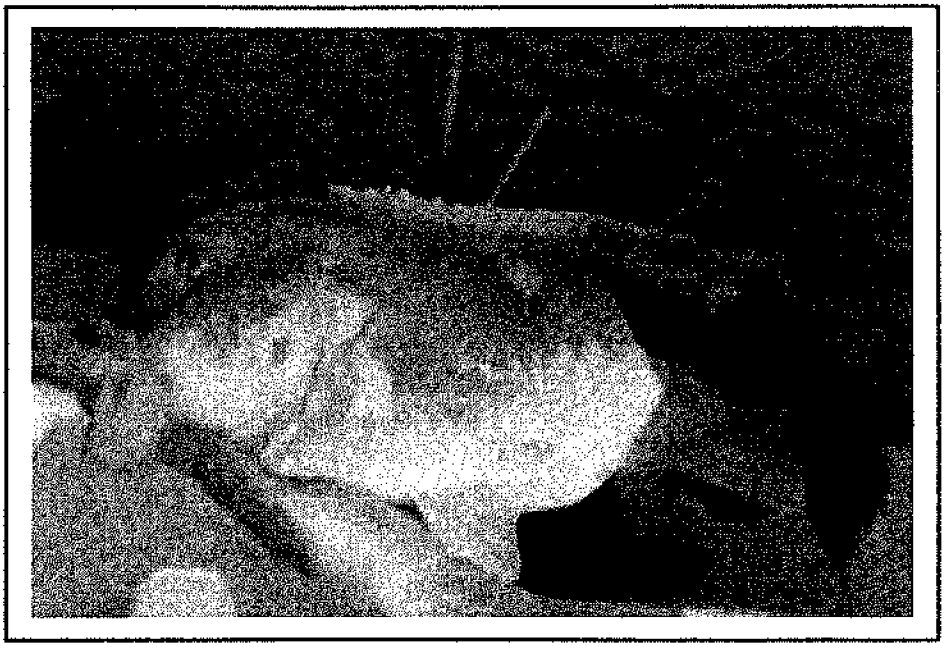
SEASONAL RESIDENCE, MOVEMENT, AND ACTIVITY OF ADULT TAUTOG, *TAUTOGA ONITIS*, IN LOWER CHESAPEAKE BAY



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and
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Virginia Institute of Marine Science
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Primary Support - Virginia Saltwater Fishing License Funds

Seasonal Residence, Movement, and Activity of Adult Tautog (*Tautoga onitis*) in Lower Chesapeake Bay

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Cover photograph (VIMS, Jon Lucy): A tautog about to be released at its recapture site with transmitter tag surgically implanted (note sutured incision line in lower abdomen just above pelvic fin). Fish also double tagged externally with two t-bar tags at base of dorsal fin (green $50 "reward" tag and orange Virginia Game Fish Tagging Program tag, the latter just forward of researcher's thumb.)

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ACKNOWLEDGMENTS

This research project constituted Mike Arendt's thesis in partial fulfillment of the requirements for his Masters program at the School of Marine Science of the College of William and Mary, his thesis being successfully defended in late fall 1999. Mr. Jon Lucy and Dr. William DuPaul were Mr. Arendt's co-advisors. Special thanks also go to Drs. Tom Munroe, John Hoenig, David Evans, and Jack Musick, Mr. Arendt's additional Thesis Committee members, for strengthening the quality of this study with numerous suggestions, comments, and ideas. Without doubt, the study would not likely have been feasible nor as productive without the shared knowledge, input, and fishing expertise of Captain Jim Jenrette of the charter boat *Buccaneer* from Cape Charles, Virginia. The innovative thinking and dedication of Captain Charles Machen of VIMS *R/V Langley* were also crucial to the project's success.

The project was primarily funded by Virginia Saltwater Fishing License Funds, administered by the Recreational Fishing Development Fund Advisory Board of the Virginia Marine Resources Commission (VMRC). The Virginia Institute of Marine Science also contributed very significant amounts of vessel support, logistical and technical input from Vessel Operations and the Department of Physical Sciences, as well as considerable matching funds to bring the project to its successful completion.

Much of the project's field work schedule depended upon lulls in highly variable weather conditions. The research team and vessel captain often had to depart for Cape Charles at odd hours to take advantage of weather windows in which fish could be captured, surgically implanted with transmitter tags, and released. However, the majority of sea time was spent retrieving and resetting automated acoustic receivers, which often required use of VIMS Dive Team, to download weeks of tautog transmitter tag signal data. In addition, long hours were spent methodically searching the study sites, and areas outside the study area, to confirm the presence of tagged fish as a backup to the receiver data (using acoustical hydrophones mounted on the *R/V Langley*). Working off Cape Charles throughout fall-winter (1998-99), and spring-summer-fall 1999, the *R/V Langley* often found itself weathered into Cape Charles Harbor for days at a time. Charles Machen, Captain of the *R/V Langley*, gave up holidays and weekends and did everything in his power to make sure that we got the job done (even working through New Year's Eve!).

Very special thanks also go to Mr. David Zwerner at VIMS, a talented and very patient fish pathologist, and Dr. Bob George, D.V.S., for advising us on the surgical procedures used in the study and helping to interpret the results of various fish necropsies required to evaluate whether transmitter tags were significantly affecting abdominal organs and tissue in the study fish.

Thanks to Mr. Randy Cutter and Dr. Bob Diaz for working with us in making Benthic Imaging Sled runs in the study area and helping in identifying the various benthic and epifaunal organisms collected from dredge and trawl samples. Dr. Woody Hobbs helped in describing Smith-MacIntyre grab sediment samples. The skill and experience of Mr. Bob Gammisch in operating the side-scan sonar system aboard the *R/V Langley* and his invaluable interpretation of the resulting data were crucial to understanding the habitat documented in this study to support tautog throughout fall, winter, spring and summer in the lower Chesapeake Bay. He was an integral part of the research team, both as a geologist, and as a diver.

Thanks also to John Olney, Jr. for substantial assistance testing, deploying, and retrieving hydrophones and with numerous other aspects of this study. VIMS divers (Messrs. Bob Gammisch, Wayne Reisner, Buck Stockhausen, and Tom Chisholm) were responsible for 25% of VR1 receiver retrievals during this study. Problems with some of the VR1 mooring systems were also rectified by VIMS divers and Captain Charles Machen.

Other individuals who provided considerable advice and technical assistance to the project were Captain George Pongonis (head, VIMS Vessel Operations), Mr.Steve Synder, and Mr. Sam Wilson. Brainstorming sessions with these gentlemen early in the project enabled us to put together a mooring design for long-term deployment of VR1 receivers such that a 98% recovery rate was achieved.

Thanks also to thank Mr. Fred Voegli and Mr. Wayne Conrad from Vemco, Ltd., and Mr.Todd Nelson and Mr. Steve Clukey from VIMS for getting us on track early in the game when we were experiencing technical problems between our telemetry equipment and vessel engine-electronic systems. Also for technical support, thanks go to the ITNS staff (Mr. Kevin Kiley, Mr. Gary Anderson, Ms. Pat Hall, Ms. Kathy Goodwin, and Ms. Tanya Utt) for their patience, understanding,

and know-how to fix most computer problems. Very special thanks to Bill Seward, VIMS Volunteer Extraordinare, for showing us the "tricks of the trade" regarding using MS Excel to manage our large databases.

As previously indicated, we would like to especially thank Captain Jim Jenrette, of the charter boat *Buccaneer*, for showing us some of the unique habitat areas supporting tautog off Cape Charles Harbor. We also very much appreciate the fact that Captain Jenrette was willing to allow us to conduct our research on some of his favorite fishing grounds, being just as intrigued as we were to understand tautog behavior patterns. With regard to the latter, Captain Jenrette provided us the benefit of his considerable fishing experience, without which we could not have captured and tagged the numbers of fish required for the study, and significantly contributed to our understanding of the telemetry data detection patterns.

Captain Jennette also joined the Virginia Game Fish Tagging Program and, along with another program tagger Mr. Sonny Spiers, was responsible for a large proportion of the conventionally tagged tautog we required in the study area for comparison of movement patterns between such fish and transmitter-tagged fish. These same individuals were also responsible for a significant proportion of recapture reports of conventionally tagged tautog, reporting over 40 tag-recapture events with which to compare our findings. Finally, they also were responsible for recapturing two transmitter tagged fish, providing us critical information on how well such fish were handling the implanted tags and documenting the fact that they were feeding and in good condition.

Also special thanks go to Dr. Jim Wright and Captain E.K. Morrison for assisting us in collecting tautog to evaluate the transmitter tag surgical procedure. We also greatly appreciate Captain Scott Jones, Captain Donny Stiles, and personnel at George's Seafood for reporting recaptures of transmitter tagged fish.

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EXECUTIVE SUMMARY

Prepared For: Recreational Fishing Development Fund Advisory Board
Virginia Marine Resources Commission

Environmental factors such as water temperature, photoperiod, and tidal cycle, affect residence, movement, and activity patterns of marine fishes on both diel and seasonal time scales. Changes in light intensity and tide stage occur several times each day and may exert strong influence on diel activity patterns. Annual fluctuations in water temperature and day length are considered to be the primary environmental cues that trigger migratory behavior for migratory species and reduced activity for non-migratory species. Geographic position on earth largely determines the magnitude of change, as well as absolute values, for seasonal variation in climate. For species with large geographic distributions, regional differences in the intensity of seasonal cycles may result in different seasonal distribution and activity patterns. Because such regional differences can occur, understanding the response of local populations to seasonal changes in climate throughout a species' geographic distribution is necessary for understanding population dynamics and implementing appropriate local management strategies.

Seasonal residence, movement, and activity patterns of tautog (*Tautoga onitis*), while relatively well documented for northern populations, have not been adequately defined for populations south of New Jersey. Long-term residence, movement, and activity patterns of tautog in the natural environment were never previously addressed anywhere in the species' geographic range. Virginia fishery patterns and tag-recapture data from the Virginia Game Fish Tagging Program (VGFTP) (1995-1999) suggest regional differences exist between northern (New York to Rhode Island) and southern (Virginia) tautog. Using telemetry tagging and tracking methods, this study documented that such differences consistently occurred throughout the year.

Ultrasonic transmitters were surgically implanted into the body cavity of 33 adult tautog (400-514mm; 15.75-20.25 in. TL) at four sites in the lower Chesapeake Bay near Cape Charles, VA (natural sites: Mussel Beds and the Coral Lump; manmade sites: the Airplane Wreck and Texeco Wreck). Nineteen fish were captured-released in November-December 1998 on the four sites and monitored through mid-spring 1999 (when tag batteries expired); fourteen additional fish were then captured-released in April 1999 on the sites and monitored into the fall (September-October 1999). Tautog were captured using standard two-hook bottom rigs and fresh crab/clam bait, anesthetized, surgically implanted with transmitter tags, tagged with an external VGFTP T-Bar tag and a second T-Bar special reward tag, allowed to recover in live wells, then released within two hours at their respective capture sites.

Tank experiments in which dummy transmitter tags were implanted in tautog of the size used in the field indicated no mortality due to handling or the tagging procedure. Upon moving several 'dummy' tagged tautog into a large aquarium tank in Spring 1999, a large female and male fish began serial spawning activity. Approximately 600,000 fertilized eggs were collected between mid-April and early June, the same timeframe during which tautog spawn in the wild. Although not having fish culture facilities ready for rearing newly hatched fish larvae, VIMS finfish aquaculturists were able to rear some of the tautog fry to juvenile size, several of which remain on display in the VIMS aquarium.

Manmade materials (a shipwreck and concrete structures) comprised two study sites while the others were characterized by natural bedform (with outcropping "coquina rock") and epibenthic biological materials (large sponges, clumps of blue mussels, a large colonial bryozoan known locally as "dead man fingers", etc.). Side-scan sonar mapping and underwater video surveys revealed that at the natural habitat sites, outcroppings and biological features were discrete and patchy in an otherwise sandy environment. The sites occurred over depths of 8-17m (26-55 Ft.) and represented diverse habitats available to tautog in the lower Chesapeake Bay. Two automated acoustic receivers were deployed east and west of the perimeter of each site. Previous field studies in the same area during 1997-98 documented very low hook-release mortality rates for conventionally tagged tautog (<2 %), data essential to the success of this project. This latter work was also funded by the Virginia Saltwater Fishing License Fund.

Seventy percent (23 fish) of all tautog released remained at release sites and were never detected or recaptured away from release sites for up to 6 months (duration of transmitter battery life). Tautog remained resident near Cape Charles, VA, tolerating a wide range of winter-summer water temperatures (5-27°C; 41-81°F). Rather than move to areas of warmer water in the winter and cooler water in the summer, a pattern documented for northern tautog populations, tautog at the Cape Charles sites remained resident at the sites, only decreasing their activity slightly in response to thermal extremes. Resident tautog were detected daily, except during the coldest water temperatures (5-7°C; 41-45°F) in winter and after

abrupt (3°C: 5.5°F) decreases in surface water temperature in summer. In both instances, fish likely rested deep within structural features at each site (such behavior would block transmitter tag signals being detected by automated receivers). Tautog showed a strong diurnal activity pattern, being active primarily during daylight hours (53-80% of total detection time), but also exhibiting nighttime activity, the latter most prominent in winter and spring. Mid-April to early June is the known spawning season for tautog lower Chesapeake Bay and offshore Virginia waters.

No inshore-offshore movement of tautog was observed. Six tautog were either recaptured by commercial or recreational fishermen, or detected electronically by surface operated hydrophones, at sites located 2.2-10.2 km (1.2-5.5 nm) away from their initial capture-release sites. Tautog moved away from manmade sites only. Three tautog moved away from a single site (Texeco Wreck, 7m/55 Ft. depth), but returned to the site on several occasions, primarily moving back and forth to a previously unknown small structure site 2.2 km (1.2 nm) to the south (where they were detected using a surface hydrophone). When these tautog were not located at their release site, they were consistently detected at the smaller site with the vessel-operated hydrophone, demonstrating high site affinity for both sites. This previously unknown tautog holding site showed no detectable profile on a depth finder, but through side-scan sonar was shown to consists of a scatted group of what may be large pound net poles. Four additional tautog, detected 24-106 days less than resident tautog, were never recaptured or otherwise detected away from the study sites; therefore, it was impossible to determine if these fish moved out of the study area or their transmitter tags failed for some reason.

This project involved the most extensive tracking and monitoring study ever undertaken on tautog, being the first telemetry study of the species in the southern portion of its geographical range. Of particular importance, an artificial reef is planned for the general vicinity in which the study was conducted. For the first time in the history of the reef program, seasonal utilization of the area by tautog is known. The documented residence and movement patterns of tautog can now be taken into account relative to design and placement of any future artificial reefs in Virginia waters. Another benefit of this study is that it provided the first documentation of long term hook-release mortality in tautog, conservatively estimated at 6.1% (if one assumes two fish of 33, detected only 9 and 11 days and never detected again, died). This substantiates that long term release mortality is similar in magnitude to short term release mortality (1.7%) in Virginia's recreational tautog fishery. It was critical to document that short term hook-release mortality was negligible before undertaking the telemetry tagging study.

Several other studies previously funded by Virginia Saltwater Fishing License Funds (Recreational Fishing Development Fund administered by VMRC) contributed greatly to conducting this study. Tag-recapture data from the Virginia Game Fish Tagging Program (1995-1999) provided important background knowledge of tautog movement patterns and assisted significantly in the design of this study. The side-scan sonar mapping project for artificial reef sites enabled us to use a proven method for documenting and describing important physical features of the study area as well as providing detailed digitized views of each tautog capture-release site. This information, necessary in its own right, also helped interpret some of long-term tautog detection patterns observed from the submerged hydrophone data.

The results of the project have been well-received by the angling community and fishery researchers and managers. Oral and poster presentations have been made by both authors before various sportfishing groups and at scientific meetings where anglers were specifically invited to attend. Some examples are: (1) Fishing Seminar at the Richmond Boat Show (February 1999), (2) Coastal Conservation Association-VA Sportfishing Show (Marina Shores, February 1999), (3) American Fisheries Society Tidewater Chapter meeting (at VIMS, March 1999; RFAB members attending), (4) results discussed at eight Virginia Game Fish Tagging Program Tagging Training Workshops (1999 and 2000), and (5) CCA-VA Sportfishing and Boat Show (SCOPE in Norfolk, March 2000).

Oral and poster presentations have also been made by the authors (M. Arendt being the principal and presenting author) at the following fishery meetings: (1) American Fisheries Society Tidewater Chapter meeting (VIMS, March 1999), (2) 15th Annual International Symposium on Biotelemetry (May 1999), (3) 1999Annual Meeting of the American Fisheries Society (August 1999), (4) 1st Biennial Conference on the Biology of Tautog and Cunner (December 1999), (5) National Symposium on Catch and Release in Marine Recreational Fisheries (Virginia Beach, December 1999; angling public invited), (6) Symposium on Tagging and Tracking Marine Fish with Electronic Devices (February 2000), and (7) American Fisheries Society Tidewater Chapter meeting (March 2000).

INTRODUCTION

Tautog (*Tautoga onitis*) is a highly prized game fish that is targeted by anglers fishing at structures in the mid-Atlantic Bight (Briggs 1977; Lucy and Barr 1994). Tautog are distributed between Georgia (Parker 1990) and Nova Scotia (Bigelow and Schroeder 1953), with peak abundance between Massachusetts and the Delaware Capes (Atlantic States Marine Fisheries Commission (ASFMC) 1996). Studies on age, growth, and reproduction conducted for both northern (Chenoweth 1963; Cooper 1967; Simpson 1989) and southern (Hostetter and Munroe 1993; White, 1996; White et al. 1997) populations suggest that tautog are long-lived, slow growing, and late maturing. Tautog closely associate with structure as juveniles (Olla et al. 1979; Sogard et al. 1992; Dorf and Powell 1997) and as adults (Hildebrand and Schroeder 1928; Bigelow and Schroeder 1953; Olla et al. 1974), thus local distributions are predictable. For convenience, the Atlantic States Marine Fisheries Commission recognizes a northern stock region, from Massachusetts to New York, and a southern stock region, from New Jersey to Virginia (ASMFC 1996). Although seasonal inshore-offshore migrations have been reported, no evidence of large-scale north-south movement exits (Cooper 1966; Briggs 1977; Lynch 1995; Bain and Lucy 1996, 1997; Bain et al. 1998; Lucy et al. 1999). Slow-growth rates, late age at maturity, predictable distribution, and localized population structure suggests high vulnerability to over-exploitation (Hostetter and Munroe 1993). Understanding residence, movement, and activity patterns of tautog throughout this species' geographic distribution is necessary for understanding population structure and for proper management of this resource.

Since the early 1960's, tag-recapture studies (Cooper 1966; Briggs 1977; Lynch 1995) have attempted to address seasonal residence and movement patterns of northern tautog populations. Cooper (1966) and Lynch (1995) reported that adult tautog utilized the inshore waters of Narragansett Bay, RI, during the spring and summer, but moved offshore to Block Island Sound and Rhode Island Sound in the fall where these fish over-wintered. Briggs (1977) reported that adult tautog tagged in the summer at an artificial fishing reef in Great South Bay, NY, were recaptured in coastal ocean waters of the New York Bight in the fall. Tag-recapture has also been used in Virginia in an attempt to address seasonal residence and movement patterns for southern tautog populations. Between 1995-1999, volunteer anglers in the Virginia Game Fish Tagging Program tagged and released over 4000 tautog in the lower Chesapeake Bay and coastal waters of Virginia. Approximately 88% of tautog, out of more than 600 recapture events, were recaptured at the same sites where these fish were released, regardless of the season fish were released or recaptured (Bain and Lucy 1996, 1997; Bain et al. 1998; Lucy et al. 1999; VGFTP unpublished data). Residence patterns for adult tautog from tag-recapture studies in both northern and southern populations are consistent with observations on seasonal abundance for adult tautog from both northern (Stolgitis 1970; Olla et al. 1974) and southern (Ecklund and Targett 1990; Hostetter and Munroe 1993; Adams 1993) populations. These data collectively suggest strong differences in seasonal residence and movement patterns between northern and southern tautog populations.

Although the tag-recapture method is relatively easy to use and enables large sample sizes of tagged individuals, tag-recapture is not a suitable method for evaluating residence and small-scale movement patterns because no information on location of tagged animals is available between times of release and recapture. Furthermore, tag-recapture requires tagged animals be recaptured, and be reported as recaptured, in order for any information to be available. Fewer than 10% of all animals tagged and released are usually recaptured (Winter 1996), thus, no information is ever available for a large percentage of animals tagged and released. Ultrasonic telemetry, however, enables continuous observations to be made on all tagged animals, in their natural environment, without the requirement that animals be recaptured (Winter 1996).

Ultrasonic telemetry is frequently used to study localized movements of temperate (Pearcy 1992; Szedlmayer 1997) and tropical (Holland et al. 1993; Zeller 1997) 'reef' fishes, and has been used once to study localized movements of tautog (Olla et al. 1974). Olla et al. (1974) tagged 10 adult tautog in Great South Bay, NY, during two consecutive summers. Tautog were collected at night by SCUBA divers using handheld nets, tagged externally with ultrasonic transmitters and retained in holding tanks for several days to ensure recovery, then returned to the sites where these fish where originally collected. Tagged fish were 'tracked' for up to 80 consecutive hours following release, and one fish was relocated and 'tracked' a second time a week after the initial observation period. As the only telemetry study on tautog to date, the Olla et al. (1974) study provides valuable insight into short-term residence and localized movements of tautog, as well as daily activity patterns of this species *in situ*. Although a landmark study, sample sizes were too small and observations too limited (< 500 hours single season) to understand how seasonal residence, movement, and activity patterns of tautog change in response to changing biotic (i.e. food availability) protective shelter and abiotic (i.e., temperature, photoperiod conditions).

The current study used ultrasonic telemetry to document seasonal residence, movement, and activity patterns of adult tautog in the lower Chesapeake Bay. In this study, the number of tagged fish was increased from that used in Olla et al. (1974) to provide better representation of the population through larger sample size, and total observation days were also increased to better understand seasonal effects on residence, movements, and activity

patterns. The first objective of this study was to determine if tautog remained inshore during the winter. Tautog were previously reported absent from inshore areas when water temperature reached 10°C (Olla et al. 1974). Extended periods of residence at inshore sites may increase the potential for over-exploitation of tautog due to prolonged activity (and, thus, catchability). The second objective was to determine if tautog that remained inshore through the winter also remained active during this time. Laboratory studies and direct diver observations indicated that adult tautog became less active when water temperature declined below 10°C, and activity completely ceased when water temperature was 2-3°C (Olla et al. 1977, 1980; Olla and Studholme 1978; Cooper 1966; Adams 1993). The third objective was to determine if tautog remained inshore during the summer. Tautog are suggested to move to cooler water in the summer (Cooper 1966; Briggs 1969; Adams 1993). The fourth objective was to determine if tautog that remained inshore through the summer also remained active during this time. Laboratory studies indicated that adult tautog became less active when water temperature increased above 22°C (Olla et al. 1977, 1978; Olla and Studholme 1978). The fifth and final objective of this study was to document and describe movement patterns of tautog within inshore study sites and between inshore study sites and offshore locations where applicable.

MATERIALS AND METHODS

Study Site Selection and Description

Tautog were caught, tagged, and released at four sites ("Texeco Wreck", "Airplane Wreck", "Coral Lump", and the "Ridged Bottom") situated within a 1.5 km x 6 km study area near Cape Charles, Virginia (Fig. 1). A recent study on catch-release mortality indicated that these sites supported large numbers of adult tautog (Lucy and Arendt 1999). Sites were also selected in order to evaluate seasonal inshore residence and movement patterns prior to construction of an artificial reef nearby (Meier, pers. comm.).

