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PRACTICAL TOOLS

Tracking marine tetrapod carcasses using a low-cost mixed methodology with GPS trackers, passive drifters and citizen science

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Abstract

1. Drift experiments are essential to understand stranding patterns and estimate the mortality of beached animals. Most studies do not use telemetry technology due to the high costs of this methodology. The objective of this paper is to describe the possibilities of tracking marine tetrapod carcasses with a low-cost and replicable methodology. The study was carried out on the Southern Subtropical Shelf (~28°–34°S), a highly productive and key ecological region of the southwestern Atlantic Ocean (SWA).
2. We designed and tested a low-cost mixed methodology that includes Global Positioning System trackers, passive drifters (reused glass bottles) and Citizen Science (through an instant message platform and email) to track carcasses of marine tetrapods. We conducted four drift experiments during the four seasons of 2019. We released 787 drifters (600 nonbiological and 187 carcasses of seabirds, sea turtles, and cetaceans) at sea, at five equally separated distances (5–25 km) from the coast. Beach surveys and citizen science were implemented to recover the beached drifters.
3. We recovered 71.83% of non-biological drifters and 27.27% of carcasses released. We tracked the movements of 38 carcasses (25 sea turtles and 13 cetaceans) with 17 GPS devices. The drifting time, until reaching the beach, ranged from 12 h to 17 days for carcasses and 12 h to 406 days for bottles. Citizen Science was the most important source of recovery of nonbiological drifters, representing 66.67% of the total recovered bottles. For carcasses, active search was the most important recovery source, representing 64.7% of the total carcasses recovered.
4. Our study contributes with new findings on marine tetrapod drift patterns in the SWA and describes an accessible low-cost mixed methodology for small and medium-budget projects that can be replicated in other coastal regions of the world for tracking a wide range of marine tetrapod species.

KEYWORDS
citizen science, drifters, GPS trackers, low-cost methodology, marine tetrapods

1 | INTRODUCTION

Wildlife tracking technology provides valuable information on animal movements (Marzluff & Millspaugh, 2001). Choosing the right tracking method is challenging and involves financial, operational, and technical considerations (Thomas et al., 2011). GPS-based telemetry is currently the most popular method due to smaller, cheaper, and more efficient trackers (Joo et al., 2020). Fastloc-GPS and Argos systems are often preferred for air-breathing marine vertebrates (Dujon et al., 2014; Hays & Hawkes, 2018), as they can record multiple parameters at high rates, including physiology, behaviour and environmental data, although animal movement remains the main focus. Integration of GPS with cell-phone communication networks enables real-time data acquisition, greatly improving studies on animal movement ecology (Kays et al., 2015). However, GPS telemetry can still be expensive depending on species and environment, with costs associated with tracker size and functionality (Thomas et al., 2011).

Most studies on marine animal movements focus on live animal telemetry, particularly for air-breathing top predators, to understand their ecology and conservation (McClellan et al., 2009). However, data from stranded marine megafauna can be valuable in estimating at-sea mortality (Peltier et al., 2016). Few studies have combined strandings data with tracking methodologies to improve mortality estimates (Cook et al., 2021; Santos et al., 2018). Additionally, studies using at-sea marked carcasses to estimate drift and stranding patterns are also rare due to challenges in obtaining and storing fresh carcasses or tagging and releasing them after fisheries bycatch (Prado et al., 2013).

Negative interactions between marine megafauna and fisheries bycatch (gillnets, longlines, and trawls) have been well-documented worldwide, including in the southwestern Atlantic Ocean (SWA), where thousands of carcasses strand regularly (Lewison et al., 2014). In the South Brazil Shelf (SBS) Large Marine Ecosystem (23–34°S), over 55,000 marine tetrapods stranded between 2016 and 2019, many of them coming from bycatch, including threatened species (Tavares et al., 2021). Despite the importance of understanding global patterns of megafauna bycatch for conservation and management efforts, there are still gaps in knowledge that persist (Lewison et al., 2014). Monitoring fisheries is logistically complex; however, information obtained from beached carcasses can contribute to improving our understanding of bycatch patterns worldwide (Peltier et al., 2020).

