Chapter 152
Behavioral Response of Reef Fish and Green Sea Turtles to Midfrequency Sonar

**Stephanie L. Watwood, Joseph D. Iafrate, Eric A. Reyier,
and William E. Redfoot**

Abstract There is growing concern over the potential effects of high-intensity sonar on wild fish populations and commercial fisheries. Acoustic telemetry was employed to measure the movements of free-ranging reef fish and sea turtles in Port Canaveral, FL, in response to routine submarine sonar testing. Twenty-five sheepshead (*Archosargus probatocephalus*), 28 gray snapper (*Lutjanus griseus*), and 29 green sea turtles (*Chelonia mydas*) were tagged, with movements monitored for a period of up to 4 months using an array of passive acoustic receivers. Baseline residency was examined for fish and sea turtles before, during, and after the test event. No mortality of tagged fish or sea turtles was evident from the sonar test event. There was a significant increase in the daily residency index for both sheepshead and gray snapper at the testing wharf subsequent to the event. No broad-scale movement from the study site was observed during or immediately after the test.

Keywords Anthropogenic noise • Fish • Sea turtles • Sonar • Telemetry • Tagging

1 Introduction

Midfrequency sonar has been demonstrated to induce behavioral responses in marine mammals (Tyack et al. 2011; DeRuiter et al. 2013); however, the effect of sonar on other marine species is not well understood. Although it has been

S.L. Watwood (✉) • J.D. Iafrate
Environmental Division, Naval Undersea Warfare Center, Newport, RI 02841, USA
e-mail: stephanie.watwood@navy.mil; joseph.iafrate@navy.mil

E.A. Reyier
Kennedy Space Center Ecological Program and Environmental Services,
InoMedic Health Applications, Inc, Kennedy Space Center, Florida, FL 32899, USA
e-mail: eric.a.reyier@nasa.gov

W.E. Redfoot
Marine Turtle Research Group, Department of Biology, University of Central Florida,
Orlando, FL 32816, USA
e-mail: bredfoot@cfl.rr.com

suggested that high-intensity midfrequency sonar is potentially capable of injury or mortality in fish species that are very close to the source, neither has been demonstrated in a field setting (Jørgensen et al. 2005; Popper 2008), and behavioral studies examining the effects of midfrequency sonar on unrestrained fish in their natural habitat are limited (Popper 2008; Slabbekoorn et al. 2010; Normandeau Associates, Inc. 2012). The most prominent studies thus far were conducted in enclosed, restrained environments from which behavior cannot be extrapolated to wild animals (Schwarz and Greer 1984; Jørgensen et al. 2005; Popper et al. 2007), have only investigated the immediate behavioral responses of a single species (Knudsen et al. 1992, 1994; Gearin et al. 2000), or did not include direct behavioral observations or assess long-term survival (Culik et al. 2001).

There are also very limited studies of sea turtle behavioral response to high-intensity sounds, with most efforts focused on measuring avoidance or changes in swimming activity in response to air gun sounds (O'Hara and Wilcox 1990; Moein et al. 1994; McCauley et al. 2000; Weir 2007). Although the range of turtle hearing is likely limited to an upper level of 2 kHz, to date there have been no behavioral response studies of turtles to midfrequency sonar.

The main objective of this study was to use fine-scale acoustic telemetry to assess the residency of fish and sea turtles before, during, and after a routine submarine sonar test event. Sheepshead (*Archosargus probatocephalus*) and gray snapper (*Lutjanus griseus*) were chosen as target fish species due to known site fidelity to hard-bottom habitats in the study area (Reyier et al. 2010), hearing ranges and sensitivities that are characteristic of fish without highly derived hearing specializations (Popper 2008), and the widespread occurrence of the Sparidae and Lutjanidae families in subtropical and tropical coastal marine waters throughout the world. The green sea turtle (*Chelonia mydas*) was also a target species because it possesses similar auditory structures and presumed hearing capabilities as the six sea turtle species that comprise the family Cheloniidae, and a previous mark-recapture study has indicated the importance of the Cape Canaveral region as a foraging and resting area for juveniles (Ehrhart et al. 2007).

2 Methods

2.1 Study Area

Port Canaveral is a man-made multiuse harbor on the central east coast of Florida that supports cruise ship terminals, recreational and commercial fishing interests, and military testing and training activities. The wharf structures within the Port create valuable habitats that have resulted in robust resident populations of tropical reef fish species (Reyier et al. 2010). A significant portion of the daily feeding and resting activity of the target species is centralized on the wharf, rock revetments, and associated floating dock spaces. Although fish and turtles are exposed to low levels of anthropogenic noise regularly from the activity at Port Canaveral, pier-side testing of navy sonar systems occurs on an intermittent basis and typically for short durations.

