A REMOTELY-PILOTED ACOUSTIC ARRAY FOR STUDYING SPERM WHALE VOCAL BEHAVIOUR

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1. INTRODUCTION

Although acoustic research on groups of sperm whales (*Physeter macrocephalus*) has revealed much concerning the way that codas (short stereotyped click sequences) are shared and produced at the group level (e.g. Rendell and Whitehead 2003), the difficulty in determining which individual in a group of marine mammals is vocalizing has inhibited the investigation of the existence of individual repertoires, syntax or other complex phenomena in the communication system of this species. While recent advances in the use of passive acoustic localization have provided important tools for studying the movement, foraging behaviour, and communication patterns of marine mammals, previously described systems do not easily permit the discrimination of vocalizations made by pelagic cetaceans in very close proximity to one another. In an effort to address this problem, we developed an acoustic array consisting of small remotely-piloted vessels (RPVs) to record and localize the vocalizations of individual sperm whales in social clusters at the water's surface.

2. METHOD

2.1 Equipment

Each RPV, as well as a larger research platform (a 12-m auxiliary sailboat), is equipped with a hydrophone (Vemco VHLF; frequency response: 200 Hz-20 kHz ± 3dB; midband sensitivity: 147 dB re 1 V/µPascal) that is suspended approximately 80 cm below the water's surface. On each RPV, acoustic signals from the hydrophone are amplified, high-pass filtered at 1 kHz, and broadcast by a FM transmitter (NRG Kits PLL PRO III). Signals are then received by digital AM/FM PLL synthesized radios (SONY ICF-M260) onboard the research platform and recorded on a multi-track recorder (FOSTEX VF-160; sampling rate: 44.1 kHz). The acoustic signals from the hydrophone onboard the primary research platform are also high-pass filtered at 1 kHz and recorded on the multi-track recorder.

On each recording platform, a GPS unit (Garmin GPS25-HVS) logs position each second and saves the data to a flashcard for later retrieval. A frequency shift keying (FSK) modulator transforms the stream of ASCII sentences from the GPS unit onboard the primary research platform to an amplitude-modulated tonal signal (see Møhl et al. 2001), which is recorded as an acoustic track on the multi-track recorder in synchrony with the hydrophone signals. Thus, subsequent demodulation of the FSK timestamp during analysis allows for synchronization of the acoustic and positional data (see Møhl et al. 2001). Each RPV is 1 m in length and built of durable fiberglass. The motor and rudder of each RPV is powered by two 12-V batteries and controlled by a radio transmitter onboard the primary research platform.

2.2 Deployment / Calibration

During deployment, RPVs can be piloted to establish and maintain favorable array geometry around a group of whales, provided that they are not moving too rapidly (up to approximately 1 knot). The maximum array size possible with this system is limited by the range of the FM transmitters, which is approximately several hundred meters. The maximum duration of a recording session is limited by the life of the 12-V batteries that power the RPV payloads and is approximately 3 hours. During deployment, estimates of sea surface temperature and salinity are obtained with a thermometer and refractometer respectively.

A series of calibration tests were conducted to determine the accuracy of this acoustic array. Three RPVs were deployed from a stationary 12-m sailboat and positioned so as to form a diamond approximately 25-50 m per side. Two metal pipes were suspended from a wood plank with a distance of 1.5 m between them and hung over the sides of a dinghy. The dinghy was then rowed through the array while a hammer was used to strike the pipes in an alternating manner, thereby generating two loud and impulsive sound sources of audibly different frequencies a known distance apart. Pipes were then struck in a repetitive manner at the periphery of the array as well as in an end-fire position outside of the array (i.e. directly in line with two receivers).

2.3 Analysis

During analysis, the binary GPS files containing the phase data were downloaded from the flashcards, converted to a RINEX file, and submitted to an online Precise Point Positioning processor (Canadian Geodetic Service CSRS–PPP online processor) to improve positional accuracy. Erroneous noise in GPS positions was also reduced by discarding fixes obtained by less than 7 satellites and by independently smoothing the x- and y- coordinates for each GPS receiver by fitting quadratic equations to time segments spanning several seconds before and after each epoch in the record (see Christal and Whitehead 2001).

