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Monitoring Fish, Marine Mammal Sounds with Wave Glider

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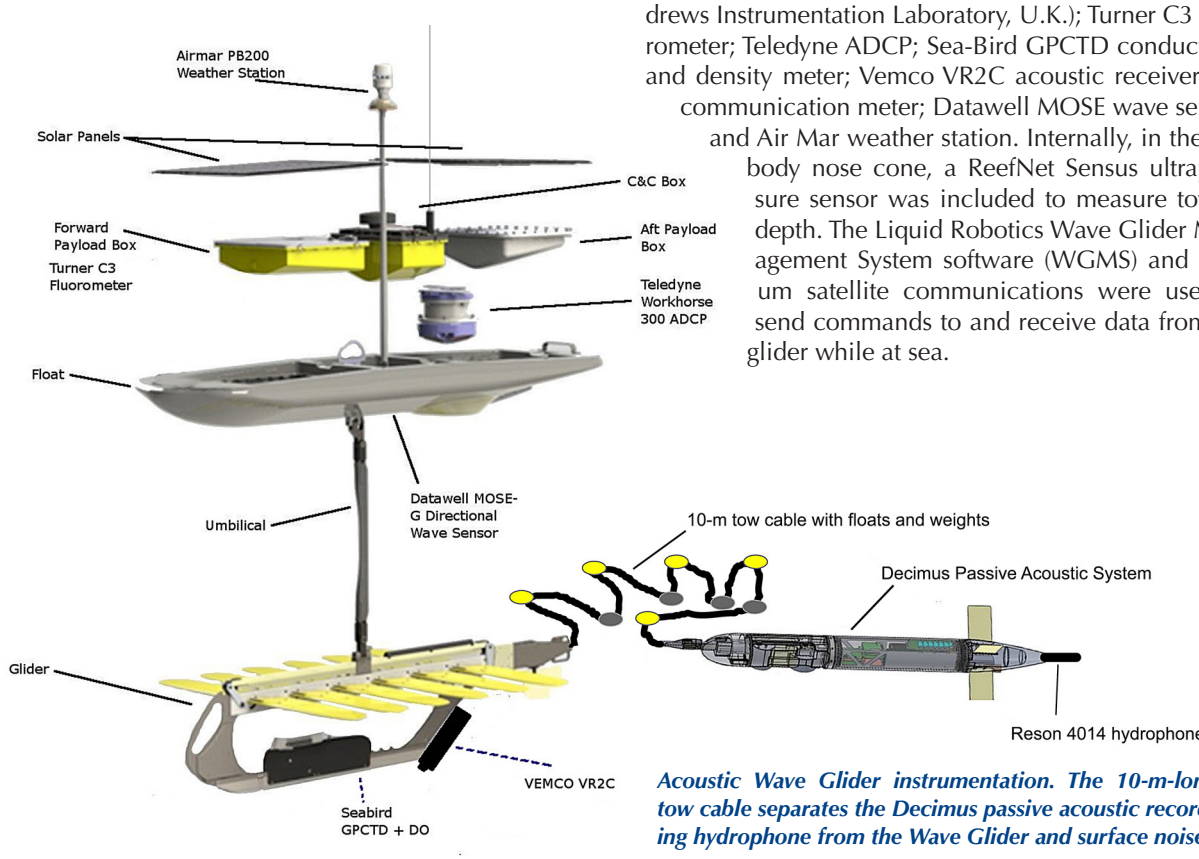
Remote observations of marine animal behavior have one distinct advantage over direct observations: The observer is not present to disturb the animals. There are no vessel noises, no diver's bubbles, no people present that could alter the behavior of the animals being observed.

