2018

Incorporation of Acoustic Sensors on a Coastal Ocean Monitoring Platform for Measurements of Biological Activity

James Locascio

David Mann

Kyle Wilcox

Mark Luther

University of South Florida, mluther@usf.edu

Follow this and additional works at: https://digitalcommons.usf.edu/msc_facpub

Part of the [Life Sciences Commons](#)

Scholar Commons Citation

Locascio, James; Mann, David; Wilcox, Kyle; and Luther, Mark, "Incorporation of Acoustic Sensors on a Coastal Ocean Monitoring Platform for Measurements of Biological Activity" (2018). *Marine Science Faculty Publications*. 2059.

https://digitalcommons.usf.edu/msc_facpub/2059

This Article is brought to you for free and open access by the College of Marine Science at Digital Commons @ University of South Florida. It has been accepted for inclusion in Marine Science Faculty Publications by an authorized administrator of Digital Commons @ University of South Florida. For more information, please contact digitalcommons@usf.edu.

Incorporation of Acoustic Sensors on a Coastal Ocean Monitoring Platform for Measurements of Biological Activity

AUTHORS

James Locascio
Mote Marine Laboratory,
Sarasota, Florida

David Mann
Loggerhead Instruments,
Sarasota, Florida

Kyle Wilcox
Axiom Data Science,
Anchorage, Alaska

Mark Luther
University of South Florida
College of Marine Science

Introduction

Ocean observatories have been implemented to create long-term, high-resolution time series for measuring and predicting variability in oceanic and atmospheric phenomena. The majority of these systems have been deployed as coastal stations and offshore buoys and more recently as mobile platforms (e.g., gliders) (Wall et al., 2012). Data from these systems are principally used to provide real-time information and forecasts of weather conditions and water level and flow (i.e., wave heights, tides, and currents) based on physical parameters. This information mainly serves the maritime industry and also assists with management of coastal residential zones during storm surges. Long-term time series data generated by ocean observatories are also useful for

ABSTRACT

Ocean observing stations have mainly focused on data collection of physical parameters measured in the ocean and atmosphere and also, to some extent, of biogeochemical parameters. Robust sensors capable of measuring biological data reflective of higher trophic level function at the same time scales as other parameters are not yet commonly incorporated into the sensor array used on observing platforms. In this project, we reengineered a coastal ocean observatory to include two hydrophones for this purpose. One hydrophone (HTI 96-MIN) was used to record ambient acoustic signals of fish reproductive sounds, and a second hydrophone (Vemco VR2C) was used to receive transmissions from acoustic tags implanted in fishes. This project demonstrates that it is possible at a regional ocean observing station to collect data on biological-physical processes at the same time scales over long periods and on a cost-effective basis. This will allow a better understanding of natural variability in ecosystem processes and potential impacts on these from anthropogenic sources and climate change. Technical details of the reengineering methods used to make the station operational and URLs of data tables and archives are provided.

Keywords: passive acoustics, fish sound production, red tide, ocean monitoring platform

addressing questions about climate change on local and regional scales.

The role of ocean observatories continues to broaden as the need for data from multiple sensor types is sought for understanding natural variability in ecosystem processes and potential impacts on these processes from anthropogenic sources and climate change. Relative to physical parameters, few sensors, besides those used to measure biogeochemical processes linked to primary production and eutrophication, have been incorporated into ocean observatories to measure biological processes. Chlorophyll sensors have been used to estimate levels of phytoplankton biomass

(Albaladejo et al., 2010), and custom light sensors (“Brev Buster”) have been used for the detection of harmful algal blooms associated with the toxin-producing dinoflagellate *Karenia brevis* (Craig et al., 2006). Iterations of this technology are in continuous development as optical plankton discriminators for use on ocean observatories (Shapiro et al., 2015). Sensors capable of measuring parameters that are associated with higher trophic levels can be reliably incorporated into the instrumentation used for long-term monitoring yet are almost never deployed as part of ocean observing systems. The hydrophone probably represents the only choice that is currently well

suited for this purpose. Hydrophones detect pressure changes associated with acoustic signals. They are factory-calibrated and require little to no maintenance during deployment, making them ideally suited for long-term data collection on remote platforms. Examples of ocean monitoring stations with cabled seafloor nodes that have incorporated hydrophones for passive acoustic monitoring include Victoria Experimental Network Under the Sea and Northeast Pacific Timeseries Underwater Networked Experiments, both located offshore Canada's west coast and the Lofoten-Vesterålen Cabled Ocean Observatory on Norway's north coast. The integration of hydrophones in more United States-based ocean observing stations is needed.

