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Seasonal Residence, Movement, and Activity Patterns of Adult Tautog, Tautoga onitis, in Lower Chesapeake Bay

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

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Michael D. Arendt

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of
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ACKNOWLEDGMENTS

On the eve of finally turning this thesis into my committee, I sense the presence of the ghost of research future and the ghost of research past. And as I reflect on where I was a year ago at this point, I'm reminded of two phrases that were drilled into me at VMI: "There is no 'I' in TEAM" and "A chain is only as strong as its weakest link". I am extremely grateful that during this project I was blessed with a solid team that didn't allow the chain to break during the weaker moments.

First, I would like to thank my co-advisor, Mr. Jon Lucy, for introducing me to the world of the tagging, tautog, for sharing my enthusiasm for this project, and for sticking it out with me through the highs and the lows. In order to break new ground we had to take some risks, some very expensive ones at times, but it paid off in the long run; thanks for allowing me to 'carry on'. To my other co-advisor, Dr. William DuPaul, I would also like to say thanks for staying with this project when the stakes were high. I wish to also thank the four remaining members on my Advisory Committee (Dr.'s Tom Munroe, Jack Musick, John Hoenig, and David Evans) for keeping me on my toes throughout the project with their numerous suggestions, comments, and ideas.

During this project, VR1 receivers remained submerged from October 1998 until October 1999. Receivers were deployed 54 times and retrieved 53 times. Without a doubt, the success of this study is attributed to a group that I collectively refer to as the "Friends of the VR1". Its never easy when your work schedule depends on Mother Nature, but 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. Thanks, Charles...see you in La Paz someday! VIMS divers (Bob Gammisch, Wayne Reisner, Buck Stockhausen, and Tom Chisholm) retrieved 25% of VR1 receivers during this study. The contribution of VIMS divers, however, is much closer to 100%. In early December, three weeks after the first tautog was tagged and released, we almost lost all eight VR1 receivers to rapid deterioration of cable used to deploy these receivers. Had VIMS divers not responded to the urgency of the situation, this entire study would have ended before it ever got started. Throughout the study, use of VIMS divers to retrieve VR1 receivers continued to be a necessity, particularly for the most critical VR1 of all, the eastern receiver at the Texeco Wreck. The Texeco Wreck was the only site where tautog were observed to move away and return periodically, and the eastern receiver just happened to be the receiver that contained about 95% of the data recorded at this site. VIMS divers were required to retrieve the Texeco East receiver two out of five times that this receiver was deployed. Other "Friends of the VR1" members deserving commendation are Capt. George Pongonis, Steve Synder, and Sam Wilson for their experience and overall dedication to this study. The brainstorming sessions with these gentlemen early in the project enabled us to put together a mooring design for long-term deployment of VR1 in the marine environment and user-friendly ways to get them back...crucial factors in the high recovery rate (98%) experienced during this study.

I would also like to thank Fred Voegli and Wayne Conrad from Vemco, Ltd., and Todd Nelson and Steve Clukey from VIMS for getting us on track early in the game when we were experiencing technical problems between our equipment and our boat. Also on the technical support side of the equation, I wish to say thanks to the ITNS staff (Kevin Kiley, Gary Anderson, Steve Clukey, Pat Hall, Kathy Goodwin, and Tanya Utt)

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I'd also like to thank God, my family, and my friends for keeping me going. Although the artwork on the refrigerator was taken down a long time ago, the message is still the same: I love you mom and I love you dad. Thanks for being so supportive. And to my brother, Wes, for the surf trips, reality checks, and understanding. And to the VB crew (Robert, Christian, Paul, Kevin, and Hugo), I wouldn't have made it this far without the road trips, advice, and knowing there was always an escape if I needed one. And to the VIMS crew (Vince Encomio, Ruben Rios, Becky Green, and Terese Rivers), thanks for being there when I couldn't escape and also when I could. You all know me better than anybody else here. That means a lot to me.

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ABSTRACT

Seasonal residence, movement, and activity patterns of fishes are influenced by physiological (i.e., reproduction), biotic (i.e., food, habitat), and abiotic (i.e., temperature, photoperiod) factors. Physiological factors are assumed to affect a species similarly throughout its geographic distribution; however, changes in biotic and abiotic conditions may not affect a species similarly throughout its geographic distribution. Different responses to changes in biotic and abiotic conditions may result in different seasonal residence, movement, and activity patterns. Seasonal residence, movement, and activity patterns are documented for northern tautog (*Tautoga onitis*) populations, but have never been examined for southern tautog populations. Seasonal abundance and tag-recapture data suggest regional differences in seasonal residence, movement, and activity patterns for southern populations. This study used ultrasonic transmitters and automated acoustic receivers to document seasonal residence, movement, and activity patterns of adult tautog (n=33, 400-514 mm TL) in lower Chesapeake Bay. Tautog were caught using standard two-hook bottom rigs, tagged with ultrasonic transmitters (surgically implanted), and released at the same sites where captured less than two hours later. From 9 November 1998 to 13 October, tautog were monitored at four sites (two natural sites, two manmade sites) near Cape Charles, VA. Seventy percent (n=23) of all tautog remained at release sites and were never detected or recaptured away from release sites for the duration of transmitter battery life (up to 6 months). Tautog remaining resident near Cape Charles, VA, tolerated a wide range (5-27°C) of water temperatures. Rather than move to areas of warmer water in the winter and cooler water in the summer, as documented for northern populations, tautog released at sites near Cape Charles, VA, remained resident and decreased activity slightly in response to the thermal extremes. Tautog were diurnally active on 53-80% of days in this study. Nocturnal activity was greatest in winter and spring. Resident tautog were detected daily, except during the coldest water temperatures (5-7°C) in the winter and after abrupt (3°C) decreases in surface water temperature in the summer. Eighteen percent of tautog (n=6) were recaptured or detected at sites located 2.2-10.2 km away from where these fish were released. Tautog moved away from manmade sites only. No evidence of inshore-offshore movement was documented. Three tautog moved away from a single site, but returned to this site on several occasions. These three tautog primarily moved between this release site and an unmonitored site 2.2 km to the south. When these tautog were not located at the release site, attempts to locate them at the unmonitored site were always successful, suggesting high site affinity for both sites. Twelve percent (n=4) of tautog released were detected 24-106 days less (mean = 175 days) than resident tautog. These four tautog were never recaptured or detected elsewhere, thus, it could not be determined whether these fish moved or if transmitters failed. When these fish were assumed to have moved, percent movement of fish away from release sites was highly suggested (R^2=0.97) to be related to size (m^2) of release sites.

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

INTRODUCTION

Tautog (*Tautoga onitis*) is a highly prized game fish that is targeted by anglers fishing at structure 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 tagged 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 (< 50 total observation days made during a 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 margins/backbarrier flat is characterized by sand flats and deep, mud-bottomed channels (Wright et al., 1987). Smith-Mac 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 tows, oyster dredge tows, 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 15-18 m of water (Fig. 2c,d) and also supported dense benthic macrofauna communities (Fig. 4).

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/backbarrrier flat (Wright et al., 1997) in 8-15 m of water, east of the Susquehanna channel (40 m deep).

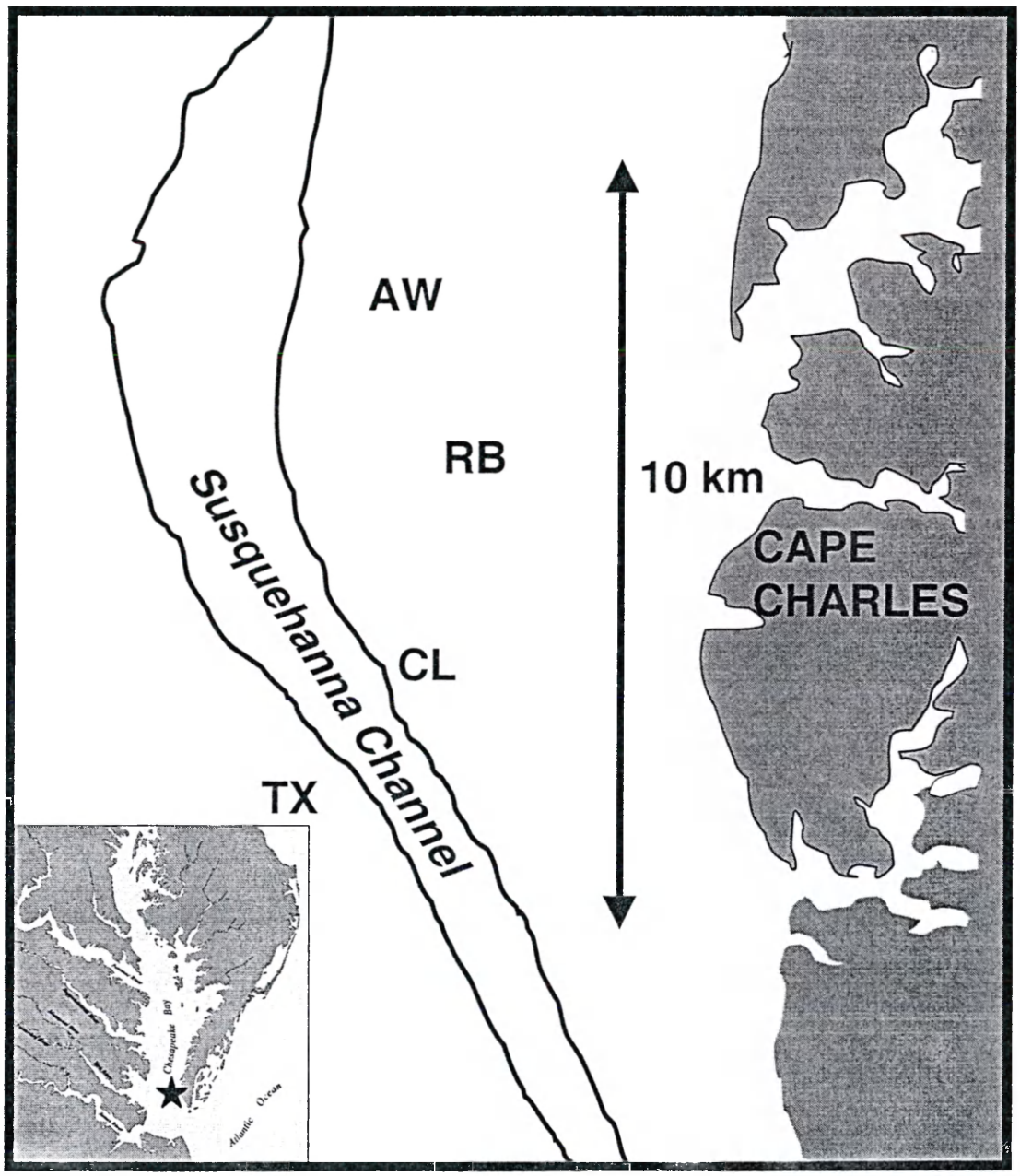
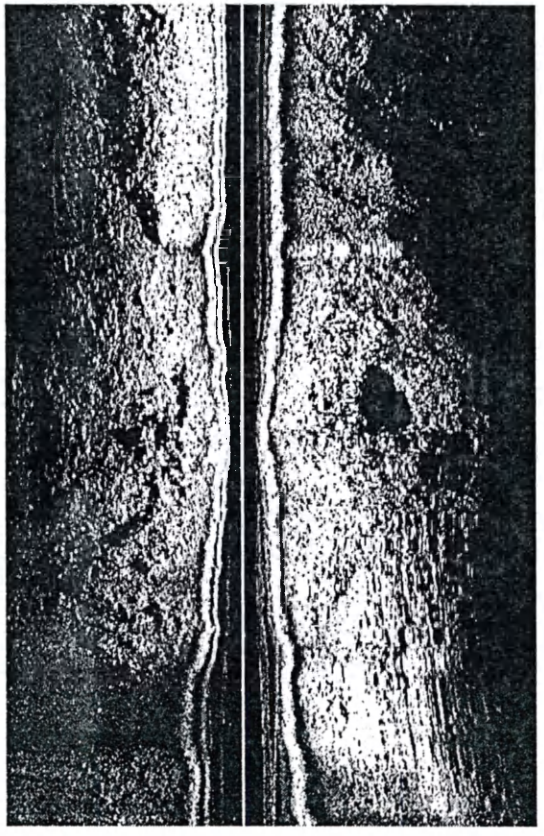

AW
RB
CL
TX
Susquehanna Channel
10 km
CAPE
CHARLES
Chesapeake Bay
Atlantic Ocean

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

Fig. 2 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.

