Northeast Fisheries Science Center Reference Document 05-06

Use of the Historic Area Remediation Site by Black Sea Bass and Summer Flounder

by

**M.C. Fabrizio, J.P. Pessutti,
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and B.A. Phelan**

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Executive Summary

This report presents the results of a two-year study to determine habitat use and residency time of black sea bass and summer flounder at the Historic Area Remediation Site (HARS) using ultrasonic tags. In 2003, fish were implanted with individually coded ultrasonic transmitters and monitored for one year with *in situ* moored acoustic receivers that covered the HARS in a grid pattern. Prior to executing the field experiment, we conducted laboratory trials to develop surgical and anesthesia protocols; we also monitored the survival and growth of experimentally treated fish for about 10 months. To elucidate habitat use observations from the field, we conducted a behavioral experiment with black sea bass aimed at understanding swimming speed, affinity to structure, and interactions with conspecifics. Results of these supporting laboratory studies are also presented here.

Based on laboratory studies conducted in 2002 with fish held in captivity at the James J. Howard Laboratory, we determined the minimum anesthetic concentration needed to anesthetize fish prior to surgery; we also developed surgical implantation techniques, and monitored the long-term effects of transmitter implantation on growth and survival of fish. Black sea bass greater than 224 mm total length (TL) required at least 40 mg/L of clove oil to achieve full anesthetic induction in less than 5 min and with a reasonable recovery time (less than 10 min); summer flounder greater than 311 mm TL required 80 mg/L clove oil to achieve similar results. Exposure of black sea bass to clove oil for periods up to 15 min beyond the time necessary to reach full induction was not detrimental in terms of recovery time, long-term growth, or survival.

Both black sea bass and summer flounder retained surgically implanted transmitters for up to 10 months and had high survival rates in laboratory trials (black sea bass survival, 100%; summer flounder survival, 92.5%). Two of the smallest summer flounder did not survive the surgery and implantation procedures; these mortalities reflect the difficulty in making incisions and suturing small fish without causing critical damage to internal organs. Black sea bass did not exhibit detrimental growth effects after 10 months; in contrast, summer flounder exposed to clove oil and surgically implanted with a transmitter may have been susceptible to slower growth. We attribute this to the size of the transmitter relative to the available space in the compressed peritoneal cavity of this flatfish.

Using anesthetic dosing and surgical techniques developed in the laboratory, we implanted V8SC-2H transmitters (Vemco Ltd.) in 129 black sea bass (between 220 and 431 mm TL) and 24 summer flounder (between 330 and 500 mm TL) at the HARS between May and July 2003. The only difference was our use of Aqui-S in the field instead of clove oil as the anesthetic agent (Aqui-S contains one of the active compounds in clove oil and is being developed for use as an anesthetic in fish). The implanted transmitters emitted a coded acoustic signal at 69 kHz every 210 s on average (the delay between signals varied randomly between 120 and 300 s); this configuration allowed us to achieve a 384-d battery life on each transmitter. Both black sea bass and summer flounder had high survival rates immediately following surgery in the field (black sea bass survival, 98.3%; summer flounder survival, 100%).

An acoustic grid was deployed in April 2003 at the HARS to passively record transmissions from surgically implanted fish. The grid consisted of 72 arrays each comprised of

a mooring, a receiver, and a pop-up buoy to facilitate retrieval. Prior to implementing the grid, we conducted a range test with a single receiver to determine the effective detection range of the receiver. We found that detection likelihoods decreased as distance between the receiver and transmitter exceeded 400 m. Thus, we spaced arrays 800 m apart. In a subsequent test, we found that the highest detection efficiency occurred when the transmitter was located between 300 and 400 m from a receiver. By September 2004, we completed the retrieval of arrays from the HARS and downloaded the data from receivers. We were unable to recover 13 arrays; 5 were likely buried in disposal material because our retrieval line broke when we attempted to bring the array up from the seafloor; the remainder were either dragged out of the HARS by commercial trawlers or damaged by ships' anchors. From the recovered receivers, we downloaded a total of 1,625,315 detections covering the period May 2003 to September 2004.

The distribution of fish at the HARS was not random; instead, fish were patchily distributed. The number of individuals and frequency of detections of summer flounder and black sea bass were highest in relatively shallow, complex habitats. These habitats occurred primarily in the region roughly corresponding to the area of capped sediments at the old mud dump site. Based on observations with laboratory-held fish, we expect that black sea bass were active during both day and night. Captive-held black sea bass rarely made use of a large concrete block shelter in the research aquarium, using the shelter for about 5.3% of the time. Thus, we do not believe that our relatively small arrays acted as attractors to fish at the HARS.

We estimated the probability of dispersal from the site using the Kaplan-Meier (KM) estimator, a nonparametric approach to compute estimates of the proportion of the sample population that remains at the study site during a particular sampling interval. We note that all 24 surgically implanted summer flounder were detected after release; however, one fish was not detected in 2003, so was not considered in the dispersal analysis. Five of the 129 transmitters from black sea bass were not detected indicating transmitter malfunctions (3.9% malfunction rate). In addition, we detected recordings for two transmitters at only one station from the time of surgery and continuing throughout the winter of 2004; we interpret this to indicate that these two black sea bass died shortly after surgery. Consequently, for dispersal analysis, we considered only the 122 live black sea bass with functioning transmitters.

Dispersal probabilities estimated with the KM approach indicate that black sea bass began dispersing from the HARS on 2 June and the likelihood of dispersal decreased about 60 d later (1 August). During this early summer period (30 May to 23 July), 25 fish dispersed from the HARS while we were actively implanting and releasing fish (3 others were captured and reported by anglers). Dispersal during the early summer did not appear to be related to temperature, salinity, or wave disturbance, as indicated by data we retrieved from two moored CTDs and the Long Island data buoy. Most of the fish that dispersed from the HARS at this time left the site through the southern (48%) or western (28%) perimeters. These fish may have been transiting toward shallower reef structures close to shore, such as Shrewsbury Rocks. After 10 September, dispersal probabilities increased slightly, presumably as fish moved offshore toward deeper overwintering habitats on the continental shelf. The median dispersal date for black sea bass was 28 October (95% confidence interval [CI]: 11 October to 5 November 2003). Between 1 and 17 November, dispersal probabilities increased dramatically, when temperatures in shallower nearshore waters fell consistently below those measured in deeper water on the eastern edge of the study area. By 18 November 2003, 75% of the implanted black sea bass had dispersed from the HARS (the 95% CI for this statistic could not be computed). Like black sea bass, summer flounder began dispersing from the HARS immediately after implantation; dispersal likelihoods appeared higher than those for black sea bass. Between 2 and 20 September, summer flounder dispersal probabilities increased significantly. The median dispersal date for summer flounder was 5 September 2003 (95% CI: 13 August to 12 September 2003). By 20 September 2003, 75% of the implanted summer flounder had left the HARS (95% CI: 5 to 21 September 2003).

Male black sea bass had dispersal likelihoods that were significantly different from those of non-males (females and fish of unknown sex). The difference appears to arise early in the period of study such that by 2 July, 25% of males had dispersed, whereas it was not until 8 September that 25% of non-males left the HARS. There were no significant effects of size on dispersal probabilities among black sea bass, but in summer flounder, total length was significantly associated with the tendency to disperse (smaller fish tended to spend longer time at the HARS).

In addition to these observations on dispersal, we noted the return of one summer flounder, and one (possibly two) black sea bass to the HARS in 2004.

Introduction

US harbors and ports are maintained for safe vessel navigation by deepening channels and deposition of dredged materials in designated disposal sites at sea. Since the late 1800s, dredged material from the Port of New York and New Jersey was disposed at the New York Bight Dredged Material Disposal Site (also known as the Mud Dump Site, MDS). Effective in 1997, the EPA terminated use of the MDS, and designated a 15.7-square nautical mile (nm) area about 3.5 nm off the New Jersey coast as the Historic Area Remediation Site (HARS). The HARS currently accepts only 'uncontaminated dredged material,' that is, material that 'will not cause significant undesirable effects' either directly or through bioaccumulation in the food web (US EPA 1997). The intention was to manage the site to reduce the effects of historical disposal activities to levels conforming to the Marine Protection, Research and Sanctuaries Act of 1972 (Public Law 92-532).

Attempts to describe significant undesirable effects require site-specific knowledge of the ecology of fish species inhabiting the HARS. Factors such as habitat use and residence time, as well as population characteristics such as dispersal rates, affect the relationship between individual fish and a specific geographic area through spatial and temporal exposures. In this study, we investigate the habitat affinity of demersal fishes (fish found in close association with or along the bottom) at the HARS. Two important demersal species targeted by recreational anglers and commercial fishers in the NY Bight are black sea bass (*Centropristis striata*) and summer flounder (*Paralichthys dentatus*). Both species use coastal habitats for feeding and spawning.

The black sea bass is a warm temperate fish in the family Serranidae; the geographic range of this species extends from Nova Scotia to southern Florida (Bowen and Avise 1990). The group of black sea bass found off the coast of New Jersey form part of the Middle Atlantic Bight population. This population spends the winter offshore in the middle- to outer-continental shelf (Musick and Mercer 1977) and migrates inshore in May as temperatures increase. Black sea bass spawn from April through October (Able and Fahay 1998) in nearshore waters at depths between 20 and 50 m (Musick and Mercer 1977; Eklund and Targett 1990). As inshore waters increase in temperature, some juvenile black sea bass migrate into estuaries where they spend their first summer. Once the waters begin to cool in October-November, young-of-the-year and adult black sea bass migrate offshore to the warmer waters of the continental shelf (Figure 1). Black sea bass use complex structured areas such as rock outcroppings, reefs, and wrecks. Their diet consists of a variety of benthic invertebrates including crustaceans, small fish and squid (Hood et al. 1994; Bigelow and Schroeder 2002).

Summer flounder (also locally known as fluke) are flatfishes in the family Bothidae. The geographic range of summer flounder extends from coastal waters of Nova Scotia to Florida (Bigelow and Schroeder 2002), but the species is most abundant in the Mid-Atlantic Bight. In the winter, adult summer flounder are found offshore along the continental shelf and in the spring, summer flounder migrate inshore towards estuaries such as Sandy Hook Bay, NJ, where they reside until fall. Summer flounder spawn in the open ocean over the continental shelf during the fall and winter (Bigelow and Schroeder 2002). The eggs hatch in shelf waters and once the larvae develop into young fish in the spring, they seek shelter and food in coastal estuaries where young summer flounder reside until fall of their first year (Morse 1980).

Summer flounder are most active during the day foraging for food along the bottom or within the water column (Olla et al. 1972), capturing mainly fish, cephalopods, and decapods. Summer flounder inhabit a variety of mud and sand substrates, and may be found in marsh creeks, sea grass beds, and sand flats (Bigelow and Schroeder 2002).

Aquatic habitat use by fish may be studied using a variety of methods. Standard fishery surveys gauge changes in abundance over time but do not provide information on habitat use of individual fish. Such individualized information can be obtained through a tagging study with acoustic "tags" (i.e., transmitters) that permit tracking of multiple, individual fish. Acoustic transmitters relay information on the location of a fish either to hand-held receivers or to passive receivers positioned in the study area; the receivers accumulate digital data on time and place. With ultrasonic tags and a series of moored receivers, the 'recovery' of information is virtually 100%, assuming no transmitter failure or rejection of transmitters by fish. Such methods have been used to measure home range sizes of individual Pacific halibut (*Hippoglossus stenolepis*: Hooge and Taggart 1998), tautog (*Tautoga onitis*: Arendt and Lucy 2000), Nassau grouper (*Epinephelus striatus*: Bolden 2000), snapper (*Pagrus auratus*: Parsons et al. 2003), kelp bass (*Paralabrax clathratus*: Lowe et al. 2003), and blacktip sharks (*Carcharhinus limbatus*: Huepel et al. 2004). Other behaviors examined include pre- and post-spawning migrations of North Sea plaice (*Pleuronectes platessa*: Buckley and Arnold 2000), and habitat use and movements of jewfish (*Epinephelus itajara*; Eklund et al. 2000), tautog (Arendt et al. 2001) and juvenile Atlantic cod (*Gadus morhua*; Cote et al. 2003).

Typically, ultrasonic tagging studies are expensive and thus, researchers have employed few fish (generally not more than 30). The question of adequate sample sizes for estimation of dispersal from a particular habitat has not been explored. In general, investigations of population-level questions such as survival and dispersal rates require the use of a reasonably large number of fish. However, researchers have attempted such studies with a wide variety of sample sizes. For instance, Cote et al. (2004) describe the winter migration pattern of juvenile cod based on only 17 fish, and Comeau et al. (2002) report using 126 adult cod to study migration in the open ocean. In an ongoing study, hundreds of implanted Atlantic salmon *Salmo salar* smolts are being released in three Maine rivers (Penobscot, Dennys, and Narraguagus), to track movement and survival of fish during their downriver migration to marine environments (J. Kocik, NOAA-NMFS, 17 Godfrey Drive, Suite 1, Orono, ME 04473, pers. comm., December 2004).

The objective of our work was to determine habitat use and residency time of black sea bass and summer flounder at the HARS using a year-long ultrasonic tagging experiment. This report presents the results of the experiment conducted at the HARS in 2003-2004. Fish were implanted with individually coded ultrasonic transmitters and monitored for one year with *in situ* moored acoustic receivers that covered the HARS in a grid pattern. Prior to executing the field experiment, we conducted laboratory trials to develop surgical and anesthesia protocols; we also monitored the survival and growth of experimentally treated fish for about 10 months. To elucidate habitat use observations from the field, we conducted a behavioral experiment with black sea bass aimed at understanding swimming speed, affinity to structure, and interactions with conspecifics. Results of these supporting laboratory studies are also presented here.

Methods

Behavioral Observations of Black Sea Bass in the Laboratory

The goal of this study was to understand activity patterns and territoriality in black sea bass, behaviors which were monitored by observing a small group of black sea bass held in a large marine aquarium at the J. J. Howard Marine Laboratory. Activity patterns were assessed by measuring swimming speed, and territorial behaviors were noted by the fish's orientation to structure and interactions with conspecifics. For this experiment, 14 adult black sea bass were collected from nearshore waters between Shrewsbury Rocks and Point Pleasant, NJ. Four of the fish were captured by hook and line in July 2001 and kept in laboratory tanks until 13 May 2002 when they were tagged with individually numbered internal anchor tags. The remaining 10 fish were captured 10 June 2002 using commercial fish traps; these fish were tagged on 25 June 2002 with internal anchor tags after treatment with clove oil (concentrations ranged from 20 to 100 mg/L; see section on anesthetic dosing trials, below). All black sea bass were moved to the large research aquarium on 27 June 2002, at which time sexual identification was somewhat unreliable because the fish were in a post-reproductive condition. Males were identifiable by small amounts of residual milt production and a high degree of contrast in external markings. The remaining black sea bass were either females or smaller males. At the beginning of the observations, the mean size of black sea bass was 286 mm total length (SD= 47.6, range=225 to 345 mm) and 366.1 g (SD=154.8, range=190-659 g). Fish were remeasured at the end of the observations to estimate growth.

Observations were made on black sea bass behavior in a 32,000-gallon research aquarium over a 5-month period (July to December 2002). The research aquarium is oval-shaped (10.6 m long, 4.5 m wide, and 3 m deep), with eight rectangular windows (0.7 m wide and 1.2 m high), one in each end and three along each side. A recirculating system replaces 10% of the water each week. The surface of the bottom of the aquarium is 46 m^2. Photoperiod is computer-controlled and was programmed to follow the natural daily and seasonal cycles at the laboratory location. Water temperatures followed natural seasonal temperatures but were capped at 20°C to prevent thermal stress. Fish were fed chopped squid (*Loligo pealeii*) once a day (weekdays) until satiation. A structure made of concrete blocks (39.4 x 19.7 x 19.4 cm) was placed at one end of the tank to provide a potential shelter for the black sea bass.

We video-taped fish for a 48-hour period every other week in August 2002 and used these recordings to measure swimming speed. The camera was directed at the tank wall on the opposite side of the tank and recordings were made for 5 min at the beginning of each hour of the 48-h observation period. Swimming speeds (cm/s) were determined by timing the passage of a randomly selected fish between vertical lines (the outline of two windows) 139.7 cm apart on the opposite tank wall. In addition, real-time behavioral observations were made three times during the day (morning, midday, and afternoon) for two days each week from July through December. Three individuals were selected and observed for five minutes each to determine the proportion of time spent resting, the number of aggressions, and the association to the structure in the tank. Other behaviors were noted as well.

Surgical Implantation of Transmitters: Laboratory & Field

To ensure suitability of transmitters and implantation methods for black sea bass and summer flounder, we conducted a series of laboratory experiments prior to the field work at the HARS. The objective of those studies was to determine transmitter retention rates and mortality associated with transmitter implantation procedures. Transmitter retention rates should be high to be useful in tracking fish over a one-year period. Some fish, however, may encyst and eject the transmitter either through the incision, the abdominal body wall, or via the intestines (e.g., channel catfish *Ictalurus punctatus*, Summerfelt and Mosier 1984; rainbow trout *Oncorhynchus mykiss*, Chisholm and Hubert 1985, Helm and Tyus 1992; African catfish *Heterobranchus longifilis*, Baras and Westerloppe 1999; and juvenile Atlantic salmon, Lacroix et al. 2004). Retention of transmitters can be improved by ensuring proper implantation methods and proficiency of the surgeon. Once a proper method of transmitter implantation is developed, we expect mortality to be low.

In some species, intraperitoneal implantation of tags can lead to size-dependent mortality (observed for Atlantic cod, S. Campana, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, Canada B2Y4A2, pers. comm., August 2001). Because neither summer flounder nor black sea bass have been previously implanted with ultrasonic tags, we also recorded size of fish so we could examine size-dependent effects on mortality and growth.

For the surgical trials conducted in the laboratory, we used dummy transmitters that matched the size, shape, and weight of actual transmitters implanted in fish in 2003 at the HARS site. Selection of the transmitter was based on size, weight, and necessary battery power life. The "rule of thumb" for determining maximum transmitter size (in weight) is no more than 2% of the fish's weight in air. This rule of thumb does not appear to be supported by empirical data (Mulcahy 2003), and some researchers reported good results with transmitters that ranged up to 8.5% of the fish's body weight (Lacroix et al. 2004). Transmitter expulsion rates increased significantly with increasing weight of the transmitter (Marty and Summerfelt 1986; Lacroix et al. 2004), and larger transmitters were associated with increases in mortality (Lacroix et al. 2004). Adams et al. (1998) investigated effects of surgically implanted transmitters covering a wide range of sizes (2.2 to 10.4% of fish body weight) and found that swimming performance and vulnerability to predation of juvenile chinook salmon *Oncorhynchus tshawytscha* were not affected when the transmitter weighed no more than 5.6% of the fish's body weight. Assuming we would implant black sea bass weighing on average 424 g and summer flounder weighing on average 608 g, a transmitter that weighed no more than 2% or 8.5 g would be needed for black sea bass and 12.2 g for summer flounder. (The mean weights reported here were estimated from 89 black sea bass and 86 summer flounder that were part of the dosing, overexposure, and surgical trials described below.) We selected the smallest transmitter with enough battery power to last at least one year, but weighing less than 8.5 g. The ultrasonic transmitter we selected for field implementation (transmitter V8SC-2H, Vemco Ltd., Shad Bay, N.S., Canada) was 30 mm long and 9 mm in diameter, and weighed 5 g in air and 3.1 g in water. This represents 1.2% of the average black sea bass weight and 0.8% of the average summer flounder weight.

Dummy transmitters used in the laboratory trials were constructed from a casting mold and embedded with stainless steel nuts. Hot glue (non-hazardous hot melt adhesive) was injected into the mold and allowed to cool before removal. Dummy transmitters were inspected for irregularities and exposure of stainless steel nuts; defective casts were discarded. Transmitters were coated with a thin layer of one-hour epoxy and dipped in melted beeswax, which provided an inert and smooth coating. We coated the transmitters with beeswax because among fish that expel surgically implanted devices, paraffin- and silicone-coated transmitters tended to have higher expulsion rates than those coated with beeswax (Helm and Tyus 1992).

We elected to use clove oil to anesthetize fish prior to surgery. Use of fish anesthetics is regulated by guidelines from the USDA Center for Veterinary Medicine (CVM), and although clove oil is a compound that is Generally Recognized as Safe (GRAS) when used as a direct food additive, it is not approved for use as an anesthetic by the CVM (www.fda.gov/cvm/guidance/guide150.doc). Regardless of this guidance, many researchers recently began experimenting with clove oil as a fish anesthetic (e.g., Peake 1998; Taylor and Roberts 1999; Schreer et al. 2001; Woody et al. 2002); most of these studies have been performed with freshwater or anadromous fish, and only one study has reported the results of clove oil as an anesthetic with marine fish species (coral reef species, Munday and Wilson 1997). To our knowledge, no published research results exist for clove oil as an anesthetic for temperate marine species, although some researchers are currently experimenting with summer flounder (J. Specker, University of Rhode Island, Graduate School of Oceanography, 218 South Ferry Rd., Narragansett, 02882, pers. comm., July 2002). The US Fish & Wildlife Service (FWS) holds an Investigational New Animal Drug (INAD) exemption for Aqui-S (Aqui-S New Zealand Ltd., Lower Hutt, New Zealand), an anesthetic agent containing 50% isoeugenol (2-methoxy-4-propenylphenol), one of the active compounds in clove oil. Aqui-S is manufactured and licensed for use in New Zealand for the "handling and harvesting of fish and other seafood." Research conducted under the INAD exemption will be used by the FWS to petition the CVM for approval of Aqui-S as a fish anesthetic. With that in mind, we initiated studies with clove oil and sought listing on the FWS INAD exemption (# 10541); our request was granted after our laboratory trials had begun, but in time for our surgical work at the HARS. At the HARS, we used concentrations of Aqui-S equivalent to those used for clove oil in the laboratory trials.

Laboratory Trials: Black Sea Bass

Collection – We collected about 125 adult black sea bass from NJ coastal waters during May and June 2002. We deployed fish traps from a commercial fishing vessel operating out of Manasquan, and used hook and line techniques at Shrewsbury Rocks to capture black sea bass. Fish captured with traps were taken from waters 70 to 80 feet deep and generally had inflated swim bladders; some had their stomachs protruding from their mouth (stomach evulsion). We deflated swim bladders by puncturing the abdominal wall with a hollow needle and exerting gentle pressure on the abdominal area (Collins et al. 1999). Fish captured by hook and line were taken from 25- to 30-ft depths and did not exhibit decompression trauma. Live fish were brought to the laboratory and held for later work (anesthetic dosing, anesthetic overexposure, or surgical trials). Not all fish survived the handling and transport process and only healthy fish (ranging in size from 224 to 445 mm total length [TL] and 191 to 1049 g) were used in subsequent experiments.

Anesthetic Dosing Trials – Clove oil solutions were prepared by dissolving clove oil in 95% ethanol and adding the resultant solution to a seawater bath (66.25 l). Prior to adding the clove oil solution to the seawater bath, we measured temperature and salinity of the water. We exposed 3 adult fish to the following clove oil concentrations: 20, 40, 60, 80, 100, and 120 mg clove oil/L and noted the time to various stages of anesthesia, which we modified from Summerfelt and Smith (1990). The 5 stages we identified for black sea bass were:

Stage	Description
1	weak or erratic opercular movement
2	sporadic loss of equilibrium; difficulty maintaining position
3	total loss of equilibrium ('belly up')
4	loss of fin movements (loss of swimming motion)
5	no opercular movement

Although we initially defined 5 stages of anesthesia, we found that transitions into the first 2 stages were gradual and determining the time a fish needed to achieve stages 1 and 2 appeared to be somewhat subjective. Stages 3, 4, and 5 endpoints were less subjective and were further considered.

We conducted dosing experiments at two different temperatures (mean temperatures: 19.7°C and 15.9°C) to examine the effect, if any, of water temperature on induction and recovery times. However, at low temperatures, we examined the anesthetic action and effect of only the 20, 40, 60, and 80 mg/L doses of clove oil. Each batch of anesthetic solution was used only once (up to 4 fish were exposed, one at a time in the bath), and a particular fish was exposed to only one combination of clove oil concentration and temperature.

Once the fish was anesthetized, we measured TL and weight, identified sex, and inserted a numbered anchor tag in the dorsal musculature. Fish were transferred to a recovery tank where we used ram ventilation to ensure adequate water flow over the gills. Recovery occurred when the fish regained equilibrium and swam in a forward direction (minimum of 3 fin strokes) in response to prodding in the peduncle area. We tested the effect of clove oil concentration and temperature on mean induction and recovery times using an ANOVA with $\alpha=0.05$.

We also examined induction times to select the minimum concentration necessary to achieve full induction (stage 5) within 3-5 min and full recovery in less than 10 min. Summerfelt and Smith (1990) note that an ideal anesthetic has an induction time less than 15 min, but preferably less than 3 min, and a short recovery time (i.e., $\leq$ 5 min). Because we could not be certain of the temperature at which we would be catching and surgically treating fish at the HARS, we conducted the dosing trials at two temperatures (means=15.8°C and 19.7°C) and with fish that averaged 285 mm and 352 g (n=33). We held fish an average of 291 d (9.7 months) and observed for mortalities or other abnormalities. At the end of the observation period, we measured length, weight, and identified sex of each fish prior to release. These observations allowed us to examine growth of fish exposed to clove oil. During the same time period (June 2002 - July 2003) we also maintained a small group of black sea bass (n=4 females, mean size = 270 mm, 269 g) that had not been exposed to clove oil; estimates of growth rates from these fish were compared with those of fish exposed to clove oil using an ANOVA with α=0.05.

Anesthetic Overexposure Trials – In addition to the clove oil dosing experiment, we conducted an overexposure test at the clove oil concentration determined to be optimal from the dosing experiments. Previous studies indicated that exposures greater than 5 min may unduly prolong recovery times (Peake 1998) or even lead to death. For example, adult sockeye salmon *O. nerka* survived 15 min exposures to clove oil concentrations up to 80 mg/L, but a 15-min exposure to 110 mg/L clove oil was lethal (Woody et al. 2002). The overexposure test provided an indication of how much longer we could expose black sea bass without incurring mortalities or prolonging the recovery period and aided in establishing a maximum permissible surgery time. We exposed a group of 9 fish to the anesthetic an additional 5, 10, and 15 min after the time necessary to achieve stage 5 anesthesia. We recorded information from these fish similar to that from the dosing trials. We tested the null hypothesis of no difference in recovery time among fish overexposed for 5, 10, or 15 min using an ANOVA with α=0.05. The overexposure trials were conducted at 21°C and 24.3‰ salinity with fish that averaged 301 mm TL (mean weight, 463 g; *n*=9). We held fish for an average of 267 d (8.9 months) and observed for mortalities or other abnormalities. At the end of the observation period, we measured length, weight, and identified sex of each fish prior to release and examined growth rates.

Surgical Trials – During July and August 2002 we implanted 47 black sea bass with dummy transmitters using surgical protocols modified for this species from methods described in Summerfelt and Smith (1990), Wooster et al. (1993), and in several protocols acquired from other federal laboratories (Standard Operating Procedures for Surgical Implantation, USGS Upper Mississippi Science Center; Smolt Surgery Protocol, NOAA-Fisheries Atlantic Salmon Program).