The underwater acoustic environment is rich in signals associated with biological activity. Sources include a broad range of taxa represented by invertebrates, fishes, and marine mammals (Mok & Gilmore, 1983). In coastal environments, particularly estuaries, fish sound production associated with courtship and spawning often dominates the acoustic environment (Rountree et al., 2002). Recordings of chorusing fishes made during the spawning season have documented strong diel patterns in fish sound production with peak levels reaching 35–40 dB SPL (re: 1 μ Pa) above daytime low levels (Locascio & Mann, 2008, 2011). Locascio (2010) also documented decreases in levels of fish sound production as an apparent response to changes in environmental conditions associated with hypoxia. Although these studies measured variability in levels of fish sound production at high temporal resolution (10 s/10 min) over long periods, independent environmental data recorded

at similar time scales were unavailable. Lack of these data prevented explanation of variability in fish sound production and behavior in relation to changing environmental conditions. The incorporation of hydrophones into coastal ocean observatories would allow the variability in fish sound production to be both measured and explained, addressing the long-standing recognition that ocean observatories should incorporate biological data reflective of ecosystem function at the same time scales as environmental data. Acoustic tags and receivers have also been widely used to document fish habitat use and movement patterns, including responses to changing environmental conditions.

The purpose of this project was to reengineer and modernize a coastal ocean observing station and to add hydrophones to the instrumentation for detecting fish sound production and behavior, potentially providing proof of concept that data relevant to higher trophic levels can be collected at the same time scales as measurements of atmospheric and oceanographic conditions.

Methods

The Ocean Monitoring and Prediction Laboratory at the University of South Florida (USF) College of Marine Science operates the nearshore component of the Coastal Ocean Monitoring and Prediction System (COMPS). The study site for this project was the COMPS station at Big Carlos Pass (BCP), located in Lee County, Florida (Figure 1). The BCP station was established as part of the COMPS network in 2004.

The reengineering of the BCP station was managed by the USF COMPS staff in cooperation with

FIGURE 1

Location of the BCP coastal ocean observing station in southwest Florida. Instrumentation is located on the center span of the bridge, indicated by the black dot on the inset image.

Mote Marine Laboratory staff and with subcontracted assistance from Loggerhead Instruments and Axiom Data Science. For this project, all of the original sensors on the BCP station were replaced, and two new sensors were added: a High Tech Instruments 96-MIN series hydrophone for detecting ambient underwater sound and a Vemco VR2C receiver for detecting and decoding acoustic tags implanted in fishes (Table 1). Installation of the new equipment was done during August to September 2016. In-water sensors were mounted on brackets attached to the deck of the fender system in the center span of the bridge where the navigation channel is located. A Campbell Scientific CR3000 data logger that controls data acquisition from in-water sensors was mounted on the deck of the fender system and connected by RS485 cable to a second Campbell Scientific CR3000 located in the bridge tender's office on the center span of the bridge. The atmospheric sensors were mounted on a 10-m fiberglass Shakespeare mast located next to the bridge tender's office and were connected by RS485 cable to the CR3000

TABLE 1

Equipment installed at the reengineered BCP Monitoring Station in Lee County, Florida. All listed equipment was purchased in new condition for installation at this site.

