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PRACTICAL TOOLS

Acoustic and archival technologies join forces: A combination tag

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Abstract

1. Technological advances are key to maximizing the information potential in electronic tagging studies. Acoustic tags inform on the location of tagged animals when they are in the range of an acoustic receiver, whereas archival tags render continuous time series of logged sensor measurements, from which trajectories can be inferred.
2. We applied a newly developed acoustic data storage tag (ADST) on 154 animals of three fish species to investigate the potential of this combination tag. Fish trajectories were reconstructed from logged depth and temperature histories using an existing geolocation modelling approach, adapted to include a likelihood for acoustic detections.
3. Out of 126 detected fish (accounting for over 700,000 detections) and 25 tag recoveries, eight ADSTs rendered both acoustic and archival data. These combined data could validate that the original geolocation model performed adequately in locating the fish trajectories in space. The acoustic data improved the timing of the daily position estimates.
4. Acoustic and archival tagging technologies provided highly complementary information on fish movement patterns and could partly overcome the limitations of either technique. Furthermore, the ongoing developments to acoustically transmit summary statistics of logged data would further increase the information potential of combination tags when tracking aquatic species.

KEYWORDS
acoustic telemetry, data storage tag, electronic tagging, geolocation model, movement ecology

1 | INTRODUCTION

Electronic tagging enables the spatiotemporal analysis of aquatic animal movements and vastly contributes to our understanding of these animals' behavioural and spatial ecology (Brownscombe et al., 2022; Hussey et al., 2015; Lennox et al., 2017). Over the past decade, technological advances have led to tag miniaturization and longer battery life, diverse attachment methods and increased data resolution (Hussey et al., 2015). Tags have been fitted with sensors (measuring e.g. pressure, acceleration, temperature and predation) to log or transmit information on behaviour, physiology and the physical environment (Brownscombe et al., 2019). These technological advances have allowed addressing a wider range of questions on a greater diversity of species (Brownscombe et al., 2022).

Two common electronic tagging technologies for aquatic animals are acoustic telemetry and archival tags. In acoustic telemetry, a tag transmits an acoustic signal, coded with a unique ID and optionally a sensor measurement. An acoustic receiver can detect this transmitted signal when the tagged individual is within the receiver's detection range. Detection data are accessed through the receiver. Archival tags, on the other hand, store sensor measurements at a predefined time interval in the tag memory. These tags must therefore be recovered or send their information through satellites to access the logged data. The resulting time series can provide fine-scale information on vertical movement behaviour (Heerah et al., 2017), and environmental preferences (Righton et al., 2010), and can be used to reconstruct migration trajectories with geolocation modelling (Pedersen et al., 2008; Woillez et al., 2016).

Double-tagging, that is, tagging an animal with two tags, has been used to benefit from specificities and complementarity of different tag types (Gatti et al., 2021; Strøm et al., 2017). Aside from providing complementary information on ecology and/or physiology, the combined use of distinct technologies allows us to evaluate the interpretation of one technology's results and ground-truth modelled outcomes (e.g. geolocation models, as reviewed by Gatti et al., 2021). In addition, double-tagging enables to assess tag retention and effect (Brownscombe et al., 2019; Verhelst et al., 2022). Although limitedly studied (Verhelst et al., 2022), double-tagging comes with reasonable concern over an increased impact of the tagged fish' welfare and movement behaviour. Combining technologies in one physical tag allows us to avoid the longer handling time in a more complex procedure and the added effect of the second tag. In this study, we report on the first utilization of a novel type of electronic tag that combines the technologies of acoustic telemetry and archival tagging.

2 | MATERIALS AND METHODS

2.1 | Tag specifications

We used the acoustic data storage tag (ADST; Figure 1), developed by Innovasea Ltd., in two sizes: ADST-V9TP (diameter 13 mm, length 65 mm, weight in air 8.5 g, transmitting power output 151 dB) and ADST-V13TP (diameter 16 mm, length 75 mm, weight in air 14.2 g, transmitting power output 154 dB). The ADST was equipped with a pressure sensor (maximum depth 68 m, accuracy ±1.0 m, resolution 0.3 m) and a temperature sensor (range −5 to 35°C, accuracy ±0.5°C, resolution 0.15°C). Tags were coloured bright red and fitted with a sticker with the contact details of the principal investigator and the mentioning of a reward (€25 or a T-shirt), to increase the probability of tag recoveries. The built-in floatation enabled tags to drift ashore when they got separated from the fish (e.g. due to predation, fishing or natural death).

