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REVIEW

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A review of electronic devices for tracking small and medium migratory shorebirds

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Abstract

Small- to medium-sized shorebirds (< 200 g) can be particularly difficult to track with electronic devices due to their small size and long-distance migrations which place restrictions on device weight and size. A lack of comparative information on suitable tracking devices makes selecting the most appropriate technology time consuming and complex and can result in duplication of effort for each research project. The purpose of this paper is to address this issue by presenting a review of the scientific literature and commercially available devices to help inform device selection as well as options for attachment. The ideal device for tracking small to medium migratory shorebirds would be light weight (< 5% of a bird bodyweight), flat in profile, durable, have high battery longevity, remote data download, easy to attach from a bird welfare perspective, high spatiotemporal resolution and would be low in cost (so that a large enough sample size can be obtained). This ideal device does not yet exist due to the limitations on the weight of the power supply necessary to obtain frequent, high resolution location fixes over long time periods. As a result, the current choice of device depends on the purpose of the study. Platform Transmitter Terminal (PTT) doppler devices are suitable for tracking long distance movement due to their smaller size and lighter weight (around 2 g), but produce lower resolution location data and are expensive. For tracking smaller-scale movements (i.e., tens of kilometres), Global Positioning System (GPS) devices are more suitable, because they produce higher-resolution location data and are often more cost effective but tend to be heavier. Other device options for obtaining movement data include radio telemetry and light-level geolocators, which are generally lighter and cheaper than GPS or Doppler devices but require more effort to retrieve data and often produce lower resolution location data. Attachment methods and materials vary, but the most suitable is usually leg loop harnesses made with soft materials that are likely to degrade (e.g., elastic). Device type and harness design need to be carefully chosen to minimize potential impacts on the animal.

Keywords Movement, Migration, Transmitters, Conservation, Animal welfare

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Background

Wildlife tracking enables a greater understanding of how individual animals move around the landscape and how species migrate around the world [1, 2]. The collection of this information is important for better management of populations and conservation of habitat [3]. More specifically, this includes use of habitat, impacts of land use, effects of climate change, estimations of population size, transmission of disease, wildlife trafficking and other applications [1, 4–6]. Methods used to track wildlife include banding (ringing), flagging, tagging, marking, branding, electronic tracking devices and biologging [2, 7, 8]. Biologging is a broad term that encompasses numerous devices to track animal behaviour such as cameras, accelerometers, or salinity loggers [7, 9].

Historically, animal movement studies have relied on capturing individuals at one location, and then re-capturing or re-sighting those individuals at another location [10]. Large-scale banding studies have provided important insights into the timing of migration, as well as effects of weather and other large-scale processes on the behaviour of migrants [10]. They also provide valuable historical data [11]. Colour banding (including engraved leg flagging) can overcome some of the issues associated with the use of small metal bands and the need to recover birds, because they have visible numbers of colour combinations observable with binoculars or telescopes [12]. However, these methods are unable to precisely track the routes taken during movements or stopover sites used, particularly in remote areas [9], and re-sightings can be challenging for cryptic species. Many species migrate at night and at high altitudes [10] further limiting observation opportunities. To obtain data, many birds need to be marked and there needs to be numerous observers in many locations. In general, recovery rates of banded birds are low [13]. This results in significant gaps in our understanding critical for decision-making about management and conservation [10].

To overcome some of these challenges, electronic tracking devices that store and transmit data can be used to provide information on location. These have rapidly diversified and advanced in capability in recent years. Technology commonly used includes Global Positioning Systems (GPS), Platform Transmitting Terminals (PTT), radiotelemetry, and geolocators [2, 7, 8]. This technology is helping to fill gaps in information associated with traditional methods [14]. Recent improvements include development of smaller and lighter devices, better accessibility to satellite systems and higher resolution GPS data [15, 16].

There can be considerable financial and reputational costs to researchers and adverse impacts on animal welfare if the wrong tracking technology is deployed [3]. Therefore, selection of the most appropriate device is paramount. Making the right decision about which device to choose can be difficult, because information is scattered and often relevant only to individual studies. There is a lack of comparative information on devices, which makes selecting the most appropriate device time consuming and complex and needs to be duplicated for each research project.

Considerations for choosing a device include the purpose of the study (e.g., study of local movements versus global-scale migration patterns) [15], the research questions being answered or hypothesis being tested, animal welfare (size, weight, attachment), animal behaviour, likelihood of retrieving data, cost, ease of use, data download frequency, accuracy and timely technical support [1, 2, 5, 6, 13, 17]. The ideal device needs to be light enough to be safely carried by the animal, cheap enough to deploy enough devices to obtain rigorous data, and reliable enough to transmit high resolution data remotely to (preferably) avoid the need for recapture. Tracking small to medium migratory shorebirds provides additional challenges, due to their small size and bodyweight and long distances travelled [10, 16]. Small to medium shorebirds for the purposes of this paper are defined as those which are under 200 g in weight. For birds, the maximum allowable weight of a device is 5% of a bird's body weight as stated in the Manual for Wildlife Radio Tracking [18]. However, a figure of 3% is generally accepted as preferable for migratory birds to take into account weight loss during migration [19, 20]. In general, only 19% of bird species are large enough to be tracked with 5 g tags or greater, without needing to recapture the animals [5].

