyond this area caused a decrease in the number of tag returns from areas further away, but data still suggests that these fish move a great distance away from the spawning grounds.

Several other studies have shown the migratory nature of Atlantic cod. In Canadian waters, Hunt et al. (1999) report that there is movement of cod between the Bay of Fundy, inshore areas of southern Nova Scotia, Browns Bank, and Georges Bank. The greatest of these movements was between the offshore Browns Bank area and inshore

Browns Bank and the Bay of Fundy (Hunt et al. 1999). They also report some movement of cod across the U.S. and Canadian boundary on Georges Bank, but these movements were made close to the line and were based on only a few recaptures (Hunt et al. 1999).

Rose (1993) stated the existence of “migration highways” in the northwest Atlantic. These highways consisted of trenches of warm oceanic water that occur along the Newfoundland shelf. Through tagging, cod were determined to use these highways to move along the northeastern Newfoundland shelf during the spring feeding migrations, then move north during the summer. Tagging also suggested that cod make return migrations in the fall to the offshore parts of the highway.

In conclusion, movement of Atlantic cod in the western Gulf of Maine can be described as a contraction of the population into area 133 in the spring to spawn. This is followed by a post-spawning dispersion out of area 133 to areas offshore. This dispersion pattern away from an area was also observed in cod tagged in the Georges Bank area (Hunt et al. 1999). These factors suggest that cod in the Gulf of Maine area may not follow any specific geographic route, but rather other factors (either biological or non-biological) must exist that influence cod movement.

The factors governing these movements remain unknown. When size, days at large, and distanced traveled were compared, a weak relationship, or no relationship was found. The fact that there was no relationship between size and distance traveled and a weak relationship between size and days at large may be due to cod moving away from and returning to the same areas yearly. These relationships may also be due to some cod exhibiting migratory movements while other cod exhibited resident movements. It is

possible that the cod in the western Gulf of Maine may be using “migratory highways” to move in and out of the area, as was suggested by Rose (1993). It is also possible that timings of movement may be linked to plankton production as was suggested by Brander (1994).

Evidence of two separate spawning groups of Atlantic cod in the western Gulf of Maine

Atlantic cod are broadcast spawners that form dense aggregations (>1 fish m3) in a localized region (Bigelow and Schroeder 2002; Rose 1993). Cod are a highly prolific species in which a 50cm female is capable of producing 250,000-500,000 eggs (Bigelow and Schroeder 2002). Various spawning grounds in the U.S. northwest Atlantic Ocean include Georges Bank, Browns Bank, the Gulf of Maine, and the Nantucket Shoals region (Bigelow and Schroeder 2002; Colton et al. 1979). The timings of spawning have been historically reported as being either continuous throughout the year or at one distinct period of the year (Colton et al 1979; Fahay 1999).

During the course of the study, observations of cod in spawning condition (ripe) were made at two separate time periods in the western Gulf of Maine (area 133). Atlantic cod were first observed to be ripe from late April 2001 to mid-July 2001. This corresponds to a time period when cod have been historically observed

to spawn in this area. Atlantic cod were again observed to be ripe from late November 2001 to mid-January 2002. Finally, the spring-spawning cod were again observed from mid-April to the end of June when sampling in the study concluded. Since sampling was conducted regularly in these areas, it can be said with great certainty that there was no temporal overlap between the observations of ripe fish. This suggests that there may be two separate groups of fish that spawn in area 133.

As previously stated, Atlantic cod aggregate in large numbers to spawn (Rose 1993). This aggregation would cause a spike in the catch-per-unit-effort. The graph of catch-per-unit-effort for area 133 (fig 40), illustrates that there were 2 spikes in catch-per-unit-effort. These occurred in April-May and in December-January; both times when ripe cod were present. It should be noted that the biomass of fish was larger in the spring than it is in the winter suggesting that the spring spawning group is the larger, in numbers, of the two.

