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The Use of Electronic Tags to Study Fish Movement: a case study with yellowtail flounder off New England

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Abstract

Archival tags enhance the interpretability and power of tagging studies, as illustrated by results from a mark-recapture study of yellowtail flounder off New England. Until recently, the well-studied yellowtail flounder was thought to be a "sedentary" fish, feeding on epibenthic fauna and limited to relatively shallow, sandy habitats. This strict habitat preference and the discontinuous distributions of such habitats were considered to limit movement among offshore banks and shelves, thereby maintaining geographic stock structure. However, recent information obtained from data-storage tags documents frequent off-bottom movements associated with movement to different habitats. Similar to results from historical tagging studies for yellowtail, a mark-recapture study off New England that began in 2003 confirms a low frequency of movement among stock areas. However, the movement likely involves passive drift in midwater currents, similar to patterns observed for other flatfish species. Therefore, the use of electronic tags reveals an important aspect of yellowtail behavior that was not apparent after decades of intense research.

Keywords: data storage tags, archival tags, electronic tags, movement, yellowtail flounder

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Introduction

Yellowtail flounder is one of the principal resources of the northeastern U.S. groundfish complex, with major fishing grounds on Georges Bank, off southern New England and off Cape Cod (Figure 1). The fishery is among the most productive and valuable New England fish species, yielding 16 million lb and US$15 million in 2001 to U.S. fishermen (NMFS 2002). Because of its commercial value, the life history of yellowtail flounder has been extensively studied for nearly a century. Based on their morphology, cryptic coloration, and diet of small, benthic invertebrates, yellowtail were believed to have relatively sedentary behavior.

> *"The diet of yellowtail suggests that it is one of the more sluggish of our flatfishes, and there is no reason to suppose that it ever travels about much after it once takes to the bottom…" (Bigelow and Schroeder 1953).*
>
> *Yellowtail flounder "… appear to be relatively sedentary in habit although seasonal movements have been documented." (NEFC 1982)*

Important corollaries of this perspective on yellowtail behavior are inferences about stock structure. Yellowtail inhabit a relatively narrow depth range (Scott 1982a, Perry and Smith 1994, Murawski and Finn 1988, Walsh 1992, Helser and Brodziak 1996, Johnson et al. 1999), and prefer sandy bottom to prey on demersal invertebrates (Pitt 1976, Scott 1982b, Langton 1983, Collie 1987, Bowering and Brodie 1991, Walsh 1992). Therefore, bathymetric features like deep channels or shallow shoals may form natural barriers that limit interchange of juvenile and adult yellowtail among fishing grounds (Royce et al. 1959, Lux 1963). Stock definitions for U.S. yellowtail resources are partly based on these barriers: the southern New England-Mid Atlantic stock is limited by unfavorable shallow habitats of Nantucket Shoals to the east and unfavorable water temperatures to the southwest; the Georges Bank stock is delimited by deep waters of the continental slope to the southeast, the northeast channel, and the Great South Channel, and the Cape Cod-Gulf of Maine stock is limited to the northeast by deep water and by narrow bands of preferred depth to the north and south (Royce et al. 1959, Lux 1963, Cadrin 2003; Figure 1). If yellowtail are sedentary, then movement among offshore banks by juveniles and adults would be negligible.

In 2001 and 2002, Walsh and Morgan (2004) released yellowtail on the Grand bank with archival tags, and data from all 30 recaptured tags indicated off-bottom movements. Depth recordings documented periods of remaining on the bottom for months at a time, periods of infrequent vertical movement, and periods of regular off-bottom movements at night. In discussing the possible reasons for off-bottom movements, they ruled out feeding, predation avoidance and spawning, leaving mid-water transport as the leading hypothesis.

Off-bottom movement by yellowtail flounder should be considered in the interpretation of movement patterns and stock structure. Furthermore, diel vertical migrations may also influence catch rates in fisheries or research surveys. The objective of this study is to document vertical migrations of yellowtail in U.S. waters and to explore the patterns of off-bottom movements.

Methods

Cooperative Research Approach - Members of the fishing industry have been integrally involved in this study from its inception. In 2003, fishermen from Hampton, New Hampshire; Provincetown, Chatham, Green Harbor and New Bedford, Massachusetts; and Point Judith, Rhode Island have contributed insights, ideas and resources to the project design. The objectives of the tagging study rely on accurate tag reporting. All cooperative industry partners are leaders and role models in their communities and greatly influence tag returns. Industry also serves as an on-the-ground information source for project updates and announcements. In January 2004, the NEFSC hosted a Yellowtail Tagging Participants meeting, attended by 35 federal, state, academic and industry cooperators. The outcome of the discussions was a balanced, scientifically rigorous plan for 2004 tagging. Industry members continue to provide input in all phases of tagging, reporting, data analysis and interpretation. Working cooperatively not only contributes to the success of a research project, but benefits the building of stronger and more trusting relationships between science and industry over the long term.

Experimental Design - In 2003 and 2004, commercial fishing vessels were contracted to tag and release yellowtail on fishing grounds from the Gulf of Maine to the Mid Atlantic Bight. The experimental design is based on geographic fishing areas (Figure 1). Doing so allows an estimate of movement among areas and mortality by stock area. The number of tags released is proportional to geographic patterns of yellowtail abundance based on NMFS survey tows. Releasing tagged fish in proportion to population distribution and demographics will facilitate population estimates of movement and mortality. The tagging study is designed to compliment current stock assessment science and strengthen new relationships between industry and science.

Principal investigators of concurrent tagging efforts agreed to cooperate to adopt a single tagging protocol and common experimental and analytical designs. Canada Department of Fisheries and Oceans began tagging yellowtail on Georges Bank in 1999 and has also agreed to collaborate on the experimental design and administering Canadian recapture information.

Chartered fishing vessels used otter trawls with legal specification flatfish nets to catch yellowtail. Vessels captains were free to modify or change nets as deemed appropriate for the fishing area in order to catch an adequate number of yellowtail in short tows without much bycatch. Tows were between 20-40 minutes in duration.

Specification of Tags - Fish were tagged externally with either Peterson discs (7/8" round, fluorescent pink; Floy Tag Inc., Seattle, WA) or depth-sensing Data Storage Tags (DSTs) (LTD 1100, 32K memory, 8mm x 16mm x 27mm; Lotek, St. Johns Newfoundland). DSTs record pressure (+/- 0.04psi) and temperature (+/- 0.19^{o} C) at the same moment, at regular time intervals. Battery life is up to 3 years. Tags have a 500m depth rating and weigh 2 grams in water. DSTs are equipped with Time Extension Recording (TER), a memory management option that adjusts the sampling interval over time to capture the full record, regardless of the length of the recording session. Tags were recovered with observations at 4 minute intervals (from the DSTs with the shortest time at large) to 60 minute intervals (for those with the longest time at large). DST's were re-initialized before deployment by activating a magnetic reed switch located at one corner. Returned DST's were downloaded using specialized Lotek software onto a computer via infrared signals from a light emitting diode in the tag to a receiver plugged into the computer.

Tagging Protocol - Peterson discs were applied using a 3 inch nickel pin and blank pink disc. All fish were sexed by externally candling and measured to the nearest 1cm. Fish length ranged from 29-55cm. Each fish suitable to tag, either in excellent or good condition, were pierced using the nickel pin with a blank disc for backing. Piercing was done on the dorsal side of the lateral line arch on the blind side of the fish, assuring a smooth puncture at a perpendicular angle to the body to put the blank flush on the blind side. After placing the numbered tag on the upward-facing pin, pliers were used to trim, crimp and bend the end of the pin to secure the tag. Fish were released immediately unless condition noticeably worsened during tagging. Most fish were out of the water less than one minute during the tagging procedure and no anesthesia was used. Tags were labeled as "$1000 Lottery" or "$100 Reward". Scales were plucked from the caudal area for all "$100 Reward" and periodically for "$1000 Lottery" tags, and specially-marked scale blanks were used in these cases.

Data Storage Tags were applied using 2 nickel pins with specially-fitted pink oval blanks (3/8" x 1-1/8" Floy Tag, Inc.). Fish length ranged from 30 to 51cm. Scale samples were taken for all DSTs. Pins were trimmed and crimped in the same manner as for Peterson application, leaving approximately 4 mm for growth.

In 2003, approximately 10,000 yellowtail were tagged and released from the Gulf of Maine to the Mid Atlantic Bight (9,476 disc tags and 131 DSTs). Tagging in 2004 is nearly completed and will release over 15,000 tagged fish (including another 200 DSTs), distributed by relative abundance in each statistical area (Table 1). A third year of tagging is funded to tag another 5,000 fish coast-wide.

Reward System – Tag recaptures are reported via a toll free number. All tag returns receive a map and description of release and re-capture information, a thank you letter, and a brochure or reward poster. Posters are available in English and Portuguese.
All pink discs marked "$1000 Lottery", reported with complete re-capture information, are entered in lotteries. One tag is drawn for each lottery event from a large fishbowl containing the actual tags, and all tags remain in the drawing for the duration of the project. Drawings are held at industry association meetings throughout New England to support and enhance the cooperative effort. Specially-marked, high reward pink discs ("$100 Reward") and all DSTs reported with complete information are redeemable for $100. High reward tags allow an estimate of reporting rate. Announcements of reward winners and lottery schedules, as well as updates on the tagging project, are posted and updated regularly on the project website (www.cooperative-tagging.org).

Analytical Approach – Data from tag returns were examined for temporal and spatial patterns of returns using a Geographic Information System (GIS, Minami 2000). Data from DSTs were downloaded and examined graphically and statistically. Pressure records were converted to water depth observations (pounds per square inch x 0.6805). Depth series were examined to confirm date, time and depth of release and recapture. Descriptive statistics were calculated for depth and temperature series. Time series of depth and temperature were also plotted to identify periods of on-bottom observations, (indicated by a semi-diurnal tidal cycle of depth observations) as well as episodes of off-bottom movement (identified as a decrease in depth of at least 1m in one time step, interrupting the regular tidal cycle).

For each off-bottom movement, a series of variables were recorded or calculated to explore possible environmental cues associated with movements (time on bottom after release, last time on bottom before off-bottom movement, depth of bottom before episode, minimum depth during episode, time back on bottom, depth of bottom after episode, temperature before episode, 1hour lagged temperature, 1day lagged temperature, tidal stage, tidal range [0: high tide; 0.5 low tide], days at large, duration of episode, depth off-bottom, change in depth before and after episode, 1 hour change in temperature before episode, 1 day change in temperature before episode, and time since last episode).

All off-bottom movements were analyzed for geographic and seasonal comparisons of off-bottom movement frequency. Variables associated with nearly 300 off-bottom movements were explored using descriptive statistics and histograms. Geographic and seasonal differences in frequency of off-bottom movements were tested with analysis of variance, and change statistics (e.g., depth and temperature difference before and after movement) were tested for significant difference from no change using a t-ratio test (Sokal and Rohlf 1995).

Movement trajectories were inferred for two fished tagged with DSTs on the northern edge of Georges Bank. The semidiurnal pattern of temperature records confirmed that each fish remained near the shelf-break front over the northern edge of the Bank. Based on release location, return location, recorded depth, and an assumption of minimum movement per day, daily locations were approximated using GIS. These inferred trajectories are one of many that could have produced the recorded depth and temperature profile, but they are the ones that involve the least movement among depths.

Results

Disc tag recaptures - As of June 20 2004, tags from 655 recaptured fish were reported (approximately 7% of 2003 releases, with up to 350 days at large). Fishermen reported 603 recaptures (92% of all returned tags), fish dealers reported 32 tags (5%), and scientific observers reported 20 tags (3%). The average time at large was 103 days. The average distance traveled was 12 nautical miles (23 km), with a maximum distance traveled of 139 nautical miles (258 km). The relationship between time at large and distance traveled is not direct, with the maximum distance traveled in only 12 days, and some short-distance movements after nearly a year at large (Figure 2).

Preliminary results indicate frequent movements within the Cape Cod and Georges Bank stock areas with a low frequency of movement between the Cape Cod grounds and Georges Bank (Table 2, Figure 3). The only recapture of a yellowtail tagged in the Gulf of Maine was by an observer on Stellwagen Bank (on the Cape Cod grounds). Nearly all of the recaptured yellowtail that were tagged on the Cape Cod grounds remained in that area (97%), with 3% moving to Georges Bank, one to Fippennies Bank (in the central Gulf of Maine) and two to Nantucket Shoals. Nearly all of the recaptured yellowtail that were tagged on Georges Bank remained in that area (98%), with 2% moving to the Cape Cod Grounds. Less than three weeks after access to area II began (June 1), 29 tags were recaptured in the area. The only recapture of a yellowtail tagged in the southern New England area was on southwestern Georges Bank.

