

Performance Review of the Current GPS-Argos Technology and Deployment Protocol in Use for Tracking Cetaceans in Southern Iceland



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Introduction

Telemetry, otherwise known as remote tracking, is an incredibly powerful tool in the ecological study of species that are difficult to observe directly, such as cetaceans (the collective term for whales and dolphins). This technique involves using on-animal data-logging devices to store and transmit recorded data, such as positional information, from the study animal to a researcher, often through satellite networks (Cooke et al., 2004). Without telemetry, spatial data on cetaceans would be restricted to field observations of surfacing behaviour, placing significant constraints on the detail and duration of data collected as well as making it difficult to observe behaviours free of influence from human presence (Cooke et al., 2004). Attaining this type of data is, however, crucial to researchers and authorities who are monitoring wild populations to make informed decisions about area usage and conservation measures (Liu et al., 2021).

Cetaceans are of particular interest in conservation research as they are often the top predators in their respective ecosystems and, as such, their abundance has a cascading effect on the trophic levels below them in a pattern known as top-down control (Block et al., 2011; Samarra and Estaban, 2022). They also typically have large ranges and so a large area of influence as well as being known to exert complex social behaviours both intra and interspecifically (Bisther and Vongraven, 1995; Selbmann et al., 2022).

In the Westman Islands of Iceland, this type of conservation-based research has been taking place since 2008 (Icelandic Orca project, 2023). Situated just south of mainland Iceland, the Westman Islands are part of an archipelago whose bathymetry and global location cause its surrounding waters to be highly productive (Vikingsson et al., 2015) (*figure 1*). As such, the area supports a variety of cetaceans with sightings confirmed for killer, humpback, Fin, minke, sperm and pilot whales as well as white-beaked dolphins and harbour porpoises in 2023 alone (Martinez Catalan et al., 2023). These cetaceans all interact, both with each other and with the man-made influences of Vestmannaeyjar Harbour, to showcase a variety of interesting behavioural patterns (Clerck et al., 2019; Selbmann et al., 2022).

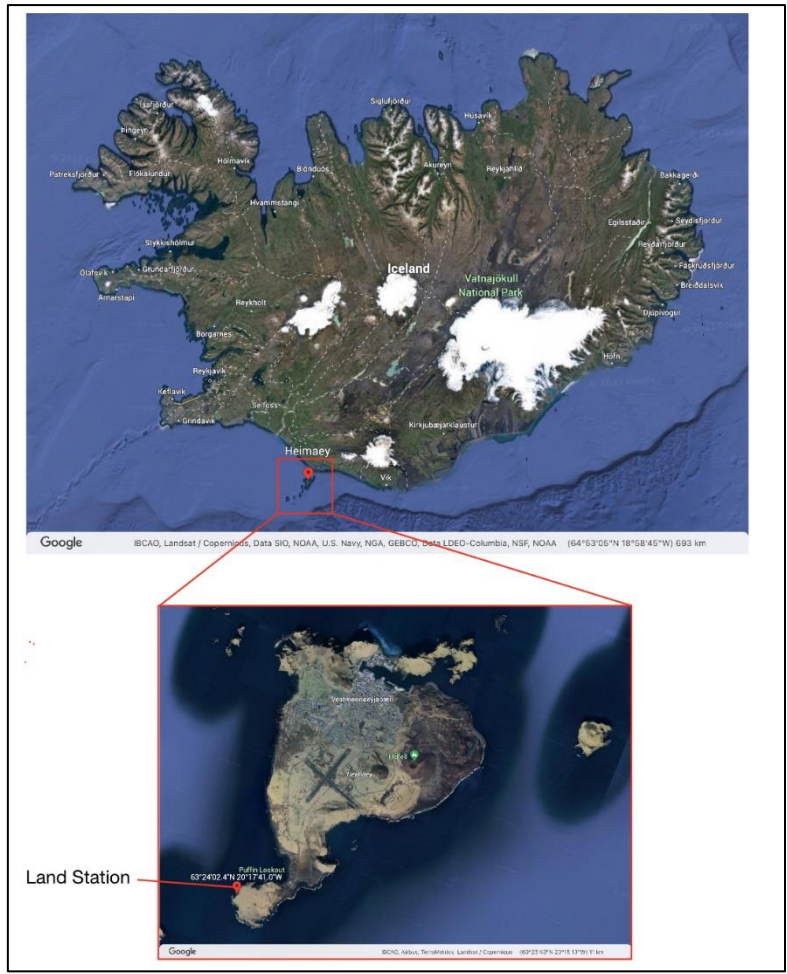


Figure1: Map of The Westman Islands Study Area

Location of the study area in relation to mainland Iceland. A key data collection point for this study, The Land-Station, is highlighted as being on the south tip of the largest island in the archipelago; Heimaey. (Google Earth, 2023)

