

Article

Asset Tracking Whales—First Deployment of a Custom-Made GPS/GSM Suction Cup Tag on Migrating Humpback Whales

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Abstract: The study of marine mammals is greatly enhanced through fine scale data on habitat use. Here we used a commonly available asset tracker Global Positioning System/Global Systems for Mobile Communication (GPS/GSM) integrated into a CATS suction cup tag to test its feasibility in providing real time location position on migrating humpback whales in coastal waters of eastern Australia. During two deployments—one on a suspected male and another on a female humpback whale—the tags provided location points with relatively high accuracy for both individuals albeit different swim behavior and surface intervals. In combination with an integrated archival data logger, the tag also provided detailed information on fine scale habitat use such as dive profiles. However, surface intervals were too short to allow for an upload of location data during deployment. Further improvements of the tag design will allow remote access to location data after deployment. Preliminary results suggested location acquisition was better when the tag was positioned well above the midline of the whale body. The technology promises less expensive, more reliable and more accurate short-term tracking of humpback whales compared to satellite relay tags, and it has the potential to be deployed on other marine mammals in coastal waters.

Keywords: suction cup tags; biotelemetry; biologging; humpback whales; fine scale movement; migratory behavior



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1. Introduction

Biotelemetry (remotely monitoring, recording, and measuring of a living organism's physical behavior) is an essential tool in marine ecology because it allows the tracking of wild individuals [1] and can be helpful in contributing to filling knowledge gaps in habitat use and behavior of marine mammals. Telemetry or radio tags for applications in the marine environment were developed by the Woods Hole Oceanographic Institute (USA) and became available in the 1960s. In the late 1980s, they were adapted to include satellite telemetry [2,3]. The success and progression of telemetry studies on marine mammals has been documented in a number of reviews [4,5]. With the introduction of satellite tags, technology quickly advanced further, and Global Positioning System (GPS), accelerometers, magnetometers, pressure sensors, and acoustic recorders were integrated into tags. This allowed for the collection of a wide range of biological and environmental information from which we can infer animal behavior, including underwater behavior. With the addition of data loggers, different deployment techniques were developed to increase tag retention and reduce impacts from tagging. While pinnipeds and small odontocetes may be captured for tagging, allowing for the use of harnesses, rings, epoxies, and acrylic glues [6], large whales cannot be captured, and their sloughing skin makes the use of traditional epoxy or glue methods unfeasible. Attachments for large whales therefore range from anchored and consolidated tags using darts, petals, needles or spears [7–9] to minimally invasive suction cup tags [10–13].

Suction cup tags do not have to penetrate the animals' skin and can be used for short term deployments (hours to days), making them applicable for fine scale habitat use studies that investigate movements within the range of meters to kilometers. Information on fine scale habitat use of cetaceans can provide important insights into habitat preferences and sensitivity to environmental drivers (hydrodynamics, temperature gradients, salinity, bathymetry) as well as anthropogenic impacts [12,14]. The study of habitat use also plays an important role for conservation management in the light of increasing anthropogenic impacts in coastal habitats. Short-term tagging can assist with detecting behavioral changes and assess physical conditions in combination with aerial imagery from remote operate unmanned aerial vehicles (UAVs) [15]. Large scale patterns (100–1000 km) of cetacean movement have been successfully studied using satellite tags in the past [16]. For example, telemetry studies have been undertaken to assess humpback whale residency [17], feeding and breeding behavior [18,19], movement patterns [20], energy budgets [21], health or vessel strike risks [22] and population connectivity [23,24]. Predominantly, tagging studies have focused on breeding grounds [16], feeding grounds [25] and large scale migration [26]. Very few studies have investigated resting areas where humpback whales display prolonged surface time and reduced swim speed and fine scale migratory behavior [27].