To perform the surgery, we exposed black sea bass to 40 mg/L clove oil at an average temperature of 17°C and average salinity of 26.7‰ and allowed each fish to remain in the anesthetic bath for 1 to 2 min after achieving full induction. A few minutes of additional exposure to the anesthetic bath were beneficial, as fish thus exposed maintained full anesthesia during the surgical procedure. Once anesthetized, a fish was placed dorsal side down in the V-shaped surgical cradle which was lined with wet foam and covered with a moist chamois cloth. Anesthetic solution (40 mg/L clove oil) was continuously circulated across the gills via a flexible tygon tube inserted through the mouth and into the gill cavity. Individual scales were removed from a small area on the ventral body wall just posterior to the pectoral fins and along the midline. We found that scale removal was necessary to permit making an incision. A dummy transmitter, sterilized in a glutaraldehyde solution, was inserted into the peritoneal cavity through a small incision (about 2.5 cm long) in the ventral midline area. We used nonabsorbable monofilament nylon sutures (Ethilon® 3-0 and 4-0 with FS-1 cutting needle, Ethicon, Somerville, NJ) in a simple interrupted suture pattern to close the incision. The incision was closed with three sutures and covered with a small amount of cyanoacrylate (VetBond™, 3M, St. Paul, MN), a tissue adhesive. Monofilament sutures are recommended for fish surgical procedures by veterinarians (Mulcahy 2003), and when applied in an interrupted pattern, these sutures are associated with significantly less tissue damage (Wagner et al. 2000). The tissue adhesive was used to bond the skin and may aid in the reduction of wound contamination following surgery. To further reduce the likelihood of infection, antibiotic ointment was swabbed over the sutured area. Each fish was then weighed, it's length recorded, and an individually numbered anchor tag was inserted into the musculature below the dorsal fin.

Recovery was as described for the dosing trials. For these fish, we also recorded induction, surgery, and recovery times.

We monitored fish until 22 July 2003 (average time of 310 d or 10.3 months; *n*=32) and observed for transmitter loss and mortality associated with surgery. Prior to releasing fish, we obtained length and weight information which we used to calculate daily growth rates for the subset of fish that retained their anchor tag (*n*=32). Growth rates for surgically treated fish were compared with those from fish exposed to clove oil and no surgery, and with growth rates of a small group (*n*=4 females) of control fish using an ANOVA with α=0.05.

Laboratory Trials: Summer Flounder

Collection – We collected about 25 summer flounder from NJ coastal waters during May and June 2002 using hook and line techniques from the R/V *Gloria Michelle*; an additional 15 fish were collected from either Sandy Hook Bay or the Navesink River, NJ, from small boats using hook and line. Live, healthy fish were returned to the laboratory and held for later work (anesthetic dosing or surgical trials). In November 2002, we acquired 15 summer flounder (ranging from 313 to 509 mm TL) from an aquaculture facility in New Hampshire (Great Bay Aquaculture, Portsmouth, NH). These fish (subsequently referred to as the 'cultured' fish) were transported to the J. J. Howard Marine Laboratory and allowed to acclimate to laboratory conditions. We used active feeding as an indicator of acclimation and postponed surgical trials until all fish were fully acclimated. The acclimation period was long – we noted that one or two fish began eating in late December, and by early January most of the cultured fish were actively feeding. One cultured fish died on 20 December, but we could not discern the cause of death (necropsy revealed no gross organ damage, parasites, or other abnormalities). Only healthy summer flounder (ranging from 268 to 509 mm TL) were used in subsequent experimental trials. Ten of the 12 summer flounder from anesthetic dosing trials were later used in surgical trials because we had difficulty capturing sufficient numbers of fish with which to conduct the surgical trials. Also, J. Specker (University of Rhode Island, Graduate School of Oceanography, 218 South Ferry Rd., Narragansett, RI 02882, pers. com., July 2002) indicated that repeated exposure of summer flounder to clove oil had no adverse effects.

Anesthetic Dosing Trials – Clove oil solutions (40, 60, 80, and 100 mg clove oil/L) were prepared as described for black sea bass dosing trials. We exposed 3 adult fish to clove oil and noted the time to 5 stages of anesthesia (modified from Summerfelt and Smith 1990):

Stage	Description
1	weak or erratic opercular movement
2	sporadic loss of equilibrium; difficulty maintaining position
3	total loss of equilibrium; inability to regain upright position
4	mouth open
5	no appreciable opercular movement

Although we initially defined 5 stages of anesthesia for summer flounder, we found that transitions into the first 2 stages were gradual and determining the time a fish needed to achieve stages 1 and 2 appeared to be somewhat subjective. Stages 3, 4, and 5 endpoints were less subjective and were further considered.

Each batch of anesthetic solution was used only once (up to 3 fish were exposed, one at a time in the bath), and a particular fish was exposed to only one concentration. We conducted dosing experiments at 20.7°C and 27.1‰ salinity. Because we later performed surgery with both wild captured and cultured summer flounder, we exposed 3 of the cultured fish to 80 mg/L clove oil (at 15.1°C and 22‰ salinity), measured induction and recovery times, and compared results with those observed for wild captured fish.

Once the fish was anesthetized, we measured TL and weight, and inserted a numbered anchor tag in the dorsal musculature. Fish were transferred to a recovery tank where we used ram ventilation to ensure adequate water flow over the gills. Recovery occurred when the fish swam in a forward direction in response to prodding in the peduncle area. We examined induction times to select the minimum concentration necessary to achieve full induction (stage 5) within 3-5 min and full recovery in less than 10 min. We monitored these fish from 29 July to 11 December 2002 during which time most of the fish had become part of the surgical experiments.

Surgical Trials – In August 2002, we began surgical trials with summer flounder. Preliminary observations indicated that fish with incisions on the pigmented side exhibited significant hemorrhaging near the incision site within two weeks post-surgery; we also noted incomplete closure of the incision. Post-surgical observations of fish with the incision on the unpigmented side indicated accelerated wound healing and complete closure of the incision. We subsequently adopted this method to perform surgical implantations with summer flounder.

Between August 2002 and January 2003 we implanted 53 summer flounder with dummy transmitters using surgical protocols similar to those developed for black sea bass. Summer flounder in the surgery trials ranged in size from 281 mm to 508 mm TL and 202 to 1623 g (mean=389 mm TL and 685 g; *n*=48) and included both wild captured (*n*=41) and cultured fish (*n*=12). As before, we used dummy transmitters that matched the size, shape, and weight of actual transmitters. In these surgical trials, dummy transmitters represented 0.7% of the average summer flounder weight (685 g; *n*=48). Perhaps more important than weight considerations was size of the transmitter, as flatfish have a small peritoneal cavity and identifying an appropriately sized transmitter was paramount (Paukert et al. 2001; Mulcahy 2003).

We also implanted 20 additional summer flounder with dummy transmitters on 20 and 24 September 2002, but these fish died shortly after surgery when the dissolved oxygen in the holding tanks dropped to lethal levels. Because these fish died on 4 October 2002, little could be learned about post-surgical survival, growth, or transmitter expulsion, so they were omitted from further consideration.

To perform the surgery, we exposed summer flounder to 80 mg/L clove oil at an average temperature of 17.8°C and average salinity of 24.6‰ and allowed each fish to remain in the anesthetic bath for 1 to 2 min after achieving full induction. As with black sea bass, a few minutes of additional exposure to the anesthetic bath were beneficial to ensure full anesthesia during the surgical procedure. Once anesthetized, a fish was placed pigmented side down in a surgical cradle and anesthetic solution (80 mg/L clove oil) was continuously circulated across the gills. Scale removal was not necessary and an incision was made about halfway between the pectoral and pelvic fins, but posterior to the pectoral fin insertion. The 2.5-cm long incision was oriented from anterior to posterior (i.e., parallel to the long axis of the body). A dummy transmitter coated in beeswax and sterilized in a glutaraldehyde solution was inserted into the peritoneal cavity through the incision. We used nonabsorbable monofilament nylon sutures (Ethilon® 3-0 and 4-0 with FS-1 cutting needle, Ethicon, Somerville, NJ) in a simple interrupted suture pattern to close the incision. The incision was closed with three or four sutures, covered with a small amount of cyanoacrylate (VetBond), and swabbed with antibiotic ointment. Each fish was then weighed, it's length recorded, and an individually numbered anchor tag was inserted between the pterygiophores of the dorsal fin. Recovery was as described for the dosing trials. For these fish, we also recorded induction, surgery, and recovery times.

During the post-surgical observation period, we investigated patterns of recovery and healing in summer flounder by inspecting for signs of infection and inflammation associated with surgical implantation. These post-surgical observations were conducted seven times, about every two weeks (10 September 2002, 26 November 2002, 11 and 23 December 2002, 7 and 28 January 2003, and 12 February 2003). An eighth assessment was conducted on 25 March 2003, about one month after the last biweekly assessment, and a final assessment was conducted on 20 November 2003. The mean assessment time interval from date of surgery to final assessment was 383 d (or 12.6 months). All fish were assessed for a minimum of 310 d after date of surgery. The post-surgery observation protocol consisted of capturing fish from the holding tank with rubber nets and visually inspecting the incision site and the overall health of the fish. The incision site observations included: number of remaining and functioning sutures, signs of irritation along the incision site, signs of irritation at the suture site, percent closure of the incision, and whether the closure was tenuous or robust. A tenuous closure occurs when the inner layer of muscle tissue closes completely, but the outer layer and skin remain unclosed. A robust closure was defined as 100% closure through all layers of tissue (dermal and muscle layers). Observations on the overall health of the fish, the presence of parasites, and the functioning level of the dermal adhesive, Vetbond, were also noted.

In addition to evaluating the healing process, we monitored fish for at least 310 d (mean=383 d or 12.6 months) post-surgery for transmitter loss and mortality associated with surgery. By 20 November 2003, we terminated the post-surgical observation period for all surviving summer flounder. Prior to releasing fish, we obtained length and weight information which we used to calculate daily growth rates for the subset of fish that retained their anchor tag (n=46). Growth rates of surgically treated fish were compared with those from a small group of control fish (n=3 cultured summer flounder) that had not been exposed to clove oil or surgery; this comparison was performed with an ANOVA at a significance level of α=0.05. In addition, a subset of fish (n=5) was euthanized to permit examination of internal organs and inspection for tissue damage including adhesions, hemorrhaging, and the presence of necrotic tissue.

HARS: Black Sea Bass

We used hook and line techniques and fish traps (3 traps per string) to capture black sea bass at the HARS from 30 May to 16 July 2003 (Table 1). The traps were allowed to soak at the site for 1-3 nights before retrieval. Catch rates of black sea bass in the fish traps were low during late May and early June, and many undersized (< 225 mm TL and < 210 g) black sea bass were captured. Undersized black sea bass and other species were released alive at the HARS (Table 2).

As a result of changes in pressure associated with capture, black sea bass swim bladders were inflated when the fish were brought on deck. We followed the recommendation of Collins et al. (1999) and attempted to deflate swim bladders using hypodermic needles and gentle abdominal compression, but we were unable to successfully deflate swim bladders of most fish, and the excessive handling required by this technique appeared to further stress fish (as evidenced by notable changes in coloration). Therefore, we retrieved the traps and 'hung' them at 30 feet for 15 min to permit decompression of swim bladders. This decompression procedure alleviated some of the problem, but did not completely eliminate it. Neufeld and Spence (2004) reported similar mixed results using the same decompression technique with burbot. Black sea bass captured using hook and line techniques also exhibited swim bladder inflation.

We used Aqui-S to anesthetize fish in preparation for surgical implantation. At 40 mg/L, black sea bass required more than 10 min (mean, 12.6 min; *n*=2) to achieve full induction (stage 5). Although this concentration was ideal in the laboratory, the captured fish tended to exhibit stress (dark coloration) and were not reacting to the anesthesia in a manner consistent with laboratory-held fish (we had difficulty achieving stage 5 anesthesia). Previous laboratory studies indicated that black sea bass could readily tolerate clove oil concentrations up to 120 mg/L. We therefore increased the anesthetic concentration to 80 mg/L and this provided us with quick induction times (mean, 3.3 min; *n*=127), thus minimizing additional stress to the fish.

We implanted beeswax-coated V8SC-2H transmitters (Vemco Ltd.) in 129 black sea bass at the HARS (*n*=84 fish captured in traps; *n*=45 fish captured by hook and line) using surgical techniques identical to those developed in the laboratory. These transmitters emitted a coded acoustic signal at 69 kHz every 210 s on average (the delay between signals varied randomly between 120 and 300 s); this configuration allowed us to achieve a 384-d battery life on each transmitter. After surgery, but while fish were anesthetized, we recorded TL, weight (using a motion-compensated scale), and sex of the fish; we also inserted a numbered anchor tag into the dorsal musculature. This tag was imprinted with an identification number, a phone number to call should the fish be recaptured, and the statement 'Not for human consumption'. Recovery of fish required ram ventilation, and usually more than 10 min. Fish were closely monitored during the recovery period. As soon as fish exhibited strong fin movements (i.e., fish swam forcefully to the bottom of the holding tank), we released the fish within the HARS site and recorded location and time of day. Some of the fish had difficulty with swim bladder inflation (as previously noted), but upon release, all fish were able to swim downward towards the sea floor. Table 3 summarizes the tagging procedure (anesthesia, surgery, and recovery) for black sea bass.

The average size of black sea bass implanted with transmitters was 307 mm TL (range, 220-431 mm; *n*=129) and 408 g (range, 195-995 g; *n*=91). Most of the fish appeared to be females (59%), but we could not determine sex for about 13% of the fish. Surgeries were conducted at a mean temperature of 17.8°C (range, 13.6 to 24.2°C) and 27.1‰ salinity (range, 22.1 to 31.0‰). On average, black sea bass exposed to 80 mg/L Aqui-S required 3.3 min (*n*=127) to achieve induction (range, 1.1 to 7.7 min). Recovery time was not recorded because most fish required 10 or more min to recover. Surgery time varied between 2.0 and 11.7 min (mean, 4.1 min; *n*=128).

Some of the implanted black sea bass were recaptured by anglers or commercial fishers who reported their catches (Table 4).

HARS: Summer Flounder

We captured 24 summer flounder at or near the HARS site from 17 June to 16 July 2003 using hook and line techniques (*n*=23) or a bottom trawl (*n*=1) (Table 1). Catch rates for summer flounder were low. Other species captured were released alive at the HARS (Table 2).

We implanted beeswax-coated V8SC-2H transmitters (Vemco Ltd.) in 24 summer flounder larger than 280 mm TL and 215 g using surgical procedures developed during laboratory experiments in the previous year, except we used Aqui-S as the anesthetic agent (at 80 mg/L). After surgery, but while fish were anesthetized, we recorded TL and weight (using a motion-compensated scale) and inserted a numbered anchor tag into the dorsal musculature. This tag was imprinted with an identification number, a phone number to call should the fish be recaptured, and the statement 'Not for human consumption.' Recovery of fish required ram ventilation, and usually more than 10 min. Fish were closely monitored during the recovery period. As soon as fish responded to prodding in the caudal peduncle by swimming away, we released the fish within the HARS site and recorded location and time of day. Table 3 summarizes the surgical implantation procedure (anesthesia, surgery, and recovery) for summer flounder.

The average size of summer flounder implanted with transmitters was 388 mm TL (range, 330-500 mm; *n*=24) and 585 g (range, 320-1080 g; *n*=13). Surgeries were conducted at a mean temperature of 21.7°C (range, 16.1 to 23.7°C) and 27.3‰ salinity (range, 26.5 to 30.0‰). On average, summer flounder exposed to 80 mg/L Aqui-S required 2.3 min (*n*=24) to achieve full induction (range, 1.7 to 5.3 min). Recovery time was not recorded because most fish required 10 or more min to recover. Surgery time varied between 2.1 and 6.8 min (mean, 4.2 min; *n*=24).

Some of the implanted summer flounder were recaptured by anglers or commercial fishers who reported their catches (Table 4).

HARS Acoustic Grid Design

Array Construction and Deployment

The objective of this portion of the study was to determine the effective detection range of receivers deployed at the HARS and to investigate factors associated with variation in detection efficiency such as distance to receiver and depth of the transmitter.

In October 2002, we conducted a range test in the southeastern portion of the HARS site using a single moored receiver and a transmitter which we deployed as a 'dummy fish.' We successfully deployed and recovered the moored receiver (using a pop-up buoy on loan from Benthos Inc., North Falmouth, MA). Based on the latitude-longitude position of the vessel from which the transmitter was deployed and the latitude-longitude position of the moored receiver, we calculated surface distances. Inspection of the data from the single receiver indicated that transmitters were detectable up to 600 m from the receiver, although detection frequency was significantly diminished beyond 400 m (Figure 2). Based on this likelihood of detection, we elected to place arrays 800 m apart in a grid pattern covering most the HARS (Figure 3).

Each array consisted of a 400-lb pyramidal anchor, an acoustic receiver (model VR2, Vemco Ltd., Shad Bay, Nova Scotia), a lobster float, and a pop-up buoy (shallow water release SWR, ORE Offshore, West Wareham, MA) fastened together with low stretch, 9,800-lb test line (Amsteel, Samson Rope Technologies, Ferndale, WA; Figure 4). Pop-up buoy canisters contained a 140-ft tether of braided line capable of lifting the 400-lb mooring. Two of the arrays included a conductivity, temperature, and depth (CTD) sensor (SBE 16, Sea-Bird Electronics, Bellevue, WA) below the pop-up buoy, and about 3 m above the substratum. The CTDs were programmed to continuously record temperature and salinity every 30 min.

From 14 to 25 April 2003, we deployed one array at each of 72 stations at the HARS site (Figure 3). Arrays with CTDs were deployed in the northwest (Station B1: 40˚ 24.6046' N; 73˚ 53.126' W) and southeast (Station H7: 40˚ 21.9910' N; 73˚ 49.7739' W) corners of HARS. The CTD at the inshore site (Station B1) was located at a depth of 24 m, whereas the offshore site (station H7) was 29 m deep and closer to the Hudson Canyon. The grid of receivers covered a 13.43 nm^2 area (or 4,608 hectares). [The HARS site is 15.7 nm^2.] A local notice to mariners was filed with the U.S. Coast Guard in March 2003 to alert mariners to the presence of our arrays. In addition, the ACOE established a 250-ft buffer zone around each of our arrays where disposal of remediation material was prohibited.

Array retrievals in 2003 – In August-September 2003, the acoustic arrays were retrieved, the data were transferred from the receivers, and arrays were re-deployed. We successfully retrieved 70 of the 72 arrays (see Table 5) and collected data from 68 of the 70 recovered receivers. Two recovered receivers contained no data because the battery compartment had flooded (A7, H5). One array (B4) was not retrieved because a survey vessel damaged the pop-up buoy after it had surfaced and before our vessel could reach the floating canister. In an effort to retrieve the arrays at B4, I2, and F8, three dives were conducted in late September-early October. Divers were unsuccessful at finding the arrays at B4 and I2, but successfully recovered the array at F8.

A number of our arrays were covered by mud, presumably from disposal of remediation material (Table 5). The mud did not cover the receiver, so the array functioned properly, however, retrieval of these units was difficult and in many cases resulted in damaged instruments (3 pop-up buoys were damaged, 1 was beyond repair; 1 receiver was damaged, although the data could be retrieved and the unit was later repaired).

Once the arrays were retrieved, we transferred data from the receivers to a laptop computer (model VR2PC receiver-PC interface, Vemco Ltd., Shad Bay, Nova Scotia) for later analysis. Overall, the 68 receivers recovered in 2003 recorded a total of 1,333,205 detections.

Array retrievals in 2004 – During July-September 2004, we retrieved a total of 59 arrays from the HARS. We successfully activated 36 pop-up buoys and retrieved 34 of these on the same day (buoy tether lines broke on retrieval at two stations). Most of the remaining arrays were retrieved several days after the initial activation of the pop-up buoys (Table 5). We believe the buoys did not surface on the day we activated the acoustic release because the buoy tether lines became tangled but were eventually shaken loose after the region experienced a strong northeasterly wind. We were unable to retrieve three of the late-surfacing buoys that managed to float to the surface because the tether line broke during retrieval and divers were unable to find arrays. An additional eight arrays could not be found, bringing the total number of unrecovered arrays to 13. We transferred data from the recovered receivers to a laptop computer for later analysis. Because of a defective circuit board on one of the receivers (recovered at station B1), we were able to obtain data from only 58 receivers, and these recorded a total of 292,110 detections.

Combining the downloaded data from 2003 and 2004 produced a total of 1,625,315 detections covering the period April 2003 to September 2004. The distribution of detections is depicted in Figure 5 for black sea bass and summer flounder separately.

Receiver Efficiency Test

On 25 June 2004, we conducted a receiver efficiency test at the HARS by towing a transmitter near stations A1-2, B1-2-3, C1-2-4, D2-3, E1-2-3, F1-2-3, G1-2, H1-2, and I1-2 (Figure 6). Stations included in the efficiency test were selected based on observed gaps in time in the transmitter detection records from receivers moored at those stations (as indicated in the data obtained from the data transfer activity in 2003). Stations were also selected to represent the varying depths and levels of structural complexity across the study area. We hypothesized that these gaps may be associated with the presence of oceanographic features such as a thermocline, which is known to affect acoustic transmissions in water. The V8SC-2H transmitter (with a transmission rate of once every 10 s) used to perform the receiver efficiency test was mounted to a tow line stabilized with a planer; the line was also outfitted with a miniature data logger that measured and recorded temperature and depth every 3 s (Minilog ML08-TDR, Vemco Ltd., Shad Bay, Nova Scotia). We also deployed a CTD profiler (model SBE 23, Sea-Bird Electronics, Inc.) at five selected sites (Figure 6). We towed the transmitter above, through, and below the thermocline. We examined the effect of the transmitter's depth and distance to the nearest receiver on the efficiency of receivers by analyzing the transmissions detected by the affected receivers.

Positions of the transmitter were derived from a GPS log file of the vessel and additional calculations to account for depth and use of a tow line. Latitude and longitude coordinates from the GPS file were converted from decimal degree units to UTM (Universal Transverse Mercator) units to permit calculations in meters. Data for the vessel's heading in the GPS file were converted from magnetic north degrees to true north degrees, and subsequently transformed to a unit vector angle by assuming 90 degrees true north as the positive *x* axis (Figure 7A). From this angle, unit vectors were calculated providing the direction of the offset. Any vector may be decomposed into two vectors that are orthogonal with a magnitude of 1; the orthogonal vectors are called unit vectors. The *x*- and *y*-component unit vectors are represented by *i* and *j*. To obtain the east and north correction factors for the transmitter's position (relative to the vessel), we multiplied the negative of the *i* and *j* unit vectors by the distance from the transmitter to the vessel (Figure 7A). The distance from the transmitter to the vessel (in the *x-y* plane) was simply the sine of the tow-line angle multiplied by the length of tow line (Figure 7A).

Actual "through-the-water" distances from the transmitter to the receiver were estimated using transmitter and receiver depths (Figure 7B). We obtained transmitter depths from the data logger, which was mounted on the tow line just above the transmitter, by transferring data from the data logger to a PC (Minilog PC interface, Vemco Ltd.). Receiver station depths were acquired from the fathometer aboard the vessel used to deploy the receivers the previous year; depth of the receiver was calculated as station depth minus 2 m (the height of the receiver off the seafloor). The actual distance between the transmitter and the receiver was given by the hypotenuse of the triangle having sides representing the distances in the *x-y* and *x-z* planes (Figure 7B).

We calculated distances between the transmitter and each receiver within 1,000 m of the transmitter and binned these into 100 m increments. We next examined the number of transmissions sent by the transmitter to the receiver and the distance between them. Detected transmissions were assembled from the receiver data files, which we transferred to a PC. Percentages of transmitted signals detected by the receivers for each 100-m increment were calculated. In addition, for each 100-m bin, we calculated the proportion of signals received from the transmitter and reported these proportions for various 5-m (transmitter) depth bins. We tested for significant differences in the proportion of detected transmissions when the transmitter was within 400 m of the receivers vs. more than 400 m away using a χ^2 test for the comparison of proportions from independent samples and using α=0.05 (Fleiss 1981).

Habitat Characterization

In this portion of the study, we synthesized information on habitat characteristics that were postulated to affect habitat use or dispersal. We examined depth, sediment characteristics, and an indicator of potential wave disturbance at the HARS using readily available data from the USGS or NOAA data buoys.

An analysis relating the distribution of fish with physical characteristics of the HARS requires consideration of environmental variables at the same resolution as our fish presence/absence data. Continuous grid coverages of environmental variables or their indices must be averaged over zones equivalent to the detection zones of our receivers. Receiver detection zones are circular with a radius of about 400 m. Depth and sediment grain-size coverages at the HARS in 2000 were provided by the USGS (Butman et al. 2002). A geographic information system (ArcGIS, ESRI, Redlands, CA) was used to convert all coverages into UTM (Universal Transverse Mercator) units, and to perform all necessary calculations. An index based on the mean bottom slope was calculated to reflect changes in depth over each 100-m^2 grid cell. Figure 8 displays zonal averages for depth, sediment grain size, and mean bottom slope at the HARS.

To better understand the effect of environmental changes on fish dispersal, we examined maximum near-bottom horizontal orbital velocities (U_m) in $cm \cdot s^{-1}$ as an index of potential wave disturbance and changing weather patterns in the vicinity of the study area. U_m was calculated as:

$$U_m = H\pi/T\sinh(kh)$$

where H is the significant wave height (m), T is dominant wave period (s), h is bottom depth (m), and k is the wave number (Dyer 1986). The value for k was calculated from the angular frequency, $2\pi/T$, and water depth, h; we set h equal to 15.5 m, the depth of shallowest station at the HARS (F5). Significant wave height and dominant wave period data were taken from the Long Island buoy maintained by NOAA's National Data Buoy Center (Station 44025; 40°15'01"N, 73°10'00"W; http://www.ndbc.noaa.gov/station_page.php?station=44025).

Analysis of Transmitter Data

Receiver records were organized into a relational database we constructed for this study; such databases are useful for examining fish tagging data (Fabrizio and Nelson 1995). We constructed 3 primary tables: (1) Transmitter Detection (this data set contained the 1.6 million records transferred from receivers moored at the HARS); (2) Surgery (this data set contained information associated with the surgical implantation and release of fish at the HARS); and (3) Array Deployment/Retrieval (this data set summarized information associated with the deployment and retrieval operations). Other tables were constructed to facilitate merging of information from one table to the other (e.g., Transmitter Lookup Table, and Pop-up Buoy Code Table).

We contacted scientists at Vemco [manufacturer of transmitters and receivers] to assist with interpretation of false detections ('noise') in the database. With 1.6 million records, even a very small false detection rate of 0.1% results in 1600 false detections, or about 10 false detections per fish. False detections were observed at the beginning or more commonly, at the end of individual transmitter records. In some cases, we could readily identify a detection as noise because the fish had not yet been captured or released with a transmitter (i.e., detections for dates prior to surgical implantation were clearly erroneous). However, in other cases, identification of false detections was more difficult. We therefore inspected records for each fish separately to identify and remove false detections from the database. A single detection for a particular transmitter (i.e., fish) was removed if

1. the detection could have resulted from acoustic interference of simultaneous pulse-trains (termed 'pulse train collisions'), or
2. the detection occurred at a non-adjacent station and with a time lag of more than 24 hours (in this case the noise was likely due to 'environmental' interference.).

A pulse train refers to the sequence of coded acoustic data emitted by each transmitter. In a few cases, we noted less than 5 detections in a 24-h period; these were considered unreliable and removed from the database. In many of these cases, we were able to identify acoustic interference, but occasionally 2 to 4 detections occurred immediately after valid detections and we could not identify a source of interference (e.g., the transmitter was the only one detected at that station, or the station was a border station from which a fish could swim in and out of detection limits). To recognize that these situations may have resulted from valid transmissions, we constructed an alternative database containing these observations (*n*=1,440,651 detections) but caution that these represent a less conservative interpretation of the acoustic data. The main database (i.e., the conservative one) did not include these observations (*n*=1,440,536 detections). Excluded from both databases were the 186 detections associated with the receiver efficiency test (previously described).