Component	Manufacturer and Model
Data collection platform	Campbell Scientific CR3000
Satellite transmitter	Campbell Scientific TX320
Real-time communications	Raven XTV
Line of sight data acquisition	Campbell Scientific Loggernet
Tide measurement	Aquatrak 5002
Conductivity & water temperature	Greenspan EC250
Wind data (analog)	RM Young 5103
Wind data (sonic)	RM Young Marine 86106
Air temperature-RH sensor	RM Young 41382 VC
Rain gauge	Sutron 5600-0425-2
Passive acoustic receiver	Loggerhead Instruments
Active acoustic receiver	Vemco VR2C

datalogger located in the bridge tender's office (Figures 2A–2D).

Data from oceanographic and atmospheric sensors are taken as the average of 10-s periods made during 6-min sampling intervals (e.g., the average of thirty-six 10-s periods), except for sonic and analog wind gust measurements, which were based on a maximum 5-s running average and water level measurements (tide), which were based on a 1-Hz sampling rate over a 3-min sampling period centered within the 6-min interval. Data from acoustic tag detections recorded by the VR2C receiver and its diagnostics were stored in memory onboard the device and then acquired by the CR3000 on the 12-min polling cycle. The hydrophone used to detect ambient underwater acoustic signals was controlled by the Teensy 3.2 circuit board (PJRC) with an audio interface board that sampled at 44.1 kHz and interfaced with the CR3000 datalogger through an RS485 serial interface. The Teensy uses an ARM Cortex-M4 microcontroller

that is capable of sampling at audio sampling rates. Acoustic data were recorded for 10 s every 12 min and stored on a microSD card on the audio board. Data were transferred to the compact flash memory card on the Campbell datalogger over an RS485 serial interface. Each sensor was polled by the CR3000 to acquire data on a 12-min cycle. The resulting data string was time and date stamped and saved to compact flash memory. Data from all sensors were formatted as ASCII, except for hydrophone data for ambient acoustic signals, which were stored as .wav files. Each 10-s .wav file was divided into two 5-s files because of data transfer limitations on the Campbell CR3000.

Data were transmitted from the BCP station through the GOES satellite system and IP modem. The GOES transmission format was a Campbell Scientific 18-bit binary integer format, which transmitted at 1,200 baud, and data were encoded with a base-20 algorithm. The GOES system was queried at 15-min intervals using the Local Read-

out Ground Systems software (LRGS, Cove Software, LLC) to receive data through the NOAA GOES data collection system for the previous 12 h. The raw binary data messages were stored in a database and decoded with a custom program written in Python, converted to CSV and netCDF formats, and parsed for archival storage and further analysis. Data were integrated into the Southeast Coastal Ocean Observing Regional Association (SECOORA) data system and made available through the SECOORA portal and other data access services. More information on the SECOORA data system can be found at <http://laxds.co/2FmzdrG>. Data from all sensors could also be transmitted via IP modem and downloaded with LoggerNet software (Campbell Scientific, Inc.) for archival and display purposes.

Raw acoustic data were saved in flash memory on the recorder and datalogger. Root-mean-square (RMS) sound levels (dB SPL re: 1 μ Pa) were calculated and transmitted in the GOES stream as summary data. For analysis of raw acoustic signals, data were plotted in the time domain to examine spectrum level sound pressure levels (dB SPL re: 1 μ Pa). These data were Fourier-transformed to examine sound pressure levels within the specific frequency bands of <1 kHz that are generally used by fishes. Spectrograms of acoustic .wav files were also examined in Adobe Audition to identify the species present in the recordings.

Range tests were conducted to estimate the active space of acoustic tags at the study site. Vemco V16-4H ('high-power') and V16-4L ('low-power') acoustic range tags transmitting at 69 kHz and source level of 160 and 151 dB (re: 1 μ Pa), respectively, were lowered to approximately mid-depth in the water column, while at anchor, and allowed to transmit at 1-min intervals

FIGURE 2

A. Campbell datalogger and instrumentation fixed to the deck of the fender system along the navigation channel in the center span of the bridge (technician perspective). B. Campbell datalogger and instrumentation fixed to the deck of the fender system along the navigation channel in the center span of the bridge (perspective looking at bridge). C. Campbell datalogger and instrumentation fixed to the deck of the fender system along the navigation channel in the center span of the bridge (perspective looking at water). D. Bridge tender's office where Campbell CR3000 and communication equipment for data transmission are located. Atmospheric sensors are mounted on the mast next to the office building.

for 15–20 min at each location. Water depths varied between approximately 2–4 m at the locations used for range tests. The bottom was unconsolidated shell hash and sandy mud. GPS coordinates were recorded at each range test location to measure the distance to the receiver. Range tests were conducted at six different locations between approximately 120 and 600 m from the location of the receiver during midday (Figure 3).