The sonar test examined in this study occurred at the northern end of Trident Wharf over a 2-day period in June 2012. The sonar signals, duty cycle, and source levels followed a typical protocol for a pier-side submarine sonar test event.

2.2 Acoustic Telemetry Arrays

Two array configurations were utilized in this study to collect data at different temporal and spatial scales. Vemco VR2W (AMIRIX Systems, Inc.) autonomous telemetry receivers were deployed in the West, Middle, and Trident Basins to provide broad-scale coverage within the Port Canaveral area (Fig. 152.1).
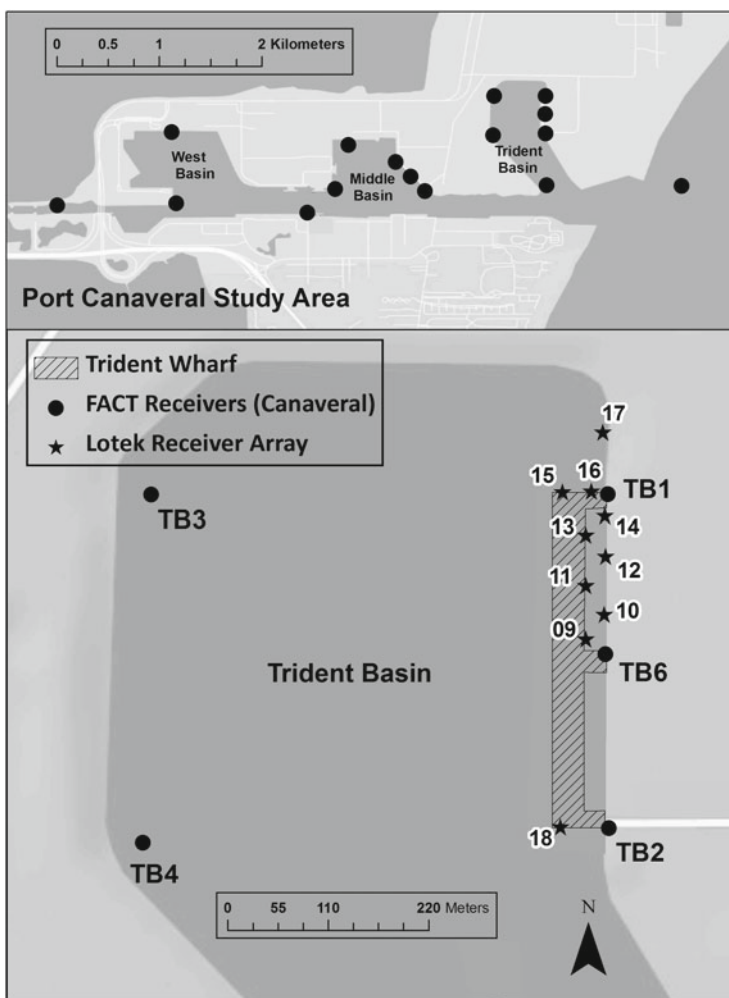

Fig. 152.1 Vemco and Lotek receiver arrays within Port Canaveral. FACT, Florida Atlantic coast telemetry

Regional tracking for those tagged fish that emigrated out of the Port Canaveral study area was accomplished via the Florida Atlantic coast telemetry (FACT) array, which at the time consisted of 200 acoustic receivers deployed across a 300-km section of the east Florida coastline. Vemco receivers within the immediate Canaveral Harbor study area were bottom mounted and secured via a guy anchor.

Lotek WHS3250 receivers (Lotek Wireless, Inc.) comprised the second fine-scale array and were secured via a guy anchor or bracket mounted directly offset from pilings on the interior of Trident Wharf in the Trident Basin only. Receivers mounted on wharf pilings were outfitted with acoustic scatterboards to help minimize acoustic reflection and localization errors. These custom-built boards were composed of closed cell foam and plywood mounted directly to pilings supporting a receiver.

2.3 Collection and Tagging

Lotek multimode transmitters (MM-MR-8-SO-TP) were used to gather movement data for both fish species and a subset of the turtles. These transmitters emit two discrete coded signals that are separately compatible with existing Vemco and Lotek receivers. The expected battery life for the transmitters ranged from 73 to 163 days depending on the pulse interval of signal emissions. Seventeen of the turtles were tagged with Vemco V9P-2L tags, which are only compatible with Vemco receivers.