Data-Storage Tags - Twenty-one DSTs were returned, with one data failure (5% failure rate, possibly associated with a test deployment during winter off a dock in Woods Hole). The average time at large was 133 days. Temperature ranged from 1 to 15^{o} C, and depth ranged from 5 to 155m.

All tags that were at large for at least one month had distinct off-bottom movements (two tags recaptured soon after deployment did not). A total of 648 off-bottom movements were observed over 2,665 observed days at large (Figure 4, Table 3). All but three tags settled to the bottom within 30 minutes of tagging, with one settling in two hours, one in 19 hours and one in 22 hours. Only three males with DSTs were recaptured, but this reflects the skewed sex ratio experienced during tagging trips (80% of fish tagged with DSTs were female; 70% of fish tagged with Peterson disks were female). The size distribution of recaptured DSTs was similar to that of all fish tagged with DSTs (Figure 5).

The overall frequency of off-bottom movements was 0.24 per day, or approximately once every four days, but movements were generally clustered in periods of daily events (Figure 4). Off-bottom movements were significantly more frequent on Georges Bank (0.38 per day or approximately once every three days) than in the Cape Cod area (0.10 per day or once every ten days; ANOVA P=0.001).

Off-bottom movements were observed in every month of the year, with most observations in November (Figure 6). However, given that nearly all fish were tagged in summer, observations were not uniformly distributed across seasons. The seasonal frequency of off-bottom movements (movements per day observed) was not significantly different by month (ANOVA P=0.188; Figure 6).

Close inspection of 295 off-bottom movements indicates that the typical pattern of off-bottom movements is a rapid ascent to the minimum depth followed by a more gradual descent to the bottom. Off-bottom movements usually began in evening hours, with the frequency of off-bottom movements peaking at 19:00, the majority of movements beginning between 18:00 and 22:00, and relatively few off-bottom movements during daylight hours (Figure 7). There was no apparent association of off-bottom movements with tidal stage (Figure 8). The duration of off-bottom movements averaged four hours, with one at 32 hours, and most less than three hours (Figure 9). Movements averaged 15m off-bottom, with a maximum of 56m off-bottom (Figure 10). Change in depth from beginning to end of off-bottom movements ranged from a decrease of 31m to an increase of 40m, but the average depth moved was not significantly different than zero (P=0.940), and most movements were within a 10m range of bottom depth (Figure 11). Daily or hourly changes in temperature preceding off-bottom movements were not significantly different than zero (P>0.96). There does not appear to be a relationship between frequency of off-bottom movement and time at large (Figure 12).

Inferred Trajectories - Tag 3031: On July 16, 2003, a 38cm mature female was tagged and released with a data-storage tag on the northern edge of Cultivator Shoal, Georges Bank. On August 19, 2003, the fish was recaptured, and the time, pressure and temperature data were downloaded. The semi-diurnal cyclical pattern of depth recordings reflects the tidal cycle on Georges Bank and indicates long periods of the fish being on the bottom, interspersed with episodes of off-bottom activity (Figure 4). The temperature records also reflect the tidal cycle, indicating that the fish was near the tidal front over the northern edge of the Bank, with warm Bank water flooding over the slope during flood, and cold Gulf water ebbing over the northern slope of the Bank. The depth recordings indicate that the fish quickly descended to 150m (82 fathoms), but gradually climbed to 80m (43 fathoms). The pattern of depth on bottom was punctuated with distinct off-bottom movement, usually during ebb tides, when the shelf-break front was moving up the slope. After approximately one week at 80m, the fish incrementally moved up to 50-60m (27-33 fathoms) for the remaining weeks until capture. The initial movement to deep water was probably northwest, followed by a general southwest movement along the 80m (43 fathom) contour (Figure 13). At the northwestern corner of Cultivator Shoal, the fish ascended to 50m (27 fathoms) and moved generally south to the recapture location on the western edge of Cultivator Shoal. The inferred trajectory is 28 nautical miles, to travel from the release site to the recapture location, over 33 days, a straight-line distance of 17 nautical miles.

Tag 1497: On July 19, 2003, a 36cm mature female was tagged and released with a data-storage tag on the western edge of Cultivator Shoal, Georges Bank. On September 13, 2003, the fish was recaptured, and time, pressure and temperature data were downloaded. The cyclical pattern of depth recordings reflects the tidal cycle on Georges Bank and indicates long periods of the fish being on the bottom, interspersed with episodes of off-bottom activity (Figure 4). The temperature records also reflect the tidal cycle, indicating that the fish was in the tidal front over the northern edge of the Bank, with warm Bank water flooding over the slope during flood, and cold Gulf water ebbing over slope. Similar to tag 3031, the pattern of changes in depth on bottom were punctuated with distinct off-bottom movements of 5-20m (3-10 fathoms). The depth recordings indicate that the fish quickly descended to 95m (52 fathoms) for less than a day, then descended again to 115m (63 fathoms), but rose 65m (36 fathoms) off the bottom to settle at a new depth of 65m. Over the next five days, the fish briefly rose off the bottom at night (between 19:00 and 02:00) to settle at a new depth. After staying at approximately 65m (36 fathoms) for two days and approximately 75m (41 fathoms) for four days, the fish moved off bottom each night over a period of six days in early August (between 19:30

and 02:30) and settled at a slightly different depth. Over the next two weeks (in mid August), the fish stayed on bottom gradually moving from 75m (41 fathoms) to 65m (36 fathoms) and back to 75m. The fish then moved to 80m (44 fathoms) and briefly to 100m (55 fathoms) with two off-bottom movements (at 21:00 and 22:00), then to 70m (38 fathoms) for the final week before capture. The initial movement to deep water was probably northwest, followed by a general northeast movement along the northern edge of the Bank (Figure 14). The inferred trajectory is 45 nautical miles, to travel from the release site to the recapture location, over 58 days, a straight-line distance of 32 nautical miles.

Discussion

Results from conventional tags generally confirm results from earlier tagging studies. Royce et al. (1959) concluded that groups of yellowtail are relatively localized (e.g., most tagged fish were recovered within 80 km of the release site), short seasonal migrations occur, and little mixing occurs among fishing grounds. Lux (1963) concluded that groups of yellowtail move seasonally within fishing grounds, with a small amount of seasonal mixing among groups. A summary of all published yellowtail movements off the northeast U.S. (Cadrin 2003) indicated that 97% of fish recaptured from release sites on Georges Bank remained in the area (3% moved to southern New England) and 98% of fish recaptured from release sites on the Cape Cod grounds remained in the area (1% moved to the northern Gulf of Maine, <1% moved to Georges Bank, and 1% moved to southern New England). Our preliminary results indicate a greater rate of movement between Cape Cod and Georges Bank: 2% of fish recaptured from Cape Cod releases moved to Georges, and 2% of fish recaptured from Georges releases moved to Cape Cod). However, differences may result from changes in effort patterns, and returns will be analyzed more rigorously when we have more recaptures with longer time at large.

The depth and temperature information from data tags offer valuable habitat information. The range of observed temperatures (1-15^{o} C) is greater than previously published for this species off New England (Johnson et al. 1999 report a range of 2-12^{o} C). The observed bottom depths (average 55m, maximum 151m) are similar to previously reported ranges (Johnson et al. 1999 report a normal range of 10-360 m). These data illustrate that archival tags may be a more comprehensive and direct method of sampling habitat information.

The most important result from these data is the documentation of off-bottom movements by yellowtail flounder off New England. Our results are similar to those reported by Walsh and Morgan (2004), with diel patterns of vertical movements, relatively brief duration of movements, and three distinct patterns of prolonged period on-bottom, infrequent off-bottom movements at night, and daily movements at night for weeks at a time (Figure 5). One reassuring aspect of the comparison is that Walsh and Morgan used tags from a different manufacturer and had similar results to ours. The seasonal pattern of off-bottom movements observed on the Grand Bank may result from the seasonal patterns of releases (i.e., tagging was in summer, and there were more observed days in summer and fall than in winter and spring).

There are some differences between results from yellowtail flounder and those from archival tags deployed on North Sea plaice (Arnold and Holford 1995; Metcalfe and Arnold 1997; Arnold 2001; Bolle et al. 2001; Hunter et al. 2004a, 2004b). For example, off-bottom movement of yellowtail flounder appears to be more strongly associated with time of day than with tidal cycle, though tidal transport may be important along shelf break fronts (e.g., tags 3031 and 1497). Furthermore, patterns of off-bottom movement do not appear to be seasonal for yellowtail flounder off New England. Finally, duration of off-bottom movements of yellowtail flounder (generally hours) is much less than observed for North Sea plaice (up to two weeks).

Although these analyses and results are merely exploratory, they beg the question of why yellowtail move off-bottom. The lack of seasonal patterns in our data suggests that off-bottom behavior is not associated with spawning, which occurs in spring. The strong diel pattern may be associated with the cessation of daily feeding, because yellowtail feed primarily during daylight, on benthic invertebrates (Pitt 1976, Langton 1983, Collie 1987). Langton (1983) reported that daytime diet consisted mostly of polychaetes, but nighttime diet consisted of more amphipods. An ongoing behavioral study associated with the tagging program also indicates greater frequency of off-bottom swimming in the laboratory (H. Jackson, Northeast Fisheries Science Center, personal communication). The occasional change in bottom depth after an off-bottom movement supports the hypothesis of mid-water transport posed by Walsh and Morgan (2004).

The two examples of inferred movement trajectory reported here were relatively easy to accomplish, because the semidiurnal temperature cycles indicated that the two fish stayed in the shelf-break front, a relatively narrow corridor between release and recapture sites. Data from archival tags can also be used to infer trajectories by overlaying geographic grids of bottom temperature, bottom depth and tidal range with the observed time series of temperature and depth (e.g., Arnold and Holford 1995; Metcalf and Arnold 1997; Hunter et al. 2004a 2004b).

As described by Bolle et al. (2001), DST observations can help to interpret results from conventional tag recaptures. For example, DST data indicate that tagged yellowtail generally settle to the bottom relatively quickly (within one day). There also doesn't appear to be a different frequency of off-bottom movement immediately after tagging (Figure 12). Inferred trajectories illustrate how distance and speed are underestimated by conventional tag results. The mode of transport and lack of seasonality will help to structure the analysis of conventional tag data.

Our results also show that cooperative research is particularly useful in a tagging study. Working with industry members who are leaders in their communities can influence tag returns and help with port outreach. Many yellowtail fishermen have expressed great interest in the data tag returns. Cooperation and tagging intrigue work both ways. Without good working relationships, tag returns would suffer, and in the absence of interesting DST results, intrigue would be minimal and tag returns might be less. Working cooperatively with fishermen and research institutes has been key in Georges

Bank tag returns. Cooperation with industry can also help with data interpretation, often confirming fishermen's on-the-water observations, i.e. vertical night time movements.

These results have important implications for research and fishery management of yellowtail flounder. The frequent off-bottom movement and occasional movement to different depths (Figure 11) strongly suggests that yellowtail flounder can move among fishing grounds or stock areas using mid-water currents. Therefore, the potential for movement across current stock boundaries (e.g., shallow shoals or deep channels) should be considered. Furthermore, catchability of yellowtail may be affected by diel movement patterns. For example, several studies have shown that catchability of yellowtail flounder by otter trawls is greater at night than during the day (Shepherd and Forrester 1987; Walsh 1988, 1991; Casey and Myers 1998). Most importantly, these data offer a much different perspective on yellowtail behavior than previous descriptions suggest.

Summary

Preliminary results from recapture of conventional tags indicate frequent movements within the Cape Cod and Georges Bank stock areas with a low frequency of movement between the Cape Cod grounds and Georges Bank. Twenty-one data storage tags were recovered from deployments on yellowtail flounder off New England. All tags at large more than one month indicated distinct off-bottom movements. Off-bottom movements were typically in evening hours, between 18:00 and 22:00, lasting an average of four hours, ascending to an average of 15m off-bottom. The frequency of off-bottom movements varied geographically, an average of once every ten days off Cape Cod, and once every three days on Georges Bank. The frequency of off-bottom movements did not significantly vary by season.

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Table 1. Geographic distribution of the yellowtail flounder resource off New England (as indicated by research surveys), and number of tagged yellowtail released by area and year.