For fine scale movement, the spatial and temporal resolution of satellite relay tags (e.g., Advanced Research and Global Observation Satellite (ARGOS) spatial resolution > 1 km, temporal > 5 min) is not sufficient enough. Tags transmitting information using satellites are also costly [28–30]. GPS provides much better spatial accuracy (within meters) than ARGOS, but it has been ineffective for tracking of marine species that surface too briefly for complete acquisition of satellite information [28]. However, fast-acquisition GPS (e.g., Fastloc-GPS) can acquire a position within less than a second (according to manufactures), and if combined with the Global Systems for Mobile Communication (GSM) network instead of relaying data via satellite, it can transmit location information at a fraction of the cost [29,31].

GPS/GSM tags are commonly used for live asset tracking and in some cases for tracking marine mammals such as pinnipeds with prolonged resting time on the surface including land [32,33]. However, GPS/GSM tags only work in areas with sufficient GSM network coverage and animals with sufficient surface time. The tags are therefore limited to developed coastlines and certain species for short term deployments. If an animal or released tag comes within GSM range, data can be relayed provided sufficient battery power [34]. The technology has not been used on whales to our knowledge due to their short surface intervals (surface series for breathing between consecutive dives), which limit real time tracking and can result in the loss of tags in remote locations.

Humpback whales are a suitable target species to test this technology due to their nearshore migration passing developed areas and their prolonged resting on the surface in coastal waters. The first deployments of suction cup tags on humpback whales were undertaken in New Foundland in combination with very high frequency (VHF) transmitters to study short-term movement [35]. Since then, suction cup tags have been used on various species (e.g., *Orcinus orca*, *Balaenoptera musculus*, *Balaenoptera bonaerensis*) [36–38] and with different archival loggers attached (temperature, velocity, depth, sound, cameras) using cross bows or poles for deployment. For example, DTAGs originally focusing on sound, and then with added archival data loggers, were successful in studying humpback whale mother–calf pairs [11,39]. While the principle of using suction cups for minimally invasive deployments has not changed much over the years, the tags themselves have gone through further improvements helping to revolutionize the study of large baleen whales [40]. State-of-the-art suction cup tags with various archival data loggers, predefined release mechanism and lightweight, hydrodynamic shapes can now contain GPS modules that can relay location via satellite (e.g., ARGOS or Iridium) for easier retrieval at sea, but their price can range between 2000–5000 USD for a single module.

We aimed to develop a cost-effective alternative by using a suction cup tag that integrates a commonly available GPS/GSM asset tracker used for live fleet tracking. We

aimed to trial the feasibility of this low-cost technology to determine if an animal's position can be acquired, if live tracking in coastal waters is achievable, and if behavioral modes displayed during deployment can be assessed with a stand-alone micro-CTD attached to the tag.

2. Materials and Methods

We chose the Gold Coast bay as a study site; it is a shallow open embayment located at 27 °S, 153 °E in South East Queensland, Australia (Figure 1). The region is an important aggregation site for humpback whales located along their migratory pathway during southern and northern migrations between June and October each year [41,42]. The embayment provides shelter from the dominant southeasterly trade winds and has an average annual sea surface temperature (SST) ranging between 19.3 °C to 28 °C (<https://www.seatemperature.org/australia-pacific/australia/>). The migratory corridor is within 10 km of the coastline, and humpback whales are either resting, socializing or migrating in this region [41,43]. Animals were chosen for tagging when displaying no avoidance behavior towards the presence of the vessel over a prolonged period of time (30–60 min).

