Ecological Informatics 48 (2018) 60–68

Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

Localizing individual soniferous fish using passive acoustic monitoring

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ARTICLE INFO

Keywords:
Passive acoustic monitoring
Localization
Fish ecology
Environmental management
Soniferous fish

ABSTRACT

Identifying where fish inhabit is a fundamentally important topic in ecology and management allowing acoustically sensitive times and areas to be prioritized. Passive acoustic localization has the benefit of being a non-invasive and non-destructive observational tool, and provides unbiased data on the position and movement of aquatic animals. This study used the time difference of arrivals (TDOA) of sound recordings on a four-hydrophone array to pinpoint the location of male oyster toadfish, *Opsanus tau,* a cryptic fish that produces boatwhistles to attract females. Coupling the TDOA method with cross correlation of the different boatwhistles, individual toadfish were mapped during dawn (0523–0823), midday (1123–1423), dusk (1723–2023) and night (2323 – 0223) to examine the relationship between temporal and spatial trends. Seven individual males were identified within 0.5–24.2 m of the hydrophone array and 0.0–18.2 m of the other individuals. Uncertainty in passive acoustics localization was investigated using computer simulations as < 2.0 m within a bearing of 033 to 148° of the linear hydrophone array. Passive acoustic monitoring is presented as a viable tool for monitoring the positions of soniferous species, like the oyster toadfish. The method used in this study could be applied to a variety of soniferous fishes, without disturbing them or their environment. Understanding the location of fishes can be linked to temporal and environmental parameters to investigate ecological trends, as well as to vessel activity to discuss how individuals' respond to anthropogenic noise.

1. Introduction

Passive acoustic monitoring underwater has improved understanding of the repertoire and temporal distribution of soniferous aquatic animals. Many ecological applications would gain substantial benefits from knowing an animal's location (Spiesberger and Fristrup, 1990). The location of soniferous animals can also be linked to time of day, habitat type, salinity and temperature to investigate ecological trends, or used to monitor how individuals respond to anthropogenic sound, such as vessel traffic. As such, passive acoustic localization increasingly is used to locate soniferous animals, such as fish or marine mammals (Gebbie et al., 2015; Locascio and Mann, 2011; Mann, 2006; Spiesberger and Fristrup, 1990), which are difficult to observe using traditional visual methods. It also has the benefit of being a non-invasive and non-destructive observational tool, unlike underwater diver surveys (Barimo and Fine, 1998) or mark recapture studies (Marques et al., 2013), and provides unbiased data on the position and movement of the sound source in question.

Sound can propagate great distances in all directions underwater without the signal losing considerable energy (Urick, 1983). Acoustic localization uses the mathematics of acoustic propagation and parabolic geometry to determine source positions. Using one hydrophone, the distance to a sound source can be estimated from the amplitude and arrival times of the direct and surface reflected signals (Aubauer et al., 2000; Cato, 1998). Adding a second hydrophone, the bearing to a source can be calculated using the time difference of arrivals (TDOA) (Spiesberger and Fristrup, 1990). At least three hydrophones are needed to pinpoint exact source location because multiple TDOA bearings can be calculated and intersected (Møhl et al., 2001; Spiesberger and Fristrup, 1990; Wahlberg et al., 2001; Watkins and Schevill, 1972). Hydrophone arrays potentially can determine fish distributions that could not be obtained with single hydrophone recordings, but require a higher level of sophistication for setting up, operating and analyzing the data (Ricci et al., 2017).

Many fish sounds are species specific and repetitive, which enables passive acoustic recordings of sound production to be used to identify their distribution and behavior (Wall et al., 2013). Batrachoidid fishes (toadfish and midshipman) produce sounds through contractions of sexually dimorphic sonic muscles attached to the swimbladder, and are some of the best studied vocal fishes (Amorim et al., 2015; Bass and McKibben, 2003). The oyster toadfish, *Opsanus tau*, is a benthic ambush predator that inhabits estuaries and coastal waters along the

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https://doi.org/10.1016/j.ecoinf.2018.08.004
Received 25 April 2018; Received in revised form 15 June 2018; Accepted 7 August 2018
Available online 13 August 2018
1574-9541/