A. CORAL LUMP (CL)

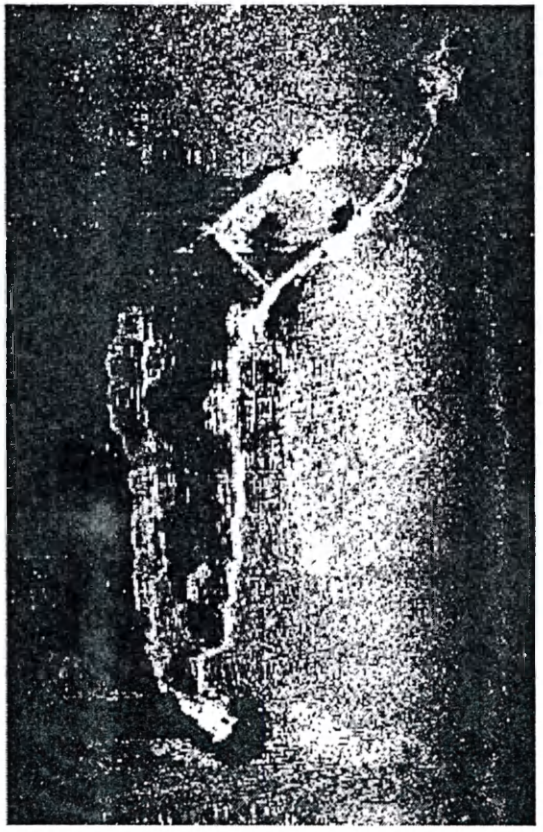


Dimensions:	300 m x 100 m
Area:	9000 m^2
Relief:	1 m
Depth:	10.7 m

B. RIDGED BOTTOM (RB)

Dimension:	120 m x 30 m
Area:	1900 m^2
Relief:	1 m
Depth:	8.5 m

C. TEXECO WRECK (TX)



Dimensions:	100 m x 30 m
Area:	1600 m^2
Relief:	1 m to 3.5 m
Depth:	16.8 m

D. AIRPLANE WRECK (AW)

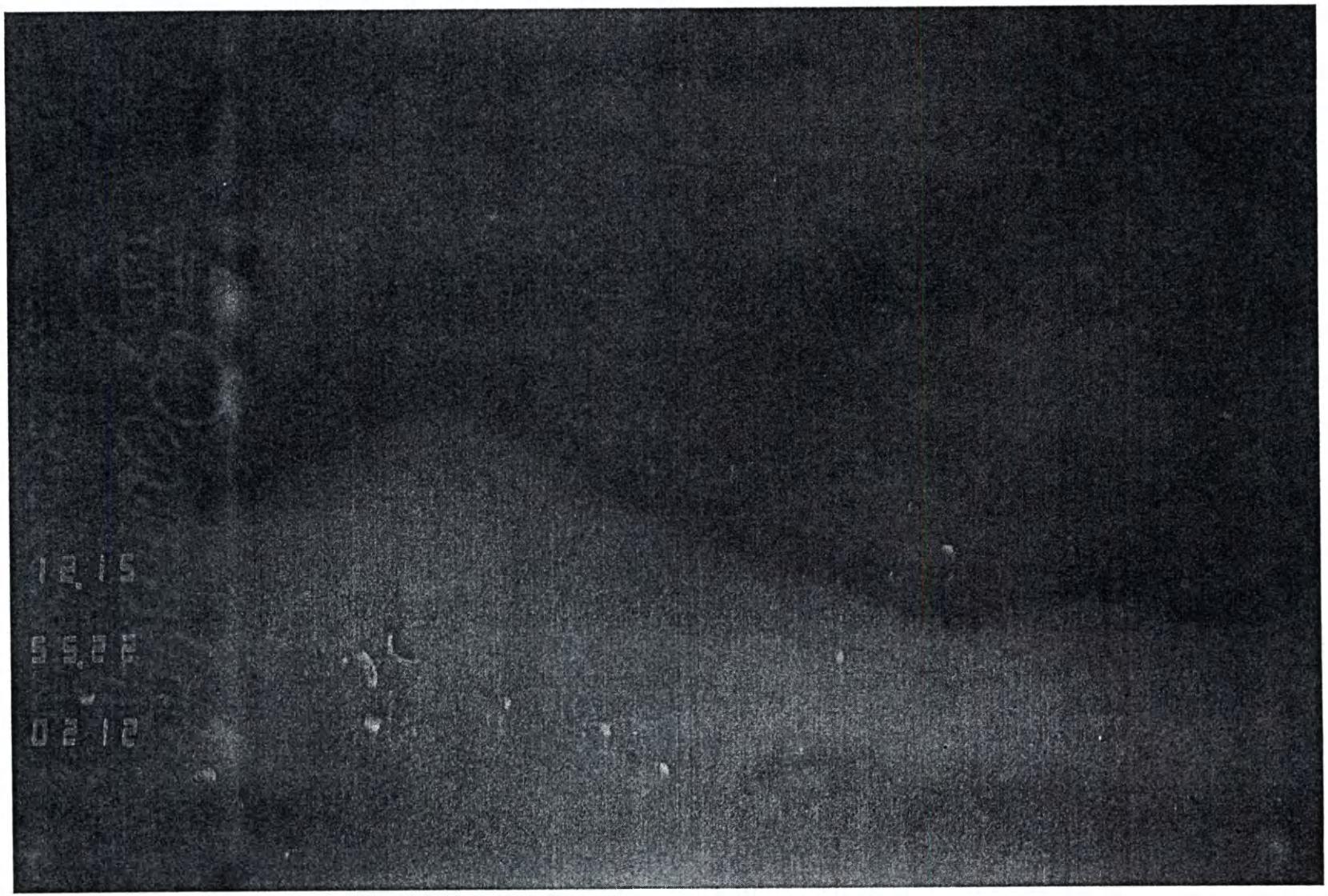
Dimensions:	40 m x 20 m
Area:	300 m^2
Relief:	1 m
Depth:	13.7 m

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		

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

A



B

C

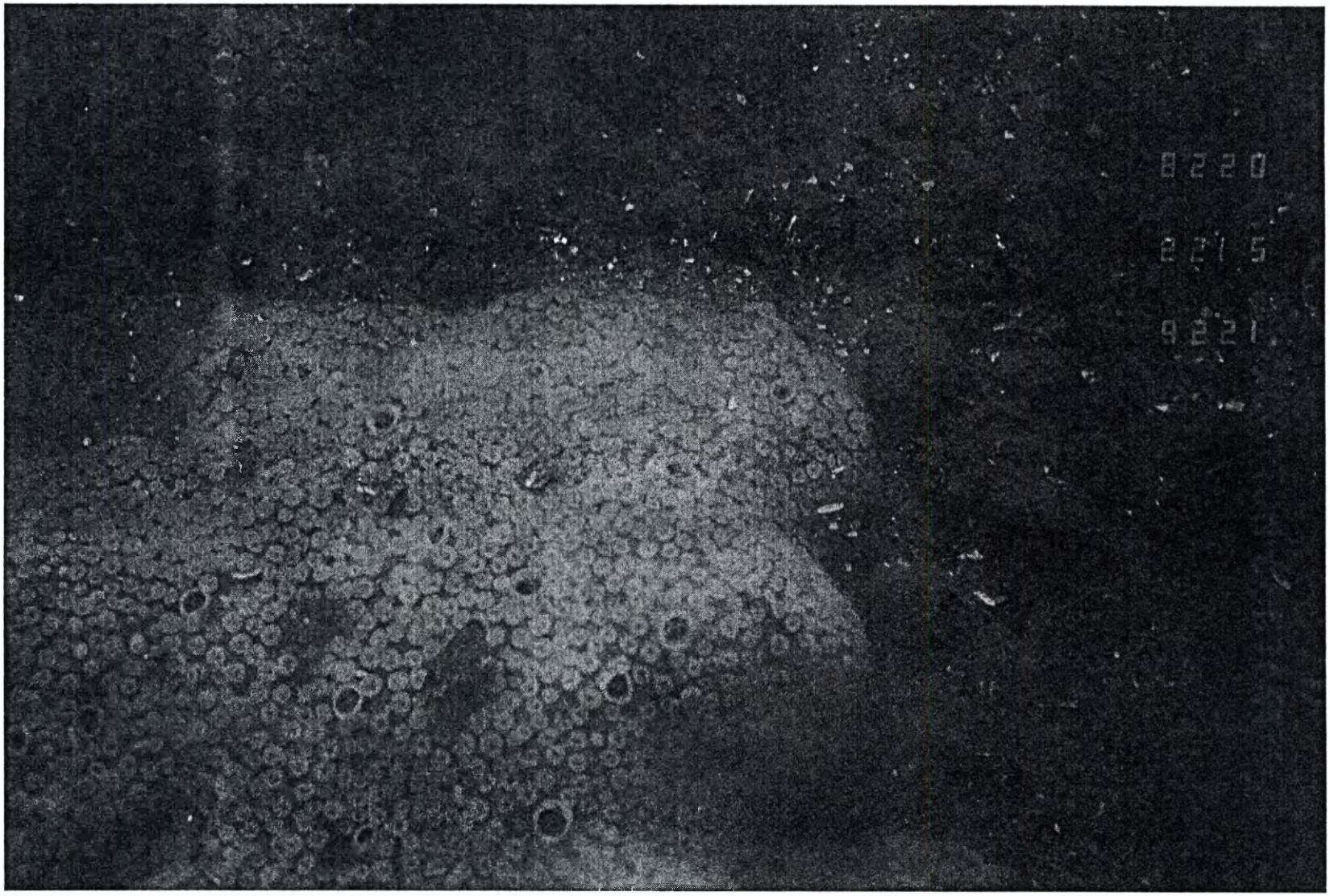


Fig. 4 Photographs of *Cliona celata* attached to section of the Texeco Wreck. Specimen collected with R/V *Langley* boat anchor, 6 December 1998.

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.

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 (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 were 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.

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.

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.

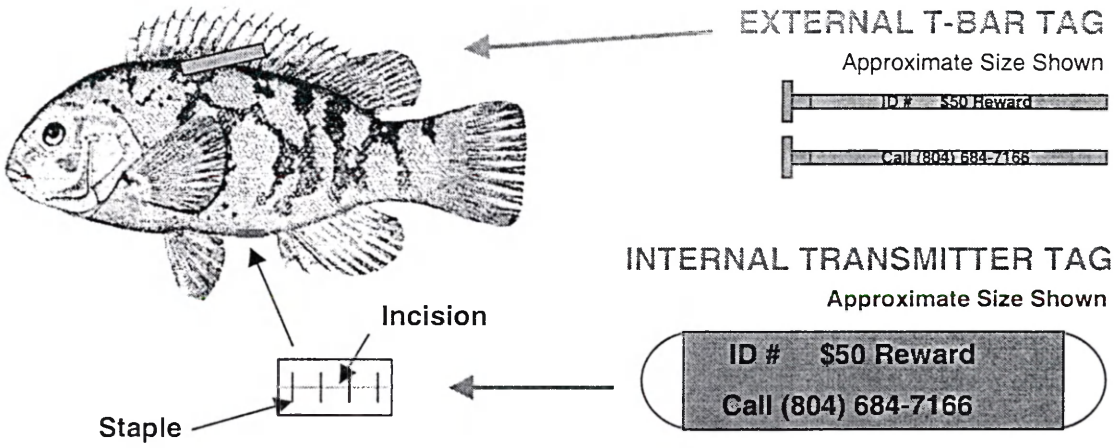
Public Awareness of Study

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 again between April-August 1999. While on display, a computer slide-show and several posters describing the study were readily available to visitors.

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.

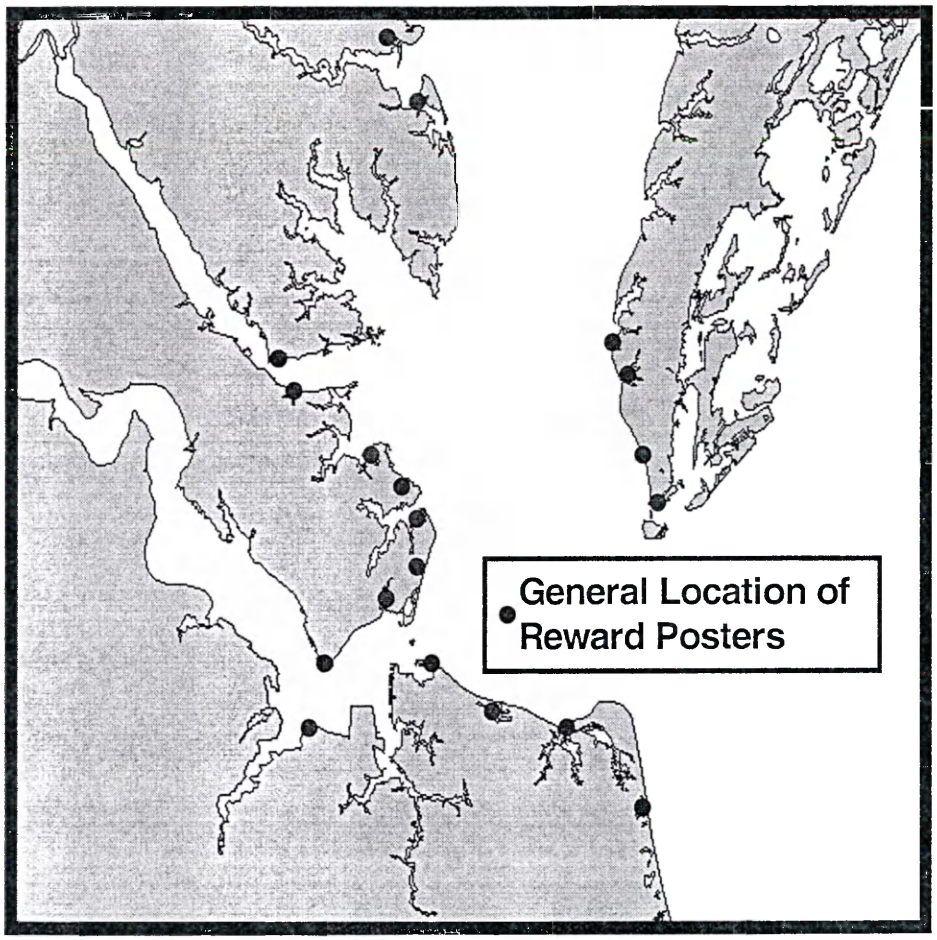
•For more information, call VIMS Marine Advisory Program:

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.

B



Detecting Ultrasonically-Tagged Tautog

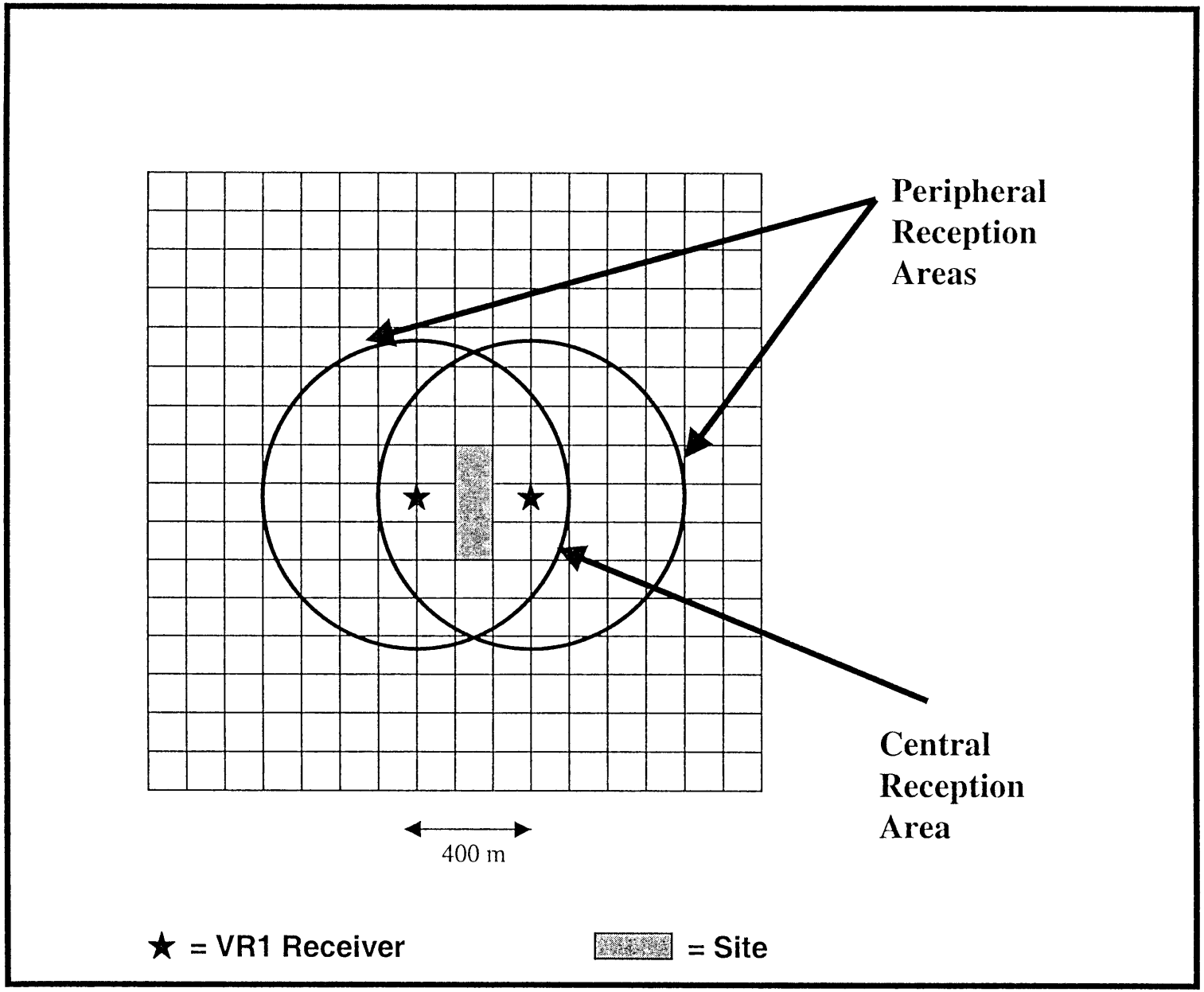
A VR60 receiver (Vemco, Ltd.) and two acoustic hydrophones (V10 directional and VH65 omni-directional, Vemco, Ltd.) enabled detection of ultrasonically tagged tautog from aboard the R/V *Langley*. Both hydrophones were mounted at the base of an aluminum pipe (3.7 m x 3.2 cm). To reduce background noise 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 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 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

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.