Tables 6 and 7 present transmitter and tagging information for each fish released at the HARS; the tables are annotated with comments that identify transmitter malfunctions and fish that were captured by recreational anglers or commercial fishers.

Dispersal of Fish from the HARS

We monitored the occurrence and dispersal of surgically implanted black sea bass and summer flounder at the HARS during the course of one year (June 2003 to July 2004). Using these data, we estimated the probability of dispersal of fish from the site using the Kaplan-Meier (KM) estimator. The KM estimator can be used to compute estimates of the proportion of the sample population that remains at the study site during a particular sampling interval (Bennetts et al. 2001). Because no assumptions are made about the underlying hazard function, the KM approach is nonparametric. The KM estimator is robust and easy to compute (using the LIFETEST procedure in SAS, SAS Institute, Cary, NC); the variance of this estimator is also well described (Pollock et al. 1989a). In addition, an extension of the KM estimator permits analysis when new individuals are added to an ongoing study (Pollock et al. 1989b).

Observations considered in a KM analysis may be of two types: uncensored and censored. An uncensored observation is one for which the status (e.g., present at the HARS vs. absent from the HARS) is known with certainty. Censoring occurs when the ultrasonic signal is 'lost' (due to transmitter failure or receiver malfunction) or when the experiment is terminated. We also followed the example in Bennetts et al. (2001) and censored observations from fish that died prior to dispersal. Such deaths occurred when an angler reported harvesting one of the study fish (see Table 4) or when we determined that the transmitter signal originated from a fish that had died. Three such occurrences were observed: two black sea bass died on the day of surgery (one from the 18 June releases, and one from the 16 July releases); a third black sea bass died 33 d after surgery (released 23 June, died 26 July). Other censored observations required further consideration. Consider the case of a fish present in the middle of the HARS at time *t*; say this fish is captured by an angler at time *t+1* but the angler does not report the catch to us. The observation at time *t* from our receiver would be considered a censored observation because at time *t+1* we did not have a record of the fish leaving the HARS (i.e., we have no record of the fish crossing a perimeter station) and the fate of the fish at time *t+1* is unknown. With this censored observation, we could be certain that the fish is alive and present in the interior of the HARS at time *t*, but the status of the fish at time *t+1* remains unknown. (The fish may be dead or it may have slipped past a perimeter station undetected.) It should be emphasized that with the KM approach, the probability of not dispersing is estimated as the proportion of the tagged fish that did not disperse out of the total number of tagged fish (alive and status known) available to disperse during that time interval (Bennetts et al. 2001). The properties of the hazard function (how quickly the dispersal function changes in a given time interval) can affect uncertainty of the estimates.

The first reported application of the KM approach to estimate dispersal has only recently been described (Bennetts et al. 2001). In that example, 117 juvenile snail kites were fitted with radio transmitters over a 3-year period to determine dispersal from natal areas. The sample size was large enough to permit testing of differences in dispersal functions for birds from two different natal habitats (lakes vs. marshes) with the log-rank test. Results showed that juvenile birds dispersed within 220 d, with a pulse of dispersal at around 30 d (Bennetts et al. 2001). The probability of dispersing from lakes (stable environments) was significantly less than the probability of dispersing from wetlands (less stable environments). Stratification of the data allowed researchers to investigate the effect of natal habitat type on the propensity of birds to disperse. These types of statistical tests are critical to understanding ecological constraints on the behavioral responses of organisms and provide more insight on behaviors (in this case, dispersal behavior) than a simple, pooled analysis. In our study, male and non-male black sea bass were examined for differences in dispersal rates using the log-rank test and an approximate χ^2 statistic, which we estimated using the LIFETEST procedure in SAS. We also investigated size effects on the likelihood of dispersal using both length and weight data. We examined the nature of the dispersal functions and followed Collett's (2003) recommendation to use the log-rank test when dispersal (survival) functions were roughly proportional.

Transmitter detection data for black sea bass and summer flounder were analyzed for each fish individually. Using the first and last date each fish was detected at the HARS, we calculated total elapsed time at the HARS and assigned a dummy variable to indicate censoring (0=not censored, 1=censored). We considered information from recaptured fish reported to us by anglers in determining which observations to censor. We also censored all observations for which the last detection occurred at a non-perimeter station at the HARS; we reasoned these fish were either captured and not reported to us, or swam past the perimeter stations undetected. In either case, after they were last detected, these fish provided little information on dispersal time.

Results

Behavioral Observations of Black Sea Bass in the Laboratory

The group of 14 adult black sea bass was active during both day and night for the duration of captivity (July through December 2002). There was no discernable activity pattern related to time of day as measured by swimming speeds (Figure 9). We found no significant difference in swimming speeds by month (*F*=1.142; df=4, 207; *P*=0.34); swimming speeds pooled over months showed no significant diurnal differences (*F*=3.091; df=1, 210; *P*=0.08). The mean swimming speed of black sea bass held in captivity from July through December was 22.66 cm/s (*N*=212 observations; standard error=0.48; range, 9.1 to 65.6 cm/s).

We observed and defined a number of daytime behaviors. During resting, fish supported themselves upright on the substrata (either the tank bottom or a flat surface of the shelter) using the paired pelvic fins and the anal and caudal fins. Displaying, which was limited to males, involved extending all the fins, usually while resting on the bottom, and increasing the contrast in the black and white markings. During a display, two males were oriented in a parallel manner, with the head of one male opposite the tail of the other male. The degree of contrast in body markings was heightened in the early post-spawning period and became less noticeable with time. Displaying appeared to be a form of conflict resolution when the contestants competed for a resource, in this case, territory. The display may serve as reciprocal exchange of information about relative size and fighting ability and usually served to settle conflict without fighting. When the contestants were two males of similar size or involved a particularly antagonistic individual, aggression would take place. Aggression involved pursuit of a fish (subordinate) by another fish (dominant) and was usually observed between two males. Aggression included some degree of chasing, ranging from simply turning and moving headfirst in the direction of the subordinate fish, to chasing the subordinate across the length of the aquarium. The chase sometimes ended in the dominant fish biting a subordinate on the caudal fin, a behavior referred to as nipping. More subtle chases resulted in the displacement, or the movement of a subordinate fish to a new location several feet away. Subordinate fish and other smaller fish often swam in a submissive fashion near dominant fish with territories. Submissive swimming was marked by the use of pectoral fins for propulsion while folding the other fins close to the body. Early in the captivity period, aggression was high among males especially after feeding; aggressive behaviors diminished over time (Figure 10). Conversely, the resting behavior of males increased over time. Other fish, which were smaller and identified as females, were not aggressive (Figure 10).

Black sea bass were observed on 18 different days from 8 AM to 4 PM (*N*=1,498; 107 occasions with 14 fish per occasion) to determine use of the concrete shelter as habitat. Fish were seen occupying the shelter 79 times (5.3%). We defined the index of occupation as the proportion of fish in the shelter out of the group of 14 summed over all observations times, divided by the total number of independent observation periods. We found no pattern over time in the index of occupation. One male was observed to use the shelter as a territory on several occasions but different males mostly used areas of the tank that did not contain structure.

All 14 black sea bass survived captivity and grew in TL and weight (mean change in TL, 87.6 mm; mean change in weight, 531.8 g). On average, black sea bass grew 0.54 mm/d and 3.3 g/d over the 161 d in captivity.

Surgical Implantation of Transmitters: Laboratory Trials

Black Sea Bass

Anesthetic Dosing Trials – We selected 40 mg/L as the minimum dose necessary to achieve full induction in less than 5 min (mean time to stage 5 at either temperature was 2.0 min) and with a reasonable recovery time (at 15.9°C, mean recovery time was 3.2 min; at 19.7°C, mean recovery time was 4.6 min).

In trials at the lower temperatures (mean=15.8°C), we found no significant difference in the time necessary to attain stages 3, 4, or 5 among the doses examined (20-80 mg/L), but the means tended to decrease with increasing clove oil concentration (Table 8). Similarly, higher concentrations of clove oil did not require significantly longer recovery periods at 15.8°C (mean=3.8 min; *n*=15), but mean recovery time tended to increase with increasing concentration (Table 8). We attribute the lack of significant differences in induction and recovery times among concentrations of clove oil to small sample sizes and to a narrow range of concentrations tested. Nevertheless, clear differences in induction and recovery times were observed at the two extremes (20 mg/L vs. 80 mg/L; Table 8).

In trials at the higher temperatures (mean=19.7°C), mean times to stages 3 and 5 varied significantly among the doses examined (20 to 120 mg/L clove oil), such that fish exposed to higher doses required less time to achieve either stage 3 or 5 (Table 8). We did not detect a significant difference in mean time to stage 4 among the doses examined, but this may be due to the variation in individual fish response (e.g., one fish achieved stage 5 anesthesia before stage 4). Large variation in induction time among individual fish was also reported for other species (Hoskonen and Pirhonen 2004). At 19.7°C, the mean recovery time for black sea bass was 364 s (6.1 min; *n*=18) and did not depend on clove oil concentration; however, higher concentrations of clove oil tended to require slightly longer recovery times (Table 8).

Comparison of the results of the dosing trials at two temperatures indicate that at lower doses (20 and 40 mg/L), mean time to stages 4 and 5 did not differ significantly among temperatures tested (Table 9). However, black sea bass required significantly more time to attain stages 4 or 5 anesthesia at lower temperatures (15.8°C) for clove oil doses of 60 and 80 mg/L (Table 9). These results are consistent with those observed in salmonids and other freshwater species (Hoskonen and Pirhonen 2004; Woolsey et al. 2004), and imply a slower uptake of clove oil at lower temperatures. Black sea bass may require additional time to recover from full anesthesia at higher temperatures (Table 9). In contrast, several freshwater species exposed to clove oil had significantly reduced recovery times at higher temperatures (Hoskonen and Pirhonen 2004; Woolsey et al. 2004; Prince and Powell 2000). We note that black sea bass held in captivity do not survive well at temperatures above 20°C (D. Nelson, NOAA-NMFS, 212 Rogers Ave., Milford, CT, 06460, pers. com., July 2002) and our observations with clove oil solutions at 19.7°C may reflect a physiological response to thermal stress as well as anesthesia.

For a given dose of clove oil, we detected no significant difference in mean growth rates of black sea bass exposed at different temperatures (Table 10). One of the *F*-tests (for the 60 mg/L comparison) yielded a significant result for mean growth rate expressed in length, but we believe this is spurious (Table 10). We therefore pooled our observations among the trials conducted at two temperatures and also among doses because we wished to test for the effect of overall exposure. Black sea bass exposed to clove oil and observed for an average of 291 d grew an average of 0.293 mm/d or 1.535 g/d (*n*=28). These rates appear to be somewhat higher than rates estimated from four fish not exposed to clove oil and observed for a similar period: 0.212 mm/d or 1.156 g/d. Although no formal statistical test was performed, it appears that black sea bass growth is unaffected by exposure to clove oil.

None of the fish in the clove oil dosing trials died as a result of the experimental treatment; however, nine black sea bass exposed to clove oil died on 10 April 2003 when temperatures in the seawater tanks exceeded the lethal limit (due to seawater system problem).

Anesthetic Overexposure Trials – Exposure of fish to clove oil for periods up to 15 min beyond the time necessary to reach stage 5 was not detrimental in terms of recovery time, long-term growth, or survival of black sea bass.

Although mean recovery times of black sea bass exposed to an additional 5, 10, or 15 min of anesthesia tended to increase with increasing exposure, we detected no significant difference in these means ($F = 2.08$; $P > 0.05$). Overall mean recovery time was 5.6 min, or 1 min more than the mean recovery time for fish that were not overexposed to 40 mg/L clove oil.

Fish overexposed to 40 mg/L clove oil grew an average of 0.224 mm/d or 1.448 g/d (*n*=6). Although we overexposed 9 fish, 2 shed their tag so although we could obtain final length and weight measurements from those fish, we had no way of knowing which initial measures corresponded to the final ones. In addition, one other fish died on 14 July 2002 when it escaped from the post-exposure observation tank. Growth rates of fish overexposed to 40 mg/L clove oil compared favorably with growth rates of fish that were not overexposed (at the same dose), which grew 0.225 mm/d or 1.492 g/d (*n*=5).

Besides the single fish that escaped from the tank, no other mortalities were observed during the 267 d post-exposure period, indicating that overexposure to clove oil at 40 mg/L for periods up to 15 min did not cause short- or long-term mortality.

Surgical Trials – Black sea bass larger than 224 mm TL (and 210 g) exposed to clove oil and surgically implanted with a transmitter recovered from the procedure fairly rapidly and retained their transmitters for long periods of time (at least 10 months). In addition, these fish exhibited neither detrimental growth effects after 10 months, nor long-term mortality associated with surgery or the dummy transmitters.

Black sea bass in the surgical trial averaged 313 mm TL and 468 g at the time of surgery (range, 224-445 mm, 207-1049 g; *n*=47). We implanted 27 female fish (mean size, 287 mm and 368 g) and 20 male fish (mean size, 348 mm and 602 g). Fish exposed to 40 mg/L clove oil and surgically implanted with a dummy transmitter required an average of 4 min to achieve stage 5 anesthesia (compared with an average of 2.4 min observed for fish in the dosing trials at 15.8 and 19.7°C) and 5.5 min to recover (compared with an average of 4.6 min observed for fish in the 19.7°C dosing trials). Mean induction and recovery times were higher in the surgically treated fish than observed in the dosing trials, even though mean temperature of surgical trials (17.0°C) was intermediate relative to the temperatures used in the dosing trials. Based on the dosing trials, we expected induction time to be about 2.4 min and recovery to take about 4 min.

The average time to perform the surgery was 4.8 min (*n*=47) but ranged from 2.7 to 9.8 min. This compares favorably with other times reported for surgical implantation of transmitters: Prince and Powell (2000) reported an average surgery time of 5.8 min (range, 4.0-7.4 min), and Cooke et al. (2003) reported an average of 4.2 min for an expert surgeon and 6.0 min for a novice surgeon performing similar surgery. All 47 fish survived the surgery, recovered, and were actively feeding within a few days. During the 310 d post-surgical observation period, we found no signs of fish rejecting the transmitters.

Due to a problem with our seawater system (elevated temperature), eight surgically implanted black sea bass from a single tank died on 10 April 2003. Necropsies on these fish confirmed the lack of transmitter rejection or other post-surgical complications. Due to a problem associated with an electrical storm (loss of aeration in tanks), two surgically implanted black sea bass died on 19 July 2003. In addition to these accidental mortalities, we observed four additional losses: one of the dead fish exhibited 'popeye' and the remaining three died after escaping from the holding tanks. When possible, we obtained length and weight measurements from fish that died during the observation period.

The average growth rate of surgically implanted black sea bass was 0.220 mm/d (*n*=32) or 1.435 g/d (*n*=30). Females, which started out smaller in length than males, tended to have higher grow rates when measured in terms of length (mean for females, 0.248 mm/d; mean for males, 0.184 mm/d). In contrast, males tended to gain weight more rapidly during the course of the 310 d post-surgical observation period (mean for males, 1.631 g/d; mean for females, 1.264 g/d). Growth rates of surgically implanted fish were similar to those of fish exposed to 40 mg/L clove oil (0.225 mm/d and 1.492 g/d; *n*=5) and similar to growth rates of fish that were not exposed to clove oil or surgery (mean growth rates, 0.212 mm/d and 1.156 g/d; *n*=4 females). The lack of an effect of surgical implantation on growth was also observed in a similar species, the European sea bass *Dicentrarchus labrax*, though the post-surgical observation period was only 47 d (Bégout Anras et al. 2003). Atlantic cod exhibited no significant difference in growth among surgically implanted fish and nonimplanted fish (Cote et al. 1999); the same was true for Colorado pikeminnow *Ptychocheilus lucius* and razorback suckers *Xyrauchen texanus* (Tyus 1988).

Summer Flounder

Anesthetic Dosing Trials – We selected 80 mg/L as the optimal anesthetic concentration for summer flounder from 311 to 440 mm TL (mean=366 mm) or 296 to 828 g (mean=481 g); fish achieved full induction in about 4.1 min and recovered in 5.1 min.

We found no significant difference in the time necessary to attain stages 3 or 4 among the doses examined (40-100 mg/L), but the means tended to decrease with increasing clove oil concentration (Table 11). Higher concentrations of clove oil led to significantly quicker induction to stage 5 anesthesia (Table 11). Higher doses, however, did not require significantly longer recovery periods (Table 11). We attribute this lack of significance to small sample sizes and a narrow range of concentrations tested. Nevertheless, clear differences in induction and recovery times were observed at the two extremes (40 mg/L vs. 100 mg/L; Table 11).

The response of the cultured fish to 80 mg/L clove oil was not significantly different from that of the wild captured fish, except that cultured fish appear to recover quicker from the anesthetic exposure (Table 12). Although cultured fish were exposed to clove oil at a lower temperature than wild captured fish (15.1°C vs. 20.7°C), the difference in temperature probably did not account for the observed difference in mean recovery times among these fish. If this were the case, we would have expected to find a significant difference in induction time as well. Instead, we believe the difference in observed recovery time was due to size difference of the exposed fish. The 3 cultured fish, which ranged in size from 398 to 460 mm TL (mean=428 mm) and 770 to 1009 g (mean=855 g), were larger than the 3 wild captured fish (TL: 311-345, mean=326 mm; weight: 296-388 g, mean=357 g) exposed to 80 mg/L clove oil. The longer recovery time observed for the smaller, wild captured fish may simply reflect the added time a smaller fish needs to clear the anesthetic and regain equilibrium.

Surgical Trials – Summer flounder exposed to clove oil and surgically implanted with a transmitter recovered from the procedure fairly rapidly and retained their transmitters for long periods of time (at least 10 months). In addition, these fish exhibited negligible mortality associated with implanted dummy transmitters, but may have been susceptible to slower growth.

We implanted 53 summer flounder in the surgical trial; these fish averaged 389 mm TL and 685 g at the time of surgery (range: 281-508 mm TL, 202-1623 g; *n*=48). Fish exposed to 80 mg/L clove oil at 17.9°C and surgically implanted with a dummy transmitter required an average of 3.9 min to achieve stage 5 anesthesia and 5.0 min to recover. This compares favorably with observations from the dosing trials conducted at 20.7°C (mean induction time, 4.1 min; mean recovery time, 5.0 min).

The average time to perform the surgery was 7.0 min (*n*=53) but ranged from 4.1 to 13.4 min. These times are longer than the surgery times for black sea bass and reflect the extra care necessary when working with a laterally compressed fish. All 53 fish survived the surgery, recovered, and were actively feeding soon after surgery (some individuals began feeding as early as one day post-surgery). None of the fish rejected the transmitters and we achieved a retention rate of 100% at least up to 310 d (or 10.3 months) post-surgery.

Five fish died during the post-surgical observation period. Because two of the fish that died were the smallest we attempted to surgically implant (TL=281 mm, 214 g and 286 mm, 202 g), we suspect that summer flounder exhibit size-dependent tagging mortality. These two fish died 3 and 10 d after surgery; one fish died from the accidental nicking of the intestine by the surgeon’s scalpel, and the incision of the other fish did not fully close. One of the cultured fish that was surgically implanted died 16 d after surgery; a necropsy revealed full closure of the incision, no redness or swelling near the incision, no apparent damage or swelling of internal organs, and no apparent infection. In addition, this fish had fed the day before it died. We do not know the cause of death. Another fish died 166 d after surgery, with no apparent inflammation or infection, and the fifth fish died 41 d after surgery when it attempted to escape from the holding tank. Surgical treatment of summer flounder larger than 286 mm resulted in 3.8% mortality, but the observed mortality may be unrelated to the surgery and presence of the transmitter. Summer flounder smaller than 286 mm or 214 g should be avoided in surgical experiments because delicate tissues were difficult to suture and there is increased risk for accidental damage of internal organs during the incision or suturing procedures.

Post-surgery observations indicate that summer flounder are able to heal and recover quickly from surgery. Two weeks after surgery, 89.3% of fish acquired 100% closure of the incision site (tenuous closure with internal tissue layers completely healed, but external layers incompletely closed; Figure 11). After 4 weeks, 69.8% of fish acquired robust closure of the incision site, and by 12 weeks post-surgery all fish exhibited and maintained robust closure of the incision site (Figure 11). The level of skin irritation at the incision and suture puncture sites varied during holding time and may be a function of handling effects, type of substrate in the tank (coarse sand), and the number of animals in the holding tank. In general, incision site irritation decreased rapidly among fish but was present up to 1 year after surgery in 30% of the summer flounder (Figure 11). Between 60 and 80% of fish exhibited irritation at the suture site during the first 12 weeks post-surgery; about 60% of summer flounder exhibited suture site irritation up to 1 year after surgery (Figure 11). Necropsies on five fish revealed that the level of irritation did not compromise tissue closure or penetrate beneath the dermal tissues. We found no signs of adhesions, hemorrhaging, necrotic tissue or any other damage; dummy transmitters were free and intact. Summer flounder tolerated the implantation of dummy transmitters, although they exhibited irritation of the skin at the incision and suture sites. Overall, we found no deleterious effects of surgery (as determined by gross morphological inspection).

Mean initial size of surgically treated fish that survived at least 310 d and retained their tag (*n*=43) was 394 mm TL (range: 285 - 508 mm) and 707 g (range: 266 - 1623 g); mean initial size of control fish was 470 mm TL (range: 420 - 509 mm TL) and 1019 g (range: 701 - 1317 g). The mean growth rate of surgically implanted summer flounder was 0.075 mm/d or 0.524 g/d (*n*=43). Growth rates of surgically implanted fish were lower than those of control fish that were not exposed to clove oil or surgery (mean growth rate, 0.114 mm/d and 2.359 g/d; *n*=3). Six of the surgically implanted fish had negative growth rates. Slower growth rates may have resulted from reduced feeding of the transmitter-implanted fish, although we have no estimates of consumption for the two groups of fish because all summer flounder were fed *ad libitum*. It should be noted that in all other respects, the control fish were handled similarly during the post-surgical assessments so handling stress was equal among surgery and control fish.

HARS Acoustic Grid

We formulated a series of hypotheses about the arrays that we were unable to recover from the HARS in 2004:

> *The arrays were dragged out of the HARS site by commercial trawling in the area*. We believe this was a major contributor to our inability to retrieve arrays. During early 2004, a broken pop-up buoy was returned to us by a commercial fisher who operated a trawler in local waters. In addition, the G7 array was recovered west of the location at which it had been deployed, implying the array was dragged away from its deployment site.
>
> *The pop-up buoys (and arrays) were damaged or fouled by ships' anchors*. The damage may entail breaking of the hydrophone on the pop-up buoy such that the acoustic release signal cannot be received (and therefore the buoy is not activated to pop), or entanglement of the array such that the pop-up buoy cannot break free to float to the surface. Many party boats from Atlantic Highlands and Point Pleasant, NJ routinely anchor in the area. Some of our arrays sustained damage (e.g., the stainless steel strongbacks on 10 of the receivers recovered in 2004 were bent and one receiver had a broken hydrophone), indicating possible fouling with trawl warps or anchor rodes.
>
> *The moorings or pop-up buoys were covered in disposal material*. Although a 250-ft buffer zone had been established around our deployment locations in which no material placement was permitted, in at least one case, the buffer zone appears to have been violated (station C2; see Figure 12). Disposal activities from April 2003 to July 2004 were somewhat associated with our failure to recover some of the arrays. In addition, we noted that arrays retrieved from stations B2, B3, B7, C1, C2, and I1 had a thick layer of mud or clay covering the mooring (Table 5). Arrays at stations C5, D5, D6, E6, and H4 were not recovered because the buoy tether lines broke when we attempted to lift the moorings off the seafloor; we suspect that some (perhaps all) of these stations received dispersal material that may have buried the moorings.

Receiver Efficiency Test

The highest receiver efficiency was observed when the transmitter was located between 300 and 400 m from a receiver (25.3% detection rate; Figure 13). We identified a significant ($\chi^2 = 470.6$, df=1, $P<0.05$) difference in receiver efficiency when transmissions were sent within 400 m (19.7% detection rate) of a receiver relative to those sent from 400 m or more (1.3% detection rate; Figure 13).

Receiver efficiency varied with transmitter depth, but tended to be highest when the transmitter was below the thermocline or within 5 m of the surface (Table 13). For example, at a distance of 300 to 400 m, the highest receiver efficiency occurred when the transmitter was within 5 m of the surface (89.5% detection rate). We suspect this high efficiency may be associated with sound waves reflecting off the sea surface. Another possibility is that the directional tilt of the transmitter (transmissions are emitted from one end of the transmitter) may have facilitated a direct signal to the receiver. The tilt of the transmitter at deeper depths may not have been optimal and may have led to lower detection efficiency for transmissions emitted in deeper waters. Receiver efficiency was lowest when the transmitter was in the thermocline (see efficiency data for 10-15 m depth interval, Table 13). Temperature profiles taken along the test track indicated the presence of a thermocline between 12 and 15 m (Figure 14). Receivers consistently detected transmissions when the transmitter was located between 15 and 25 m (i.e., below the thermocline). Because both black sea bass and summer flounder are demersal, transmissions from individual fish are likely to be sent from depths below the thermocline, and we achieved better receiver efficiencies in these circumstances.

The angle at which the transmitter was attached to the towing line as well as the speed of the transmitter through the water may have negatively biased our estimates of detection efficiency (i.e., the receivers may achieve higher efficiencies than those reported here). Although detection rates appear low (on the order of 3% or less), we caution that the transmitter was moving through the water at a faster rate than expected for fish. We expect detection rates for transmitters implanted in fish to exceed those reported here. In addition, the results of the efficiency test support the receiver placement used at the HARS because we achieved good detection results when the transmitter was no more than 400 m away from the receiver.

Habitat Characterization

Bottom water temperatures in the study area increased from 10˚C on 30 May 2003 (date of first release) to values periodically exceeding 20˚C at both inshore and offshore CTD sites from 18 to 22 September 2003 (Figure 15). Temperatures decreased in the fall but remained above 7˚C until early January. Black sea bass are reported to migrate to offshore areas when bottom water temperatures approach 7˚C (Musick and Mercer 1977). Water at the inshore site was generally warmer ($\overline{X}$ = +2˚C, max= +7˚C) than at the offshore site from May through October 2003. However, this relation changed between November 2003 and mid-April 2004 when temperatures were consistently higher at the offshore site. The lowest temperatures were recorded during February and March 2004 (minimum= 3˚C). Shelf water warmed in the spring and was consistently higher than 7˚C at the inshore site after mid-May 2004.

Conductivity sensors on both CTDs lost calibration in early December 2003. As a result, bottom water salinity data are available only for 2003. Salinity in the study area averaged 31.3‰ and increased over the season. Salinities were about 0.3‰ below average from June through mid-August and 0.3‰ higher than average through November 2003 (Figure 15). Bottom water was about 0.5‰ lower at the inshore site than the offshore site (max=3.9‰; min= -7.2‰). However, from 13 to 18 September 2003, relatively low salinities were observed at the offshore site. During this period, Hurricane Isabel moved through the study area as indicated by the presence of high long-period waves at the Long Island Buoy.

Potential wave disturbance of bottom habitats in the HARS was relatively low from June through August and then increased during the fall of 2003 (Figure 16). Maximum near-bottom horizontal orbital velocities calculated for the shallowest station averaged 0.2 $cm \cdot s^{-1}$ (SD=1.3; range, 0 - 0.61) during the summer months. The potential for wave disturbance was high during September (mean near-bottom horizontal orbital velocity, U_m = 0.44, SD = 0.26) particularly from September 18 to 19 when high long-period waves generated by Hurricane Isabel moved through the study area. Near-bottom horizontal orbital velocities as high as 1.72 $cm \cdot s^{-1}$ were calculated for this period. The potential for high wave disturbance was also evident in the study area from October through December (mean U_m=0.32, SD=0.28, max=1.72), but these conditions were not sustained for long periods of time.