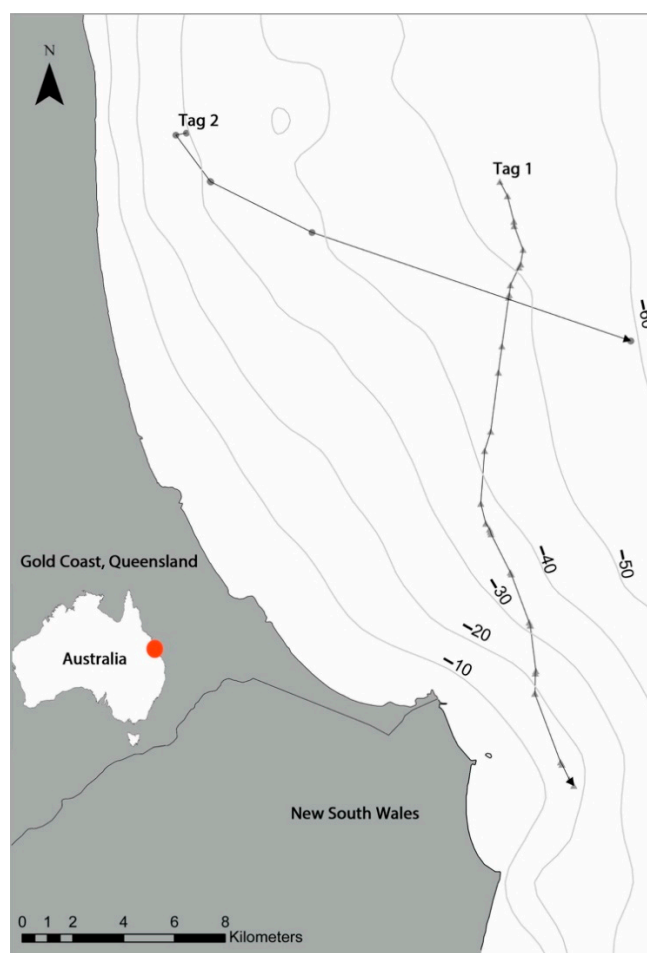


Figure 1. Map of study area and two tracks with arrows indicating direction of movement. The received locations from the GPS/GSM tag are shown by triangles (Tag 1) and dots (Tag 2). Bathymetry contour lines in 10 m depth intervals.

The GSM network is available several kilometers offshore (varying with distance to towers) making it a suitable location to trial the custom-made tag.

The custom-made tag was based on a CATS (Customized Animal Tracking Solutions) suction cup base unit specially designed for whales (<https://www.cats.is>, access date: 15 May 2021). These systems are fitted with 4 silicon suction cups, a galvanic release

mechanism and a VHF transmitter for retrieval. They have extensively been used on a variety of whales [37,40,44]. The galvanic release was set to release within approximately 4 h after tag deployment to ensure timely retrieval. The electronics of an Oyster 2 GPS/GSM tracking module (<https://www.digitalmatter.com/>, access date: 15 May 2021) commonly used for asset tracking were embedded into the suction cup tag and sealed watertight using epoxy with a 7 Ah rechargeable lithium battery providing sufficient power to the unit in logging mode for up to 6 days and a wireless charging module. The transmission of positions via GSM was possible during and after deployment as soon as the unit was at the surface for a sufficient amount of time and within GSM coverage. The location data can be retrieved via a live tracking application. The interval between location attempts was set at its shortest possible rate of 30 s. Additional information provided from the GPS/GSM model included location accuracy in meters, bearing, speed and speed accuracy based on the recorded GPS locations.

A Star Oddi DST conductivity, temperature, depth logger (CTD) was attached in a predefined notch at the front of the tag using zip ties. The CTD tag was set to 5 min intervals for the first deployment (Tag 1) and 5 s intervals for the second deployment (Tag 2) to test different settings. We tested the suction cup tag prior deployment at sea for buoyancy and acquisition of data.

For the deployment of the tag, we used a 6 m rigid-hull inflatable vessel and a 5 m carbon fiber pole. During deployment, we aimed to attach the tag near the dorsal fin to improve exposure of the tag during the whale's surface intervals. Whales were approached slowly (< 6 knots) for the deployment and dive times, behavior and swimming speed were observed visually and recorded before and after deployment. Whales were followed at a distance of several hundred meters after deployment for as long as possible (until unable to resight or too far from port). GPS data were linked to the same timeframe the whale was followed to estimate percentage of surface intervals achieved for location fixes.