Results

The BCP monitoring station was successfully reengineered and modern-

ized by replacement of all original sensors and the addition of hydrophones to measure biological activity of fishes. The data flow from generation at the study site to archive and display on the SECOORA portal and servers required new encoding and decoding to support data transmission through the GOES system. This was accommodated by replacing the base-10 encoding system with a base-20 system. The program for decoding the GOES message is written in Python3 and located at <https://gist.github.com/kwilcox/87af72559e16bbc135a6f96535311627>. The BCP data are located in the SECOORA portal at <http://portal.secoora.org/#metadata/75364/station>.

portal.secoora.org/#metadata/75364/station. These data are also accessible through the SECOORA Environmental Research Division's Data Access Program and Thematic Real-Time Environmental Distributed Data Services servers at http://erddap.secoora.org/erddap/tabledap/edu_usf_marine_comps_1407d550.html and http://thredds.secoora.org/thredds/catalog/secoora/sensors/edu_usf_marine_comps_1407d550/data/catalog.html. Raw and decoded messages retrieved from GOES via the LRGS software package can be queried using the web service located at <http://goes.secoora.org/messages/>. Parsed meteorological ocean data (met ocean) can be queried using the web service located at <http://goes.secoora.org/metocean/>. Both the messages and the met ocean web services return paginated responses of 50 records per page. They can be filtered using the HTTP parameters of *starting* (ISO date string), *ending* (ISO date string), and *page* (integer). For example, to retrieve 1 day of raw GOES message and met ocean data, one would make the following requests: <http://goes.secoora.org/messages/?starting=2018-01-01&ending=2018-01-02> and <http://goes.secoora.org/metocean/?starting=2018-01-01&ending=2018-01-02>. A mapping from the decoded message to scientific units can be found here: <http://l.axds.co/2qO8Uhr>. Firmware for controlling the Teensy board is located at <https://github.com/loggerhead-instruments/CampbellAudio>. Data can be filtered by parameter and period and downloaded.

Range tests demonstrated that the V16-4H ("high-power," 160 dB) output acoustic tag was detectable only at the shortest distance tested, approximately 120 m. The V16-4L ("low-power," 151 dB) acoustic tag was not detected at any distances used in

FIGURE 3

Locations of range tests for V16-4H (high output) and V16-4L (low output) acoustic tags. The single green marker, at approximately 120 m from the receiver, indicates the only location where transmissions were received from the high output level acoustic tag. Signals from the low power tag were not received from any test locations. Red markers indicate test sites where no transmissions were received. The farthest range tested was approximately 600 m.

these tests and so would have had a transmission range of <120 m at the study site. Bioacoustic data recorded above 1,000 Hz were mainly associated with invertebrates (i.e., snapping shrimp), whereas fishes, including the gulf toadfish (*Opsanus beta*) and spotted seatrout (*Cynoscion nebulosus*), were recorded in the lower spectra (<400 Hz) (Mok & Gilmore, 1983; Locascio & Mann, 2008) (Figure 4). Time-series data for broadband sound pressure levels demonstrated diel periodicity that is characteristic of estuarine/coastal soundscapes (Figure 5). Sound pressure levels dropped off gradually near the end of October 2016 and declined through the early part of November (Figure 6). Concentrations of the red tide organism, *K. brevis*, were also increasing during this period (Figures 7A and 7B).

Discussion

The reengineered COMPS monitoring station at BCP demonstrates that sensors capable of collecting data

on biological processes can be incorporated into ocean observing systems to collect data at the same time scales as physical processes are measured. This serves as proof of concept for the design of future observing stations and the redesign of existing stations.