Seafloor characteristics at the HARS vary and include areas of both relatively homogeneous and highly variable bottom characteristics (Figure 8). An example of the heterogeneity of the site is depicted in Figure 8C where similar relatively flat bottom habitat is found at stations in the southern portion of the study area; in contrast, the bottom slope in the remainder of the HARS is more variable from station to station. The portion of the study area with the greatest change in bottom slope occurs within a ‘box’ formed by stations D1 to D4 and G1 to G4. This box is characterized by contiguous stations with large changes in depth (both positive and negative) adjacent to stations with relatively small changes in depth. This area includes stations that are relatively deep adjacent to the most shallow stations in the study area. Large changes in depth also characterize the eastern edge of the study area, where depth changes are continual and unidirectional.

The southern portion of the HARS is characterized primarily by medium-grain, muddy sands; the northern and central areas have primarily fine-grain muddy sediments. However, variations in sediment grain size composition exist within these areas. The ‘box’ formed by stations D1 to D4 and G1 to G4 is characterized by large variations in sediment grain size; within the box, an area of relatively coarse sediments is surrounded by stations with fine, muddy sediments.

Dispersal of Fish from the HARS

We examined the transmitter data collected by receivers at the HARS for evidence of transmitter malfunction and fish mortality. All 24 surgically implanted summer flounder were detected after release; however, one fish was not detected in 2003, so was not included in the dispersal analysis (Table 7). Receivers at the HARS did not detect 5 of the 129 transmitters (3.9% malfunction rate) from black sea bass indicating that implanted transmitters malfunctioned shortly after implantation or release (Table 6). Transmitter malfunction rates of

2-3% are typical and failure rates of 5% are not uncommon (T. Sheehan, NOAA-NMFS, 166 Water St., Woods Hole, MA 02543, pers. comm., April 2002). In addition, we detected recordings for two transmitters at only one station from the time of surgery and continuing throughout the winter of 2004; we interpret this to indicate that the fish had died shortly after surgery. Consequently, for dispersal analysis, we considered only the 122 live black sea bass with functioning transmitters.

Because the implantation period for black sea bass and summer flounder extended over several weeks (black sea bass: 30 May to 16 July; summer flounder: 17 June to 16 July), and because anglers were actively fishing at the HARS during our implantation period, we could not make the following necessary assumptions: (1) that implantation occurred over a short period of time (relative to the time period of interest) and (2) that no fish were removed from the HARS (e.g., through angler harvests) prior to the completion of all surgical implantation. Therefore, we adjusted the elapsed time for each fish to permit estimation of total time spent at the HARS. We assumed that all black sea bass were present at the HARS by 2 June 2003 and calculated the adjusted elapsed time relative to this date. For example, if a fish was surgically implanted on 7 June 2003, and it dispersed from the HARS 25 d later, then it's adjusted elapsed time would be 30 d (25 + 5). Similarly, for summer flounder we assumed all fish were present at the HARS by 24 June 2003. These dates were selected to minimize the number of fish for which negative adjustments were made (e.g., if a black sea bass was surgically implanted on 30 May 2003, we would subtract 3 d from it's elapsed time). In addition to the adjustments, we note that 53.3% of black sea bass observations were censored and 4.4% of summer flounder observations were censored. Many of the censored black sea bass observations were due to last detections that occurred within the HARS but not at a perimeter station; whether these fish were captured (and therefore removed from the study site) or the transmitter ceased to function, the fate of these fish remains unknown. As such, censored fish contribute no further information on occurrence at the site after the time of their last detection.

Dispersal probabilities estimated with the KM approach and using the adjusted data indicate that black sea bass began dispersing from the HARS on 2 June and the likelihood of dispersal decreased about 60 d later (1 August) (Table 14). In the early portion of the study period (30 May to 23 July), 25 fish dispersed from the HARS while we were actively implanting and releasing fish (3 others were captured and reported by anglers). Most of the fish that dispersed from the HARS at this time left the site through the southern (48%) or western (28%) perimeters. After 10 September (100 d after 2 June), dispersal probabilities increased slightly (Figure 17A). The median dispersal date for black sea bass was 28 October (95% confidence interval: 11 October to 5 November 2003). Between 1 and 17 November, dispersal probabilities increased dramatically, and by 18 November 2003, 75% of the implanted black sea bass had dispersed from the HARS. Unfortunately, the confidence interval (CI) around this date is inestimable because the largest observation was censored, and when this occurs, the dispersal function is undefined beyond that time period (Collett 2003). Like black sea bass, summer flounder began dispersing from the HARS immediately after implantation (Table 15); dispersal likelihoods appeared higher than those for black sea bass (Figure 17B). Between 2 and 20 September, summer flounder dispersal probabilities increased significantly (95% CI for 2 September: $p_{\text{dispersal}} = 0.2739 - 0.6959$; 95% CI for 20 September: $p_{\text{dispersal}} = 0.7097 - 1.0$). The median dispersal date for summer flounder was 5 September 2003 (95% CI: 13 August to 12

September 2003). By 20 September 2003, 75% of the implanted summer flounder had left the HARS (95% CI: 5 to 21 September 2003).

We also examined the KM estimates of dispersal probabilities using the less conservative data set for black sea bass and summer flounder detections. (Recall that the less conservative data set included detections omitted from the conservative data set as described in the Methods section, HARS Acoustic Grid Design, Analysis of Transmitter Data.) We found little difference in the probabilities of dispersal between the conservative and less conservative data (Figure 18). The median dispersal date was 3 November 2003 (95% CI: 12 October to 5 November) for black sea bass, and 3 September 2003 (95% CI: 13 August to 11 September) for summer flounder. As before, 75% of the black sea bass dispersed from the HARS by 18 November 2003 (95% CI: 5 November to 6 December 2003), and 75% of the summer flounder dispersed by 20 September 2003 (95% CI: 5 to 21 September 2003).

Because the conservative and less conservative data sets provided similar estimates for these two species, we worked with the conservative data set to further investigate factors associated with dispersal likelihoods. Results of the log-rank test for sex and size effects on black sea bass dispersal probabilities indicated that male fish dispersal likelihoods were significantly different from those of non-males (females and fish of unknown sex; $\chi^2 = 4.838$, $P=0.03$). The difference appears to arise early in the period of study such that by 2 July, 25% of males had dispersed, whereas it was not until 8 September that 25% of non-males dispersed from the HARS. There were no significant effects of size (measured as TL or weight) on dispersal probabilities among black sea bass ($\chi^2_{\mathrm{TL}} = 0.051$, $P=0.82$; $\chi^2_{\mathrm{weight}} = 0.304$, $P=0.58$).

Results of the log-rank test for size effects on summer flounder dispersal probabilities indicated that fish size (TL) was significantly associated with tendency to disperse ($\chi^2 = 3.465$, $P=0.06$) and fish weight was somewhat less so ($\chi^2 = 3.056$, $P=0.08$). Because we had few summer flounder in this study, we did not calculate a size-based dispersal likelihood. We note, however, that smaller fish tended to spend longer time at the HARS than larger fish of this species.

In addition to these observations on dispersal, we noted the return of one summer flounder, and one, possibly two, black sea bass to the HARS in 2004. The summer flounder (transmitter # 98) had not been detected at the HARS in 2003, but did return on 29 May 2004; this fish stayed at the HARS until 7 June 2004, when it was no longer detected (the lack of detection for this fish after 7 June 2004 may be due to the end of the battery life of the transmitter). One black sea bass (transmitter # 48), which left the HARS on 17 November 2003, returned on 13 May 2004 and was present for only one day. Our receivers also recorded six detections at H5 for an additional black sea bass (transmitter # 167) between 10 May and 21 June 2004; this fish may have returned to the HARS, but because we had so few detections (and not more than 1 per day), we can not be certain these are 'true' detections. However, we note that this period possibly represents the last days of the battery life and inconsistent transmissions may occur during that time. These observations of fish returning to the HARS represents a relatively high return rate for summer flounder, and possibly also for black sea bass, given that both species are exploited year-round, in nearshore waters from the spring to the fall, or offshore in the winter otter trawl fishery (Shepherd and Terceiro 1994).

Discussion

Survival of Surgically Implanted Fish – Both black sea bass and summer flounder retained surgically implanted transmitters and had high survival rates in laboratory trials (black sea bass survival, 100%; summer flounder survival, 92.5%) and in the field (black sea bass survival, 98.3%; summer flounder survival, 100%). The mortality observed with laboratory summer flounder was most likely size-dependent and may have reflected the difficulty of novice surgeons working with small fish (Cooke et al 2003). We attribute the high retention rate of transmitters in the surgical trials with black sea bass and summer flounder to the use of appropriately sized transmitters coated in beeswax. For summer flounder, the size of the transmitter (rather than the weight) may have been a factor contributing to the slower growth rates observed for laboratory-held fish. The cylindrical transmitter was accommodated in a flattened peritoneal cavity and may have prevented the fish from ingesting sufficient food, thus leading to poorer growth. No long-term growth effects were observed for black sea bass. Overall, by carefully monitoring size and performing surgery on fish capable of surviving the procedure, we achieved excellent results from the implantation of ultrasonic transmitters in these species at the HARS.

Effect of Arrays on Aggregation of Fish – We note that the 72 arrays at the HARS may be construed as placement of new structure which could serve to aggregate black sea bass at the HARS, thus possibly compromising information on habitat use. However, arrays represented an insignificant volume compared with the available volume at the HARS. The 72 arrays (pop-up buoy, receiver, float, line, and mooring) comprised 4.73 m^3. Assuming that black sea bass use the bottom 2 meters of water and that the HARS is 15.7 nm^2 (1 nm=1,852 m), the space potentially occupied by black sea bass is 107.7 million m^3; the arrays represent an insignificantly small proportion of the potential habitable space.

Association of Fish with Bottom Substrates – Although black sea bass were detected at every HARS station from which we recovered a receiver, and summer flounder were detected at 60 of the HARS stations, the distribution of fish at the HARS was not random. Instead, fish were patchily distributed. The number of individuals and frequency of detections for summer flounder and black sea bass were highest in relatively shallow, complex habitats. These habitats occurred primarily in the region defined by north-south transects C-G and east-west transects 1-5. This roughly corresponds to the area of capped sediments at the old Mud Dump Site. Topographic complexity and substrate heterogeneity appeared to be high in this region as variation in bottom slope and sidescan sonar reflectance were also relatively high (Figure 19). Variable slope and sonar reflectance values indicate that the region may comprise a mosaic of hard structures embedded within a matrix of softer substrates. Seventy-three percent of black sea bass detections (detections from 116 individuals), and 89% of summer flounder detections (detections from 19 individuals) were recorded in this area, which accounted for 35% of total surface area of the HARS.

Fish were also detected (although less frequently) in the southwestern region of the study area (north-south transects A-C, and east-west transects 6-8), where relatively large changes in bottom slope were associated with large sand waves visible in sidescan sonar imagery (Figure 19). These sand waves are also conspicuous features further south and west of the HARS.

Three percent of black sea bass detections (detections from 18 individuals) and 9.4 % of summer flounder detections (detections from 12 individuals) were recorded in this area.

Patterns of habitat association observed in our study are consistent with those reported elsewhere for these species. Black sea bass use hard structures for resting and refuge but feed on benthic invertebrates on adjacent soft substrates (Steimle and Figley 1996). This species has also been reported as relatively abundant in sand wave habitats (Wigley and Theroux 1981). In estuaries, summer flounder are most often associated with soft substrates adjacent to structurally complex habitats such as eelgrass beds and oyster reefs that are rich in food resources (Able and Kaiser 1994; Packer and Hoff 1999).

Dispersal Analysis and Censored Observations – Acoustic 'gates' are often used to passively monitor the passage of fish from an area of interest to an adjacent area (e.g., Egli and Babcock 2004; Comeau et al. 2002). However, we found that such 'gates' or 'perimeters' are not always fully reliable. Not all of the black sea bass implanted with a transmitter dispersed through a perimeter station at the HARS. Some of the fish were captured by anglers (and reported to us), and others were last detected in the interior of the HARS. We considered the hypothesis that these fish may have dispersed from the HARS by swimming past the outer perimeter of the acoustic grid without detection. Using observations on the swimming speed of black sea bass, we investigated this possibility. Non-detection at a perimeter station occurs if the fish is able to swim past the station during an interval of time in which the transmitter is silent (i.e., 3 to 5 min). If a black sea bass is 800 m away from a perimeter station at the HARS, say at D2, and if the fish swam in a straight-line path at the average speed observed in the research aquarium (22.66 cm/s), then it would require about 58.8 min to reach D1, a perimeter station 800 m away. If the fish were swimming at the maximum speed (65.6 cm/s), then it would require about 20.3 min to reach D1. During that time, the transmitter in the fish swimming at the mean speed would have transmitted about 15 signals, and the one in the fish swimming at the maximum speed would have transmitted about 5 signals. Thus, even fast swimming fish should be detected as they swim past a perimeter station. Fast moving black sea bass were observed at the HARS; for instance, on 21 August 2003, one fish (transmitter # 33) was detected at 10:37 a.m. at station G6 and at 10:59 a.m. at station H6. We note, however, that sound detection is complex and some transmissions from fast-swimming fish may have gone undetected at perimeter stations. As we demonstrated at the HARS, the likelihood of detection is clearly affected by the distance between the transmitter and the receiver, the position of the transmitter relative to the thermocline, and by interactions from environmental 'noise'.

We believe the most likely explanation for some of the censored data is capture by anglers; during the summer and fall, fishing pressure for black sea bass at the HARS is intense and 89.2% of our censored observations occurred at 12 stations that were in the area most heavily fished (stations D3-4, E3-4-5, F4-5-6, and G3-4-5-6); 21.5% of censored observations were at station F5, which is adjacent to the yellow "NY" buoy also known as the Mud Buoy. [The Mud Buoy is located at 40° 22' 49"N 73° 50' 42"W and is 370 m from F5, 550 m from F6, 605 m from G5, and 725 m from G6.] The 12 black sea bass recaptured by anglers or commercial fishers and reported to us represent 9.8% of the total number of live, implanted black sea bass released at the HARS. This compares favorably with the 13.1% recapture rate reported for black sea bass tagged and released off Long Island and northern New Jersey in 2002-2003 (Consensus Assessment Report 2004). Assuming the reporting rate for black sea bass along the Atlantic coast (north of Cape Hatteras) is 63.6% (Consensus Assessment Report 2004), then we would expect that about 19 fish were captured. This number is much lower than the number of fish that were censored because they were last detected at an interior station at the HARS but not reported as being captured (*n*=61). Either the exploitation rates at the HARS are significantly higher than the overall rates estimated from Massachusetts to North Carolina, or reporting rates for fish captured near the HARS are significantly lower (around 18-20%) than the overall rate reported in the Consensus Assessment Report (2004). Without additional tagging studies, we can not be certain which factor (exploitation, reporting rate, or both) contributed to the discrepancy.

Dispersal of Fish from the HARS – Black sea bass dispersal from the HARS appeared to be highest in the early summer and late fall (Figure 17A). A relatively large number of fish (*N*=19) dispersed from 13 June to 2 July 2003. Dispersal during this period did not appear to be related to temperature, salinity, or wave disturbance (Figure 20). Many of the fish dispersing during this early summer period moved through the western perimeter of the study area. These fish may have been transiting toward shallower reef structures close to shore, such as Shrewsbury Rocks. The dispersal rate of black sea bass from July through mid-October was relatively low (~ 4.5 fish per month). Dispersal increased during late October and November, presumably as fish moved offshore toward deeper overwintering habitats on the continental shelf (Musick and Mercer 1977). A large number of fish (*N*=7) dispersed from the study area in mid-November when temperatures in shallower nearshore waters fell consistently below those measured in deeper water on the eastern edge of the study area (Figure 20). The last black sea bass was detected in the study area on 14 December when temperatures averaged about 9°C; it resided at the HARS for 175 d (unadjusted). Black sea bass are reported to migrate offshore to overwintering habitats when bottom water temperatures approach 7°C in the fall (Colvocoresses and Musick 1984; Shepherd and Terceiro 1994).

Summer flounder dispersal from the HARS was relatively constant throughout the summer and fall of 2003 (~3.3 fish per month; Figure 20). A relatively large number of fish (*N*=8) moved out of the study area on 20 September when near-bottom orbital velocities and temperatures were elevated as a result of the passage of Hurricane Isabel. The last summer flounder dispersed from the study area on 18 November, when temperatures averaged about 13-14°C; it resided at the HARS for 148 d (unadjusted). Summer flounder are reported to migrate offshore to overwintering and spawning areas where temperatures exceed 8°C (Sissenwine et al. 1979).

Our acoustic tagging results with black sea bass and summer flounder clearly show that both species use the HARS; some individual fish are present at the HARS for short periods (less than 1 month), whereas other individuals may reside at the HARS for a significant period of time. Summer flounder were present up to 155 d and black sea bass were present up to 199 d, but the actual residency time of a particular fish is highly variable.

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Table 1. Summary of black sea bass and summer flounder capture information at the HARS, 2003. Asterisks indicate that a single transmitter failed from that batch; although 129 black sea bass were implanted, only 124 fish had functional transmitters. Of those, 2 died on the day of surgery, shortly after release (noted in parentheses). All transmitters implanted in summer flounder were functional at the time of surgery.

Date	Capture method	Research vessel	Number implanted
		Black sea bass	
27 May 2003		Gloria Michelle	initial setting of traps
28 May 2003	traps	Gloria Michelle	0 (additional traps set)
30 May 2003	traps	Gloria Michelle	8
2 June 2003	traps	Gloria Michelle	10
4 June 2003	traps	Gloria Michelle	0 (seas too rough)
5 June 2003	traps	Gloria Michelle	4
9 June 2003	traps	Gloria Michelle	11*
12 June 2003	traps	Gloria Michelle	8
16 June 2003	traps	Gloria Michelle	11
17 June 2003	hook & line	Gloria Michelle	18*
18 June 2003	traps	Gloria Michelle	9* (1 died)
19 June 2003	traps	Gloria Michelle	13
23 June 2003	traps	Gloria Michelle	10*
7 July 2003	hook & line	Loosanoff	9
8 July 2003	hook & line	Loosanoff	5
9 July 2003	hook & line	Loosanoff	6*
16 July 2003	hook & line	Walford	7 (1 died)
		Summer flounder	
17 June 2003	hook & line	Gloria Michelle	1
23 June 2003	bottom trawl	Gloria Michelle	0

Date	Capture method	Research vessel	Number implanted
24 June 2003	hook & line	Gloria Michelle	6
25 June 2003	hook & line	Gloria Michelle	0
26 June 2003	hook & line	Gloria Michelle	6
27 June 2003	hook & line	Gloria Michelle	0
2 July 2003	bottom trawl	Walford	1
3 July 2003	bottom trawl and hook & line	Walford	0
8 July 2003	hook & line	Loosanoff	6
9 July 2003	hook & line	Loosanoff	3
16 July 2003	hook & line	Walford	1

Table 2. Other species captured at the HARS in May - July 2003 in fish traps, by bottom trawl, or by hook and line.

Common name	Scientific name
sand dollar	*Clypeaster subdepressus*
squid	*Loligo pealeii*
rock crab	*Cancer irroratus*
Jonah crab	*Cancer borealis*
spider crabs	*Libinia* spp.
shrimps	*Crangon* spp.
American lobster	*Homarus americanus*
clearnose skate	*Raja eglanteria*
little skate	*Raja erinacea*
spinydogfish	*Squalus acanthias*
smooth dogfish	*Mustelus canis*
conger eel	*Conger oceanicus*
red hake	*Urophycis chuss*
spotted hake	*Urophycis regia*
silver hake	*Merluccius bilinearis*
pollock	*Pollachius virens*
ocean pout	*Macrozoarces americanus*
scup	*Stenotomus chrysops*
butterfish	*Peprilus triacanthus*
tautog	*Tautoga onitis*
cunner	*Tautogolabrus adspersus*
striped sea robin	*Prionotus evolans*
windowpane flounder	*Scophthalmus aquosus*
smallmouth flounder	*Etropus microstomus*
winter flounder	*Pleuronectes americanus*

Table 3. Mean time and range of times observed for anesthetic induction and surgery of black sea bass and summer flounder implanted with transmitters at the HARS. All fish were exposed to 80 mg/L Aqui-S. Induction time is the time to stage 5 anesthesia as described in the text. Induction time for 127 black sea bass excludes 2 fish dosed at 40 mg/L anesthetic solution. All fish required more than 10 min to recover from anesthetic exposure.

	Induction time (min)	**Surgery time (min)**
	Black sea bass	
Minimum	1.1	2.0
Maximum	7.7	11.7
Mean	3.3	4.1
N	127	128
	Summer flounder	
Minimum	1.7	2.1
Maximum	5.3	6.8
Mean	2.3	4.2
N	24	24

Table 4. Black sea bass (BSB) and summer flounder (SF) captured and reported by sport and commercial fishers. Tag # is the external tag number; the Mud Buoy (yellow buoy) is located in the center of the HARS site, 370 m from station F5.

Recapture date	Species	Tag #	Size (approximate)	Location (approximate)	Fate of fish
14 Jun 03	BSB	226	--	near yellow buoy	unknown
25 Jun 03	BSB	146	15 inches	near NY Buoy	eaten by angler
26 Jun 03	BSB	235	11.5 inches	off Sea Bright	released alive
30 Jun 03[1]	BSB	206	--	--	not known
6 Jul 03	BSB	175	13 inches	17 fathom bank near Ambrose light	released alive
6 Jul 03	BSB	192	13 inches	NW of Mud Buoy	released alive
18 Jul 03[2]	BSB	196	13.25 inches	N-NW of Mud Buoy	released alive
20 Jul 03	BSB	222	12 inches	Rockaway Inlet	swallowed hook & died
12 Aug 03	BSB	76	11 inches	off Staten Island	released alive
22 Sep 03	BSB	167	--	near yellow buoy	unknown (anchor tag removed)
6 Oct 03[2]	BSB	harvested by NJ/NY commercial fisher who refused to provide additional information			
6 Nov 03[2]	SF	100	19.75 inches	18 miles off Ocean City, MD	harvested
6 Jan 04[2]	BSB	178	--	97.3 nm east of Cape Hatteras, NC	harvested
19 Feb 04[2]	SF	89	13.5 inches; 1.5 lbs.	in Albemarle Sound, NC	harvested
22 Apr 04	BSB	181	--	off Virginia Beach, VA	harvested commercially

[1] Date of capture is unknown: 30 Jun 2003 is the postmark date (Lincroft, NJ) on the envelope used to mail the tag to the lab.

[2] Date reported; date of capture is unknown.

Table 5. Acoustic array retrievals at 72 stations at the HARS with notes concerning method of retrieval and condition of acoustic array. In 2004, some retrievals occurred days after the acoustic release on the pop-up buoy was activated (both dates are listed) because the buoy failed to surface on the day of activation.

	2003 Retrievals				2004 Retrievals				
Station	**Retrieval date**	**Method of retrieval**	**Condition of array**	**Data collected?**	**Pop-up activation date**	**Retrieval date**	**Method of retrieval**	**Condition of array**	**Data collected?**
A1	27-Aug-03	Vessel	Good	Yes	20-Jul-04	02-Sep-04	Divers	Pop-up buoy destroyed	Yes
A2	27-Aug-03	Vessel	Good	Yes	20-Jul-04	–	Divers	Not found	No
A3	27-Aug-03	Vessel	Good	Yes	20-Jul-04	09-Aug-04	Vessel	Strongback bent; entangled in line	Yes
A4	27-Aug-03	Vessel	Good	Yes	20-Jul-04	–	Divers	Trawl hit	No
A5	27-Aug-03	Vessel	Good	Yes	22-Jul-04	22-Jul-04	Vessel	Good	Yes
A6	26-Aug-03	Vessel	Good	Yes	22-Jul-04	22-Jul-04	Vessel	Good	Yes
A7	26-Aug-03	Vessel	Receiver flooded; strongback bent	No	22-Jul-04	09-Aug-04	Vessel	Good	Yes
A8	26-Aug-03	Vessel	Good	Yes	22-Jul-04	09-Aug-04	Vessel	Strongback bent	Yes
B1	22-Sep-03	Vessel	Good	Yes	20-Jul-04	06-Aug-04	Vessel	Good	No[1]

Station	2003 Retrievals Retrieval date	Method of retrieval	Condition of array	Data collected?	2004 Retrievals Pop-up activation date	Retrieval date	Method of retrieval	Condition of array	Data collected?
B2	30-Sep-03	Vessel	Strongback bent; hydrophone tip broken	Yes	22-Jul-04	09-Aug-04	Vessel	Mooring covered in mud	Yes
B3	30-Sep-03	Vessel	Mooring covered in mud	Yes	22-Jul-04	09-Aug-04	Vessel	Mooring covered in mud	Yes
B4	30-Sep-03	Divers	Pop-up buoy damaged by another vessel; not found[2]	No	None	–	–	Trawl hit[3]	No
B5	26-Aug-03	Vessel	Good	Yes	22-Jul-04	06-Aug-04	Vessel	Good	Yes
B6	26-Aug-03	Vessel	Good	Yes	22-Jul-04	–	Divers	Not found	No
B7	26-Aug-03	Vessel	Good	Yes	22-Jul-04	09-Aug-04	Vessel	Mooring covered in mud; Pop-up buoy cracked	Yes
B8	26-Aug-03	Vessel	Good	Yes	22-Jul-04	09-Aug-04	Vessel	Strongback bent	Yes
C1	27-Aug-03	Vessel	Good	Yes	21-Jul-04	09-Aug-04	Vessel	Mooring covered in mud	Yes

Station	2003 Retrievals				2004 Retrievals				
	Retrieval date	Method of retrieval	Condition of array	Data collected?	Pop-up activation date	Retrieval date	Method of retrieval	Condition of array	Data collected?
C2	27-Aug-03	Vessel	Good	Yes	21-Jul-04	13-Sep-04	Divers	Mooring buried in mud	Yes
C3	27-Aug-03	Vessel	Good	Yes	21-Jul-04	09-Aug-04	Vessel	Good	Yes
C4	27-Aug-03	Vessel	Good	Yes	21-Jul-04	–	Divers	Not found, line broke[4]	No
C5	27-Aug-03	Vessel	Good	Yes	21-Jul-04	–	Divers	Not found, line broke[4]	No
C6	27-Aug-03	Vessel	Good	Yes	21-Jul-04	21-Jul-04	Vessel	Pop-up buoy lid cracked; strongback bent	Yes
C7	27-Aug-03	Vessel	Good	Yes	21-Jul-04	21-Jul-04	Vessel	Strongback bent	Yes
C8	28-Aug-03	Vessel	Good	Yes	21-Jul-04	09-Aug-04	Vessel	Good	Yes
D1	28-Aug-03	Vessel	Good	Yes	21-Jul-04	21-Jul-04	Vessel	Good	Yes
D2	28-Aug-03	Vessel	Good	Yes	21-Jul-04	21-Jul-04	Vessel	Good	Yes
D3	28-Aug-03	Vessel	Good	Yes	21-Jul-04	21-Jul-04	Vessel	Good	Yes