To better understand the origin and trajectories of beached carcasses, we designed and tested a low-cost mixed methodology using active GPS trackers, passive drifters, biological and nonbiological drifters, and active and citizen science beach monitoring for marine tetrapods. Our main objectives were (a) to provide an accessible approach, particularly reducing the cost of real-time tracking, using a low-cost GPS device (designed for vehicle tracking through the GSM network); (b) to demonstrate the benefits of a mixed methodology; and (c) to contribute to encourage the use of drift monitoring techniques in regions with limited budgets, which has prevented the advancement of knowledge about bycatch and mortality of marine tetrapods in many regions of the world. We present the results of a drifting experiment and discuss the cost–benefit of our mixed methodology, and how it can be replicated and adapted to be used elsewhere.

2 | MATERIALS AND METHODS

2.1 | Study area

The study area is in southern Brazil (Figure 1), within the Rio Grande ecoregion of the Warm Temperate Southwestern Atlantic province (Spalding et al., 2007). This region is characterized by the seasonal influence of two main marine currents: the warm Brazil Current, which transports tropical water toward the SBS for most of the year, and the coastal branch of the cool sub-Antarctic Malvinas Current, which moves northwards during winter (Odebrecht & Castello, 2001).

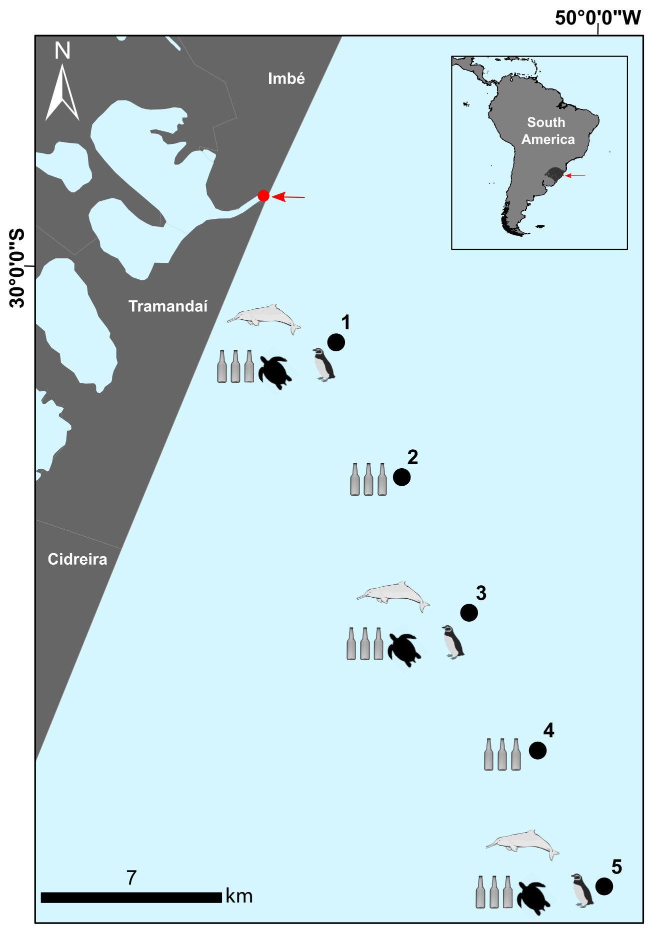

FIGURE 1 Map of the study area with release points (black points) of the drift experiment conducted in southern Brazil and schematic representation of the composition of drifters (bottles and carcasses) by point. Red point = Imbé harbour.

2.2 | Biological and nonbiological drifters

We used fresh carcasses of marine tetrapods (seabirds, sea turtles and cetaceans; Table S1) as biological drifters to simulate their natural trajectories after death at sea. Carcasses were obtained from two sources: (a) beached carcasses (decomposition codes 2 or 3, according to Tavares et al., 2021) found during systematic beach surveys in southern Brazil between 2017 and 2019, or (b) carcasses (decomposition code 2) from a wildlife rehabilitation center. The carcasses were stored frozen at −20°C until the drift experiment and thawed at room temperature for up to 24h before release. The carcasses were collected according to Brazilian regulations and permits from the Ministry of Environment (Licence #20185).