A total of 25 sheepshead and 28 gray snapper were captured either by gill net or hook-line angling 1 week before the test event. Target fish had a minimum weight of 300 g in air to ensure that the tag accounted for no more than 2% of body weight (Winter 1983). Fish were anesthetized in a solution of 75 mg/L of tricaine methanosulfonate (MS-222, Western Chemical, Inc.) in seawater in a 10-gal holding tank. The fish were then placed ventral side up for surgical implantation of acoustic transmitters while the gills were irrigated with fresh seawater. The incisions were closed with two absorbable sutures followed by application of tissue adhesive and triple antibiotic ointment. Standard length, weight, method of capture, and release condition were recorded for all fish. Each fish was fitted with a small external dart tag (Hallprinta) in case of angler recapture. The fish were allowed to fully recover in aerated seawater for a minimum of 10 min and were observed swimming normally before release.

Twenty-nine green sea turtles were captured using tangle nets or dip nets. The tangle nets consisted of multifilament nylon twine mesh hung from a braided polypropylene top line and a braided polypropylene continuous lead-core bottom line. The turtles were also opportunistically captured with long-handled, large-hoop dip nets. After transport to the shore, standard morphometric measurements were recorded and the turtle was tagged externally using inconel alloy flipper tags and a passive internal transponder (PIT) tag (Destron-Fearing) inserted subcutaneously in the right front flipper proximal to the wrist joint. The Vemco or Lotek acoustic transmitters were attached externally with two-part marine epoxy to the 3rd and 4th right or left costal scutes depending on the condition of the scutes. Once the epoxy hardened, the turtle was released back into the basin.

2.4   Residency

Raw detection data from each receiver were filtered to minimize the probability of accepting false-positive detections (Pincock 2008). Residency indexes (RIs) were calculated on a daily basis for all fish to represent the proportion of a given time window that an individual was detected on the Trident Wharf Vemco receivers (TB1, TB2, and TB6). RIs were also calculated for combined detections on all three wharf receivers (a fish was considered present if it was detected on any of the three wharf receivers) to examine broader scale residency at the wharf. Before, during, and after sonar test time windows utilized in comparisons were structured by days 1–7, 8–9, and 10–16 posttagging, respectively. The Wilcoxon matched-pairs signed-rank test was used to test for significant differences between the pretest and posttest time windows at $\alpha \leq 0.05$.

RIs were also calculated for Lotek receivers along the Trident Wharf for fish only. Before, during, and after sonar test periods were structured in 36-h continuous-time windows. For this comparison, detections were combined into three receiver zones representing subsections of the wharf habitat. Receiver (REC) zones 1, 2, and 3 were composed of REC09/10/11, REC12/13/14, and REC15/16/17, respectively. Tests for significance between groups were conducted utilizing a nonparametric repeated-measures one-way ANOVA. Post hoc tests for significance between paired groups (before to during, during to after, and before to after) were conducted utilizing Wilcoxon matched-pairs signed-rank test. Significant differences were considered at $\alpha \leq 0.017$ after a Bonferroni correction for multiple comparisons.

3   Results

Fish and turtle data were monitored on the Canaveral Vemco and FACT arrays for 125 days after release of the animals. The tagged fish were detected on Vemco receivers for a median of 88 days (range 5–125 days, mode 125 days), while turtles were detected on Vemco receivers for a median of 63 days (range 6–125 days, mode 115 days). Figure 152.2 shows the number of detections of each species on Trident Wharf for the first 60 days after the start of tagging.

Table 152.1 shows a summary of the mean ± SE values for the RI on Trident Wharf. For sheepshead, there was a significant increase in the RI at TB6 ($z=-2.06$, $n=25$, $P=0.04$) and at the Trident Wharf receivers combined ($z=-2.36$, $n=25$, $P=0.02$) after the test event. Gray snapper showed a significant decrease in residency at TB2 posttest ($z=-2.50$, $n=28$, $P=0.013$), although there was a significant increase at the Trident Wharf receivers combined ($z=-2.01$, $n=287$, $P=0.045$). Green sea turtles overall had lower RI values on the wharf and also showed a significant decrease in residency at TB2 only ($z=-2.72$, $n=29$, $P=0.007$).