	2003 Retrievals				2004 Retrievals				
Station	**Retrieval date**	**Method of retrieval**	**Condition of array**	**Data collected?**	**Pop-up activation date**	**Retrieval date**	**Method of retrieval**	**Condition of array**	**Data collected?**
D4	28-Aug-03	Vessel	Good	Yes	21-Jul-04	09-Aug-04	Vessel	Strongback bent; entangled in line; Pop-up buoy lid cracked	Yes
D5	28-Aug-03	Vessel	Good	Yes	21-Jul-04	–	Divers	Not found; line broke[4]	No
D6	28-Aug-03	Vessel	Good	Yes	21-Jul-04	–	Divers	Not found; line broke[4]	No
D7	28-Aug-03	Vessel	Good	Yes	21-Jul-04	09-Aug-04	Vessel	Good	Yes
D8	28-Aug-03	Vessel	Good	Yes	21-Jul-04	09-Aug-04	Vessel	Good	Yes
E1	28-Aug-03	Vessel	Good	Yes	20-Jul-04	20-Jul-04	Vessel	Good	Yes
E2	29-Aug-03	Vessel	Good	Yes	20-Jul-04	20-Jul-04	Vessel	Good	Yes
E3	29-Aug-03	Vessel	Good	Yes	20-Jul-04	09-Aug-04	Vessel	Towing line from barge entangled mooring	Yes
E4	29-Aug-03	Vessel	Good	Yes	20-Jul-04	06-Aug-04	Vessel	Good	Yes
E5	29-Aug-03	Vessel	Good	Yes	19-Jul-04	06-Aug-04	Vessel	Good	Yes
E6	29-Aug-03	Vessel	Mooring covered in mud	Yes	19-Jul-04	–	Divers	Not found; line broke[4]	No

	2003 Retrievals				2004 Retrievals				
Station	**Retrieval date**	**Method of retrieval**	**Condition of array**	**Data collected?**	**Pop-up activation date**	**Retrieval date**	**Method of retrieval**	**Condition of array**	**Data collected?**
E7	29-Aug-03	Vessel	Mooring covered in mud	Yes	19-Jul-04	09-Aug-04	Vessel	Good	Yes
E8	29-Aug-03	Vessel	Good	Yes	19-Jul-04	22-Jul-04	Vessel	Good	Yes
F1	08-Sep-03	Vessel	Good	Yes	19-Jul-04	06-Aug-04	Vessel	Good	Yes
F2	08-Sep-03	Vessel	Good	Yes	19-Jul-04	19-Jul-04	Vessel	Good	Yes
F3	08-Sep-03	Vessel	Good	Yes	19-Jul-04	06-Aug-04	Vessel	Strongback bent; entangled in line	Yes
F4	08-Sep-03	Vessel	Good	Yes	19-Jul-04	06-Aug-04	Vessel	Good	Yes
F5	29-Aug-03	Vessel	Good	Yes	19-Jul-04	19-Jul-04	Vessel	Good	Yes
F6	29-Aug-03	Vessel	Good	Yes	19-Jul-04	19-Jul-04	Vessel	Good	Yes
F7	29-Aug-03	Vessel	Good	Yes	19-Jul-04	19-Jul-04	Vessel	Strongback bent	Yes
F8	30-Sep-03	Divers	Pop-up buoy damaged	Yes	19-Jul-04	19-Jul-04	Vessel	Good	Yes
G1	08-Sep-03	Vessel	Good	Yes	19-Jul-04	19-Jul-04	Vessel	Good	Yes
G2	08-Sep-03	Vessel	Good	Yes	19-Jul-04	19-Jul-04	Vessel	Good	Yes

	2003 Retrievals				2004 Retrievals				
Station	Retrieval date	Method of retrieval	Condition of array	Data collected?	Pop-up activation date	Retrieval date	Method of retrieval	Condition of array	Data collected?
G3	08-Sep-03	Vessel	Mooring covered in mud	Yes	19-Jul-04	06-Aug-04	Vessel	Good	Yes[5]
G4	08-Sep-03	Vessel	Good	Yes	16-Jul-04	16-Jul-04	Vessel	Good	Yes
G5	08-Sep-03	Vessel	Good	Yes	16-Jul-04	–	Vessel	Not found	Yes
G6	08-Sep-03	Vessel	Good	Yes	16-Jul-04	16-Jul-04	Vessel	Good	Yes
G7	11-Sep-03	Vessel	Good	Yes	16-Jul-04	19-Jul-04	Vessel	Good	Yes
G8	11-Sep-03	Vessel	Good	Yes	16-Jul-04	16-Jul-04	Vessel	Good	Yes
H1	22-Sep-03	Vessel	Mooring covered in mud	Yes	16-Jul-04	16-Jul-04	Vessel	Good	Yes
H2	22-Sep-03	Vessel	Good	Yes	16-Jul-04	16-Jul-04	Vessel	Good	Yes
H3	22-Sep-03	Vessel	Good	Yes	16-Jul-04	16-Jul-04	Vessel	Good	Yes
H4	22-Sep-03	Vessel	Mooring covered in mud	Yes	16-Jul-04	–	Divers	Not found; line broke[4]	No
H5	22-Sep-03	Vessel	Mooring covered in mud; receiver flooded	No	16-Jul-04	16-Jul-04	Vessel	Good	Yes
H6	22-Sep-03	Vessel	Good	Yes	16-Jul-04	16-Jul-04	Vessel	Good	Yes

	2003 Retrievals				2004 Retrievals				
Station	**Retrieval date**	**Method of retrieval**	**Condition of array**	**Data collected?**	**Pop-up activation date**	**Retrieval date**	**Method of retrieval**	**Condition of array**	**Data collected?**
H7	22-Sep-03	Vessel	Good	Yes	20-Jul-04	20-Jul-04	Vessel	Good	Yes
H8	11-Sep-03	Vessel	Good	Yes	16-Jul-04	16-Jul-04	Vessel	Good	Yes
I1	22-Sep-03	Vessel	Mooring covered in mud	Yes	15-Jul-04	15-Jul-04	Vessel	Mooring covered in mud	
I2	01-Oct-03	Divers	Not found	No	15-Jul-04	–	Vessel	Not found	No
I3	11-Sep-03	Vessel	Good	Yes	15-Jul-04	15-Jul-04	Vessel	Good	Yes
I4	11-Sep-03	Vessel	Good	Yes	15-Jul-04	15-Jul-04	Vessel	Strongback bent	Yes
I5	11-Sep-03	Vessel	Good	Yes	15-Jul-04	15-Jul-04	Vessel	Good	Yes
I6	11-Sep-03	Vessel	Good	Yes	15-Jul-04	15-Jul-04	Vessel	Good	Yes
I7	11-Sep-03	Vessel	Good	Yes	15-Jul-04	15-Jul-04	Vessel	Strongback bent; hydrophone broken	Yes[6]
I8	11-Sep-03	Vessel	Good	Yes	15-Jul-04	–	Vessel	Not found	No

[1] = Receiver sent to Vemco for inspection and data recovery; data could not be recovered due to a faulty circuit board.

[2] = Pop-up buoy (at the surface) cut loose from array and damaged by R/V *Beavertail*. Divers could not find mooring and receiver.

[3] = Array was hit by a trawler in January 2004 (cracked pop-up buoy recovered). Divers could not find mooring and receiver.

[4] = The line to the array broke during the retrieval process, leaving the mooring and receiver on the seafloor.

[5] = Data 'indicator light' not working, receiver sent to Vemco to extract data.

[6] = Receiver had a broken hydrophone and flooded battery compartment; receiver sent to Vemco to extract data.

Table 6. Black sea bass released at the HARS site (N=129). Transmitter ID is the electronic identification number associated with the transmitter, external tag refers to the number on the external tag, and number of detections was obtained from recovered receivers.

Transmitter ID	External tag	Number of detections	Comments
3	46	7,943	
5	35	2,662	
6	44	8,421	
7	48	16,093	
10	145	22,271	
12	181	4,548	Captured 22 Apr 2004
13	98	1,716	
14	31	14,154	
15	117	1,741	
23	174	37,065	
24	166	5,409	
25	183	7,732	
26	190	17,385	
27	206	2,321	Captured before 30 Jun 2003[1]
28	209	5,327	
29	189	3,611	
31	200	4,375	
32	36	14,553	
33	151	41,361	
34	207	26,672	
35	149	7,642	
36	38	17,116	
37	37	0	Fish died on release date (16 Jul 2003)
40	201	25,715	
41	247	21,770	
42	204	16,320	
43	218	521	
44	167	3,605	Captured 22 Sep 2003
45	158	12,502	
46	165	4,366	
47	188	6,662	
48	171	22,348	
49	213	79	

Transmitter ID	External tag	Number of detections	Comments
50	182	16,075	
51	170	14,586	
52	176	24,355	
58	229	21,092	
59	228	2,638	
60	226	2,517	Captured 14 Jun 2003
62	126	7,942	
63	234	46,621	
64	241	1,504	
65	242	40,798	
69	90	30,322	
76	147	522	
78	134	2,533	
81	148	10,087	
82	135	11,623	Fish died on 26 Jul 2003
86	177	31,062	
90	92	2,164	
91	131	0	Transmitter malfunction
92	146	43	Captured 25 Jun 2003
93	139	212	
95	144	7,674	
100	32	0	Transmitter malfunction
101	173	33,256	
102	195	0	Transmitter malfunction
103	196	6,402	Captured & released, 18 Aug 2003
104	175	10,659	Captured & released, 6 Jul 2003
106	185	10,232	
107	211	3,110	
108	83	14,572	
109	225	24,583	
110	221	5,038	
111	224	12,739	
112	248	13,513	
113	164	43	
114	150	160	
115	169	12,884	

Transmitter ID	External tag	Number of detections	Comments
116	243	7	
117	236	5,437	
118	194	7205	
121	205	34,268	
122	198	11,399	
123	197	2,414	
125	116	761	
128	230	20,484	
129	235	2,927	Captured & released, 26 Jun 2003
131	237	36,100	
132	192	1,622	Captured & released, 6 Jul 2003
133	212	2,040	
135	232	151	
137	245	107	
138	97	34,412	
141	233	1,707	
142	219	7,410	
143	240	31,999	
144	95	18,823	
145	231	2,812	
147	112	267	
148	27	19,152	
149	76	206	Captured & released, 12 Aug 2003
150	162	15,929	
151	94	4,497	
152	110	144	
154	153	0	Fish died on release date (18 Jun 2003)
155	217	2,519	
156	179	245	
157	216	1,894	
158	154	2,243	
159	152	2,643	
160	163	10,625	
161	180	6,139	
162	129	12,622	
167	215	14,436	

Transmitter ID	External tag	Number of detections	Comments
169	115	746	
170	246	898	
172	106	2,132	
173	222	0	Transmitter malfunction Captured 20 Jul 2003
174	223	5,484	
175	127	1,853	
176	155	2,485	
177	238	5,667	
178	210	20,445	
179	187	664	
180	86	13,579	
181	114	1,399	
184	99	2,387	
187	160	3,587	
192	178	13,446	Captured before 6 Jan 2004[1]
193	159	0	Transmitter malfunction
196	220	4,084	
197	249	22,600	
198	168	8,600	
199	244	20	
200	184	14,865	
201	186	4,246	
202	203	362	
203	208	1,834	

[1] Date of capture unknown; see Table Recaps.

Table 7. Summer flounder released at the HARS site (N=24). Transmitter ID is the electronic identification number associated with the transmitter, external tag refers to the number on the external tag, and number of detections was obtained from recovered receivers.

Transmitter ID	External tag	Number of detections	Comments
20	100	4,586	Captured before 6 Nov 2003[1]
21	101	48	
22	45	8,090	
38	51	5,844	
74	123	8,242	
77	140	5,647	
79	137	7,428	
80	120	22,358	
83	102	5,253	
85	121	2,355	
87	124	17220	
88	113	15,799	
89	85	6,177	
96	49	15,567	
97	227	1,662	
98	108	491	Detected in 2004 only
99	87	12,967	
120	193	3,032	
146	30	1,383	
163	89	7,936	Captured before 19 Feb 2004[1]
164	138	529	
165	111	12,474	
166	82	7,813	
168	88	15,039	

[1] Date of capture unknown; see Table 4.

Table 8. Mean anesthetic induction and recovery times (s) for black sea bass exposed to various concentrations of clove oil at two temperatures. Induction times are for stages 3, 4, and 5 as defined in the text; recovery is also defined in the text. N is number of fish in trial and df is degrees of freedom. The *F*-statistic tests the hypothesis of equal mean times across clove oil concentrations; asterisks denote significance at $P \leq 0.05$. The overall mean time to stages 3, 4, and 5 at 15.8°C was 49, 118, and 118 s; overall mean recovery time was 227 s. The overall mean time to stage 4 at 19.7°C was 63 s; overall mean recovery time 364 s.

	Clove oil concentration (mg/L)								
	20	**40**	**60**	**80**	**100**	**120**	**df**	***F***	***P***
			15.8°C						
Stage 3	61	46	43	49	--	--	3, 14	1.72	0.22
Stage 4	142	129	101	105	--	--	3, 14	1.10	0.39
Stage 5	163	122	110	89	--	--	3, 14	2.97	0.08
Recovery	195	189	272	245	--	--	3, 14	1.35	0.31
N	3	4	4	4	--	--			
			19.7°C						
Stage 3	161	47	36	35	39	30	5, 17	4.76 *	0.01
Stage 4	--	99	59	51	51	56	4, 14	3.20	0.06
Stage 5	825	174	66	55	62	65	5, 17	6.81 *	<0.01
Recovery	300	275	419	349	422	420	5, 17	1.14	0.39
N	3	3	3	3	3	3			

Table 9. Mean anesthetic induction and recovery times (s) for black sea bass exposed to four concentrations of clove oil at two temperatures. Induction times are for stages 3, 4, and 5 as defined in the text; recovery is also defined in the text. N is number of fish in trial; df is degrees of freedom. The *F*-statistic tests the hypothesis of equal mean times across temperatures; asterisks denote significance at $P \leq 0.05$.

	Temperature				
	15.8°C	**19.7°C**	**df**	***F***	***P***
	20 mg/L				
Stage 3	61	161	1, 5	3.09	0.15
Stage 4	142	--	--	--	--
Stage 5	163	825	1, 5	5.31	0.08
Recovery	195	300	1, 5	1.56	0.28
N	3	3			
	40 mg/L				
Stage 3	46	47	1, 6	0.03	0.87
Stage 4	129	99	1, 6	1.07	0.35
Stage 5	122	174	1, 6	3.39	0.13
Recovery	189	275	1, 6	12.42*	0.02
N	4	3			
	60 mg/L				
Stage 3	43	36	1, 6	0.86	0.40
Stage 4	101	59	1, 6	14.46*	0.01
Stage 5	110	66	1, 6	9.05*	0.03
Recovery	272	419	1, 6	2.56	0.17
N	4	3			
	80 mg/L				
Stage 3	49	35	1, 6	5.00	0.08
Stage 4	105	51	1, 6	3.04	0.14
Stage 5	89	55	1, 6	12.18*	0.02
Recovery	245	349	1, 6	19.70*	0.01
N	4	3			

Table 10. Mean daily growth rates (mm/d and g/d) for black sea bass exposed to four concentrations of clove oil at two temperatures; TL is total length. Numbers in parentheses are number of fish measured for length or weight; df is degrees of freedom. The *F*-statistic tests the hypothesis of equal mean growth rates across exposure temperatures; asterisks denote significance at $P \leq 0.05$.

	Temperature				
	15.8°C	**19.7°C**	**df**	***F***	***P***
	20 mg/L				
Mean growth, TL (mm/d)	0.343 (3)	0.310 (3)	1, 5	0.32	0.60
Mean growth, weight (g/d)	1.732 (3)	1.944 (3)	1, 5	0.25	0.64
	40 mg/L				
Mean growth, TL (mm/d)	0.183 (3)	0.286 (2)	1, 4	4.04	0.14
Mean growth, weight (g/d)	1.299 (3)	1.782 (2)	1, 4	0.42	0.56
	60 mg/L				
Mean growth, TL (mm/d)	0.239 (4)	0.386 (3)	1, 6	7.17*	0.04
Mean growth, weight (g/d)	1.243 (4)	1.610 (3)	1, 6	1.07	0.35
	80 mg/L				
Mean growth, TL (mm/d)	0.331 (2)	0.255 (3)	1, 4	4.58	0.12
Mean growth, weight (g/d)	1.260 (2)	1.430 (3)	1, 4	0.24	0.66

Table 11. Mean anesthetic induction and recovery times (s) for summer flounder exposed to various concentrations of clove oil at 20.7°C. Induction times are for stages 3, 4, and 5 as defined in the text; recovery is also defined in the text. N is number of fish in trial and df is degrees of freedom. The *F*-statistic tests the hypothesis of equal mean times across clove oil concentrations; asterisks denote significance at $P \leq 0.05$. The overall mean times to stages 3 and 4 were 65 and 98 s; overall mean recovery time was 365 s.

	Clove oil concentration (mg/L)						
	40	**60**	**80**	**100**	**df**	***F***	***P***
Stage 3	111	51	55	42	3, 11	2.78	0.11
Stage 4	149	79	72	62	3, 7	1.99	0.26
Stage 5	599	373	244	182	3, 11	9.48 *	0.01
Recovery	439	387	303	331	3, 11	0.76	0.56
N	3	3	3	3			

Table 12. Mean anesthetic induction and recovery times (s) for summer flounder exposed to 80 mg/L clove oil at 20.7°C. Induction times are for stages 3, 4, and 5 as defined in the text; recovery is also defined in the text. N is number of fish in trial and df is degrees of freedom. The *F*-statistic tests the hypothesis of equal mean times for wild-captured and cultured fish; asterisks denote significance at $P \leq 0.05$. The overall mean times to stages 3, 4, and 5 were 60, 91, and 290 s.

	Summer flounder				
	wild-captured	**cultured**	**df**	***F***	***P***
Stage 3	55	64	1, 5	1.14	0.35
Stage 4	72	109	1, 3	3.49	0.20
Stage 5	244	336	1, 5	3.95	0.12
Recovery	303	64	1, 5	57.22*	<0.01
N	3	3			

Table 13. Efficiency of moored receivers measured as percent of transmissions detected at the HARS, 2003-2004. The highest receiver efficiency occurred when the transmitter was within 5 m of the surface and 400 m away from the receiver (89.5% detection rate). Depth and distance combinations that were not tested are indicated by '–'.

Distance to receiver (m)	Depth of transmitter (m)					
	0-5	**5-10**	**10-15**	**15-20**	**20-25**	**25-30**
100	--	0	0	2	0	--
200	--	0	0.5	2.1	1.4	0
300	0	0	0.6	3.1	0.9	--
400	89.5	2.5	0.3	2.4	1	--
500	0	0	0	0.7	1.3	0
600	0	0	0.4	0.1	1.4	0
700	3.2	0	0	0	0.4	1.4
800	0	00	0	0	0.2	1.6
900	0	0	0	0	0.2	0
1000	0	0	0	0	0	0

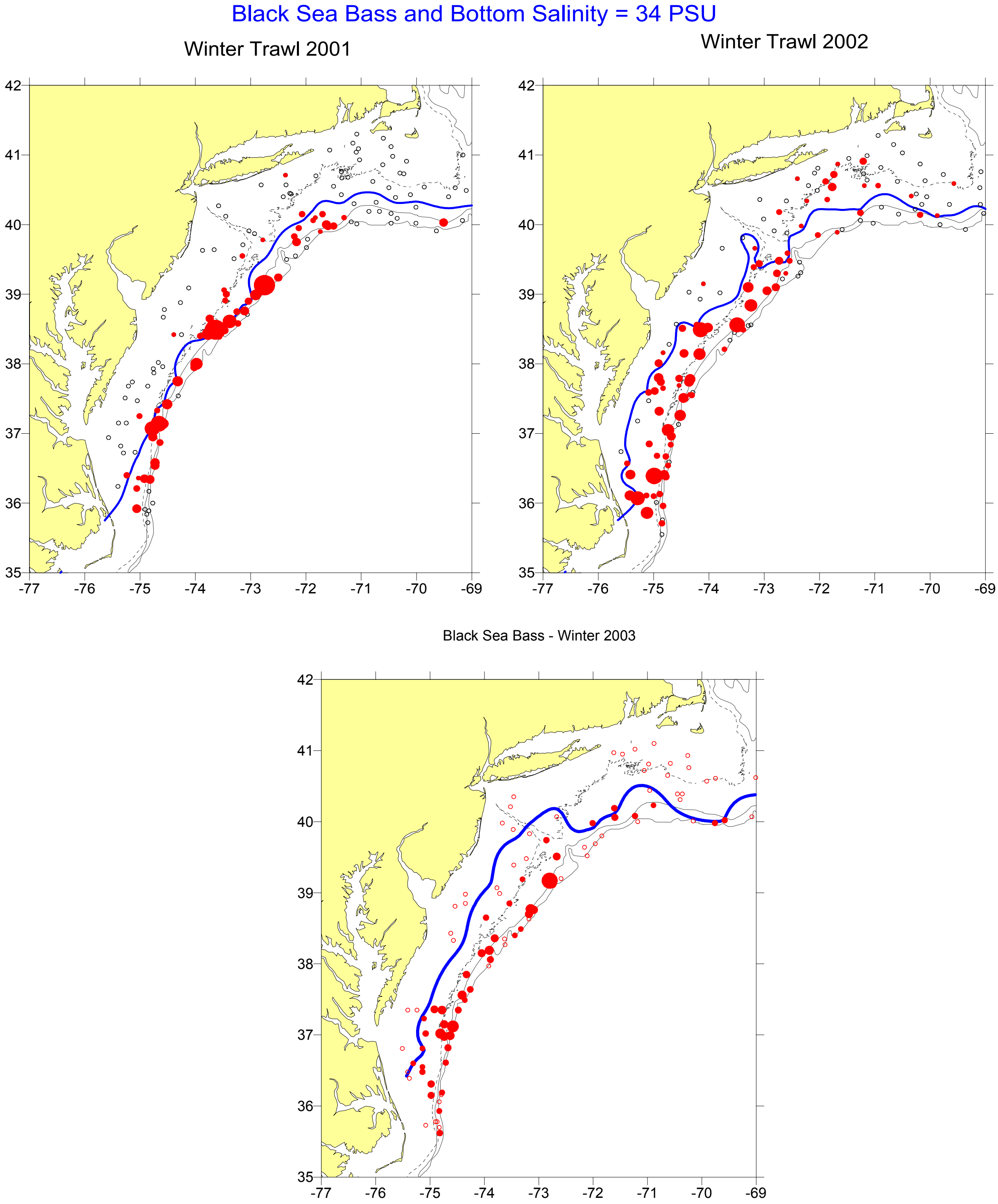
Table 14. Kaplan-Meier estimates of dispersal probabilities for black sea bass. Elapsed days are days since 2 June 2003 (see text for explanation).

Elapsed days	Actual date	Probability of dispersal	Standard error (dispersal)	Numbers dispersed (cumulative)	Numbers remaining
0	2 Jun	0	0	0	122
1	3 Jun	0.0082	0.0082	1	121
11	13 Jun	0.0656	0.0224	8	114
24	26 Jun	0.1231	0.0298	15	106
30	2 Jul	0.1646	0.0337	20	100
46	18 Jul	0.1992	0.0364	24	91
51	23 Jul	0.2265	0.0384	27	85
76	17 Aug	0.2559	0.0406	30	70
98	8 Sep	0.2792	0.0425	32	57
100	10 Sep	0.2920	0.0437	33	55
111	21 Sep	0.3322	0.0470	36	49
120	30 Sep	0.3636	0.0497	38	40
131	11 Oct	0.4149	0.0539	41	30
147	27 Oct	0.4993	0.0606	45	21
152	1 Nov	0.5482	0.0638	47	18
168	17 Nov	0.7289	0.0657	54	9
171	20 Nov	0.8024	0.0656	56	5
187	6 Dec	0.9012	0.0772	57	1
196	15 Dec	–	–	57	0

Table 15. Kaplan-Meier estimates of dispersal probabilities for summer flounder. Elapsed days are days since 24 June 2003 (see text for explanation).

Elapsed days	Actual date	Probability of dispersal	Standard error (dispersal)	Numbers dispersed (cumulative)	Numbers remaining
0	24 Jun	0	0	0	23
2	26 Jun	0.0435	0.0425	1	22
16	10 Jul	0.1739	0.0790	4	19
27	21 Jul	0.2174	0.0860	5	18
34	28 Jul	0.2609	0.0916	6	17
41	4 Aug	0.3043	0.0959	7	16
50	13 Aug	0.3478	0.0993	8	15
65	28 Aug	0.4381	0.1042	10	12
70	2 Sep	0.4849	0.1055	11	11
87	20 Sep	0.8595	0.0749	19	3
148	20 Nov	1.0	0	22	0

Figure 1. Distribution of black sea bass between Cape Hatteras and Cape Cod as determined from NEFSC bottom trawl surveys conducted in winter, 2001-2003. The size of the circles represents relative abundance of black sea bass in the catch; open circles indicated no black sea bass were captured at the site; the blue line represents the 34‰ isobar.


Black Sea Bass and Bottom Salinity = 34 PSU

Winter Trawl 2001

Winter Trawl 2002

Black Sea Bass - Winter 2003

Figure 2. Proportion of transmissions detected by a single VR2 receiver moored at the HARS in 22.2 m waters. The test was conducted in October 2002, when the thermocline was virtually nonexistent. The transmitter was positioned 4 m below the surface (solid line) or at 21 m depth (dotted line). Distances measured were along the surface plane (i.e., the distance between the receiver's coordinates and the transmitter's coordinates on a surface projection).

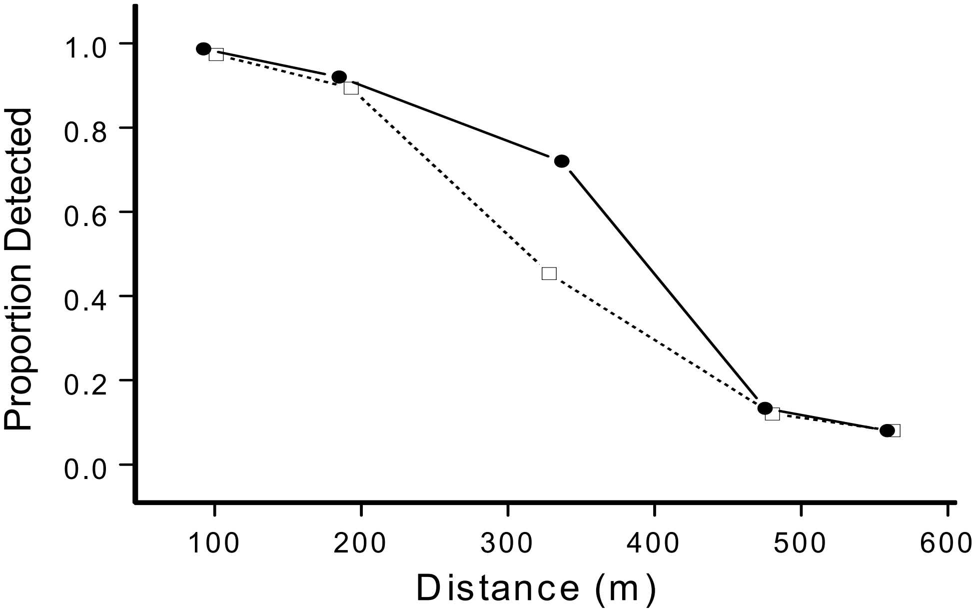


Figure 3. Station locations at the HARS, including bathymetry; the black line designates the priority remediation areas at the HARS; column headings (A, B, ... I) and row designations (1, 2, ...8) represent naming conventions for each station; darker isobaths represent deeper waters. We did not place arrays in the northernmost areas of the HARS (i.e., north of row 1) due to the presence of a large number of shipwrecks in those areas.