With exception of the Texeco Wreck (located in a Bay-stem plain), all sites were located in a Bay-stem margin/backbarrier flat as described in Wright et al. (1987). A Bay-stem plain consists of flat, relatively featureless bottom topography and a Bay-stem margin/backbarrier flat is characterized by sand flats and deep, mud-bottomed channels (Wright et al. 1987). Smith-MacIntyre Bottom Grab samples collected at these sites were described (Hobbs pers. comm.) as sand, mud, shell, or rock material (Table 1). Side-scan sonar (Sea Scan Technology, Ltd.) was used to measure dimensions of the four study sites and to map the surrounding seafloor. The Ridged Bottom and Coral Lump sites (Fig. 2a,b) consisted of natural bedforms and were located in 8-10 m of water. Otter trawl, oyster dredge, and underwater video (Benthic Imaging Sled, VIMS Benthic Ecology Unit) indicated that these natural bedforms (Fig. 3a) were populated by dense benthic macro-fauna (Table 2, Fig. 3b,c). The Texeco Wreck (shipwreck) and the Airplane Wreck (concrete rubble) were located in

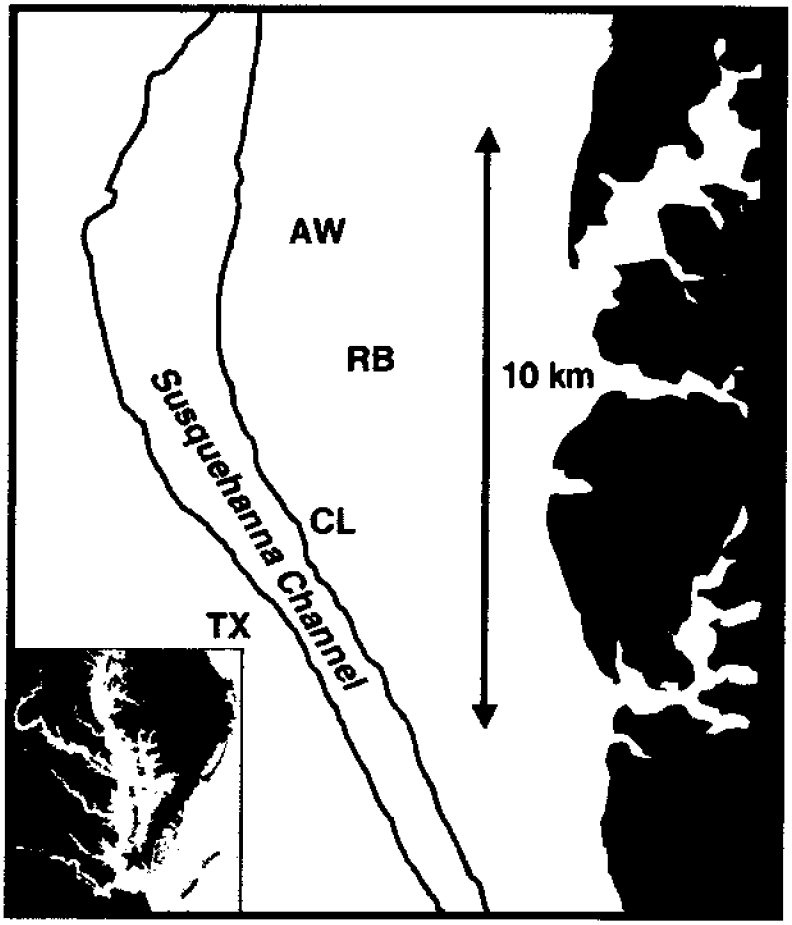


Fig. 1 Location of study sites near Cape Charles, VA. The Texeco Wreck (TX) is located in a Bay-stem plain (Wright et al., 1997) west of the Susquehanna channel, in 18 m of water. The Coral Lump (CL), Ridged Bottom (RB), and Airplane Wreck (AW) are located in a Bay-stem/backbarrier flat (Wright et al., 1997) in 8-15 m of water, east of the Susquehanna channel (40 m deep).

15-18 m of water (Fig. 2c,d) and also supported dense benthic macrofauna communities (Fig. 4).

Ultrasonic Transmitters and Transmitter Attachment

V-16-1H-R256 coded transmitters (16 mm x 48 mm; 9 g in water; Vemco, Ltd.) were used in this study. Codes for these transmitters consisted of six ultrasonic pulses: three activation pulses and three unique identifier pulses. Two versions of transmitters were used. Fixed-rate coded transmitters (FCODE) were set on four frequencies (60, 63, 72, and 75 kHz) with code repeat intervals of 6, 8, 10, and 12 seconds, respectively. Due to the rapid time interval between code transmissions and the fixed-rate nature of signal transmission, these transmitters were used for obtaining positional fixes on fish. Manufacturer estimates for battery lives for FCODE transmitters ranged from 26 days (6-second repeat) to 40 days (12-second repeat). Random-repeat coded transmitters (RCODE) were set on a single frequency (69 kHz) and time between code transmissions varied between 45 and 75 seconds. Due to the random-repeat nature of these transmitters and the long delay between code transmissions, multiple transmitters set on a single frequency were easily distinguished. The long delay between code transmissions in RCODE transmitters also extended battery life to 111 days.

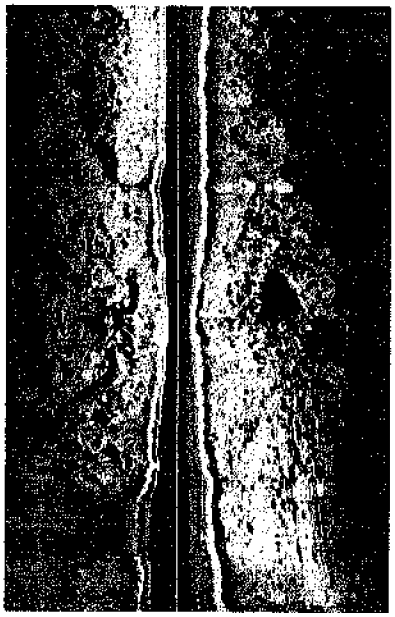
Table 1 Gross categorization of sediments collected with Smith-MacIntyre Grab Sampler at study sites in lower Chesapeake Bay, February 1998.

Site	Sand	Mud	Shell	Rock/Type
Texeco Wreck	Brown	Yes	No	No
Airplane Wreck	Brown	Yes	No	No
Coral Lump	Brown	No	Large	Coquina
Ridged Bottom	Brown	No	Hash	Gravel

Table 2 Benthic macrofauna collected from oyster dredge and otter trawl tows near Cape Charles, VA, in the lower Chesapeake Bay, June 1998. An asterisk (*) denotes specimen collected with R/V Langley anchor, 6 December 1998.

Taxon	TX	AW	CL	RB
Sertularia sp.	x	x	x	x
Alcyinidium verilli	x	x	x	x
Chaetopterus sp.	x	x		
Cliona celata	x*		x	x
Leptogorgia virgulata			x	x
Microciona prolifera			x	
Mytilus edulis	x	x	x	x
Spisula solidissima			x	
Mellita sp.				x
Crepidula sp.				x
B. carica or B.canaliculatus			x	x
Caprilid amphipod			x	x
Limulus polyphemus				x
Xanthidae	x	x	x	x
Paguridae	x			
Majidae	x	x		

A. CORAL LUMP (CL)



Dimensions:	300 m x 100 m
Area:	9000 m²
Relief:	1 m
Depth:	10.7 m

B. RIDGED BOTTOM (RB)

Dimension:	120 m x 30 m
Area:	1900 m²
Relief:	1 m
Depth:	8.5 m

C. TEXECO WRECK (TX)

Dimensions:	100 m x 30 m
Area:	1600 m²
Relief:	1 m to 3.5 m
Depth:	16.8 m

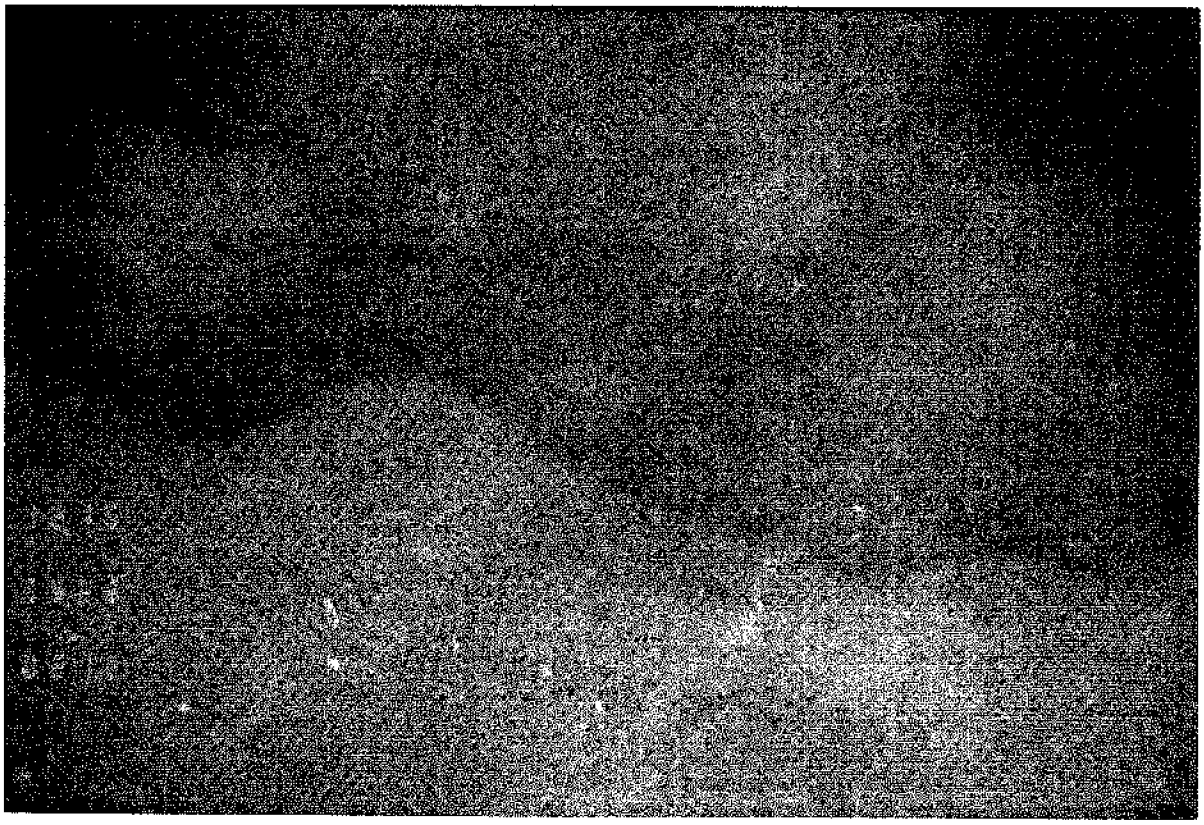
D. AIRPLANE WRECK (AW)

Dimensions:	40 m x 20 m
Area:	300 m²
Relief:	1 m
Depth:	13.7 m

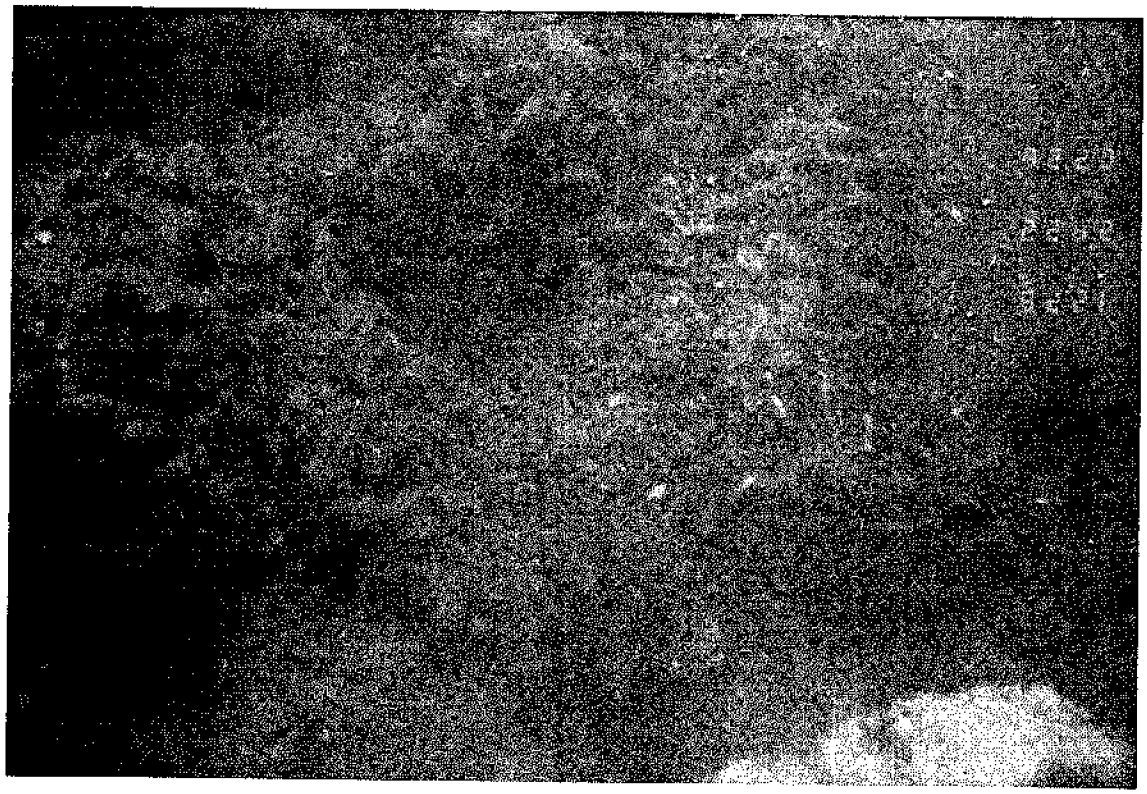
Fig. 2 *[opposite page]* Side-scan sonar images of natural (a = Coral Lump; b = Ridged Bottom) and manmade (c = Texeco Wreck; d = Airplane Wreck) sites, near Cape Charles, VA, in the lower Chesapeake Bay. Note: vertical line through center of image for the Coral Lump represents the path of the side-scan 'fish'; bottom features occurring within 75 m swaths to either side of the 'fish' were mapped and recorded.

Fig. 3 *In Situ* photographs (Benthic Imaging Sled, VIMS Benthic Ecology) of bedform material (a) and macrofauna (b = *Mytilus edulis*[next page]; c = *Cliona celata* [next page]) from the Ridged Bottom study site, June 1998.

A

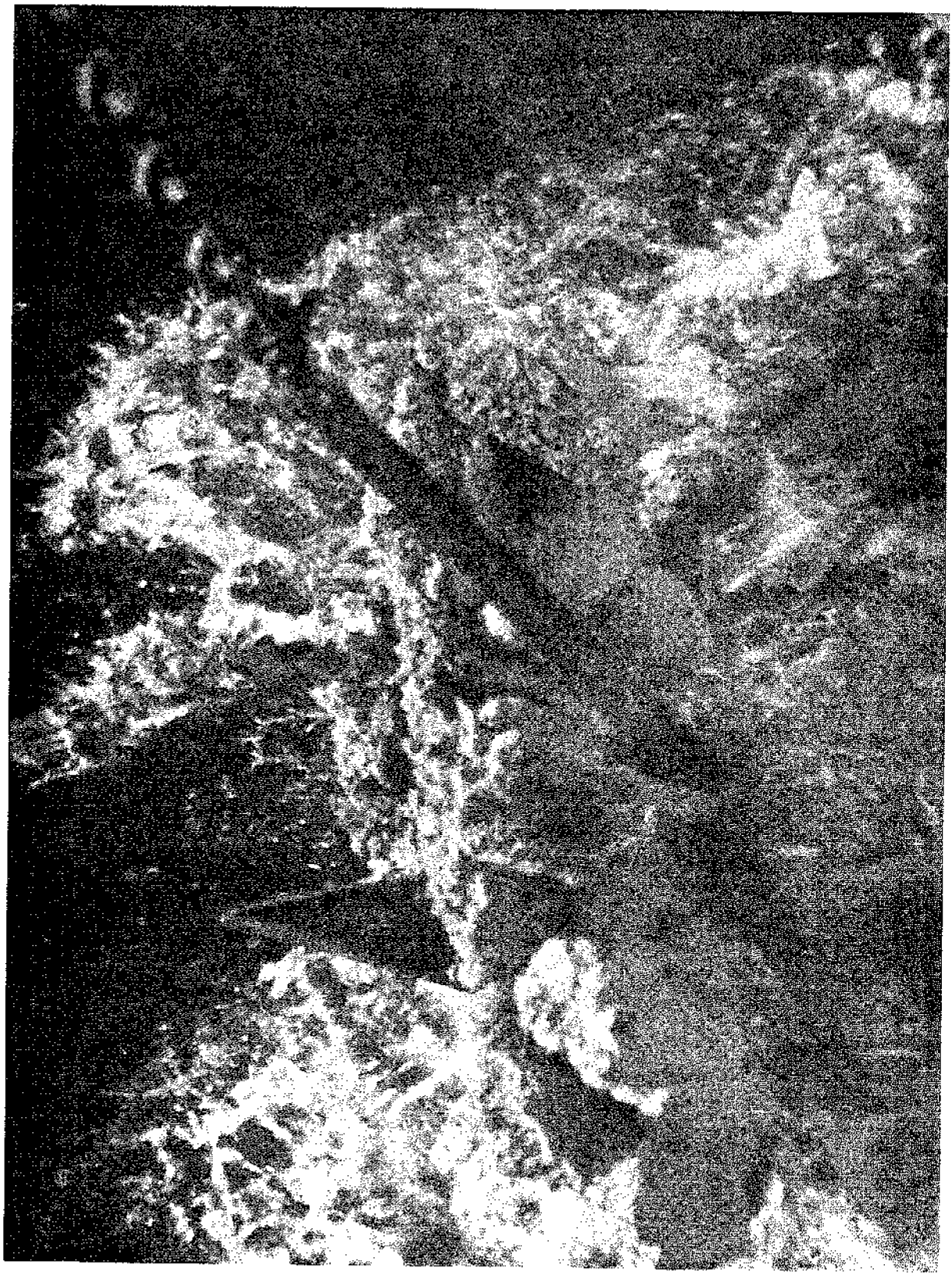


B



C

Fig. 4 Photographs of *Cliona celata* attached to section of the Texeco Wreck. Specimen collected with R/V Langley boat anchor, 6 December 1998.



Surgical implantation of transmitters was selected based on the criteria of long-term transmitter retention. Surgical implantation was used with similar sized 'reef' fish (Mathews 1992, Pearcy 1992, Holland et al. 1993, Szedlmayer 1997), but had not previously been used with tautog. Surgical procedures and behavioral and physiological effects of tagging were evaluated using 'dummy' transmitters in a controlled, laboratory setting before commencing actual field studies. Transmitter signal attenuation was evaluated using actual transmitters. All surgical procedures were approved by the Research on Animal Subjects Committee (RASC) at the College of William and Mary.

Tautog were caught using standard recreational angling gear, tagged, and released at the same sites where they were caught. After being brought to the surface, fish were netted, placed in an aerated livewell, and observed for up to two hours before attaching transmitters. Total length (mm) and sex of each fish were recorded. Males were identified by a pronounced white chin, blunt forehead, solid black to gray coloration on the upper half of the body with white underneath, and a small white circle laterally, immediately ventral to the dorsal fin (White 1996). Females were identified by a less pronounced chin, sloped forehead, and a mottled brown coloration (White 1996). After length and sex were recorded, a small t-bar internal anchor tag (TBA2, Hallprint Mfg.) used by the Virginia Game Fish Tagging Program (VGFTP) was placed in the anterior dorsal musculature. Fish measuring less than 400 mm TL were considered too small for inclusion in this study and released. The minimum size limit of 400 mm TL was chosen to increase the likelihood that transmitters weighed less than 1.25% of fish' body weight in water (Winter 1996). Size-weight relationships for tautog in Virginia waters were previously determined (Hostetter and Munroe 1993, White 1996, White et al. 1997). Fish were also considered unsuitable for inclusion in this study if excessively heavy or shallow respiration was observed, if excessive bleeding resulted from hook wounds, or when the body cavity of fish were too swollen (i.e., swim bladder expansion, gravid females) to surgically implant transmitters.

Coded transmitters were surgically implanted into suitable tautog. Before beginning surgery, transmitters were activated (wires cut and twisted together) and the activation wires soldered together. Quick setting epoxy was used to round both ends of the transmitter to remove rough edges. A "$50 REWARD" label (containing the transmitter identification number and a phone number to call) was applied to each transmitter and covered with clear tape to prevent disintegration of the reward label.

The first step of the surgical procedure was anesthesia. Tricaine methanesulfonate (MS 222) was selected because of its ability to induce level four anesthesia required for surgery (Mattson and Ripple 1989, Prince et al. 1995), lower mortality rates compared with other anesthetics (Schramm and Black 1984), and short recovery times following exposure (Mattson and Ripple 1989). Fish were placed in a small, plastic tank containing 325 mg MS 222 per liter of ambient seawater. Fish remained immersed in anesthetic solution until loss of equilibrium and lack of response to gentle abdominal probing, indicating fish had reached level four anesthesia (Mattson and Ripple 1989, Prince et al. 1995).

Once anesthetized, fish were removed from the tank and placed upside down in a V-shaped operating trough. An assistant poured aerated, ambient seawater containing 150 mg MS 222 per liter of seawater over the gills throughout surgery to keep fish anesthetized, to supply oxygen to fish, and to keep the gills hydrated. Betadine was used to clean the area where the incision would be made. A sterilized, disposable razor blade was used to scrape away scales and to make a small incision (30 mm) just dorsal to the ventral midline, between the anus and the pelvic girdle, on the left lateral side of the fish. The peritoneum was pierced with the surgeon's index finger. After the peritoneum was pierced, the incision area was flushed with Betadine. Transmitters were inserted into the body cavity with the transducer end forward (Fig. 5). Transmitters were sterilized with 70% Ethanol and coated with sterile mineral oil, which promoted immune response to the transmitter. Before incision closure, the incision area was again flushed with Betadine.

Incision closure was accomplished using three materials: sutures (Poppe et al. 1996, Thoreau and Baras 1997, Szedlmayer 1997), staples (Mortensen 1990, Holland et al. 1993), and adhesive (Bart and Dunham 1990, Nemetz and MacMillian 1998). Braided, polyglycolic acid sutures with polycaprolate coating (Dexon®, Sizes I-III) and a reverse cutting needle (CE-6, 24 mm) were passed through the dermis and musculature to close the incision (9 mm thick). Two to three stitches were made and the sutures tied off with a square knot. Five to seven human skin staples (Promimate Plus MD 35W, Ethicon Endo-Surgery) were then used to bind the dermal edges (2mm thick) of the incision. After stapling, the incision area was blotted dry with sterile gauze and poly-acrolyate adhesive glue (Krazy Glue®) applied to the incision. Adhesive was allowed to set for 10 seconds before transferring fish from the operating trough to a level surface for administering antibiotics, additional external tagging, and anesthetic revival.

Antibiotics were included to increase the probability of post-surgical survival (Schramm and Black 1984, Poppe et al. 1996, Bart and Dunham 1990). A single 0.5 ml dose (George, pers. comm.) of an oil-based antibiotic (NuFlor®) was intramuscularly injected near the caudal peduncle on the left ventro-lateral side of the fish. A "$50 REWARD" t-bar internal anchor tag (SHD-95, Floy Mfg.) was then placed in the dorsal musculature, anterior to the VGFTP tag. After the "REWARD" tag was attached, fish were revived in an aerated livewell. Revival techniques

consisted of manually moving anesthetized fish back and forth through the livewell and holding fish under the aeration device to facilitate water flow over the gills. Fish were considered revived when they showed resistance to being held. Fish were released shortly after being revived.

Public Awareness of Study

Extensive efforts were made to increase the probability that ultrasonically-tagged tautog were reported to us if caught. In addition to the two "$50 REWARD" notices associated with each ultrasonically tagged tautog released, several other public awareness measures were employed. Large, colorful "REWARD" posters describing the study objectives of the project and explaining how to recognize ultrasonically tagged tautog were displayed at over 40 bait and tackle shops, boat ramps, and marinas throughout the lower Chesapeake Bay (Fig. 6a,b). Black and white reprints of the "REWARD" poster and a cover letter describing the project were sent to all 140 participants in the Virginia Game Fish Tagging Program, and color reprints of the poster were sent to the top tautog anglers in the program. An article describing study methodology and objectives was featured in *The Crest*), the official newsletter of the Virginia Institute of Marine Science (Arendt 1999). Finally, several live tautog used to evaluate tagging effects were displayed in the VIMS Aquarium and Visitor's Center during a fundraiser in January 1999 and between April-August 1999. While on display, a computer slide-show and several posters describing the study were available to visitors.