FIGURE 1 Acoustic data storage tag, developed by Innovasea Ltd. (USA).

Sensor data were stored as continuous time series on the tag itself. Sensor information at the time of transmission was also transmitted acoustically (69 kHz, MAP114, protocol A69-9006). When selecting the transmit ratio of temperature versus pressure measurements, we favoured depth use for its information potential on vertical movement behaviour. The transmitting and logging intervals were selected in consideration of the study species, the study objectives and the trade-off with battery lifetime (Table 1, more details in Supporting Information). Tag settings had to be selected at the time of ordering the tags, as the programming of settings had to be performed by the manufacturer. Because the ADST lacked an internal clock, the time of activation of the tag (i.e. by removing a magnet) had to be registered to the second. Upon retrieval of an ADST, the physical tag was mailed to the manufacturer to download the data.

2.2 | Tagging procedure

From 2018 to 2021, we tagged three different fish species in the Belgian Part of the North Sea (BPNS), the Western Scheldt Estuary and the Eastern Scheldt in the Netherlands. We used the ADST-V13TP for 30 starry smooth-hound (*Mustelus asterias*

TABLE 1 Tag settings applied for different species. Temperature (T) and pressure (P) sensor measurements were logged continuously at a fixed interval and were transmitted at a fixed ratio (more details in Supporting Information)

Species	N	Type	Battery life (days)	Logging interval T - P (s)	Transmit ratio T:P
European seabass	27	ADST-V9TP	354	180–90	1:3
	40	ADST-V9TP	339	180–90	1:3
	19	ADST-V9TP	400	180–90	1:9
	23	ADST-V9TP	425	300–90	1:9
Atlantic cod	3	ADST-V9TP	339	180–90	1:3
	12	ADST-V9TP	350	180–90	1:3
Starry smooth-hound	30	ADST-V13TP	518	240–120	1:3

Cloquet 1821) and the ADST-V9TP for 109 European seabass (*Dicentrarchus labrax* L. 1758), and 15 Atlantic cod (*Gadus morhua* L. 1758). All fish were caught with rod and line. Immediately after capture, the fish were unhooked and placed in a holding tank. Prior to the surgery, seabass and cod were anaesthetised with clove oil (0.05 ml per L of seawater), whereas starry smooth-hounds were held with the ventral side up to induce tonic immobility. The tag was surgically inserted in the abdominal cavity through an incision across the midventral line, which was closed by three stitches using non-absorbable mono-filament. A Pederson disc (9.5 mm diameter; Floy Tag & Mfg., Inc.) stating 'REWARD: TAG INSIDE' and individual reference number, was attached between the dorsal and caudal fin for the majority of seabass and cod. Before release, the tagged fish was placed in a tank for 5–15 min to recover from the surgery. The animal tagging procedure was approved under the ethical certificates EC2017-080 (Belgium), 2016.D-0041.004 and 2016.D-0041.008 (The Netherlands).

2.3 | Data management

Acoustic detections could be registered on the permanent Belgian acoustic receiver network (Reubens et al., 2019), with the detection range distance (where the probability of detecting a tagged animal within a day exceeded 0.5) averaging from 500 to 700 m (Goossens et al., 2022). The data management was facilitated through the European Tracking Network (ETN) database (https://lifewatch.be/etn) (Reubens et al., 2019), archiving the data and metadata for both the acoustic and logged data.