Area	yellowtail resource	2003 releases	2004 releases	total releases	% releases
Western Gulf of Maine	7%	15	1,468	1,483	5%
Cape Cod Bay	13%	2,104	1,395	3,499	13%
East of Cape Cod	10%	2,282	66	2,348	9%
Cultivator Shoal	3%	724	765	1,489	5%
Southwest Georges Bank	12%	140	3018 *	3,158 *	12%
Northern Georges Bank	1%	428	446	874	3%
Closed Area II	43%	2,962	8,884 *	11,846 *	43%
Nantucket Lightship Area	3%	125	605	730	3%
southern New England	4%	430	368	798	3%
Mid Atlantic	3%	225	736	961	4%
Block Island Sound	1%	40	21	61	0%
	100%	9,475	17,772	27,247	100%

* projected releases

Table 2. Recaptured yellowtail by area of release and area of recapture as of June 20, 2004.

Release Area	Recapture Area: Gulf of Maine	Cape Cod	Georges Bank	S.New England	Mid Atlantic	Total
Gulf of Maine	0	1	0	0	0	1
Cape Cod	1	384	9	2	0	396
Georges Bank	0	6	248	0	0	254
S.New England	0	0	1	0	0	1
Mid Atlantic	0	0	0	0	0	0

Table 3. Descriptive statistics of 20 data-storage tags deployed on yellowtail flounder off New England.

tag number	release date	sex	length	area	days at large	distance (km)	depth (m) minimum	maximum	average	temperature (C) minimum	maximum	average	off-bottom events	frequency (per day)
2022	8/6/03	male	35	Cape Cod	130	*	40	62	57	5.3	10.3	7.7	10	0.08
3013	7/9/03	female	36	Cape Cod	1	2.1	26	41	34	5.9	6.4	6.2	0	0.00
3035	8/11/03	female	34	Cape Cod	30	14.1	28	66	55	5.3	8.7	5.9	0	0.00
3038	8/13/03	female	43	Cape Cod	113	11.3	11	65	47	5.3	11.6	7.9	5	0.04
3062	7/17/03	female	35	Cape Cod	121	49.3	22	91	42	5.2	10.5	7.5	3	0.02
3093	7/9/03	female	33	Cape Cod	9	5.9	27	39	33	5.9	6.9	6.3	2	0.23
3188	7/9/03	female	38	Cape Cod	132	7.2	18	85	37	5.9	12.2	8.1	1	0.01
3205	7/23/03	male	33	Cape Cod	329	125.2	15	106	60	2.1	11.2	5.7	42	0.13
8409	7/6/04	female	38	Cape Cod	15	29.3	20	39	37	3.7	5.5	4.1	6	0.41
1497	7/17/03	female	36	Georges Bank	58	59.6	24	117	73	4.8	14.5	8.4	25	0.43
1870	7/16/03	female	40	Georges Bank	132	55	8	91	67	8.3	14.6	10.7	90	0.68
3000	7/15/03	female	36	Georges Bank	326	92.4	23	96	78	3.3	13.4	7.5	76	0.23
3031	7/16/03	female	38	Georges Bank	34	31.9	22	151	66	4.8	13.1	8.6	14	0.41
3039	7/12/03	female	43	Georges Bank	301	*	5	89	66	3.2	14.6	8.2	123	0.41
3040	7/22/03	female	38	Georges Bank	319	35.6	22	71	43	1.0	11.4	5.6	16	0.05
3113	7/11/03	female	45	Georges Bank	267	88.8	25	95	64	3.2	14.9	8.7	89	0.33
3313	7/11/03	female	42	Georges Bank	325	56.9	16	98	72	3.3	12.6	7.7	141	0.43
3316	7/14/03	male	40	Georges Bank	8	39.4	52	92	71	4.9	11.1	6.8	2	0.26
8419	7/22/04	female	41	Georges Bank	2		44	61	58	8.2	9.3	8.6	1	0.53
2031	5/27/04	female	43	Mid Atlantic	14	13.3	31	48	42	4.9	7.9	6.1	2	0.14

Figure 1. Yellowtail flounder management areas off the northeastern U.S.

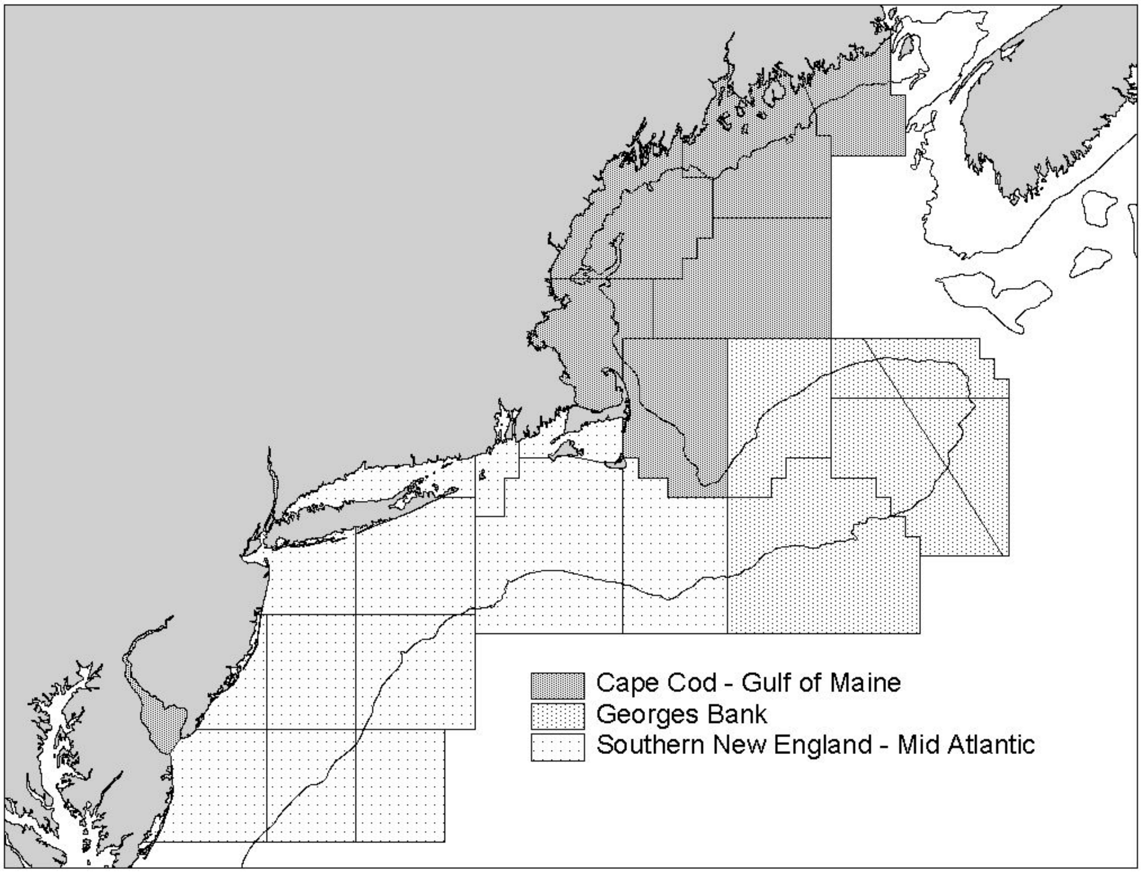


Figure 2. Distance (nautical miles) and time at large of recaptured yellowtail.

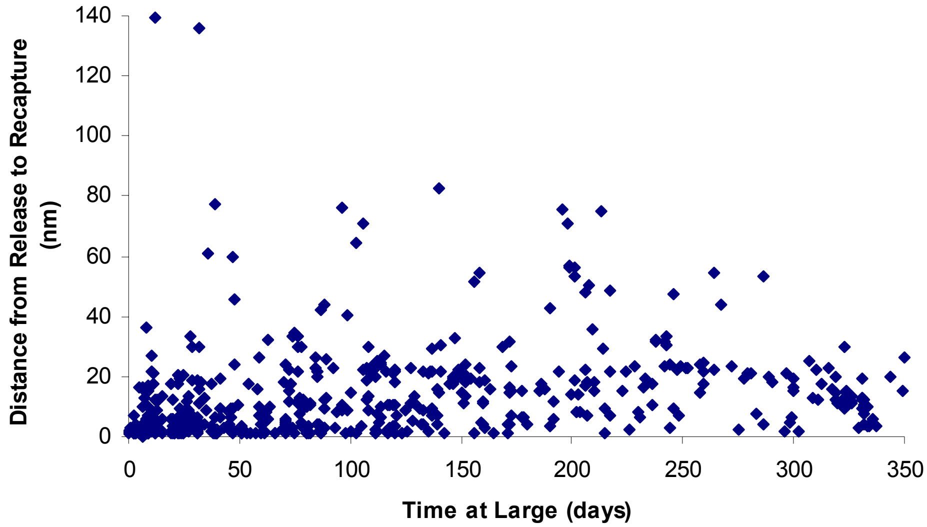


Figure 3. Locations of tagged yellowtail flounder recaptures as of June 20 2003.