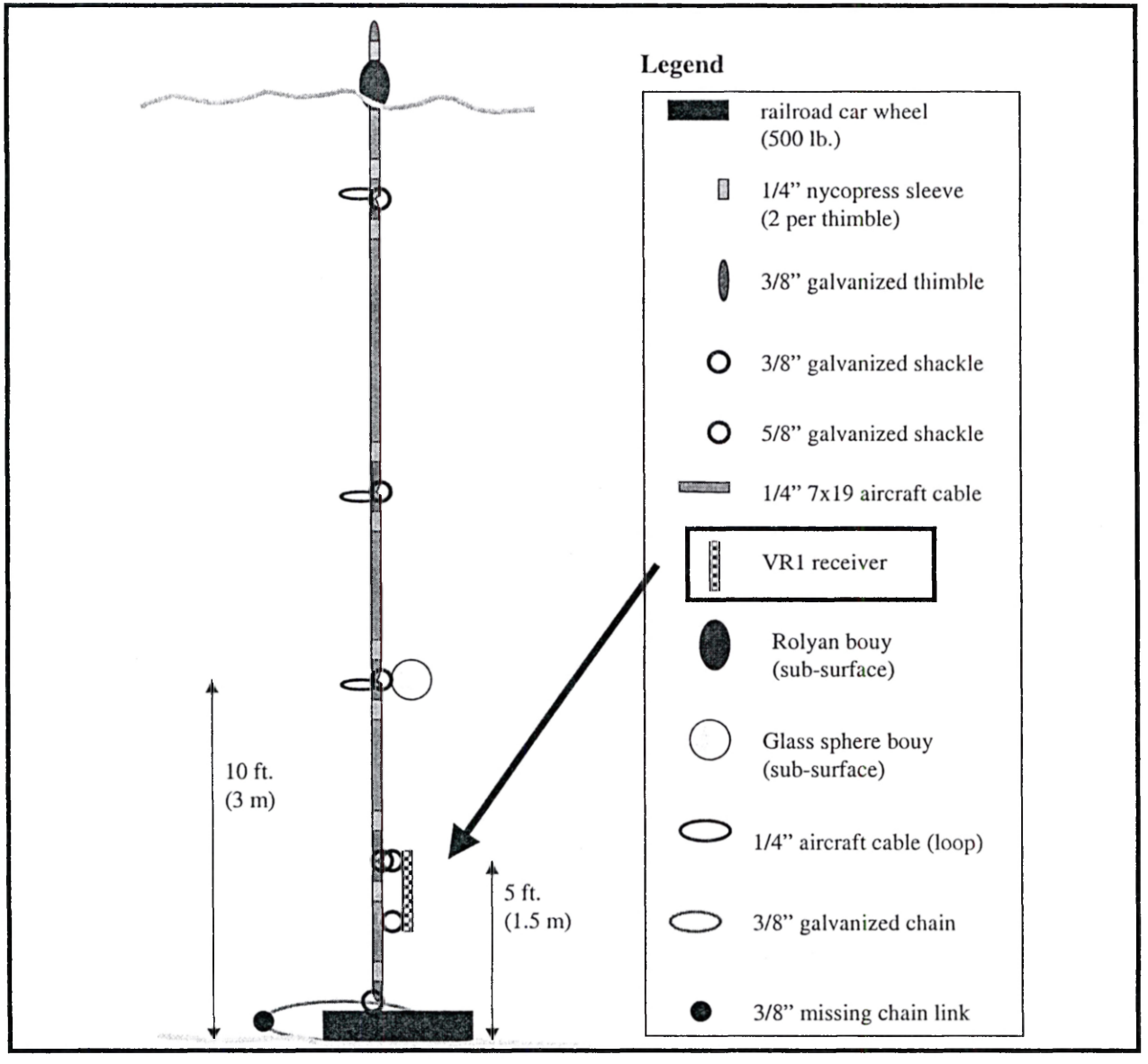

Peripheral
Reception
Areas
Central
Reception
Area
400 m
★ = VR1 Receiver
= Site

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 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

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.


Legend
railroad car wheel
(500 lb.)
1/4" nycopress sleeve
(2 per thimble)
3/8" galvanized thimble
3/8" galvanized shackle
5/8" galvanized shackle
1/4" 7x19 aircraft cable
VR1 receiver
Rolyan bouy
(sub-surface)
Glass sphere bouy
(sub-surface)
1/4" aircraft cable (loop)
3/8" galvanized chain
3/8" missing chain link
10 ft.
(3 m)
5 ft.
(1.5 m)

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 ($\leq$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 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 *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.

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 – 9 Sep 99, 34 days), surface water temperature remains at annual maximum values and photoperiod decreases (E).

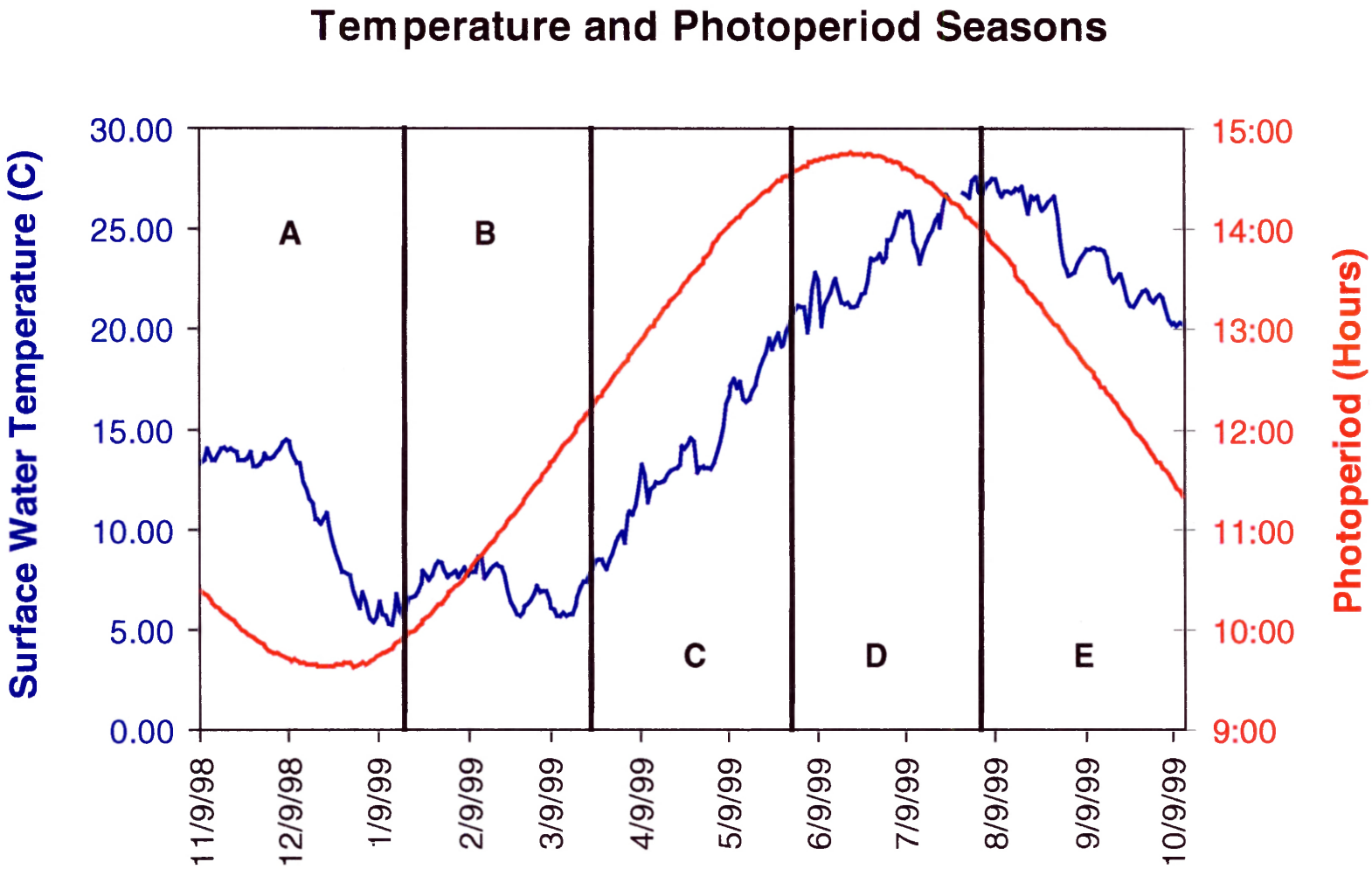
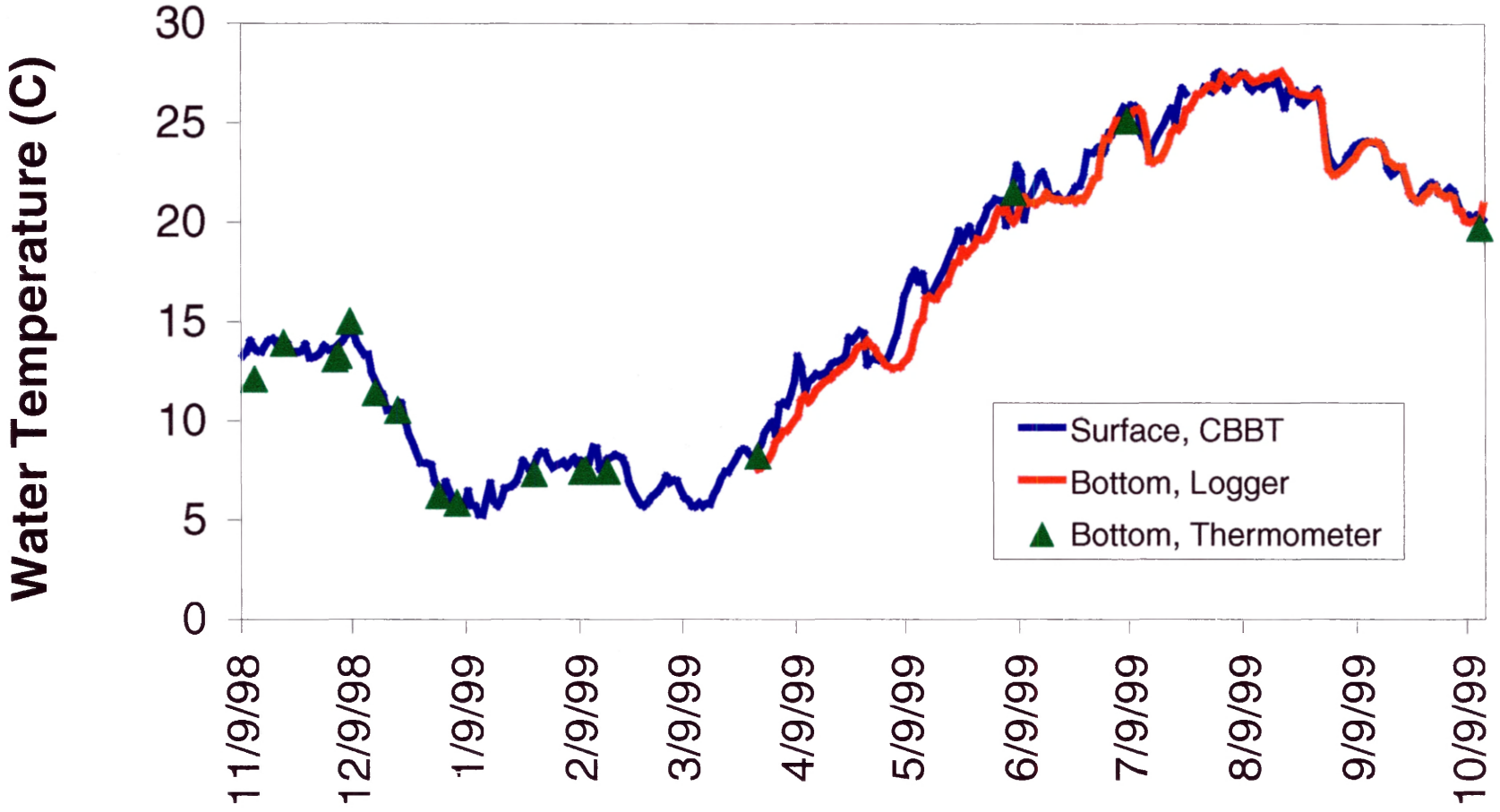

Temperature and Photoperiod Seasons
Surface Water Temperature (C)
Photoperiod (Hours)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
15:00
14:00
13:00
12:00
11:00
10:00
9:00
A
B
C
D
E
11/9/98
12/9/98
1/9/99
2/9/99
3/9/99
4/9/99
5/9/99
6/9/99
7/9/99
8/9/99
9/9/99
10/9/99

Fig. 10 Surface water temperature from the Chesapeake Bay bridge tunnel (4^{th} 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).

Surface vs. Bottom Water Temperature
(9 Nov 98 - 12 Oct 99)



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 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 (Appendices A1-A25). 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=3).

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. 10). 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).

Transmitter Attachment (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 4). 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 ± 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, in press). Post-release recovery (mean ± 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. 11), transmitter encapsulation (Fig. 12), feeding (Fig. 13), and overall good condition of fish tagged and released with ultrasonic transmitters.

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 5). 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.