2.4 | Analysis

For the recovered tags, trajectories were reconstructed with geolocation modelling, using a hidden Markov model (HMM). The hidden state (daily fish position) was estimated with an observation model, relating sensor measurements to environmental reference fields, and a movement model, describing the time dynamics of the state sequence as a Brownian random walk model (Pedersen et al., 2008). Full details on the geolocation approach were outlined in previous publications (de Pontual et al., 2022; Woillez et al., 2016), but we describe below how this HMM was adapted for the application on ADST data in our study area.

The reference fields of bathymetry and temperature at depth for the observation model were drawn from the 3D Dutch continental shelf model in flexible mesh, 3D DCSM-FM (Zijl et al., 2021). Building on an existing HMM, we decided to maintain an approach with a regular grid, rather than using the original irregular grid of the 3D DCSM-FM output (Liu et al., 2017). The depth and temperature irregular grids were rasterized to a regular grid (48.8°N - 53.0°N, 3.2°W - 5.0°E) with the field's finest resolution of 0.5′ x 0.75′ (latitude × longitude). The original 3D DCSM-FM output for the English Channel offshore area was at a coarser resolution of 1′ × 1.5′. Pixels in this area were resampled to the values of the nearest neighbouring cell to retain the highest resolution in the main area of interest (southern North Sea). The raster fields were transformed into a metric grid of a resolution of 1 km × 1 km. The temperature likelihood was estimated using a multivariate normal probability density function at the different depth layers (0, 5, 10, 15, 20, 25, 30, 50 and 100 m). This temperature likelihood was then multiplied by the depth likelihood (de Pontual et al., 2022).

Using the acoustic detection data, we implemented a detection likelihood. This likelihood layer was calculated differently for days with and without acoustic detections. If a fish was detected, the likelihood was set to 1 for the grid cell with the receiver location and 0 for the rest of the area. For days without detections, the grid cells with active receivers were assigned a detection likelihood of zero, with the rest of the field having an equal non-null value.

For European seabass, a behavioural switch was implemented (de Pontual et al., 2022) to discern two (daily) behavioural states: low versus high activity. As the behavioural pattern segmentation used here (Heerah et al., 2017) was developed specifically for seabass, we did not apply the behavioural switch for Atlantic cod and starry smooth-hound. Hence, the diffusion coefficient *D* (the mean daily distance covered by a fish, in km^2/day) of the movement model was estimated with a maximum likelihood estimation for two behavioural states for seabass and one state for the other species. From the daily posterior probability distributions of the observation and movement model combined, we calculated the most probable sequence of positions (Viterbi track).

Model performance was evaluated using the information on acoustic detections. We defined positional accuracy as the distance between the known receiver location and the trajectory as estimated by the geolocation model without including the acoustic detections (detailed explanation in Supporting Information). Track sensitivity was defined as the distance between the entire trajectories reconstructed with and without implementing the detection likelihood. To account for potential errors in the timing of the estimated track, both metrics were calculated as timed (distance to the estimated position on the exact day) and non-timed (minimum distance to the estimated positions on all days).

3 | RESULTS

Up until June 2022, 25 tags were retrieved (16.2%): four tagged seabass were caught with rods and 21 tags were found washed ashore. Plotting the depth and temperature histories of the tags, we could visually determine that two seabass and one cod died in the week after tagging; these datasets were omitted from the analysis. Two of the recovered tags experienced technical failures: an issue with the temperature sensor and another with the tag's hardware. At the time of writing, three of the recovered tags still had to be processed by the manufacturer. The acoustic data storage tags (ADSTs) resulted in over 700,000 acoustic detections from 126 out of 154 tagged animals.

