Animal Biotelemetry

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# Determination of distance away and depth of transmitters relative to a vertical acoustic telemetry array in the open ocean

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## Abstract

**Background** Many ecologically and commercially important species occur in the epipelagic marine environment and have been observed to spend a considerable amount of time associating with surface structure. The bottom depth of this habitat often exceeds transmission (~500-1000 m) and receiver (500–750 m) range specifications for commonly used acoustic telemetry methods that rely on an array of receivers deployed on the seafloor with overlapping fields of detection to provide positioning of acoustically tagged individuals. This poses logistical challenges for tracking the fine-scale movements, behaviors, and associations to moored and free-floating structure of these species. Acoustic telemetry can provide high resolution positioning data for tagged animals within an array of receivers with overlapping fields of detection; however, this technique has not been applied in deep open-ocean environments off the benthos.

**Results** Herein, we detail the development of a novel vertical acoustic telemetry array that can be mounted on, or suspended from, various moored and free-floating structures in the open ocean, thus facilitating high resolution tracking of structure-associated epipelagic animals. This new 'vertical acoustic array' (VAR) allows for the calculation of a transmitter's distance from the array and depth with average error around these metrics ranging from 16.2 to 54.8 m (distance error) and 8.6 to 61.5 m (depth error) within the tested range (~500 m radius around the array, ~300 m deep). We also validated the ability of the VAR to inform the association of an epipelagic species to surface structure by calculating fine-scale positioning for a great barracuda around a fish aggregating device (FAD), which on average was 27.9 ± 2.9 m away at a depth of 9.3 ± 0.4 m over a 9-day tracking period, demonstrating high association with the structure.

**Conclusions** This new array is able to provide two-dimensional (distance away and depth) animal behavior data around natural and anthropogenic moored and free-floating structures in open-ocean environments where bottom depths often exceed transmission (~1000 m) and receiver (~500 m) range specifications of traditional bottom moored positioning arrays. This array can also be used to quantitatively assess associations of epipelagic species beyond presence/absence using a single receiver, advancing the potential to improve understanding of the interactions between pelagic fauna and anthropogenic structures such as wind turbines, oil rigs, and fish aggregation devices.

**Keywords** Acoustic telemetry, Pelagic, Fine-scale positioning, Animal tracking, Structure, Fish behavior

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## Background

Tracking the movement of marine organisms is an actively evolving field of wide interest (e.g., [1, 12, 26]), but measuring the fine-scale movements and behaviors of fishes in the open ocean remains particularly challenging [2]. Understanding these movements can be useful in managing fisheries and conserving species [13, 17]. For example, understanding how pelagic fishes behave around structures in the open ocean—a commonly observed phenomenon underpinning the concept of 'fish aggregating devices'—can improve our understanding of their ecology, lead to better monitoring and more precise study, and inform best practices in fisheries. Blue-water net fisheries, for instance, that use drifting fish aggregating devices (FADs) to target tunas operate across the world's tropical oceans and routinely capture mixed-species assemblages, including imperiled species or juvenile stages of target species. An improved understanding of fine-scale fish behavior, beyond presence/absence, and potential interactions between species (e.g., identifying times, depths, and distances of association at or away from a FAD) could lead to more selective fishing strategies. Other artificial structures such as aquaculture cages or energy platforms (e.g., oil rigs and offshore wind infrastructure) also recruit and hold significant fish biomass (e.g., [5]) and can be located in water depths that exceed the range specifications of receivers that are on the seafloor, and therefore, it is of interest to develop technology to study fish movement in these challenging contexts.

Acoustic telemetry has been used to understand the association between pelagic fish and structures that facilitate capture (e.g., FADs; [9, 10]). However, the current state of passive acoustic telemetry research conducted in the epipelagic zone of the deep open ocean is limited, relying on a single acoustic receiver mounted beneath a drifting (e.g., FAD, Fig. 1a), fixed (e.g., oil rig), or actively