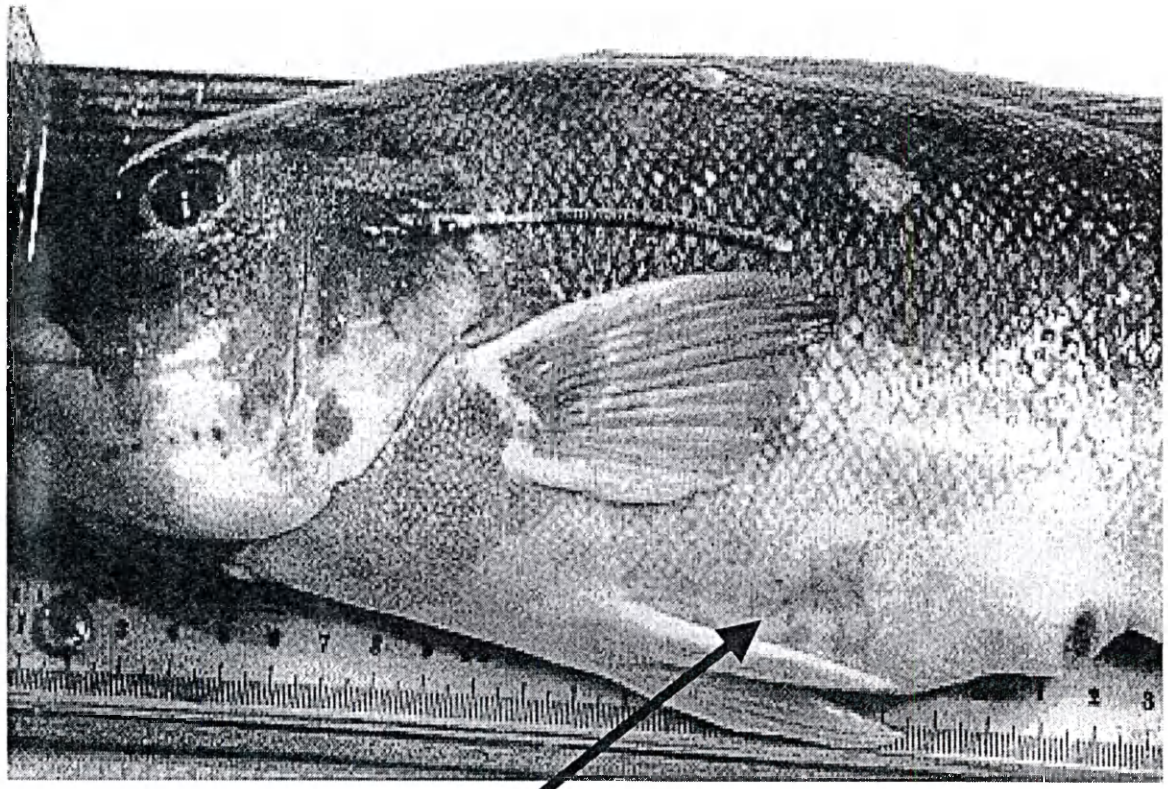
	06 JUN 1998 - 23 AUG 1999 (5-30°C)	**26 OCT 1998 - 20 DEC 1998 (10-18°C)**
Sample Size	5	4
Transmitter Retention	100%	100%
Mortality	60%*	0%
Signal Attenuation	No	Not Evaluated
Altered Behavior?	No	No
Anatomy Compromised?	Not evaluated	No
Reproduction Compromised?	No	Not Evaluated

*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).

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.

BOOT HILL
GRAVEYARD

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).



Incision Scar

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).

Stomach with food items

Mesentery Encapsulation

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

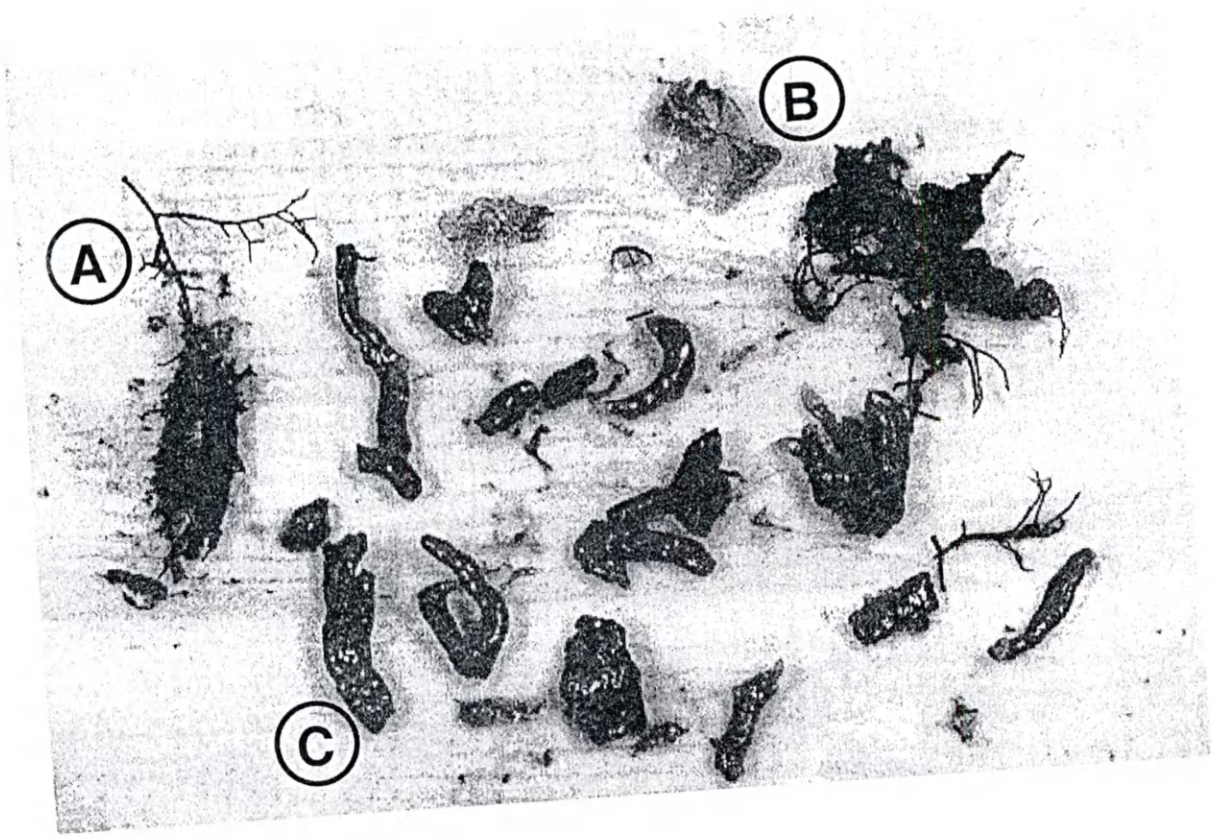

A
B
C

Table 4 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 the days detected is actually 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

Table 5 Chi-square contingency test for detection agreement, VR60 vs. VR1 receivers.

	Day (0600-1859hrs)	Night (2000-0559hrs)	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, $p \leq 0.05$ (NS)

Residence

Four RCODE tautog were released at each of the four sites between 9 November and 8 December 1998. Residence data for these fish were collected for the duration of transmitter battery life. Twelve transmitters lasted substantially longer (150-200%) than manufacturer's estimate. Transmitter battery life for these 12 fish was 174 days ± 10.2 days (mean ± std. dev.). Four transmitters were detected substantially less than 174 days: one (ID32) lasted longer (116%) and three (ID20, ID21, ID30) lasted less (0.1-90%) than the manufacturer's estimate. No significant difference in residence (days) was detected among sites (ANOVA, $p>0.05$, Table 6).

Eleven RCODE tautog were released at sites in unequal numbers in spring 1999. Four fish were released at the Texeco Wreck and Coral Lump sites, two fish were released at the Ridged Bottom, and one fish was released at the Airplane Wreck. One fish at the Texeco Wreck was released on 21 April 1999; all other fish were released between 28 May and 9 June 1999. For consistency, spring residence analysis began on 9 June 1999; data collected prior to this date were excluded from analysis. Residence data for spring RCODE tautog was not collected for the duration of transmitter battery life. Late spring/early summer residence data collection commenced on 5-6 August 1999, with retrieval of VR1 receivers (Coral Lump West, Texeco West, Ridged Bottom East and West). Three additional VR1 receivers (requiring VIMS divers) were retrieved on 9 September 1999 (Texeco East) and 13 October 1999 (Airplane East and West). Tautog last detected on 5-6 August 1999 were detected at their last known locations on 13 October 1999, 125-175 days post-release. No significant difference in residence times (days) among sites were detected (ANOVA, $p>0.05$, Table 7).

"Low detection" (<30 detections/day) fish-days (Fig. 14) were significantly different among seasons (Chi-square, $p \leq 0.05$, Table 8). "Low detection" fish-days were greatest during rapid decreases in surface water temperature (Fig. 15). Ninety-three percent of total low detection fish-days occurred during the late fall/early winter and winter seasons, when surface water temperature was 5-8°C. Six percent of total low detection fish-days occurred in the late summer month when water surface water temperature rapidly decreased from 26°C to 23°C on 30 August.

Three FCODE fish were released in both fall 1998 and spring 1999. Three FCODE fish were released at the Texeco Wreck and one FCODE fish was released at each of the three remaining sites (Airplane Wreck, Ridged Bottom, and Coral Lump). Transmitter battery life for five FCODE fish exceeded (127-185%) manufacturer's estimates. These fish were always detected at sites where released between 33-63 days after release. One FCODE fish was detected substantially less than (35%) the manufacturer's estimate. This fish was released and detected at the Airplane Wreck for 9 days.

Two fish, previously tagged and released in the Virginia Game Fish Tagging Program, were recaptured where released and subsequently tagged with RCODE transmitters. Tautog 29 was first caught and tagged on 13 November 1998 at the Airplane Wreck. Between 13-18 November, this fish was used in a hook-release mortality study (Lucy and Arendt, 1999). This fish was released on 18 November 1998. On 7 December 1998 (19 days later), this fish was recaptured at the Airplane Wreck and subsequently tagged and released with a transmitter. In spring 1999, a second fish (ID43) tagged and released in the Virginia Game Fish Tagging Program was recaptured and tagged with an ultrasonic transmitter. This tautog was first caught, tagged, and released

at the Mussel Beds/Ridged Bottom on 6 May 1999. On 9 June 1999 (34 days later), this fish was recaptured at the Ridged Bottom and subsequently tagged-released with a transmitter.

High residence times were also documented for seven ultrasonically tagged tautog, all released in spring 1999 and recaptured in fall 1999 (by recreational fishers) at the same sites where released 114-211 days earlier (Table 4). Six tautog were tagged with RCODE transmitters and one tautog was tagged with an FCODE transmitter. All six RCODE tautog were detected daily (except during Hurricane Dennis, 31 August – 5 September 1999) at their respective release sites. The FCODE tautog (ID06) was released at the Texeco Wreck on 21 April 1999 and detected (VR60) until 7 June 1999.

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 (Appendix A12). 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 the 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 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)

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.

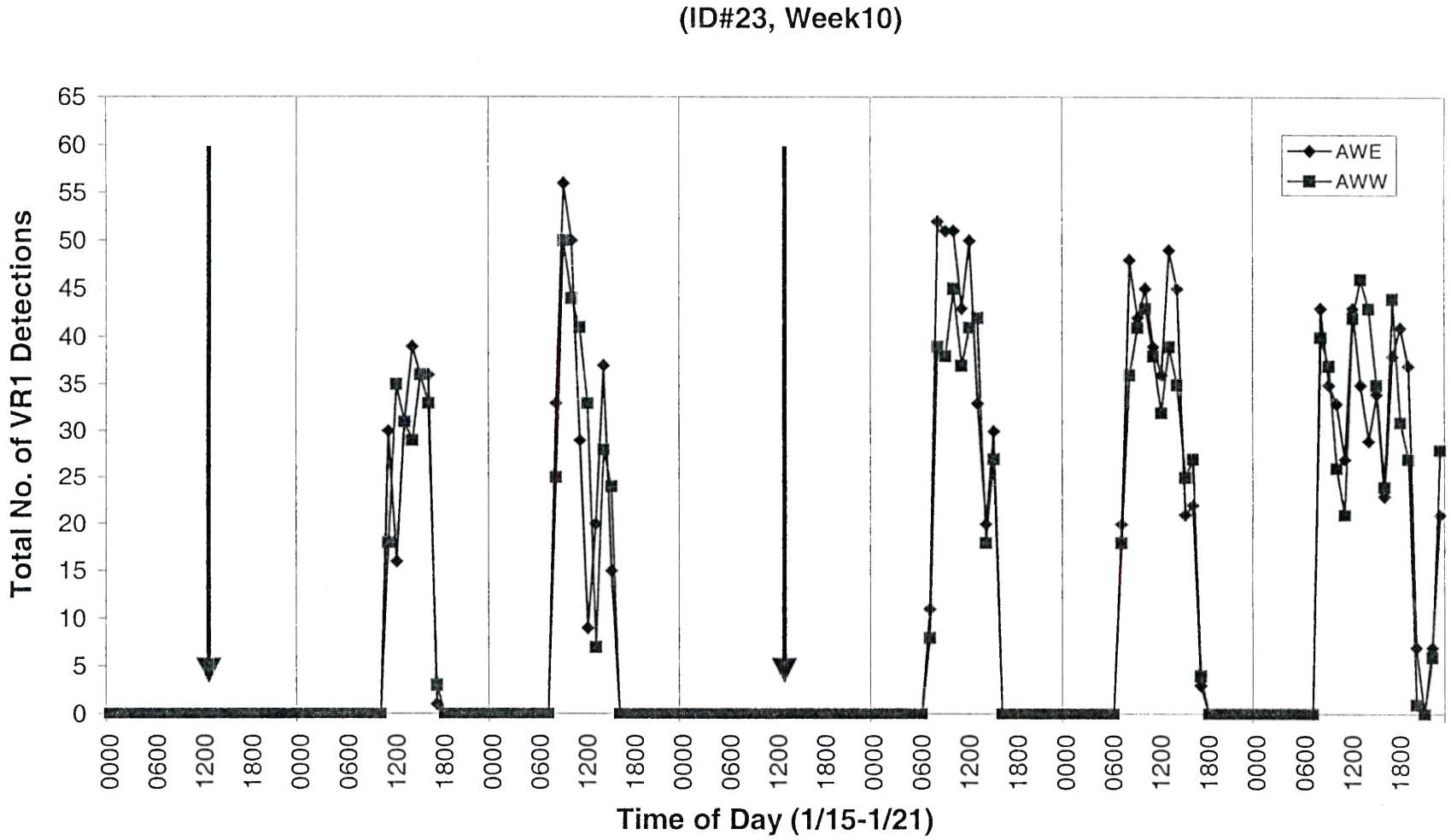

(ID#23, Week10)
Total No. of VR1 Detections
65
60
55
50
45
40
35
30
25
20
15
10
5
0
AWE
AWW
0000
0600
1200
1800
Time of Day (1/15-1/21)

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, $p \leq 0.05$ (Significant)

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.