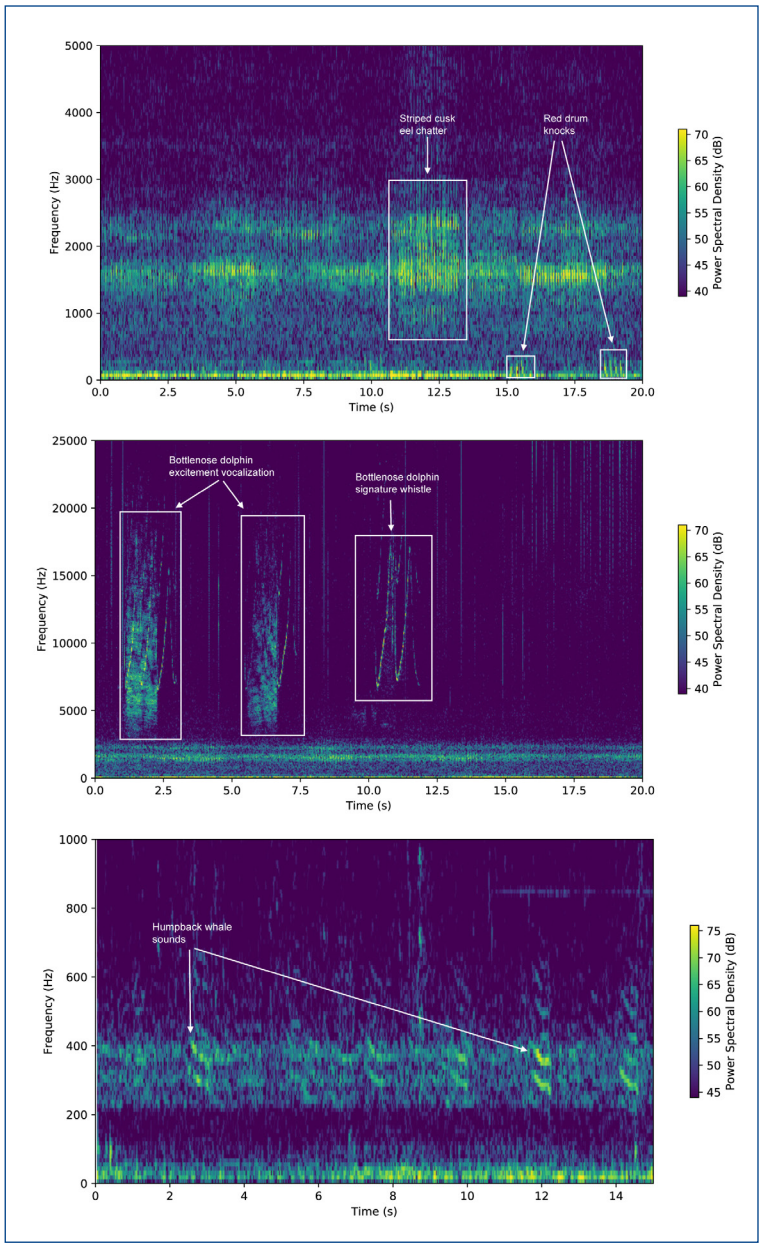
We report here on how an autonomous vehicle, a Liquid Robotics SV2 Wave Glider (Liquid Robotics, Sunnyvale, California) equipped with hydrophones and acoustic tag detectors, can be a tool to study the behavior and habitat use of fishes and whales in the coastal environment. With that objective, we have used a new instrument—"Blackbeard," the Acoustic Wave Glider (AWG)—to conduct affordable, long-term, passive acoustic monitoring of marine animals and the coastal ocean acoustic environment.

Decimus and the Acoustic Wave Glider

Blackbeard has several instrument sensors, including: Decimus towed passive acoustic system (SAIL, Saint Andrews Instrumentation Laboratory, U.K.); Turner C3 fluorometer; Teledyne ADCP; Sea-Bird GPCTD conductivity and density meter; Vemco VR2C acoustic receiver and communication meter; Datawell MOSE wave sensor; and Air Mar weather station. Internally, in the tow body nose cone, a ReefNet Sensus ultrapressure sensor was included to measure towing depth. The Liquid Robotics Wave Glider Management System software (WGMS) and Iridium satellite communications were used to send commands to and receive data from the glider while at sea.



Acoustic Wave Glider instrumentation. The 10-m-long tow cable separates the Decimus passive acoustic recording hydrophone from the Wave Glider and surface noise.



Spectrograms showing red drum knocks and striped cusk eel chattering sounds (top); bottlenose dolphin excitement calls and whistles (middle); and humpback whale calls (bottom).