Fish eggs and larvae were collected from ichthyoplankton sampling conducted through the Seabrook station environmental monitoring program. They observed that Atlantic cod eggs were abundant in both the spring and late fall/winter. Atlantic cod larvae also showed a bimodal annual occurrence. Larvae peaked in abundance between November and February and again from April to July. It was also noted that the April to July peak was larger then the fall/winter peak (Normandeau Associates 2002) This pattern of egg and larvae abundance mirrors the pattern of adult spawning behavior observed in the present study, and suggests that Atlantic cod spawn at two distinct periods of the year, spring and

fall/winter, with the spring spawners occurring in larger numbers.

Tagging, also showed two inshore movements at separate times of the year. In the spring cod moved from area 132 into 133 starting in March and aggregating in area 133 by May (figs 10a, 10b, 11a, 16a, and 16b). Cod again moved from area 132 and aggregating in area 133 in January (figs 14 and 19b). These data suggest that Atlantic cod are moving into area 133 to spawn at two separate times of the year.

Tagging had also been used to examine the spawning behavior of Atlantic cod in Icelandic waters (Thorsteinsson and Marteinssdottir 1998). Data storage tags (DST) were used to record the depth of the fish during the study. Since Atlantic cod move into shallow water to spawn, researchers were able to determine the timings of spawning by observing when cod move into shallow water. Those DST's that were in the water for more than one year displayed two distinct periods of movement into shallow water. These movements coincided with known spawning times, and the researchers concluded that the movements were associated with spawning. One cod tagged on the main spawning grounds in April 24th, 1996 stayed at that spawning depth for a period of several weeks before moving into deeper water. The same fish again moved into shallow water on February 17th, 1997 and remained there until April where it again moved into deeper water. These data supports the present studies conclusion that Atlantic cod spawn at two distinct time periods of the year, and also suggests that this may not by just a localized phenomenon in the western Gulf of Maine.

To determine if these were two separate groups of cod, or simply the same group spawning twice, average length was compared. Results showed that both the spring 2001 and 2002 groups had a significantly larger average size than the winter spawning group, suggesting that these are two different age groups of fish. Bigelow and Schroeder (2002) suggest that first time spawners breed for a shorter period of time, produce fewer egg batches, and are more likely to spawn in less optimal environmental conditions when compared to more experienced spawners. It is possible that the smaller sized winter spawners represent an inexperienced group of spawning fish. However, cod are documented to become mature at approximately around 32cm and 36cm for females and males, respectively. The smaller sized group of cod in the winter had an average size of 75.4cm and 75.1cm for females and males respectively. These fish are over 40cm larger than what is documented for first time spawner length and suggests that this group of cod may not be first time spawners. Due to this, there must exist other factors that warrant this smaller sized group of cod to spawn at a different time than the larger sized cod. One factor may be the possibility that two genetically different cod stocks are using the same area to spawn. Preliminary DNA finger printing data on these two groups suggests that these are not genetically different stocks (Berlinsky, unpublished). Given that these may not be separate stocks, the observed bimodal peaks in spawning may have resulted from differences in spawning behavior. One possible explanation for smaller cod spawning at a different time may be that they experience less competition with larger fish for space and other resources. The existence of two spawning groups may also be due to a behavioral response to overexploitation. Populations at low levels may benefit by

increasing the number of spawning events.

Future research should address these issues, as well as examine the factors driving this second spawning season composed of smaller Atlantic cod.

Evaluations of the western Gulf of Maine rolling closures

While closed areas may help to reduce fishing mortality, they are only effective if fish remain in them. Due of this, examining the movement of fish in and out of a closed area is important in determining its overall effectiveness (Appeldoorn 1997; Guenette et al. 2000; Ingram and Patterson 2001; Martell et al. 2000; Roberts 2000; Russ and Alcala 1996; Zeller and Russ 1998). A closure would be considered effective if movement of the protected species was minimal, as is the case with sedentary species (Zeller and Russ 1998; Roberts 2000; Ingram and Patterson 2001; Martell et al. 2000). Conversely, a closure would be less effective if it was designed to protect a highly migratory species and only protected that species during a small portion of its life (Roberts 2000). One way to deal with the problem of fish movement across closed area boundaries is through implementing a rolling closure system that mirrors fish movement.