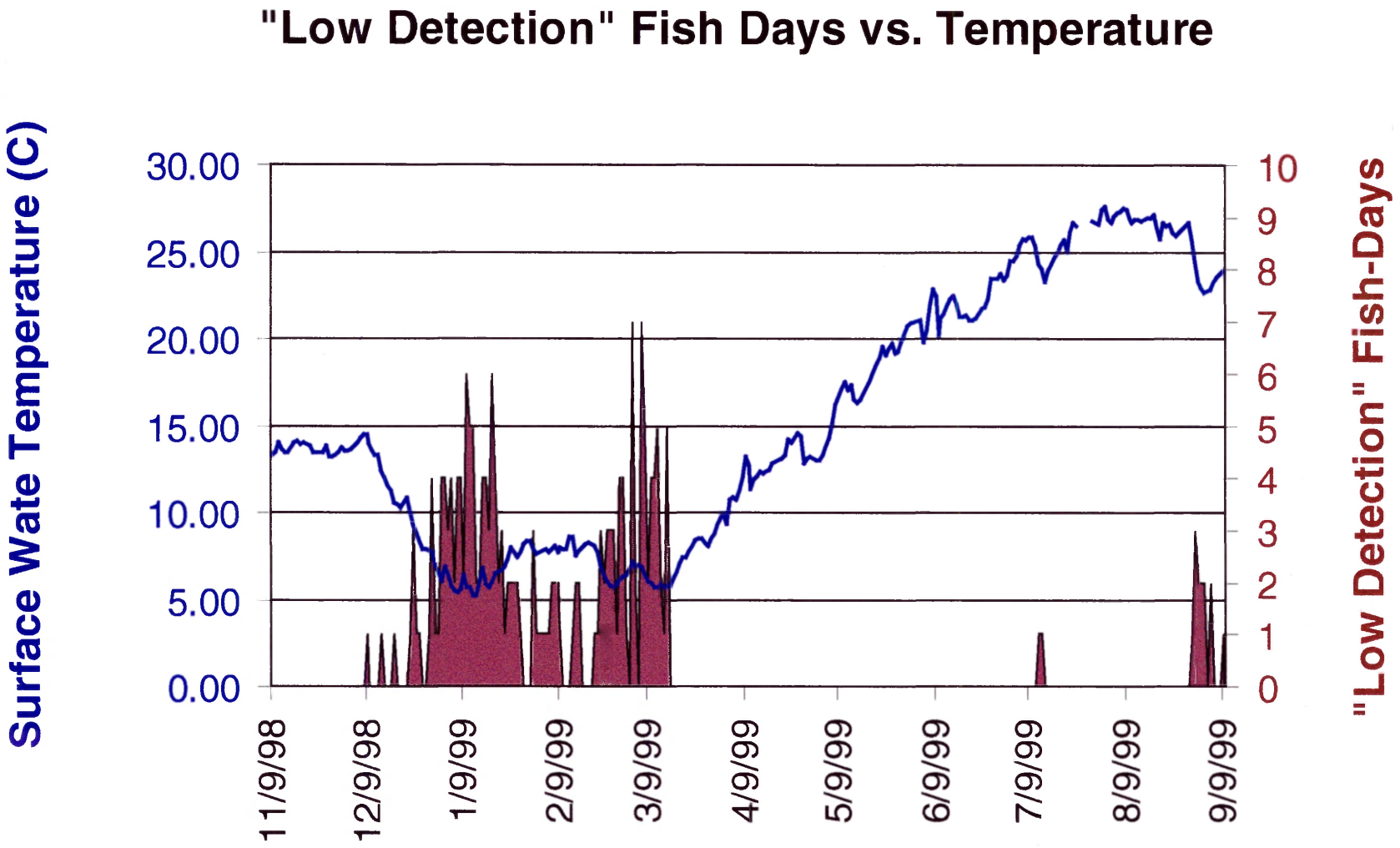

"Low Detection" Fish Days vs. Temperature
Surface Wate Temperature (C)
"Low Detection" Fish-Days
30.00
25.00
20.00
15.00
10.00
5.00
0.00
10
9
8
7
6
5
4
3
2
1
0
11/9/98
12/9/98
1/9/99
2/9/99
3/9/99
4/9/99
5/9/99
6/9/99
7/9/99
8/9/99
9/9/99

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 (black arrows) or detected (blue 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).

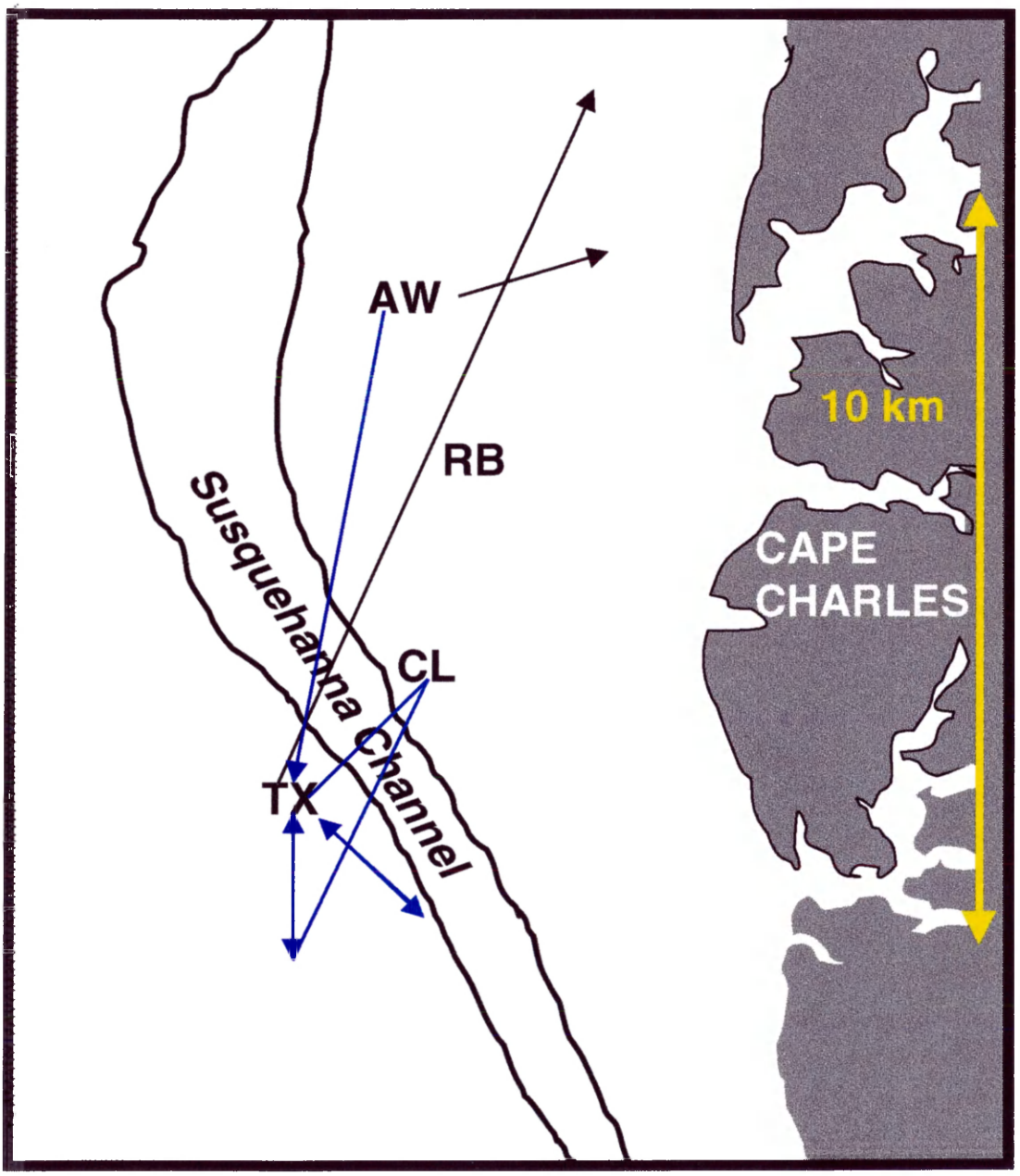

AW
RB
CL
TX
Susquehanna Channel
10 km
CAPE
CHARLES

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. 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).

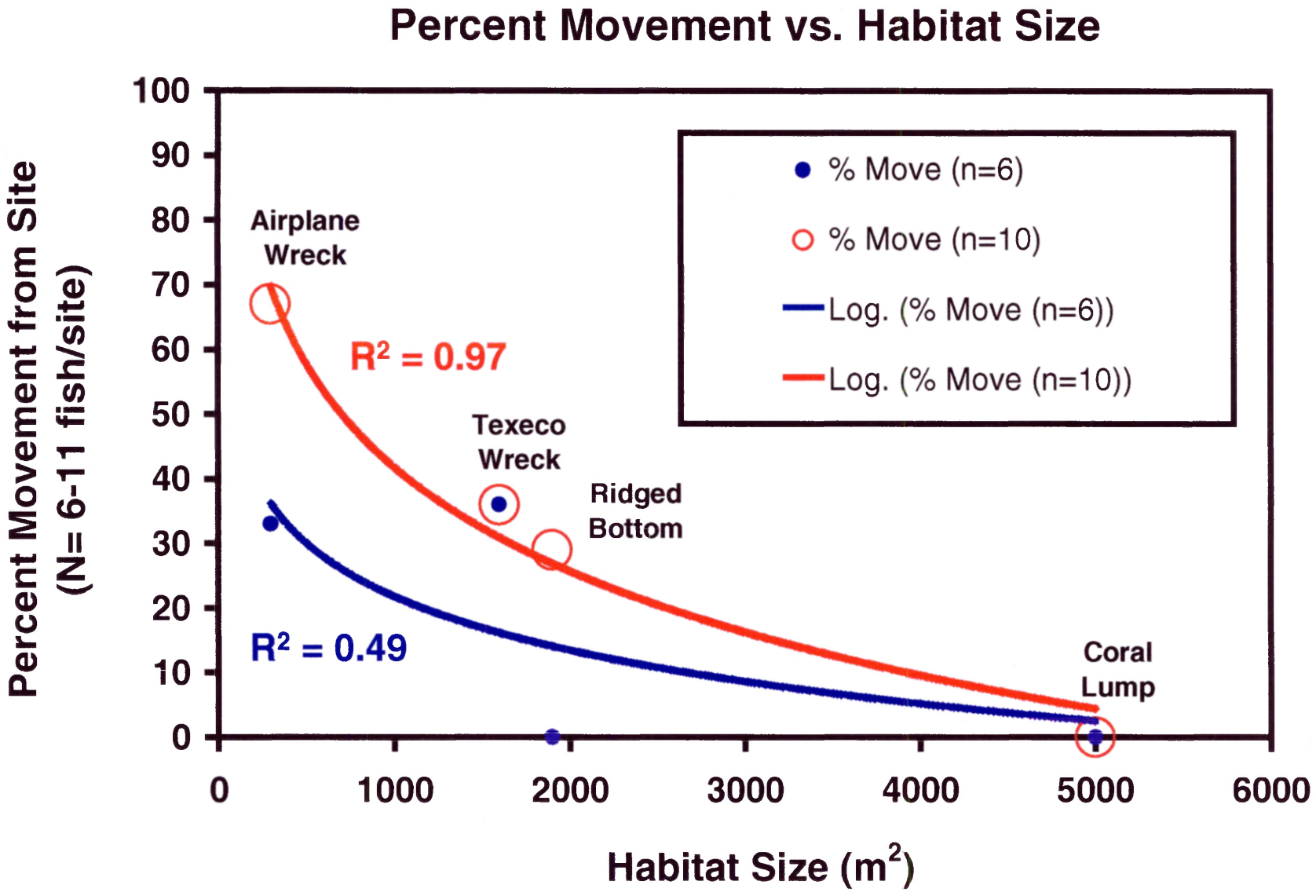

Percent Movement vs. Habitat Size
Percent Movement from Site
(N= 6-11 fish/site)
100
90
80
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
6000
Habitat Size (m2)
% Move (n=6)
% Move (n=10)
Log. (% Move (n=6))
Log. (% Move (n=10))
Airplane
Wreck
R2 = 0.97
Texeco
Wreck
Ridged
Bottom
R2 = 0.49
Coral
Lump

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.

SOUTH POLES

Dimensions:	20 m x 20 m
Area:	250 m^2
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).

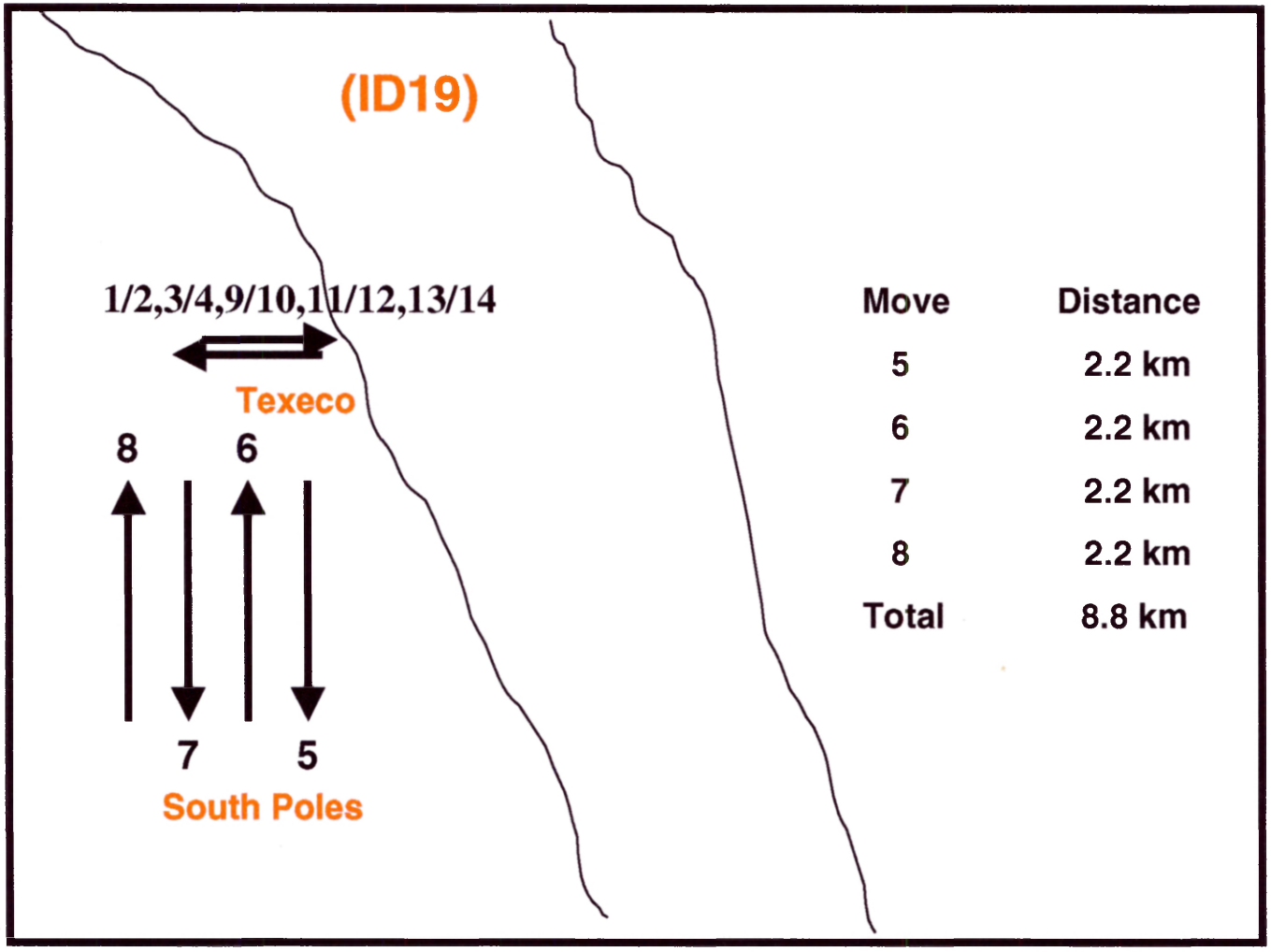
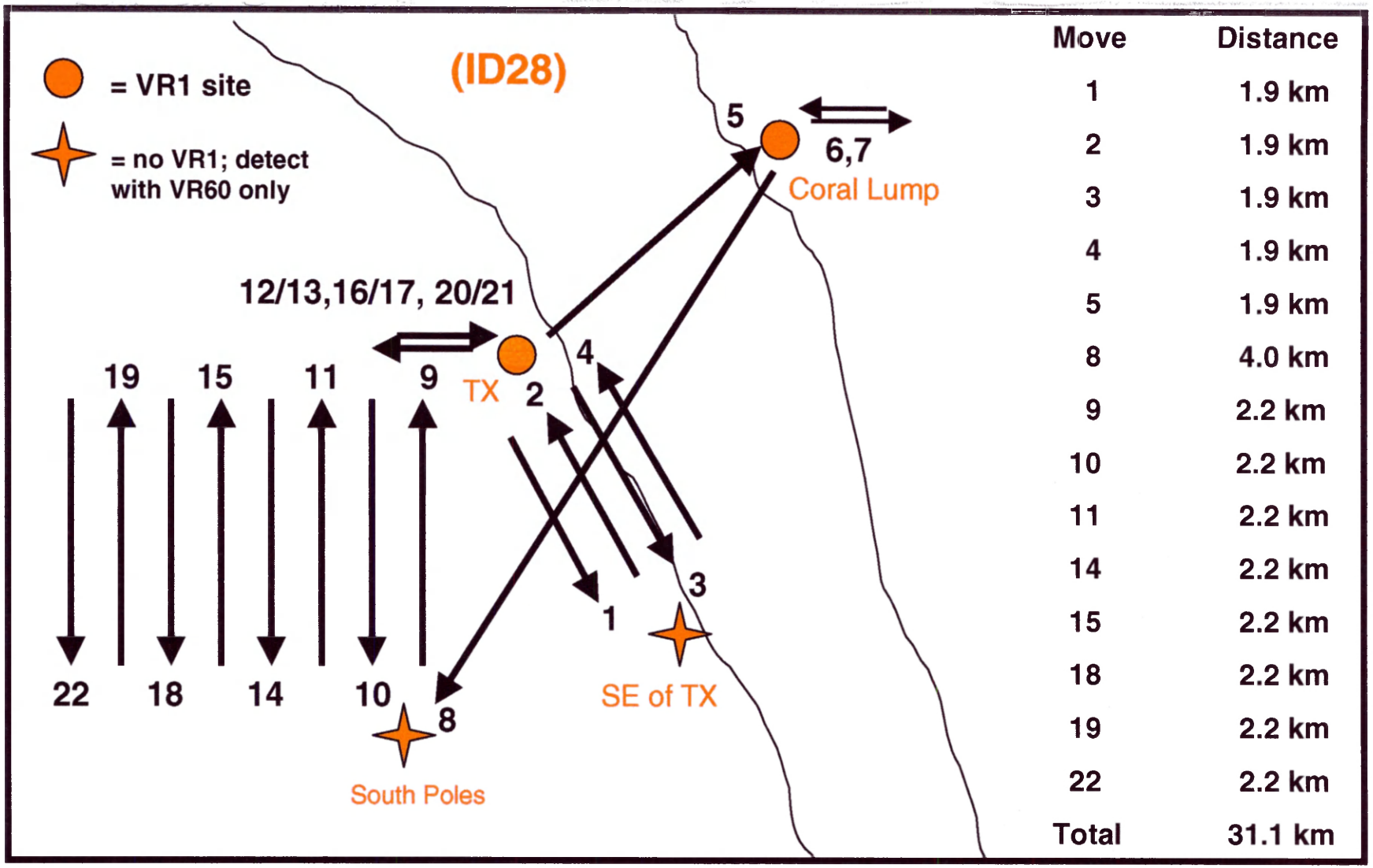