The Decimus system was adapted for use in the tow body; it consists of a Teledyne Reson 4014 hydrophone input to a SAIL high-performance data acquisition card sampling at up to 1 mHz, storing data in binary format on a 256-GB storage card, and outputting the detection data over cable connection to the WGMS. Binary audio data are converted to Windows audio file (WAV) format after Decimus recovery.

AWG Passive Acoustic Monitoring

Blackbeard AWG was deployed with the Decimus passive acoustic recorder in a series of three sea trials to tune the buoyancy of the tow body. In North Carolina sea trials starting in 2015, the AWG followed all commands and was able to navigate a course of preprogrammed waypoints at a speed of 1 to 2 kt. (0.5 to 1.0 m/s). The AWG was sent along a course to record the wild soniferous animals in sea trials three, five and six. However, because the tow body was very negatively buoyant in trials three and five, dragging along the bottom, the Decimus was damaged in trial three and had to be recovered earlier than planned. Nonetheless, the Decimus made excellent recordings during all three trials, sent autodetection data to shore via the satellite connection, and after recovery the recordings were processed for spectral analyses.

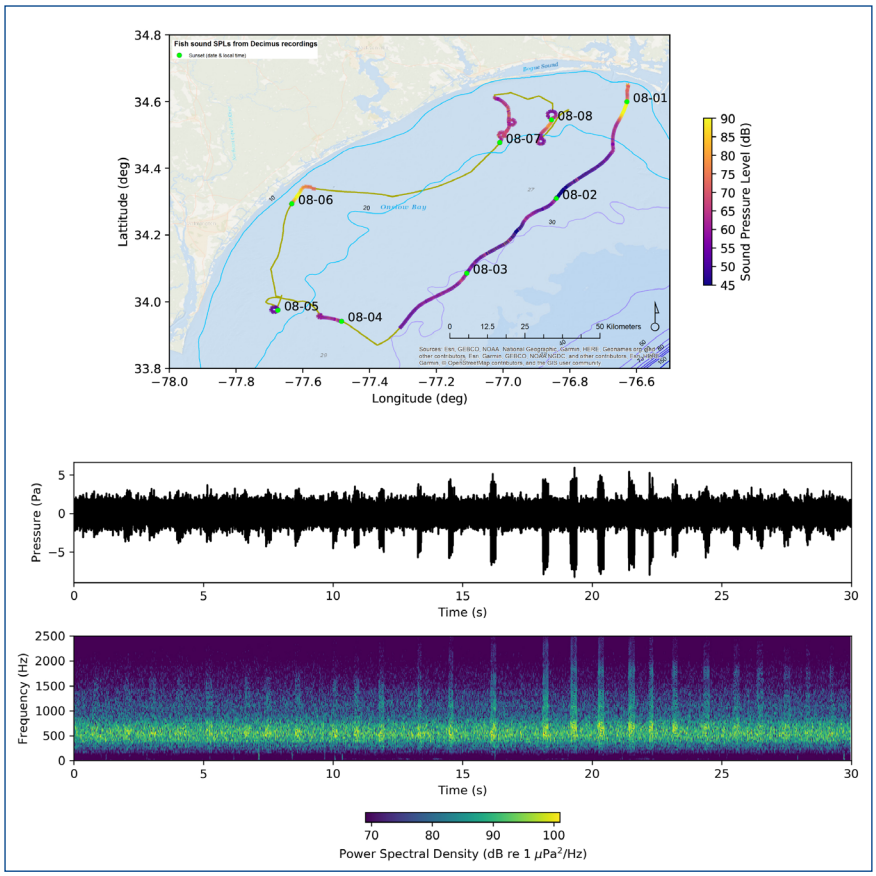
Fishes are known sound producers. They can be recorded and their species identity determined; in some cases, their behavior can be associated with specific sounds. Choruses and individual calls of many fish (red drum, *Sciaenops ocellatus*; weakfish, *Cynoscion regalis*; spotted sea trout, *Cynoscion nebulosus*; striped cusk eels, *Ophidion marginatum*; sea robins *Prionotus* sp.; and oyster toadfish *Opsanus tau*) were recorded during all sea trials. Marine mammal sounds (humpback whales, *Megaptera novaeangliae*, and bottlenose dolphins, *Tursiops truncatus*) were recorded during these excursions as well.