In the western Gulf of Maine, rolling closures were implemented by the New England Fishery Management Council to protect Atlantic cod as they moved through the areas. Their original intent was to act as a measure to protect the spawning aggregations of Atlantic cod. Species, like Atlantic cod, that aggregate in large numbers to spawn are

highly susceptible to over exploitation due to the fact that they remain highly concentrated within a specific area. So given that catchability would be high, they may benefit from a spawning closure (Roberts 1998). Spawning closures have been utilized to protect species including haddock and several species of reef fish (Halliday 1998; Beets and Friedlander 1998; Koenig et al. 2000). In the U.S. Virgin Islands for example, fisherman historically have targeted spawning aggregations of red hind. As a result of overfishing, a decrease in average size and a heavily skewed sex ratio was observed in the population. In 1990, a spawning closure was implemented to reverse the effects of overfishing. By 1997, researchers observed that the average size had increased and the sex ratio changed back to a pre-exploited level (Beets and Friedlander 1998). This suggests that the spawning closure has had a positive effect on restoring the population of red hind to a pre-exploited state.

In the northwest Atlantic, a spawning closure was implemented in the 1970's to reduce fishing pressure on haddock. Spawning closures were implemented on Brown's Bank, George's Bank, and in the Gulf of Maine (Halliday 1998). The intent was to close areas during times when catch rates were historically high. This correlated to March and April, months in which haddock aggregate to spawn. While closing an area when catch rates are historically high can be a way to lower fishing mortality, no specific information was reported on the effect of the haddock spawning closures. In fact, Halliday (1998) reported that no data were available to judge whether or not the haddock spawning closures had any positive effect.

Since fishing mortality on Atlantic cod is still considered to be too high, rolling

closures were expanded to further reduce fishing effort on the spawning aggregations. The effects of using a closure to control fishing effort were modeled on Georges Bank by Holland (2000). Modeling suggested that closing an area to fishing might result in rapid reductions in fishing mortality. This would essentially shift fishing effort to areas with lower catch rates and thus reduce the overall fishing mortality. Closing areas to control fishing effort was also examined for other groundfish species on Georges Bank. It was determined that while reductions in fishing mortality on groundfish were observed, the closures had a greater benefit to the more sedentary species such as scallops (Murawski et al. 2000).

The timings of the western Gulf of Maine rolling closures have been changed several times since their implementation, with the intent to make them more effective. This included a timing change during the course of the study. This timing change allowed for the examination of the effectiveness of two scenarios, and to determine which scenario, if any, best reflected the actual movement of the fish. In the initial stage of the study, areas 125 and 124 were closed January through April and October through November. Through an emergency action taken by the New England Fishery Management Council, the months closed were changed to April through May and October through November. Areas 133 and 132 were initially closed April and May, but as a result of the same emergency action, the month of June was added. Areas 140 and 139 were initially closed May and June, and were not changed with the emergency action.

At the beginning of this study, the rolling closures began initially in areas 125 and

124 between January and April. Tagging in these areas during this time demonstrated that Atlantic cod remain mainly within these areas (figs 6a and 6b). Catch-per-unit-effort levels were also among the higher levels observed for this area. Tagging in the areas to the north showed movement between areas 133 and 132 in January and February (figs 14 and 19b), and movement again into area 133 in March and April. No movement was observed from fish tagged in areas 133 and 132 into the southern closed areas. This suggests that no fish were moving into or out of these areas during the closed period, and suggests that the closures were achieving their desired effect for this time period.