(ID19)
1/2,3/4,9/10,11/12,13/14
Texeco
8
6
7
5
South Poles
Move
Distance
5
2.2 km
6
2.2 km
7
2.2 km
8
2.2 km
Total
8.8 km

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).



Move	Distance
1	1.9 km
2	1.9 km
3	1.9 km
4	1.9 km
5	1.9 km
8	4.0 km
9	2.2 km
10	2.2 km
11	2.2 km
14	2.2 km
15	2.2 km
18	2.2 km
19	2.2 km
22	2.2 km
Total	31.1 km

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.

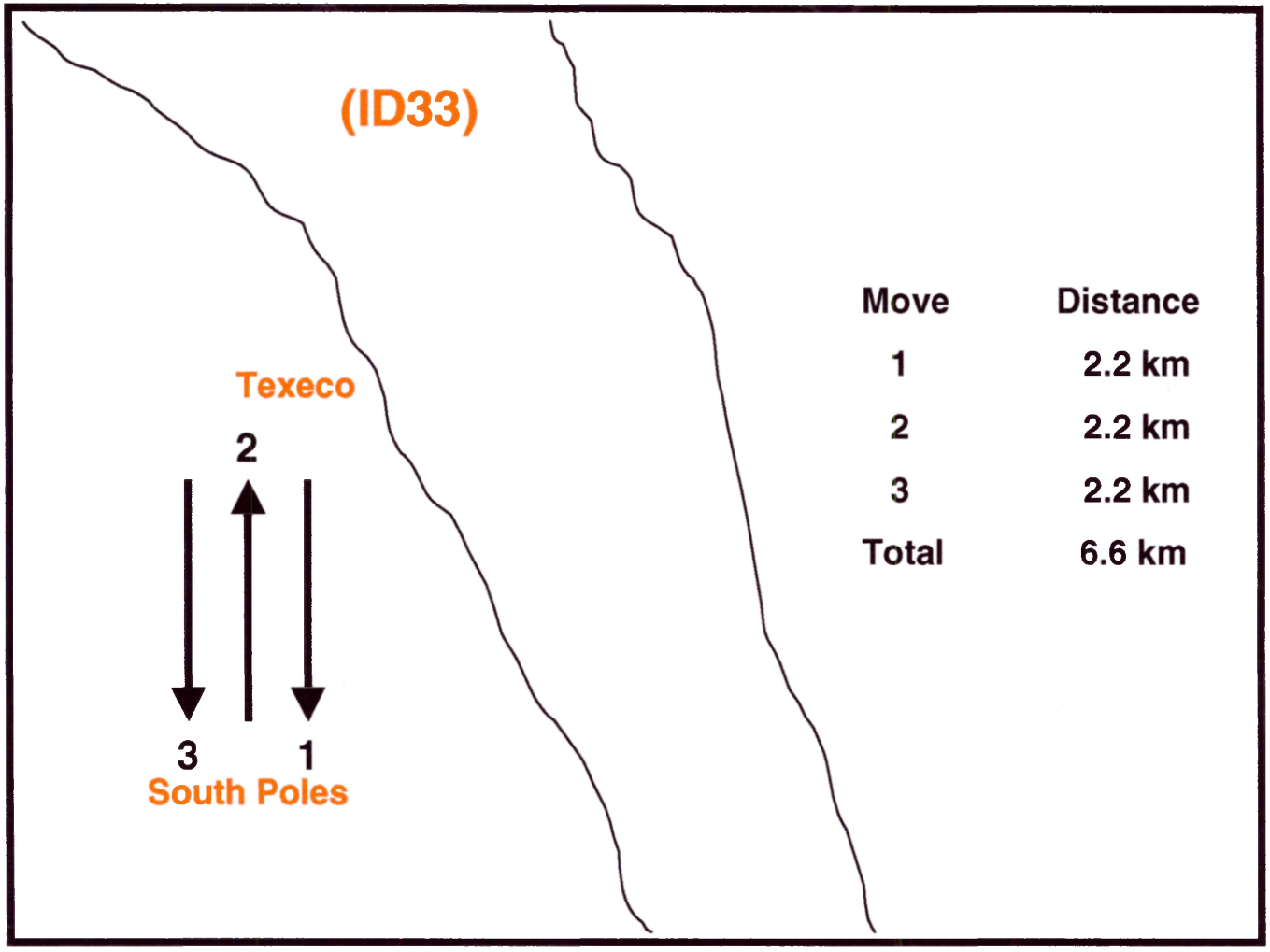

(ID33)
Texeco
2
3
1
South Poles
Move
Distance
1
2.2 km
2
2.2 km
3
2.2 km
Total
6.6 km

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'.

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=2671 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, $p \leq 0.05$, 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, $p \leq 0.05$, 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, $p \leq 0.05$, 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, $p \leq 0.05$, 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, $p \leq 0.05$, 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, $p \leq 0.05$, 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, $p \leq 0.05$, 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.

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.

Fourier Analysis (11/12/98-5/1/99)

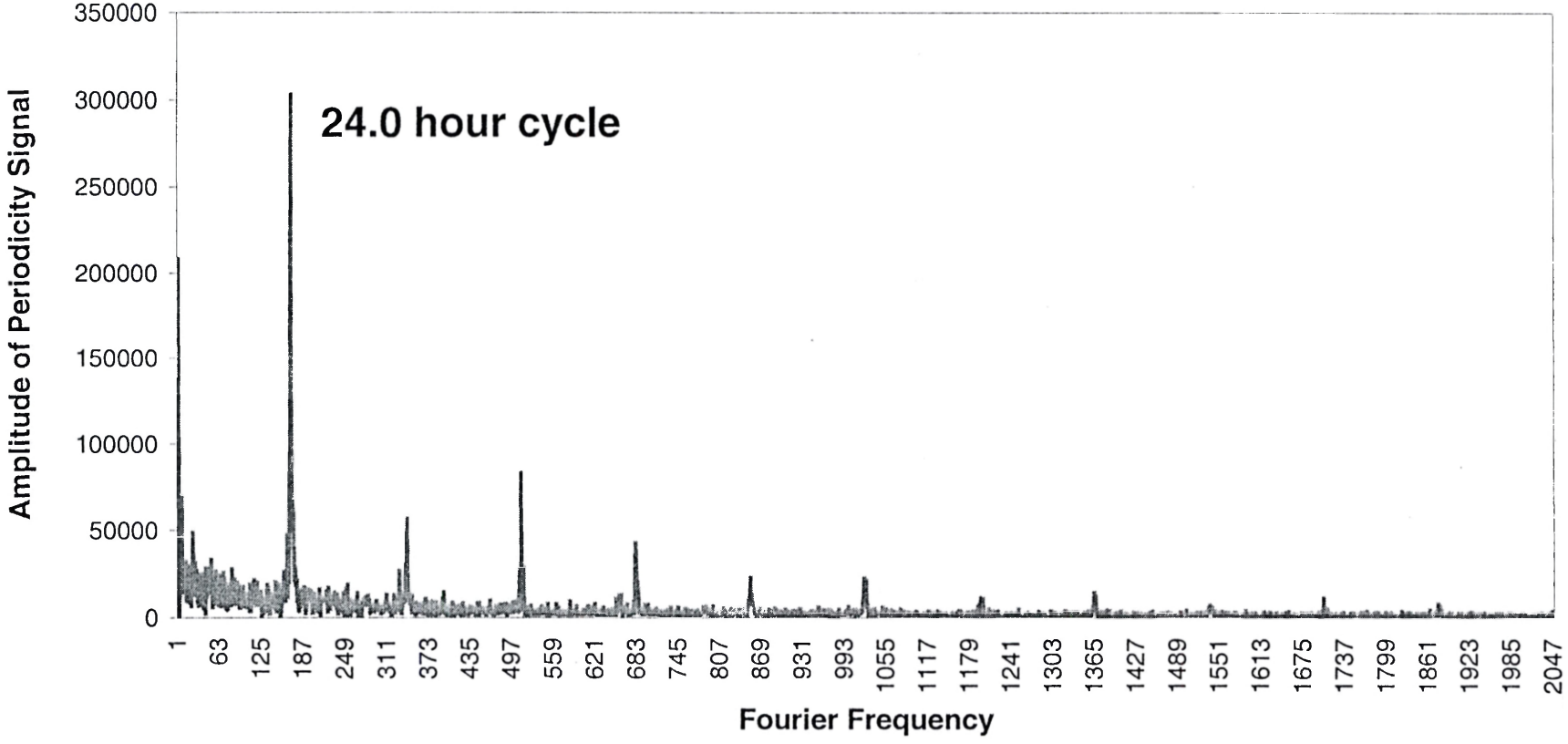


Fig. 24 Fourier analysis of detection periodicity for 2,048 consecutive hours of detections from 9 tautog released in spring 1999. A 24 h periodicity is evident.

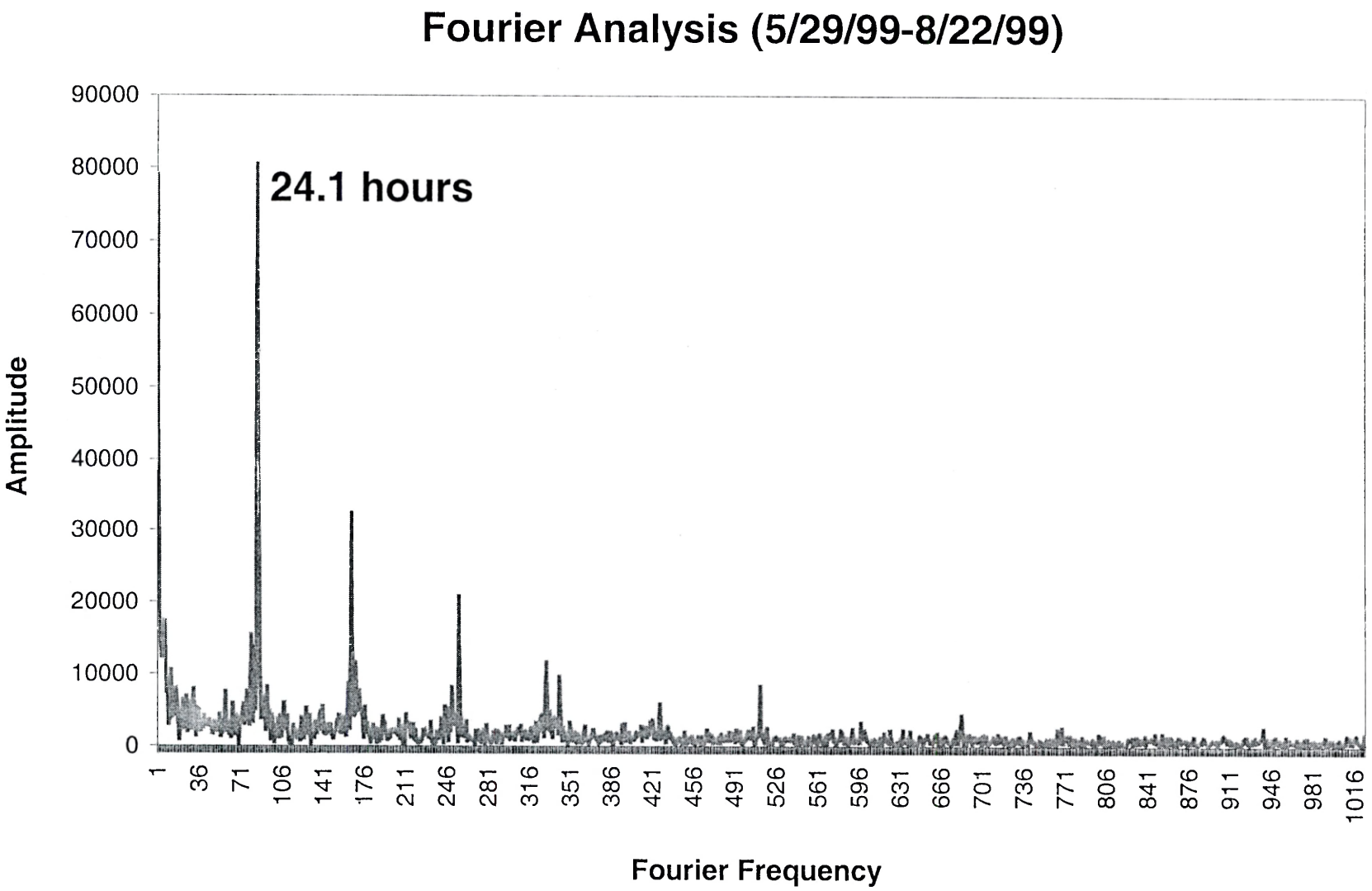

Fourier Analysis (5/29/99-8/22/99)
24.1 hours
Amplitude
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1
36
71
106
141
176
211
246
281
316
351
386
421
456
491
526
561
596
631
666
701
736
771
806
841
876
911
946
981
1016
Fourier Frequency

Fig. 25 Daily mean detection indices for fall (n=13) and spring (n=9) released tautog, 9 Nov 1998 to 9 Sep 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.