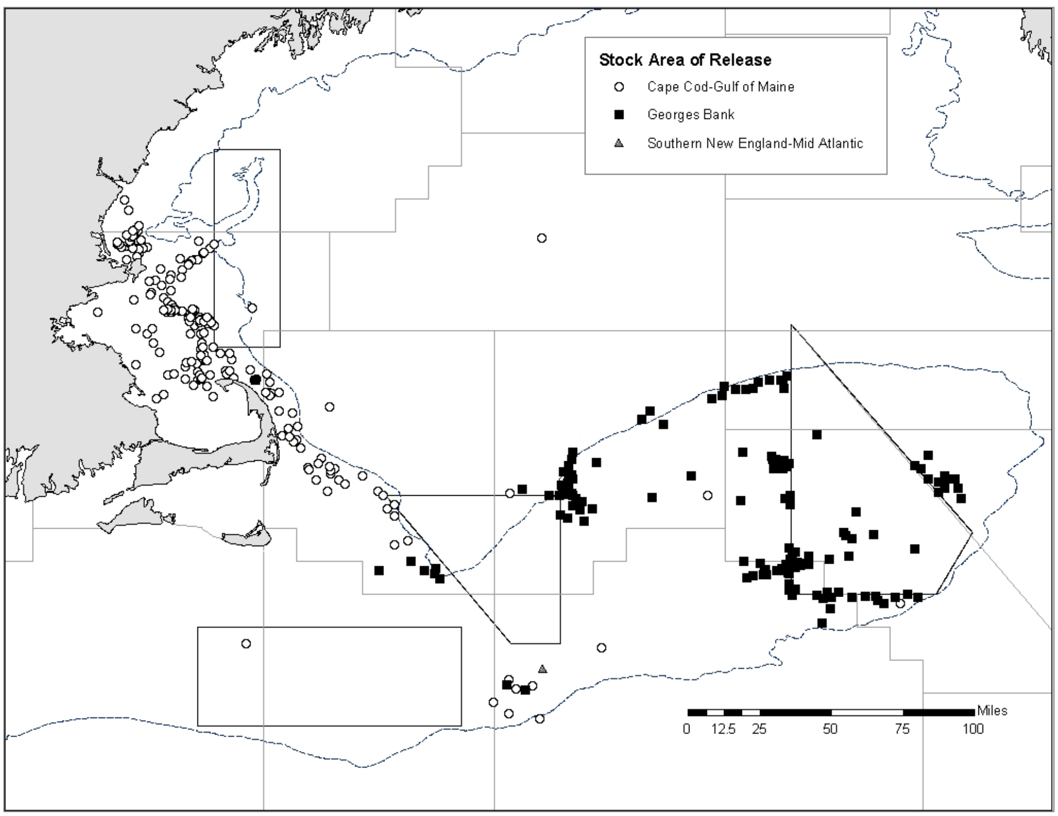
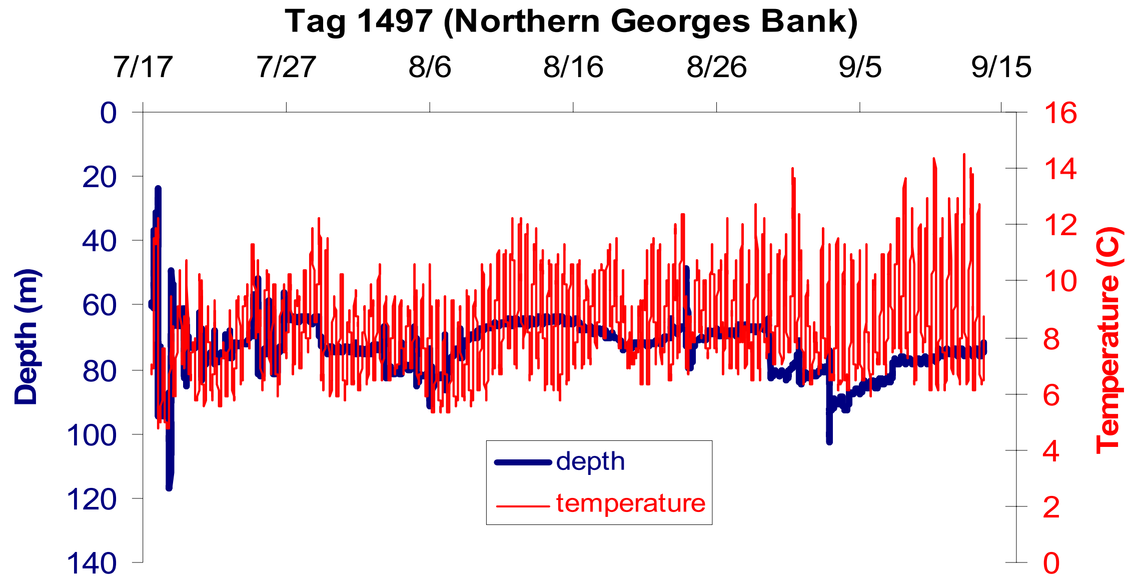
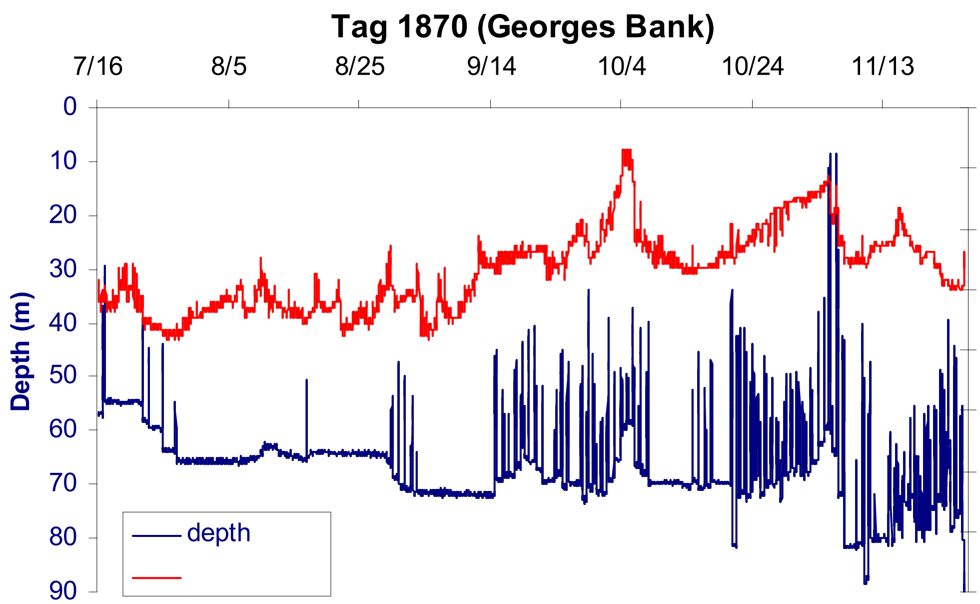
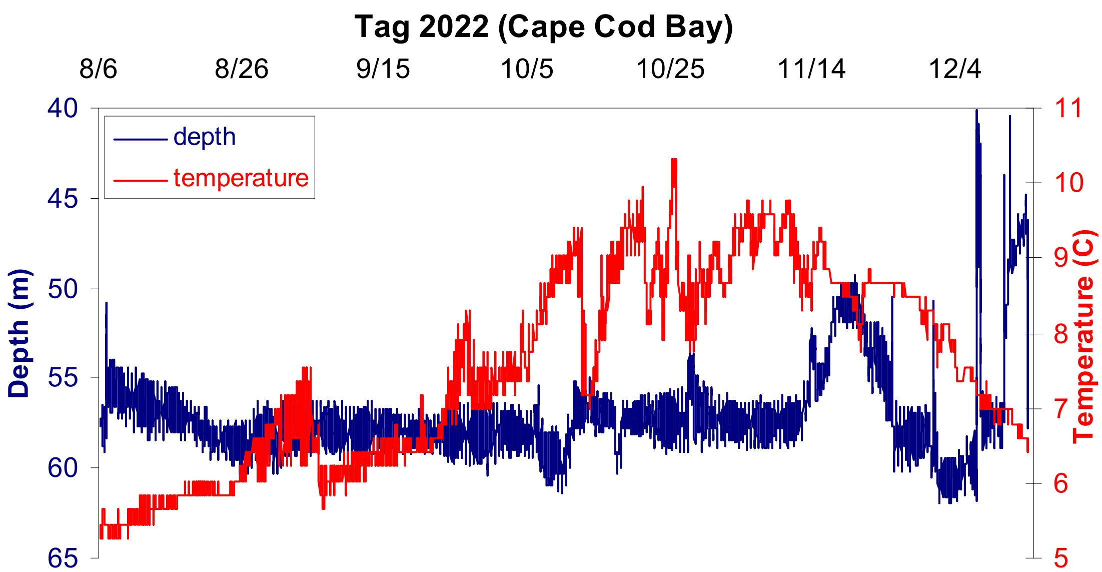
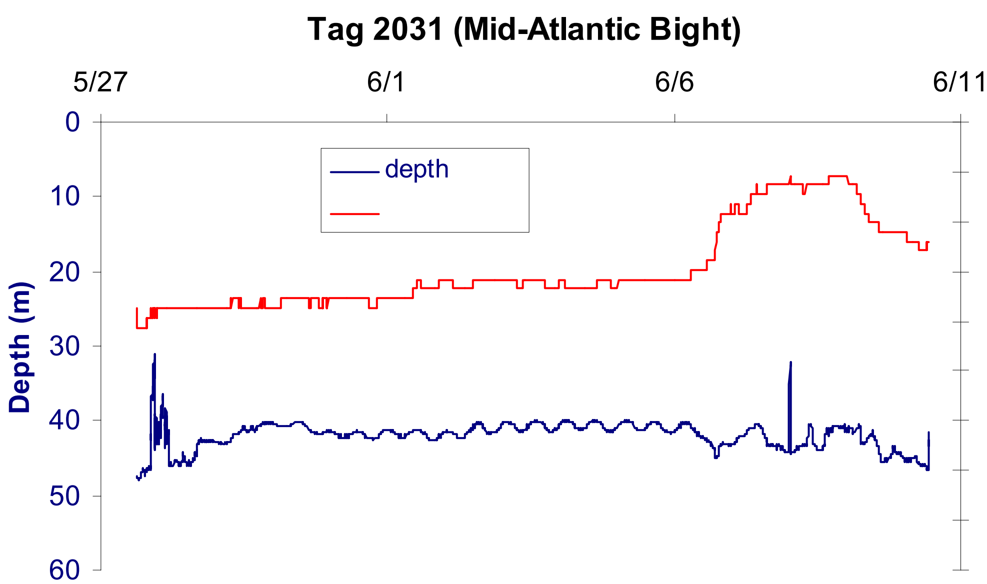


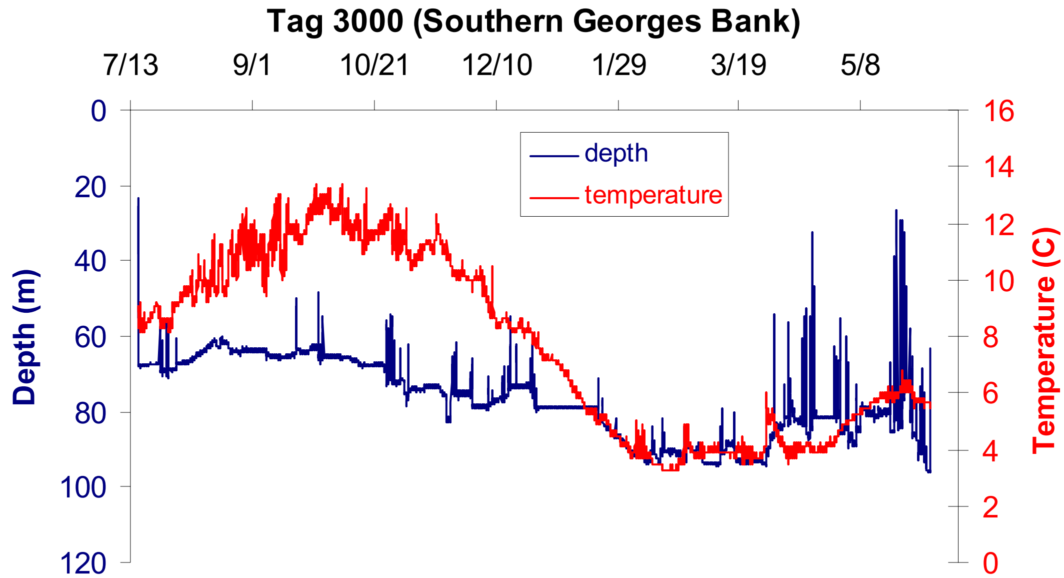
Figure 4. Depth and temperature series from tagged yellowtail flounder.



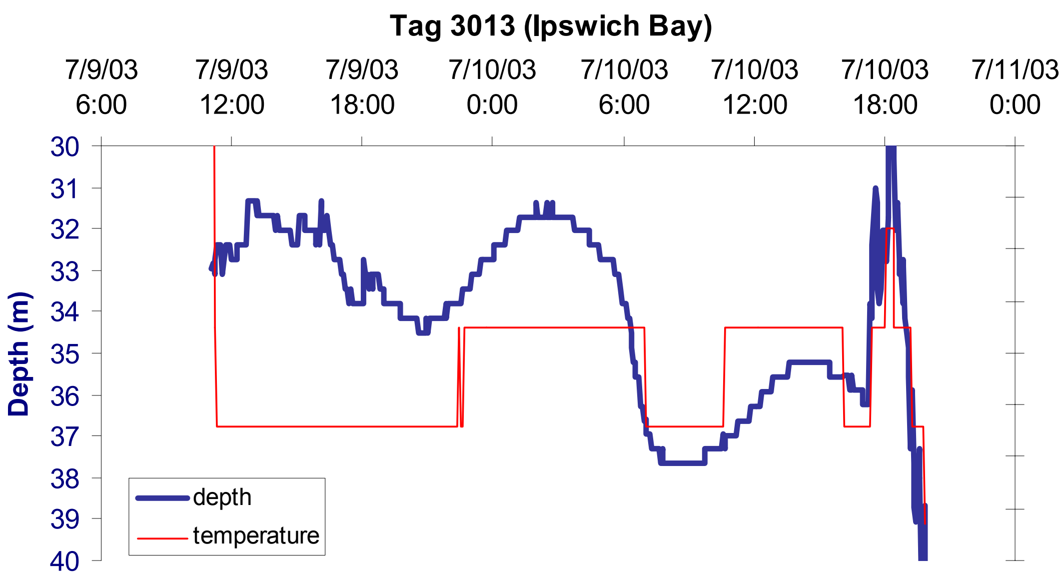



Tag 2022 (Cape Cod Bay)
8/6
8/26
9/15
10/5
10/25
11/14
12/4
Depth (m)
40
45
50
55
60
65
Temperature (C)
11
10
9
8
7
6
5
depth
temperature

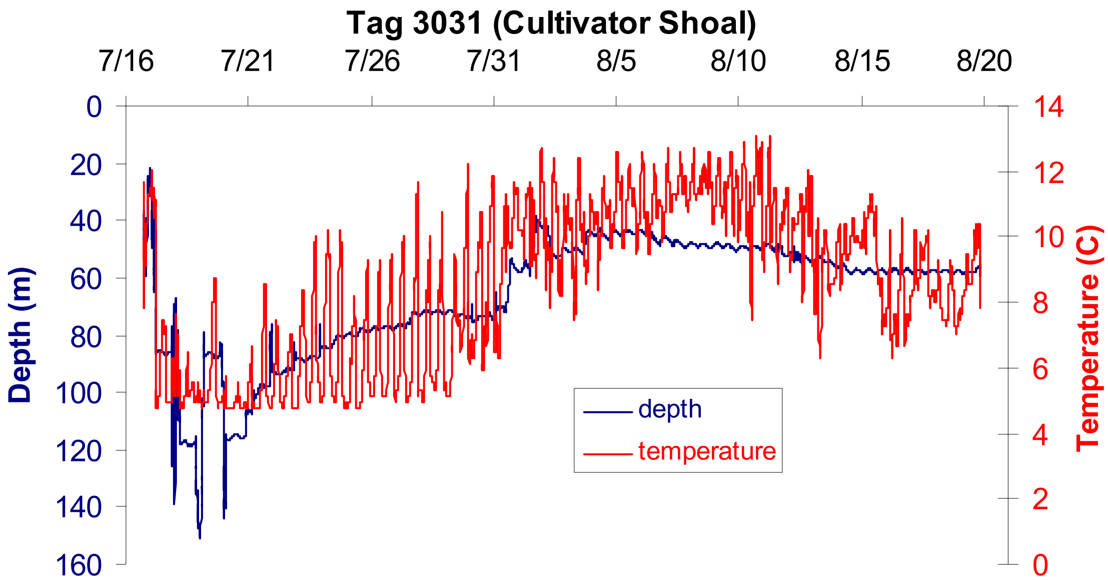

Tag 2031 (Mid-Atlantic Bight)
5/27
6/1
6/6
6/11
Depth (m)
0
10
20
30
40
50
60
depth