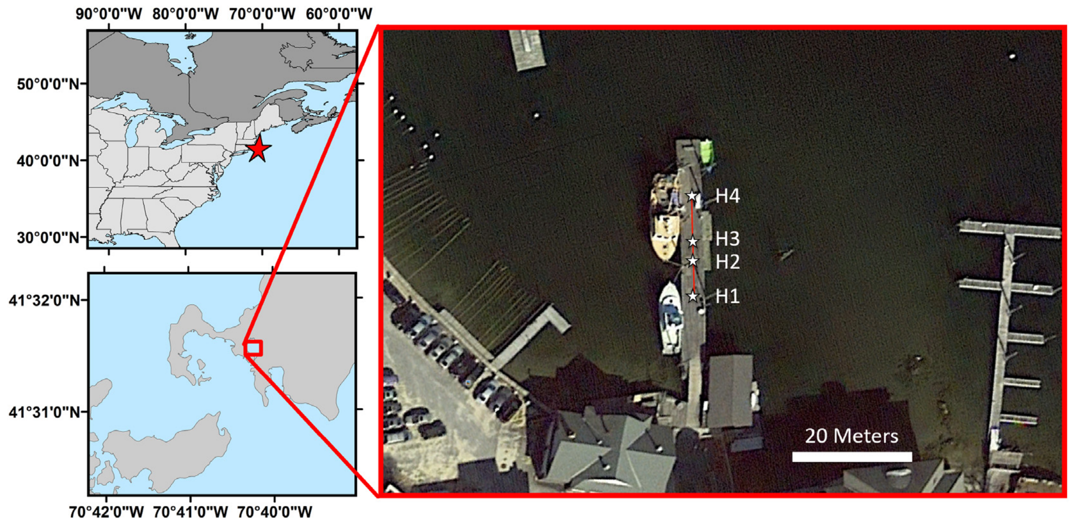

Fig. 1. Map of Eel Pond, Woods Hole, MA, with insets showing position related to state and country. The four hydrophones deployed along the dock are indicated by the white stars. Google ortho imagery 2014 was downloaded from the MassGIS website (https://www.mass.gov/service-details/massgis-data-layers/). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

northeastern seaboard of the United States (Price and Mensinger, 1999). The toadfish has an unusually rich vocal repertoire for a teleost, produced by fast contracting sonic muscles along the swimbladder (Rome and Lindstedt, 1998). Both sexes of toadfish produce a variety of grunts associated with agnostic contexts while only males produce boatwhistles which have an initial broadband grunt-like segment, followed by a tonal portion (Maruska and Mensinger, 2009). At the beginning of the mating season, in late May to early June, male toadfish establish a nest and produce trains of boatwhistles to announce territorial ownership and position to other males as well as attract females into their nests (Fish, 1972; Winn, 1972).

Individuality in acoustic signaling arises when the within individual variation is smaller than the variation between individuals in one or more acoustic characteristics (Bee and Gerhardt, 2001). Differences in waveform, sound duration and distribution of energy in different harmonic bands can therefore identify different individuals. In southern Portugal, five individual lusitanian toadfish, *Halobatrachus didactylus,* were recorded, each with distinct boatwhistles (Dos Santos et al., 2000). Additionally, toadfish were found to produce vocalizations varying in pulse structure, duration and frequency components, suggesting toadfish have a complex acoustic communication system (Maruska and Mensinger, 2009). Acoustic signals may inform the receiver about species, sex identity, the sender's location, motivation and individual quality (Forlano et al., 2017). The calling rate and calling effort (percentage of time spent calling) of Batrachoididae has been found to indicate male condition (Vasconcelos et al., 2012) because these parameters reflect sonic muscle hypertrophy and larger gonads (Amorim et al., 2010). Sound dominant frequency, amplitude and fatigue resistance may also indicate body size (Bose et al., 2018), with larger fish tending to produce lower frequency, louder and longer sounds than smaller individuals (Conti et al., 2015). Additionally, boatwhistles are involved in male competition, as closely located individuals will produce "jamming" signals. For example, a male will produce a grunt during the tonal portion of the conspecific male boatwhistle that lowers the first harmonic to a rate that is unattractive to a female, preventing competing males from attracting females (Mensinger, 2014).

Despite the large number of experimental studies on toadfish vocalizations, surprisingly little is known about the occurrence and parameters of natural calls (Conti et al., 2015) and even less on the proximity of individual males. Previous studies have used invasive methods, such as locating and recording boatwhistles with SCUBA divers (Barimo and Fine, 1998) or restricting toadfish movements by placing individuals within artificial shelters (Zeddies et al., 2012). In comparison, fixed and towed hydrophones are now a popular tool for localizing fishes. This non-invasive monitoring provides long-term continuous information on animal behavior, abundance and calling measurements in settings that are otherwise difficult to sample (Ricci et al., 2017).

A naturally occurring population of toadfish is found in Eel Pond, MA with high site fidelity from May to August. The toadfish population in Cape Cod is at the northern extent of the population range. Toadfish were thought to be extirpated from Eel Pond since at least 1990 however, during hydrophone testing in 2014 boatwhistle calls were detected (Van Wert *per comms.*). Whether these toadfish migrated into Eel Pond or had escaped from the Marine Resources Center is not clear and the population number is unknown. Additionally, as a single hydrophone consistently picked up distinct boatwhistles from the dock area, it was hypothesized that the toadfish were confined to this physical structure (Van Wert *per comms.*). Individual male toadfish exhibit high site fidelity and only change vocalizations incrementally over the course of several days, allowing individual fish to be tracked for extended periods of time (Mensinger, 2014) and making toadfish an ideal study species for acoustic localization. The aim of the present study is to localize the position of individual nesting toadfish using recordings of their boatwhistles, and test the proximity of individual nesting males using a non-invasive method.

2. Materials and methods

2.1. Data collection

Oyster toadfish, *Opsanus tau,* vocalizations were recorded in situ from beneath the Marine Biological Laboratory (MBL) Marine Resources Center dock in Eel Pond, Woods Hole, MA (41° 31′32.28" N 70°40′16.74" W) (Fig. 1) northeastern USA, from Saturday July 8 14:23 to Sunday July 9, 2017 14:23. Recordings were taken during July, as this is within the peak calling period for the species in Eel Pond (Van Wert *per comms.*). The recordings were conducted over a weekend because dock access is restricted for the public and the large MBL research vessel moored at the dock does not operate. Small recreational vessel sounds were present in recordings (Fig. 2); but had minimal interference with acoustic analysis of toadfish vocalizations.

A four-channel digital acoustic recorder (ST4300, Oceans