Catch-per-unit-effort levels decreased as areas 124 and 125 (fig. 38) reopened in May, and remained at lower levels throughout the summer. Tagging in May and July again illustrated that Atlantic cod primarily remained within the area (figs. 7a and 7b). However, while there was no movement out of these areas, there was substantial movement into these areas from cod tagged in areas 133 and 132 undergoing post-spawning movement away from these areas (fig 16a and 16b). In this case, cod were moving from an area closed to fishing, into an area open to fishing, which is contrary to the desired effect. Overall however, the data shows that CPUE in this area was decreasing despite the influx of cod into area 124. Thus, if the desired effect is to provide 100% protection to a group of fish, these data suggest that the timings were inaccurate. However, if the desired effect was to displace fishing to areas with a lower catch rate, then the timing the closures achieved this goal.

Displacing fishing effort via closures has been shown to reduce fishing mortality (Holland 2000). In a study modeling the effects of marine sanctuaries (closures), Holland

(2000) examined the seasonal movement of fish that, like cod, aggregate in certain areas. It was hypothesized that for fish that aggregate in large numbers, the location and shape may have a strong effect on how effective the closures were. It was suggested that implementation of a closure on an aggregation of fish may reduce the overall mortality of the species.

The number of months areas 124 and 125 were closed was actually reduced under the emergency action taken by the NEFMC. Under this scenario, these areas were only closed April through May and October through November. At first glance, this would appear to have obvious negative consequence. By reducing the months these areas are closed, you are by definition, increasing the months in which fishing can occur. This could potentially cause an increase in fishing mortality, which is contrary to the desired effect. However, if a reduction in months closed meant restricting the closures to only the most productive months in these areas, then a positive consequence could occur. Limiting the closures to only the most critical months would protect cod during their most vulnerable times, while allowing fishing to continue during months with lower catch rates. This is synonymous with displacing fishing effort to areas with lower catch rates (Holland 2000). Instead of spatial displacement, displacement is achieved temporally. To achieve this positive effect, careful consideration must be taken into account when choosing the months. These months should be those with the highest CPUE. Although limited, the CPUE data suggests that the closed months under the new scenario are the months with the highest catch rates. This suggests that the closures are now limited to the most productive months for area 124 and 125.

The rolling closures timings for areas 133 and 132 were initially April and May. During these times there was an increase in catch-per-unit-effort in both areas for each month. In fact, the highest catch-per-unit-effort levels observed in the study were observed in area 133 in April and May. This suggests that the biomass of fish is increasing substantially as these areas become closed, thus achieving the desired effect. Tagging demonstrates that cod move into area 133 from area 132 between March and May, just as these areas are closing. Atlantic cod then aggregated in large numbers in area 133 in May, for purposes of spawning. Post-spawning movements occurred in May and June and were characterized by dispersion from area 133 into surrounding areas (figs 16a and 16b). Three of these areas were recently opened (132, 124, and 125). Two areas (139 and 140) remained closed until June. By fish moving into an open area, there exists a potential for negating the initial benefit of the closures. However, the benefit of the closures comes in reducing the overall catachability and thus fishing mortality on the stock. During spawning, cod are aggregated in large numbers in a relatively small area. If fishing were to occur, catchability would be high, causing fishing mortality to be high as well. Through post-spawning movements, the aggregation of cod disperses into a much larger area. Because cod are now dispersed over a larger area, catchability decreases, leading to a potential decrease in fishing mortality. In addition, closing some of the areas in which cod are now found would also serve to reduce overall catchability, leading to a further decrease in fishing mortality.