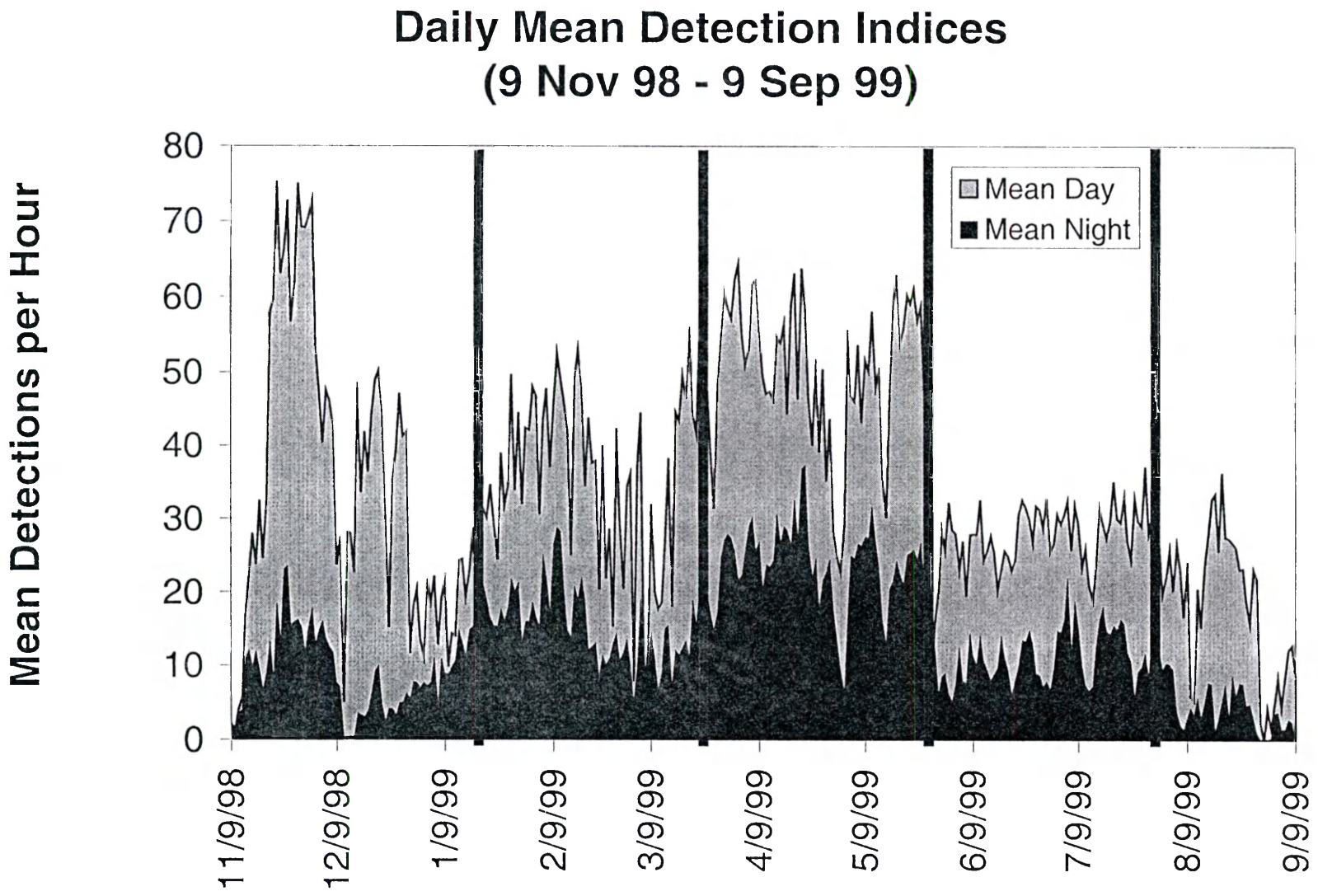

Daily Mean Detection Indices
(9 Nov 98 - 9 Sep 99)
Mean Detections per Hour
80
70
60
50
40
30
20
10
0
Mean Day
Mean Night
11/9/98
12/9/98
1/9/99
2/9/99
3/9/99
4/9/99
5/9/99
6/9/99
7/9/99
8/9/99
9/9/99

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.

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.

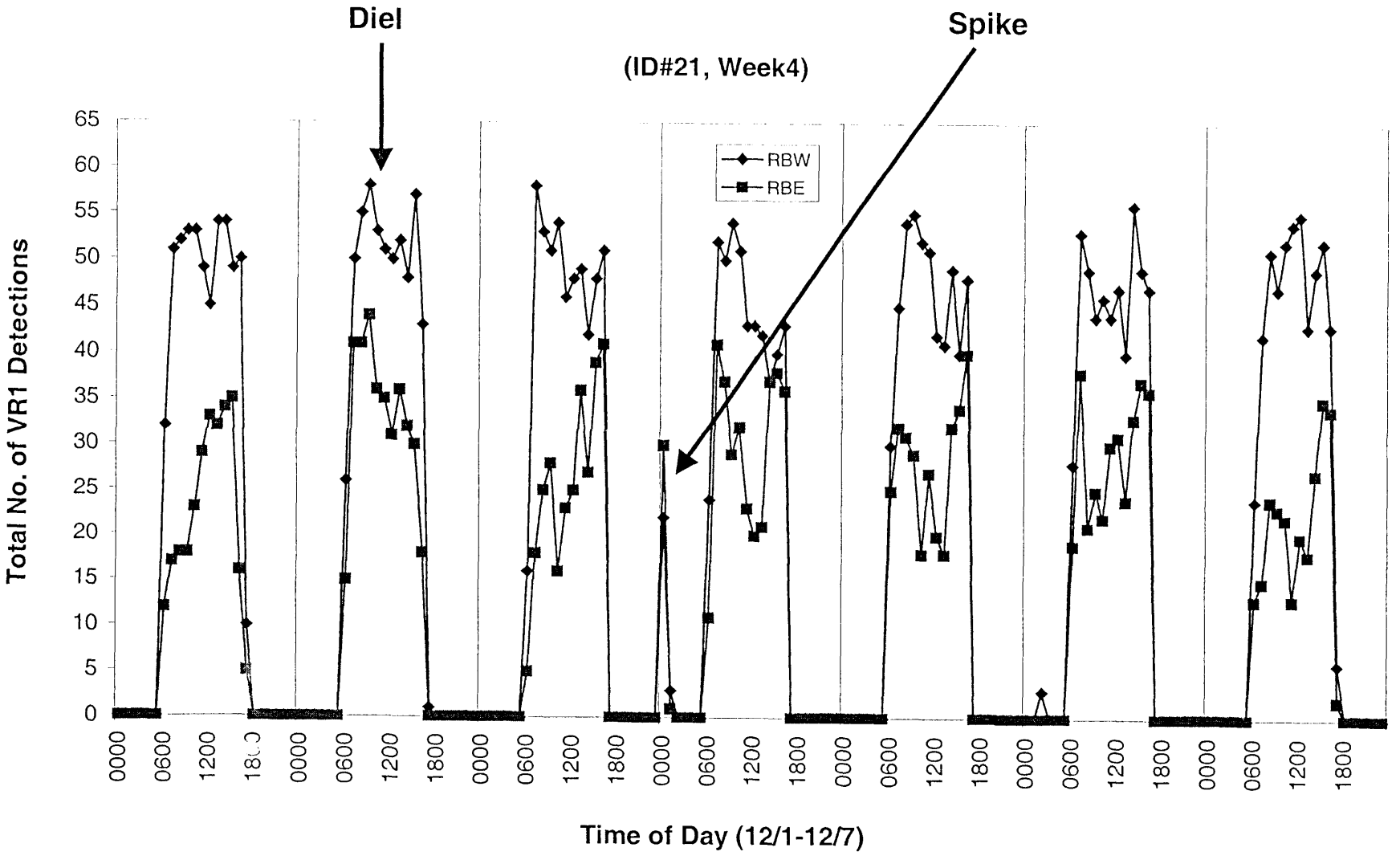

Diel
Spike
(ID#21, Week4)
RBW
RBE
Total No. of VR1 Detections
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0000
0600
1200
1800
Time of Day (12/1-12/7)

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)

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 (green circle) or "shift" patterns can begin and end on the same day (orange circle).

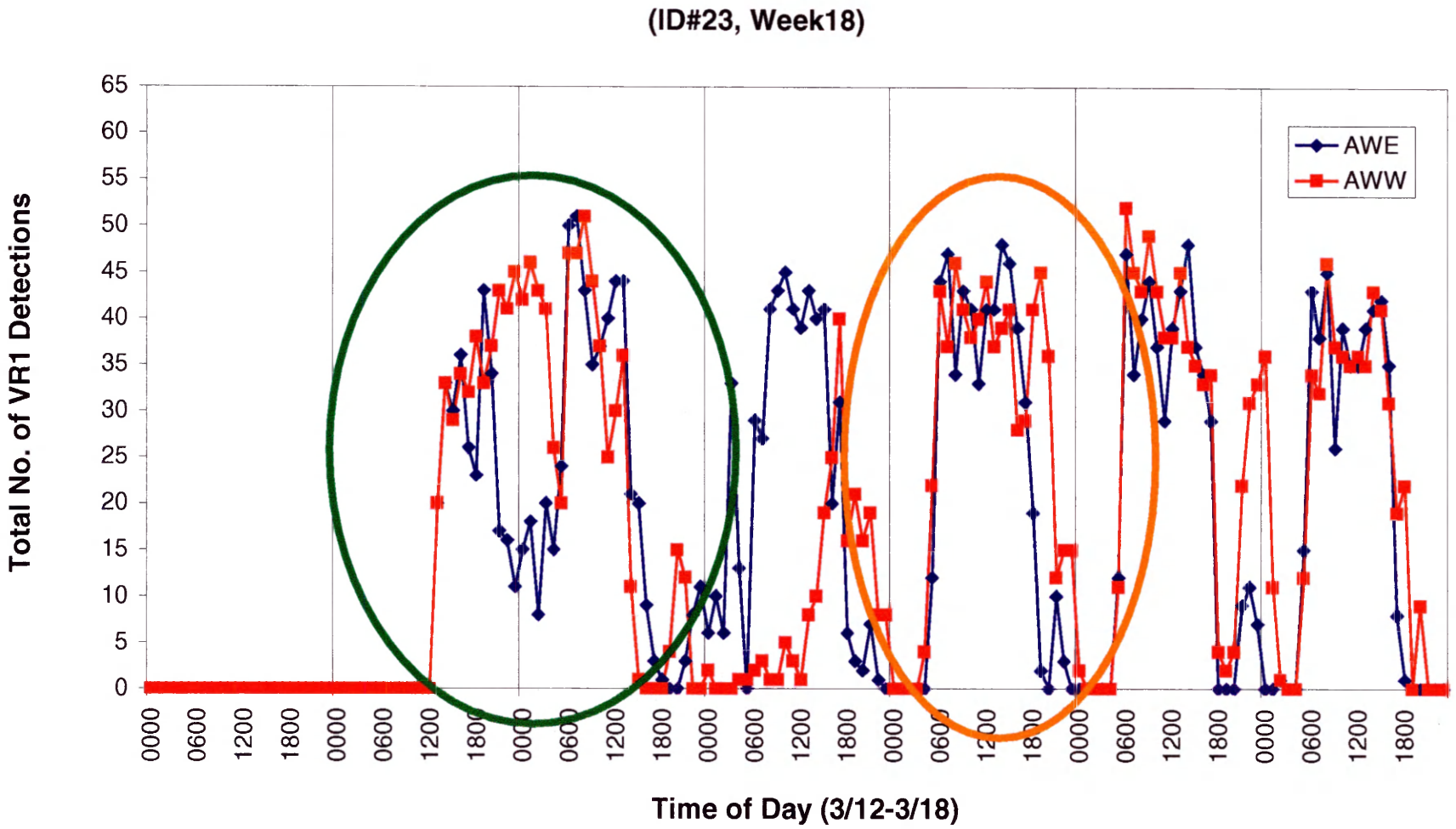

(ID#23, Week18)
Total No. of VR1 Detections
65
60
55
50
45
40
35
30
25
20
15
10
5
0
AWE
AWW
0000
0600
1200
1800
Time of Day (3/12-3/18)

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).