Eight ADSTs provided both acoustic and archival data (Table 2). The complementarity of the two electronic tagging data types was visualized in Figure 2. The cod remained in an offshore receiver array until it died, as verified by the 87 detected days, which was accurately estimated with the geolocation model (median timed positional accuracy 4.1 km). For the European seabass, the archived depth history showed a very shallow depth use (mostly the upper 5 m of the water column) during summer and a deeper occupancy during colder months, which would likely be interpreted as inshore feeding behaviour during summer and offshore excursions during winter (de Pontual et al., 2022). The acoustic data, however, showed that the seabass was detected inside a port area (Zeebrugge) for 124 days throughout the year. For the example of the starry smooth-hound, the information of solely acoustic detections would have only indicated that the shark passed by the offshore wind farms 9 months after release before returning to its area of release (Scheldt Estuary). The geolocation model unravelled the shark's winter migration to the English Channel. Supplemented with the acoustic telemetry data (55 days detected), the trajectory was shown to be more offshore. The archival depth series showed the shark went deeper than 75.5 m, the factual maximum depth. The evaluation of the model with the information of acoustic detections produced median values of 21.4 km (maximum 134.7 km) for timed and 5.9 km (maximum 46.9 km) for non-timed positional accuracy, and 6.9 km (maximum 133.9 km) for timed and 1.5 km (maximum 59.3 km) for non-timed track sensitivity. The contrast between the timed and non-timed metrics indicated the inclusion of the information on acoustic detections vastly improved the timing of the reconstructed tracks.

4 | DISCUSSION

The unique value of combination tags consisted of the possibility to understand residency and habitat use in a specific area with a receiver array, in addition to studying migration behaviour and trajectories during the period animals were not detected. As illustrated by

TABLE 2 Overview of tags resulting in both acoustic and archival data with the number of days of archived data and days detected per fish, in addition to the archived depth (m) and temperature (°C) measurements. Performance metrics were computed in km: timed (TPA) and non-timed positional accuracy (NPA), timed (TTS) and non-timed track sensitivity (NTS). Values were shown as median [range]

Species	Trajectories	Days detected	Archived days	Depth (m)	Temperature (°C)	TPA	NPA	TTS	NTS
European seabass	3	18 [1–124]	235 [38–331]	2.4 [0.0–20.2]	2.4 [4.3–25.8]	25.3 [2.5–37.2]	7.7 [0.3–7.5]	23.0 [0.1–37.6]	4.8 [0.1–29.6]
Atlantic cod	2	46 [2–89]	178 [88–268]	22.0 [0.0–25.3]	17.7 [14.5–19.9]	4.1 [0.5–27.6]	0.5 [0.5–19.7]	0.7 [0–27.3]	0.6 [0–20.0]
Starry smooth-hound	3	2 [1–55]	38 [23–367]	34.3 [0.0–75.5]	13.5 [8.6–29.2]	48.6 [9.1–134.7]	5.9 [4.3–46.9]	0.7 [0–133.9]	0.5 [0–59.3]