Detecting Ultrasonically-Tagged Tautog

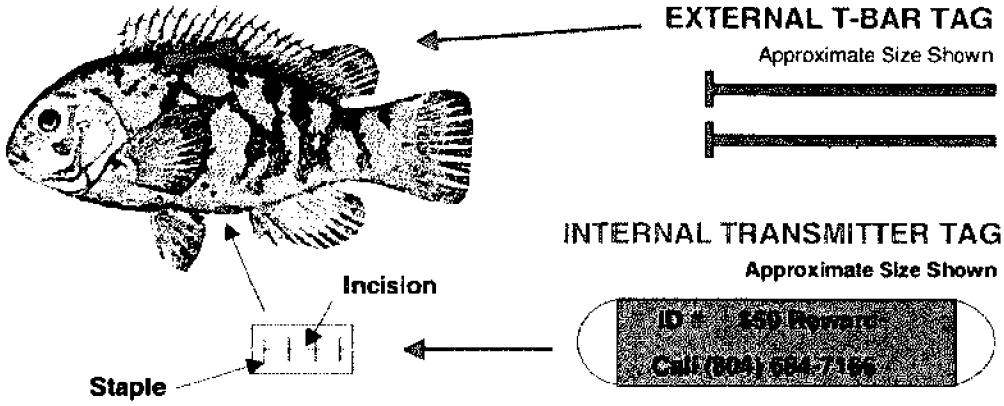
A VR60 receiver (Vemco, Ltd.) and two acoustic hydrophones (V10 directional and VH65 omni-directional, Vemco, Ltd.) enabled detection of ultrasonically tagged tautog from aboard the R/V *Langley*. Both hydrophones were mounted at the base of an aluminum pipe (3.7 m x 3.2 cm). To reduce background noise and electromagnetic interference, hydrophones were wrapped in electrical tape and separated (30 cm) from the aluminum pipe by a rubber hose clamp. A larger diameter steel pipe (1.25 m x 5 cm) encompassed the aluminum pipe and was lashed to a

Fig. 5 An ultrasonic transmitter surgically implanted into the visceral cavity of an anesthetized tautog. Transmitters were placed in the body cavity with the transducer-end of the transmitter facing forward.

Fig. 6 Poster used to advertise ultrasonic telemetry study on tautog in the lower Chesapeake Bay. A $50 reward was offered for information regarding recapture of ultrasonically tagged tautog. "Reward" posters (a) were displayed at over 40 bait and tackle shops, boat ramps, and marinas throughout lower Chesapeake Bay (b).

A

$50 CASH REWARD



Ultrasonically Tagged Tautog

•The Virginia Institute of Marine Science is studying activity patterns of tautog in lower Chesapeake Bay using ultrasonic transmitter tags. Transmitter tags are surgically inserted into the body cavity of the fish. Green external tags are placed on left side of body, below the dorsal fin.

•When you catch tautog, look for green tag and/or incision mark.

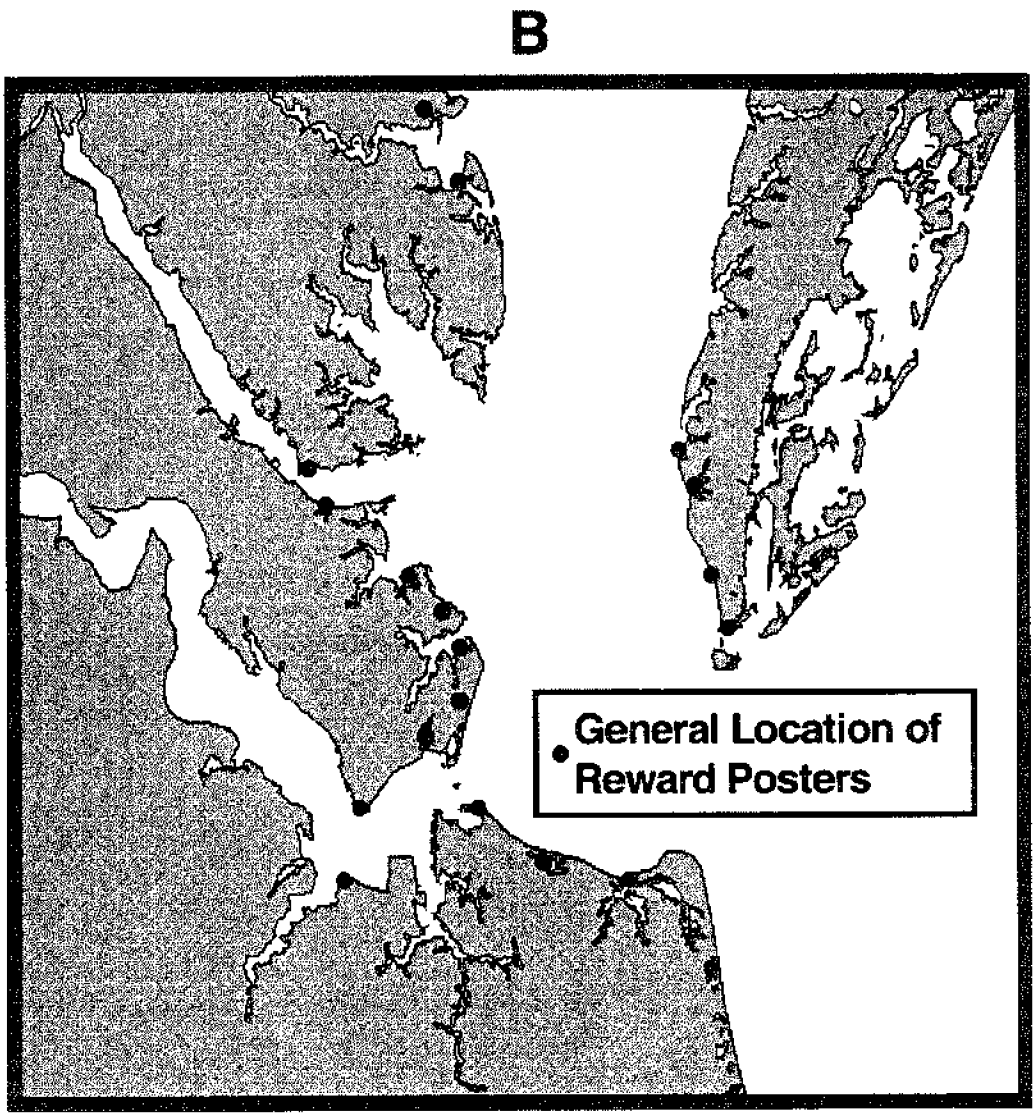
•If you catch a specially tagged tautog, KEEP FISH and record: tag number, date and exact location caught. Call immediately. We must examine tautog intact and in fresh condition for reward.

•For more information, call VIMS Marine Advisory Program:

Mike Arendt (757) 885-5751 pager; (804) 684-7647 office

Jon Lucy (804) 684-7166 office

•Project funded by Recreational Fishing Development Fund, Virginia Marine Resources Commission and VIMS/College of William and Mary.



stanchion railing on the starboard side of the boat. The orientation of the aluminum pipe inside of the outer pipe enabled the directional hydrophone to be rotated 360-degrees about a vertical axis. Physical location of hydrophones was approximately 1.5 m below the water surface and 0.3 m below the keel. The hydrophone mount was located slightly forward of starboard mid-ships, within 1 m (laterally) of the differential Global Positioning System (GPS) receiver antenna. Location of the hydrophone mount enabled visual communication between the boat captain and the hydrophone operator.

The hydrophone operator was audibly connected to the VR60 receiver, which remained inside the main cabin of the boat. The VR60 receiver recorded transmitter number, date, and time of detection. Recognition of all six pings associated with a transmitter code was necessary for transmitter identification. A switch box attached to the VR60 receiver enabled the hydrophone operator to select either of the two hydrophones. The omni-directional hydrophone was first used to determine presence/absence of fish (FCODE and RCODE). Detection radius for the omni-directional hydrophone was approximately 300 m. Linear transects over the center of each site and circular courses around the perimeter of each site were conducted. Fish not detected within 20 minutes were considered absent. The directional hydrophone was used to determine the physical position of FCODE fish. Detection range for the directional hydrophone was approximately 400 m. After determining the orientation of the fish relative to the boat, the boat was moved closer to the fish. As the boat approached the fish, the hydrophone operator rotated the hydrophone until no-directionality of the signal was detected. When no-directionality of the signal was detected, the hydrophone was assumed to be directly

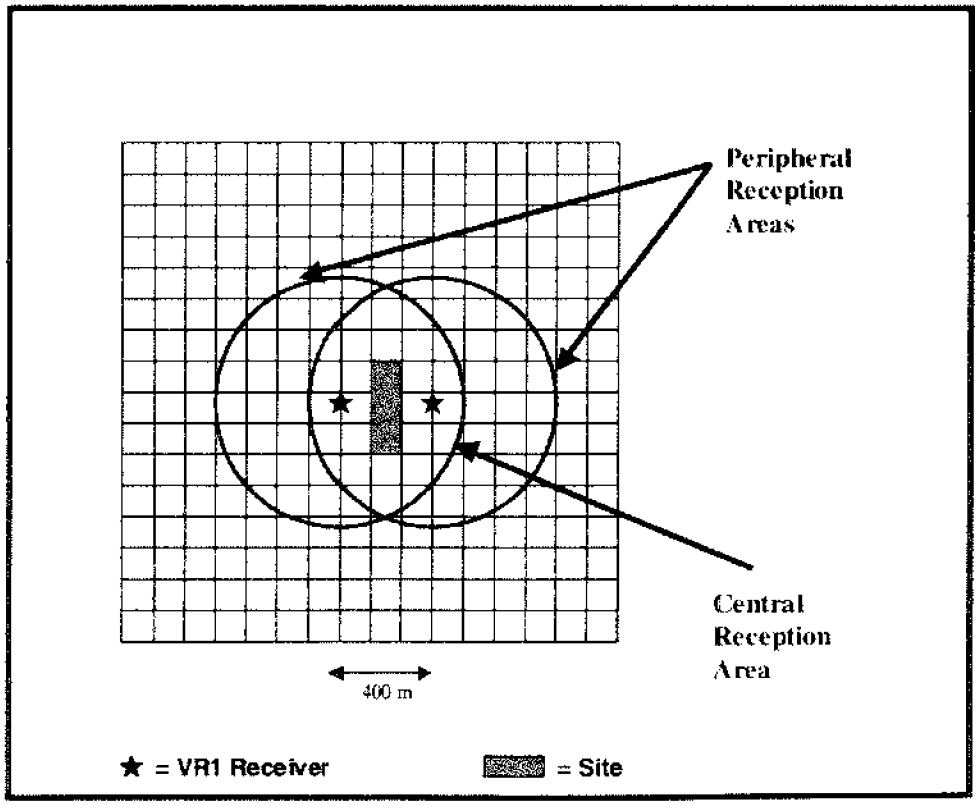
over an ultrasonically tagged tautog and date, time and position (differential GPS co-ordinates) were recorded. Differential GPS co-ordinates were considered to be accurate within 2 m of true position (<1 m error for GPS antenna, plus an additional 1 m lateral separation between GPS receiver antenna and hydrophone mount). Physical positions for RCODE fish were not determined because of the long duration (45-75 seconds) between signals and because of the inability to isolate individual fish on the same frequency (69 kHz).

Ultrasonically tagged tautog were also detected using VR1 acoustic receivers (Vemco, Ltd.). These receivers contained an omni-directional hydrophone and functioned as unattended, automated data loggers. VR1 receivers were deployed 100-150 m to the west and east of the perimeter of each of the four sites. Detection radius for each receiver was approximately 400 m. Detection areas for each of the two receivers overlapped and created three distinct transmitter reception zones: a central reception zone shared by both receivers and two peripheral reception zones unique to each receiver (Fig. 7). VR1 receivers were moored 1.5-3 m above the seafloor to provide a clear line-of-sight for transmitter signal reception (ie., positioned above the 'structure' associated with each site) and to eliminate acoustic interference from suspended material associated with strong bottom currents. Mooring units consisted of a railroad wheel (227 kg), stainless steel aircraft cable (0.64 cm; 7x19 strand), and sub-surface and surface floats (Fig. 8).

Data from VR1 receivers was downloaded approximately every six weeks. Maximum memory for receivers was 150,000 detections. Receiver data (transmitter identification, date and time of detection) was downloaded directly to a shipboard personal computer using a VR1-PC cable interface (Vemco, Ltd.). Recognition of all six 'pings' associated with a transmitter code was necessary for transmitter identification. When mooring systems were intact, two hydraulic whips were used in tandem (standard rigging) to bring each mooring unit aboard the R/V *Langley* for servicing and downloading receiver data. When mooring units could not be retrieved from the surface, VR1 receivers were retrieved using SCUBA divers from the VIMS Dive Team.

Both receiver types (VR60 and VR1) required a clear line-of-sight between the hydrophone and tagged fish in order to detect tagged fish. Because the VR1 receiver was moored in a fixed position, clear line-of-sight between the VR1 receiver and tagged fish was dependent on the

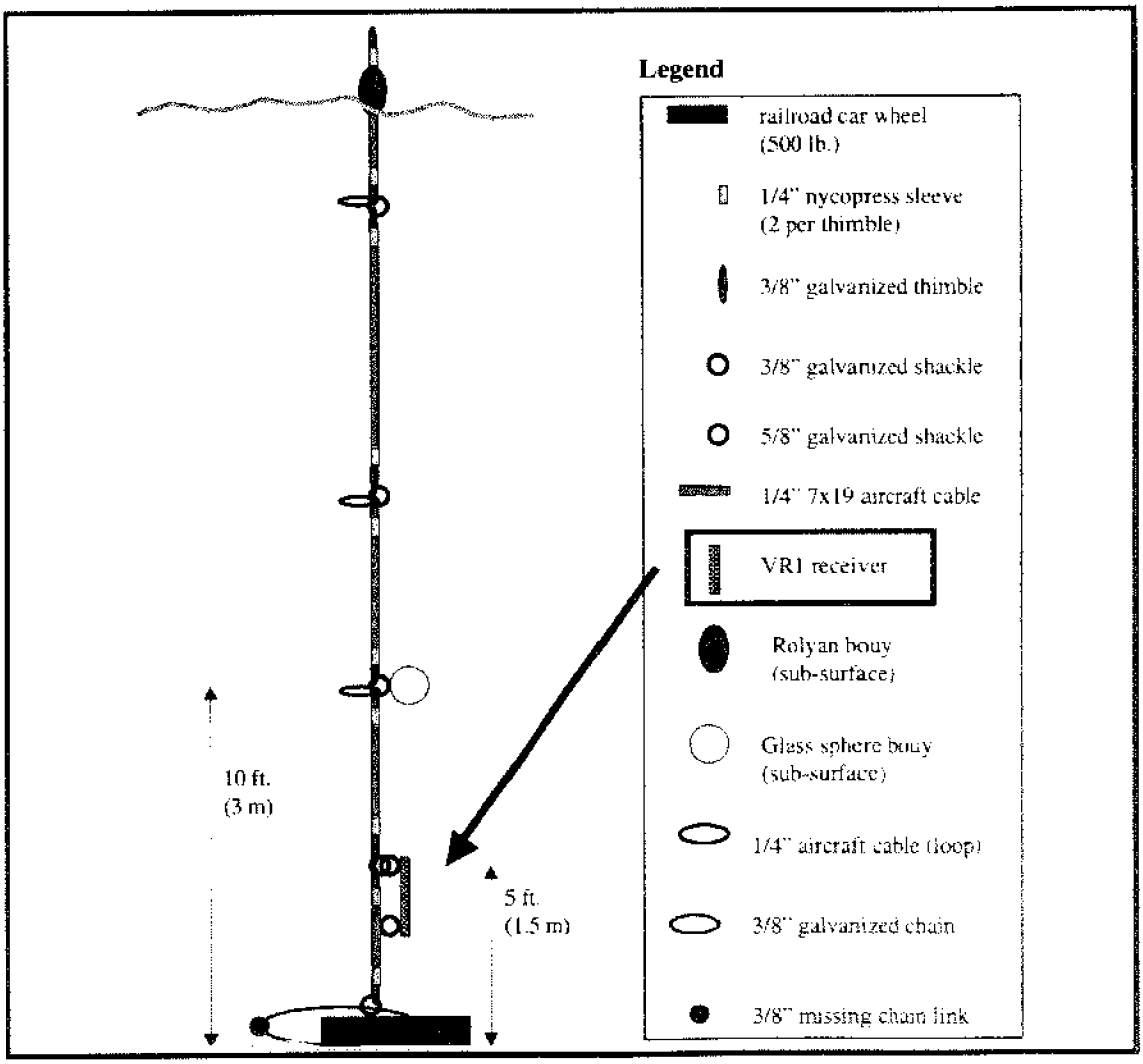
Fig. 7 Central and peripheral reception areas for VR1 receivers. Detection radii (400m) for both receivers were overlapped to create an area of dual receiver coverage (central reception area) and two unique coverage areas (peripheral reception areas). Receiver configuration enabled rough estimates of positions on tagged tautog to be made.



activity of tagged fish. Clear line of sight is compromised and ultrasonically tagged fish are much more difficult to detect when these fish hide in, under, or behind structured material (Bradbury et al. 1995,1997, Matthews 1992). When residing in, under, or behind structured material (presumably inactive), ultrasonically tagged fish should be detected less (or not at all) by VR1 receivers than when tagged fish are away from structure (presumably active). Because the VR60 was operated from a mobile platform, clear line-of-sight between the fish and the receiver was less dependent of the activity of tagged fish. Moving the position of the receiver relative to the position of tagged fish should provide a clear line of sight between the receiver and tagged fish.

Given these fundamental differences in operating characteristics between receivers, VR60 detection records and VR1 receiver detection records should be more similar when fish were active and less similar when fish were inactive. To test this idea, detection records from both receiver types were compared for percent agreement. When the time of an individual detection listed in the VR60 receiver record was also listed in a VR1 receiver record (≤ 30 seconds apart), both receivers were considered to have detected the same transmitter emission. Thirty seconds was selected as the cut-off time for determining detection of the same transmitter emission because it is less than the minimum time interval (45 seconds) between transmitter emissions, and because it allows for slight differences in the clock settings between the VR60 and VR1 receivers. A Chi-Square Contingency Test (Minitab Release 12.1, Minitab Inc.) was used to test for differences in the ratio VR60

Fig. 8 VR1 receiver mooring unit design. Mooring units consisted of a railroad wheel, stainless steel aircraft cable, and sub-surface and surface floats. VR1 receivers were shackled to a section of aircraft cable 1.5-3 m above the railroad wheel.



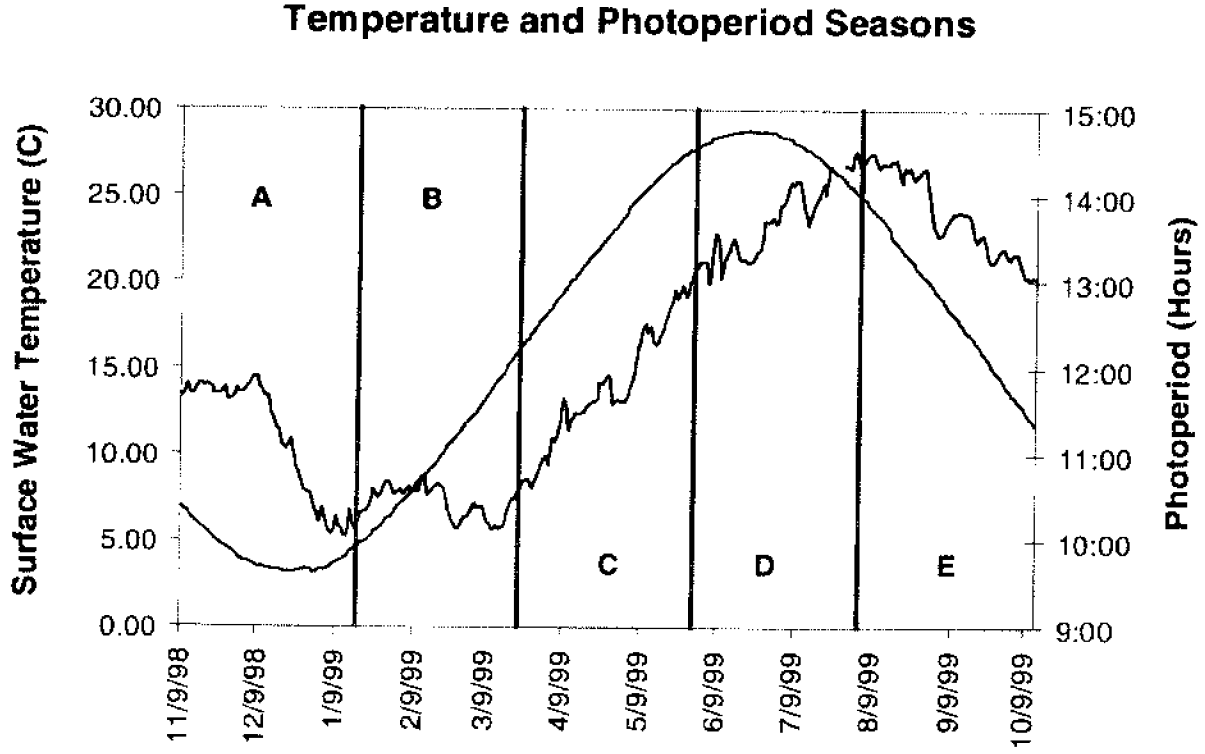
detections recorded by VR1 receivers versus not recorded by VR1 receivers between day (0600-1859) and night (1900-0559) hours.

Residence

Long-term residence (between seasons) was evaluated for RCODE fish. A single factor Analysis of Variance (Excel, Microsoft Corporation) was used to test the null hypothesis of no difference in the number of resident days among four sites. Resident days were classified as such either when a fish was detected at least 30 times during that day (eastern and western VR1 receivers combined) or when there was at least one hour of the day during which $\geq$ 10 detections (or multiple hours with $\geq$ 5 detections) occurred. Ten detections per hour was approximately equal to one detection every six minutes, thus, 30 detections per day was approximately equal to one detection every 12 minutes for six consecutive hours. A Chi-square contingency test (Minitab Release 12.1, Mintab Inc.) was used to test the null hypothesis of no difference in the number of low detection days (<30 detections/day) between seasons.

Seasons were defined by distinct relationships between surface water temperature and photoperiod (Fig. 9). In late fall/early winter, both temperature and photoperiod decreased to annual minimum values. In winter, temperature remained at minimum values and photoperiod increased. In spring, both temperature and photoperiod increased. In late spring/early summer, both temperature and photoperiod increased to annual maximum values. In late summer, temperature remained at maximum values and photoperiod decreased. Daily mean surface water temperature was computed from hourly observations at the Chesapeake Bay Bridge Tunnel (www.co-ops.nos.noaa.gov) for the entire study. Bottom water temperatures from water samples collected with a Niskin bottle were measured using a digital thermometer. Between late March and early October, mean daily bottom

Fig. 9 Temperature and photoperiod seasons (Nov 1998 – Sep 1999). During late fall/early winter (9 Nov 98 – 14 Jan 99, 66 days), surface water temperature and photoperiod decrease to annual minimum values (A). During winter (15 Jan 99 – 21 Mar 99, 65 days), surface water temperature remains at annual minimum values as photoperiod increases (B). During spring (22 Mar 99 – 27 May 99, 66 days), surface water temperature and photoperiod both increase during the spawning season (C). During late spring/early summer (28 May 99 – 5 Aug 99, 69 days), temperature and photoperiod both increase to annual maximum values and spawning has ceased (D). During late summer (6 Aug 99 – 12 Oct 99, 34 days), surface water temperature remains at annual maximum values and photoperiod decreases (E).



water temperature was computed from bi-hourly observations from an automated temperature logger (Tidbit, Onset Corp.) attached to the eastern VR1 receiver at the Airplane Wreck. Surface water temperature was not noticeably different from bottom water temperature (Fig. 10). No temperature stratification in the summer was consistent with depth-temperature profiles recorded for this area during the summer between 1997-1999 (Grubbs unpublished data) and with convergent eddy circulation patterns suggested for this area (Hood et al. 1999). Daily photoperiod (sunset – sunrise) was obtained from the Plantation Flats Current Meter Station (Tides and Currents V2.0, Nautical Software Inc.).