To simulate carcass trajectories and eliminate biological effects, we adapted 330mL glass bottles as nonbiological drifters. Each bottle contained a message with contact information (Figure S1). Furthermore, a visual ID tag (AllFlex) was attached externally to each bottle, containing a customized alpha-numeric code, an email address and a WhatsApp number for contact (Figure S1). The same type of ID tag was attached to each drifted carcass (Figure S1).

2.3 | Drift experiment, citizen science and active drifter searches

We use a commercial vehicular GPS tracker (TKSTAR TK905, Figure S2a) to monitor the carcasses trajectories of sea turtles and franciscana dolphins *Pontoporia blainvillei*. The device operates on a GSM network and GPS satellites, allowing real-time remote tracking through the Short Message Service, Application, and the Internet (technical specifications in Supporting Information S1). To extend the battery life, a 5000mAh power bank (XTRAX, Figure S2c) was connected to the device.

In 2019, we conducted four drift experiments (summer, autumn, winter and spring) in the state of Rio Grande do Sul (RS), southern Brazil, to refine estimates of at-sea mortality of marine tetrapods using a commercial vessel (Figure S3). Drifters were released at sea from five different points at varying distances from the beach (Table S2), numbered 1 to 5 from coast to offshore (Figure 1). The standard composition of drifters included 30 bottles per point and 15 carcasses (11 seabirds, three sea turtles and one dolphin) at Points 1, 3 and 5. Additional specimens were included whenever available (Table S1), maximizing the sampling effort. Seabird carcasses were not tracked due to their small average body mass (less than 2kg).

We used two methodologies to locate beached drifters (bottles and carcasses): citizen science and active search. Citizen science efforts focused on Whatsapp, one of the most popular applications in Brazil. An email was also utilized to maximize citizen feedback on drifter strandings. Lifeguards underwent a training program before the summer of 2018 to increase their knowledge about marine fauna, particularly beached animals along the RS coast. In 2019, the training program included a lecture on the drift experiment and its methodology. Information about the experiment was spread through local radio stations, television, on-line platforms, and press newspapers.

Beach surveys ($n=24$) were also carried out along the study area to recover beach drifters not reported by citizen science. The surveys began immediately after the drift experiments, with the effort adjusted based on the stranding pattern of each season (Table S3). The estimated total cost for our study was approximately 10,800 USD, covering the purchase of all items and equipment, as well as the four drift experiments at sea and beach surveys (Table S4).

2.4 | Data analysis

To compare the stranding patterns of both drifters, we analysed truncated data from the first 13days. This allowed us to include the entire uninterrupted recovery period and most of the data (see Section 3, Topic 3.1), while disregarding sporadic data that could introduce bias from longer drifting time of the bottles, which is biologically noninformative. We used nonparametric Mann–Whitney and Kruskal–Wallis tests to assess differences in the recovery pattern of drifters based on type, season and recovery methodology.

3 | RESULTS

3.1 | Spatial and temporal recovery pattern of biological and nonbiological drifters

We released a total of 600 bottles and 187 carcasses at sea, covering all seasons of 2019. Of these, 431 bottles (72%) and 51 carcasses (27%) were recovered on beaches. The bottles and carcasses had the highest recovery rates in autumn and spring, respectively. For both drifters, the lowest percentage of recovery was in winter (Figure S4). The drifters beached along 430km of coastline, covering around 130km to the north and 300km to the south of the release points (Figure 2). Approximately 22% ($n=11$) of sea turtles, 14% ($n=7$) of franciscana dolphins and 65% ($n=33$) of seabirds were retrieved.