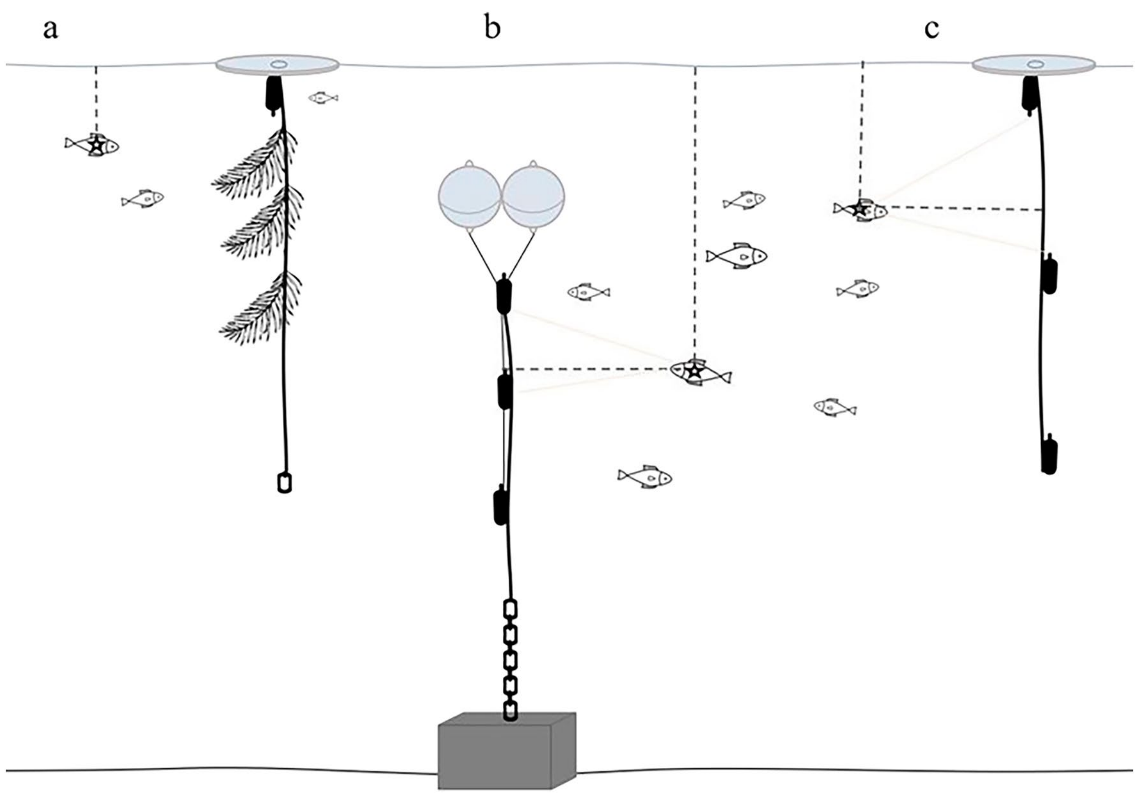


**Fig. 1** The left of the diagram (under letter '**a**') shows a typical commercial FAD (grey oval) with a single receiver directly underneath it to collect presence/absence and, if a transmitter is equipped with a pressure sensor, depth data, which represents the limits of previous epipelagic open-ocean passive acoustic telemetry applications. The center of the diagram (under letter '**b**') represents the moored sub-surface FAD used in the development of the VAR, with three receivers aligned down the taut mooring line, which can be used to calculate transmitter depth (in the absence of a pressure sensor) and distance from the array. The right of the diagram (under letter '**c**') shows the same array suspended beneath a free-drifting FAD buoy. The grey oval at the surface represents the FAD float (Zunibal Zunfloat, 180 cm diameter, 150 kg of flotation). A 200 m length of Samson 6 mm AmSteel Dyneema line was tied through the holes in the float, and the receivers in the mounting cups were clipped to this line at 15 m, 100 m, and 200 m. A 3 kg steel shackle was used as the bottom weight next to the deepest receiver. Diagram is not to scale

moving (e.g., AUV/glider) object to collect presence/absence data and, if an acoustic transmitter is equipped with a pressure sensor (which typically doubles the cost of the transmitter), depth data (see [11, 22], and [7]). In nearshore environments, a well-designed array of triangulated receivers placed on the seafloor can generate positions and tracks of tagged animals and inform the understanding of behavior and physiology. However, the deep water of the open ocean often prevents the use of a sea floor-based positioning system for tracking epipelagic species, because the distance between surface-oriented animals and bottom-based receivers cannot be greater than the transmission range, and therefore, a surface-oriented approach may be more feasible to study these species and their associations with surface structure. In addition, the unique nature of most open-ocean structures that attract fish (FADs, oil rigs, etc.) prevents the deployment of numerous receivers spread in such a way that would facilitate more specific position calculations (i.e., an array). Although basic presence–absence data can provide substantially more information, such as continuous residence times of individuals, than traditional visual or camera-based observations, they still provide an incomplete picture because of the inability to discern, for example, how animals segregate in the horizontal dimension around a structure, necessary for quantitatively assessing association. Comparing the movements or documenting associations between target and bycatch species or predator and prey species is a high priority to building an understanding of pelagic fish ecology [22]. Therefore, working towards multidimensional positioning data for pelagic species may open the door to a suite of useful research endeavors that have not yet been possible.

Acoustic telemetry-derived positioning data is most reliable in quieter systems (e.g., lakes; [25]), making epipelagic open-ocean habitats, including their relatively stable environment, lack of physical structure (except for thermoclines), and absence of many of the sound-generating organisms of the benthos, particularly conducive to acoustic signal transmission and reception [6, 14, 16]. Yet, this environment offers challenges of its own, including temperature gradients, currents, wind, and depth that require careful design and deployment of costly equipment. Herein, we detail a new acoustic telemetry array orientation (hereafter referred to as the vertical acoustic array [VAR]) designed to facilitate the collection of more specific positioning data around moored and free-floating artificial structures, flotsam, and naturally occurring debris in epipelagic habitats, necessary for quantifying association, with many other potential uses as well. Comprised of a vertical line of receivers, this technique can calculate a transmitter's distance from that line as well as depth to generate two-dimensional position data of tagged animals in reference to the array and associated structure. In addition to being able to calculate distance between the VAR and a transmitter, this approach can provide additional benefits including not having to place receivers on the seafloor, and the ability to calculate depth in situations where the integrated pressure sensors are not available for the size of transmitters needed or where budgets are restricted. Overall, the ability to passively discern fish behavior around structure and distance from structure to quantitatively assess association will facilitate in-depth investigations into pelagic fish ecology and infrastructure–wildlife interactions.

## Methods

Field trials and the development of the VAR were conducted offshore from the Cape Eleuthera Institute in the Exuma Sound in the central Bahamas under Department of Marine Resources permit MAMR/FIS/2/12A/17/17B. The VAR consists of a vertical drop line of three receivers supported by floats. The VAR can be deployed on either a moored/fixed structure (Fig. 1b) or suspended underneath a free-drifting buoy (Fig. 1c). A subsurface moored FAD (Fig. 1b, bottom depth 600 m, buoy depth 10 m; described in [20]) was used as a platform on which the VAR was first constructed in this study.