Short-term residence (within season) was evaluated for FCODE fish. FCODE fish were only detectable with the VR60 receiver, thus residence during the time interval between trips to sites could not be determined. FCODE fish were considered resident for a particular day if detected at least once during that day. Descriptive statistics were used to evaluate short-term residence of FCODE fish.

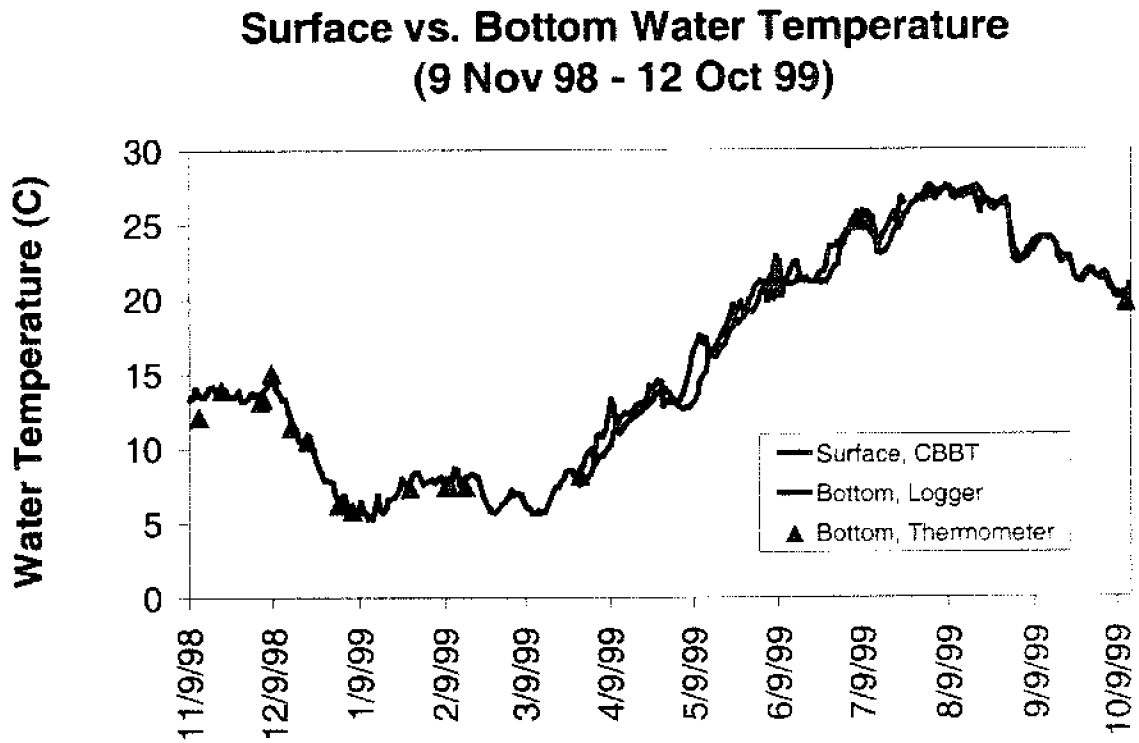
Movements

Movements were classified as such when tagged fish were reported recaptured away from release sites or when fish were detected (VR60 and/or VR1 receiver) at sites other than where released. Directionality of movements, distance traveled, and rates and frequencies of movements were evaluated. A Chi-square contingency test (Minitab Release 12.1, Minitab Inc.) was used to test the null hypotheses of no difference between the number of fish that moved away from natural versus manmade sites. A Chi-square contingency test (Minitab Release 12.1, Minitab Inc.) was used to test the null hypothesis of no difference between the number of fish that moved away from northern study sites (Airplane Wreck and Ridged Bottom) versus southern study sites (Coral Lump and Texeco Wreck). Scatter plot analysis (Excel, Microsoft Corporation) was used to compare percent movement of fish (#fish that left site / #fish released at site) with size (area in m^2) of each site. Maximum distance between positional 'fixes' and area (min. convex polygon, m^2) between positional 'fixes' for FCODE tautog were examined using the Animal Movements Extension to ArcView 1.1 (Hooge and Eichenlaub 1998).

Diel Activity

Histograms of total hourly detections for individual RCODE fish were created from VR1 receiver data (Excel, Microsoft Corporation). Mean hourly detections (i.e., sum

Fig. 10 Surface water temperature from the Chesapeake Bay bridge tunnel (1st Island) versus bottom water temperature near Cape Charles, VA (Niskin bottle samples and automated temperature logger at the Airplane Wreck). No evidence of temperature stratification was detected, consistent with depth-temperature profiles from Cape Charles in summer 1997-1999 (Grubbs, unpublished data).



of detections for all fish in one hour / number of fish detected in that hour) were subjected to Fourier analysis. Fourier analysis, a type of harmonic mean analysis, is a decomposition of a time series into the sum of its sinusoidal components and is used to detect periodicity (Bloomfield 1976). Periodicity was determined by dividing each Fourier frequency (number of cycles in the time series) by the total number of observations used in the Fourier analysis. For example, a Fourier frequency of 171 based on 4096 consecutive hours of observations corresponded to a 24 h periodicity (4096 h divided by 171 cycles equals repetition every 24 h). Amplitude was plotted against Fourier frequency to graphically illustrate periodicity among Fourier frequencies.

A One-Way Analysis of Variance (Excel, Microsoft Corporation) was used to test the null hypothesis of no difference between the number of day and night detections among seasons. In order to compare day and night detections on a relative scale, a detection index was created. Daily detection indices were created by dividing the total number of day detections (from hourly histograms) by the total number of daylight hours, and the total number of night detections (from hourly histograms) by the total number of nighttime hours. Daylight hours for a particular season were based on mean daily photoperiod for that season. In late fall/early winter, daylight was defined as 0700-1659 hours (10 h). Daylight hours for remaining seasons were defined as 0700-1759 hours (11 h), 0600-1959 hours (14 h), 0600-2059 hours (15 h), and 0600-1959 hours (14 h) for winter, spring, late spring/early summer, and late summer, respectively. Nighttime hours were defined as the difference between 24 hours and the number of daylight hours. The difference between day and night detection indices were computed for each fish for every day fish were detected (fish-days). For example, five fish detected on a given day was equal to five fish-days.

Chi-square contingency tests (Minitab Release 12.1, Minitab Inc.) were used to test the null hypothesis of no difference in the frequency of fish-days with a particular detection pattern between seasons and between lunar phase (obtained from the Plantation Flats Current Meter Station, Tides and Currents V2.0, Nautical Software Inc.). Daily detection patterns for RCODE fish were subjectively determined from graphs of hourly histogram data. Daily detection patterns (for each receiver separately) were classified as one of four types: diurnal, spike, shift, or no-pattern. A "diurnal" pattern consisted of detections between 0400-2059 hours, that when graphically illustrated had a general shape similar to a bell-shaped curve. A "spike" pattern consisted of a basic diurnal pattern, but there was at least one hour between 2100-0359 hours during which ≥10 detections were recorded. A "shift" pattern contained the basic curve associated with the "diurnal" and "spike" patterns, but detections were not restricted to 0400-2059 hours. A "no pattern" classification was assigned when no pattern was detectable between 0000-2359 hours. For analyses, data from one receiver only was used. One receiver was selected over the other receiver at a particular site according to whichever receiver recorded a more distinct detection pattern. Distinctness of detection patterns progressed from "diurnal" (most distinct) to "spike" to "shift" to "no-pattern" (least distinct).

Scatter plot analysis (Excel, Microsoft Corporation) was used to evaluate the effects of current speed (cm/s) on the number of detections per hour between 0800-1659 hours. Hourly current speed measurements were obtained from the Plantation Flats Current Meter Station (Tides and Currents V2.0, Nautical Software Inc.). Differences in current speeds were computed for six, three-hour intervals: 1600-1300, 1500-1200, 1400-1100, 1300-1000, 1200-0900, and 1100-0800. Differences in hourly VR1 detections were computed for the same six, three-hour intervals.

RESULTS

Transmitter Attachment (Evaluation)

Two groups of tautog were used to evaluate surgical implantation procedures, behavioral and physiological effects of surgical implantation, and transmitter signal attenuation. In June 1998, 12 tautog were caught at an undisclosed wreck southwest of Cape Charles, VA. In October 1998, 7 tautog were caught at the Coral Lump and Ridged Bottom sites near Cape Charles, VA. All tautog were transported to VIMS in aerated coolers and transferred to 1500 L aquarium tanks on the VIMS Oyster Pier (sand-filtered seawater, flow-through design). Tautog were acclimated to captivity between 3-6 days (October group) and for three weeks (June group) before attempting surgeries. Fish were divided into three treatment groups: implanted with 'dummy' transmitters (n=9), sham-implantation (n=3), and treatment controls (n=7).

Surgical implantation of transmitters in tautog proved to be fast and feasible. Anesthesia, surgery, and post-surgical recovery times (mean ± std.dev.) for implant and sham-implant fish were 6 ± 3 minutes, 6 ± 2 minutes, and 2 ± 1 minute, respectively. Transmitter retention was 100% for all nine implanted fish (Table 3). Mortality was minimal for fish ≥ 400mm TL (Table 3). Zero mortality was observed for sham-tag fish (330-430 mm TL) or controls. No evidence of substantial signal attenuation due to internal implantation of transmitters was detected (Table 3).

Surgical implantation of transmitters in tautog proved to be biologically compatible. Fish appeared to be fully recovered (feeding, swimming) within two days post-surgery, and differences in behaviors (feeding, swimming, social) of implant and sham-implant fish were indistinguishable from non-implant/sham-implant fish (Table 3). Necropsy examination of implant and sham-implant fish

from the October group (16-45 days post-treatment) revealed no evidence of tissue trauma or organ dysfunction related to transmitter implantation (Table 3). Transmitters were completely encapsulated in mesentery within 45 days post-implantation (Fig. 11). Transmitters did not interfere with reproduction (Table 3). Two male (both implanted fish) and three female fish (controls) from the June group were transferred to a 3000 L tank in the VIMS Aquarium and Visitor's Center after courtship behavior related to spawning was observed in a smaller tank on the Oyster Pier. Approximately 600,000 fertilized eggs were collected between mid-April and early June (Tellock, pers. comm.). Eggs were reared to juvenile forms and maintained in the VIMS Hatchery. The smaller male fish died (296 days post-implantation) from wounds inflicted by the larger male fish in order to prevent the smaller male fish from participating in spawning activities. The dominant male and the three females were released 122 days later (418 days post-implantation).

Detecting Ultrasonically Tagged Fish

All release sites were continuously monitored by VR1 receivers between 9 November 1998 and 5 August 1999, except for a two day period (10-12 December 1998) when receivers were not at sites due to a logistical problem. Receivers were deployed at sites on 54 different occasions and retrieved on 53 occasions (98% recovery rate). VIMS divers were required to retrieve VR1 receivers on 13 occasions, representing 25% of total recovery efforts and 25% of total data from VR1 receivers. Comparison of VR60 receiver detections (n=1774) with VR1 receiver records revealed significant differences between day and night (Chi-square, $p \leq 0.05$, Table 4). VR1 receivers recorded 50% of VR60 detections during the day), but only recorded 27% of VR60 detections at night, suggesting acoustic interference from structure was greater at night.

Table 3 Logistical practicality and biological feasibility of surgical implantation of ultrasonic transmitters (16 x 48 mm; 9 g in water) in adult tautog (n=9; 330-451 mm TL) collected in lower Chesapeake Bay in June and October 1998.

	06 JUN 1998 - 23 AUG 1999 (5-30°C)	**26 OCT 1998 - 20 DEC 1998 (10-18°C)**
Sample Size	**5**	**4**
Transmitter Retention	100%	100%
Mortality	60%*	0%
Signal Attenuation	No	Not Evaluated
Altered Behavior?	No	No
Anatomy Compromised?	Not evaluated	No
Reproduction Compromised?	No	Not Evaluated

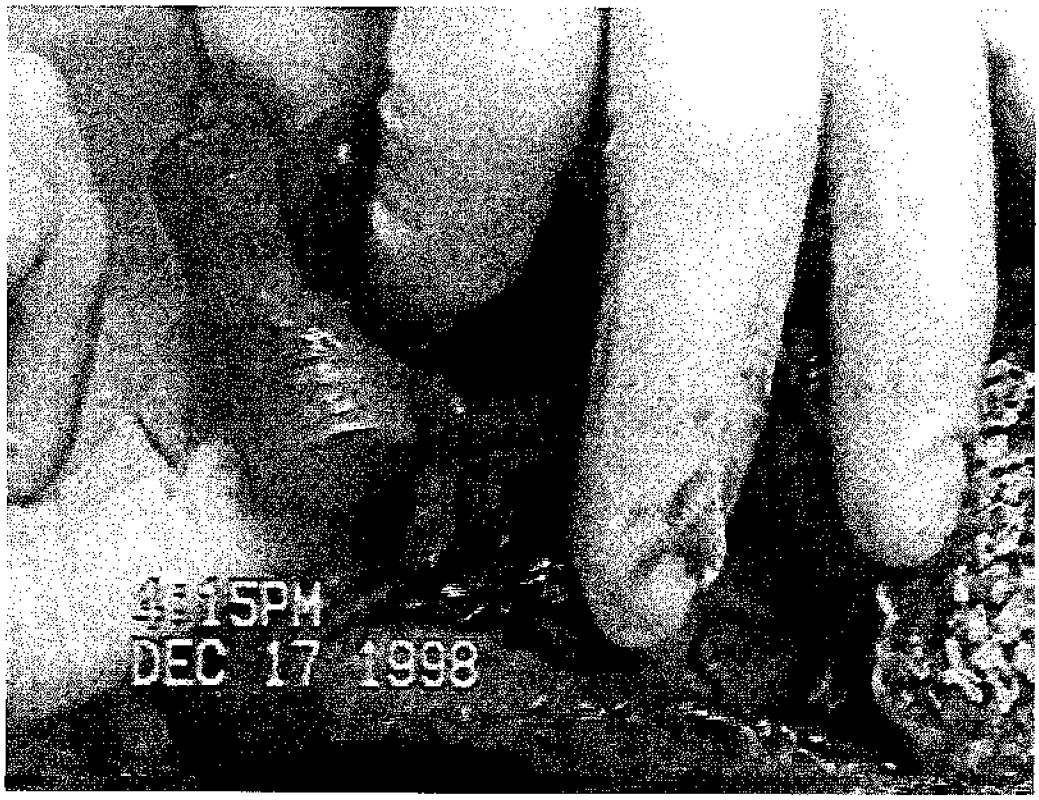
*2 fish <400 mm TL died within 48 hours post-implantation; 1 fish >400 mm TL died 37 days post-implantation when water temperature was 30°C. All other fish >400 mm TL survived until euthanized for necropsy (16-45 days), killed by intra-species interactions (296 days), or until released (418 days).

Table 4 Chi-square contingency test for detection agreement, VR60 vs. VR1 receivers.

	Day (0600-1859hrs)	Night (1900-0559hrs)	Total
VR1 Recorded	643	128	771
VR1 Did Not Record	653	350	1003
Total	1296	478	1774

H_o: No Difference in VR60 detections recorded by VR1 receivers between day and night hours.
Chi-sq=74.109, df=1, $p \leq 0.05$ (Significant)

Fig. 11 Complete encapsulation of 'dummy' transmitter in intestinal mesentery, 45 days post-surgical implantation of transmitter into a tautog (445 mm TL) used to evaluate surgical implantation procedure.



Summary of Tautog Released

Thirty-three adult tautog (400-514 mm TL) were tagged with ultrasonic transmitters and released (19 in fall 1998, 14 in spring 1999) near Cape Charles, VA (Table 5). Twenty-seven tautog were male; three female tautog were tagged in both fall 1998 and spring 1999. Seventeen tautog were released at manmade sites and 16 tautog were released at natural sites. Two tautog tagged and released with ultrasonic transmitters were previously tagged-released as part of the Virginia Game Fish Tagging Program. Mean anesthesia, surgery, and post-surgical recovery times for fish implanted with actual transmitters were comparable with times for fish implanted with 'dummy' transmitters. Anesthesia, surgery, and post-surgical recovery times (mean $\pm$ std. dev.) were 4 ± 1 minute, 9 ± 3 minutes, and 3 ± 2 minutes, respectively. Post-release recovery for RCODE fish was evaluated with VR1 receivers. Post-release recovery was denoted by irregular detection frequency prior to the onset of a consistent diel detection pattern (Arendt and Lucy, 2000). Post-release recovery (mean $\pm$ std.dev.) was 3.5 ± 1.5 days (range, 1.5 to 7.4 days) for 15 RCODE fish released in fall 1998 and 2.0 ± 1.9 days (range, 1 to 6.8 days) for 11 RCODE fish released in spring 1999. Nine tautog released were recaptured 114-211 days later. These recaptured fish confirm long-term survival, incision healing (Fig. 13), transmitter encapsulation (Fig. 13), feeding (Fig. 14), and overall good condition of fish tagged and released with ultrasonic transmitters.

Table 5 Summary of data for 33 adult tautog (400-514 mm TL) tagged and released with ultrasonic transmitters near Cape Charles, VA, in fall 1998 and spring 1999. An asterisk (*) denotes recaptured fish. For recaptured fish, the date last detected is actually recapture date and days detected is days at large.

ID	Code	Site	TL	Sex	Released	Last Detected	Days
1	RCODE	CL	432	M	11/09/98	05/10/99	183
18	RCODE	CL	406	M	11/09/98	05/02/99	175
19	RCODE	TX	495	F	11/10/98	04/24/99	166
20*	RCODE	TX	470	M	11/10/98	04/27/99	169
21	RCODE	RB	406	M	11/10/98	02/17/99	100
22	RCODE	RB	400	M	11/10/98	05/08/99	180
23	RCODE	AW	483	M	11/13/98	04/28/99	167
24	RCODE	AW	432	M	11/13/98	04/20/99	159
25	RCODE	CL	432	M	12/03/98	06/07/99	187
26	RCODE	CL	400	M	12/03/98	06/02/99	182
27	RCODE	TX	514	M	12/04/98	05/30/99	178
28	RCODE	TX	413	F	12/04/98	06/07/99	186
2	FCODE	TX	445	F	12/04/98	01/06/99	34
29*	RCODE	AW	400	M	12/07/98	05/19/99	163
30	RCODE	AW	419	M	12/07/98	02/13/99	69
3	FCODE	AW	495	M	12/07/98	12/15/98	9
31	RCODE	RB	445	M	12/08/98	05/26/99	170
32	RCODE	RB	419	M	12/08/98	04/15/99	129
14	FCODE	RB	419	M	12/08/98	02/09/99	64
4	FCODE	TX	432	M	04/21/99	06/07/99	48
6*	FCODE	TX	457	M	04/21/99	11/18/99	211
33	RCODE	TX	406	M	04/21/99	10/12/99	107
5	FCODE	CL	432	M	04/22/99	06/07/99	47
34*	RCODE	CL	432	M	05/28/99	10/30/99	155
35	RCODE	TX	445	M	05/28/99	10/12/99	137
36	RCODE	TX	——	M	05/28/99	10/12/99	137
37*	RCODE	TX	445	F	05/28/99	11/18/99	174
38*	RCODE	CL	483	M	06/07/99	10/30/99	145
39*	RCODE	CL	483	F	06/07/99	10/01/99	116
40*	RCODE	CL	432	F	06/07/99	11/06/99	152
41	RCODE	AW	445	M	06/07/99	06/17/99	11
42*	RCODE	RB	406	M	06/09/99	10/01/99	114
43	RCODE	RB	406	M	06/09/99	10/12/99	125

Fig. 12 Healed incision from a recaptured tautog (ID42). This fish was implanted with an ultrasonic transmitter on 9 June 1999 and recaptured on 1 October 1999 (114 days).

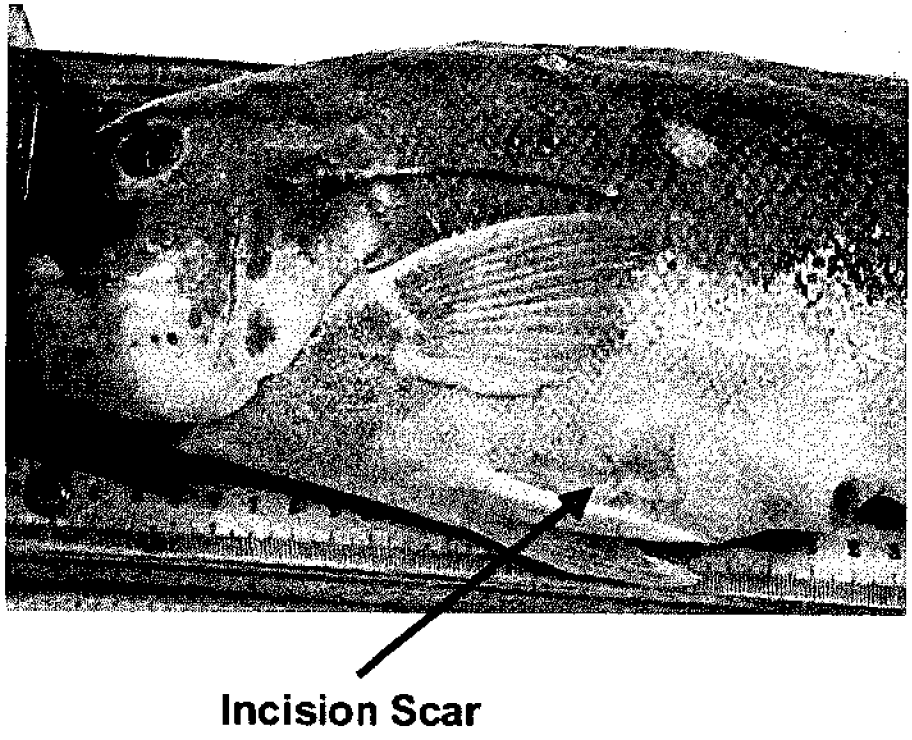


Fig. 13 Encapsulation of an ultrasonic transmitter in intestinal mesentery, 114 days after transmitter was surgically implanted in a tautog (406 mm TL). This tautog (ID42) was released and recaptured at the Ridged Bottom (9 June 1999 – 1 October 1999).

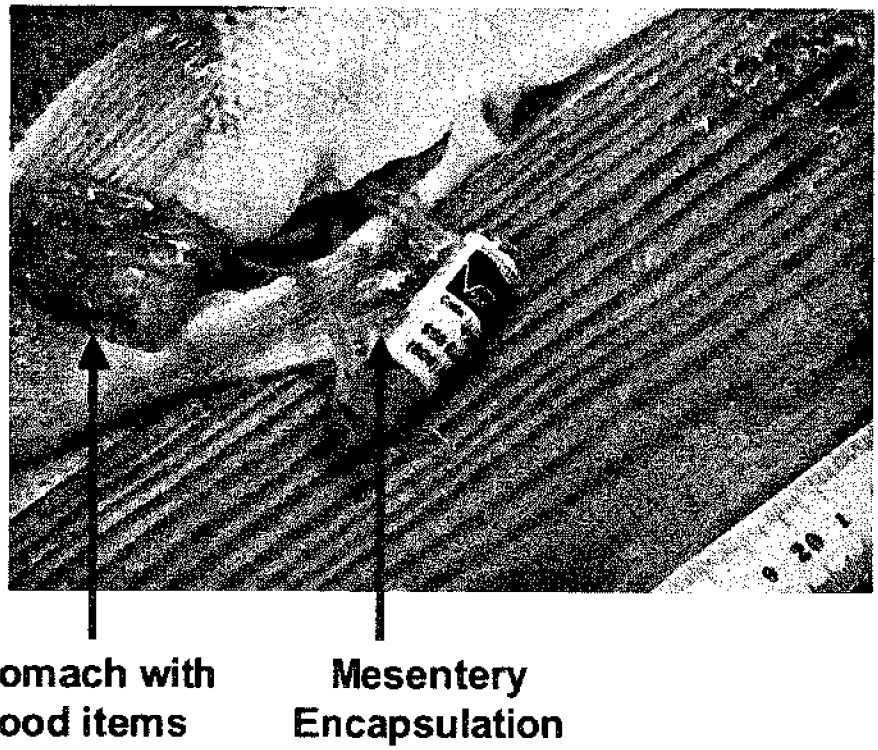


Fig. 14 Stomach contents (a = Sertularia, b = bait (cut blue crab), c = *Alycindium verilli*) from a recaptured tautog (ID42), October 1999.