3. Results

Two successful deployments were undertaken, one in September and another in October 2020 on the Gold Coast, Queensland, Australia (Figure 1). The first deployment took place 14 km offshore (49 m depth) on an adult and possible male humpback whale accompanied by another three adults individuals of the same species traveling southeast. The individual had superficial scarring likely from competitive behavior [45,46]. Prior to being approached, the group was observed displaying social behavior and surface activity in the form of tail slapping and peduncle throws. The surface activity eased once one of the whales parted from the pod, not being followed by the others. The average observed dive time of this individual was four minutes (out of eight visually recorded dives) and three blows per surface interval were observed. It was then chosen to be tagged, which was done close to and ahead of the dorsal fin, on top of the whale (Figure 2A). The sea conditions were calm with light easterly winds (10 km/hr) allowing us to approach the whale safely. The tag deployment lasted for 242 min, and 43 locations were recorded during that time (Figure 1). Based on observed average dive times prior and during deployment, it was estimated that the humpback whale had up to 60 surface intervals of which an estimated 27 surface intervals provided a location (45%). The individual covered 24.7 km with the tag attached (average swimming speed 6.2 km/hr) and continued traveling south and southwest, moving closer to shore. The CTD tag recorded 19.5 °C at maximum depth of 37 m and 20.8 °C at the surface. The tag was retrieved using the VHF tag signal the following day.

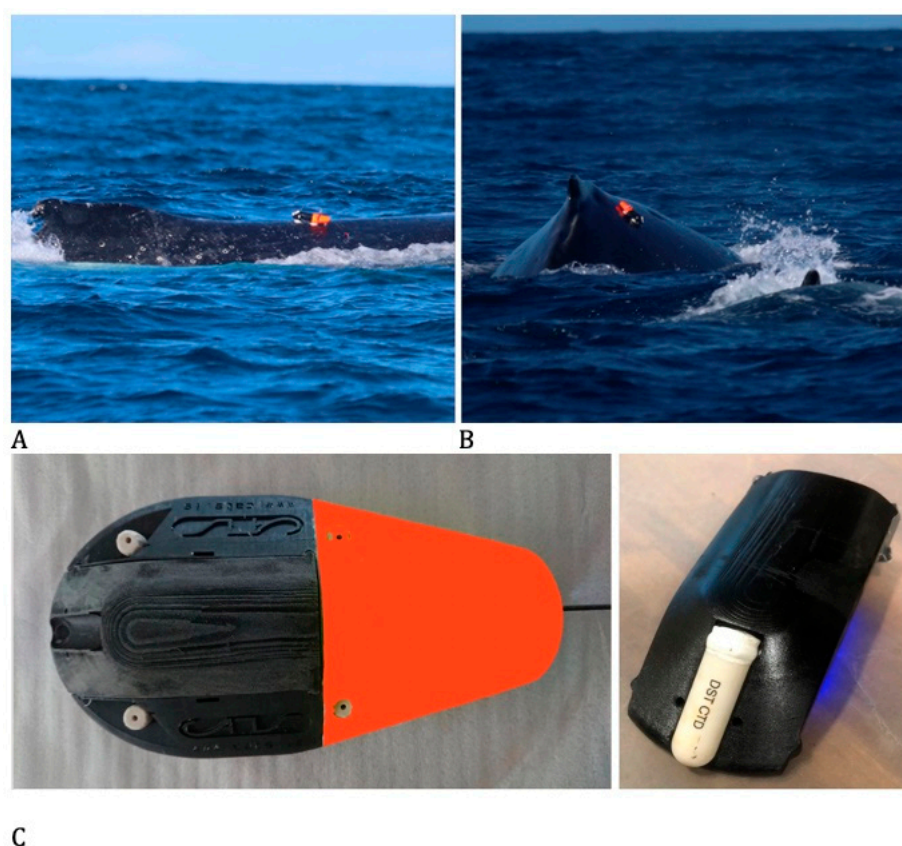


Figure 2. Suction cup tags deployment position. Near the top of the whale (A, Tag 1) and slightly lower on the whale closer to the animal's midline with the module facing more sideways (B, Tag 2). Suction cup system with embedded GPS/GSM module and CTD unit (C).