The method of attaching devices is just as important as the type of device [21, 22]. Invasive attachment methods have been found to be associated with a high incidence of adverse effects, while tail and leg attachments showed relatively few effects in comparison [7]. The choice of attachment method depends on bird morphology and behaviour [21, 22]. Regardless of the device and attachment method chosen, minimisation of potential negative effects is of the utmost importance [7, 22].

Given the complexities and considerations involved with selecting appropriate devices to track small to medium migratory shorebirds, the purpose of this paper is to provide summary information to inform other researchers intending to undertake similar studies. The objectives are to (1) conduct a review of the peer-reviewed and grey literature to synthesize information on use of devices for tracking small to medium sized shorebirds, (2) to compile information about commercially available devices suitable for tracking small to medium migratory shorebirds, and (3) to compile information on harness attachment methods.

Methods

A literature review was conducted online using scientific search engines that included Google Scholar, Web of Science and Scopus using key words that included the following search terms: Migratory AND Shorebirds AND Tracking AND Devices. This combination was designed to limit the search to the tracking migratory shorebirds only. Scopus produced 199 documents and the title and abstract of these were reviewed for relevance which resulted in review of 63 relevant documents. Web of

Science produced only five results using these keywords and therefore a broader search was undertaken using the 'related' documents search. This resulted in an additional 50 documents of which 11 were found to be relevant, bringing the total to 16 from this search platform. The Google Scholar search produced over 18,000 results and as a result additional keywords were added, specifically '5 g' or '5 g'. This yielded over 6000 results, so the search was restricted to the date range 2010–2023 and sorted by relevance. A scan of titles and the first two sentences of each abstract identified that relevance dropped significantly after the first 90 articles. These were further reviewed and of these, 79 were found to be directly relevant. All references were managed using Endnote and duplications were deleted. A total of 163 papers from all searches were found to be relevant and were subsequently reviewed in detail. These were categorized into their main area of focus including radiotracking, geolocation, GPS and satellite tracking, effects of devices and harnesses (excluding geolocators which were categorised as geolocation), tracking guidelines, platforms, conservation management and species-specific studies where tracking technology was used.

For comparative information about specific devices (Platform Transmitter Terminal (PTT) satellite transmitters, GPS-devices and radio transmitters) a web search was conducted to create a list of the main worldwide suppliers in order to assess products, device specifications and customer reviews (where available) using these terms. Ten companies that supplied devices that weighed 5 g or less that were suitable for tracking migratory birds were included for direct follow up via their websites or by contacting sales representatives where information on pricing and device availability was not readily available. This search was conducted between August 2022 and April 2023 with pricing updated in November 2023.

Geolocators were not included as part of the product review because use of this technology for tracking migratory birds is well understood and reviews already exist [23].

Finally, informal discussions were also conducted with experts working in the field of bird movement tracking, and although these have not been directly referenced, some practical insights were obtained which helped to provide context around the literature and lived experience with various products.

To evaluate the suitability of devices for shorebirds under 200 g, a list of criteria was sourced from a review undertaken by Thomas, Holland and Minot [6] who developed a decision-making tool for the selection of the most appropriate technology for wildlife tracking. Although this research was based on elephants, albatross, falcons and crocodiles, the tool provided principles and considerations important when choosing appropriate tracking devices. These principles remain the same, despite technology advancements since 2011. This paper expands on Thomas, Holland and Minot [6] by focussing on migratory shorebirds under 200 g, which have their own specific challenges in that they are small, they travel long distances, they are often cryptic and frequent habitats with water and mud. These factors limit the choice of suitable devices available. A review table was subsequently developed to compare tracking devices suitable for migratory birds under 200 g. Criteria relate to animal welfare, expense and/or resources required for deployment, ease of use and accessibility of data.

Specifically:

- Purpose of research: short-range (local movement) or long-range (migration) movement studies.
- Size and weight of device.
- Accuracy.
- Price.
- Data capture and access (including ease of use).
- Other constraints – cryptic versus visible species, bird morphology e.g., feathers that may interfere with signal transmission.

Results

The literature search determined that there was no single paper that compared tracking devices suitable for use on small to medium shorebirds, but that there were 162 papers relevant to this topic. Figure 1 shows the number of papers reviewed per topic.