Residence

Long-term residence (between seasons) was evaluated for RCODE fish. A single factor Analysis of Variance (Excel, Microsoft Corporation) was used to test the null hypothesis of no difference in the number of resident days among four sites. Resident days were classified as such either when a fish was detected at least 30 times during that day (eastern and western VR1 receivers combined) or when there was at least one hour of the day during which ≥ 10 detections (or multiple hours with ≥ 5 detections) occurred. Ten detections per hour was approximately equal to one detection every six minutes, thus, 30 detections per day was approximately equal to one detection every 12 minutes for six consecutive hours. A Chi-square contingency test (Minitab Release 12.1, Mintab Inc.) was used to test the null hypothesis of no difference in the number of low detection days (<30 detections/day) between seasons.

Seasons were defined by distinct relationships between surface water temperature and photoperiod (Fig. 9). In late fall/early winter, both temperature and photoperiod decreased to annual minimum values. In winter, temperature remained at minimum values and photoperiod increased. In spring, both temperature and photoperiod increased. In late spring/early summer, both temperature and photoperiod increased to annual maximum values. In late summer, temperature remained at maximum values and photoperiod decreased. Daily mean surface water temperature was computed from hourly observations at the Chesapeake Bay Bridge Tunnel (www.co-ops.nos.noaa.gov) for the entire study. Bottom water temperatures *in situ* water samples collected with a Niskin bottle were measured using a digital thermometer. Between late March and early October, mean daily bottom water temperature was computed from bi-hourly observations from an automated temperature logger (Tidbit, Onset Corp.) attached to the eastern VR1 receiver at the Airplane Wreck. Surface water temperature was not noticeably different from bottom water temperature between (Fig. 10). No temperature stratification in the summer was consistent with depth-temperature profiles recorded for this area during the summer between 1997-1999 (Grubbs, unpublished data) and with convergent eddy circulation patterns suggested for this area (Hood et al., 1999). Daily photoperiod (sunset – sunrise) was obtained from the Plantation Flats Current Meter Station (Tides and Currents V2.0, Nautical Software Inc.).

Short-term residence (within season) was evaluated for FCODE fish. FCODE fish were only detectable with the VR60 receiver, thus residence during the time interval between trips to sites could not be determined. FCODE fish were considered resident for a particular day if detected at least once during that day. Descriptive statistics were used to evaluate short-term residence of FCODE fish.

Table 6 One-Way Analysis of Variance (ANOVA) for resident days, fall released RCODE tautog (9 November 1998 – 7 June 1999).

	CL	TX	RB	AW
Nov Rep 1	176	61	87	153
Nov Rep 2	158	0	177	115
Dec Rep 1	183	78	147	148
Dec Rep 1	178	47	90	47

H_o: No difference in mean days resident among sites.
F=2.77, df=15; p>0.05 (NS)

Table 7 One-way Analysis of Variance (ANOVA) for resident days, spring released RCODE tautog (9 June 1999 – 5 August 1999).

	CL	TX	RB	AW
Spring Rep 1	57	0	57	8
Spring Rep 2	57	57	57	
Spring Rep 3	57	57		
Spring Rep 4	57	57		

H_o: No difference in mean days resident among sites
F=2.10, df=10, p>0.05 (NS)

Table 8 Chi-square contingency test for frequency of occurrence of "low detection" fish-days, 9 Nov 1998 to 9 Sep 1999.

	11/9-1/14	1/15-3/21	3/22-5/27	5/28-8/5	8/6-9/9	Total
Low Detect	63	126	0	2	13	204
Resident	574	664	552	583	94	2467
Total	637	790	552	585*	107	2671

* fall released (20 fish-days) and spring released (565 fish-days) combined.

H_o: No difference in number of non-resident fish-days between seasons.
Chi-sq=174.82, df=4, p≤0.05 (Significant)

Fig. 15 Example of a "low detection" detection pattern. "Low detection" classification was assigned when less than 30 detections per day were recorded (eastern and western VR1 receivers combined) for individual fish at a particular site. Arrows indicate days listed as "low detection" pattern.

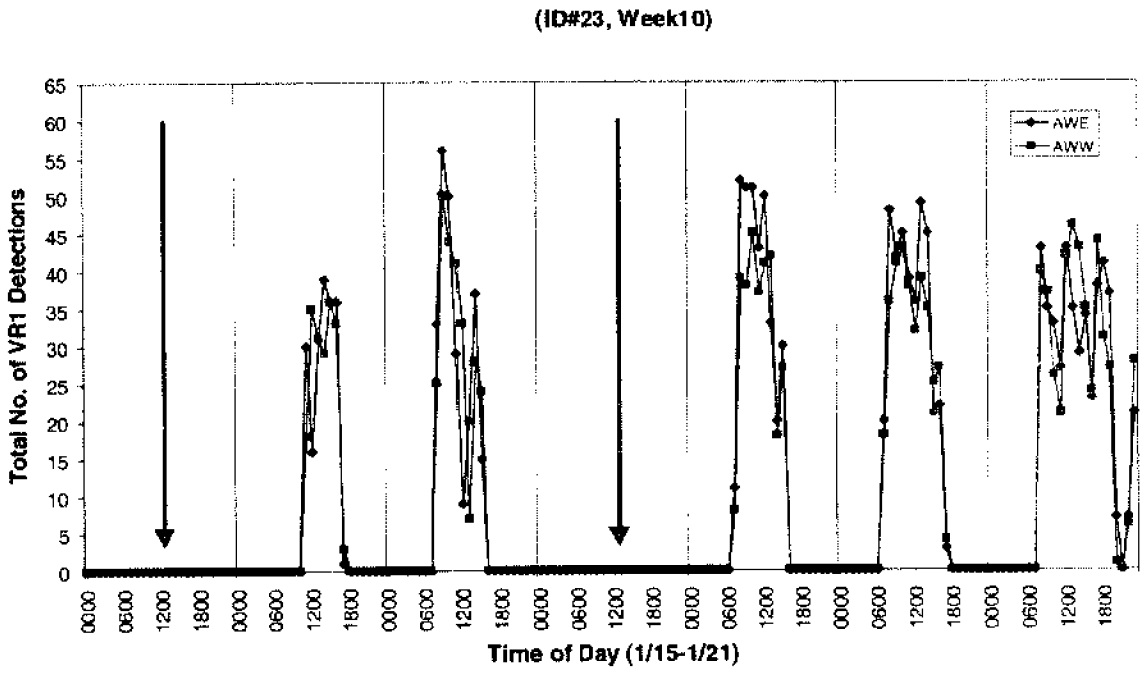
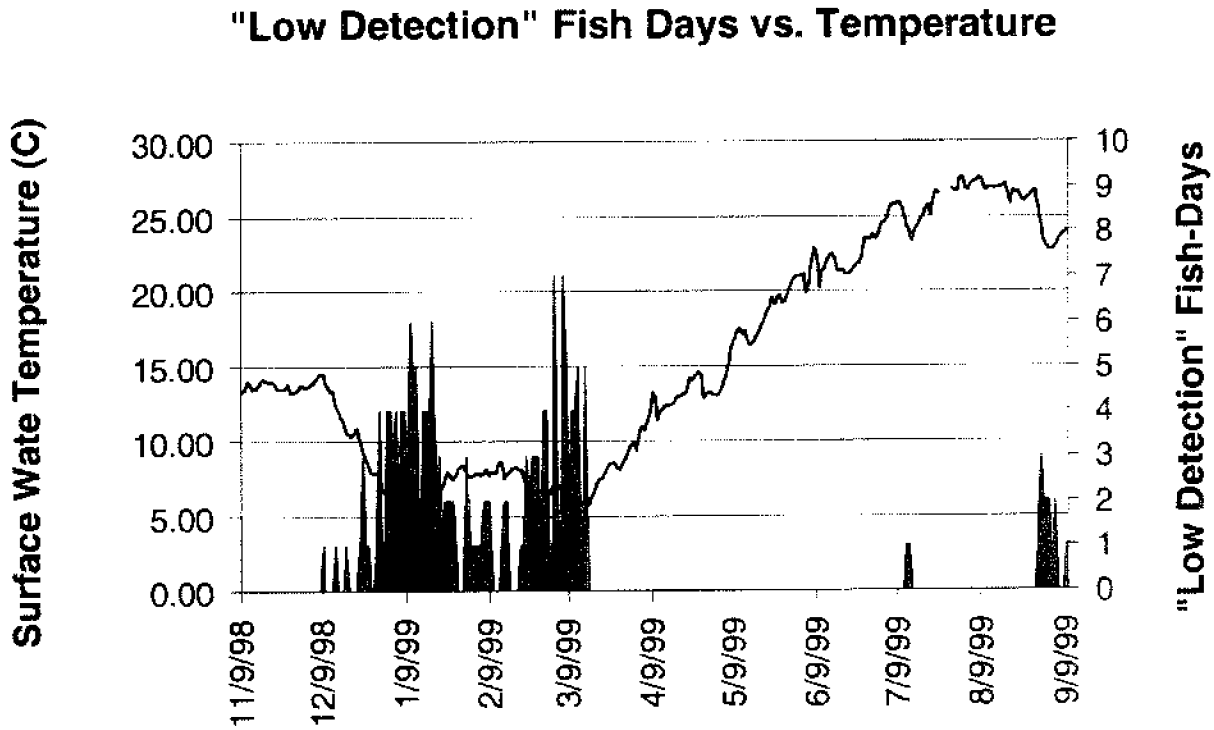


Fig. 16 "Low detection" fish-days versus surface water temperature (9 Nov 1998 – 9 Sep 1999). "Low detection" days occurred at the coldest water temperatures in the winter or during rapid declines in surface water temperature (due to storm events) in the summer.



Movements

Four tautog released in fall 1998 and two tautog released in spring 1999 were recaptured or detected away from sites where released (Fig. 17). Only localized movements between sites in the vicinity of Cape Charles, VA, were observed. Distances traveled varied between 1.9-10.2 km and rate of movement varied between 0.1 and 36.7 km/day (Table 9). All movements of fish away from release sites involved fish released at manmade sites (Airplane Wreck and Texeco Wreck). Significant difference was detected in the number of fish that moved from manmade sites versus natural sites (Chi-square, $p \leq 0.05$, Table 10). No significant difference was detected (Chi-square, $p > 0.05$, Table 11) in the number of fish that moved from northern sites (Airplane Wreck, Ridged Bottom) versus southern sites (Texeco Wreck, Coral Lump). Percent movement away from release sites versus site size was not suggested ($R^2=0.49$) for six tautog detected or recaptured away from release sites (Fig. 18). Four additional fish (ID3, ID21, ID30, ID32) were detected 46 to 106 days less than the mean (175 days) for other RCODE tautog released at the same time. Tautog 3, an FCODE tautog, was detected 24 fewer days than the other FCODE fish (ID2) released with a similar transmitter (same battery life) two days earlier. When movement for these four fish was assumed, percent movement was highly suggested ($R^2=0.97$) with site size (Fig. 18).

Two RCODE fish released in fall 1998 moved away from their respective release sites and were recaptured by commercial fishermen in spring 1999. A fish released at the Texeco Wreck (ID20) on 10 November 1998 was recaptured in a crab pot on 27 April 1999. This fish moved 10.2 km to the northeast in 169 days. When released, tautog 20 was detected at the Texeco Wreck for less than three hours. The second fish (ID29) was released at the Airplane Wreck on 13 November 1998 and was recaptured in a gill net on 19 May 1999. Tautog 29 remained resident at the Airplane Wreck until 12 May 1999. Tautog 29 moved 2 km to the east in seven days.

One RCODE fish released at the Airplane Wreck and three RCODE fish released at the Texeco Wreck were detected (VR1 and/or VR60 receivers) away from their original release sites. Tautog 41 moved 5.8 km from the Airplane Wreck to the Texeco Wreck seven days after being released, remained at the Texeco Wreck for three days, then was never detected again at any site. All tautog that moved away from the Texeco Wreck moved 2 km south to a cluster of large poles ("South Poles", Fig. 19) and periodically returned to the Texeco Wreck. The South Poles site was not monitored with VR1 receivers, thus, detection of fish at this site was only possible with the VR60 receiver. Tautog 19 emigrated from and returned to the Texeco Wreck on at least seven different occasions, traveling a minimum of 8.8 km between 10 November 1998 and 24 April 1999 (Fig. 20). Movement to the South Poles was documented on two separate occasions, but location following displacement from the Texeco Wreck on five other occasions was unknown (i.e., not detected by VR1 receivers more than seven consecutive days). Tautog 28 emigrated from and returned to the Texeco Wreck on at least 11 different occasions, traveling a minimum of 31.1 km between 4 December 1998 and 7 June 1999 (Fig. 21). Movement to the southeast of the Texeco Wreck was observed on two occasions. Movement between the Texeco Wreck and the Coral Lump was observed once, followed by movement from the Coral Lump to the South Poles. Movement between the Texeco Wreck and the South Poles was observed on four occasions. Location following displacement from the Texeco Wreck could not be determined on four occasions. Tautog 33 emigrated from the Texeco Wreck to the South Poles within 10 h following release, returned to the Texeco Wreck once, then moved back to the South Poles, traveling a cumulative distance of 6.6 km (Fig. 22). Between May and October, tautog 33 was always detected at the South Poles during site searches.

Three FCODE fish were released at each of the following sites in fall 1998: Texeco Wreck, Airplane Wreck, and Ridged Bottom. Five to seventeen 'fixes' per fish were obtained between early December and early January. Maximum distance between two 'fixes' was 30-80 m and area between 'fixes' was 1150-3000 m^2, determined by the minimum convex polygon method (Table 12). Two FCODE fish were released at he Texeco Wreck and one released at the Coral Lump between 21-22 April 1999. All three tautog were always detected (VR60 receiver) at release sites until 7 June 1999.

Table 9 Distances (km) and rates (km/day) of travel by six tautog released in fall 1998 that were recaptured (n=2) or detected (n=4) away from respective release sites.

Season	Movement	Fish ID	Distance (km)	Departure	Arrival	Time (days)	Rate (km/day)
Fall	Recapture	20	10.2	11/10/98	04/27/99	169	0.1
Spring	Recapture	29	2	05/12/98	05/19/99	7	0.3
Fall	Detect	19	2.2	12/21/98	01/27/99	37.3	0.1
Winter	Detect	19	2.2	01/27/99	01/31/99	4.5	0.5
Winter	Detect	19	2.2	02/08/99	02/09/99	0.96	2.3
Winter	Detect	19	2.2	02/09/99	02/09/99	0.06	36.7
Fall	Detect	28	1.9	12/26/98	01/01/99	6.08	0.3
Fall	Detect	28	1.9	01/01/99	01/05/99	4.08	0.5
Fall	Detect	28	1.9	01/05/99	01/06/99	0.75	2.5
Fall	Detect	28	1.9	01/08/99	01/14/99	5.54	0.3
Fall	Detect	28	1.9	01/15/99	01/16/99	0.88	2.2
Winter	Detect	28	4	01/24/99	01/27/99	3.13	1.3
Winter	Detect	28	2.2	01/27/99	02/05/99	9.13	0.2
Winter	Detect	28	2.2	02/08/99	02/09/99	1.13	1.9
Winter	Detect	28	2.2	02/09/99	02/25/99	16.38	0.1
Spring	Detect	28	2.2	03/25/99	03/29/99	4.67	0.5
Spring	Detect	28	2.2	03/29/99	04/10/99	11.75	0.2
Spring	Detect	28	2.2	04/20/99	04/22/99	2	1.1
Spring	Detect	28	2.2	04/22/99	04/26/99	4.5	0.5
Spring	Detect	28	2.2	05/13/99	06/07/99	25.13	0.1
Spring	Detect	33	2.2	04/21/99	04/22/99	0.42	5.3
Spring	Detect	33	2.2	04/22/99	05/09/99	17	0.1
Spring	Detect	33	2.2	05/09/99	05/19/99	5.21	0.4
Spring	Detect	41	5.8	06/13/99	06/15/99	2.08	2.8

Table 10 Chi-square contingency test movement of tautog from natural (Ridged Bottom, Coral Lump) versus manmade (Texeco Wreck, Airlane Wreck) sites.

	Natural	Manmade	Total
No. Moved	0	6	6
No. Stayed	16	11	27
Total	16	17	33

H_o: No difference in number of fish that moved from sites by type.
Chi-sq=6.902, df=1, $p \leq 0.05$ (Signficant)

Table 11 Chi-square contingency test for movement of tautog from northern (Airplane Wreck, Ridged Bottom) versus southern (Texeco Wreck, Coral Lump) sites.

	Northern	Southern	Total
No. Moved	2	4	6
No. Stayed	11	16	27
Total	13	20	33

H_o: No difference in number of fish moving from northern vs. southern sites.
Chi-sq=0.113, df=1, $p>0.05$ (NS)

Fig. 17 Overview of movement patterns for ultrasonically tagged tautog released near Cape Charles, VA, in fall 1998 and spring 1999. Fifteen percent (n = 6 of 33) of tautog released were recaptured (thick arrows) or detected (thin arrows) away from sites where fish were caught, tagged, and released. All movements were to nearby (<11 km apart) sites. Trapezoid shape represents movement between three sites (Texeco Wreck, Coral Lump, and South Poles) by a single tautog (ID28).

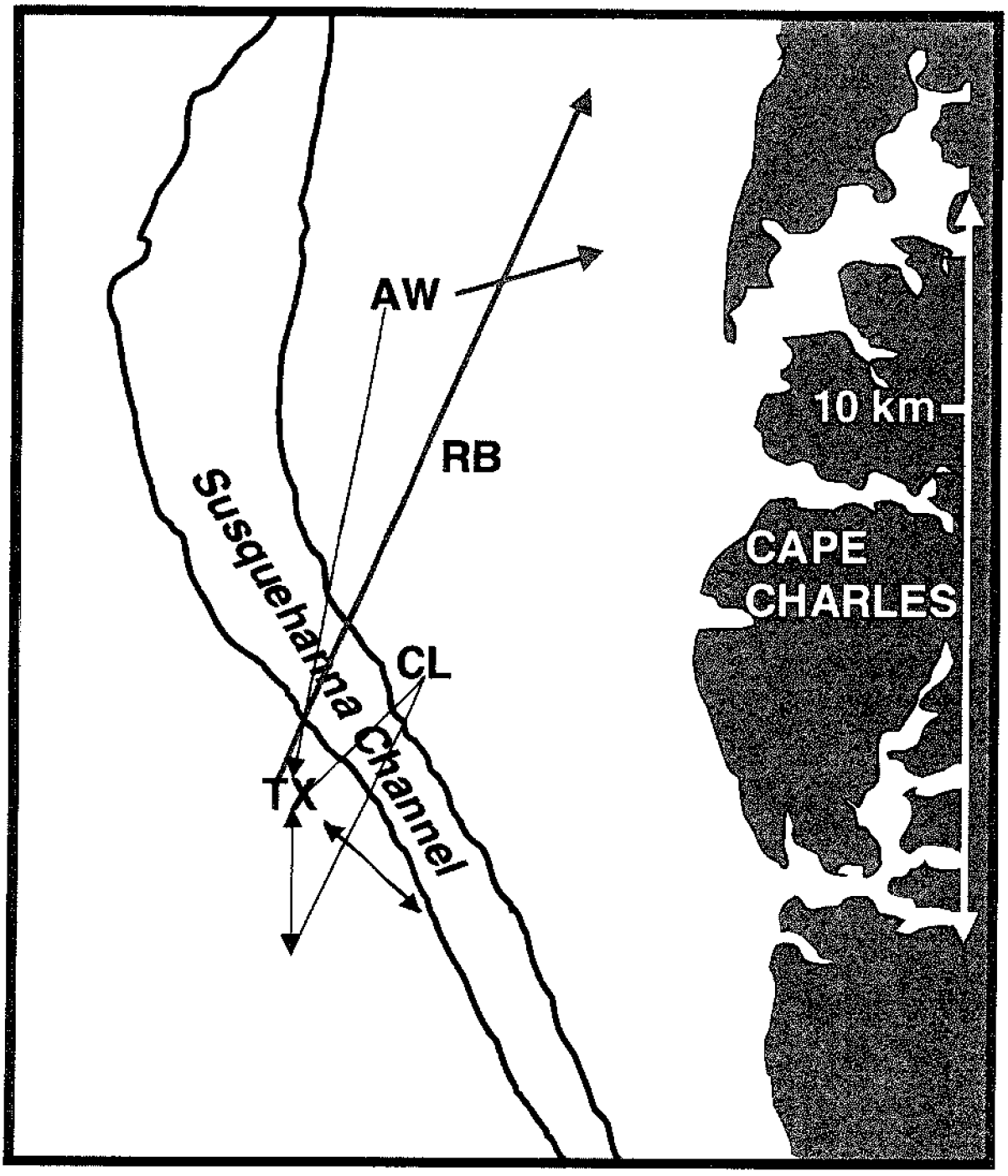


Table 12 Maximum distance (m) and area (m^2) between positional 'fixes' (Global Positioning System coordinates) on FCODE tautog, determined using the Animal Movements Extension to ArcView 1.1 (Hooge and Eichenlaub 1998).

ID	Site	Detected	Fixes	Distance	Area
2	TX	12/05/98-01/06/99	17	30 m	3000 m^2
3	AW	12/07/98-12/15/99	5	60 m	1157 m^2
14	RB	12/08/98-02/09/99	6	80 m	1772 m^2
4	TX	04/21/99-06/07/99	5	*	*
6	TX	04/21/99-06/07/99	5	*	*
5	CL	04/22/99-06/07/99	1	N/A	N/A

* Fish always detected in same general vicinity, but not able to get a 'fix'.

Fig. 18 Percent movement of tautog away from release sites versus the area (m^2) of release sites, determined with side-scan sonar. Percent movement away from release sites was not suggested (R^2=0.49) to be related to size of release sites for six tautog recaptured or detected away from release sites. Inclusion of four additional tautog that may have left release sites, but were not recaptured or detected away from sites, suggests percent movement is related to size of release site (R^2=0.97).

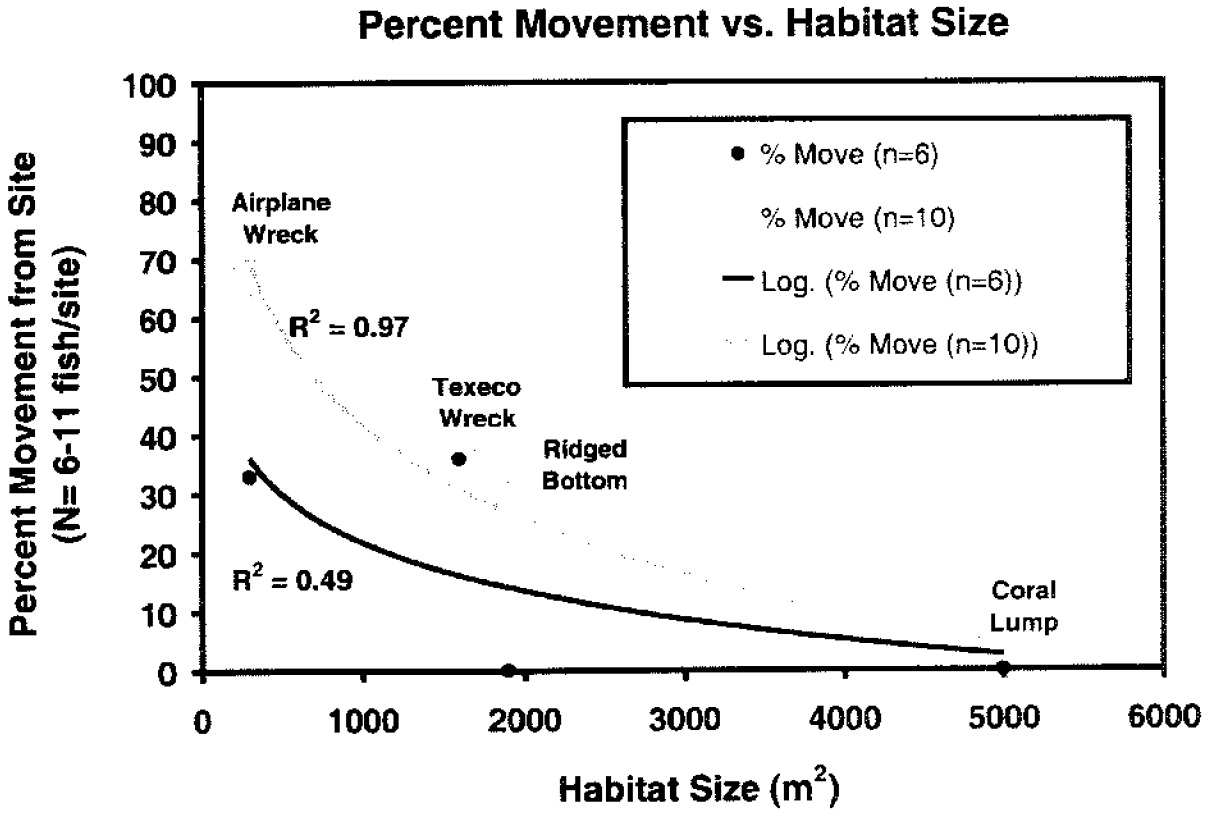


Fig. 19 Side-scan sonar image of the "South Poles" site, 2.2 km south of the Texeco Wreck, near Cape Charles, VA, in the lower Chesapeake Bay. Three tautog released at the Texeco Wreck were detected at both the Texeco Wreck and the South Poles sites.