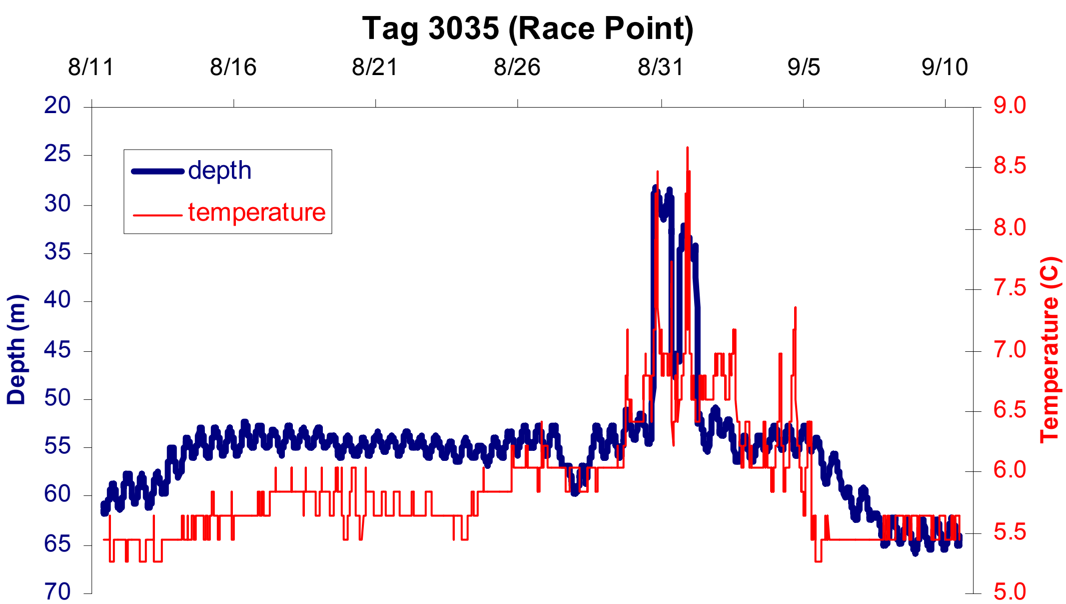


Tag 3000 (Southern Georges Bank)
7/13
9/1
10/21
12/10
1/29
3/19
5/8
depth
temperature
Depth (m)
Temperature (C)
0
20
40
60
80
100
120
16
14
12
10
8
6
4
2
0

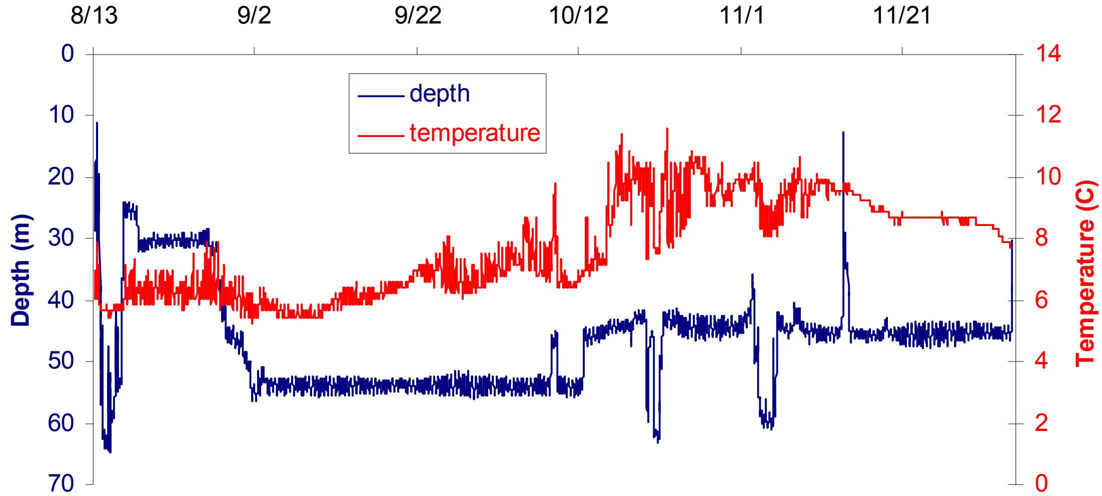


Tag 3013 (Ipswich Bay)
7/9/03 6:00
7/9/03 12:00
7/9/03 18:00
7/10/03 0:00
7/10/03 6:00
7/10/03 12:00
7/10/03 18:00
7/11/03 0:00
Depth (m)
30
31
32
33
34
35
36
37
38
39
40
depth
temperature

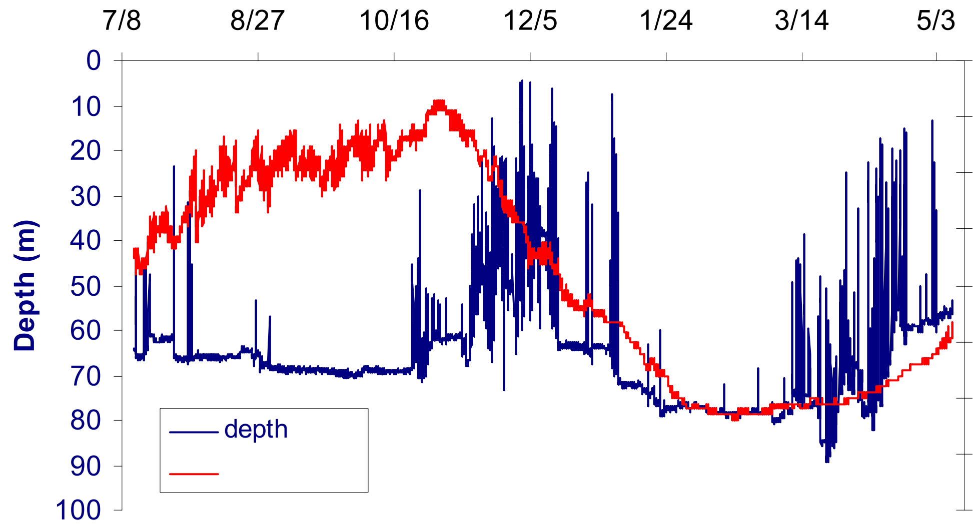

Tag 3031 (Cultivator Shoal)
7/16
7/21
7/26
7/31
8/5
8/10
8/15
8/20
Depth (m)
0
20
40
60
80
100
120
140
160
Temperature (C)
14
12
10
8
6
4
2
0
depth
temperature


Tag 3035 (Race Point)
8/11
8/16
8/21
8/26
8/31
9/5
9/10
Depth (m)
20
25
30
35
40
45
50
55
60
65
70
Temperature (C)
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
depth
temperature

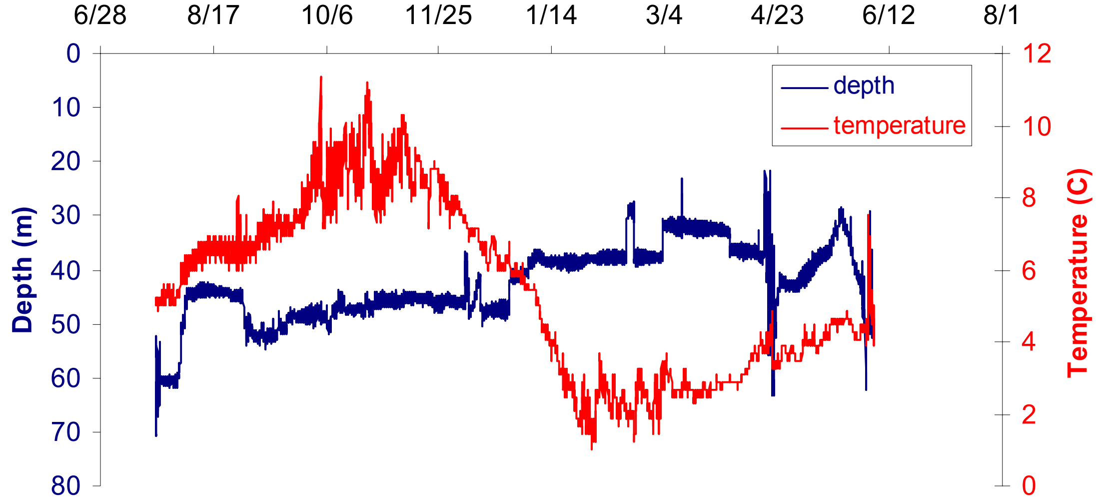
Tag 3038 (Race Point)



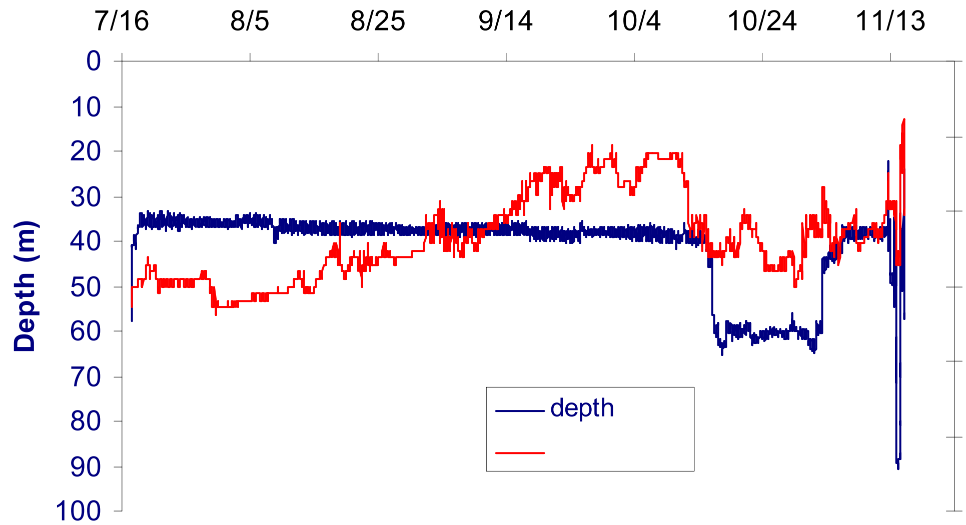
Tag 3039 (Georges Bank)