Instrumental in the study of these behaviours and of other ecological topics in The Westman Islands has been a telemetry technology known as a GPS-Argos logger. Like other telemetry technologies, this logger can be attached to the focal animal and used to track both biological movements and to recover the device with its stored data, should it detach. As the name would suggest, the GPS-Argos logger has two antennas which communicate with the GPS (ground positioning system) and Argos satellite systems respectively. Both antennas must be clear of the water in order to connect to their respective networks and so the logger can only record and send positions when a tagged cetacean surfaces for air (Argos-system, 2023). The logger is therefore programmed with a repetitive behaviour pattern where a GPS fix is attempted at set intervals and stored if successful i.e. if the GPS antenna is above the water as detected by a salt-water switch. The logger simultaneously attempts to send any successful GPS fixes to the Argos network at separate intervals using the Argos antenna (often these intervals are shorter)(figure 2). Any differences in timing are at the discretion of the researcher but usually reflect how strong the satellite coverage is in each network.

Occasionally, if the logger interacts with the GPS network less frequently than the Argos network, the same GPS fix can be sent through Argos twice, even though the cetacean has changed location; these occurrences are termed duplicates. Once information is transmitted to Argos satellites, it can be sent to dedicated ground stations which decode and publish the data so that it can be accessed on the internet by a researcher (Argos-system, 2023).

If used to obtain positional information for a study, the extent and resolution of data gathered is a direct result of how well a researcher can maximise a GPS-Argos logger's performance. This can include customising the frequency of satellite communications to suit the surfacing behaviour of the focal cetacean, minimising technological errors and matching deployments to times when there is high satellite coverage (*figure 3*)(Argos-system, 2023; Mul, Blanchet, Biuw and Rikardsen., 2019). Despite factors such as these being known to affect performance, there has never been a detailed study completed on this subject for the GPS-Argos loggers used in The Westman Islands. This paper, therefore, endeavours to fill this knowledge gap by exploring various factors hypothesised to be performance-affecting for this technology. It is hoped that the conclusions found can be used to inform management of the tag or tagging protocol in ways which are highly specific to the work and cetaceans of The Westman Islands to ease future work there.

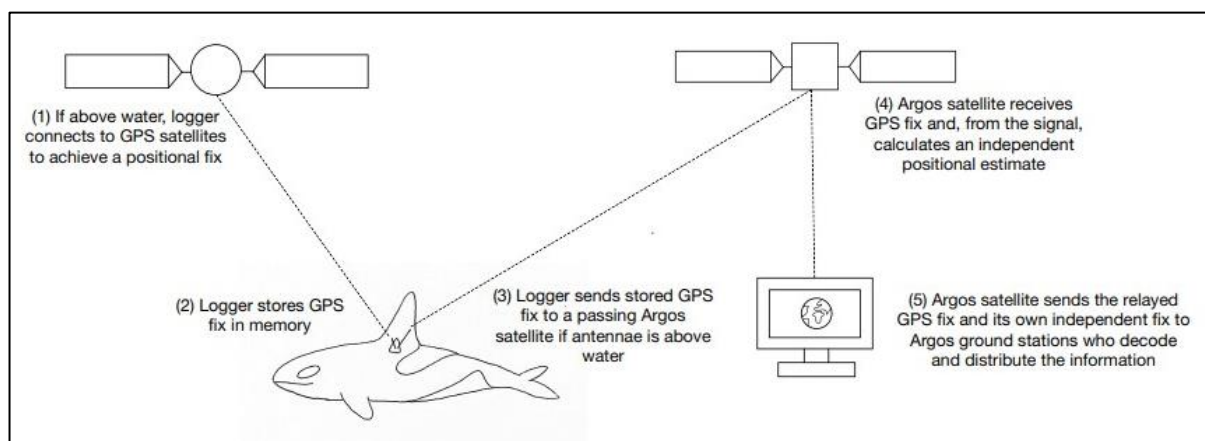


Figure 2: Summary Diagram Detailing the Process of Attaining a GPS-Argos Fix

Diagrammatic representation of how a GPS-Argos fix is achieved by a GPS-Argos logger deployed on a cetacean. The logger must both receive a GPS fix from GPS satellites and relay this through an Argos satellite before the successful position can be sent to Argos ground stations, ready for distribution on the web. Through receiving these GPS messages from the GPS-Argos logger, the Argos satellite can simultaneously calculate its own independent positional fix which it supplies to the ground stations alongside the relayed GPS fix as supplementary information and a fail-safe (Argos-System, 2023; Diagram inspired by Schwartz and Arthur, 1999)