Acoustic analysis was conducted in a standard sound-editing program (Cool Edit, Syntrillium) and a dedicated software package (Rainbow Click, IFAW). The speed of sound in water was derived from the LeRoy equation using sea surface temperature and salinity. We used routines custom-written in MATLAB® version 6.1.450, release 12.1 to calculate the time differences in which sounds first arrived at different hydrophones (see Wahlberg et al. 2001).

Using these time-of-arrival-differences (TOADs) between the four hydrophones, the positions of GPS receivers, the speed of sound in water, and the assumption that sound sources and receivers were all on the same plane, the location of a detected sound was calculated as the average over the 12 MINNA (minimum number of receivers array) solutions (see Wahlberg et al. 2001). Because a triad of receivers results in three hyperbolae and three hyperbolic intersections rather than one (a result of error in the estimation of TOADs, speed of sound, and hydrophone positions), the use of four hydrophone receivers results in four possible hydrophone triads and thus a total of 12 hyperbolic intersections, which when averaged provide the best estimate of the sound source's location while accounting for measurement error. All GPS and localization analysis used custom-written MATLAB® routines.

3. RESULTS

Inside the array, the estimated mean distance between the localized sound sources was 1.97 ± 0.3 m (n = 22), giving an overall mean absolute error of 0.48 m from the true distance of 1.5 m (Fig. 1). At the periphery of the array, this mean error increased to 0.83 ± 0.5 m (n = 7). The mean error for repeated bangs in the end-fire area (in line with two receivers) increased to 9.42 ± 7.0 m (n = 11).

4. DISCUSSION

The accuracy of this system to 0.5 m within the array is more than acceptable for differentiating the coda vocalizations exchanged between sperm whales that are approximately 6.5 m apart within a social cluster (Whitehead 2003). However, assuming errors similar to those reported for the calibration of a similarly-sized array (Watkins and Schevill 1972), the localization error at even 80 m from the array (approximately 20 m), while small enough to permit the differentiation of clicks made by different social groups, is too large to allow the confident assignment of vocalizations to individual whales found at that range. Similarly, the error estimated here of 9 m for sounds in an end-fire position prohibits the differentiation of whales vocalizing in close proximity to one another in these regions.

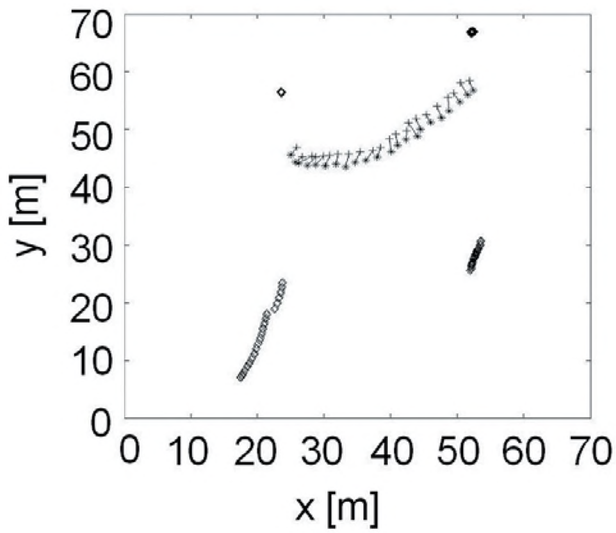

FIG. 1. The GPS receiver positions of recording platforms throughout the described calibration are represented in the figure by diamonds. The estimated source locations of the banged pipes are represented by ✕ and ✳. The mean distance between the pipes as determined by acoustic localization (see text) was 1.97 ± 0.3 m (represented by solid lines connecting the symbols representing the estimated source locations). See text for description of calibration.

The dynamic array described here was designed with the intention of maintaining preferable array geometry around a group of slow-moving pelagic cetaceans, a configuration that is clearly important in the assignment of localized vocalizations to sperm whales in close proximity to one another. This system is currently being used by the authors to study the way that codas are sequenced and exchanged by individual sperm whales as well as the spatial arrangement of vocalizing animals, thereby permitting a more thorough examination of the function of coda communication in this species.

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