Dimensions:	**20 m x 20 m**
Area:	**250 m²**
Relief:	**0.5 m**
Depth:	**16.8 m**

Fig. 20 Tautog 19 was released at the Texeco Wreck on 10 November 1999 and emigrated from and returned to the Texeco Wreck on at least seven different occasions, traveling at least 8.8 km between 10 November 1998 and 24 April 1999. Movement to the South Poles was documented on two separate occasions. Location following displacement from the Texeco Wreck on five occasions was unknown (double arrows).

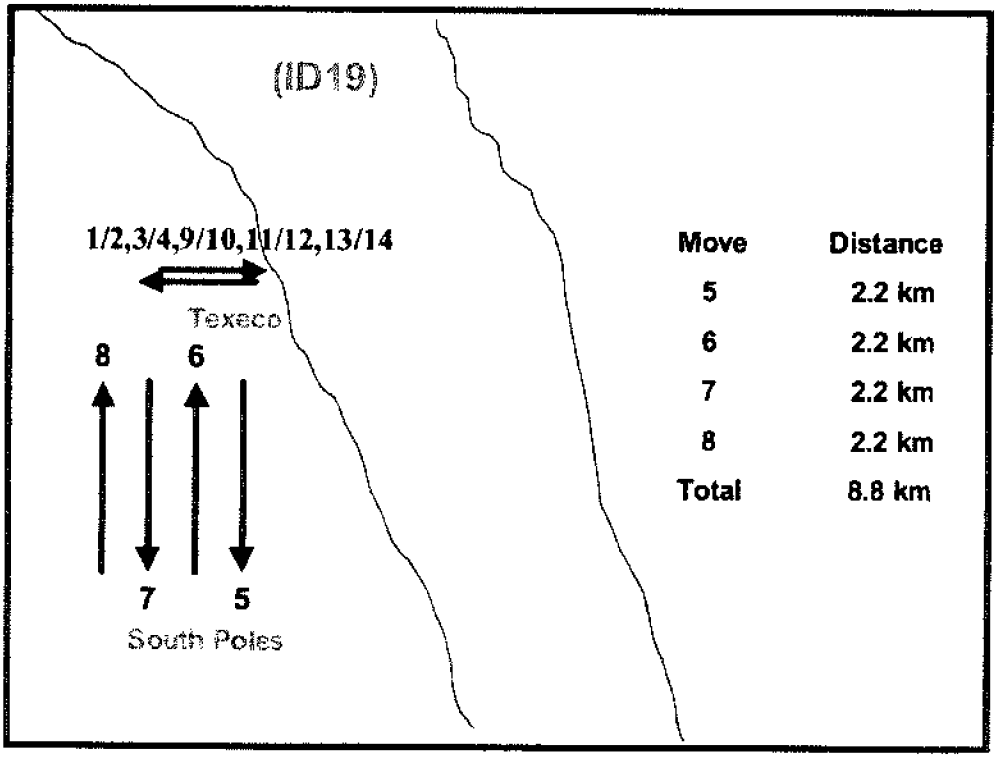


Fig. 21 Tautog 28 was released at the Texeco Wreck on 4 December 1998 and emigrated from and returned to the Texeco Wreck on at least 11 different occasions, traveling at least 31.1 km between 4 December 1998 and 7 June 1999. Movement to the southeast of the Texeco Wreck was observed on two occasions. Movement between the Texeco Wreck and the Coral Lump was observed once, followed by movement from the Coral Lump to the South Poles. Movement between the Texeco Wreck and the South Poles was observed on four occasions. Location following displacement from the Texeco Wreck was unknown on four different occasions (double arrows).

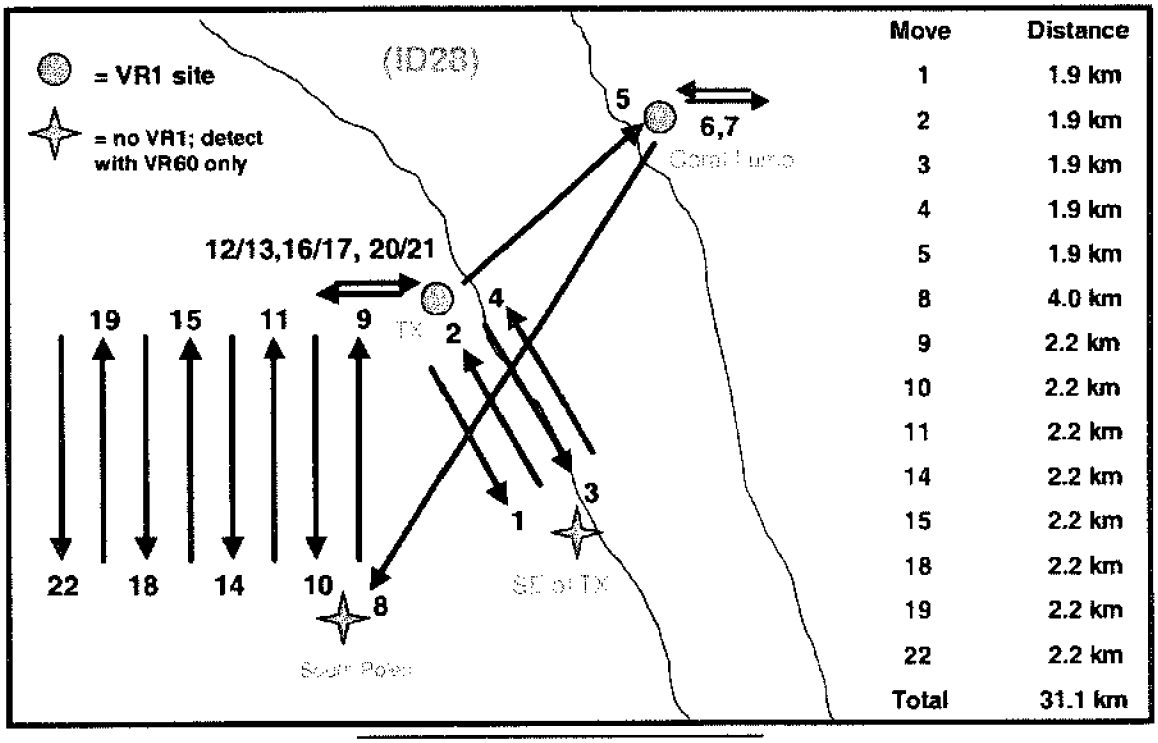
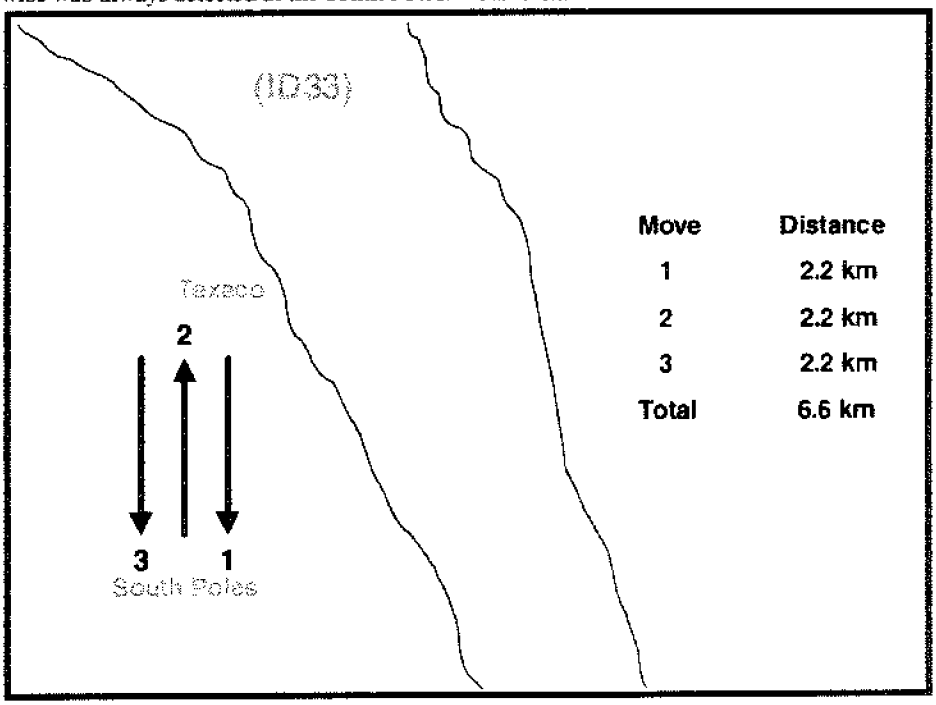


Fig. 22 Tautog 33 was released at the Texeco Wreck on 21 April 1999 and emigrated from the Texeco Wreck to the South Poles within 10 h following release. Between 21 April 1999 and 13 October 1999, tautog 33 returned to the Texeco Wreck once, otherwise was always detected at the South Poles. Total distance traveled was at least 6.6 km.



Diel Activity

Fourier Analysis of 4,096 hours (24 weeks) of observations for 16 RCODE fish released in fall 1998 (Fig. 23) and for 2,048 hours of observations (12 weeks) for 10 fish released in spring 1999 (Fig. 24) revealed very strong 24-hour periodicity.

Detection indices analysis and analysis of diel activity patterns were performed for 22 RCODE fish (n=2,671 fish-days) that remained resident at release sites. Five fish (ID19, ID20, ID28, ID33, and ID41) that moved away from release sites were excluded. Post-release recovery periods (28 fish-days in fall 1998, 11 fish-days in spring 1999) were also excluded from diel activity analysis. Additionally, six VR1 receivers were not deployed on 11 December 1998, which resulted in no data being collected for nine fish.

Daily mean detection indices (detections per hour) were greatest for daytime hours in all seasons (Fig. 25). Differences between day and night detection indices were significantly different among seasons (ANOVA, $p>0.05$, Table 13). In the late fall/early winter and spring seasons, a mean of 25 more detections per hour were recorded during daytime hours than during nighttime hours. In the winter season, a mean of 19 more detections per hour were recorded during daytime hours than during nighttime hours. In the late spring/early summer and late summer seasons, a mean of 14-16 more detections per hour were recorded during daytime hours than during nighttime hours. Differences between day and night detection indices in winter were significantly greater than differences between day and night detection indices in late spring/early summer and late summer (ANOVA, $p\leq0.05$, Table 14). Differences between day and night detection indices in late spring/early summer were not significantly different from late summer (ANOVA, $p>0.05$, Table 15).

"Diurnal" detection patterns (Fig. 26) were the predominant pattern in all seasons (Table 16). Frequency of occurrence for "diurnal" detection patterns was significantly different among seasons (Chi-square, $p\leq0.05$, Table 17). "Diurnal" detection patterns accounted for 76-80% of total fish-days in late fall/early winter and spring and 53-60% of total fish-days in the winter, late spring/early summer, and later summer seasons. Frequency of occurrence for "spike" (Fig. 26) detection patterns was significantly different among seasons (Chi-square, $p\leq0.05$, Table 18). "Spike" detection patterns accounted for 13-17% of total fish-days in the spring (spawning season) and late spring /early summer and 5-10% of total fish-days in the late fall/early winter, winter, and late summer seasons. Frequency of occurrence for "shift" (Fig. 27) detection patterns was significantly different among seasons (Chi-square, $p\leq0.05$, Table 19). "Shift" detection patterns accounted for 23-25% of total fish-days in the late spring/early summer and late summer and 3-7% of total fish-days in the late fall/early winter, winter, and spring seasons. Frequency of occurrence for "no pattern" (Fig. 28) detection patterns was significantly different among seasons (Chi-square, $p\leq0.05$, Table 20). "No pattern" detection patterns accounted for 7% of total fish-days in winter, 3-5% of total fish-days in late fall/early winter, spring, and late spring/early summer, and 0% of total fish-days in the late summer season.

Frequency of occurrence for "spike" fish-days was significantly different for lunar phase (Chi-square, $p\leq0.05$, Table 21). "Spike" detection patterns occurred on 12-14% of full and new moons (spring tides) and on 9-10% of first quarter and third quarter moons (neap tides). Frequency of occurrence for "shift" fish-days was significantly different for lunar phase (Chi-square, $p\leq0.05$, Table 22). "Shift" detection patterns occurred on 12% of first and third quarter moons (neap tides) and 8-10% of full and new moons (spring tides). Frequency of occurrence for "low detection" fish-days (see Methods, Residence) was significantly different for lunar phase (Chi-square, $p\leq0.05$, Table 23). "Non-resident" detection patterns occurred on 10% of third quarter and full moons and 5-6% of first quarter and new moons. Frequency of occurrence for "diurnal" (Chi-square, $p>0.05$, Table 24) and "no pattern" (Chi-square, $p>0.05$, Table 25) fish-days were not significantly different for lunar phase.

No relationship between changes in current speed (cm/s) and changes in hourly VR1 detections were apparent, regardless of the site fish were released or the season the data was collected (Fig. 29). Changes in current speed were computed for six, three-hour intervals during daylight hours only (0800-1600 hours), and changes in hourly detections were computed for the same six, three-hour intervals.

Table 13 One-Way Analysis of Variance (ANOVA) test for differences between day and night detection indices (late fall/early winter through late summer).

Groups	Count	Sum	Average	Variance
Late Fall/ Early Winter (11/9/98-1/14/99)	637	16095.4	25.0	602.6
Winter (1/15/99-3/21/99)	790	15176.1	19.2	570.3
Spring (3/22/99-5/27/99)	552	14519.9	26.3	364.3
Late Spring/ Early Summer (5/28/99-8/5/99)	585	9624.0	16.5	272.9
Late Summer (8/6/99-9/9/99)	107	1559.8	14.6	160.5

H_o: No difference between day and night detection indices among seasons.
F=24.6, df=2677, $p \leq 0.05$ (Significant)

Table 14 One-Way Analysis of Variance (ANOVA) test for differences between day and night detection indices (winter, late spring/early summer, and late summer).

Groups	Count	Sum	Average	Variance
Spring	790	15176.1	19.2	570.3
Late Spring/ Early Summer	585	9624.0	16.5	272.9
Late Summer	107	1559.8	14.6	160.5

H_o: No difference between day and night detection indices among seasons.
F=4.4, df=1481, $p \leq 0.05$ (Signficant)

Table 15 One-Way Analysis of Variance (ANOVA) test for differences between day and night detection indices (late spring/early summer and late summer).

Groups	Count	Sum	Average	Variance
Late Spring/ Early Summer	585	9624.0	16.5	272.9
Late Summer	107	1559.8	14.6	160.5

H_o: No difference between day and night detection indices between seasons.
F=1.24, df=691, $p > 0.05$ (NS)

Table 16 Seasonal occurrence (fish-days) of daily detection patterns. Two thousand, six hundred seventy-one daily detection records (VR1 receiver records for 22 resident RCODE tautog) were subjectively classified as one of five detection patterns.

Pattern	11/9-1/14	1/15-3/21	3/22-5/27	5/28-8/5	8/6-9/9	Total
Diurnal	487 (76%)	477 (60%)	441 (80%)	309 (53%)	64 (60%)	1778
Spike	42 (7%)	79 (10%)	69 (13%)	99 (17%)	5 (5%)	294
Shift	27 (4%)	52 (7%)	19 (3%)	147 (25%)	25 (23%)	270
No Pattern	18 (3%)	56 (7%)	23 (4%)	28 (5%)	0 (0%)	125
Low Detection	70 (11%)	126 (16%)	0 (0%)	2 (0%)	13 (12%)	204
Total	637	790	552	585*	107	2671

*fall released (20 fish-days) and spring released (565 fish-days) fish combined.

Table 17 Chi-square contingency test for seasonal effects on the frequency of occurrence of the "diurnal" detection pattern.

	11/9-1/14	1/15-3/21	3/22-5/27	5/28-8/5	8/6-9/9	Total
Diurnal	487	477	441	309	64	1778
Other	150	313	111	276	43	893
Total	637	790	552	585*	107	2671

*fall released (20 fish-days) and spring released (565 fish-days) combined.

H_o: No difference in the frequency of "diurnal" fish-days among seasons.
Chi-sq=137.46, df=4, $p \leq 0.05$ (Significant)

Table 18 Chi-square contingency test for seasonal effects on the frequency of occurrence of the "spike" detection pattern.

	11/9-1/14	1/15-3/21	3/22-5/27	5/28-8/5	8/6-9/9	Total
Spike	42	79	69	99	5	294
Other	595	711	483	486	102	2377
Total	637	790	552	585*	107	2671

*fall released (20 fish-days) and spring released (565 fish-days) combined.

H_o: No difference in the frequency of "spike" fish-days among seasons.
Chi-sq=40.01, df=4, $p \leq 0.05$ (Significant)

Table 19 Chi-square contingency test for seasonal effects on the frequency of occurrence of the "shift" detection pattern.

	11/9-1/14	1/15-3/21	3/22-5/27	5/28-8/5	8/6-9/9	Total
Shift	27	52	19	147	25	270
Other	610	738	533	438	82	2401
Total	637	790	552	585*	107	2671

*fall released (20 fish days) and spring released (565 fish days) combined.

H_o: No difference in the frequency of "shift" fish-days among seasons.
Chi-sq=227.89, df=4, $p \leq 0.05$ (Significant)

Table 20 Chi-square contingency test for seasonal effects on the frequency of occurrence of the "no pattern" detection pattern.

	11/9-1/14	1/15-3/21	3/22-5/27	5/28-8/5	8/6-9/9	Total
Non-Diel	18	56	23	28	0	125
Other	619	734	529	557	107	2546
Total	644	790	552	585*	107	2671

*fall released (20 fish days) and spring released (565 fish days) combined.

H_o: No difference in the frequency of "no pattern" fish-days among seasons.
Chi-sq=20.78, df=4, $p \leq 0.05$ (Significant)

Table 21 Chi-square contingency test for lunar effects on the frequency of occurrence of the "spike" detection pattern.

	1Q	3Q	FM	NM	Total
Spike	62	59	96	77	294
Other	586	621	602	568	2377
Total	648	680	698	645	2671

H_o: No difference in the frequency of "spike" fish-days with lunar phase.
Chi-sq=11.09, df=3, $p \leq 0.05$ (Significant)

Table 22 Chi-square contingency test for lunar effects on the frequency of occurrence of the "shift" detection pattern.

	1Q	3Q	FM	NM	Total
Shift	75	80	53	62	270
Other	573	600	645	583	2401
Total	648	680	698	645	2671

H_o: No difference in the frequency of "shift" fish-days with lunar phase.
Chi-sq=8.62, df = 3, $p \leq 0.05$ (Significant)

Table 23 Chi-square contingency test for lunar effects on the frequency of occurrence for the "low detection" detection pattern.

	1Q	3Q	FM	NM	Total
Low Detection	37	66	69	32	204
Other	611	614	629	613	2467
Total	648	680	698	645	2671

H_o: No difference in the frequency of "low detection" fish-days with lunar phase.
Chi-sq=19.09, df = 3, $p \leq 0.05$ (Significant)

Table 24 Chi-square contingency test for lunar effects on the frequency of occurrence of the "diurnal" detection pattern.

	1Q	3Q	FM	NM	Total
Diurnal	437	436	454	451	1778
Other	211	244	244	194	893
Total	648	680	698	645	2671

H_o: No difference in the frequency of "diurnal" fish-days with lunar phase.
Chi-sq=6.05, df = 3, $p > 0.05$ (NS)

Table 25 Chi-square contingency test for lunar effects on the frequency of occurrence of the "no pattern" detection pattern.

	1Q	3Q	FM	NM	Total
No Pattern	37	39	26	23	125
Other	611	641	672	622	2546
Total	648	680	698	645	2671

H_o: No difference in the frequency of "no pattern" fish-days with lunar phase.
Chi-sq=6.46, df = 3, $p > 0.05$ (NS)

Fig. 23 Fourier analysis of detection periodicity for 4,096 consecutive hours of detections from 13 tautog released in fall 1998. A 24 h periodicity is evident

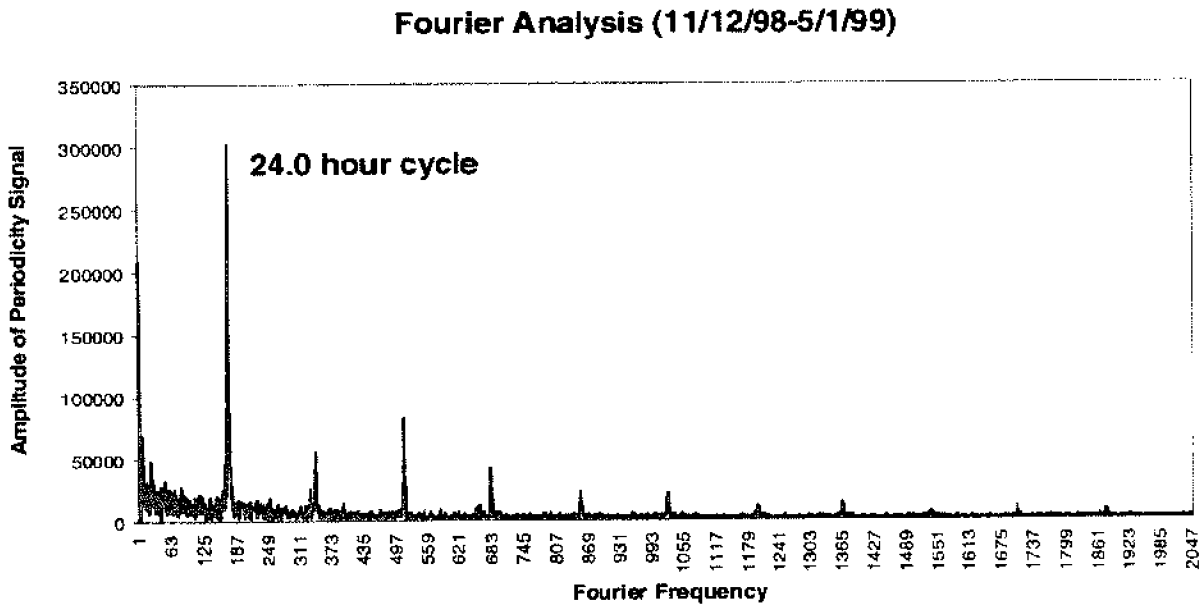


Fig. 24 Fourier analysis of detection periodicity for 2,048 consecutive hours of detections from 9 tautog released in spring 1999. A 24 h periodicity is evident.