The time between the release of drifters and the stranding events ranged from 12h to 406days for bottles and from 12h to 17days for carcasses. Most of the recovered bottles ($n=375$; 87%) and all recovered carcasses ($n=51$; 100%) stranded within 17days after being released at sea (Figure 3). The recovery of both carcasses and bottles occurred daily without interruption until the 11th and 13th days, respectively, after which there was a sporadic recovery pattern. The drifting time of the carcasses varied between taxonomic groups and between the two sources of carcasses of marine tetrapods (Table S5).

In terms of spatial recovery, during the first 13days, carcasses stranded slightly further south than bottles (Figure 2c). However, the differences between the medians of latitude of strandings of both drifters were not significant (Mann Whitney $U=7783.5$, $p=0.10$). Despite a similar trend of latitudinal recovery, the interquartile range shows that carcasses had a higher latitudinal spread than bottles.

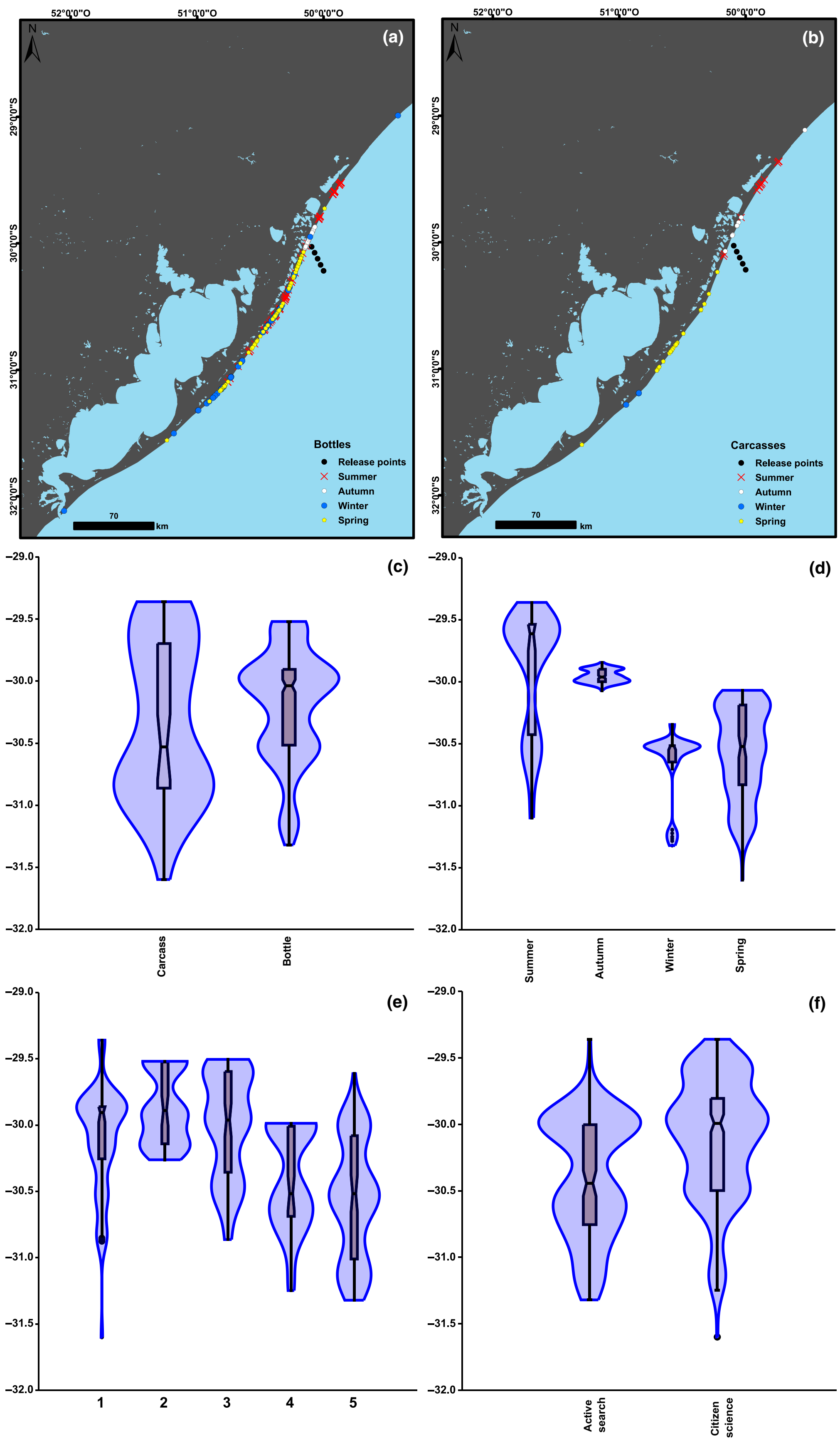

FIGURE 2 Distribution of recovered drifters by season along drift experiments conducted in southern Brazil in 2019. (a) bottles and (b) carcasses. Violin plots, by degree of latitude (vertical axis), comparing medians of recovery locations among drifters (c), seasons (d), points of release (e) and source of search (f). For the statistical analysis, the data were truncated in the first 13 days.