Spectrograms of the recordings were produced as a function of time and sound frequency, with various colors showing the sound intensity (power spectral density in decibels referenced to 1 $\mu Pa^2/Hz$). The fish sounds are in the lower frequency range (the red drum "knock" calls have a dominant frequency of 0.125 kHz; striped cusk eel "chattering" calls are dominant at 1.5 kHz, with a range of 1.0 to 2.5 kHz).

Recordings shown in accompanying spectrograms were taken September 16, 2015 at 17:30:14 local time during sea trial three, when red drum were spawning in North Carolina. The red drum calls are advertisement or spawning calls. This recording marks the first time this species has been recorded making spawning calls offshore in North Carolina and not in an estuary, and thus extends the knowledge of their critical spawning habitat to include offshore areas.

Bottlenose dolphin and marine mammals prey heavily on these soniferous fishes. The bottlenose dolphins were likely listening for soniferous fish prey, using the fish sounds for general location, then localizing them with higher frequency echolocation vocalizations. The whistles with overlapping bursts of sounds from the bottlenose dolphins (spectrogram at 1 to 3 sec., then again 5 to 7 sec., 4 to 20 kHz) heard later in the recording are likely to be dolphin excitement calls. There were still fish calling after the dolphins' whistles and excitement calls, but these sounds were lower in intensity and perhaps from distant fish choruses far from the recording hydrophone.

The objective of sea trial five was to test the Decimus passive acoustic tow body buoyancy adjustments. Trial



Fish-associated sound pressure levels varied as the AWG moved. Spectrogram shows SPL in a recording of a spotted sea trout call as the AWG passed by.

five was conducted June 8 to 12, 2016. Although we successfully launched and recovered the AWG, the tow body continued to be negatively buoyant and dragged along the bottom (confirmed by the acoustic records of the housing dragging the bottom). However, no damage was detected upon recovery.

As a result of the negatively buoyant tow body dragging along the bottom, the AWG was difficult to control and had a reduced water speed. The AWG was swept up in the Gulf Stream northeasterly current and taken away from the preprogrammed course. After passing by Cape Lookout Shoals, navigational control was established, and the AWG was recovered off Ocracoke Inlet, North Carolina.

Excellent sound recordings of oyster toadfish and other marine fishes were recorded on this mission in spite of the buoyancy issues with the tow body. Additionally, the AWG pilots learned about navigational limitations in strong currents, steering it away from Cape Lookout Shoals. After passing these shoals, the current speed remained strong while near the Gulf Stream, but the pilots were able to slow the AWG down-current velocity (speed over ground) by heading directly into the current. In this situation, the AWG was pointed into the current and the tow body was extended behind the submarine while the AWG traveled down-current at a speed equal to the difference between the current speed and the AWG water speed. This orientation allowed the AWG to spend more time recording the soundscape and to delay the arrival of the AWG at Ocracoke Inlet until recovery.

Additional tow body buoyancy tests were conducted during the summer of 2017 to solve the buoyancy problems encountered during the first two trials. The buoyancy of the tow body was tuned while deployed from the dock at Morehead City in a tidal current, with the pressure sensor included in the nose cone to measure depth after adding various weights and buoyancy foam. The best adjustment was 386 grams of lead in the nose cone and 475 cubic centimeters of #6 foam in the tail cone. These tests resolved the buoyancy problems with the Decimus tow body.

In sea trial six from August 1 to 9, 2017, the AWG was sent along a programmed sequential course for nine days, reporting back to shore with AWG telemetry position data, current profiles, fluorometry measurements, sound recordings, wave data and weather data. Blackbeard towed the Decimus passive acoustic recorder at approximately 10-m depth without touching the bottom or colliding with any underwater reefs, because the tow body was neutrally buoyant using the buoyancy adjustments as described above. The AWG was able to navigate in a southwesterly direction against the prevailing Gulf Stream current and return to navigate around artificial and natural reefs offshore in Onslow Bay. It was recovered without incident on August 9, 2017 near the initial release point, as planned. It was judged to be fully commissioned and ready for future deployments.