### Moored FAD-based array

The moored FAD used in this component of the array trials was constructed with a subsurface (10 m deep) flotation buoy (Fig. 1b) that resulted in the mooring line being taut and vertical in the water column. This allowed for the use of a shuttle-like rigging system to deploy receivers down the length of the mooring line. First, three VR2Tx receivers (Innovasea, Bedford, Nova Scotia, Canada) were initialized and set to record diagnostic data (tilt, temperature, and acoustic noise) every minute, with the internal transmitter set to 'sync tag' (540–660 s) on 'very high' power (160 dB). Each receiver was individually secured in a protective PVC mounting cup (Fig. 2) and attached to the beginning, middle, and end of a 200 m line (6 mm potwarp), such that 100 m separated each receiver. The receiver cups allowed for receivers to be quickly and easily removed and replaced (to download data, for example) while ensuring they were replaced at the correct spot on the line. At 50 m intervals, a 50 cm diameter hoop made of 1 inch vinyl hose was attached to the receiver line with a small cable tie that had been cut half-way through to weaken it for retrieval. Scuba divers opened and closed each hoop around the top of the mooring line directly beneath the FAD flotation buoys, and the rigging was slowly lowered using the weight of

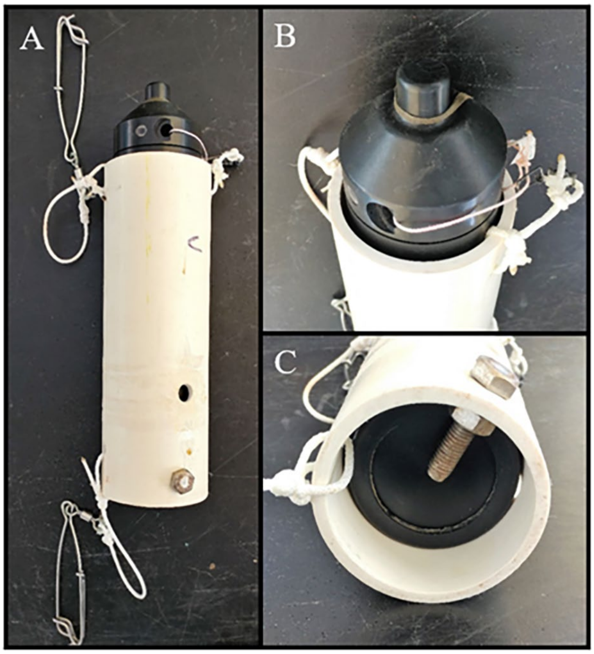


**Fig. 2** Vemco VR2Tx receiver in a mounting cup. **A**: 3″ PVC pipe was cut to length as a protective receiver cup. Short tethers were tied through holes drilled in the top and bottom of the pipe and attached to longline snaps that were used to quickly attach and detach the cup from the array's main 6 mm line at predetermined intervals. **B**: Two additional holes in the top of the pipe were used to tie the receiver into the cup (connected with a snap swivel for easy removal and replacement) and to affix a rubber band around the top of the receiver to ensure a snug and motionless fit without impeding signal reception. **C**: A 1.5″ long bolt was tightened through the bottom of the cup as a stopper

the receivers. Once the entire rigging line had been lowered, the end was tied off beneath the FAD buoy.

A great barracuda (*Sphyraena barracuda*, fork length: 92 cm) was then caught by rod and reel at the FAD and externally tagged with a Vemco V9 acoustic transmitter (V9P-2x, high power output) using a traditional dart tag crimped through the external attachment cap (following [8]). The fish was quickly released at the FAD structure, and the receivers were collected 9 days later.

### Drifting buoy-based array

The rigging was then adapted to suspend the array under a drifting buoy. Three VR2Tx receivers were individually secured in protective mounting cups (Fig. 2) and attached at 15 m, 100 m, and 200 m down the length of a line (Samson 6 mm AmSteel Dyneema), such that 85–100 m separated each receiver. A 3 kg weight was fixed to the end of the line, and the top of the line was fixed to a fish aggregating device (FAD) buoy (Zunibal Zunfloat, 180 cm diameter, 150 kg of flotation). This combination of bottom weight, thin line (6 mm), and a low-profile surface float (7.5 cm thick Zunfloat) reduced windage and drag, such that the three receivers remained in a vertical line as the array drifted (Fig. 1c). A short pole was mounted on top of the buoy which held a GPS unit (Garmin eTrex 10, ± 3 m accuracy at the study site) that recorded the track of each drift.

### Drift tests

Drift tests of the free-floating array were then conducted to measure detection range and to compare the distance and depth calculations of transmitters by the array against those derived from the known GPS-based locations and transmitter and receiver depths during the drift (i.e., testing the array's functionality). The drift tests occurred in the northeast Exuma Sound (24.83566 N, − 76.38979 W) in an area that does not have a strong prevailing unidirectional current. Tides and wind influence water movement in the epipelagic zone in this area, and during the course of the drift tests the wind speed was less than 10 km/h, Beaufort sea state was between a 1 and 2, and the mean drift speed of the array during the tests was 1.28 km/h.

To avoid providing redundant results because the moored FAD-based array and the drifting buoy-based array involved the same spacing and orientation of the receivers, all drift test results reported hereafter are based on the VAR suspended beneath a free-drifting buoy. To conduct the drift tests, a transmitter line was assembled consisting of a 60 cm diameter spherical buoy, 300 m of line (6 mm potwarp), and a 3 kg steel weight at the end. Nine Vemco V9 transmitters were affixed along the 300 m line at 25 m or 50 m intervals using rubber bands and cable ties. An archival temperature and depth recorder (TDR) with a depth sensor accuracy of ± 1% (Lotek LAT-1400) was attached to the line adjacent to each transmitter to record actual transmitter depth for comparison to the array-calculated depths, and to understand whether a strong thermocline was present which is known to affect signal transmissions [15]. A GPS unit (Garmin eTrex 10, ± 3 m accuracy at the study site) was attached to a 1 m pole mounted onto the surface buoy to record the transmitter line's locations during drifts, and the line was released into the water at varying haphazard distances within 1 km of the drifting receiver array. The spherical buoy on the transmitter line had more windage than the FAD buoy that the receiver array was suspended from, allowing the transmitter line to drift faster than the receiver array. The transmitter line was collected after 20–50 min of drifting past the receiver array. Seven drifts were conducted during a 5-h period. Following the trials, the receivers were retrieved, and the data downloaded.