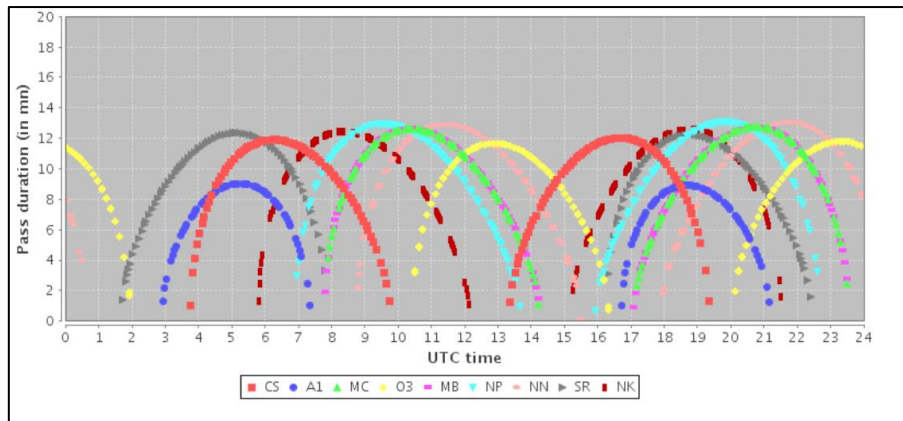


Figure 3: Predicted Coverage of The Westman Islands by Argos Satellites for a Period of 20 Days Beginning June 23rd, 2023.

The graph is set so that the x-axis represents one day in hours and the different colours represent the individual satellites that make up the Argos network in their orbits. During the represented day-range of 23rd June – 12th July, this fly-over pattern should remain constant. That is, the highest density of satellites on any given day should be over head at ~19:00 and the lowest at ~02:00 making these times the best and worst choices for spatial data collection respectively (Argos-System, 2023).

Materials

Detailed Composition of the Physical Tag:

For this paper, four tags were used which all varied slightly in composition. The main difference was that two of the tags did not carry video loggers (integrated Dtags) while the two others did (mixed Dtags+), however, all four tags carried identical GPS-Argos loggers so any variation in other elements was not a major confounding variable in this study. The detail description of the tag below is, therefore, included for extended clarity only.

The tag itself is composed of multiple instruments housed in one casing so that composition and layout are easy to alter. The included instruments are: a video logger by Little Leonardo (mixed Dtag+ only), a GPS logger which was able to uplink to the Argos satellite network and a digital acoustic recording tag (Dtag) that records pressure, acceleration, orientation and acoustic data as well as having a VHF component for radio tracking (*figure 4*) (Johnson and Tyack, 2003). The tag attaches to a cetacean using four silicon suction cups which are programmed to release at a desired time by means of their seal being broken. Once this occurs, the tag is free of the animal and can float to the surface to be retrieved using a mixture of the GPS locations it has sent through the Argos network and the VHF signal it constantly provides. This VHF signal gives a more accurate location at short range than can be attained by GPS. Once retrieved, the tag has its data downloaded onto a computer and then wiped from its memory so that it may be redeployed on a new animal.