The station redesign included two acoustic sensors not previously incorporated in the system. The Vemco VR2C is a cabled version of the VR2W acoustic tag receiver and is designed for integration into an existing system operating with a laptop or third-party datalogger. Integration of the VR2C was relatively straightforward with the Campbell CR3000 datalogger using ASCII commands. Range test results demonstrated that the V16-4H have an effective transmission distance of at least 120 m, but not more than 230 m, at the study site based on the conditions of our tests. Signals from the V16-4L range tag were not received at the shortest distance used in the test, and so transmission range is known only to be less than 120 m. The acoustic tags transmit at 69 kHz, and transmission distances are affected by environmental conditions

FIGURE 4

Spectrogram of passive acoustic data recorded at the BCP monitoring station on September 27, 2016. Examples of spotted seatrout (*C. nebulosus*) “dual-pulse” calls are encircled. Broadband signal at higher frequencies (> 900 Hz) are associated with invertebrates, mainly snapping shrimps.

FIGURE 5

Acoustic time series of four consecutive days of recording (10 s every 12 min) at the BCP station, which demonstrate nightly peaks in fish sound production lasting several hours; this is characteristic of coastal/estuarine systems. The nightly peaks are aligned with the x-axis tick marks.

such as salinity (absorption of signal due to salts), bathymetry, reflective physical structures, and background noise levels (Gjelland & Hedger, 2013). In dynamic, high-energy environments with reflective surfaces and physical barriers, the transmission range of acoustic tags is typically much shorter than in open-field environments where high power output tags may transmit several hundred meters (Loher et al., 2017). Various bottom types including seagrass, mud, and algae will also influence signal transmission of the acoustic tags. Data from the present study represent preliminary results of range estimates

at the BCP study site and should be re-evaluated at finer distance scales and for longer duration to understand the effects of tide and weather.

Integration of the hydrophone for recording ambient acoustic signals was more challenging than the VR2C because an “off the shelf” product was unavailable. The Arduino and Teensy add-on boards are a cost-effective solution for acoustic field recording; however, the high sample rate and large file sizes generated (1 MB) are not within the typical range that the CR3000 data logger normally operates. This required splitting the 12-s file into two 6-s segments and storing each in the

FIGURE 6

Acoustic time series data recorded from September through mid-November 2016. The decline in sound production during late October is generally consistent with the timing of the end of the spawning season but may also be associated with increased concentration of red tide detected in the vicinity of the study site (see Figures 7A and 7B). Acoustic data are broadband (0–44.1 kHz), and sources include fishes and invertebrates.

FIGURE 7

A. Red tide concentrations in southwest Florida near the BCP site during October 2016. Increased red tide concentrations during this month are coincident with a decline in levels of ambient sound production at the study site toward the end of October. B. Red tide concentrations in southwest Florida near the BCP site during November 2016. Increased red tide concentrations during this month are coincident with lower levels of ambient sound production at the study site during the beginning of November.

A **B**

cache prior to the data being acquired by the CR3000 during a polling cycle. For this reason, the programming associated with data transfer from the Arduino and CR3000 was the most challenging aspect of the redesign.

The decline in sound pressure levels around the end of October and beginning of November at the study site is generally consistent with the end of the spawning season for several coastal sciaenid fishes in this region (Locascio, 2010) and alone may be

a reasonable explanation for decline in sound pressure levels during this period. However, the decline in sound production was also accompanied by increased levels of red tide in the study area, which could also have contributed to decreased levels of bio-acoustic activity during this period. Previous red tide events in southwest Florida have been used to explain anomalous decreases in ambient sound pressure levels in habitat similar to the BCP study site (Indeck et al., 2015). Although it is not possible to resolve the differences between the effects of season and red tide on fish sound production in this study, the co-occurrence of these factors demonstrates the usefulness of additional monitoring stations for use as control sites.

Hydrophones are low-cost, robust sensors that can be incorporated into ocean observing stations to collect data on biological activity across many trophic levels and are particularly useful for documenting the timing and location of diagnostic species-specific fish spawning calls. When integrated with a suite of other environmental sensors such as optical sensors capable of measuring dissolved oxygen, turbidity, and primary production, ecosystem level monitoring becomes possible with ocean observing stations. This is especially relevant in dynamic coastal systems that experience variable freshwater input to estuaries and occurrences of harmful algal blooms.