### Data analysis

To assess detection efficiency during the trials, a detectability analysis was performed. For each receiver–transmitter combination, the number of detected transmissions was divided by the number of transmissions that should have occurred based on the average transmission period over a given time (length of each drift). The transmitters were set to transmit ('ping') at pseudorandom intervals from 33 to 57 s.

First, time synchronization was performed between the receivers in the array, using the same time correction techniques as a standard Vemco Positioning System (VPS), to correct detection times to a common clock. Next, detection time differences (DTDs) were calculated for each transmitter by 2-receiver pairing. These underpin the hyperbolic positioning calculation by creating hyperbolas of possible locations that a transmitter can be on for each transmission on a plane coplanar with the vertical array. Using two pairs of receivers, the intersection of the two hyperbolas can be calculated, resulting in a point on the plane. Rotating the plane around the vertical array creates a circle of possible positions from the calculated $x$, $y$ coordinate.

For each transmission that was detected at a pair of receivers, DTD was calculated as

$$\mathrm{DTD}_{\mathrm{Ra,\,Rb}} = \mathrm{DT}_{\mathrm{Rb}} - \mathrm{DT}_{\mathrm{Ra}}$$

with DT denoting detection time and $R_a$ and $R_b$ denoting two receivers in the array. DTD error was then calculated by subtracting this observed DTD from the predicted DTD that is calculated using known GPS-based locations of the array and the transmitters during the trial, as well as the known depths of the receivers and transmitters. This DTD error was then converted from time to distance using the speed of sound in water (1,534 m/s when temperature is 25 °C and salinity is 35 ppt). The internal sync tags within each receiver were used to generate the maximum DTD for each receiver pairing based on the known distances between the receivers, allowing the estimation of propagation time from one receiver to another. Valid DTDs are those within that range, and those outside of the range are expected to have encountered multipath error, meaning they travelled a greater distance than a straight line between two receivers (e.g., reflecting off the sea surface before reception) and were deemed unreliable.

When presenting depth calculations, we differentiate between positive and negative depth error to indicate calculated depths that were shallower (positive) or deeper (negative) than the transmitter's known depth, and we also use absolute values to show the magnitude (in either direction) of the error in the results that follow.

## Results

Mean water temperature at the study location, measured by TDRs along the transmitter line and receivers in the array, increased slightly from 25.0 °C near the surface to a peak of 25.6 °C at 53 m, and then decreased steadily to 19.1 °C at 310 m (Fig. 3).

### Detectability analysis

Across the seven drift tests, detection efficiency was calculated for each combination of receiver and transmitter (Fig. 4). There were nine test tags and six VR2Tx

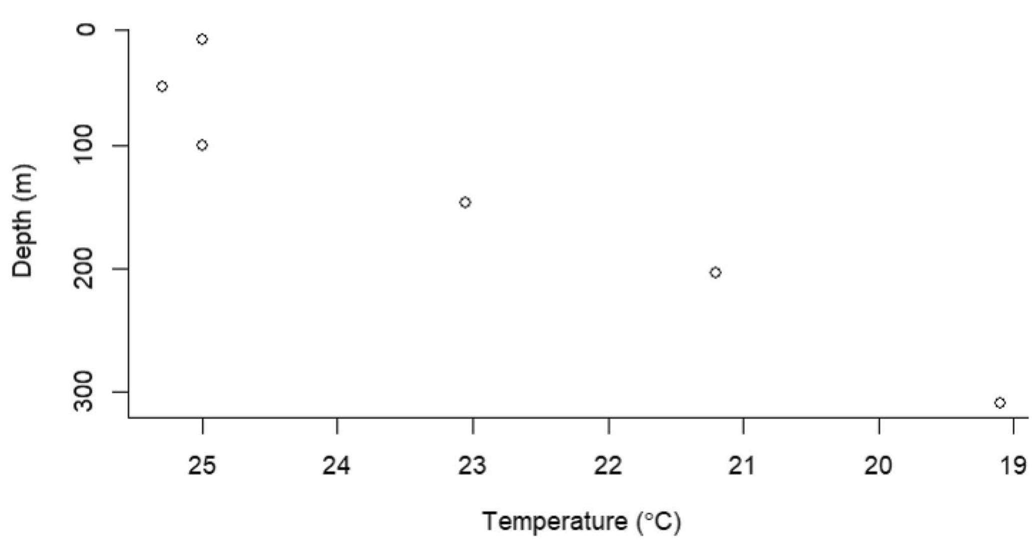


**Fig. 3** Mean water temperature through the water column at the study site measured by temperature and depth recorders (TDRs) during the drift tests