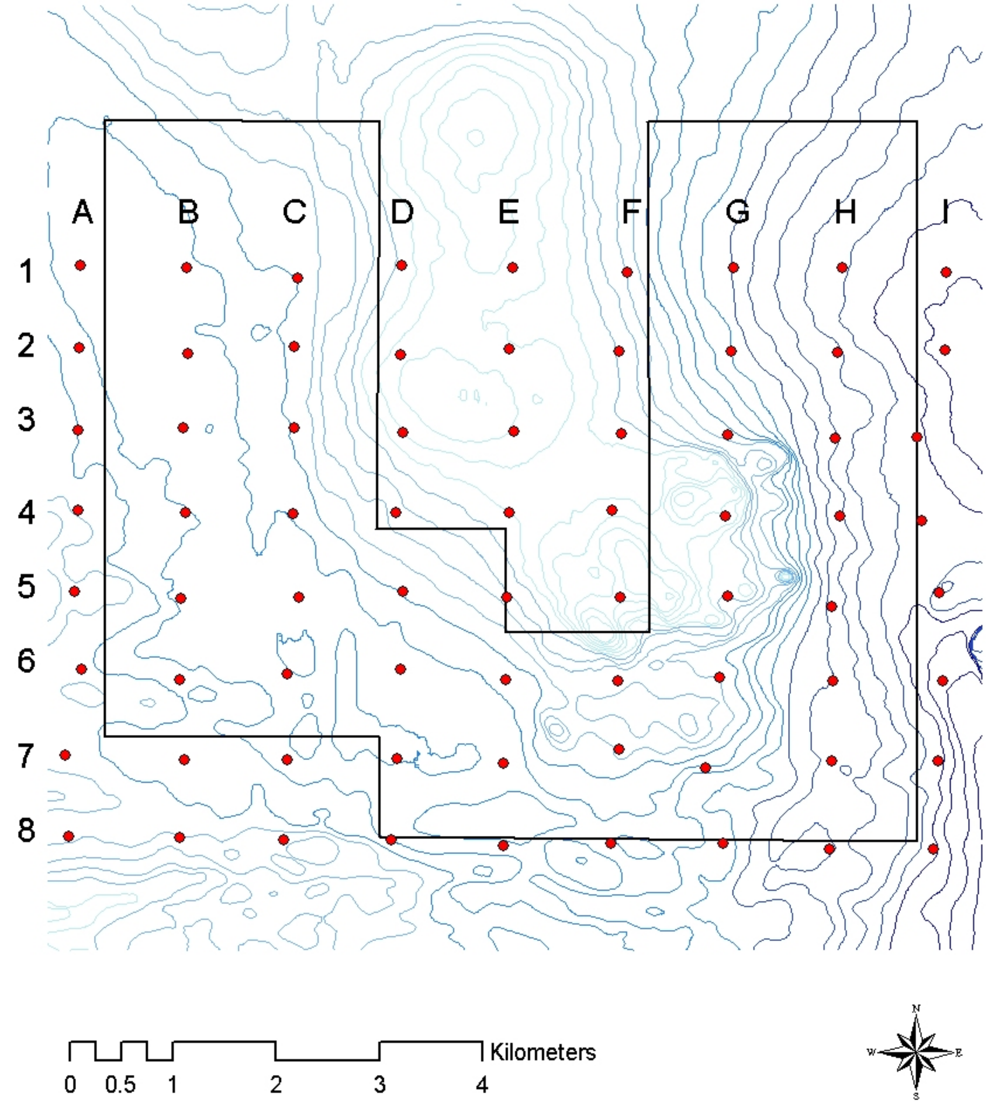


Figure 4. Schematic of acoustic array deployed at the HARS.

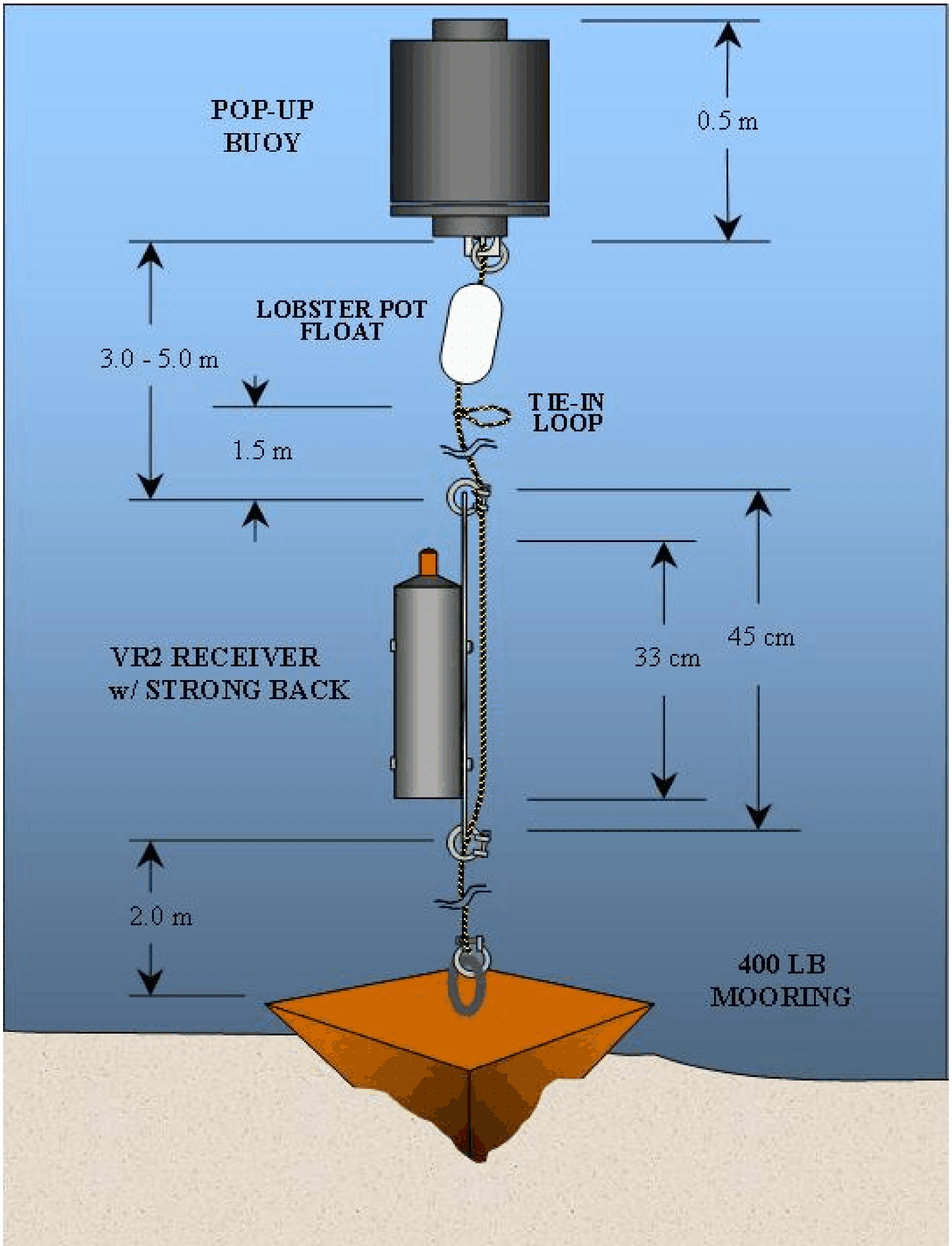


Figure 5. Transmitter detections for black sea bass (A) and summer flounder (B) at the HARS; the size of the circles corresponds to percentages of total detections. Data recorded between 30 May and 25 August 2003 are coded "retrieval 1" and are represented as blue circles; data recorded after 25 August 2003 are coded "retrieval 2" and are represented as yellow circles; green circles correspond to stations for which data from both retrieval periods were available. Stations marked with a black "x" are stations in which the equipment was not recovered in either retrieval effort.

(A)

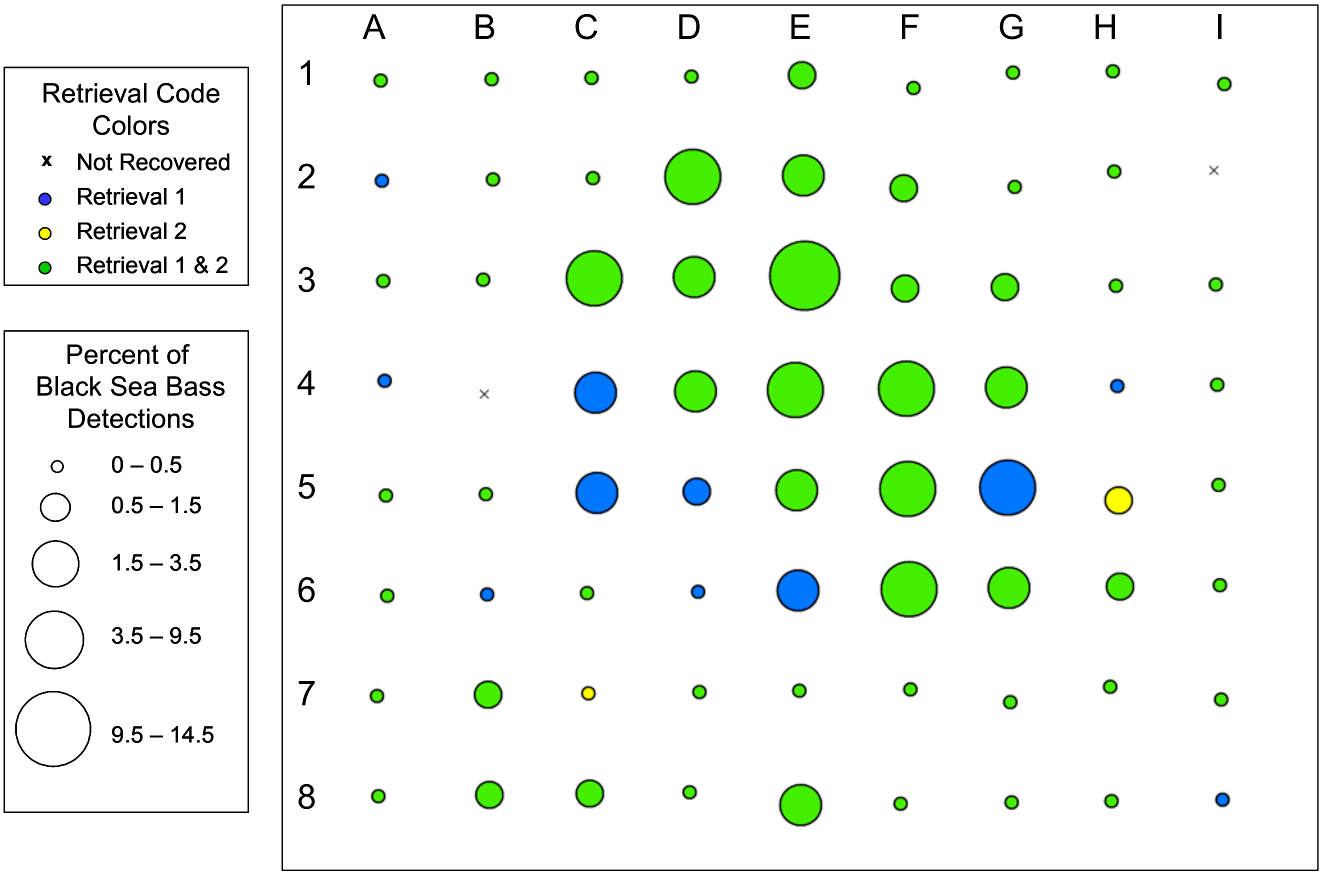


Figure 5 (continued).

(B)

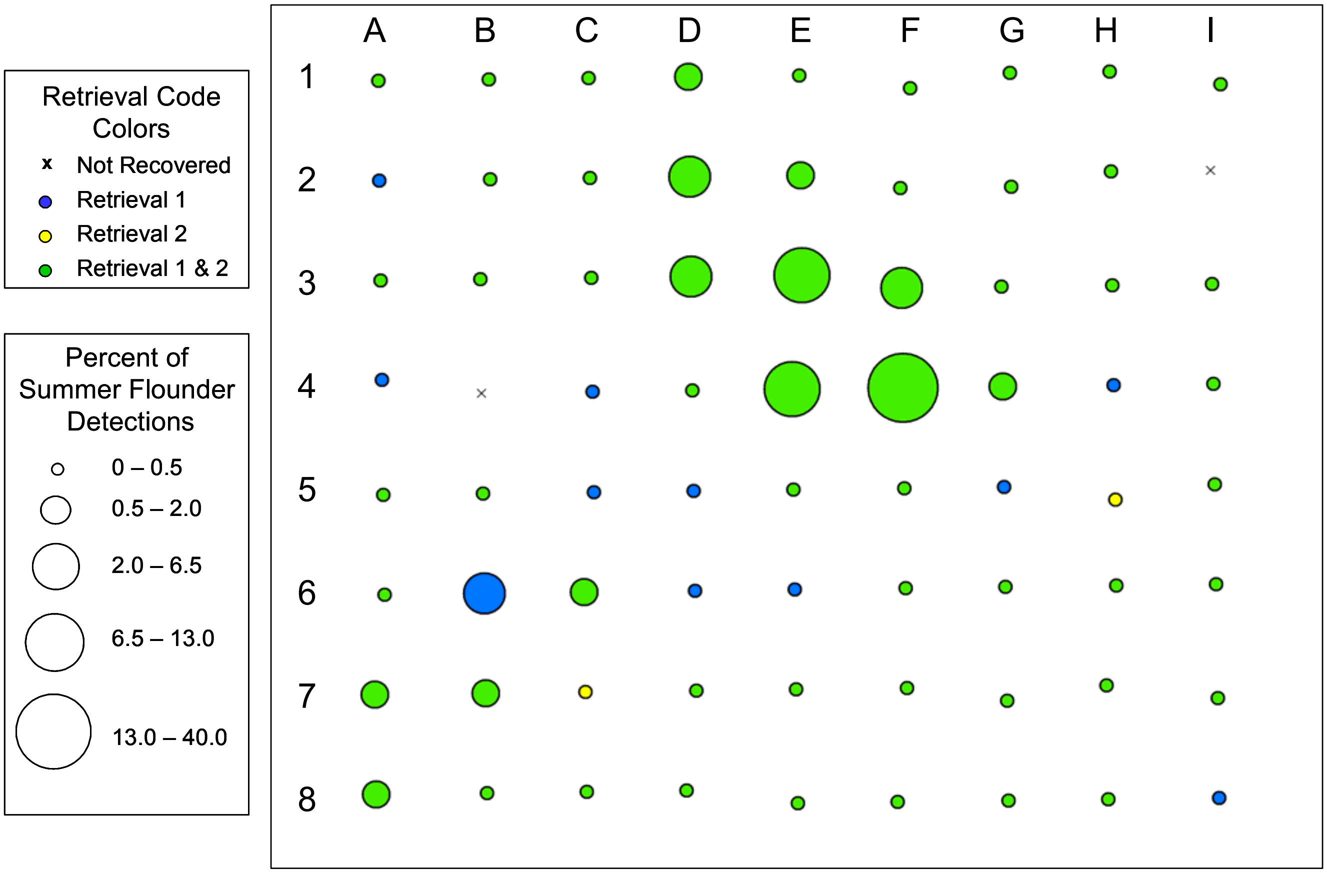


Figure 6. Vessel track (blue line) and CTD casts (green circles) from the receiver efficiency test conducted at the HARS, June 2004. Receivers were not recovered from stations marked by an X. The violet area includes the PRAs (priority remediation areas); the pink area is the buffer zone around the HARS.

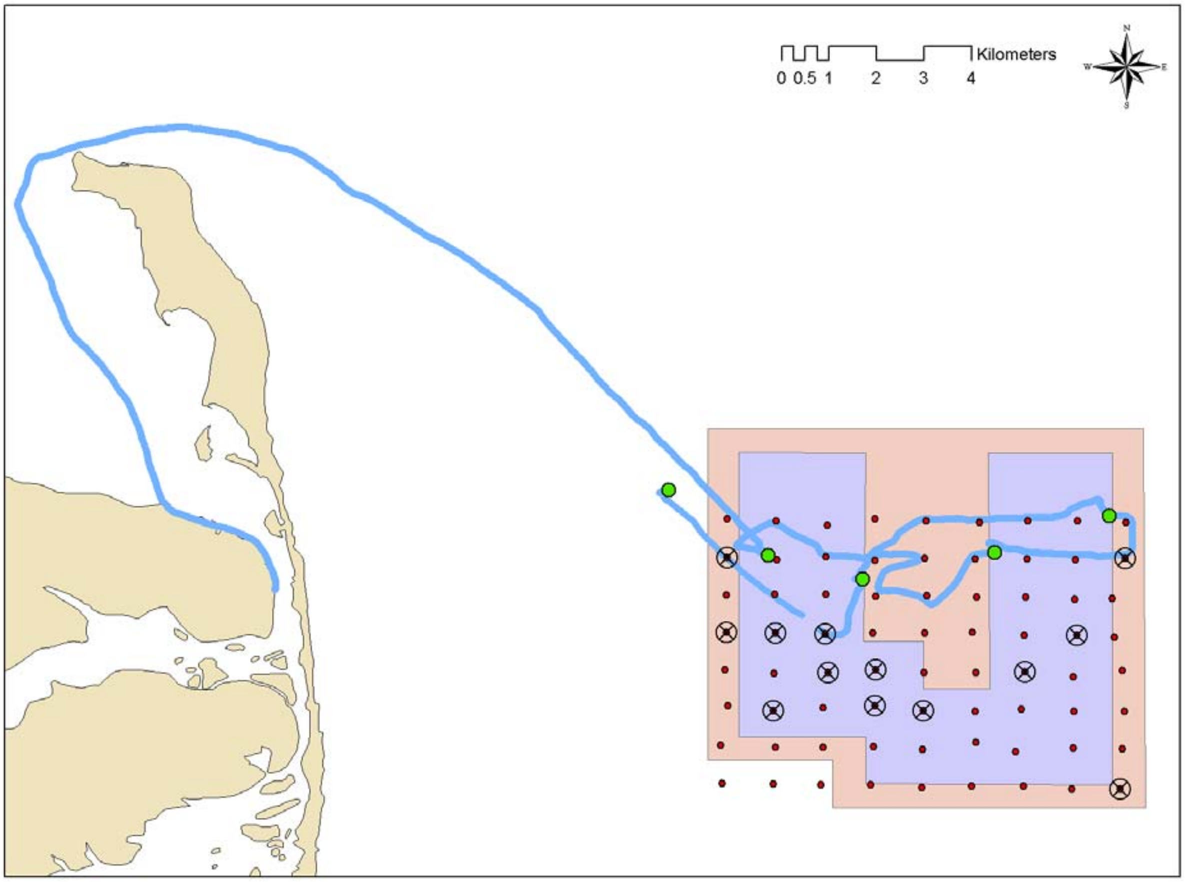
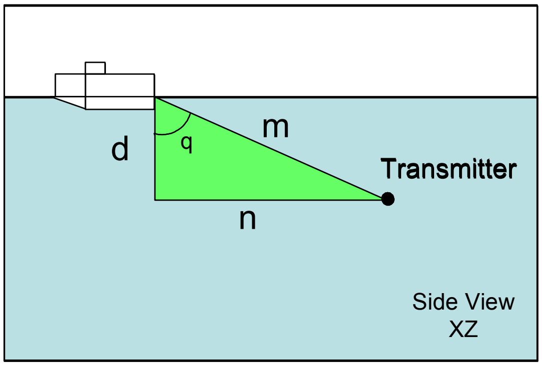
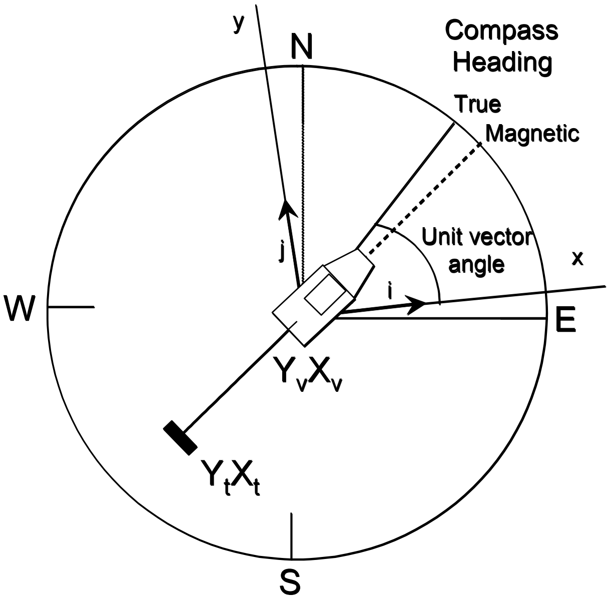


Figure 7. Measured (depth, towing line length) and calculated distances used to determine position of the transmitter relative to the boat (A) and to the receiver (B). These data were used to estimate the efficiency of receivers moored at the HARS in June 2004.

(A)





m is the length of the towing line

d is the transmitter's depth

q is the angle of the towing line

n is the distance from the transmitter to the vessel

n = msin(q)

Unit vectors:

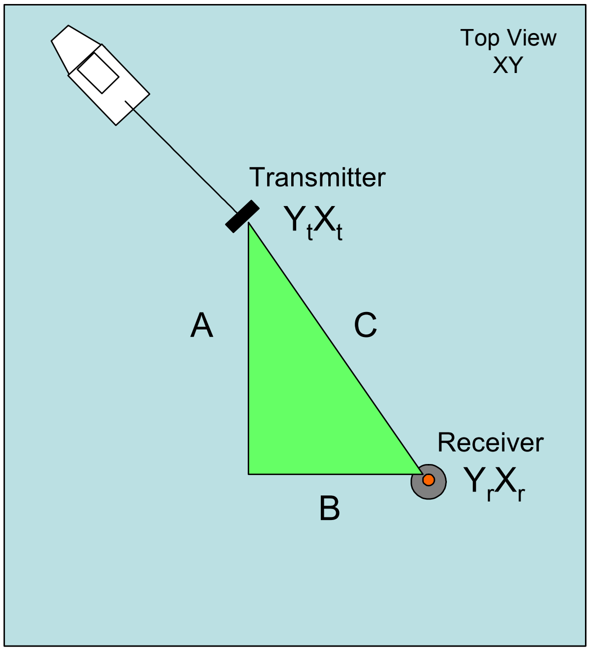
i = sin(unit vector angle)
j = cos(unit vector angle)

UTM Positon of transmitter (Y_tX_t):

$Y_t = Y_v – n(-1)i$
$X_t = X_v – n(-1)j$

Figure 7 (continued).

(B)



$A = (\text{UTM meters north}_t - \text{UTM meters north}_r)$

$B = (\text{UTM meters east}_t - \text{UTM meters east}_r)$

or

$A = Y_t - Y_r$

$B = X_t - X_r$

D = (receiver station depth – transmitter depth)

C is the apparent distance from the transmitter to the receiver

$C = \sqrt{(A^2) + (B^2)}$

E is the actual distance from the transmitter to the receiver

$E = \sqrt{(C^2) + (D^2)}$

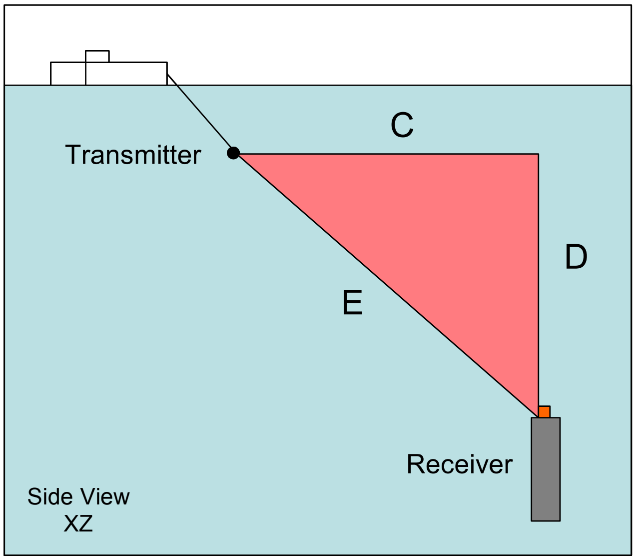


Figure 8(A). Mean depth (A), sediment grain size (B), and bottom slope (C), within a 400-m detection range from each receiver. (A) Depths in light blue are about 16 m and the darkest blue is about 34 m.

(A)

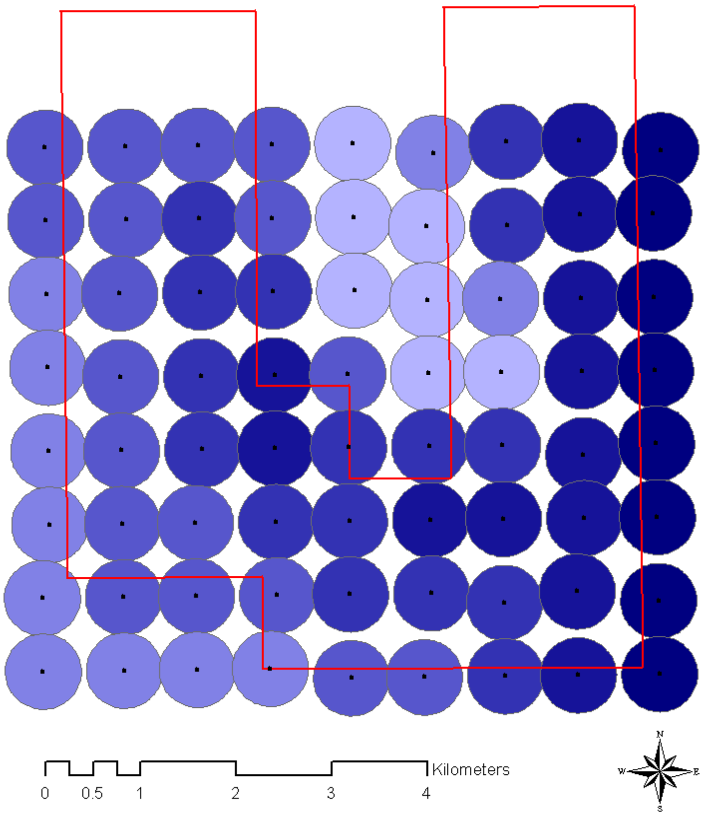


Figure 8(B). Three sediment classifications were generated based on sediment grain size values calculated from ground-truth reflectance values from sidescan sonar data. These values were averaged within a 400-m receiver detection range and displayed with a corresponding sediment classification. Light yellow represents coarse grain sizes, light brown is intermediate and dark brown represents fine grain sizes.