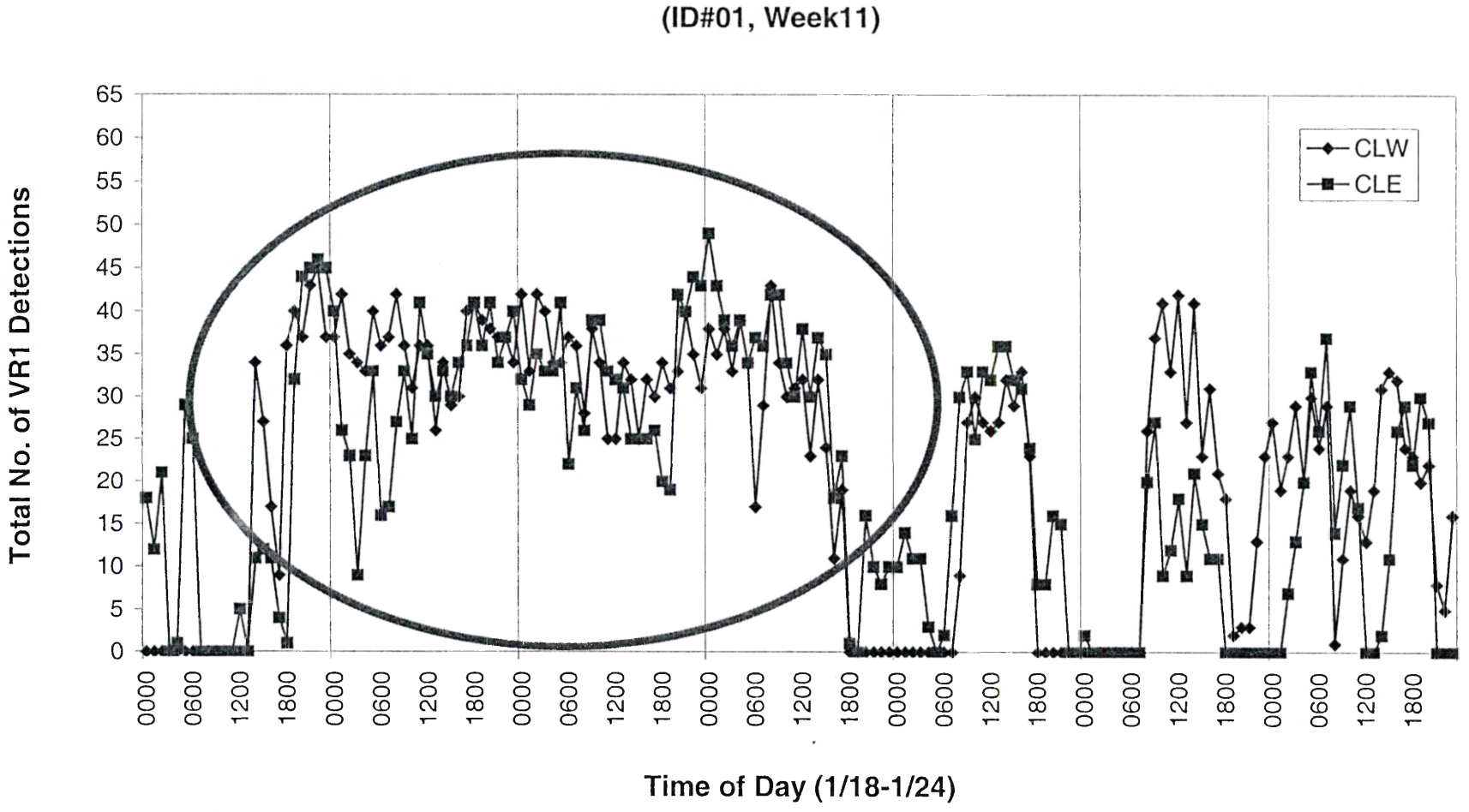

(ID#01, Week11)
Total No. of VR1 Detections
65
60
55
50
45
40
35
30
25
20
15
10
5
0
CLW
CLE
0000
0600
1200
1800
Time of Day (1/18-1/24)

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	625	623	694	629	**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	645	583	**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)

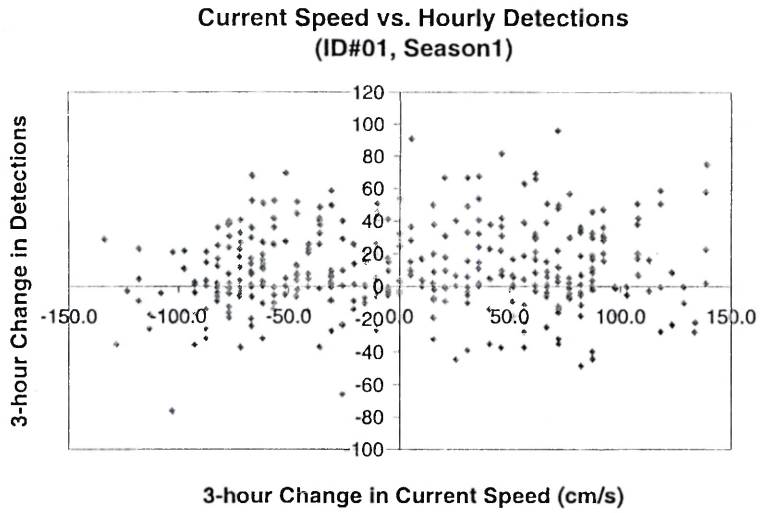
Table 25 Chi-square contingency test for lunar effects on the frequency of occurrence of the "no pattern" detection pattern.

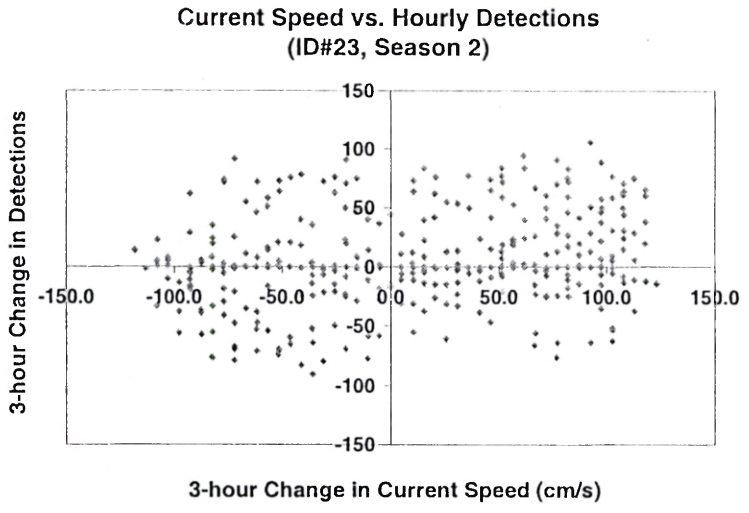
	1Q	3Q	FM	NM	Total
No Pattern	37	39	26	23	**125**
Other	611	641	672	622	**2546**
Total	648	680	698	645	**2671**

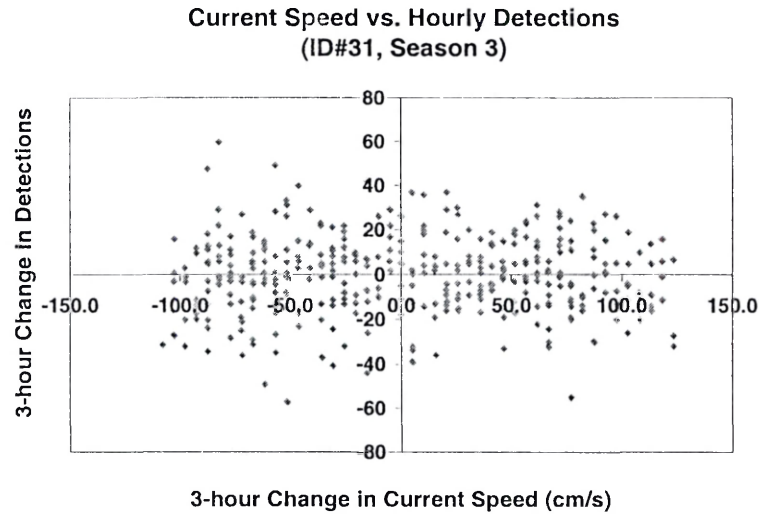
H_o: No difference in the frequency of "no pattern" fish-days with lunar phase.

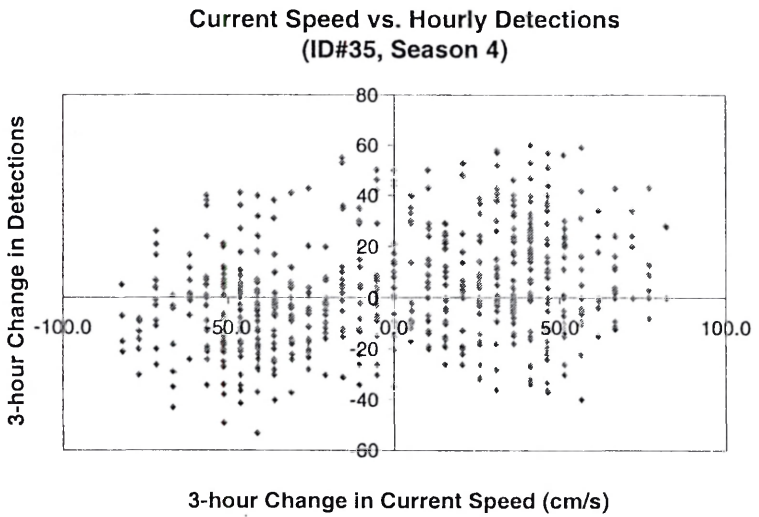
Chi-sq=6.46, df = 3, p>0.05 (NS)

Fig. 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 fish was released or season data was collected.


Current Speed vs. Hourly Detections
(ID#01, Season1)
3-hour Change in Detections
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
3-hour Change in Current Speed (cm/s)


Current Speed vs. Hourly Detections
(ID#23, Season 2)
3-hour Change in Detections
150
100
50
0
-50
-100
-150
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
3-hour Change in Current Speed (cm/s)


Current Speed vs. Hourly Detections
(ID#31, Season 3)
3-hour Change in Detections
80
60
40
20
0
-20
-40
-60
-80
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
3-hour Change in Current Speed (cm/s)


Current Speed vs. Hourly Detections
(ID#35, Season 4)
3-hour Change in Detections
80
60
40
20
0
-20
-40
-60
-100.0
-50.0
0.0
50.0
100.0
3-hour Change in Current Speed (cm/s)

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 these fish were 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. 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. Significant vertical relief (1-3 m) only occurred at the Texeco Wreck. Discrepancies between receivers were most frequently observed at this site (Appendix A10, A17-A19). Extended periods of detections of individual fish by one receiver only were uncommon (Appendix A5, A12, and A15). 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.

Tautog remained at or in the vicinity of release sites at night. Tautog were more difficult to detect at night using the VR60 receiver. 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). 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). Lack of detections by VR1 receivers at night was probably related to close association of tautog with structure at night (Olla et al., 1974; Olla et al., 1980). 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 (Appendix A1, A7-A9, A12, A14, A15). 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, 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" or "pusely" (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, 1996). 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; however, these fish could have theoretically moved after transmitter expiration. 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 (Appendix A23).

All documented movements (n=6) of tautog away from release sites occurred at manmade sites. Stone et al. (1979) concluded that artificial reefs reach a stable state after at least five years. 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), further supporting the notion that manmade sites as defined in this study have reached a steady state. Given this argument, habitat size may have 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, Appendix A4; ID30, Appendix A13), and mid-April (ID32, Appendix A15). 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. 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 an ultrasonically tagged tautog moved rapidly to an artificial fishing reef late in the second day of tracking. In October 1998, artificial reef materials were added to Cherrystone Reef, located approximately 5 km 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 (Appendix B4, B13) and recapture of two tautog within 2 km of Cherrystone Reef in April-May 1999.

The patterns of high inshore residence, high site affinity, and localized movements reported in this study are consistent with results reported for 10 adult tautog tracked in Great South Bay, NY, during summer and early fall (Olla et al., 1974). In that study, five tautog remained within 0.5 km of their overnight resting site and returned to the same overnight resting site each night. One fish initially exhibited this pattern, but late in the second day of tracking moved 6.7 km to an artificial fishing reef. Four fish traveled further than 0.5 km away from home sites each day and did not return to the same resting site each night. Instead, these fish moved between one and six different locations each day. An ultrasonically tagged tautog was sighted inshore by divers 49 days after the last tracking event, suggesting this fish remained inshore and highly localized throughout the summer and early fall.

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 bouy 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 (Bain 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 (Bain 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

Table 26 Recaptured tautog tagged and released at sites near Cape Charles, VA (Virginia Game Fish Tagging Program, 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
10/02/99	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

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 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 15.4-15.7 h.

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 (Appendices A1-A25). 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.

Late fall and spring are also the two primary seasons when tautog have been reported to be diurnally and nocturnally active (Olla et al., 1977, 1980; Olla and Studholme, 1978). Nocturnal activity in the late fall was 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 (13% of fish-days) in the late fall/early winter. 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 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. 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; Appendix A11, A12). 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. 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 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.

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,

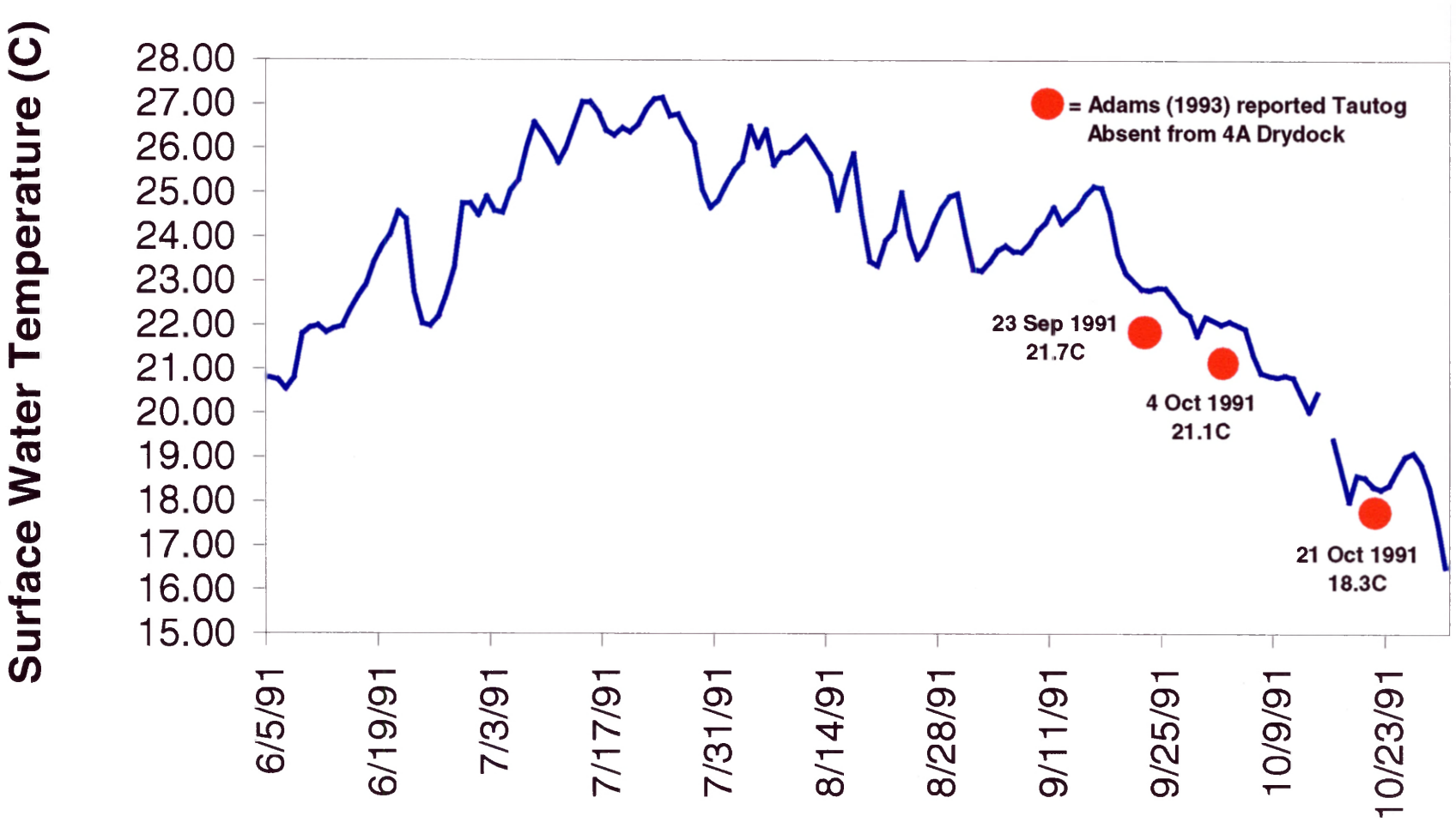
1978; Olla et al., 1977, 1980; Adams, 1993). Significance of these "low detection" days with lunar phase during winter may have been coincidental. The coolest water temperatures of the winter occurred during a two-week period in early-mid January and again during a two-week period in early-mid March. 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.

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.

Surface Water Temperature
Chesapeake Light Tower (JUN-OCT 1991)



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.

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