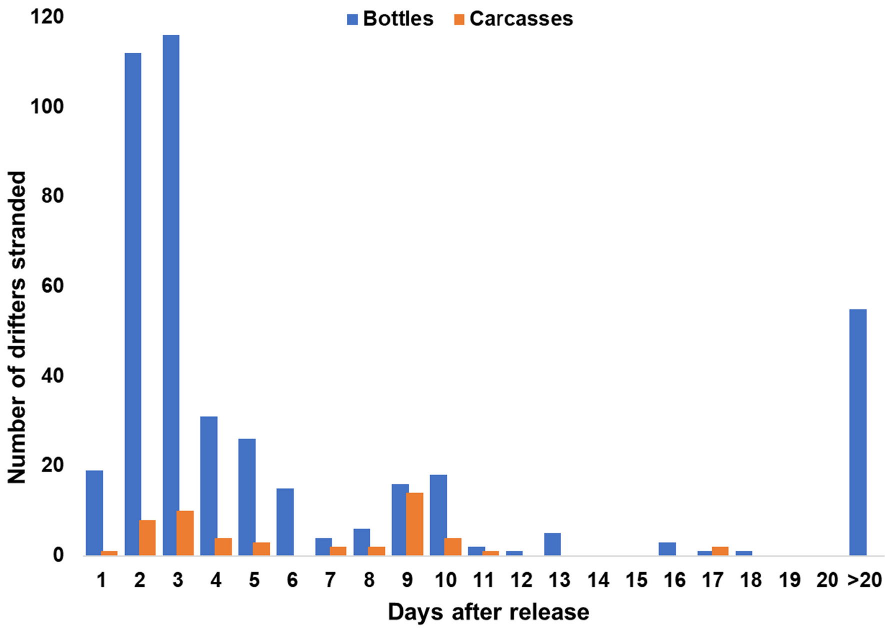

FIGURE 3 Number of drifters (bottles and carcasses) recovered by day after being released in the four drift experiments in southern Brazil, in 2019.

Grouping both drifters revealed seasonal variations in stranding patterns. In summer and autumn, drifters washed predominantly up to the north of the release area, which was significantly different from winter and spring, when drifters washed predominantly up to the south (Kruskal–Wallis, $p<0.0001$; Figure 2d). Furthermore, the stranding pattern varied depending on the release points. The drifters released at Points 4 and 5 were found significantly further south compared to those released at Points 1, 2 and 3 (Kruskal–Wallis, $p<0.0001$; Figure 2e).

3.2 | Tracking carcasses

We monitored the movement of 25 sea turtles and 13 dolphins using GPS trackers (Figure 4). Carcasses that did not strand were assumed to have sunk or been scavenged at sea. However, some of the GPS trackers stranded without carcasses and could be utilized in subsequent experiments. As a result, we tracked a total of 38 carcasses using only 17 GPS trackers. The recovery rate of the trackers varied between seasons, with 100% recovery in summer, 83% in winter, 78% in autumn and 67% in spring.