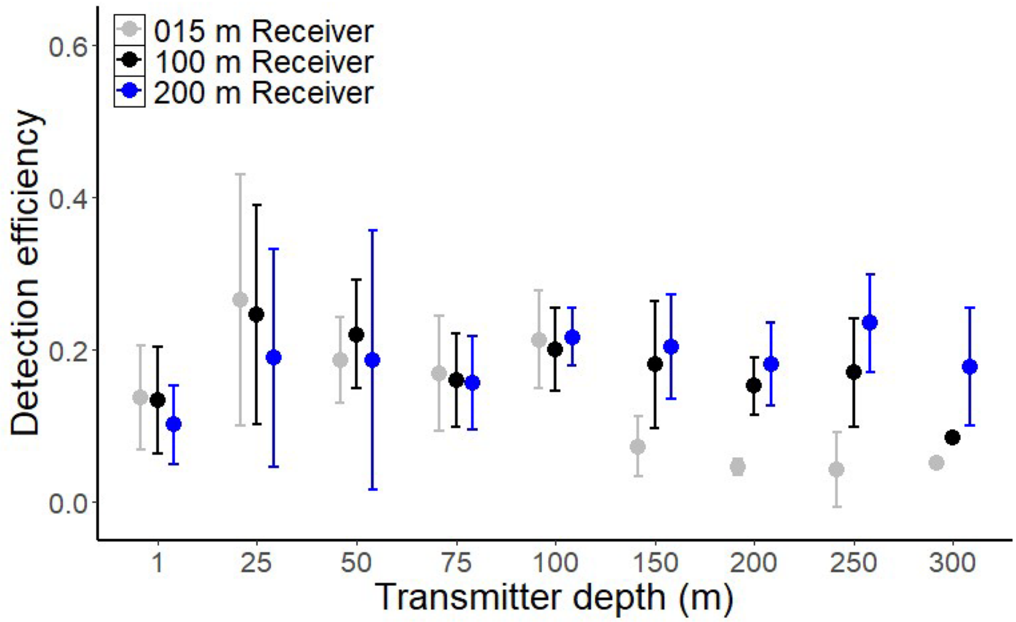


**Fig. 4** Mean detection efficiency (successful/expected transmissions) with 95% confidence intervals of transmissions from V9 transmitters to VR2Tx receivers during seven trials. The nine transmitters were fastened along a vertical line and their depths are listed across the *x* axis. The three receivers (Fig. 1c) were positioned along a vertical line suspended from the FAD at 15 m (grey), 100 m (black), and 200 m (blue)

sync tags in the system, and, based on their transmission delays, a predicted detection efficiency of approximately 20% was expected for the test tags due to tag collisions (F. Smith, pers. comm.). The receiver at 15 m (V015) detected 13.7% (± 1.1% SE) of total transmissions < 100 m depth compared to 3.8% (± 0.6% SE) of total transmitters from > 100 m depth (Fig. 4). Transmitters at 1 m depth were detected at an average rate of 7.5% (± 1.1% SE) across all receivers. The deepest receiver, at 200 m, detected 18.7% (± 1.6% SE) of transmissions from the deep transmitters (100, 150, 200, 250, and 300 m), whereas it only detected 7.7% (± 1.9% SE) of transmissions from the shallow transmitters (1, 25, 50, and 75 m).

### Calculated positions and error

The mean (± SE) of the absolute value of calculated depth errors (24.0 ± 2.5 m across all trials, excluding unreliable measures identified when the DTD value fell outside those calculated by the internal sync tags) generally increased as transmitter depth increased. Mean calculated depth error ranged from + 8.6 ± 2.0 m when the transmitter was at 24.2 m deep to − 61.5 m when the transmitter was at 255.5 m deep, although there was only one reliable calculation at the 255.5 m depth (Fig. 5). We differentiate between positive and negative depth error to indicate calculated depths that were shallower (positive) or deeper (negative) than the transmitter's known depth, and we use absolute values to show the magnitude (in either direction) of the error.

The mean of the absolute value of calculated distance errors (± SE) was 26.1 ± 4.0 m and was relatively stable across drift tests (excluding unreliable measures). Mean calculated distance errors ranged from 16.2 ± 1.0 m during the third drift test to − 54.8 ± 19.7 m during the sixth drift test (Fig. 6).

### Great Barracuda positioning

The moored FAD receiver array was retrieved 9 days after the great barracuda was released with an externally attached transmitter, and a total of 1,179 detections were recorded. During this time, the longest span without a detection was 10.5 h, and the mean time between detections was 10.75 min. The great barracuda's mean depth (± SE) was 9.3 ± 0.4 m, which was nearly identical to the depth of the FAD's floats (10 m) (Fig. 7). The mean distance from the array was 27.9 ± 2.9 m over this 9-day span, with a maximum calculated distance of 821 m from the array. A 40-min snapshot of the VAR-calculated positions (distance from the array and depth) of the tagged barracuda are presented in Fig. 7, during which the detection efficiency was 77.5% (transmission rate was every 45 s). Therefore, given the minimal distance of the barracuda to the FAD (previously not possible to determine with more traditional approaches), the mean depth of the barracuda relative to that of the FAD structure (possible