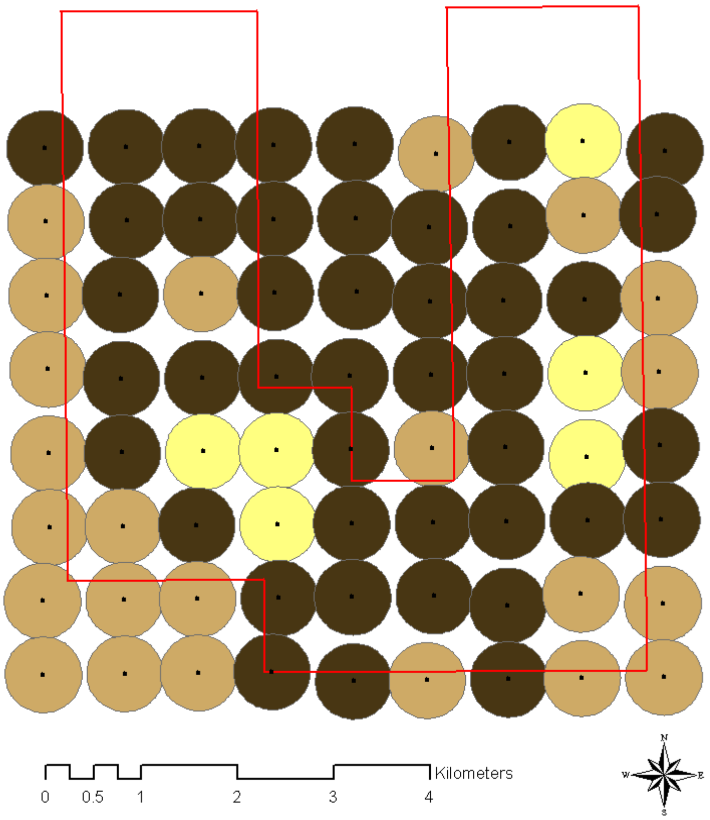


Figure 8(C). Mean bottom slope was calculated for each bathymetric grid cell in the study area. The absolute values of these slopes were then averaged within the 400-m detection range for each station. The lighter values represent small slopes (flat) and darker areas represent larger slopes.

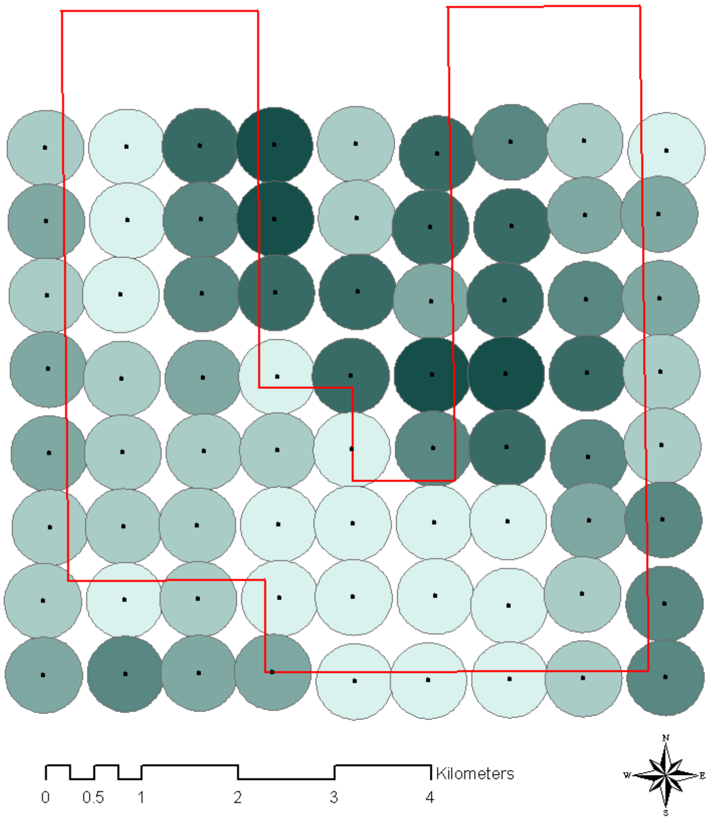


Figure 9. Monthly 48-hour swimming speed (cm/s) of adult black sea bass held in captivity from July to December 2002.

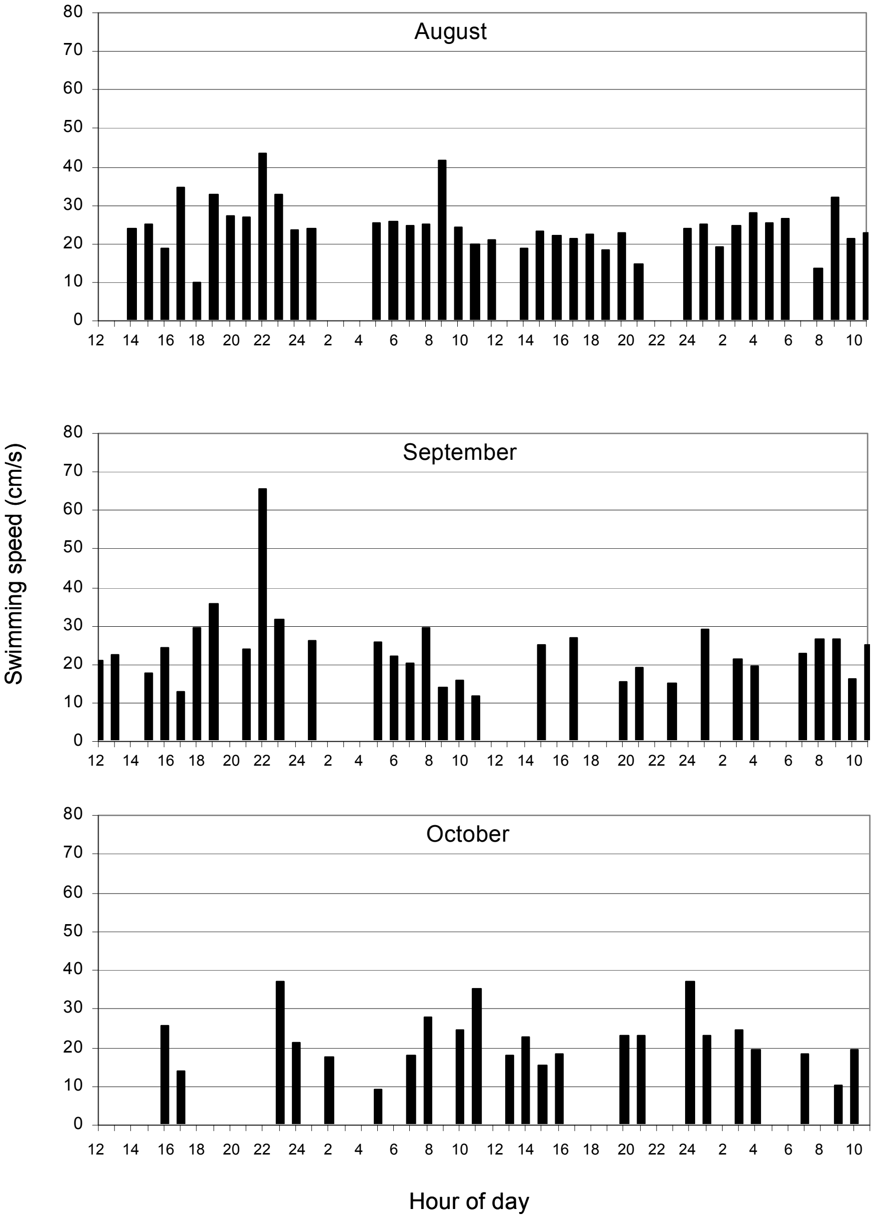
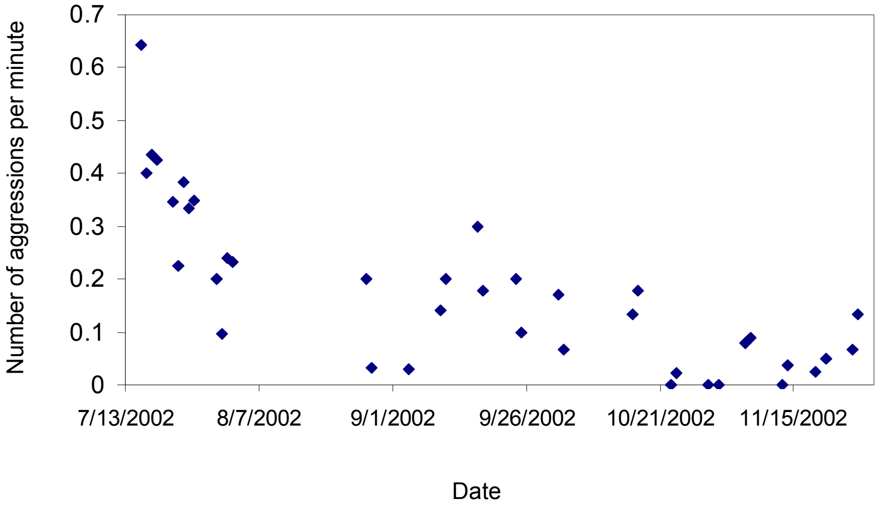


Figure 10. Number of aggressions per minute measured from male (top panel) and female (bottom panel) black sea bass held in captivity from July to December 2002. Note that the observation period for females was shorter than that for males.



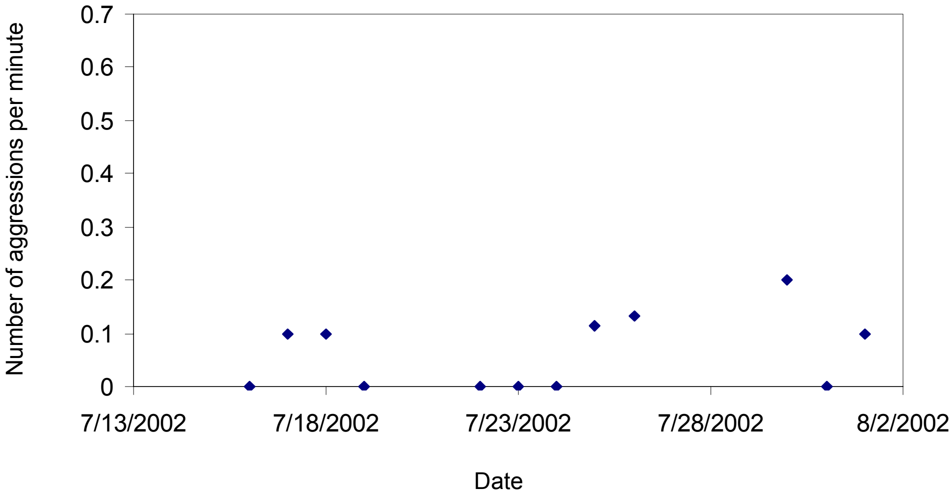


Figure 11. Post-surgical observations on summer flounder surgically implanted with dummy transmitters and monitored for up to one year. Graphs depict the proportion of fish with 100% closure, type of closure (tenuous or robust, as defined in the text), irritation of the incision site, and irritation of the suture sites.

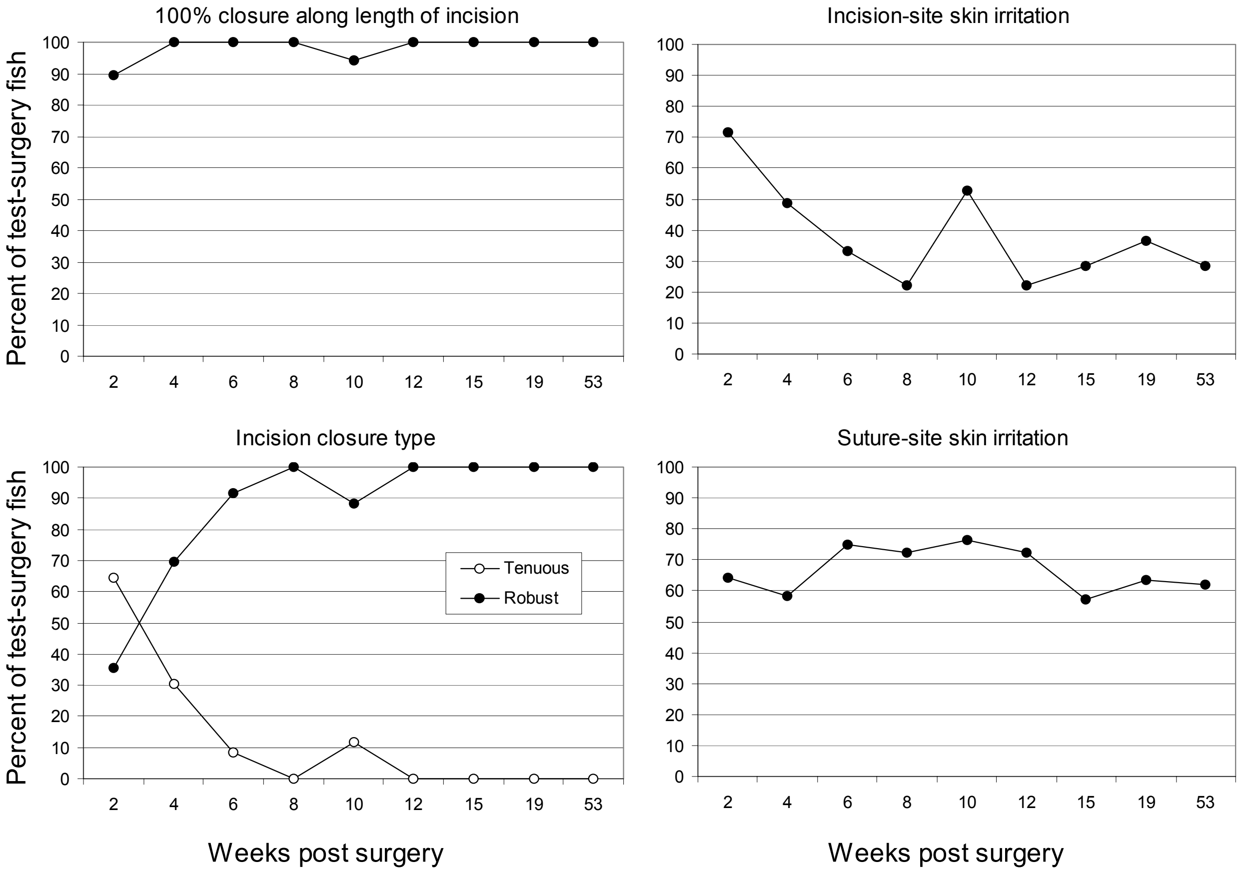


Figure 12. Disposal activity at the HARS, April 2003-August 2004 relative to locations of acoustic arrays. Some of the stations depicted in red (lost) were later retrieved. This image also shows bottom type.

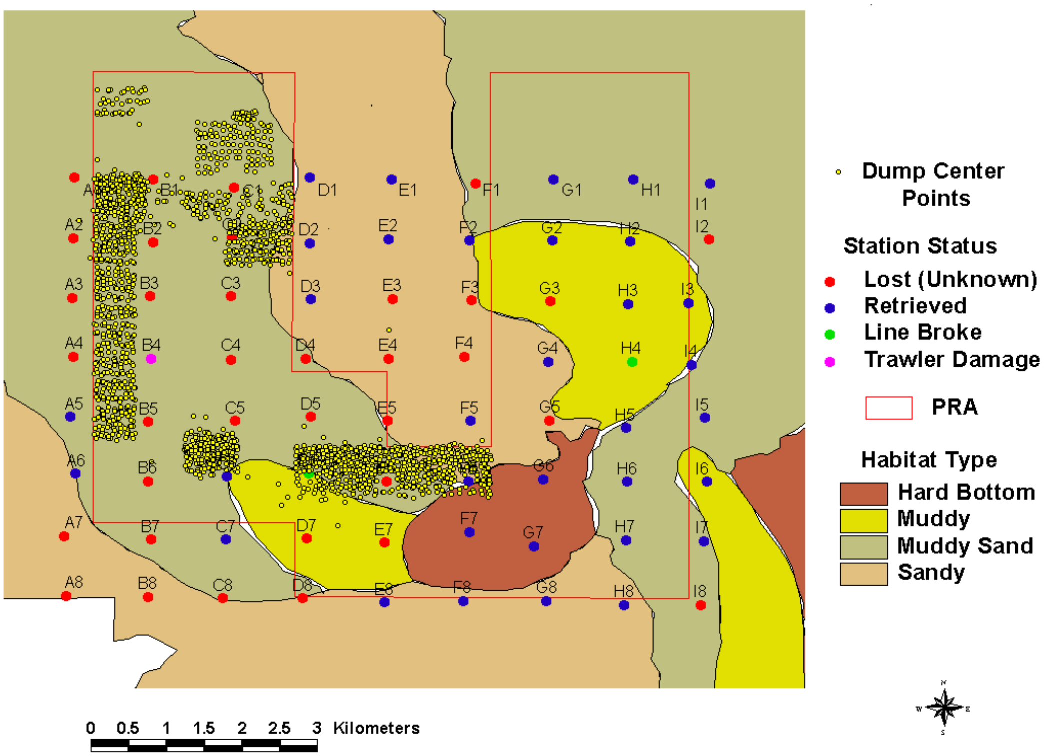


Figure 13. Proportion of transmissions detected by acoustic receivers at the HARS as determined during the receiver efficiency test, June 2004.

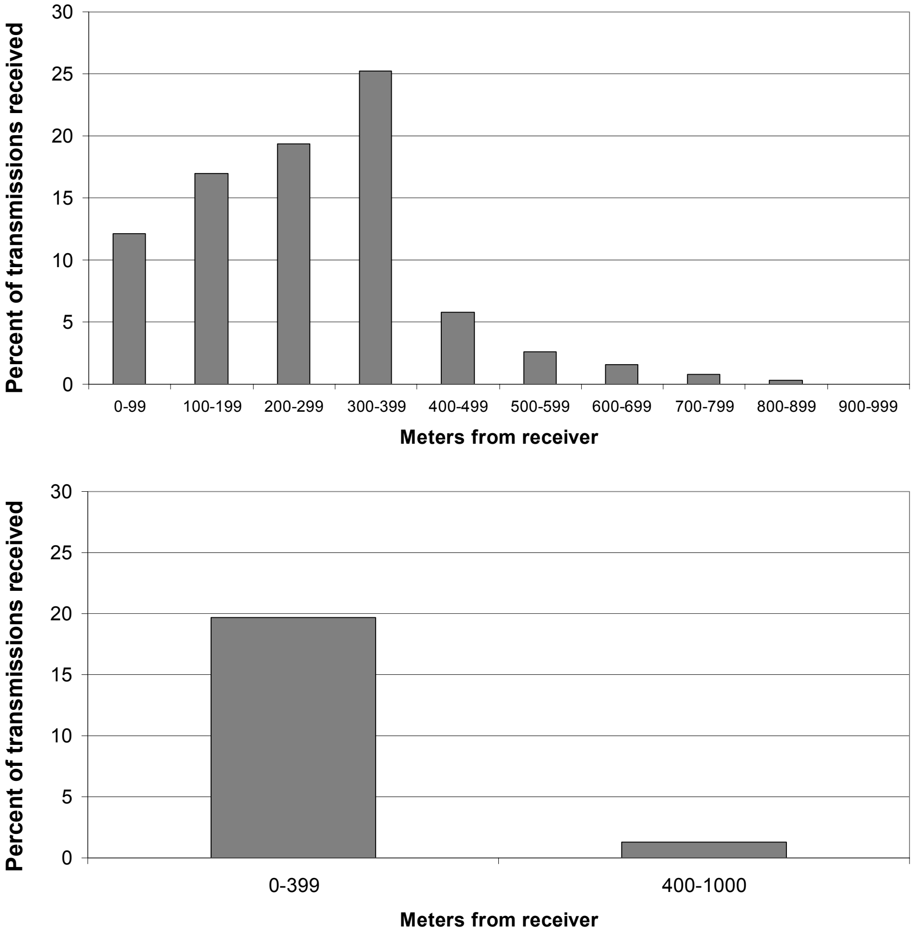


Figure 14. Salinity (left panel) and temperature (right panel) profiles obtained northeast of station F2 on 25 June 2004; a sharp thermocline was detected between 12 and 17 m.

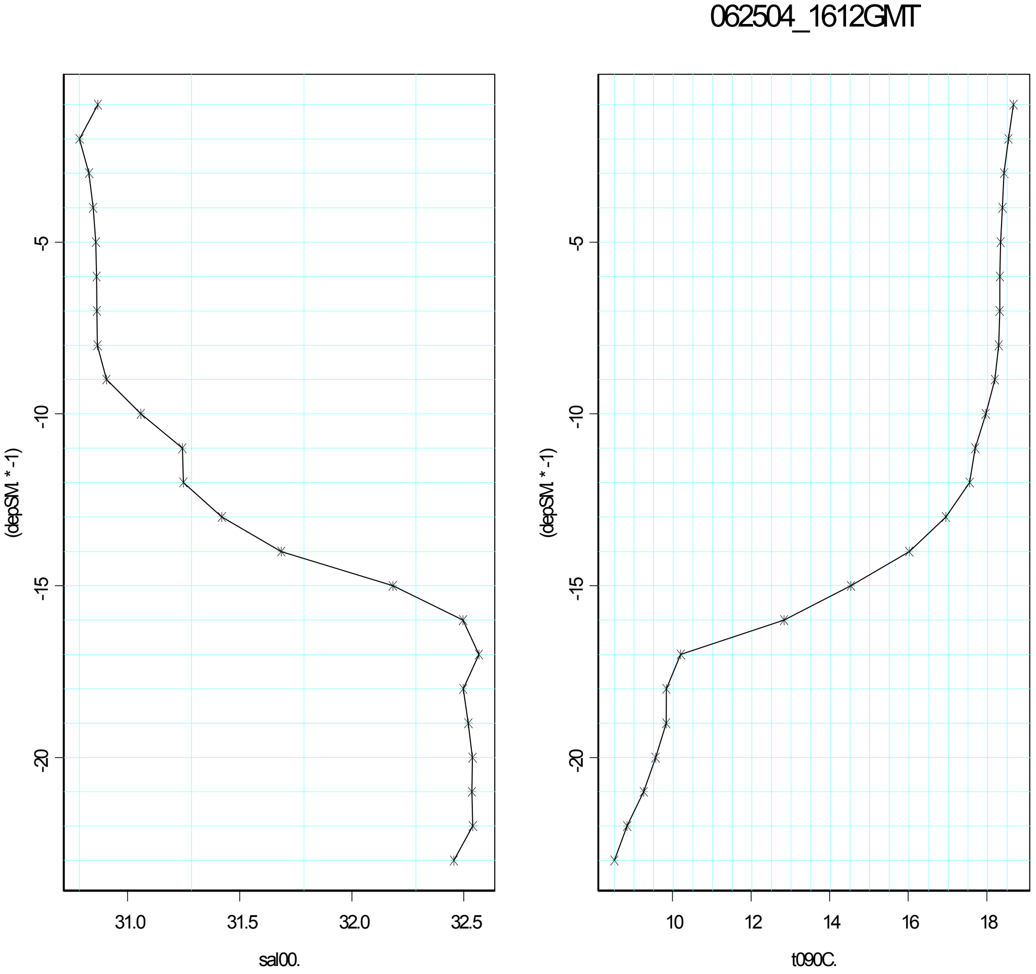


Figure 15. Bottom water characteristics at two HARS stations. (A) Bottom water temperature (°C) recorded from May 2003 to July 2004. (B) Salinity (‰) recorded from May 2003 to November 2003. Station H7 was in the southeast and station B1 was in the northwest portion of the HARS.

(A)

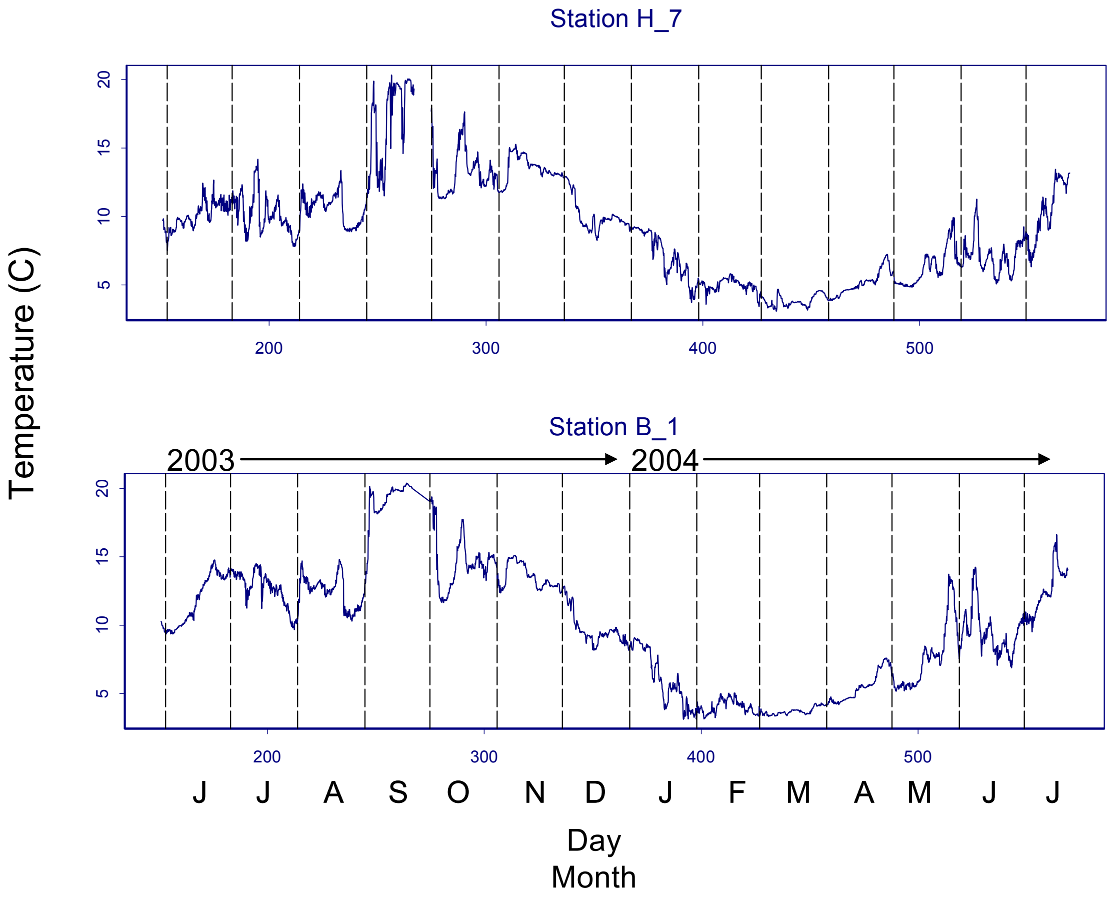


Figure 15 continued.

(B)

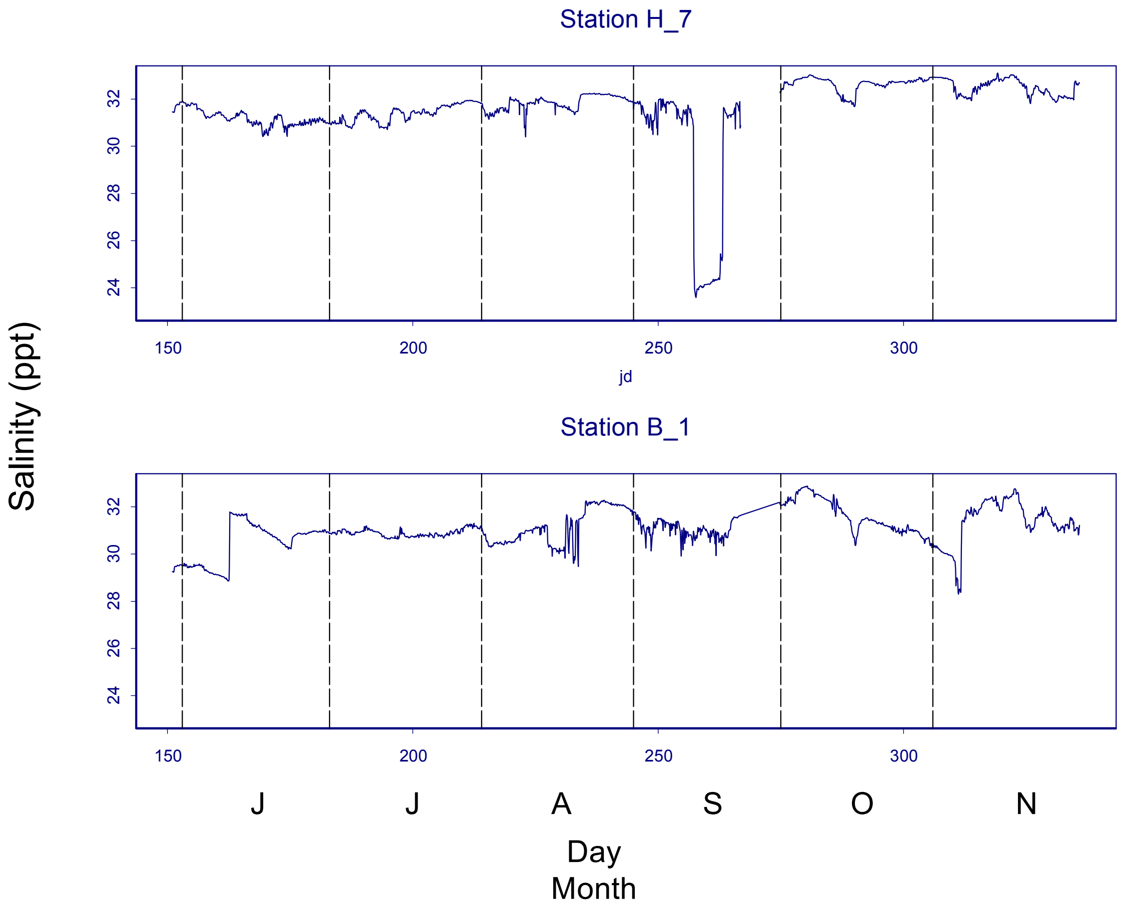


Figure 16. (A) Dominant period (s) and wave height (m) from the Long Island Data Buoy (NOAA National Data Buoy Center) for June 2003 to December 2003. (B) Potential wave disturbance of bottom habitats at the HARS as indicated by the near-bottom horizontal orbital velocity (cm/s).