In the short term, significant differences between time periods were reported for the hourly RI for sheepshead at REC09/10/11 ($H=10.71$, df$=2$, $P=0.005$) and for
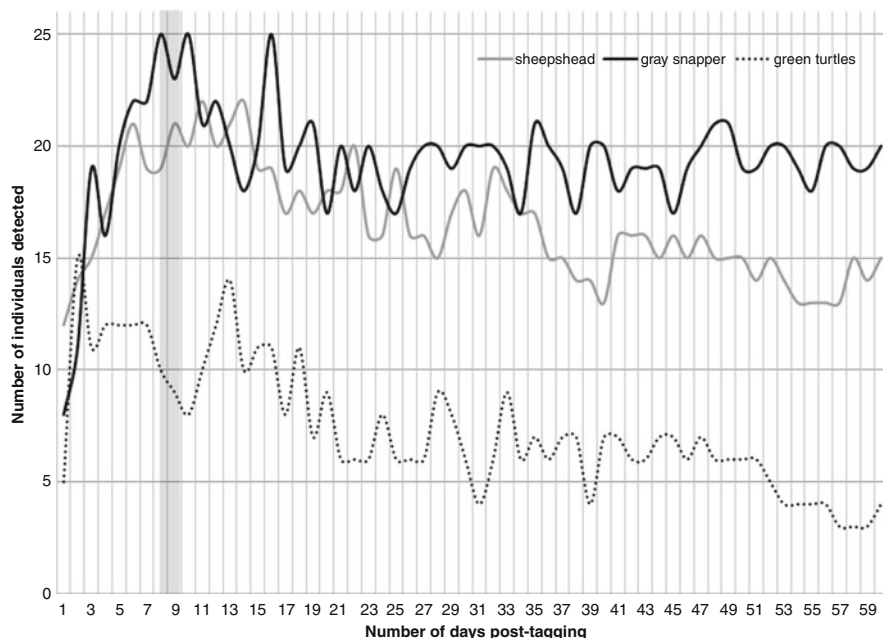
Fig. 152.2 Daily detections of sheepshead, gray snapper, and green sea turtles at Trident Wharf Vemco receivers (TB1, TB2, and TB6). *Gray area* is the sonar test period (days 8–9)

Table 152.1 Daily residency index for sheepshead, gray snapper, and green sea turtles before, during, and after the sonar test

	Sheepshead	Gray snapper	Sea turtle
TB1 receiver			
Before	0.35±0.07	0.44±0.06	0.07±0.03
During	0.36±0.09	0.57±0.09	0.05±0.04
After	0.36±0.09	0.46±0.07	0.08±0.03
TB2 receiver			
Before	0.09±0.03	0.20±0.04	0.26±0.05
During	0.12±0.06	0.27±0.08	0.16±0.05
After	0.12±0.05	0.32±0.08	0.13±0.05
TB6 receiver			
Before	0.43±0.07	0.09±0.03	0.22±0.06
During	0.52±0.09	0.09±0.04	0.24±0.08
After	0.57±0.09	0.12±0.04	0.26±0.07
Trident Wharf			
Before	0.67±0.06	0.60±0.04	0.39±0.06
During	0.80±0.07	0.86±0.05	0.33±0.08
After	0.82±0.05	0.77±0.05	0.37±0.08

Values are means±SE. Before, days 1–7; during, days 8–9; after, days 10–16

Table 152.2 Hourly residency index for sheepshead and gray snapper for 36-h windows before, during, and after the sonar test

	Sheepshead	Gray snapper
REC09/10/11		
Before	0.68±0.08	0.43±0.06
During	0.61±0.08	0.36±0.06
After	0.65±0.08	0.39±0.06
REC12/13/14		
Before	0.78±0.06	0.57±0.08
During	0.75±0.06	0.50±0.06
After	0.81±0.06	0.47±0.06
REC15/16/17		
Before	0.61±0.07	0.62±0.08
During	0.61±0.07	0.58±0.06
After	0.67±0.06	0.55±0.06
Trident Wharf		
Before	0.74±0.06	0.55±0.08
During	0.78±0.06	0.49±0.07
After	0.79±0.05	0.46±0.07

Values are means±SE. Before, days 6.5–8; during, days 8.5–9; after, days 9.5–11

gray snapper at all Lotek receivers combined ($H=6.46$, df$=2$, $P=0.040$). Post hoc comparisons showed a significant decrease in hourly residency for sheepshead at REC09/10/11 for the before test compared with the during test time period ($z=-3.15$, $n=25$, $P=0.002$). Post hoc comparisons for gray snapper were not significant. A summary of mean±SE values for the hourly RIs in the Trident Basin are presented in Table 152.2.

4   Discussion

Sheepshead and gray snapper exposed to a typical pier-side submarine sonar test event showed some short-term declines in residency near particular individual receivers during and after the test, but no long term displacement from the wharf habitat overall was observed for any species. Sonar testing is infrequent in the Trident Basin, especially within the short-term residence time of 2–4 weeks typical of these species. Although the sonar signals may represent a novel stimulus, Port Canaveral is a very urban environment, and marine species here may be habituated to higher levels of anthropogenic sound, including vessel and construction noise. These individuals could therefore be less likely to respond than naïve populations. Nevertheless, the sheepshead, gray snapper, and green sea turtles present in the Trident Basin did not demonstrate significant displacement in response to a typical pier-side submarine sonar test event.

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