The GSM network signal was effective within approximately 15–20 km from the coastline, around the release points 1 through 3. However, it weakened or was lost at greater distances. The signal was effective latitudinally between 29–30.5°S, and south of 31°S was consistently weak, even near the coastline. The battery life ranged from 4 to 7 days, and power consumption varied depending on the level of movement exhibited by the tracked carcasses.

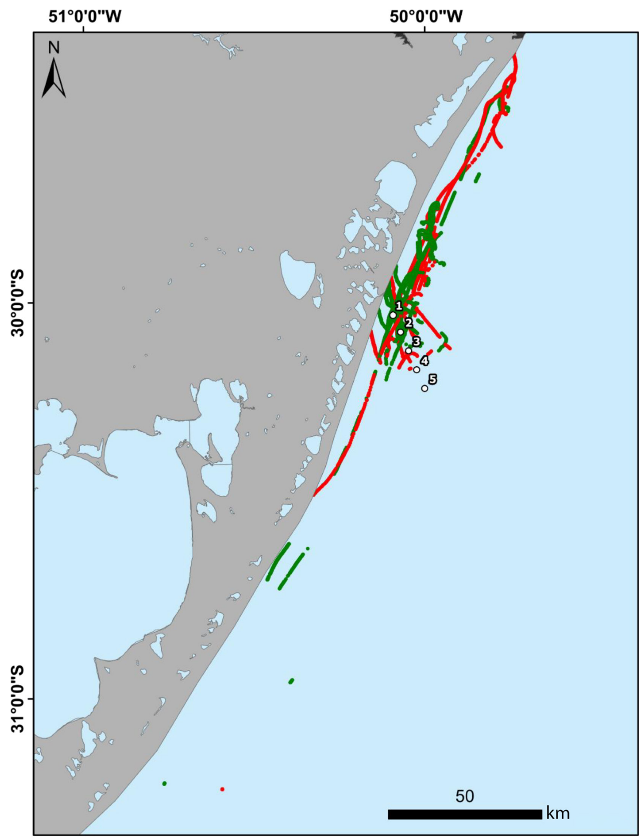

FIGURE 4 Complete drift tracks of 38 carcasses tracked during the four drift experiments in Southern Brazil in 2019. Green = sea turtles. Red = franciscana dolphins (*Pontoporia blainvillei*). Numbers 1–5 indicate the release points of the drifters.

3.3 | Citizen science and active drifter searches

Citizen science was the primary source of recovery for bottle drifters, accounting for 67% of the total bottles recovered. Meanwhile, active search was the main source carcasses, representing 65% of the total carcasses retrieved. Analysis of recovery sources revealed that drifters recovered through citizen science were significantly further north compared to those recovered through active search (Mann–Whitney $U=1248$, $p<0.0001$; Figure 2f). During the first drift experiment in the summer season, the support of lifeguards was crucial in communicating and collecting bottles, particularly on highly urbanized beaches. Conversely, local fishermen reported both biological and nonbiological drifters beached in nonurbanized areas during all four drift experiments. In terms of communication channels, WhatsApp was overwhelmingly the primary form used by citizens, accounting for 93% of bottles and 72% of carcasses recovered through the citizen science network.

4 | DISCUSSION

4.1 | Wildlife tracking and cost considerations

In our study, we employed a low-cost mixed methodology that integrated vehicular GPS trackers, passive drifters, and citizen science to document the movement of marine tetrapod carcasses at sea and their stranding patterns. This approach provides an accessible and cost-effective tool for ecological studies and represents the first effort to compare a large number of biological drifters from three large groups of megafauna, along with nonbiological drifters, in controlled experiments that covered all seasons of the year in a large ocean area. The vehicular GPS tracker proved to be effective in tracking the coastal displacement of carcasses of sea turtles and franciscana dolphins, and can be used for any species of interest over 2 kg. For tracking seabirds, smaller devices with similar technical features can be considered an option.