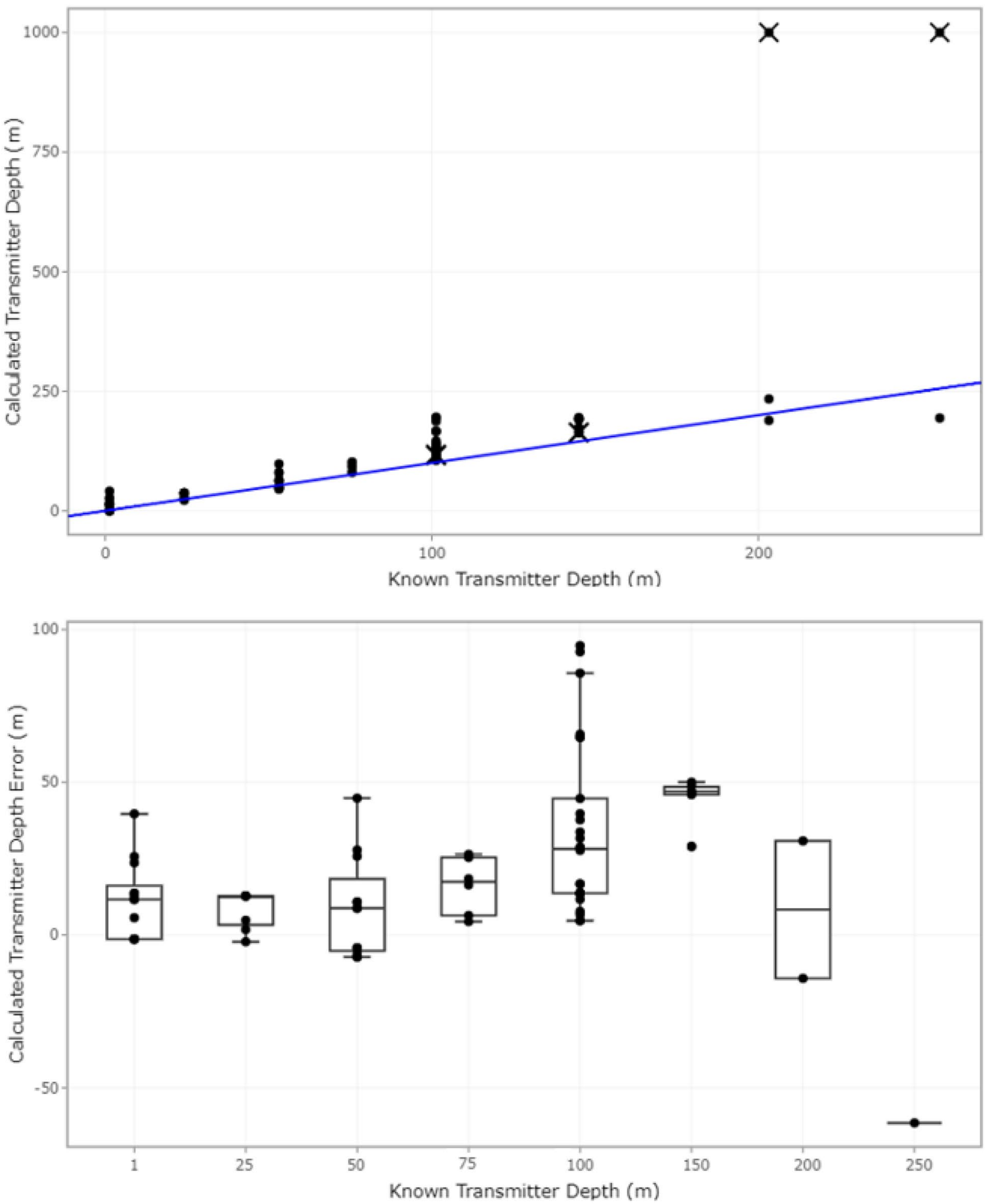


**Fig. 5** Calculated transmitter depth and depth error for the VAR drift tests. The top panel shows VAR-calculated transmitter depth against TDR-based known transmitter depth. The blue line has a slope of 1 and intercepts the origin, meaning that it represents where each calculated depth point should fall if no error occurred. Points with an X on them represent unreliable measures that experienced a multipath transmission that are not included in the error calculations. The bottom panel shows VAR-calculated transmitter depth error across the range of tested depths