Through emergency action taken by the NEFMC, the month of June was added, in 2002, to the existing closures for areas 133 and 132. This measure was taken to extend

the protection of spawning cod. Catch-per-unit-effort data in this study showed a decrease in catch rates in area 133 from May to June in both 2001 and 2002. This would suggest that under the old scenario, biomass was decreasing as an area reopened to fishing, which is a positive effect. With the new scenario, there is no real significant benefit, with respect to CPUE, in keeping the area closed an additional month. In contrast, with area 132, there was an increase in CPUE from May to June for both 2001 and 2002. This was a direct result of fish moving from area 133 into 132, as shown from the tagging data. By this area reopening, as under the old scenario, these fish became vulnerable to overfishing before they had a chance to disperse farther away. However, with an additional month of closure, as under the current scenario, the biomass of cod has added protection and thus more time to disperse further offshore. This in turn, would serve to lower catchability, on the overall fish population and may lead to a reduction in fishing mortality. So while the additional month of closure may not be extremely beneficial to area 133, it may be significantly beneficial to area 132.

In addition to area 133 being an important spawning area for Atlantic cod, it may also represent a source area for larvae. Data presented in Fahay et al. (1999) show that the concentration of cod eggs in the western Gulf of Maine is high during the months of April and May and again in November and December. Under the larval-export hypothesis, these eggs and larvae would be transported from the source area (133) into surrounding areas (Crowder et al. 2000; Dayton et al. 2000; Roberts 1998; Russ and Alcala 1996). Because of this, closing area 133 during this time would not only aid in the protection of spawning cod, but may also ensure better recruitment of cod into

surrounding areas.

Areas 140 and 139 were initially closed in May and June. These closures appear to be the most accurate with respect to catch-per-unit-effort, as CPUE is highest in these two months for both 2001 and 2002. In fact, May and June were the only two months in which a significant biomass of fish was actually observed in these areas. Tagging shows that fish move into these areas as part of post-spawning movements away from area 133. Both the catch-per-unit-effort as well as the tagging data suggests that cod may only inhabit these areas for a short period of time each year. This period appears to coincide closely with the timings of the rolling closures for these areas, and suggests that the closures accurately reflect Atlantic cod behavior. The timings of the rolling closures for these areas were not changed as part of the emergency action taken by the NEFMC.

The rolling closures began again in October through November for areas 125 and 124. During these months, there was an increase in catch-per-unit-effort (fig 38) in area 124. Movement of cod during this time was consistent with previous months, with fish staying within the area (fig 8). Tagging of Atlantic cod in the northern areas showed little movement into areas 124 and 125 during these months (figs 30a and 34a). Again, we see the closure beginning as CPUE increases. This, in combination with fish staying in the area suggests that the timing of the closure is achieving its desired effect.

Conversely during these same months, CPUE in area 133 was also increasing as fish begin to aggregate and again move inshore. In fact, CPUE was at the highest levels observed for this area during October and November. Although it should be noted that these months were only sampled in 2001 and thus there is no data on possible interannual

variation. Despite that, this area remains open despite the increase in CPUE.

In conclusion, it has been suggested that an optimal reserve site would be one that was placed in a habitat that was critical to the species being protected (e.g. spawning) (Conover et al. 2000). Rolling closures are a means for: 1) providing protection for specific time period, often when a species is most vulnerable and: 2) providing protection for a highly mobile species that may not remain in the same areas for long periods of time. The six rolling closures in the western gulf of Maine have been implemented to protect cod, a highly mobile species, as they move through and spawn in the area. It is therefore necessary that the timings of the rolling closures accurately reflect the movement of the species. The current study provided a means to assess this by offering information on cod movements and abundance using mark and recapture and CPUE data.

Data illustrates that the timings or the rolling closures are generally accurate, and that they serve to lower fishing mortality on the spring-time spawning aggregations. The closures do not offer 100% protection to post-spawning movements, as some cod move into open areas. However, as cod highly disperse after spawning, the group of cod that is exposed to fishing mortality is smaller than the spawning aggregation. This suggests that the rolling closures are serving to displace fishing effort to areas with lower catch rates. This is beneficial both to cod stocks and the people who utilize them.

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