(A)

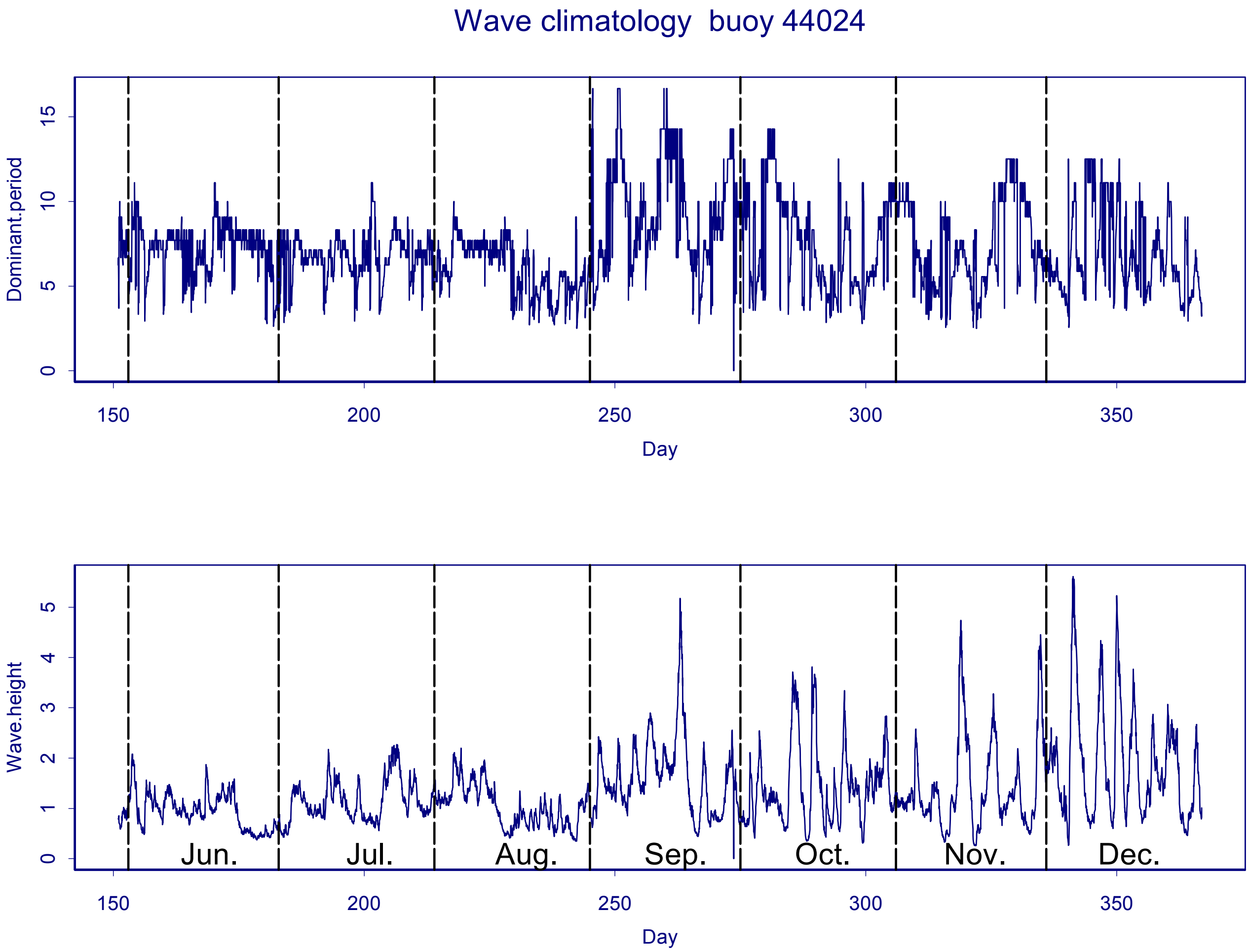


Figure 16 (continued).

(B)

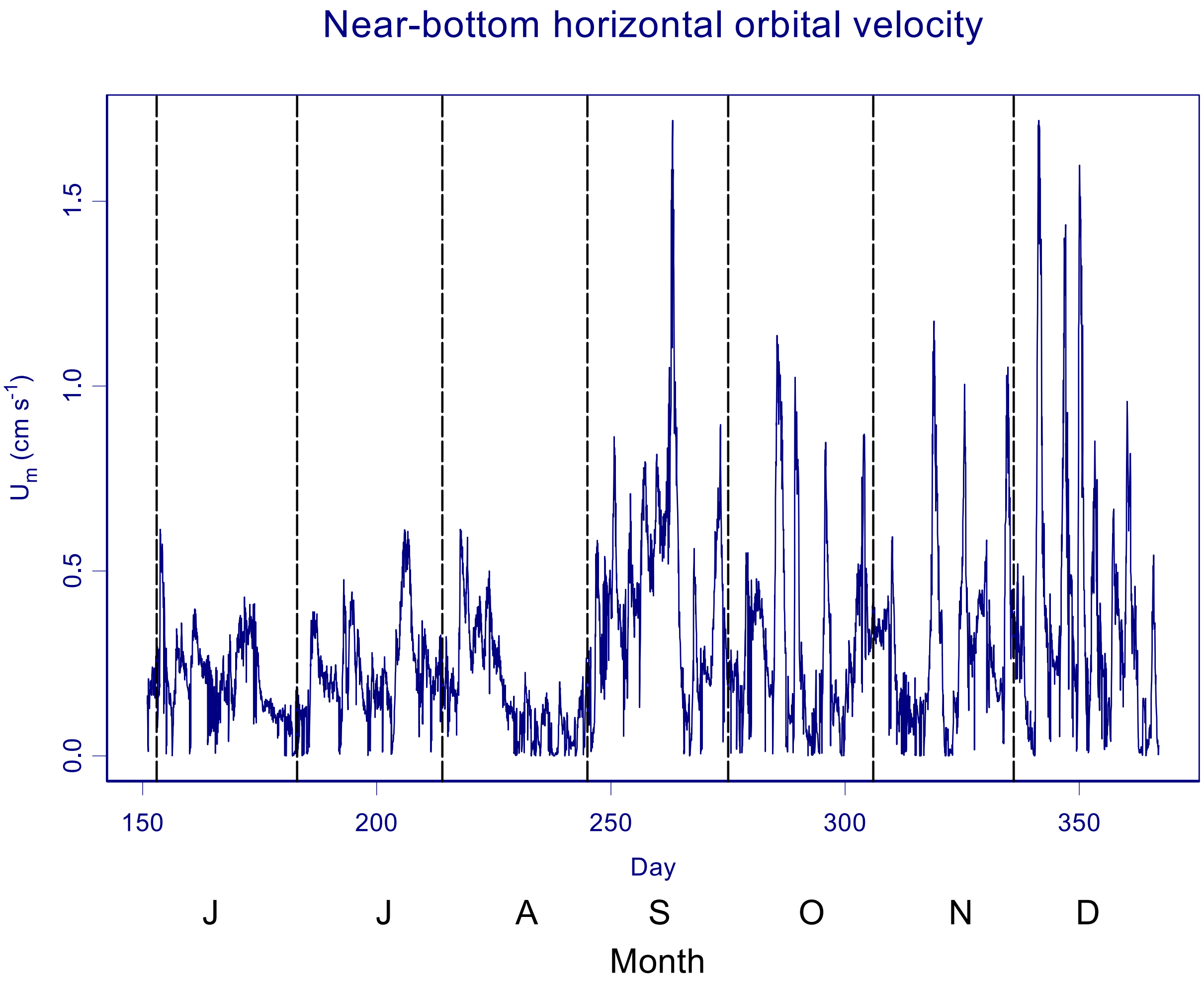


Figure 17. Proportion of fish that dispersed (circles) and 95% confidence intervals (dotted line) for black sea bass and summer flounder at the HARS. Probability of dispersal was estimated using the Kaplan-Meier approach. (A) Dispersal probabilities for black sea bass with time measured in days since 2 June 2003. (B) Dispersal probabilities for summer flounder with time measured in days since 24 June 2003.

(A)

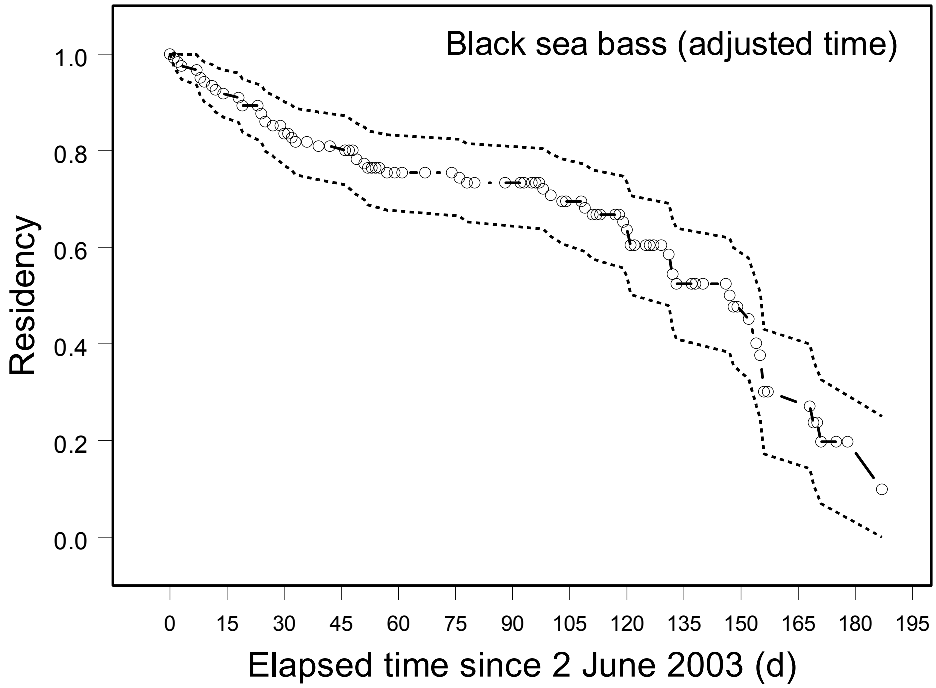


Figure 17 (continued).

(B)

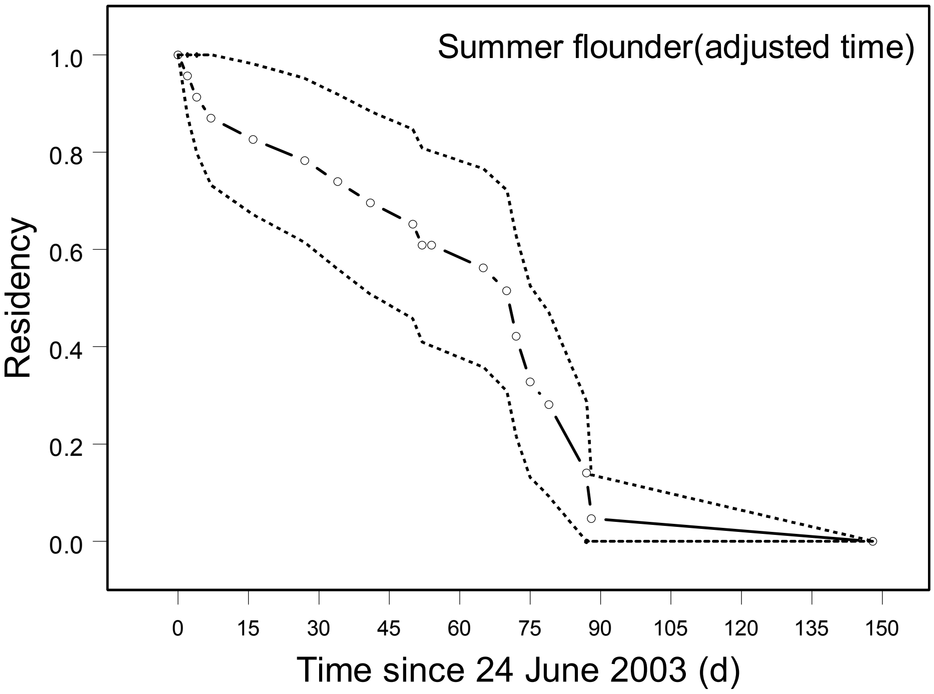


Figure 18. Comparison of estimated proportion of fish that dispersed for black sea bass and summer flounder at the HARS. Probability of dispersal was estimated using the Kaplan-Meier approach. (A) Dispersal probabilities for black sea bass with time measured in days since 2 June 2003 and using two data sets, conservative (solid line) and less conservative (dotted line); see text for explanation. (B) Dispersal probabilities for summer flounder with time measured in days since 24 June 2003 and using conservative (solid line) and less conservative (dotted line) data sets.

(A)

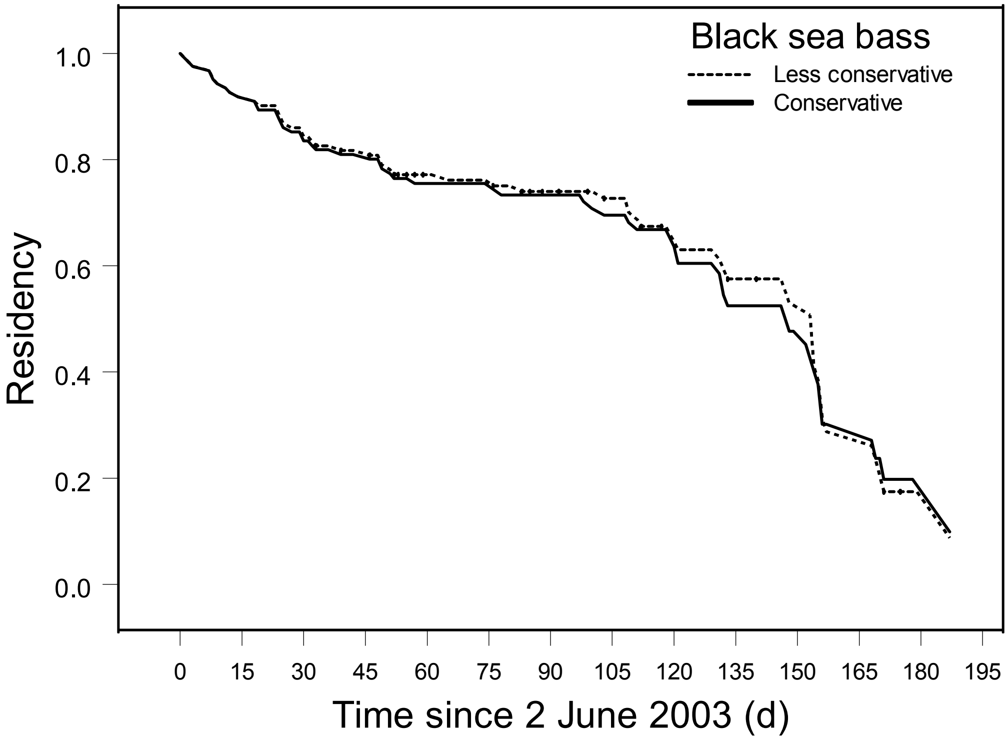


Figure 18 (continued).

(B)

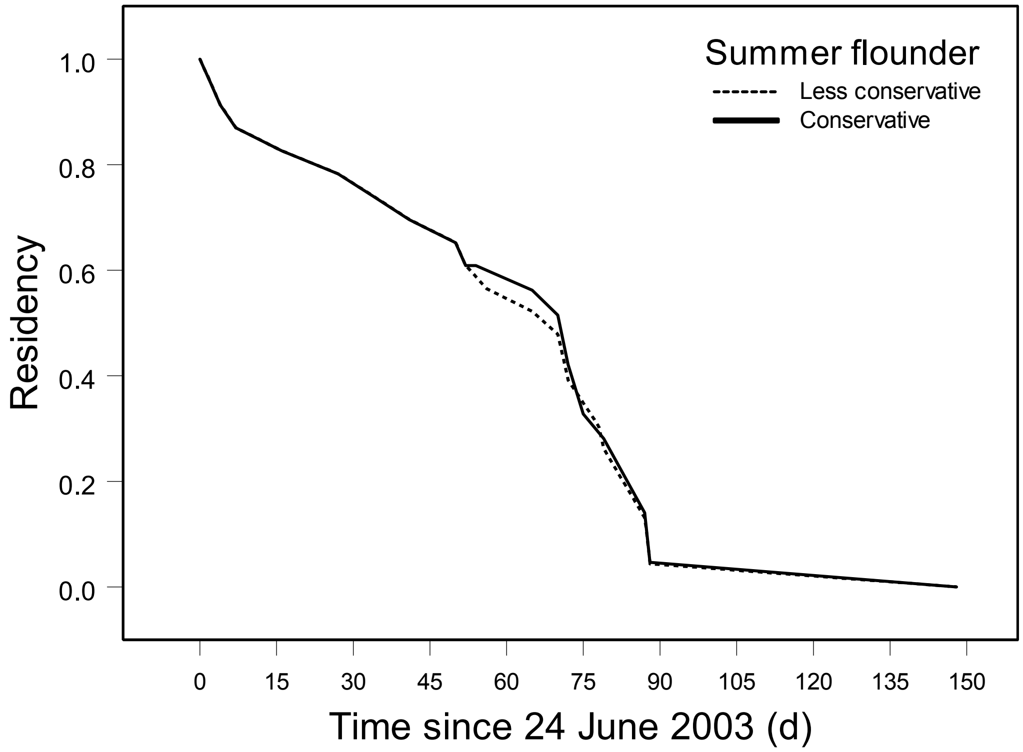


Figure 19. Sidescan sonar image of the HARS (composite of data collected 1995-1998) overlaid with station locations. High backscatter is represented by light tones, low backscatter by dark tones. Note the variability in acoustic backscatter over short spatial scales (100 s of meters), indicating heterogeneity of the sea floor. One of the prominent features is the Mud Dump Site, which is roughly defined by the 20-m isobath, and is about 10 m shallower than the adjacent sea floor (the region corresponds to D-E-F and 1-6). The Mud Dump Site is marked by numerous small high-backscatter 'dots,' which are interpreted as individual disposals of dredge and other material that has been deposited here since the late 1800's. The image reveals that historical dumping was not contained within any designated disposal site. Data and interpretation from Schwab et al. 2000.

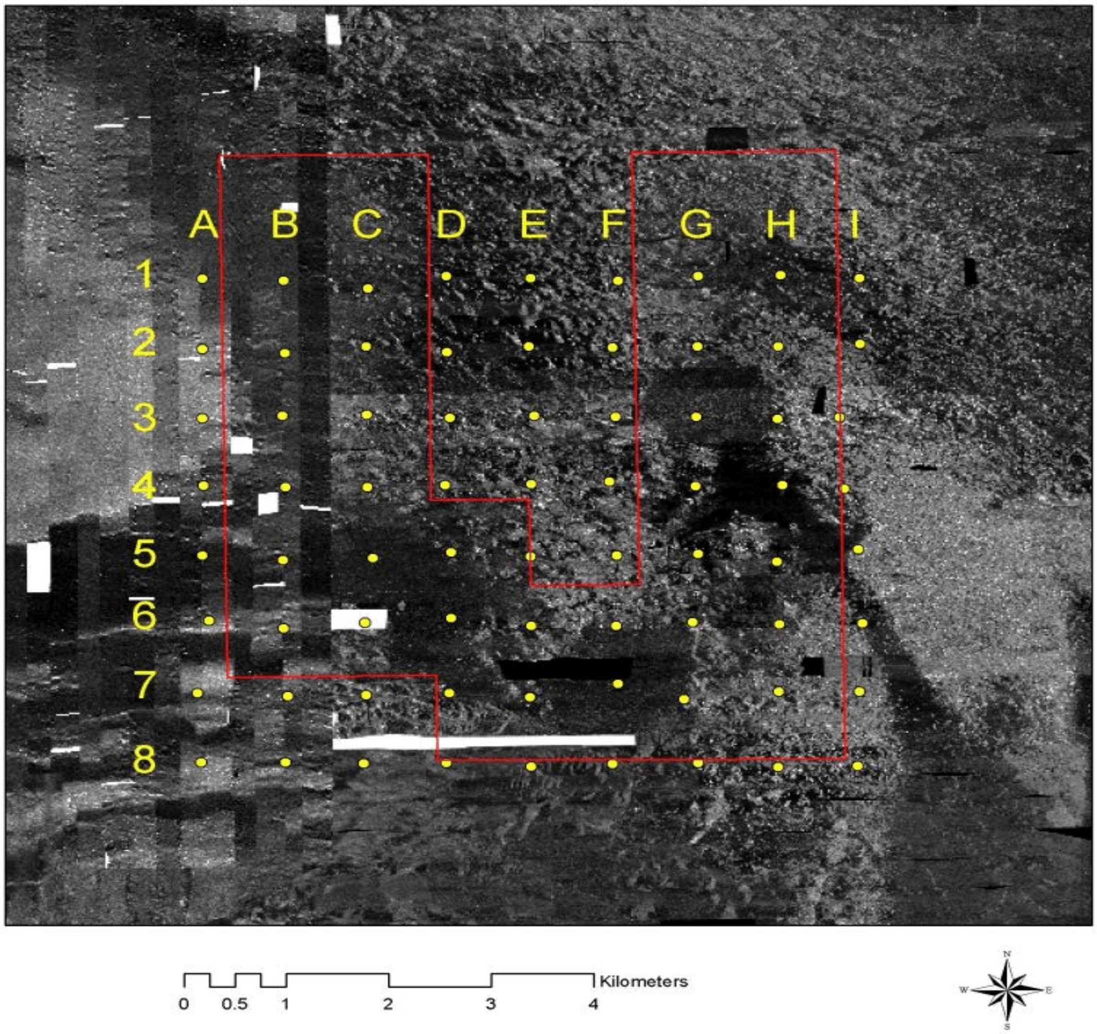
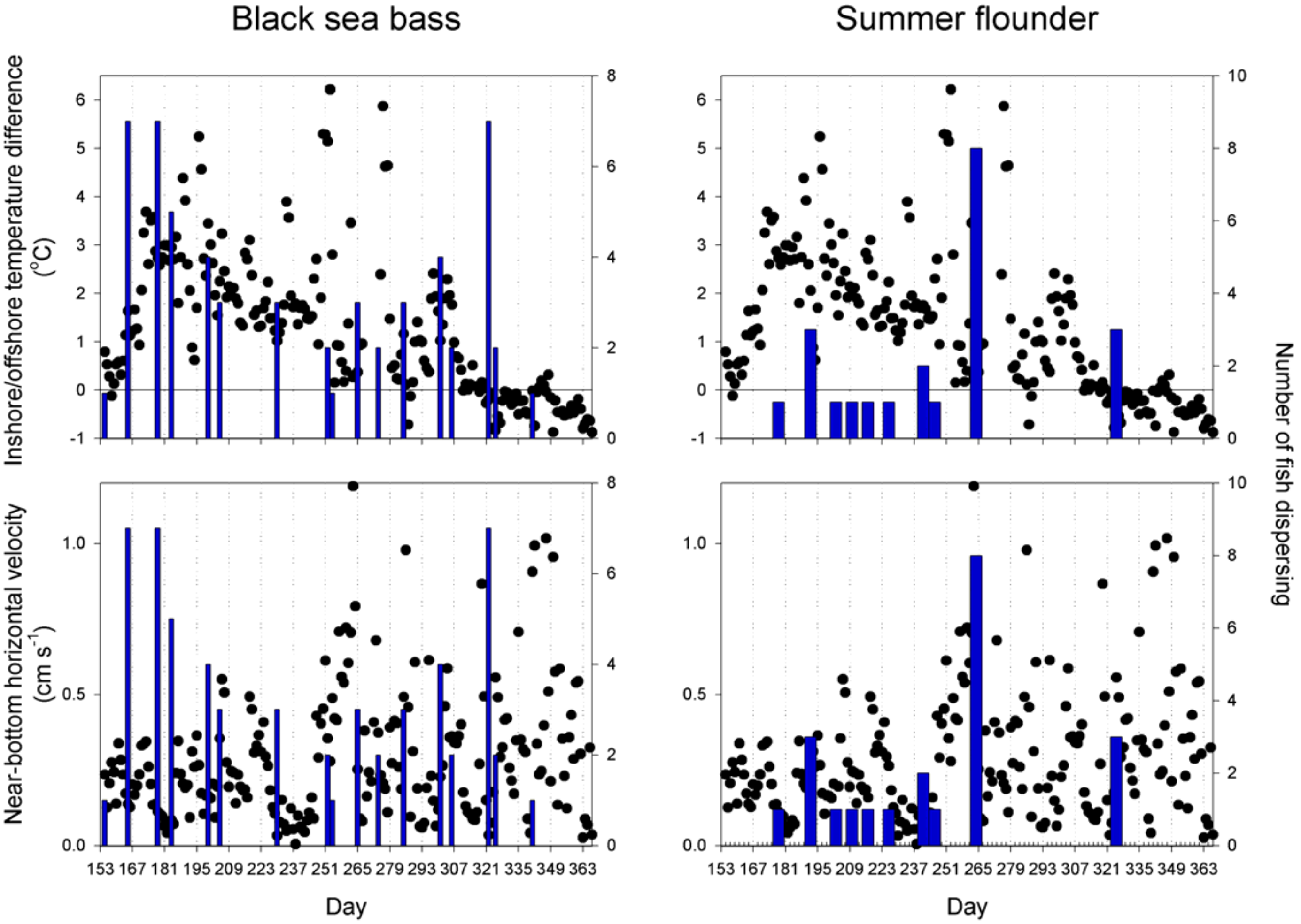


Figure 20. Number of fish dispersing from the study area (solid bars) and average daily differences in temperature at inshore (B1) and offshore (H7) stations (top panels). Number of fish dispersing (solid bars) and near-bottom horizontal orbital velocities in 2003 (bottom panels). The left axes indicate scales for physical parameters and the right axes indicate numbers of fish dispersing. Negative values of inshore-offshore temperature differences indicate warmer waters at the offshore station. Day is the day of the year in 2003 (153=2 June; 363=29 December).



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