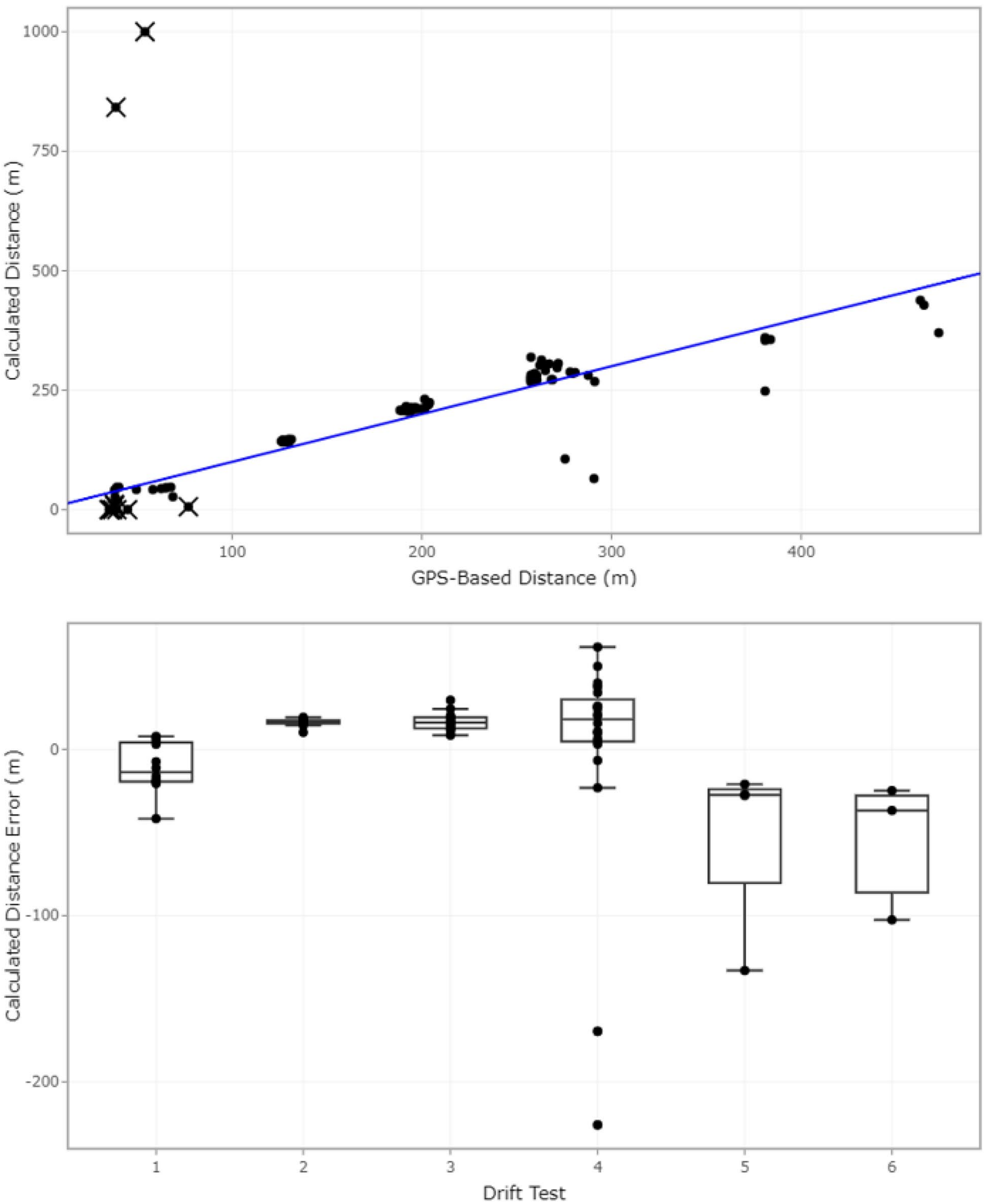


**Fig. 6** Calculated transmitter distance and distance error for the VAR drift tests. The top panel shows VAR-calculated transmitter distance (from the array) against GPS-based known distances between the drifting tag line and the array. The blue line has a slope of 1 and intercepts the origin, meaning that it represents where each calculated distance point should fall if no error occurred. Points with an X on them represent unreliable measures that were not included in the error calculations. The bottom panel shows VAR-calculated distance error across each drift test

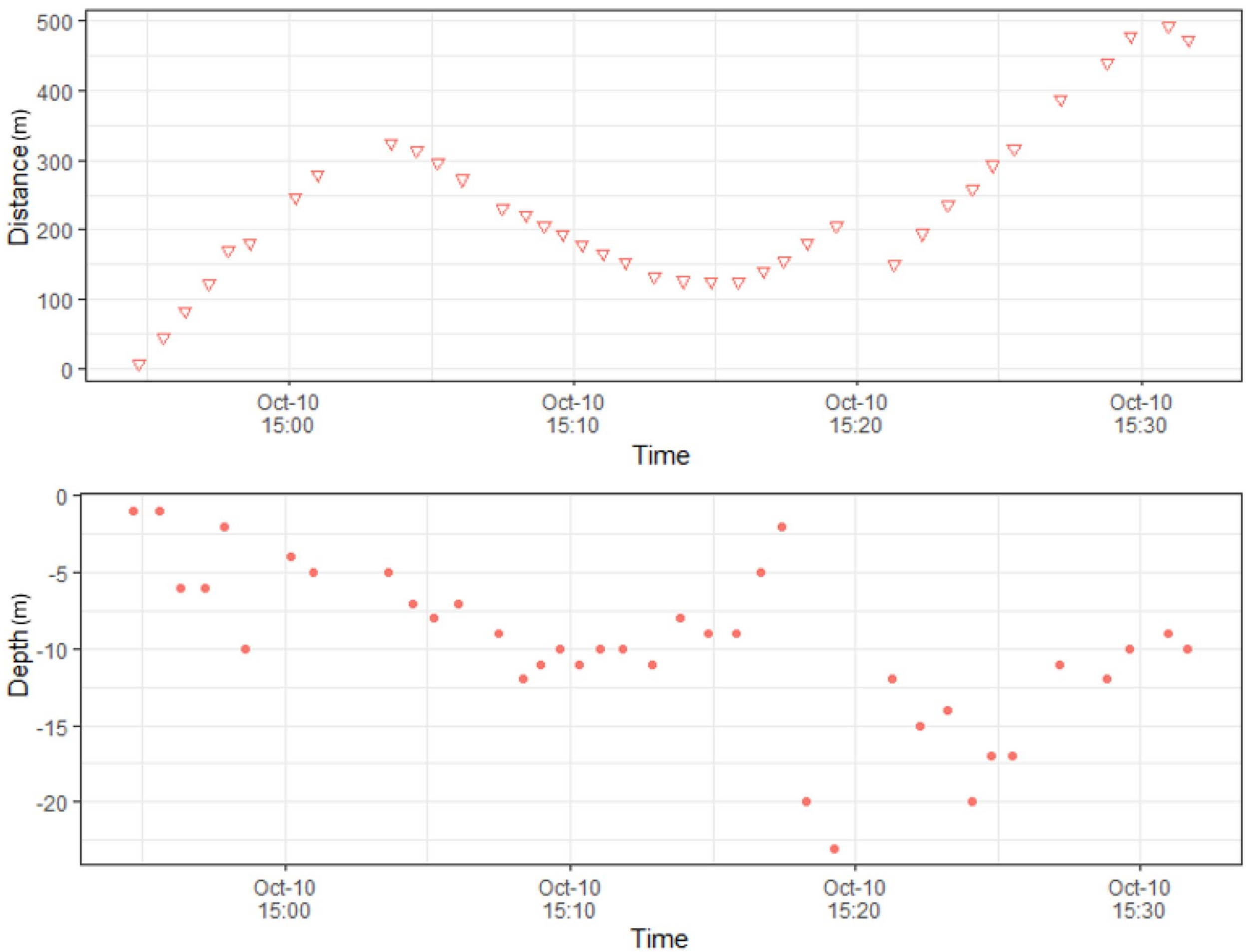


**Fig. 7** Forty-minute snapshot of calculated distances from the array-equipped FAD (top panel) and depths (bottom panel) of a tagged great barracuda derived from the moored FAD-based VAR

with conventional approach if the transmitter is paired with a pressure sensor), and the high amount of residency time within the array, the data were unequivocal of a high degree of association with the FAD structure.