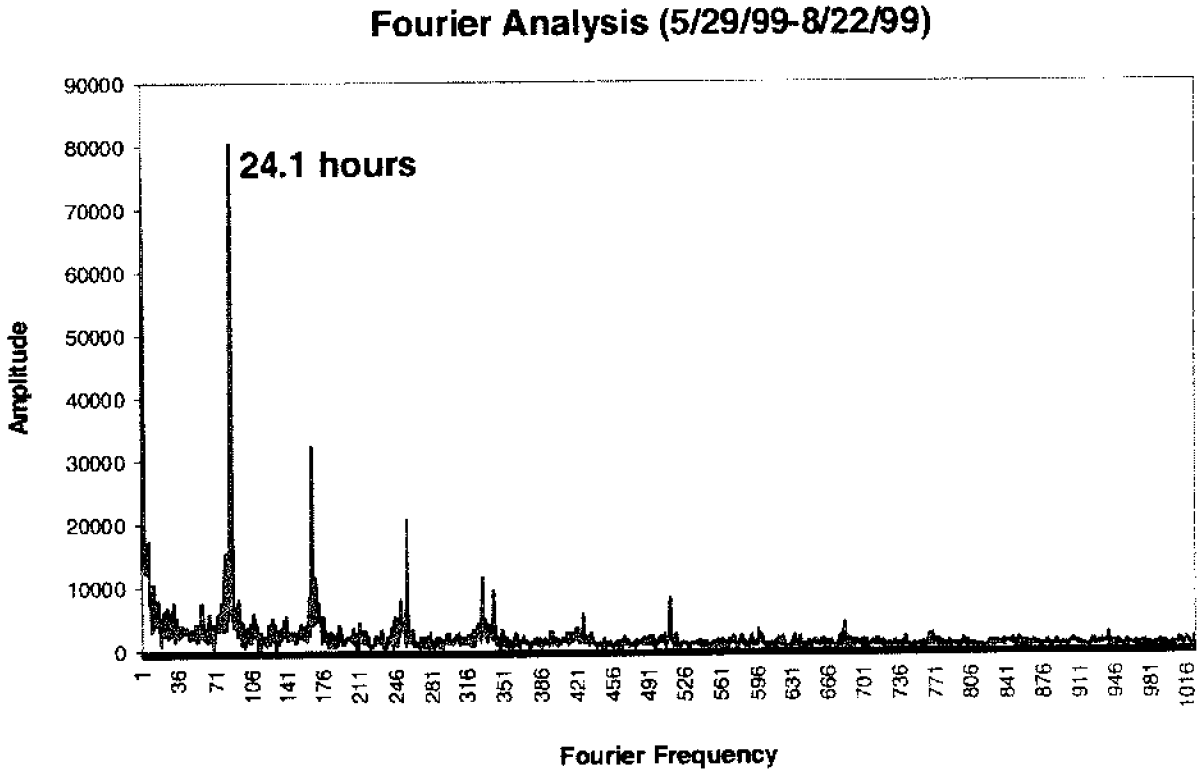


Fig. 25 Daily mean detection indices for fall (n=13) and spring (n=9) released tautog, 9 Nov 1998 to 9 Sept 1999. Detection indices were computed by dividing the total number of daylight detections by the total number of daylight hours (day) and by dividing the total number of nighttime hours by the total number of nighttime hours (night). Daily detection indices (day, night) for all tautog were used to determine daily mean indices.

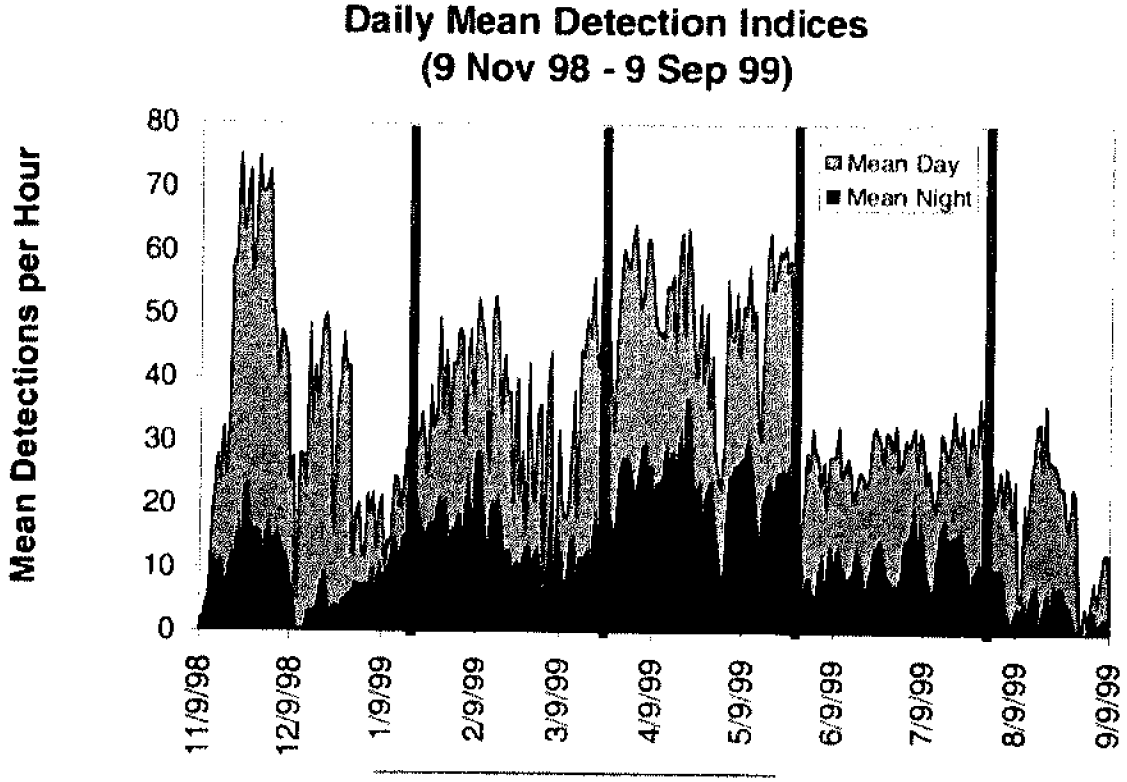


Fig. 26 "Diurnal" and "spike" detection patterns. "Diurnal" patterns consist of detections between 0400-2059 hours only, with a curved shape similar to a bell-shaped curve. "Spike" patterns contain the basic "diurnal" pattern, but there is also at least one peak in detections between 2100-0359 hours when ≥ 10 detection/hr occur.

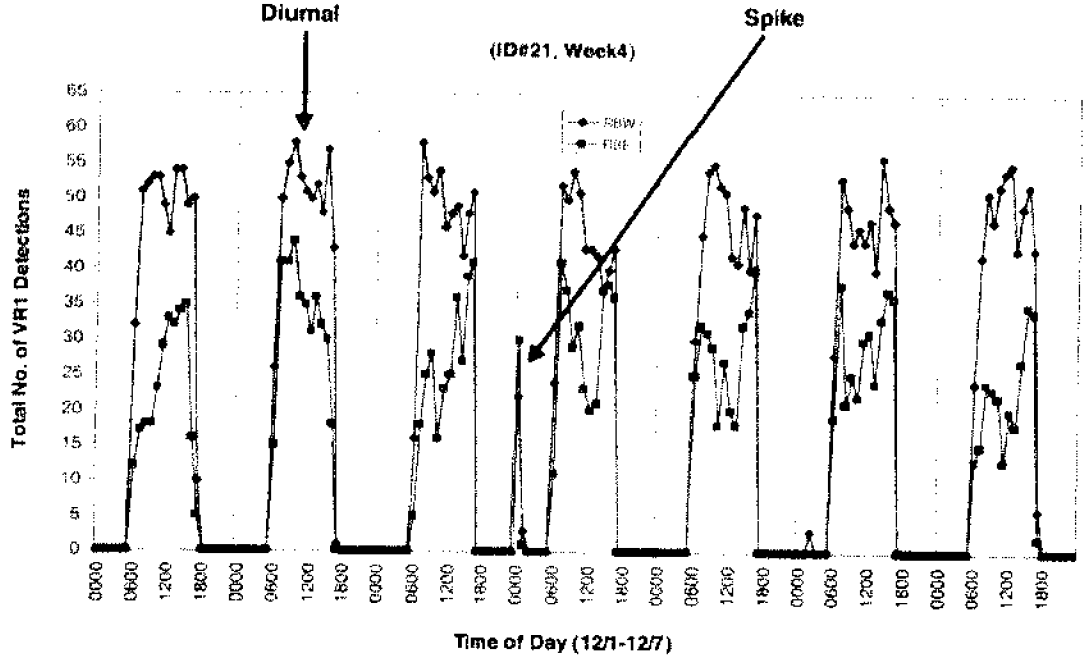


Fig. 27 "Shift" detection pattern. "Shift" patterns are similar to "diurnal" patterns, but detections do not exclusively occur between 0400-2059 hours. "Shift" patterns can begin one day and end the next day (black circle) or "shift" patterns can begin and end on the same day (grey circle)

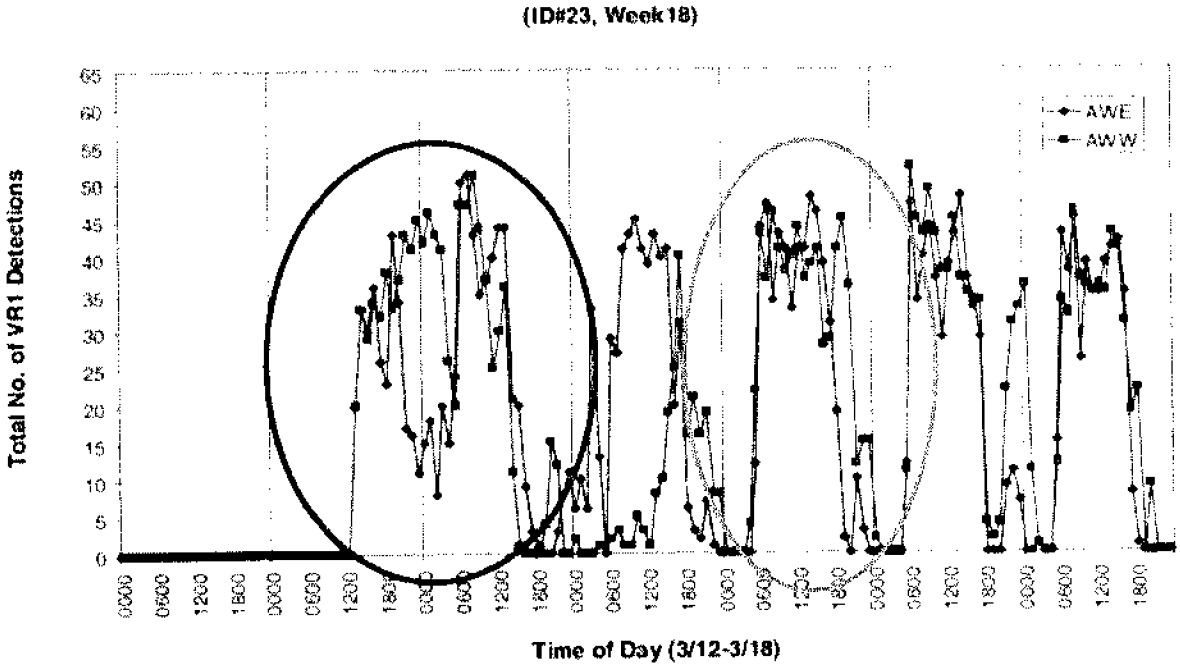


Fig. 28 "No Pattern" detection pattern. A "no pattern" classification was assigned when no pattern was evident between 0000-2359 hours (circle = "no pattern" days)

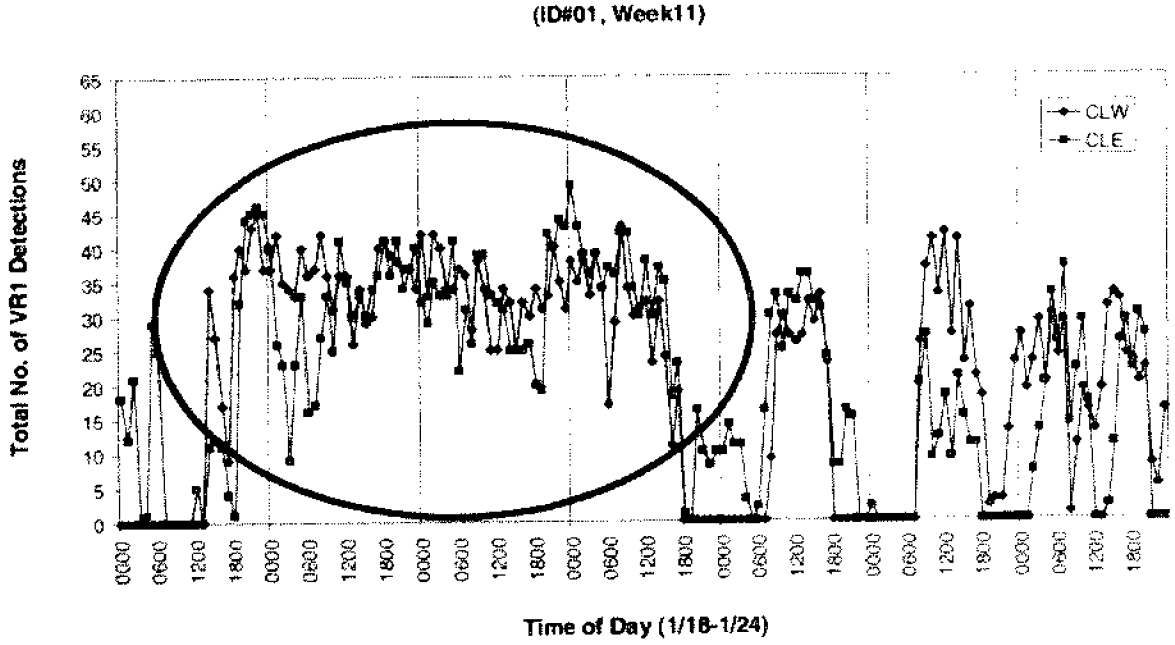
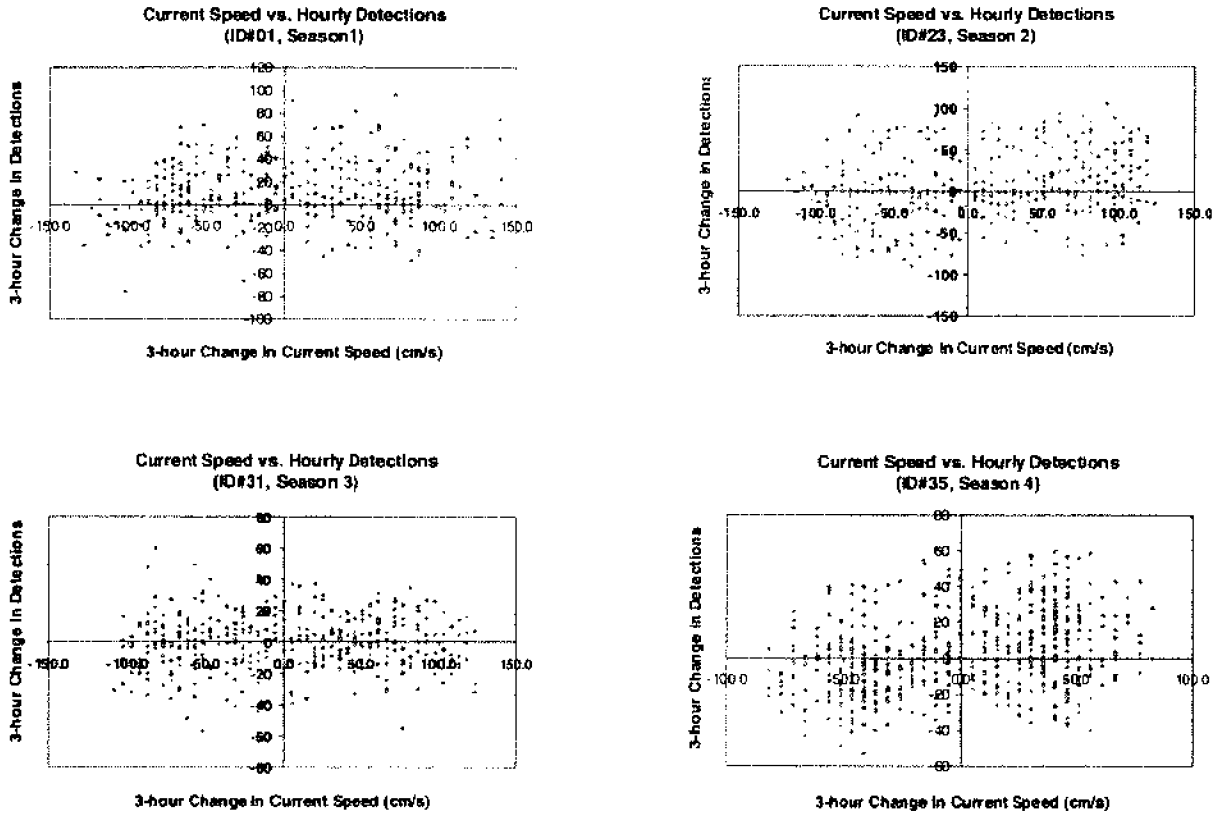


Fig. 29 Example scatter plots of current speed (cm/s) versus hourly detections. Differences in current speed were computed for six, three-hour intervals: 1600-1300, 1500-1200, 1400-1100, 1300-1000, 1200-0900, and 1100-0800 hours. Differences in hourly VR1 detections were computed for the same six, three-hour intervals. No relationship between current speed and hourly detections were apparent, regardless of site or season data was collected.



DISCUSSION

Residence and Movements

Tautog released near Cape Charles, VA, were highly resident inshore and exhibited high site affinity. Seventy percent (n=23) of all tautog released remained at their respective release sites for up to 6 months (transmitter battery life) and were never detected or recaptured away from their respective release sites. Eighteen RCODE fish (67% of total RCODE fish) were detected daily by VR1 receivers at release sites, except occasionally at minimum water temperatures (5-7°C) in the winter and during periods of rapid decrease in surface water temperature in the late summer (see Discussion, Diel Activity). Seven RCODE fish released in April-June 1999 were recaptured in October-November 1999 at the same sites where originally released. Tautog tagged with FCODE transmitters could only be detected with the VR60 receiver. Five FCODE fish (83% of total FCODE fish) were always detected at release sites on subsequent boat trips to release sites for up to 2 months (transmitter battery life).

Tautog remained in the general vicinity of release sites during the day. Similar detection patterns were almost always recorded by both VR1 receivers at release sites, indicating that tautog remained within the central signal reception area (Fig. 7) of both VR1 receivers. Tautog were previously reported to remain within 500 m of home sites during the day (Olla et al., 1974). Remaining in the general vicinity of release sites has also been documented for large temperate labrids from the Southern Hemisphere. Barrett (1995) reported four labrid species (*Notolabrus tetricus, Notolabrus fucicola, Pictilabrus laticlavius, Psuedolabrus psittaculus*) in Tasmania were recaptured within 100 m x 25 m areas from where the fish were released. The pattern of remaining close to release sites during the day is consistent with 'fixes' obtained for FCODE fish.

Occasionally, one VR1 receiver recorded substantially more detections for individual fish than did the other receiver at the same site. This receiver discrepancy scenario may have been due to exclusive occupancy of one side of the site, or due to the presence of an acoustic barrier (i.e., structured material) which interfered with line-of-sight reception. Significant vertical relief

(1-3 m) only occurred at the Texeco Wreck. Discrepancies between receivers were most frequently observed at this site. Extended periods of detections of individual fish by one receiver only were uncommon. These events may have resulted when a particular fish moved away from the site such that it was within range of one receiver, but out of range of the other receiver. Tautog were rarely detected with the VR60 receiver out of the central reception area. Close association of tautog with structure during the daytime was previously reported by Adams (1993), who observed that tautog exclusively occupied the reef crest and reef edge habitats at a wreck 15 km off the coast of Virginia.

Tautog remained at or in the vicinity of release sites at night. Tautog were generally not detected by VR1 receivers at night, however, on several occasions one VR1 receiver detected an individual fish at night while the other VR1 receiver only detected the same fish during the day. Tautog were more difficult to detect at night using the VR60 receiver. Coded transmitters used in this study would be less likely to be detected by VR1 receivers when hidden behind or in structure because all six 'pings' of the transmitter code must be recognized as opposed to a standard single 'ping'. Successful detection of tagged fish known to be within range of VR1 receivers was significantly less during nighttime hours than during the day (Table 5). Researchers using ultrasonic telemetry equipment report increased difficulty detecting tagged animals when animals hide in or under structured material (Matthews 1992; Bradbury et al. 1995,1997). These data support the idea that tautog were detected less often (or not at all) at night because fish were quiescent in or near structure (Olla et al. 1980), and therefore effectively out of range of VR1 receivers due to the presence of an acoustic barrier.

Tautog in this study remained inshore during the winter, at sustained water temperatures between 5-8°C. Inshore, winter residence of tautog has been documented in eastern Long Island Sound (Auster, 1989), in Delaware Bay (Eklund and Targett 1991), and in the lower Chesapeake Bay (Hostetter and Munroe 1993). Provided water temperatures remain above 9-10°C, a viable inshore winter fishery for tautog exits in the lower Chesapeake Bay (White et al., 1997). The occurrence of an inshore winter fishery for tautog in Virginia is unique within its geographic distribution. Within the winter fishery, most inshore landings occur in December and March; January and February landings are primarily from offshore sites (White et al. 1997). Inshore catches of tautog in December and March occur predominantly near the mouth of the bay (Bain and Lucy 1996, 1997, Bain et al. 1998; Lucy et al. 1999). Tautog have been caught as far west as the Monitor-Merrimac Bridge-Tunnel in the James River in January and as far north as Cape Charles in December (Bain et al. 1998; Lucy and Arendt 1999).

Tautog remained inshore during the summer at a maximum sustained water temperature of 27°C, contrary to the suggestion that tautog move to cooler water when water temperatures approach 20°C (Adams 1993). Hager (pers. comm.) observed tautog (some swimming, others resting) at Plantation Light (2 km southeast of the Texeco Wreck) in July 1999 while snorkeling. Summer, inshore residence of tautog was previously documented in the Chesapeake Bay (Bain and Lucy 1996, 1997, Bain et al. 1998). Summer, inshore residence has also been documented in Great South Bay, NY, when water temperature was 19-24°C (Olla et al. 1978) and in Narragansett Bay, RI, at maximum sustained water temperatures of 22°C (Castro pers. comm.).

Tautog remained inshore during the summer in the absence of blue mussels (*Mystilus edulis*), contrary to the suggestion of Steimle and Shaheen (1999) that tautog move away from sites when blue mussels die off. In June 1998-1999, large clusters of live blue mussels were documented at study sites using underwater video, otter trawl and oyster dredge tows, and growth of mussels on VR1 mooring units. By July 1998-1999, mussels were not present. At an artificial fishing reef near Cape Charles, VA, Feigenbaum et al. (1985) reported tautog consumed a variety of crustaceans, shellfish, bryozoans, and hydroids. Tautog have been reported to feed on hardshelled organisms attached to bryozoans and to consume bryozoans in the process (Osburn, 1921). Stomach contents from an ultrasonically tagged tautog recaptured in October 1999 at the Ridged Bottom site consisted primarily of the bryozoan, *Alcyinidium verilli*, commonly known as "dead mans fingers" (Fig. 12).

Fifteen percent (n=5) of fish released in fall 1998 were detected substantially fewer days (one of which was later recaptured) than other fish in the study released at the same time. It was unclear whether these fish were never detected again due to movement away from release sites or due to transmitter failure. Winter (pers. comm.) suggested that a 15% transmitter failure rate should be expected; however, transmitter failure is usually detected within several days after transmitter activation (Winter pers. comm.). Coded transmitters used in this study dramatically exceeded manufacturer's expectations for battery life. Information on transmitter failure rates for the coded transmitters used in this study were not available. Researchers using similar transmitters made by the same manufacturer used in this study report much lower (0-6%) transmitter failure rates (Holland et al. 1993; Pearcy 1992; Zeller 1997) than suggested by Winter (1999). Transmitter failure rates for transmitters made by the same manufacturer used in this study have been reported to be as high as 18% (Matthews 1992).

Eighteen percent (n=6) of all tautog released moved 1.9-10.2 km away from release sites. No movement of tagged fish to offshore locations was documented. Of fall

released tautog, only four could have possibly moved offshore during the late fall/early winter. The first of these tautog (ID20) was detected at the Texeco Wreck less than three hours after release on 10 November 1998. No further information was available regarding this fish until 27 April 1999, when it was recaptured 10.2 km northeast of the Texeco Wreck. This fish potentially could have moved offshore in the winter, then returned inshore in the spring; however, no conclusions can be made regarding residence or movement between release and recapture. A second tautog (ID3) was detected at the Airplane Wreck between 8-15 December and then was never detected again. Two FCODE fish (ID2, ID14) remained resident until early January and early February, respectively. Both of these fish were detected substantially longer than expected; however, these fish could have theoretically moved after transmitter expiration.