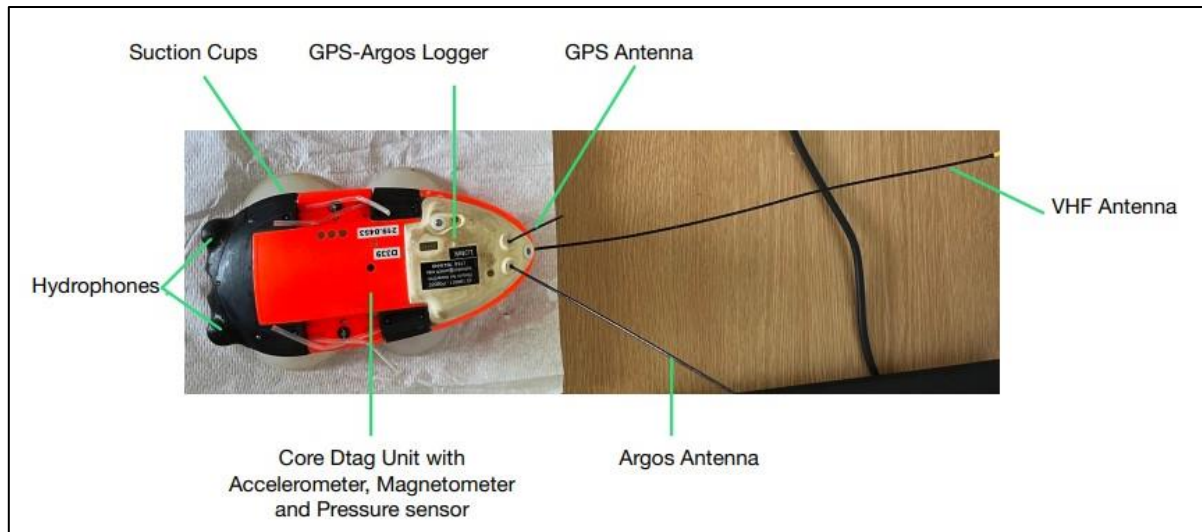


Figure 4: Labelled Diagram of an Integrated Dtag

Image of an integrated Dtag which has been annotated to show where each individual element sits within the casing.

Methods:

This study was conducted in the waters of Vestmannaeyjar, an archipelago south of mainland Iceland (*figure 1*). Tags carrying the GPS-Argos logger were deployed when weather would permit during the summer of 2023 from 25th of June to the 19th of July. To apply these tags to an animal, a land-based observation team located on Heimaey would guide a rigid-hulled inflatable boat (RHIB) to any group of cetaceans they identified (although preference was afforded to killer whales to best support adjacent research). The RHIB was equipped with a small platform on the bow and from this, tags were applied to the cetacean using a seven metre carbon fibre pole when they surfaced within range (*figure 5*).

For each application, tags were focused so that they adhered at the base of the dorsal fin with antennas directed to the posterior of the cetacean and parallel to the water surface. This allowed the tags to be at the highest point of the animal, and so remain outwith the water for the longest duration, while being as streamlined as possible for minimal disturbance. However, tag placement could not be strictly controlled and so varied substantially across tag deployments.

Once applied, the tagged animal was photographed so that it could be identified and the antenna angles achieved could be measured. At this time a hand-held antenna was also used to listen to the VHF frequency of the tag and estimate how many VHF ‘beeps’ were heard on average per surfacing. If conditions made this impossible, beeps per surfacing (bps) was estimated from the average bps rate multiplied by the average length of surfacing event as measured by the acoustic data on the recovered tag. Tags were programmed to stay on the animal for as close to 24 hours as possible with regard to the weather. They would then detach and float until collection by a 12m engine-powered vessel. During collection, a record of sea-state was also kept.

After recovery, the GPS data stored on the GPS-Argos loggers was downloaded using the FastGPS programme by Lotek (Lotek., 2023). The associated data was also downloaded from ArgosWeb at least 24 hours after the tag was recovered to allow for any messages to be decoded in full by the Argos ground stations. Both of these data files were filtered through FastGPS software where any duplicates were removed and all errors were shown. The filtered data files were then copy-pasted from the processing window and into excel for analysis. During analysis, tags which were on-animal for less than 1 hour before becoming dislodged were disregarded due to low likelihood of satellite communication to the Argos network (Mul, Blanchet, Biuw and Rikardsen., 2019).

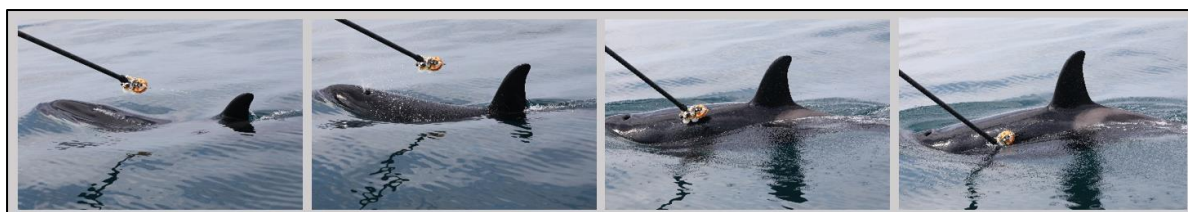


Figure 5: Application of a Mixed Dtag to a Female/Juvenile Killer Whale

Photo series illustrating how a tag is placed onto a cetacean using a pole during a surfacing event. In this example the tag slipped on application and so, although successful, placement is lower on the body than optimal. This event helps highlight the difficulty of achieving the tag placement intended (Photography by Tatiana Marchon, 2023).