Analysis

Upon recovery, the recorded sounds from this mission were analyzed. Sound pressure levels (SPL in decibels referenced to 1 μPa) were measured from the calibrated hydrophone along the track of the AWG in each mission, and auto-call detection algorithms were used to identify whale and dolphin calls. The auto-detection of whistles, moans and specific whales was reported in real time from the Decimus, and reports were sent to shore via WGMS; these were confirmed in processing.

After recovery, the recordings on the disk were downloaded and audio files (WAV files) analyzed using standard bioacoustics software. The Pamguard software (pamguard.org) was used here in post-mission processing of the recordings to detect bottlenose dolphin whistles. Fish sounds were characterized by playbacks in Pamguard and identified by human listeners. Excellent recordings were made of spotted sea trout choruses, with the AWG passing directly over calling individual fish

about 7 m below the tow body. Thus, spotted sea trout were heard in the area to the east of Beaufort Inlet in August, demonstrating that they likely spawn outside of the estuary at this time of year.

Humpback whales were recorded in quieter water farther offshore near the Gulf Stream. Sciaenidae (spotted sea trout, weakfish and red drum) calling was summarized using a power spectral band sum between the frequencies (0.25 to 0.5 kHz), and the SPL was plotted along the track of the AWG. SPL associated with *Cynoscion nebulosus* and other fishes was greatest after sunset each night, as has been noted for Sciaenidae fishes. Many of these calls were recorded in a depth of 20 to 30 m and close to the inlets and artificial reefs, demonstrating the importance of access to estuarine waters and complex structure for these fishes during spawning. Deeper water along the 30-m isobath had lower fish-associated SPL, suggesting these fish prefer shallower spawning habitats (less than 30-m depth).

Conclusions, Future Studies

The Wave Glider and Decimus towed passive acoustic system worked very well after buoyancy tuning was completed. The system allowed us to record red drum, weakfish and spotted sea trout spawning calls on the continental shelf near inlets and an artificial reef for the first time off North Carolina. The passive acoustic system documented essential fish habitat locations for these important recreational and commercial fish species. Such fishes could be negatively affected by seismic surveys, wind power, and oil and gas energy development projects planned for the continental shelf off North Carolina.

In addition, we documented other soniferous species of fishes (striped cusk eel and oyster toadfish), which are prey for marine mammals such as bottlenose dolphins.

Although we did not detect any North Atlantic right whales (*Eubalenoptera glacialis*) in these trials, these marine mammals are critically endangered and occur off North Carolina during their migration from feeding areas off Canada to calving grounds off the Georgia and Florida coast. The AWG could be deployed to detect right whales during their migration and alert energy companies and scientists about their location. Because the Wave Glider is mobile with an Iridium satellite connection, the Decimus system could be towed into areas scheduled for construction and seismic surveys during energy development projects, and it could provide real-time alerts (via the Liquid Robotics WGMS) to onshore and vessel-based operators when right whales are nearby. Real-time algorithms on the Decimus can process the recorded signals while still at sea and send a message alert via WGMS if a signal matches either dolphin whistles or right whale "up calls"; similar detection algorithms are being developed for common species of fishes.

A fleet of passive-acoustic-equipped Wave Gliders could be used to monitor offshore areas proposed for energy development and provide additional protection against injury to whales and spawning fish populations during offshore construction projects.

Acknowledgments

We acknowledge the support of the National Science Foundation Major Research Instrumentation grant (1429315) to the co-authors and JP Walsh.

Captain Eric Diaddorio and Mark Keusenkothen, ECU Office of Diving and Water Safety, assisted with launch and recovery operations.

We thank the ECU Wave Glider pilot team: Tyler Peacock, Cecilia Krahforst, Patrick Harris, Ramone Lopez, Rebecca Asch, Chuck Bangley, Phil Deville, Chris Thaxton, Ryan MacKenzie and Ryan Bradley.

The Division of Research and Economic Development and Engagement (REDE), Thomas Harriot College of Arts and Sciences, Department of Biology, Department of Physics, and Institute for Coastal Science and Policy (ICSP) at East Carolina University supplied matching funds for this work.

We thank Graham Weatherup, Richard Baggaley, Angus Aitken (Saint Andrews Instrumentation Laboratory) and Ryan Carlon (Liquid Robotics), who helped with tuning the buoyancy of the tow body and operation of the Decimus.

References

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