The second deployment took place 3.3 km offshore and was deployed on a female humpback whale accompanied by a calf, likely three months of age. A suspected escort was later identified as a likely male displaying mating behavior. After deployment the tagged female whale was moving further inshore and then turned offshore in an easterly direction. A number of breaches by the calf and vocalizing and peduncle slaps by the female were noted. The male was closely following behind. The average dive time was recorded at 5 min, but it largely varied between 2 min and 12 min, and the number of blows changed from two up to three to four per surface interval in deeper waters. The tag recorded 8 locations during 5 surface intervals out of a total of 52 surface intervals (10 % of the surface intervals) (Figure 1). The CTD unit showed no further dives after 319 min, coinciding with the release of the tag. The average travel speed based on the GPS location was 5 km/h and the whale likely traveled 22 km during tag deployment. A detailed dive profile was recorded by the CTD unit showing that the female humpback whale was performing benthic dives while moving offshore. The deepest dive was to 60 m and the temperature ranged from 18.5 °C at depth to 22.1 °C at the surface. The length of surface intervals ranged from a few seconds to a maximum of two minutes with locations only acquired when surface intervals were longer than 30 s (Figure 3). In addition, the CTD unit provided detailed information on temperature and salinity gradients along the whale's dive profile. A thermocline was recorded at 25 m depth, coinciding with a decrease in salinity from 33.4 to 32.7 following a dive to 60 m depth (Figure 4).

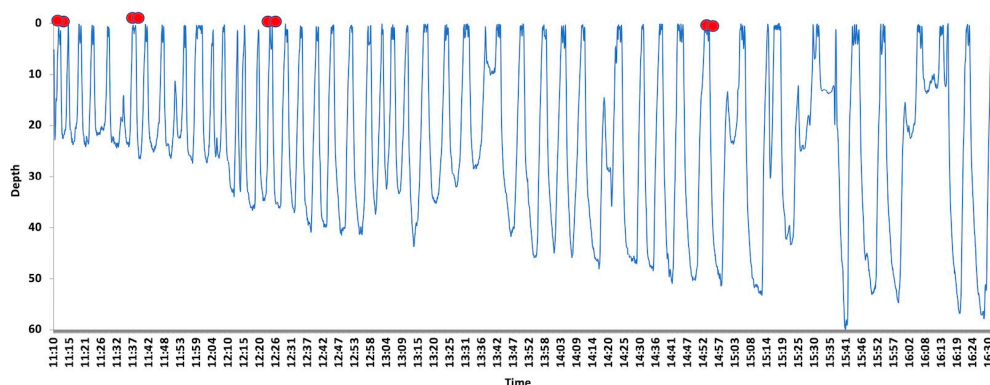


Figure 3. Dive profile from the second deployment (Tag 2) recorded by the micro-CTD attached to the GPS/GSM module. Red dots indicate time of GPS location acquired by the module.