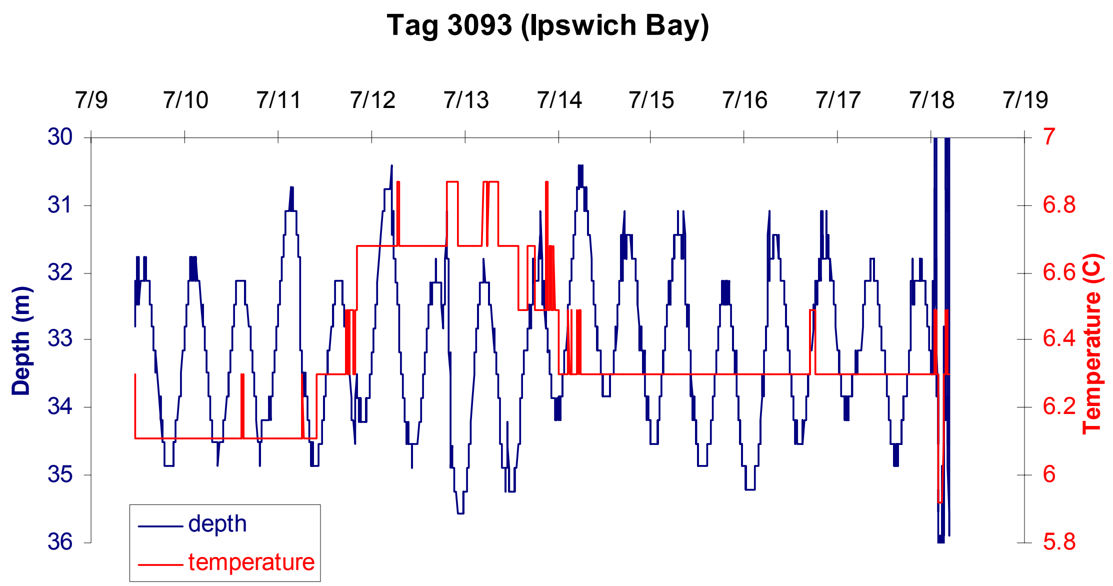


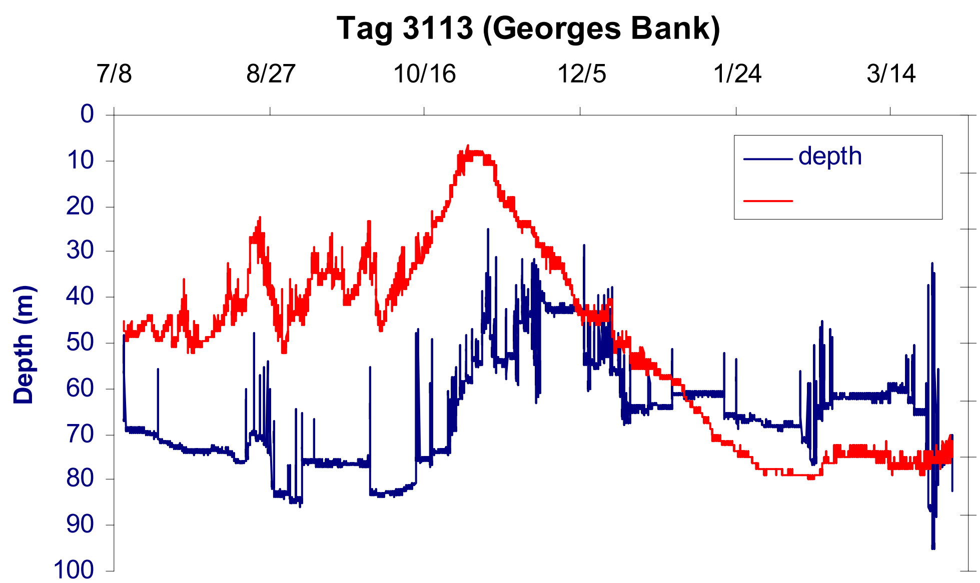
Tag 3040 (outer Cape Cod)

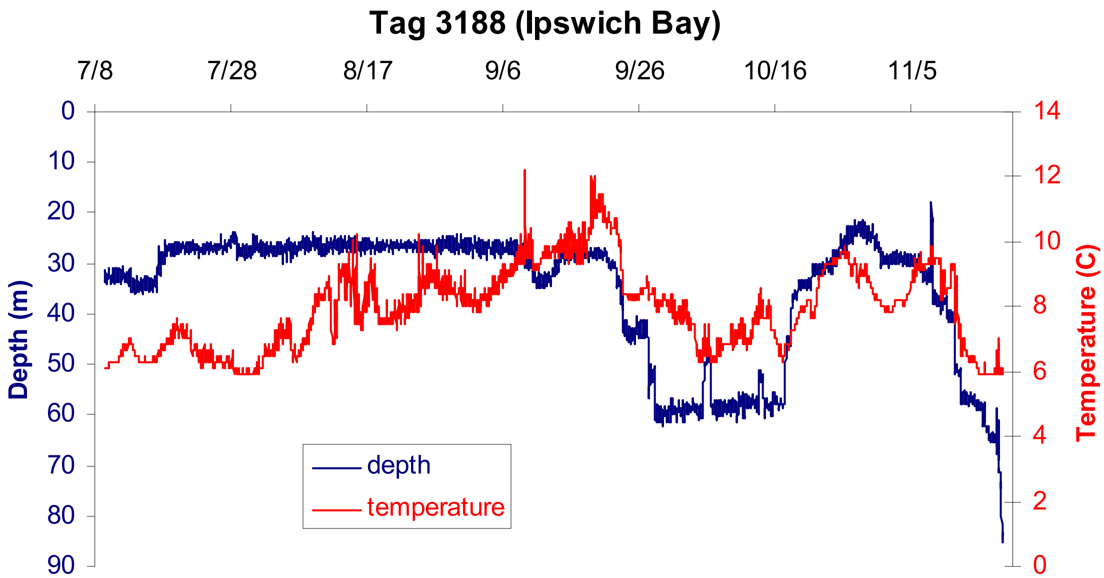


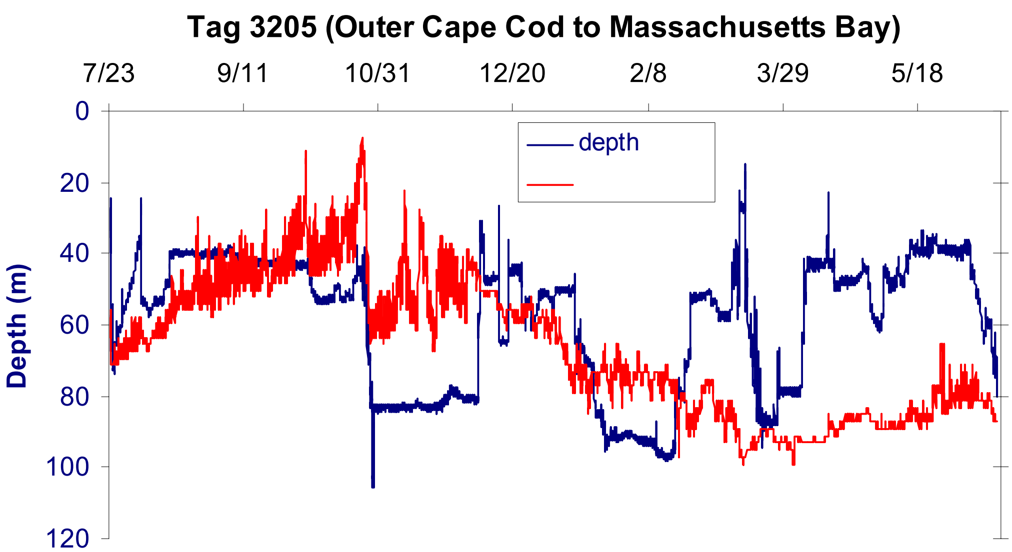
Tag 3062 (Ipswich Bay to Stellwagen)

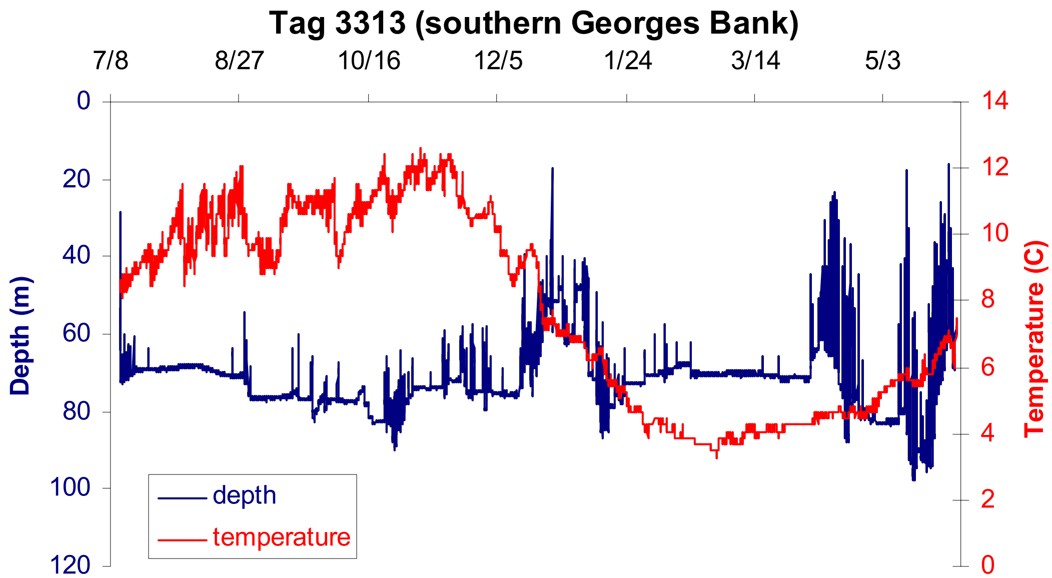



Tag 3093 (Ipswich Bay)
7/9
7/10
7/11
7/12
7/13
7/14
7/15
7/16
7/17
7/18
7/19
30
31
32
33
34
35
36
Depth (m)
7
6.8
6.6
6.4
6.2
6
5.8
Temperature (C)
depth
temperature

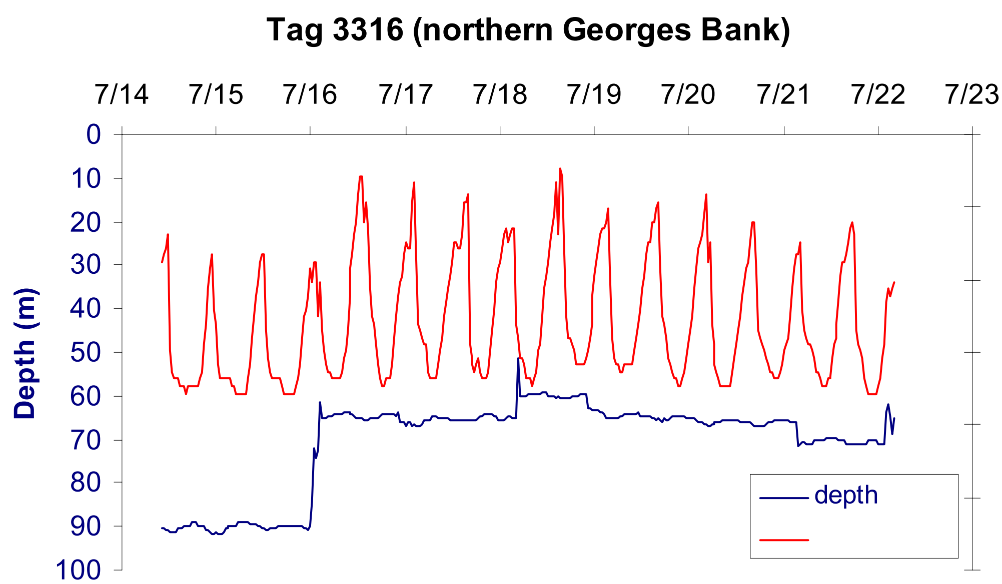

Tag 3113 (Georges Bank)
7/8
8/27
10/16
12/5
1/24
3/14
0
10
20
30
40
50
60
70
80
90
100
Depth (m)
depth


Tag 3188 (Ipswich Bay)
7/8
7/28
8/17
9/6
9/26
10/16
11/5
Depth (m)
0
10
20
30
40
50
60
70
80
90
Temperature (C)
14
12
10
8
6
4
2
0
depth
temperature

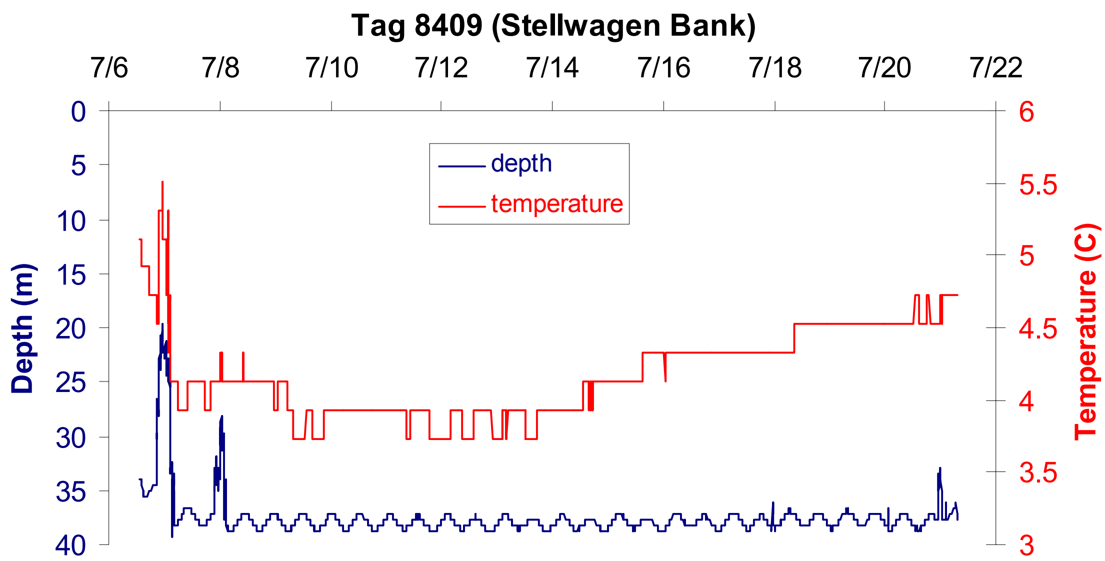

Tag 3205 (Outer Cape Cod to Massachusetts Bay)
7/23
9/11
10/31
12/20
2/8
3/29
5/18
Depth (m)
0
20
40
60
80
100
120
depth