Results and Discussion

Quantifying Performance

Deployments of acceptable quality were achieved on ten cetaceans in total, including one long-finned pilot whale (*Globicephala melas*), two humpback whales (*Megaptera novaeangliae*) and seven killer whales (*Orcinus Orca*).

During these deployments, performance of the GPS and Argos elements of the logger were quantified separately by the rate of positional fixes that each attained and stored. It was found that, on average, 1.04 Argos positions and 1.45 GPS positions were achieved per hour across all loggers making these elements very similar in terms of how many positional fixes could be downloaded from the logger upon its recovery. To add to this, performance was then also quantified for the logger as a whole by taking the rate of GPS positions that were successfully relayed through the Argos network. This yielded a value of 0.21 GPS-Argos fixes per hour.

Unfortunately, most studies to date omit the GPS-Argos performance detail from their publications and so these statistics are challenging to qualify (Mul et al., 2019). However, observing them here for the first time is a crucial step in being able to make performance comparisons and investigations in the future. It is especially insightful to be aware that only 16% of successful GPS fixes are accessible through Argos as this means that researchers have limited access to positional data during the remote portion of any experiments. This is a topic we went on to investigate during this research effort with a view to improvement.

Investigations

Tag Placement:

This study considered placement of the tag on the body of a cetacean as a factor potentially affecting performance. To achieve this, number of VHF 'beeps' per surfacing was used as a proxy for time above water; a factor usually correlated with body placement. The more beeps heard, the longer the tag was out of the water and the higher the tag was likely placed on the body, although it should be recognised that this statement assumes that surfacing behaviour and technological performance were constant across the deployments.

From our results, it was clear that number of VHF bps were positively correlated with performance and so we can conclude that tags placed higher on the body performed better than those which were lower down (*figure 6*). This trend would likely have been even stronger than shown if it had not been for the two outlying points at which Rate of GPS-Argos positions was ~0 per hour but VHF beeps were high (and so position was likely good). In these deployments, the GPS-Argos logger had technological issues connecting to either one or the other satellite networks and so almost no positional fixes were relayed despite a favourable placement.