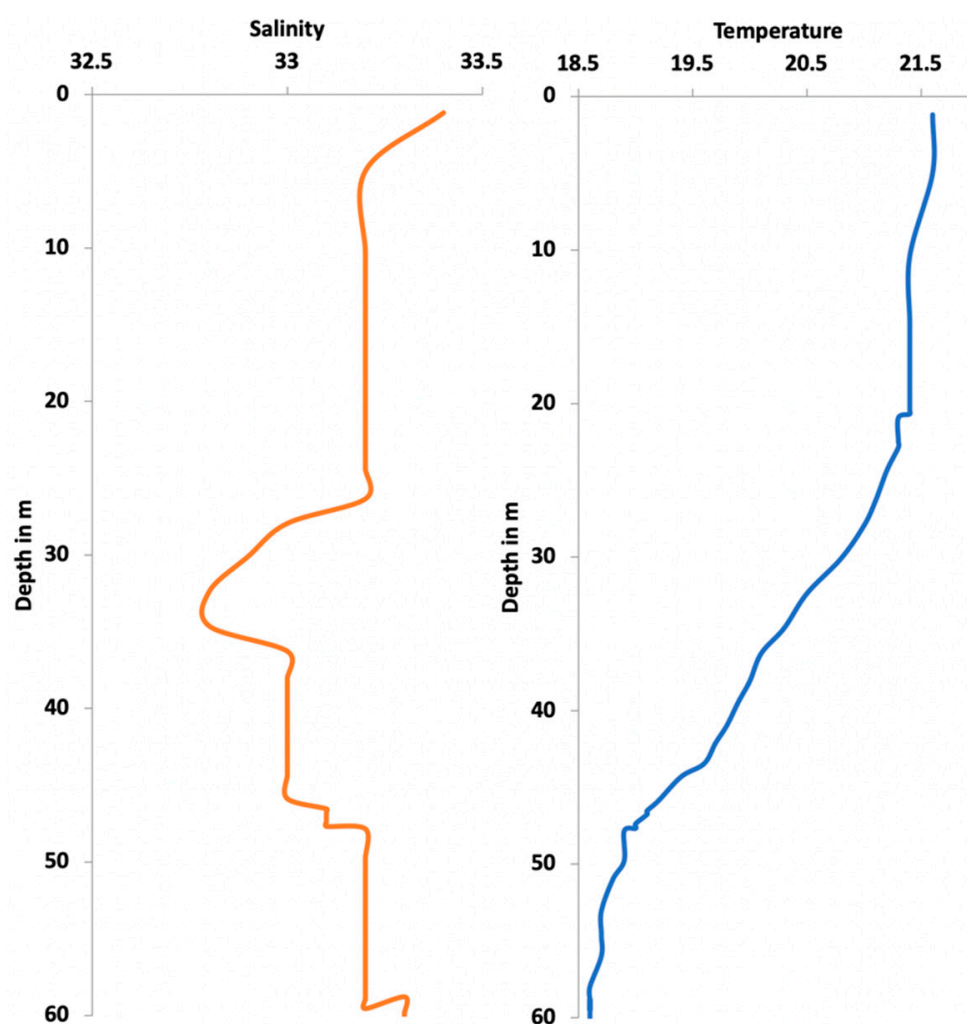


Figure 4. Sample of a depth and temperature profile derived from a CTD unit attached to the suction cup tag. The profile shows the thermocline at 25 m depth followed by a decrease in salinity.

4. Discussion

The suction cup tag with an integrated GPS/GSM module successfully acquired multiple locations during two deployments and, in combination with a CTD unit, provided information on dive times and surface intervals. The trial confirmed the feasibility of this technology for tracking whales and inferring animal behavior but requires further testing and improvements. It is desirable to collect a location fix for every surface interval

to allow for the highest spatial resolution. The concept of using the GSM network is to transmit GPS locations with high frequency during deployment (for possible live tracking) or after release to aid with recovery. If a recovery is not possible, at least the locations are transmitted and can be assessed by the researchers. When used in coastal regions in combination with a VHF tag, a recovery is likely, making it also a good platform for archival devices like a CTD unit.