Tag 3313 (southern Georges Bank)
7/8
8/27
10/16
12/5
1/24
3/14
5/3
Depth (m)
Temperature (C)
depth
temperature



Tag 3316 (northern Georges Bank)
7/14
7/15
7/16
7/17
7/18
7/19
7/20
7/21
7/22
7/23
Depth (m)
depth


Tag 8409 (Stellwagen Bank)
7/6
7/8
7/10
7/12
7/14
7/16
7/18
7/20
7/22
depth
temperature
Depth (m)
0
5
10
15
20
25
30
35
40
Temperature (C)
6
5.5
5
4.5
4
3.5
3

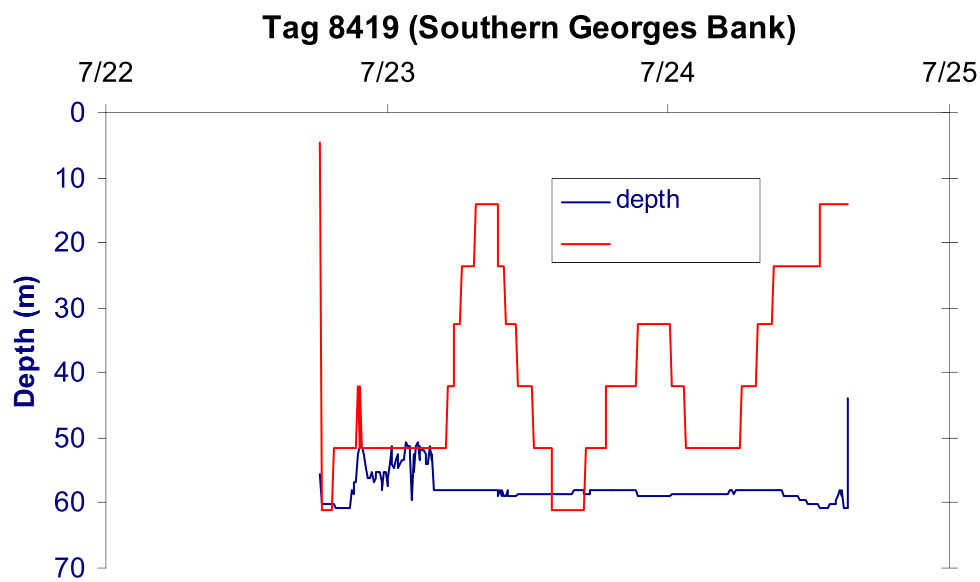

Tag 8419 (Southern Georges Bank)
7/22
7/23
7/24
7/25
depth
Depth (m)
0
10
20
30
40
50
60
70

Figure 5. Size distribution of yellowtail tagged with DSTs and those recaptured.

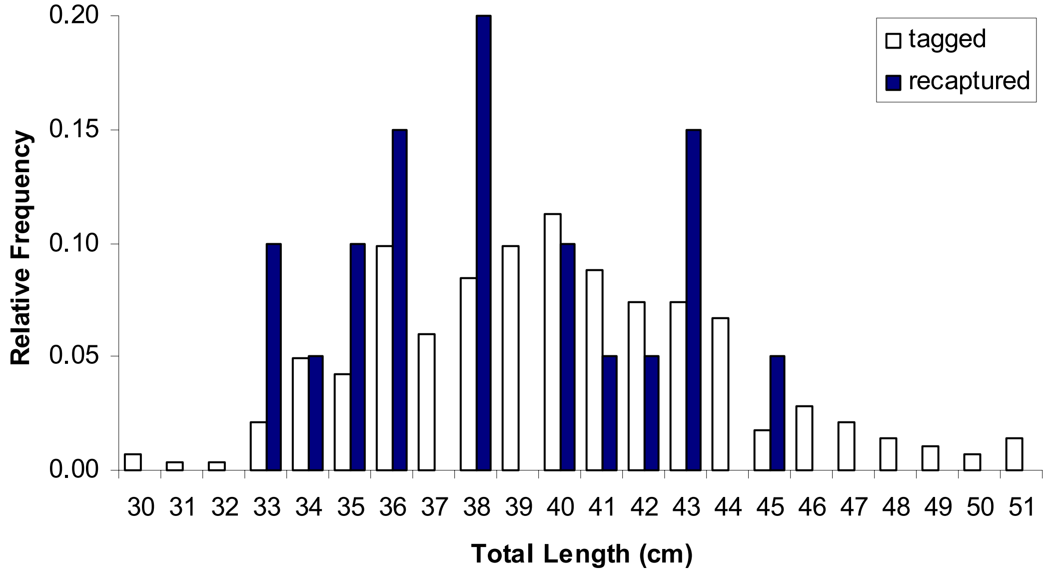


Figure 6. Seasonal frequency of off-bottom movements and observed days (upper panel) and monthly movement per day (lower panel, indicating range and 95% confidence interval).

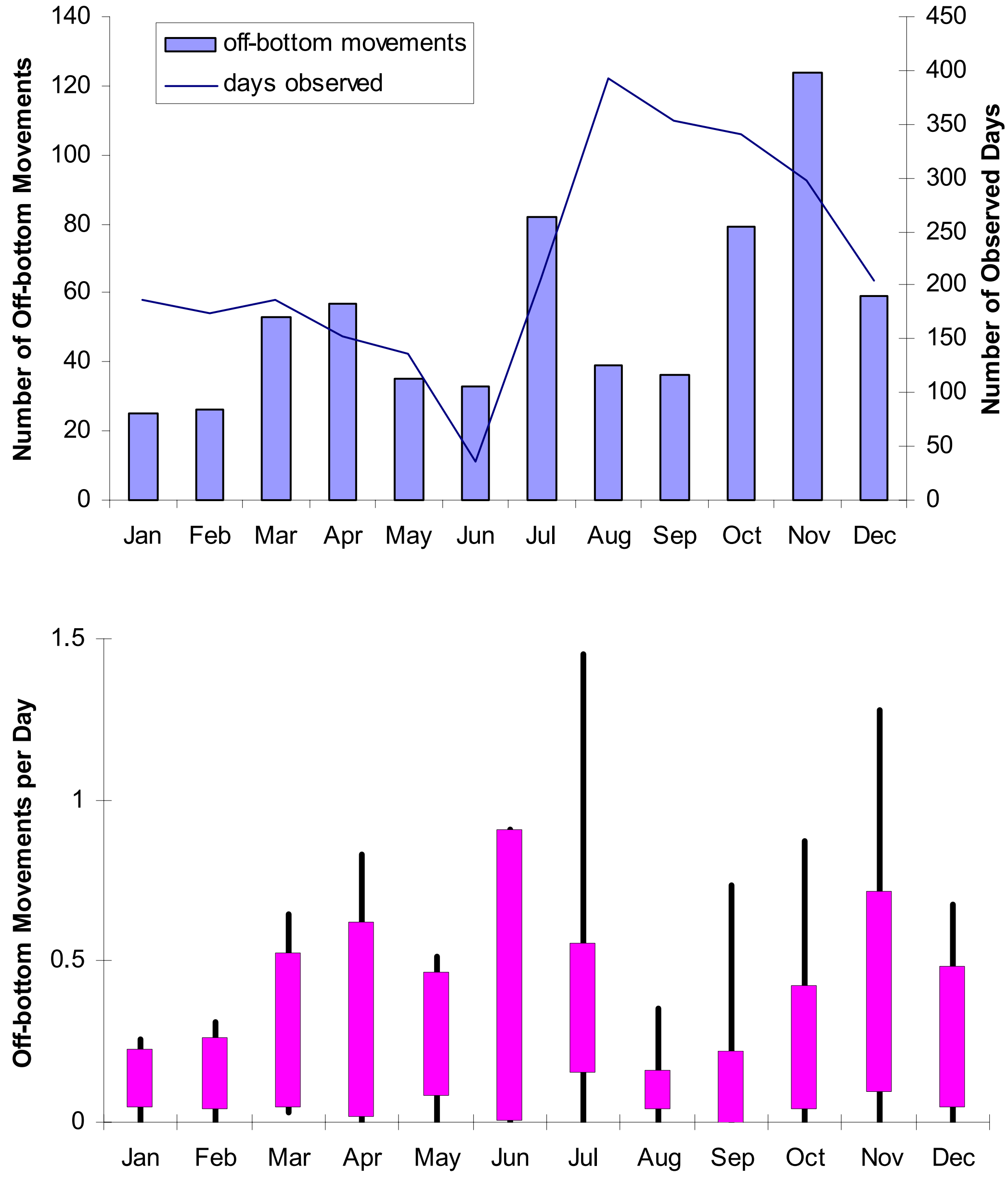


Figure 7. Frequency of off-bottom movements by time of day.

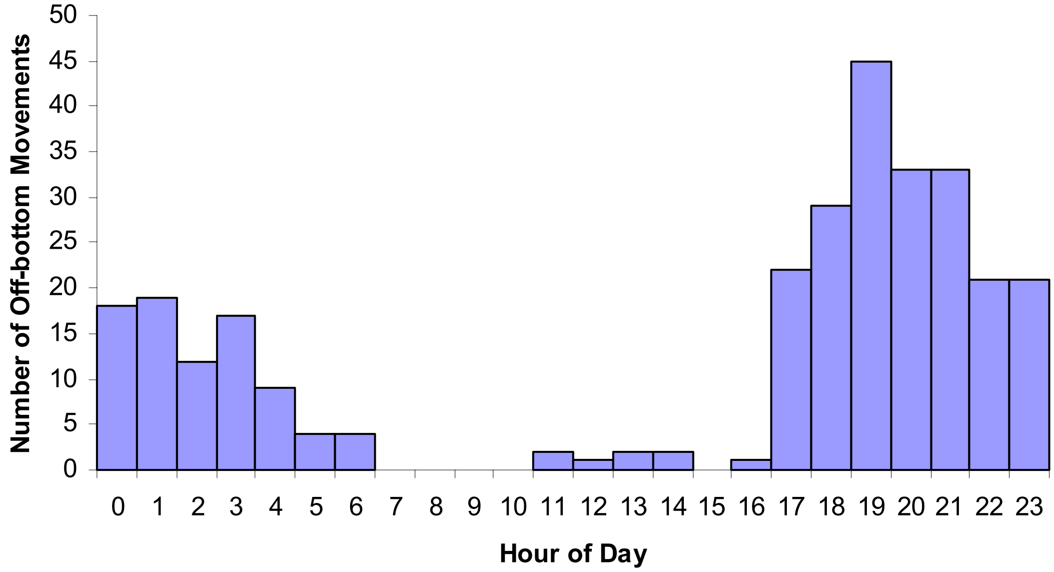


Figure 8. Frequency of off-bottom movements by tidal stage.

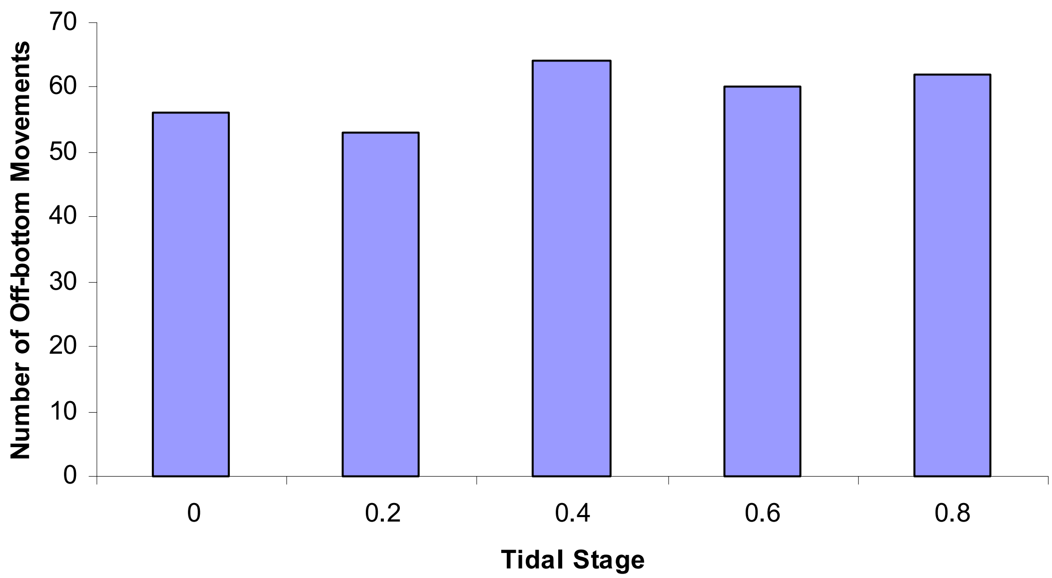


Figure 9. Distribution of duration of off-bottom movements.