The total cost for one device in our experiment was approximately USD 131 per year, which is considerably less expensive than the next cheapest satellite option available (SPOT Trace GPS, USD 272 per device per year). It is important to note that the total cost depends on the length (monthly or yearly) and type of contract (basic or advanced) for tracking. Therefore, our results demonstrate that a commercial vehicular GPS tracker can be an excellent and cost-effective option for real-time tracking, even for small-budget projects. Additionally, the high recovery rate of the trackers in our study (with a mean of 82% for all seasons combined) allowed us to track 38 carcasses using only 17 trackers, significantly reducing costs.

4.2 | Biological versus nonbiological drifters: Trade-offs

Drift experiments have been widely used for various purposes, such as estimating mortality hotspots of marine tetrapods, identifying potential fisheries bycatch and assessing mortality from oil pollution (Peltier et al., 2020; Santos et al., 2018; Wiese & Jones, 2001). However, the purchase and use of biological drifters can pose challenges due to their accessibility and cost, especially when dealing with large animals such as sea turtles and dolphins. As a viable alternative, nonbiological drifters have been commonly used in numerous studies to simulate the movement of biological drifters (Cook et al., 2021), as well as to record current drift patterns and their impacts on larval dispersal (Tegner & Butler, 1985).

It should be noted that nonbiological drifters may have different persistence times at sea compared to carcasses, as they are not influenced by biological processes such as decomposition and scavenging. Nonbiological drifters typically persist longer at sea than biological drifters. In our study, most bottles (86%) were washed ashore within the maximum persistence time range of carcasses (17 days). Nonbiological drifters allow for monitoring drifting patterns with larger sample sizes at a lower cost (Koch et al., 2013). Therefore, both types of drifters are complementary in drift experiments and provide essential information to estimate the mortality of stranded animals.

For an accurate estimate of carcass persistence time at sea, we also recommend using carcasses of the target species. Additionally, whenever possible, we suggest using fresh carcasses, as the buoyancy of carcasses changes over time due to decomposition, which could introduce bias in drifting experiments (Santos et al., 2018). Compliance with ethical and biohazard regulations at the study site must be taken seriously. However, in cases where carcasses are not available, nonbiological drifters can still provide important data on the timing and location of strandings. In such cases, the drifting time must be truncated to ensure biological relevance to the stranding data.

Both biological and nonbiological drifters exhibited similar spatial distribution patterns of strandings. However, differences in recovery rates were observed between seasons and distance of release, likely attributable to the complex surface water circulation system in the study area, which is influenced by river discharges and winds (Möller et al., 2008). Therefore, we strongly recommend incorporating both temporal (seasons) and spatial (latitude and distance to coast) conditions in designing drifting experiments.

4.3 | Citizen science

Our experiment highlights the importance of a robust citizen science network in enhancing drifter recovery, as evidenced by previous studies (Schöneich-Argent & Freund, 2020). However, we have identified a northward bias in citizen science recoveries compared to active search efforts, which can be attributed to differences in human population density in the study area, a known factor affecting recovery rates of drifters (Tegner & Butler, 1985). Therefore, we recommend the use of active search efforts to complement drifter recovery and account for potential biases introduced by citizen science. Furthermore, offering a range of accessible and popular communication channels for reporting findings contributed to increased recovery rates.

4.4 | How to track a marine tetrapod carcass in other scenarios?

Our study presents an accessible and low-cost tracking methodology that can be replicated in coastal regions worldwide. Our approach is efficient in tracking a wide range of marine tetrapod species weighing more than 2 kg, such as sea turtles, pinnipeds, sea otters, and cetaceans. Our results demonstrate the advantages of a mixed approach, utilizing both active and passive trackers, biological and nonbiological drifters, as well as active and citizen science efforts. However, the diversity of methods can be adjusted to suit the specific needs of different projects.

Although real-time active tracking is preferred, it is also the most expensive method. Our innovative approach involves the use of low-cost vehicle GPS trackers, which are readily available worldwide. One drawback is that good GSM coverage is essential, so the spatial distribution of the target species must be taken into account. Our methodology has been found to be effective in waters within 20 km of the coastline with good GSM coverage. In areas without a GSM network or further from the coast, a more expensive device with satellite communication may be necessary.