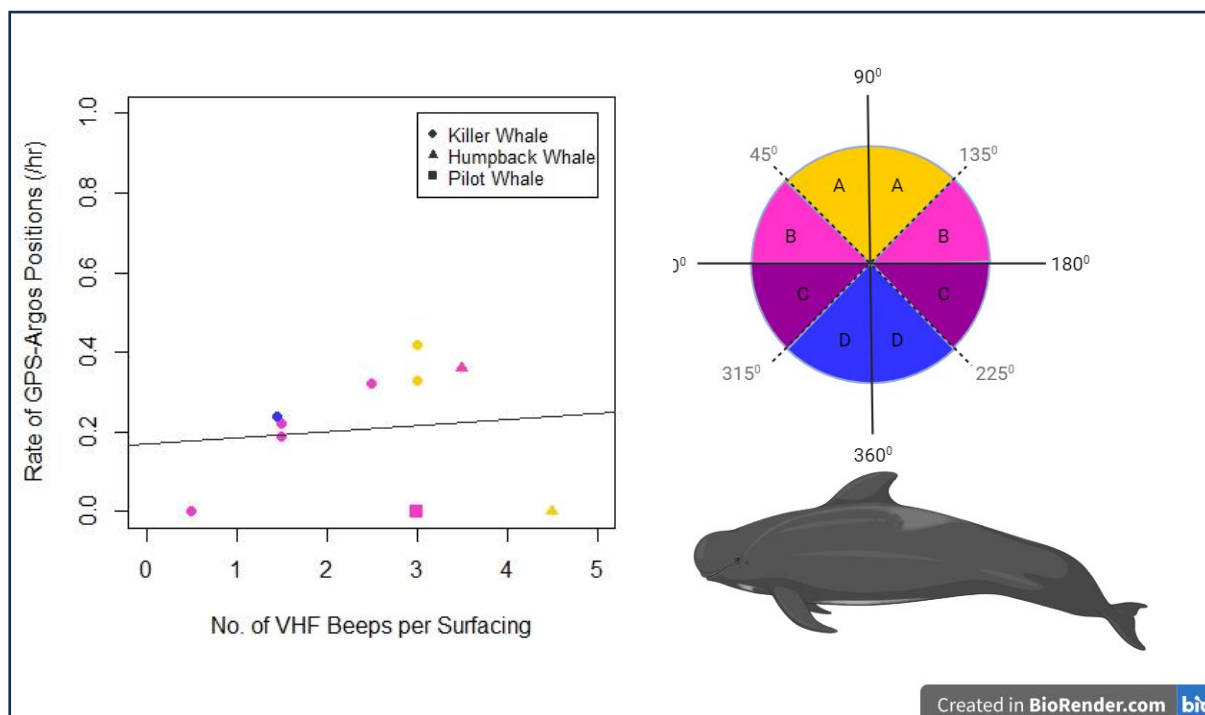


Figure 6: Positive Correlation Between Time out of Water and Rate of GPS-Argos Positions

Graph detailing how rate of GPS-Argos positions improve with the number of VHF beeps per surfacing as a proxy for time out of water. Colours used represent the angle of the tag antennas with yellow representing angles A (45° - 135°), pink representing angles B (0° - 45° and 180° - 135°), purple representing angles C (0° - 45° and 180° - 225°) and blue representing angles D (315° - 225°). Cetacean species is also indicated by circles, triangles and squares to represent killer, humpback and pilot whales respectively. The graph has two outliers, one humpback and one pilot whale which skew the overall trend. For these data points, number of VHF beeps per surfacing is >3 so position can be assumed to be satisfactory, however rate of GPS-Argos positions is ~ 0 (figure created with Biorender.com).

This evidence that tag placement impacts GPS-Argos performance is in line with studies carried out on similar technologies and could prove informative for future investigations in Vestmannaeyjar (Mul et al., 2019). For example, although the weight and size of the current tags used in Vestmannaeyjar mean they are already placed as high as possible on the body (ideally), the knowledge that placement is a key factor in performance could warrant an investigation into whether lateral movements also have effect. To elaborate, despite the base of the dorsal fin being the highest point on the body, it is possible that moving the tag laterally along the cetacean's back so that it is no longer 'shaded' by the dorsal fin could improve the logger's sky view factor and therefore its connection to satellites of either network despite it being above-water for a shorter time.

Angle of Antennae:

A second investigation included in this research effort quantified whether antennae angle, as a separate factor from placement, impacted performance. The results of this can be seen illustrated as part of *figure six* and suggest there is a correlation between an increasingly 'upright' antennae angle and improved performance. This means that tags with antennae angle A, which was almost perpendicular to the water surface, allowed the strongest performance compared to all other angles.

Despite this indication however, more replicates would need to be carried out concerning this data before a robust conclusion between antennae angle and performance could be made. This requirement is due to the high variation in technological error and lateral tag placement on the cetacean which has given the current data a high variance. This is demonstrated by the one tag represented on *figure six* which had an antennae angle D and so was expected to perform poorly yet performed as well as tags with antennae angle B and similar time out of water. Therefore, the relationship between antennae angle and GPS-Argos performance cannot be confirmed until more data is collected to account for this high variation.

Sea-State:

Finally, this study also considered sea-state as a factor with potential impact on GPS-Argos performance. It was hypothesised that increased swell and spray would trigger the logger's saltwater switch more often than if conditions were calm and, therefore, the logger would fail to identify itself as above-water and so connect to satellites for a reduced overall time. This hypothesis was investigated by measuring the rate of GPS-Argos positional fixes that loggers provided while free-floating in various sea-states, post-deployment. This free-floating stage was chosen to eliminate any influence from antennae angle or tag placement from the analysis.

From this investigation, the data showed that increased sea-state was negatively correlated with performance (*figure 7*). However, this trend was observed to be weaker than predicted as well as being heavily influenced by one outlying data point. This unexpected result may be explained partly by the equally unexpected result achieved when performance was measured against time out of water (*figure 8*). It appears that, even when sea-state was disregarded, performance did not increase with time out of water as was the observed trend with the on-animal data used earlier in this study. This irregularity is suggestive of an uncontrolled confounding variable which is impacting our data and will require further investigation in future. Therefore, before rejecting our hypothesis, we will reconsider our experimental design regarding this measure and collect another data set to analyse.