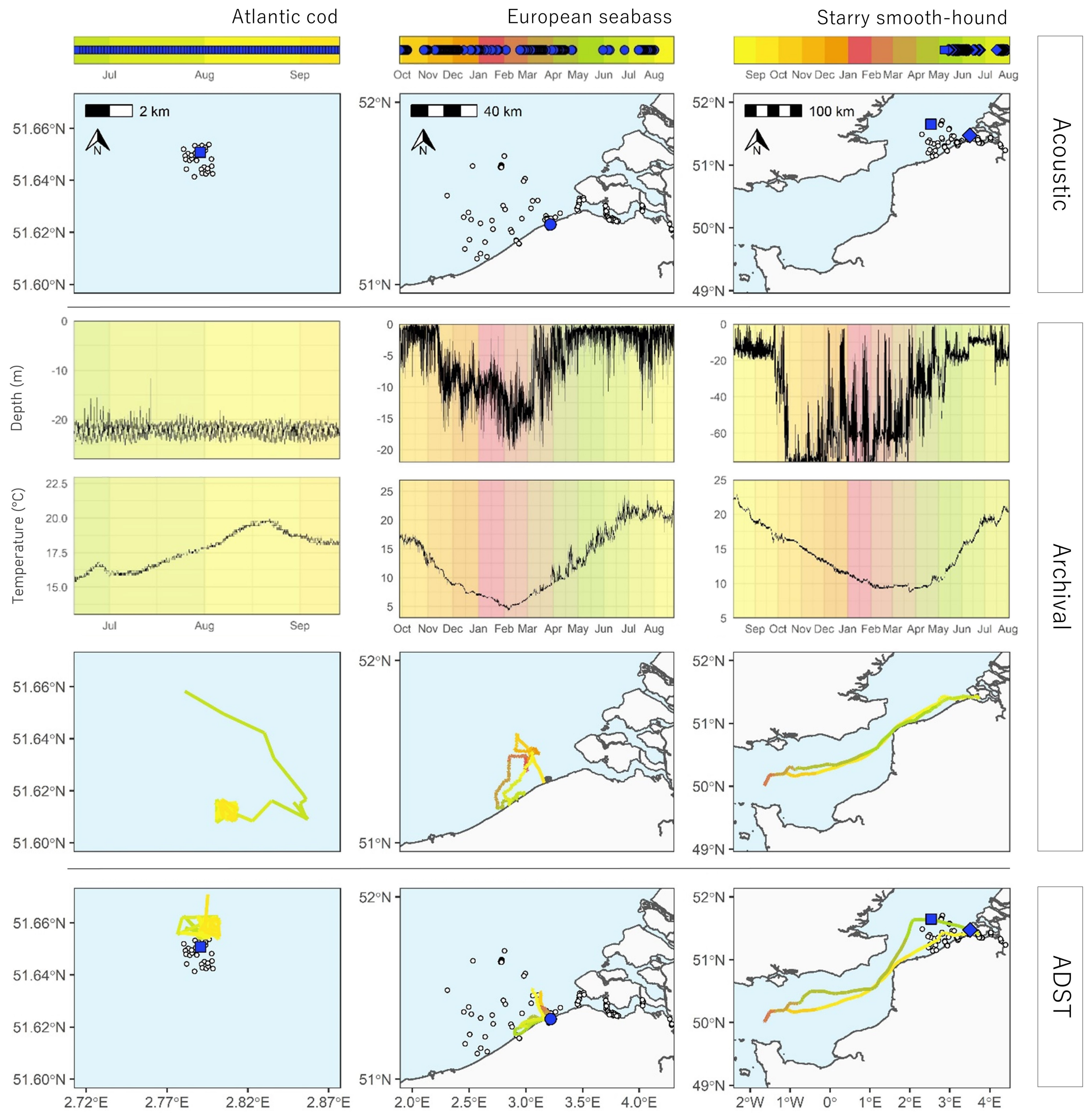

FIGURE 2 Examples of tagging results for an Atlantic cod (left), European seabass (middle) and starry smooth-hound (right), shown with only the acoustic detection data (top), only the archival data (middle) and the combination of both in the ADST (bottom). White dots represent the locations of the active receivers with the locations of detections in blue (square: offshore wind farm; diamond: estuarine station; circle: harbour station). Archival depth and temperature histories were plotted over time and the modelled trajectories were visualized on the map in the timeline's colouring. Combining acoustic and archival data, trajectories were estimated with the inclusion of acoustic detection data in the geolocation model.

the seabass in the port area, the bathymetry and temperature variability of (secluded) inshore areas might not reliably be accounted for in environmental reference fields. Acoustic data were vital to recognize the fish presence in this specific habitat. The inclusion of acoustic data could thus overcome the limited performance of geolocation models in coastal areas (due to an insufficient resolution of environmental reference fields), where the deployment of acoustic arrays would be relatively convenient. The vast contribution of the archival component was illustrated in the starry smooth-hound example. A solely acoustic tag would have only informed on site fidelity and some residency in the estuary, whereas with the archival data we were able to reconstruct its southward migration trajectory.

Acoustic detections informed on presence at specific locations, whereas the archival data contributed large-scale modelled trajectories on a low resolution and fine-scale information on behaviour and temperature experience on a high resolution.

The acoustic detections enabled the validation of the geolocation model, which was shown to perform in line with expectations for demersal and pelagic fish (Gatti et al., 2021). As illustrated by the smaller distances of the non-timed performance metrics, the geolocation model would adequately position the trajectory in space but would often err in the timing of the daily position estimates along the track. Building on an assumption of Brownian motion (Pedersen et al., 2008), the movement model of the geolocation assumed a fish to move to an area of high likelihood rather gradually. The acoustic detections, however, showed that fish movement could be abrupt in distinct periods of time.