Biological drifters provide a more accurate representation of the conditions that carcasses face while drifting at sea. Whenever feasible, preference should be given to the use of carcasses of proper species or other biological drifters with similar features (i.e. body mass and tegument) to the species of interest. However, budget constraints, carcass availability (depending on access, ethical and biohazard limitations), and logistic considerations (such as storage and transport) are important factors to be taken into account. Therefore, we recommend using GPS trackers in conjunction with biological drifters, whenever possible.

Passive drifters, especially nonbiological ones, are complementary cost-effective options. Glass or plastic bottles, as well as other floating materials, are widely available worldwide. However, ethical and legal considerations regarding ocean pollution should be carefully considered when selecting materials. Moreover, the size and buoyancy of drifters should be considered, as they can affect the wind exposure, recovery probability, and logistical aspects. Based on our findings, we recommend using small glass bottles as drifters, as they exhibited drift patterns similar to those of biological drifters.

Citizen-science efforts were very effective in recovering drifters in our study, but are biased toward denser areas, and an active search is usually necessary. The benefits of citizen science go beyond recovery success, as it generates community awareness of conservation issues. We strongly recommend the inclusion of a citizen science component whenever possible.

We anticipate that our approach will enhance efforts to monitor negative interactions between marine megafauna and fisheries, particularly in areas where budget limitations have been prohibitive.

AUTHOR CONTRIBUTIONS

Maurício Tavares, Paulo Henrique Ott and Márcio Borges-Martins contributed to the conception and design of the study. Maurício Tavares and Paulo Henrique Ott conducted fieldwork. Maurício Tavares wrote the first draft of the manuscript and all authors reviewed, read and approved the submitted version.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

All track file data are available at Dryad Digital Repository: https://doi.org/10.5061/dryad.cvdncjt7p.

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SUPPORTING INFORMATION

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

Table S1. Taxonomic composition of marine tetrapods used in the carcass drift experiment with their respective number (*n*) of specimens released at sea and body mass in kilograms (kg).

Table S2. Geographical position and distance from the coast of the five release points of the drifters used at the four drift experiments in the state of Rio Grande do Sul, southern Brazil, in 2019.

Table S3. Survey effort of active search to find drifters released in drift experiments by season in southern Brazil in 2019.

Table S4. Budget estimate to track marine tetrapod carcasses in four drift experiments conducted in 2019 in the state of Rio Grande do Sul, southern Brazil. The costs were calculated in Brazilian Real (BRL) and converted to United States Dollar (USD) based on the exchange rate on 29 June 2021 (1 USD = 4.96 BRL).

Figure S1. (a) Message, in Portuguese, placed inside each bottle with project contacts and information. (b) Bottle drifter with the visual ID tag (AllFlex) attached. (c) carcass of green turtle (*Chelonia mydas*) with the visual identification tag (AllFlex) attached. Photos: Paulo Henrique Ott.

Figure S2. (a) GPS tracker device (TKSTAR TK905) used to monitor the trajectories of the carcasses of sea turtles and cetaceans, (b) three cylindrical polypropylene dry food storage containers used as a waterproof box, two of them with a crochet net, (c) 5000 mAh power bank (XTRAX) used to extend the battery life of GPS tracker devices, (d) GPS tracker device inside a waterproof box with crochet net fixed on the carcass of green turtle (*Chelonia mydas*) by a resistant waxed cord. Photos: Paulo Henrique Ott and Lucas Antonio Morates.

Figure S3. Aerial view of the commercial vessel *Sea Green* used in the drift experiments (a), onboard routine before the deployments (b), carcasses of sea turtles and franciscana dolphin with GPS trackers attached (c), researcher releasing bottles used as nonbiological drifters at sea. Photos: Guilherme Frainer and Nathalia Serpa (a); Lucas Antonio Morates (b–d).

Figure S4. Number of drifters recaptured by season and by search type. (a) Carcasses of marine tetrapods. (b) Bottle drifters.

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