## Discussion

The results from the drift tests showed the potential for two-dimensional positioning data, specifically distance from the array, to be generated in epipelagic oceanic zones using this VAR. The detectability analysis gives useful insight into the effectiveness of certain receiver–transmitter depth combinations at transmitting and receiving data, and this can inform study design in the future. In addition, the versatility of the array components will facilitate the investigation of animal movement around various types of structure that have previously been difficult to design for [11], allowing for the calculation of distance away from an array or structure and depth of non-pressure sensing tags, metrics that had not been previously possible to collect using passive acoustic telemetry in open water, or bottom depths that exceed transmission (~ 500–1000 m) and receiver (500–750 m) specifications for using a VPS. For example, distance away (between the transmitter and array) cannot be calculated with a single acoustic receiver, so this VAR shows promise for making this potentially important metric available in contexts where a full array deployment (e.g., Vemco Positioning System) is not feasible. In addition, the VAR's calculation of depth can also potentially save significant costs when conducting a large study, because adding the pressure sensor required for depth calculations roughly doubles the cost of acoustic transmitters. However, depending on the goals of a future study in which this array might be used, it could still be advantageous to use the pressure sensor-integrated transmitters which have a notably smaller error around their depth measurements, despite higher cost.

Detection efficiency during the drift tests was lower than expected for a system with this number of tags (~ 20% expected: F. Smith, pers. comm.) but was high during the great barracuda trial. The low detection efficiency during the drift tests was likely due to signal collision that occurred from having many tags in the system; however, some useful patterns still emerged. Detection efficiency was highest for the shallow receiver (15 m) and shallow transmitter (0–100 m) combinations at 13.7% and for the deep receiver (200 m) and deep transmitter (100–300 m) combinations at 18.7%. As these rates dropped off considerably for shallow-deep combinations, this indicated a barrier between 100 and 150 m that impeded signal transmission. This barrier was likely the observed thermocline (Fig. 3) over which water temperature dropped nearly 4 °C in 100 m after having stayed relatively constant at 25 °C for the first 100 m. A recent study on detection efficiency in a temperate, thermally stratified lake using the same V9 transmitters as in this study showed that both detection efficiency and detection range are reduced when signals pass through a thermocline [15]. Furthermore, transmissions produced and received beneath a thermocline can actually result in increased detection efficiency as the stratification may buffer the system from surface noise [19]. As a number of epipelagic fishes that may be of research interest frequently dive into and through thermoclines to feed in the deep scattering layer (e.g., [3, 4, 27]), it will be important to understand receiver placement in relation to the depth profiles of study animals to maximize detections.

Detection time difference (DTD) values that fell outside of those calculated from the internal sync tags and thus were unreliable occurred on 5.6% of calculations. These were likely due to a multipath signal, where the signal reflects off the sea surface or another boundary and arrives at the receiver later than expected, as it did not travel in a straight line [24]. Some multipath signals are to be expected, and these distorted signals may occur up to 5% of the time without substantially affecting the performance of one position-calculating algorithm [24]. Understanding this balance between receiver spacing and multipath error is important for study and array design.

Several considerations can be made in relation to receiver spacing, as some contexts may allow for further spacing, and some may be constrained to less than 100 m spacing. First, standard convention for receiver spacing in an array is typically 200–500 m for VR2Tx receivers using a traditional VPS to calculate positions, and 50–150 m is common in high-resolution 180 kHz systems (VPS; e.g., [12, 18, 21]). There is a tradeoff between the potential for multipath error or lack of DTD resolution (at short distances) and transmission efficiency (at long distances), so range testing should be used in array adaptation and study design. Another factor that can contribute to multipath error is the receiver proximity to the sea surface, as this provides a highly reflective surface off of which transmissions can bounce [23]. This factor alone did not result in unacceptable multipath issues in our study, as evidenced by acceptable levels of multipath error between receiver pairings involving the receiver at 15 m, in addition to many other studies that had receivers within similar proximity to the surface [12]. However, the combination of receiver spacing and proximity to a reflective surface should be considered and tested before undertaking any investigation.

Knowing the importance of receiver spacing for reliable VAR-based calculations, it may become apparent that depth (or lack thereof) may be a potential limitation to the application of the VAR. We estimate that a minimum of approximately 100 m depth would be necessary for this VAR to function, although this would depend on receiver type and site conditions, and we did not test for this. However, in these shallower situations, alternative approaches are available and more commonly used, and this is the exact reason why the VAR system was created: in deep water where a seafloor-based array is unfeasible, the VAR should have ample depth for adequate receiver spacing. Where shallower depths do not allow for adequate receiver spacing, it is likely that a seafloor-based array can be deployed.

## Conclusions

Tracking the fine-scale movements of animals in the open-ocean continues to be challenging. However, progress is being made in our ability to investigate behaviors in greater detail, specifically as it pertains to quantifying animal association with structure, especially near or at the surface, in open-ocean environments—a central topic in fisheries research. This VAR has generated acceptable DTD, distance, and depth data resulting in a biologically plausible great barracuda track in the epipelagic zone, and a way to quantitatively assess association based on distance from the structure. This advance, specifically, holds great promise for increasing our understanding of pelagic fish behavior around structure in open water where traditional methods may not be feasible. We will continue to develop this technique in hopes of using similar principles to calculate bearing (direction) with the ultimate aim of creating a three-dimensional tracking system for use in open-water habitats.

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### Author contributions
Conception/design: EVCS, TEVL, FIS, DMW, and CEM, data collection: EVCS and BST, analysis and interpretation of data: FIS and EVCS, writing—original draft: EVCS, and editing: all authors contributed.

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### Availability of data and materials
The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

### Ethics approval and consent to participate
Not applicable—no human subjects were used. Animal care and welfare followed standards from the Cape Eleuthera Institute's animal care and use protocol, as well as those set forth by The Bahamas Department of Marine Resources and Department of Environmental Planning and Protection.

### Consent for publication
Not applicable—no human subjects or personal data were used.

### Competing interests
The authors declare no competing interests.

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