To fully benefit from this information potential, combination tags should be highly modular. We regarded the floatability option as an important asset, as we retrieved the majority of recovered tags after washing ashore. Depending on the study species, researchers might opt for pressure and temperature sensors with a different range and resolution. Since the fish' temperature experience could have been drawn from existing temperature data series in the study area, the acoustic transmission of depth use information was preferred. The ability to (re-)program transmitting and logging settings and performing the data offload of recovered tags yourself, as well as the inclusion of an internal clock, would highly increase user-friendliness. Other acoustic and archival tags on the market do entail these features, as well as a wider range of options regarding tag size, battery time and storage memory, sensor range and resolution, pop-off mechanisms, etc. Although using one tag instead of two may be less invasive and reduces fish handling time, the flexibility of a more diverse set of options remains a crucial advantage of double-tagging.

With regard to future developments, however, combining technologies in one physical tag entails the possibility of transmitting information collected before the time of transmission. Like satellite tags (pop-up satellite archival tags and smart position and temperature transmitting tags), ADSTs could transmit summary metrics of the archived data, but through an acoustic receiver rather than through satellite transmission. Currently, an acoustic signal can only transmit a very small amount of data (8 bites at the time of the study) in addition to the tag ID. The limited computing power within tags prevents the use of advanced algorithms. Considering the present technological challenges, the transmitted information will likely consist of simple summary statistics. To maximize this potential future utility, combination tags should be customizable, enabling users to prioritize the transmission of information on individual location (e.g. time stamped maximum depths), behaviour (e.g. seasonal depth range), or habitat (e.g. seasonal temperature range), depending on their research objectives.

AUTHOR CONTRIBUTIONS

Jolien Goossens led the analysis and writing. Jan Reubens, Pieterjan Verhelst, Tom Moens, Els Torreele and Jolien Goossens designed the study. Jolien Goossens, Jan Reubens and Pieterjan Verhelst carried out the field work. Mathieu Woillez and Jolien Goossens performed the geolocation analysis. Arnault LeBris and Jan Reubens contributed to the writing. All authors read and reviewed the drafts and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Supporting Information S1

Table S1 Tag settings applied for different species. Temperature (T) and pressure (P) sensor measurements were logged continuously at a fixed interval and were transmitted at a fixed ratio. Signals were transmitted at a random delay between a minimum and maximum interval for a fixed period of time.

Supporting Information S2

Table S2 Definition of geolocation model performance metrics.

Figure S1 Visual explanation of performance metrics for evaluating the geolocation model. In this situation, the tagged fish was detected at day T3 (red dot). The trajectory was reconstructed without the information of the acoustic detection (dotted line) and with using the detection likelihood (undashed line). Blue arrows indicated which distance was used to calculate each metric. Positional accuracy was calculated as the distance between the receiver location and the daily positon estimate for the day of the detection (timed) or the closest daily position estimate of the track (non-timed). Track sensitivity was calculated as the distance between daily position estimates of the same dates (timed) and as the minimum distance between daily position estimates of all dates (non-timed).

Figure S2 Performance metrics positional accuracy and track sensitivity, timed (purple) and non-timed (red), over time for the shark example (tag SN1293308).

Figure S3 Performance metrics timed (TPA, top left) and non-timed positional accuracy (NPA, bottom left) and timed (TTS, top right) and non-timed track sensitivity (NTS, bottom right) for the shark example (tag SN1293308). The displayed track (thin black line) was reconstructed without using the detection likelihood. Receiver locations with acoustic detections were displayed as black dots. For positional accuracy (left), the daily position estimates of dates with a detection were displayed with a thick line in a colour scale of the distance (km) from the receiver location to the daily position estimate of the same date (timed) and of all dates (minimum distance, non-timed). For track sensitivity (right), the track reconstructed with the inclusion of the detection likelihood was displayed with a thick line in a colour scale of the distance (km) to the daily position estimates of the track reconstructed without using the detection likelihood (thin black line).

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