The first deployment on a humpback whale was able to acquire and store a location in almost half of all surface intervals despite the higher swim speed (6.2 km/hr) of the whale compared to the second deployment. This exceeded our expectation, and more location fixes may be achievable by altering the position of the tag or for animals with more time spent at the surface. The location accuracy of the data was determined by the tag between 20–40 m. The tag was placed well on top of the animal's body (Figure 3). This allowed for longer exposure times of the tag and better acquisition of GPS. The position of telemetry tags is known to influence location results [47]. The first whale was moving with constant swim speed and constant dive times in a steady southeasterly direction. There was no live transmission of location even when the whale moved closer to shore (14 km at start and 3 km towards the end of deployment) where GSM coverage would have been sufficient. The second deployment on the female humpback whale was on an animal with changing dive times and changing swim speed, and the tag was deployed lower on the animal's body (Figure 3B). The tagging took place close to shore on a mother–calf pair with lower swim speed (4.9 km/hr), longer dive times and varying dive times (2–12 min). Only eight positions were recorded during the deployment. This suggests that the position of the tag on the whale and diving behavior were important to determine success in acquiring a position from the GPS/GSM module. The importance of tag positioning was reported in previous tagging studies [48] and is an important consideration for future deployments.

During the second deployment, the mother–calf pair was closely followed and at times charged by a suspected male. The offshore swimming direction and the dive profile to the maximum available depth suggested that the female humpback whale was avoiding the suspected male humpback whale. Males are known to seek and, in some cases, harass mother–calf pairs for possible mating [49]. The behavior was not typically expected for a mother–calf pair, which are known to have short dive times and long surface intervals [21]. The last recorded location from the deployed tag was 90 min prior to its release. Based on the dive profile, the whale remained in deeper waters (> 60 m) further offshore and did not return inshore. A number of times, the female humpback whale stayed between 10–20 m water depth without taking a breath. It is likely that the calf was at the surface during these times as supported by initial visual observations that showed shorter dive times for the calf compared to the two adult whales. A benefit of using the CTD at high recording intervals is a fine resolution of salinity and temperature profiles, and it allows us to use the animal's dives as a CTD cast [50]. However, battery usage of archival loggers such as the CTD increase exponentially with sampling frequency (https://www.star-oddi.com/media/1/battery_life_ctd.pdf, access date: 15 May 2021). A lower sampling rate of 10 s will likely be sufficient to assess a humpback whale's dive behavior.

The two deployments of the tag reported here also demonstrated some limitations of the equipment being tested. The surface intervals of the whales were not long enough to allow for data upload during deployment. Location data was only uploaded at time of retrieval at sea. The design of the unit did not allow for transmissions when afloat. In the next phase, the unit will be modified so it can also transmit when afloat (positioning of antennas in the float/balancing of the float). Retrieval in coastal waters is also possible using the VHF tag as a backup option but prolonged offshore movements would make retrieval unlikely.

Further and longer-lasting deployments will provide better insights into the variation of location data and are possible with the current set up. The GPS/GSM tag was tested prior to deployments to last 5–6 days with the current set of batteries, and suction cup tags can remain on humpback whales for several days depending on the water temperature

and position of tag [37]. Prolonged deployments in the range of days would provide enough location data to study resting behavior of mother–calf pairs or movement patterns in relation to remotely-sensed environmental covariates such as chlorophyll-a concentration or SST [27]. However, it does increase the risk of tag loss in the event of the animal moving too far offshore for retrieval. Live transmission of locations might be possible when an animal rests at the surface for an extended period of time. This will need to be confirmed with additional deployments. If deployments of suction cup tags can be extended to last for weeks, they can also replace some of the invasive tagging techniques [51].

Overall, the GPS/GSM suction cup tag represents a promising tool for the relatively inexpensive (Supplementary Material Table S2) and accurate tracking of humpback whales and other marine mammals in nearshore environments, especially in the light of the rapidly expanding GSM network around the globe. The tags may become very useful for studying behavior in that context of interactions with anthropogenic developments, ship traffic and whale watching. The tags are robust, lightweight, provide the possibility of remote access to locations, speed and heading data at least after release and in combination with archival data loggers can reconstruct underwater behavior. Such information will be important to fill the gap of fine scale coastal habitat use of humpback whales and other marine mammals in different parts of the world.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/jmse9060597/s1>, Table S1: Tagging details for two humpback whales, Table S2: Itemized budget for GPS/GSM suction cup tag.

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