Acknowledgments

Funding for this project was made possible by a grant from the Southeast Coastal Ocean Observing Regional Association. Jeffrey Scudder (College of Marine Science) provided technical assistance. This project is dedicated to the memory of Vembu Subramanian.

Corresponding Author:

James Locascio
Mote Marine Laboratory,
1600 Ken Thompson Parkway
Sarasota, FL 34236
Email: locascio@mote.org

References

- Albaladejo**, C., Sanchez, P., Iborra, A., Soto, F., Lopez, J.A., & Torres, R. 2010. Wireless sensor networks for oceanographic monitoring. *Sensors*. 10(7):6948-68.
- Craig**, S.E., Lohrenz, S.E., Zhongping, L., Mahoney, K.L., Kirkpatrick, G.J., Schofield, O.M., & Steward, R.G. 2006. Use of hyperspectral remote sensing reflectance for detection and assessment of the harmful alga, *Karenia brevis*. *Appl Optics*. 45(21):5414-25. <https://doi.org/10.1364/AO.45.005414>.
- Gjelland**, K.Ø., & Hedger, R.D. 2013. Environmental influence on transmitter detection probability in biotelemetry: developing a general model of acoustic transmission. *Methods Ecol Evol*. 4(7):665-74. <https://doi.org/10.1111/2041-210X.12057>.
- Indeck**, K.L., Simard, P., Gowans, S., Lowerre-Barbieri, S., & Mann, D.A. 2015. A severe red tide (Tampa Bay, 2005) causes an anomalous decrease in biological sound. *R Soc Open Sci*. 2:150337. <https://doi.org/10.1098/rsos.150337>.
- Locascio**, J.V. 2010. Passive acoustic studies of estuarine fish populations of southwest Florida. Graduate Theses and Dissertations. <http://scholarcommons.usf.edu/etd/1700>.
- Locascio**, J.V., & Mann, D.A. 2008. Diel periodicity of fish sound production in Charlotte Harbor, Florida. *Trans Am Fish Soc*. 137:606-15.
- Locascio**, J.V., & Mann, D.A. 2011. Diel and seasonal timing of black drum (*Pogonias cromis*) sound production. *Fish Bull*. 109: 327-38.
- Loher**, T., Webster, R.A., & Carlile, D. 2017. A test of the detection range of acoustic transmitters and receivers deployed in deep waters of southeast Alaska, USA. *Anim Bio-*
- telemetry*. 5:27. <https://doi.org/10.1186/s40317-017-0142-y>.
- Mok**, H.K., & Gilmore, R.G. 1983. Analysis of sound production in estuarine fish aggregations of *Pogonias cromis*, *Bairdiella chrysoura*, and *Cynoscion nebulosus* (Sciaenidae). *Bull Inst Zool. Academia Sinica (Taipei)*. 22:157-86.
- Rountree**, R.C., Goudey, C., Hawkins, T., Luczkovich, J.J., & Mann, D.A. 2002. Listening to fish. In: *Proceedings of listening to fish: An international workshop on the applications of passive acoustic applications in marine fisheries*. p. 24. Cambridge, MA: Massachusetts Institute of Technology Sea Grant.
- Shapiro**, J., Dixon, L.K., Schofield, O.M., Kirkpatrick, B., & Kirkpatrick, G.J. 2015. New Sensors for Ocean Observing: The Optical Phytoplankton Discriminator. In: *Coastal Ocean Observing Systems*. Ed. Liu, Y., Kerker, H., & Weisberg, R.H. pp. 326-50. Amsterdam, Netherlands: Elsevier.
- Wall**, C.C., Lembke, C., & Mann, D.A. 2012. Shelf-scale mapping of sound production by fishes in the eastern Gulf of Mexico, using autonomous glider technology. *Mar Ecol Prog Ser*. 449:55-64. <https://doi.org/10.3354/meps09549>.