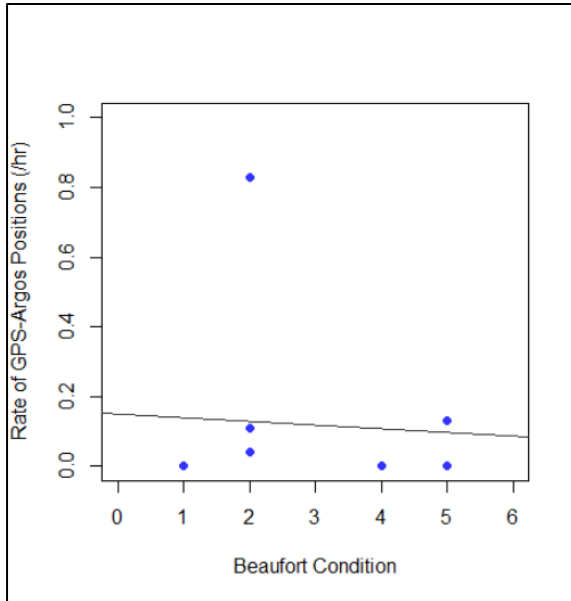


Figure 7: Performance of GPS-Argos Logger Decreases with Increasing Sea-State

Scatterplot showing a weak correlation between sea-state and rate of GPS-Argos positional fixes. This trend is largely influenced by one outlying data point at a GPS-Argos value of 0.8 hr⁻¹ and so is potentially inaccurate.

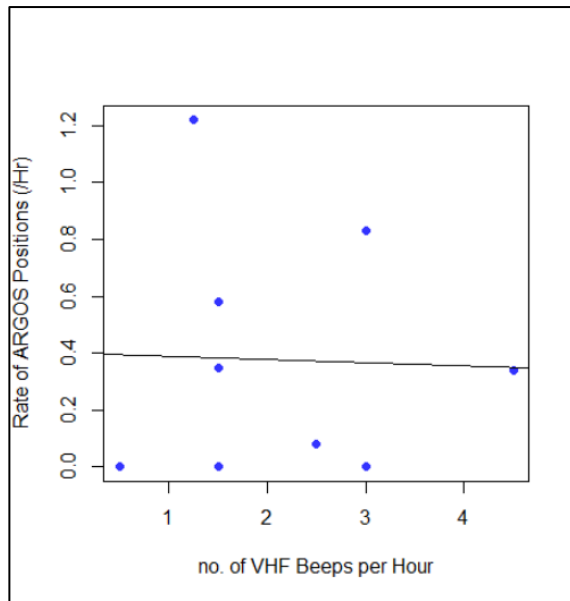


Figure 8: Relationship between Rate of GPS-Argos positions and Number of VHF ‘Beeps’ per Hour

Scatterplot showing the high levels of variation in data for this analysis. Little to no trend can be seen between the two variables. This is unexpected due to the clear trend observed when data is taken from on-animal measurements.

Conclusions

To summarise, through this investigation, we have provided the first numerical performance review of the GPS-Argos loggers currently in use for tracking cetaceans in Vestmannaeyjar. Not only does this provide a reference point for future experimental work carried out here, but has also allowed us to test some initial hypotheses as to what factors may be most influential on GPS-Argos performance. Of these factors, it can be concluded that time out of water, as linked to height of placement on the body, is one of the most prominent in affecting performance. There is also evidence that antennae angle and sea-state impact performance too, however more replicates are required before any robust conclusions can be made regarding these.

In order to provide such replicates, a second pilot study is currently being carried out in Mozambique using the same four GPS-Argos loggers as used in this report. It is hoped that, when the data from this pilot study and Mozambique are combined, we will be able to draw reliable conclusions on the factors above. Not only will these conclusions inform the main study that these pilot studies are working to support, but they will also be key in increasing the efficiency of any future work involving these loggers in Vestmannaeyjar.

Acknowledgement

I would like to extend my gratitude to Professor Miller for supervising me on this adventure and for all his guidance and patience throughout. I would also like to recognise Ms Ellen Hayward for her intrinsic role in training me to work with this technology and who this project would have been impossible without.

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Images

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