Only four ultrasonically tagged tautog released in spring 1999 could have possibly moved offshore in the summer. Three FCODE fish remained highly resident at release sites between late April and early June and were detected substantially longer than expected. These fish could have theoretically moved after transmitter expiration; however, one (ID6) was recaptured at the Texeco wreck on 18 Nov. 1999, 211 days after being released at the Texeco wreck. A fourth fish, tautog 41 was released at the Airplane Wreck on 7 June 1999, where it remained until 13 June 1999. This fish was detected at the Texeco Wreck between 15-17 June 1999 (VR1 receivers), but was never detected again, at any site, after 17 June 1999.

All documented movements (n=6) of tautog away from release sites occurred at manmade sites. No information was available regarding the origin of these two manmade sites; however, both have been in place for at least 20 years. The Texeco Wreck was present prior to 1967 (NOS, 1998) and the Airplane Wreck was present prior to 1980 (Jenrette, pers. comm.). Benthic macrofauna collected at manmade sites was similar to macrofauna collected at natural sites (Fig. 4). Stone et al. (1979) concluded that artificial reefs reach a stable state after at least five years. Given this argument, habitat size may be as important a factor in determining movement as habitat materials. Two additional fish released at the Airplane Wreck and two additional fish released at the Ridged Bottom were detected much less than other fish released at the same time and may have moved in mid-December (ID3), mid-February (ID21, ID30), and mid-April (ID32). Percent movement of fish away from release sites was highly correlated (R^2=0.97) with habitat area when these four fish were assumed to have moved away from release sites (Fig. 15).

Movement patterns were qualitatively different between northernmost sites and southernmost sites. Location of one tautog (ID20) that moved away from the Texeco Wreck on the day of release was not known until this fish was recaptured 169 days later. Three other tautog that emigrated away from the Texeco Wreck returned at least once (ID33) or several times at 1-3 week intervals (ID19, ID28). Tautog that alternated between the South Poles and the Texeco Wreck were resident at the Texeco Wreck between 0.1% and 37% of the total days between release and day of last detection. When not detected at the Texeco Wreck, attempts to locate these fish at the South Poles were always successful, indicating high site affinity for both sites. Both fish that moved away from the Airplane Wreck did not return to the Airplane Wreck. Tautog 29 remained resident at the Airplane Wreck from 18 November 1998 until 12 May 1999, but was recaptured in a gill net 2 km east of the Airplane Wreck on 19 May 1999. The second tautog (ID41) that moved away from the Airplane Wreck was released on 7 June 1999 and was detected at this site until 13 June 1999. Between 15-17 June, this fish was detected at the Texeco Wreck. Between 17 June 1999 and 13 October 1999 (when both VR1 receivers at this site were retrieved), this fish was not detected at the Airplane Wreck. This fish was also not detected at any other sites monitored by VR1 receivers (Texeco Wreck VR1 coverage until 9 September 1999; Ridged Bottom and Coral Lump VR1 coverage until 5-6 August 1999).

Differences in movement patterns of tautog at northernmost sites may have been related to their closer proximity to an existing artificial fishing reef. In October 1998, artificial reef materials were added to Cherrystone Reef, located approximately 5km northeast of the Airplane Wreck and 4 km north of the Ridged Bottom (Meier, pers. comm.). One attempt was made (10 February 1999) to locate ultrasonically tagged tautog at Cherrystone Reef. No tautog were detected at Cherrystone Reef that day, however, this was prior to the disappearance of two fish from the Ridged Bottom and Airplane Wreck sites in mid-February and recapture of two tautog within 2 km of Cherrystone Reef in April-May 1999. Studies on the colonization of artificial reefs document higher exploitation rates by fishers at artificial reefs (Low and Waltz 1991) and uni-directional movement of tagged fishes from natural reefs to artificial reefs (Matthews 1985; Solonsky 1985; Fast and Pagan 1974). Olla et al. (1974) reported uni-directional movement of an ultrasonically tagged tautog moved rapidly to an artificial fishing reef late in the second day of tracking.

Inshore residence and movement patterns exhibited by ultrasonically tagged tautog were also consistent with patterns reported for tautog released at these sites from the Virginia Game Fish Tagging Program (Table 26). Between April 1998 – October 1999, 40 tautog tagged-released at these sites were recaptured, including one tautog recaptured twice (ID29). Six fish tagged-released at the Texeco and Airplane Wrecks were recaptured away from these sites and two fish tagged-released at these sites were recaptured at these sites. Of the six fish that moved away from these sites, three fish moved to the Coral Lump and Ridged Bottom/Mussel Beds; the remaining three fish moved to sites 26.9-43.2 km away.

Thirty-two fish tagged-released at the Coral Lump and Ridged Bottom/Mussel Beds sites were recaptured, all but two of which were recaptured where released. Two fish moved from the Ridged Bottom to the Coral Lump. One additional fish moved to the Coral Lump from the 38A buoy near Cherrystone Reef.

Inshore residence and movement patterns exhibited by ultrasonically tagged and conventionally tagged tautog at these sites were also consistent with large-scale patterns reported from the Virginia Game Fish Tagging Program. Between 30 March 1995 and 11 October 1999, 563 tautog (tagged in lower Chesapeake Bay, excluding Cape Charles sites, and offshore) were recaptured. Eighty-five percent (n=476) of recapture events involved fish recaptured at the same sites where released 0-1,214 days earlier (Lucy et al., 1999). Multiple recapture of the same tagged individual at the same site where originally released occurred on more than 20 occasions (Baum et al., 1998). Only five percent of total recapture events involved movement of tagged tautog between inshore and offshore locations (n=23). Fifteen tautog tagged inshore were recaptured offshore (17-97 km away), including five fish released at sites other than where caught (Baum et al., 1998), between 21 and 333 days later. Eight tautog tagged offshore were recaptured inshore (8-76 km away) between 21 and 731 days later. All other movements occurred within inshore areas (n=27, 25-618 days later) or within offshore areas (n=23, 11-409 days later) between sites located <1 to 68 km apart. Rate of movement between sites from within inshore or within offshore areas varied between <1 to 3 km per day (VGFTP, unpublished data).

Adult tautog from northern populations appear to spend the spring and fall months inshore, but may move offshore during the warmest summer months and again during the coldest winter months. Stolgitis (1970) reported strong correlation between water temperature and adult tautog catches in the Wewantic estuary, MA, when water

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Table 26 Recaptured tautog tagged and released at sites near Cape Charles, VA (VGFTP, 1997-1999)

Released	Location	Recaptured	Location	Days Out
10/27/98	38A Buoy (Old C-12 Buoy)	11/17/98	Coral Lump off Cape Charles	21
11/18/98	Airplane Wreck	12/07/98	Airplane Wreck	19
12/17/97	Airplane Wreck	04/29/98	Cape Henry Wreck	133
12/17/97	Airplane Wreck	10/02/99	Coral Lump off Cape Charles	654
12/17/97	Coral Lump off Cape Charles	11/01/98	Coral Lump off Cape Charles	319
12/17/97	Coral Lump off Cape Charles	11/29/98	Coral Lump off Cape Charles	347
10/30/98	Coral Lump off Cape Charles	11/08/98	Coral Lump off Cape Charles	9
11/08/98	Coral Lump off Cape Charles	12/10/98	Coral Lump off Cape Charles	32
12/17/97	Coral Lump off Cape Charles	11/28/98	Unidentified off Cape Charles	346
12/17/97	Coral Lump off Cape Charles	11/28/98	Unknown	346
12/17/97	Texeco Wreck	05/11/99	CBBT, 3rd Island	510
12/05/97	Texeco Wreck	05/21/99	CBBT, 4th Island	532
12/10/97	Texeco Wreck	10/25/98	Mussel Beds	319
12/05/97	Texeco Wreck	11/20/98	Texeco Wreck	350
12/17/97	Texeco Wreck	10/24/98	Thimble Shoals Light	311
10/27/98	Mussel Beds	10/27/98	Coral Lump off Cape Charles	0
10/30/98	Mussel Beds	12/10/98	Coral Lump off Cape Charles	41
11/20/97	Mussel Beds	10/10/98	Mussel Beds	324
11/25/97	Mussel Beds	10/27/98	Mussel Beds	336
11/25/97	Mussel Beds	11/09/98	Mussel Beds	349
11/25/97	Mussel Beds	11/09/98	Mussel Beds	349
10/12/98	Mussel Beds	11/09/98	Mussel Beds	28
10/12/98	Mussel Beds	11/10/98	Mussel Beds	29
10/12/98	Mussel Beds	11/14/98	Mussel Beds	33
11/09/98	Mussel Beds	11/10/98	Mussel Beds	1
11/09/98	Mussel Beds	12/07/98	Mussel Beds	28
11/09/98	Mussel Beds	10/02/99	Mussel Beds	327
12/02/98	Mussel Beds	09/14/99	Mussel Beds	286
12/04/98	Mussel Beds	09/14/99	Mussel Beds	284
12/12/98	Mussel Beds	10/02/99	Mussel Beds	294
05/06/99	Mussel Beds	06/09/99	Mussel Beds	34
09/26/99	Mussel Beds	10/02/99	Mussel Beds	6
09/26/99	Mussel Beds	10/03/99	Mussel Beds	7
09/26/99	Mussel Beds	10/03/99	Mussel Beds	7
09/26/99	Mussel Beds	10/03/99	Mussel Beds	7
09/26/99	Mussel Beds	10/03/99	Mussel Beds	7
09/26/99	Mussel Beds	10/03/99	Mussel Beds	7
10/02/98	Mussel Beds	10/03/99	Mussel Beds	1
10/30/98	Mussel Beds	12/07/98	Off Cape Charles	38
10/27/98	Mussel Beds	11/28/98	Unidentified off Cape Charles	32
10/27/98	Mussel Beds	11/28/98	Unknown	32

temperature was 7°C. Cooper (1966) and Lynch (1995) reported movement of tautog into Narragansett Bay to spawn between late April and June. Tautog depart inshore waters at varying rates between July and October (Cooper 1966; Lynch 1995). By mid-fall, fish are recaptured in offshore coastal waters or recaptures are highly directional, indicating movement offshore (Cooper 1966; Briggs 1977). Only limited evidence of a seasonal inshore - offshore migration exists for tautog in the Chesapeake Bay and coastal Virgina waters (Bain et al. 1998). In Virginia and Maryland, tautog have been observed offshore throughout the year and in spawning condition during the spawning season (Eklund and Targett 1990, 1991; Hostetter and Munroe 1993; White, 1996). Tag-recapture studies, ultrasonic telemetry, and seasonal abundance data from different studies over time, suggest that adult tautog in the lower Chesapeake Bay and coastal Virginia waters remain inshore or offshore year-round.

Diel Activity

Tautog were detected significantly more during daylight hours than during nighttime hours, indicating diurnal activity and nocturnal quiescence, a behavior previously documented for tautog (Olla et al., 1974) and for other labrids (Hobson, 1965; Bradbury et al., 1997). Field studies on diel activity of tautog report that tautog are active during the day and inactive and quiescent at night, at least between July and October (Olla et al., 1974). Onset of diel activity was reported to begin between 10 minutes prior to and 69 minutes after the start of morning twilight; cessation of activity was more variable and activity ceased between 222 minutes prior and 69 minutes after evening twilight. Inactivity and unresponsiveness of fish at night were so low that SCUBA divers were able to touch fish or catch them easily with hand-held nets (Olla et al., 1974). Controlled, laboratory observations also report tautog are active during the day and inactive and quiescent at night during the non-reproductive and non-migratory season (Olla et al., 1977, 1978; Olla and Studholme, 1978) when mean water temperatures were 13.9-15.8°C and mean photoperiod was 15.4-15.7h.

In this study, a mean of 14-16 more detections per hour were recorded during daytime hours than nighttime hours during the late spring/early summer and late summer seasons. Fifteen more detections per hour approximated to being detected 25% more during each hour of daylight than during each hour at nighttime. Mean surface water temperature was 23.5°-25.7°C in the summer. Maximum photoperiod (14.8 h) was less than reported for these seasons by Olla et al. (1977, 1978) and Olla and Studholme (1978) because the current study defined photoperiod as sunset minus sunrise, without inclusion of twilight. "Diurnal" detections constituted 53-60% of fish-days during the summer.

"Diurnal" detection patterns usually contained fewer detections during mid-day hours than in the early morning or early evening. Decline in detections during mid-day hours may have been related to fish resting during maximum sunlight. Bradbury et al. (1997) reported that cunner rested at daytime resting sites during maximum sunlight. At Plantation Light (2 km southeast of the Texeco Wreck), Hager (pers. comm.) observed some tautog moving about during mid-day while other tautog rested. Tautog that rested were observed oriented head first into rock crevices, such that their head and eyes were secluded from light while their bodies remained exposed. Orientation of fish head-first into crevices may result in transmitter signal attenuation due to the fact that the transducer-end of the transmitter was also pointed towards the head of the fish.

Decreased detections during mid-day hours may also have been related to current speed; however, no relationship between changes in current speed and hourly detections (0800-1600 hours) was apparent. The inability to detect the influence of currents on activity may have been a result of the type of information obtained from VR1 receivers. VR1 receivers only recorded date, time, and ID of each fish detected, thus providing information on the presence or absence of tagged individuals only, which may or may not reflect actual activity. Sensitivity of tautog to tidal flow has been documented during the spawning season. White (1996) reported daily spawning incidence to be highly correlated with ebb tides. An alternative explanation for the inability to detect a relationship between current speeds and hourly detections is that no relationship existed. Lindquist and Pietrafesa (1989) reported that benthic reef species (*Haemulon aurolineatum* and *Diplodus holbrooki*) showed no statistically significant abundance in relation to current field at a reef located at 18m depth in Onslow Bay, NC.

"Diurnal" detection patterns were most dominant in the late fall/early winter and spring (76-80% of total fish-days). Differences between day and night detection indices were greatest in the late fall/early winter and spring seasons.In the late fall/early winter and spring seasons, 25 more detections per hour were recorded during daytime hours than during nighttime hours. Twenty-five more detections per hour are approximately equal to being detected 50% more during each hour of daylight than during nighttime hours. Given that these seasons also correspond to the primary fishing seasons for tautog in the Chesapeake Bay (White et al. 1997), increased detections during these seasons may correspond to increased fish activity.

Nocturnal activity was observed on 20% of fish-days in the spring, 47% of fish days in the late spring/early summer, and 28% of fish-days in the late summer, 13% of fish-days in the late fall/early winter, and 24% of fish-days in winter. Nocturnal activity in the late fall was previously reported at water temperatures between 6-7°C, when tautog were observed to swim in schools through the night (Olla et al. 1978, 1980; Olla and Studholme 1978). Nocturnal activity was observed infrequently. In this

study, nocturnal activity during the winter was observed on 24% of fish-days and at the same temperatures (6-8°C) reported by Olla et al. (1977, 1980) and Olla and Studholme (1978) for nocturnal activity during the late fall. Nocturnal activity has been reported during the spawning season (Olla and Studholme, 1978). In the Chesapeake Bay, tautog spawn between mid-April and early June (Hostetter and Munroe, 1993; White, 1996; White et al., 1997). Although nocturnal detections were observed during the spawning season, nocturnal detections during the spawning season (spring) were less frequently observed than during the summer months.

Nocturnal activity occurred as a "spike", "shift", or "no pattern" detection pattern. Frequency of occurrence for "spike" detection patterns was greatest in the spring and late spring/early summer seasons, during which spawning occurs. "Spike" detection patterns occurred during 14% of full moons and 12% of new moons. New moons and full moons correspond to spring tides. Given the sensitivity of tautog to tidal cycles during the spawning season, increase in frequency of occurrence of "spike" detection patterns during spring tides in the spawning season may result from tautog becoming active at night in response to strong tidal cycles. An alternative explanation for the increase in "spike" detection patterns with full moons is increased illumination at night.

Frequency of occurrence for "shift" detection patterns was greatest in the late spring/early summer and late summer seasons, occurring on 23-25% of total fish-days. Given the low frequency of occurrence of this detection pattern in other seasons (3-7% of fish-days), increase in "shift" detection patterns in late spring/early summer and late summer likely resulted from maximum photoperiod experienced during these seasons. "Shift" detection patterns in the late fall/early winter, winter, and spring seasons may have resulted from fish becoming less active during the day and more active at night, as previously discussed. "Shift" detection patterns were also significantly greater during first and third quarter moons. First quarter moon generally rise between 1200-1800 hours and set between 0000-0600 hours. Third quarter moons generally rise between 0000-0600 hours and set between 1200-1800 hours. Given these definitions, late first quarter moons rise during evening twilight and late third quarter moons rise during morning twilight. "Shift" patterns may have been greater during these moon phases due to increased illumination during twilight, thus, effectively extending daylight.

Frequency of occurrence for "no pattern" detection patterns was greatest in the winter. More than half of the occurrences of this detection pattern were attributed to two fish (ID27, ID29). It was unclear whether this pattern represented continuous activity throughout the day and night or whether this detection pattern represented inactive fish resting outside of structure in a location accessible to VR1 receivers. Tautog monitored in aquarium tanks during this study also showed grouping behavior and tendency to rest outside of structure at water temperatures between 5-9°C. The pattern of swimming through the night at low water temperatures and the pattern of resting outside of structure at low temperatures are both reported in the literature for this species. Olla et al. (1977, 1980) and Olla and Studholme (1978) observed tautog swimming through the night in schools when water temperature was between 6-8°C. Olla et al. (1977, 1980) and Olla and Studholme (1978) also observed tautog grouped together and remaining outside of or slightly under structure at temperatures between 3-5°C. Adams (1993) reported tautog to be sluggish when bottom water temperatures were between 6.1°C and 7.2°C.

Tautog were detected daily except occasionally at the coolest water temperatures in the winter or after rapid decrease in surface water temperature (from 26°C to 23°C) in late August 1999. Frequency of occurrence of these "low detection" patterns at the coolest water temperatures in the winter was consistent with previous reports on intermittent activity of tautog during the winter (Cooper, 1966; Olla and Studholme, 1978; Olla et al., 1977, 1980; Adams, 1993). Significance of these "low detection" days with lunar phase during winter may have been coincidental. The coolest water temperatures of the winter occurred during a two-week period in early-mid January and again during a two-week period in early-mid March. Because the second cold spell occurred exactly two complete lunar cycles after the first cold spell, "low detection" days appeared to be significantly greater in two consecutive (full moon and third quarter) moon phases. Frequency of occurrence for "low detection" events in response to rapid decreases in surface water temperature in the late summer has not previously been reported, although Adams (1993) may have observed this phenomenon.

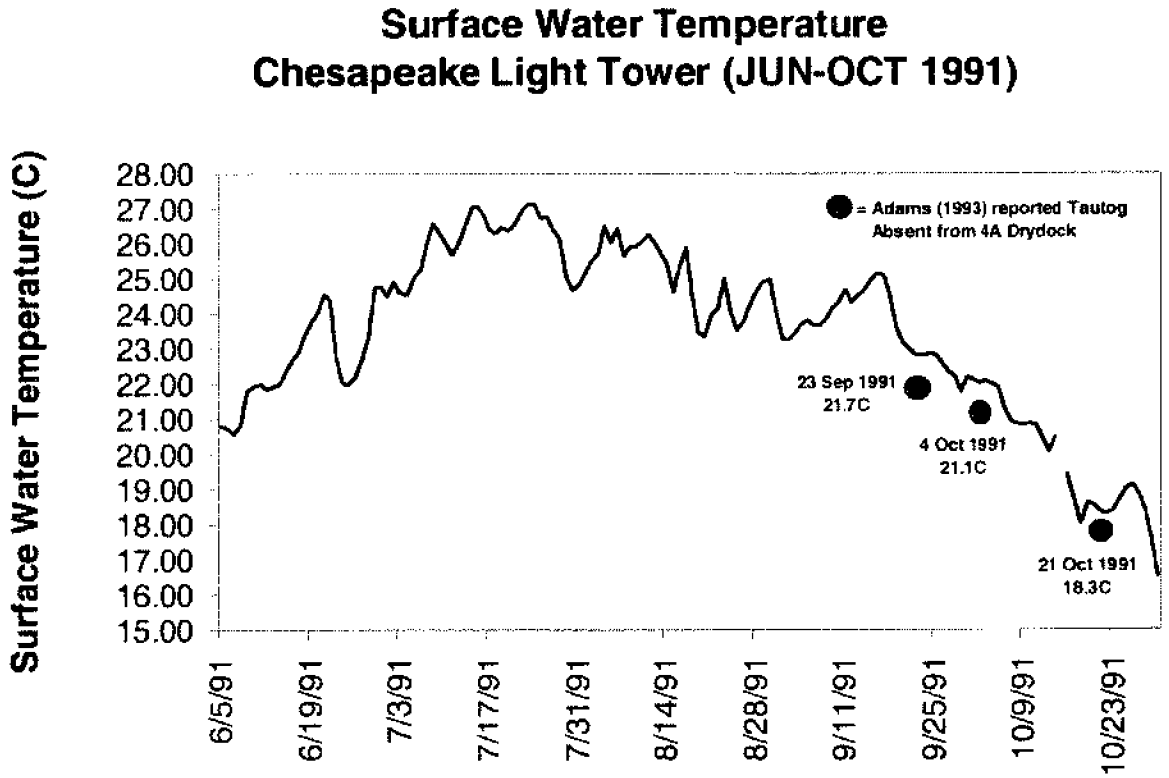
Adams (1993) reported mean abundance of tautog decreased between early summer (bottom water = 16.1-20°C) and late summer (bottom water = 18.3-22.8°C) at the 4A Drydock Wreck (20 m depth; 15 km from nearest shore). Mean surface water temperature at the Chesapeake Light Tower (CHL-V2) was 24.7°C in early summer and 22.2°C in late summer (www.ndbc.noaa.gov/data). Adams (1993) reported tautog "absent" from the 4A Drydock Wreck on three occasions when bottom water temperature was 18.3-21.7°C and suggested that tautog move to cooler water when bottom water temperatures approaches 20°C, even though tautog were observed at the wreck when bottom water temperature was 22.8°C. Examination of surface water trends in the days prior to these "absent" days reported by Adams (1993) reveal that these "absent" days occurred immediately after rapid declines in surface water temperature (Fig. 30).

Rapid decline in surface water temperature is most likely due to increased mixing following periods of heavy

precipitation or storm events. Rapid decline in surface water temperatures observed in this study occurred during Hurricanes Cindy and Dennis. Tautog were detected daily at the Texeco Wreck before and after, but not during Hurricanes Cindy and Dennis. Given this observation, movement deep into structure, as opposed to movement away from structure, likely occurred during these storms. These observations may also indicate why Adams (1993) did not observe tautog at the 4A Drydock Wreck on 21 September, 4 October, and 21 October 1991. Adams (1993) reported that during winter, tautog often were seen until crevices in the 4A Drydock Wreck were illuminated with a flashlight, further supporting the suggestion that tautog could move deep into the structure and be out of view of SCUBA divers.

Ultrasonically tagged tautog released at sites near Cape Charles, VA, tolerated a wide range (5-27°C) of water temperatures during this study. Rather than move to areas of warmer water in the winter and cooler water in the summer, tautog remained resident and decreased activity slightly in response to the thermal extremes. Daily detections of tagged tautog were greatest during the late fall/early winter and spring, and tautog were diurnally detected on 76-80% of fish-days during these seasons. Spring and fall are the primary fishing seasons for tautog in the lower Chesapeake Bay (White et al., 1997), which also suggests that tautog are more active during these seasons. Nocturnal detections of tautog were greatest during the winter, late spring/early summer, and late summer seasons. Nocturnal detections attributed to "spike" detection patterns were greatest during full moons, likely due to increased illumination. Increase in tidal magnitude during full and new moons may also have been a factor, particularly during the spawning season when tautog are sensitive to tidal cycle (White, 1996). Nocturnal detections attributed to "shift" detection patterns during 1st and 3rd quarter moons may have resulted from increased illumination during twilight.

Fig. 30 Surface water temperature at Chesapeake Light Tower (NOAA) versus bottom water temperature at the 4A Drydock Wreck (Adams, 1993), June – October 1991. Red circles correspond to the date and bottom water temperature for three occasions when Adams (1993) reported tautog absent from the 4A Drydock Wreck while SCUBA diving.



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