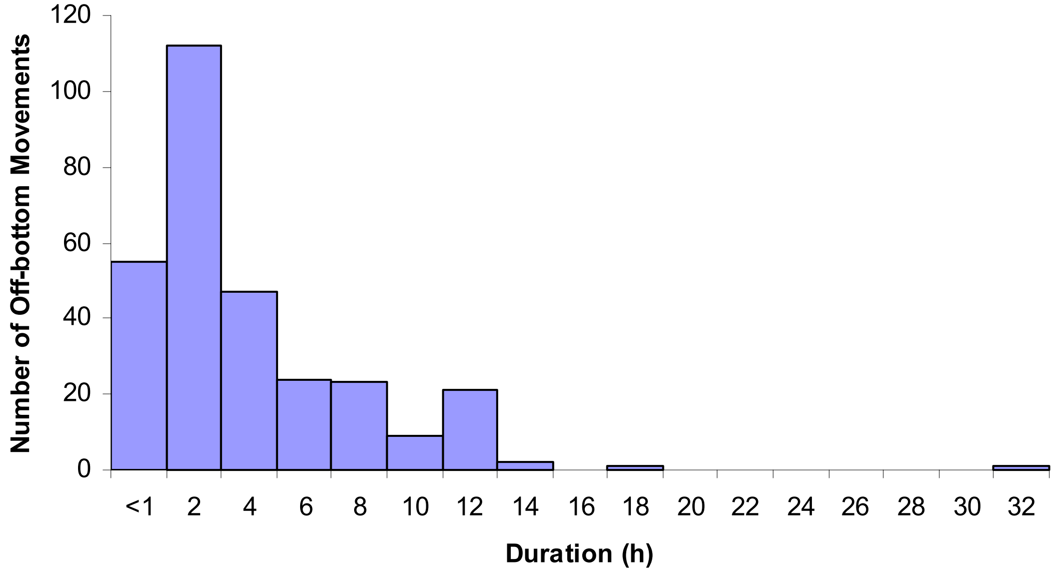


Figure 10. Distribution of depth off-bottom for off-bottom movements.

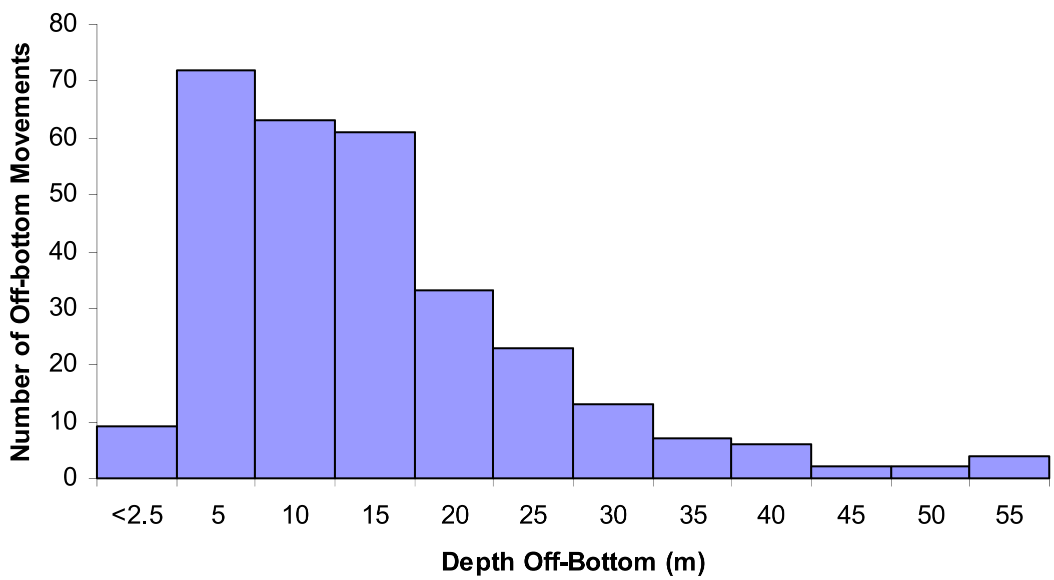


Figure 11. Distribution of change in depth before and after off-bottom movements.

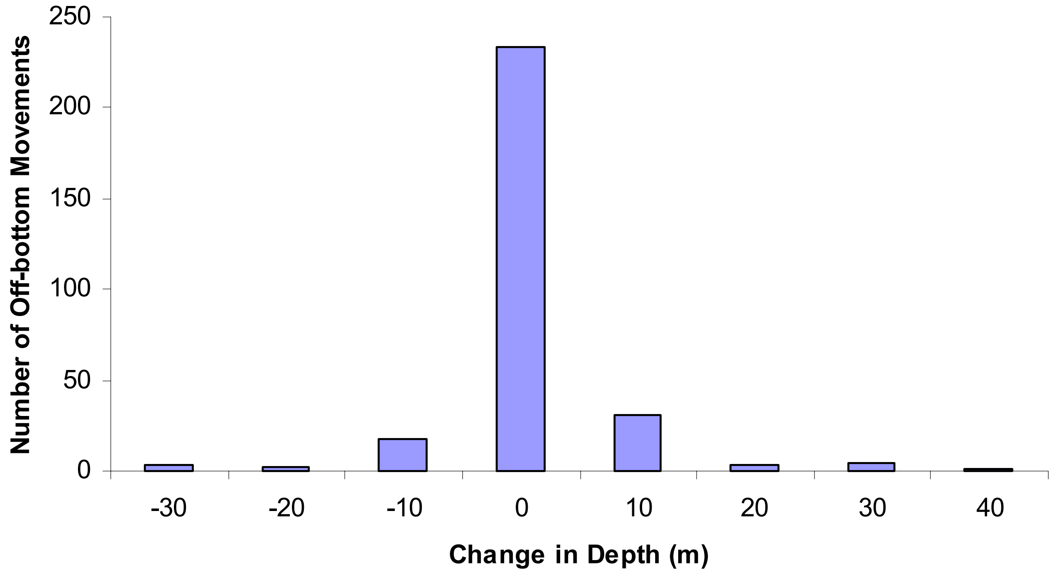


Figure 12. Distribution of time at large for off bottom movements and all observed days.

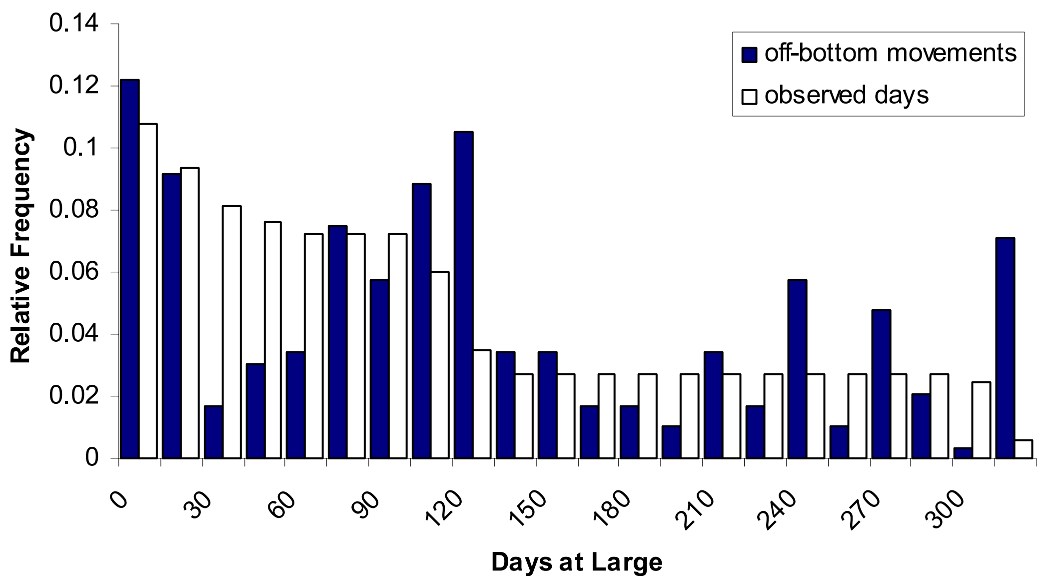


Figure 13. Inferred movement of a yellowtail flounder (tag 3031) on Cultivator Shoal.

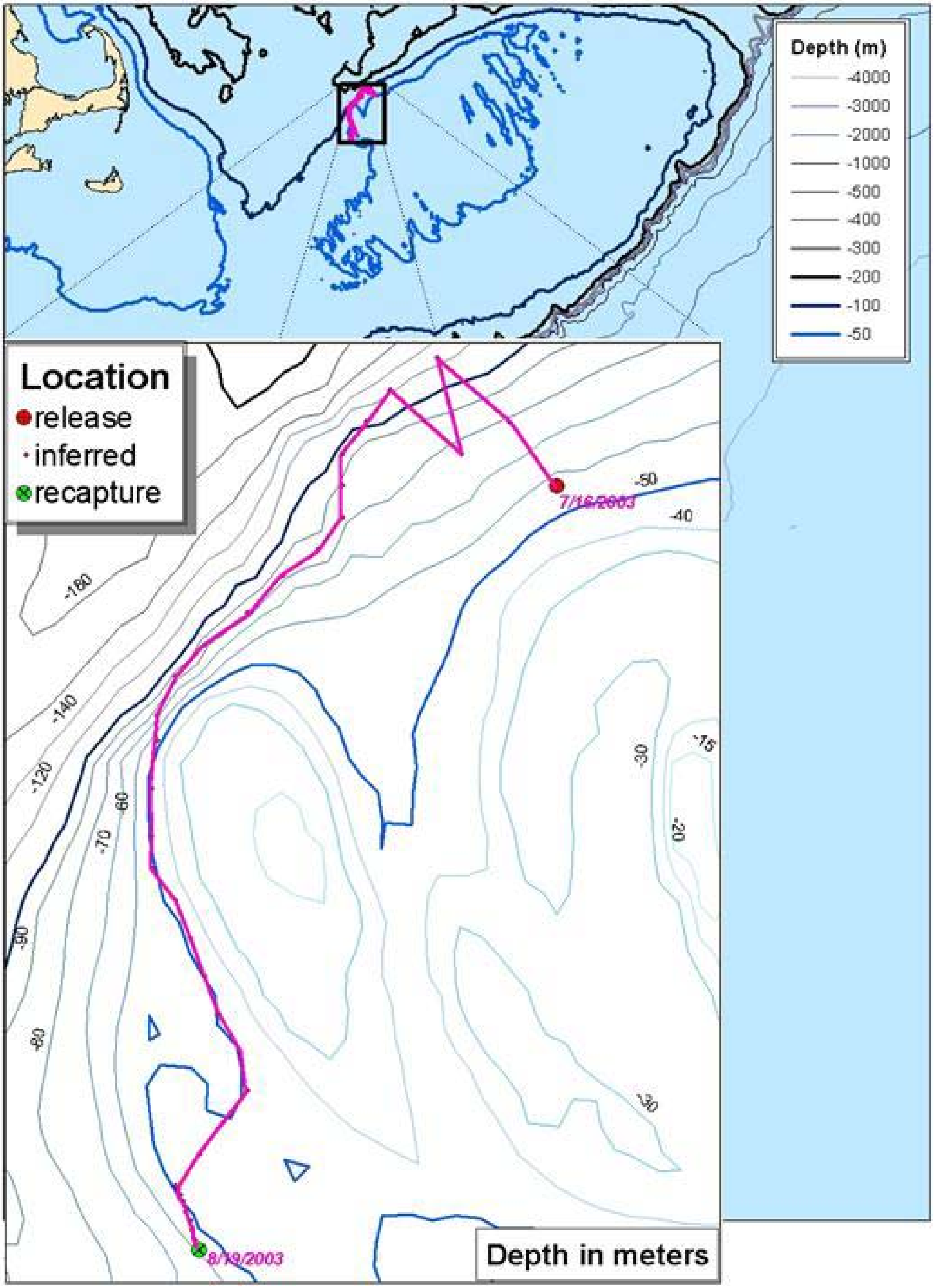


Figure 14. Inferred movement of a yellowtail flounder (tag 1497) on Northern Georges Bank.