One paper, however, did provide a recent review on the application of GPS or PTT devices [20]. This looked at 116 primary papers relevant to birds under 500 g in weight, between 2006 and 2021. This research had a different focus to the current review, in that it was primarily summarising study findings (in relation to tag use), reviewing tag success, and looking at the level of hypothesis-driven research among other things. This paper was useful in that it provided relevant information to help understand the potential for technology application. Additional file 1 provides a full list of references reviewed by topic.

Tracking devices

Technologies suitable for tracking small to medium shorebirds include solar-powered or non-solar powered GPS devices which use different combinations of Bluetooth, wifi, UHF and/or VHF to transmit and receive data, and Doppler PTT devices with UHF transmission… Additional file 2, Table S1 provides a description and relative advantages and disadvantages of tracking

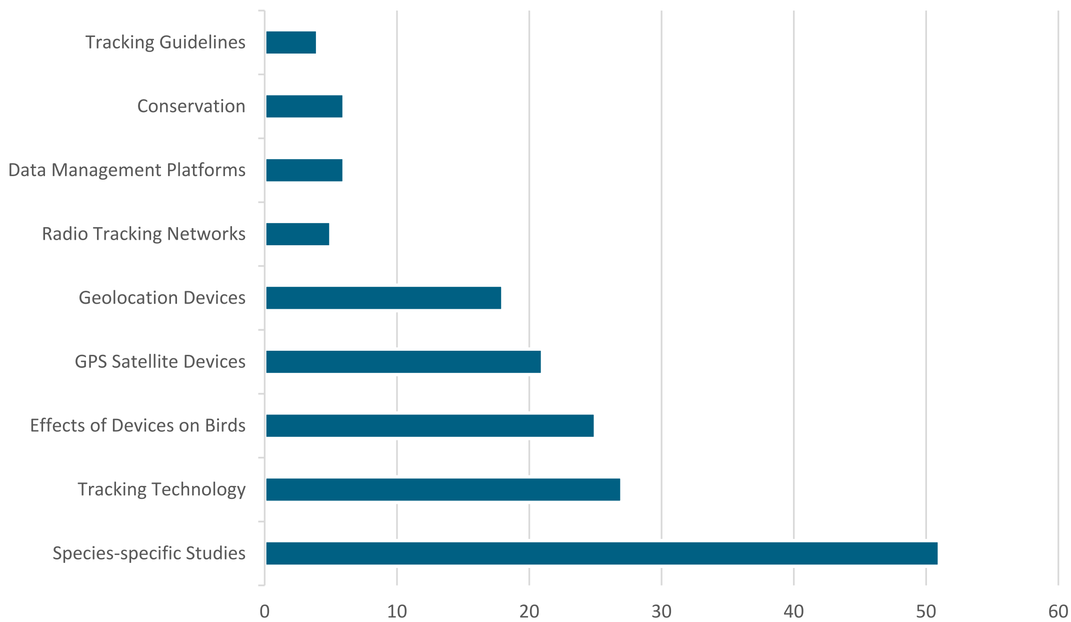

Fig. 1 Results of the literature search showing the number of publications for each tracking-related topic

technology focusing only on GPS, satellite, and automated telemetry approaches (Additional file 2).

Three satellite devices were found to be suitable for tracking long-range movement of birds under 200 g. Of these, two use Doppler signals and the other uses GPS to obtain location fixes. The Doppler devices are less accurate than GPS technology and can have an error between 150 m—> 1000 m [10]. In comparison, GPS devices are typically more accurate (5–100 m depending on the number of satellites available), but they are heavier because they need more power which reduces the battery life [5]. Battery life can be extended using solar panels, however, this increases the overall weight. The difference can be as low as 2 g for PTT's compared with more than 5 g for GPS devices. Doppler devices include the Microwave Telemetry Solar Argos PTT (2 g and 5 g options) and the Lotek Sunbird (2 g). Examples of research on small birds using the ARGOS technology include Red Knot (*Calidris canutus)* [24] and Black-tailed Godwit (*Limosa limosa)* [25]. Studies on the Upland Sandpiper (*Bartramia longicauda*) [26] used the Lotek devices. There is a large price difference between these two devices with the former upwards of A$6000 and the latter less than A$2000 (excluding data access costs). It is unclear why there is such a price difference, and this would need to be assessed if choosing between these devices. Additional file 3, Table S2 provides comparative information about different device types suitable for tracking small and medium migratory wader birds under 200g (Additional file 3).

The only GPS satellite devices within an acceptable weight range were the Global Messenger/HQXS HQBG0803 (3.3 g) or 0804 (4 g), but both of these have a limited battery life (depending on settings) and the inclusion of a solar panel increases weight. For example, when used in the field on Black-tailed Godwits (*Limsoa limosa)* [26]and Grey Plovers (*Pluvialis squatarola)* [27] the attachments increased the weight from 4 g (0804) to 5.5 g which would make them unsuitable for birds under 200 g.

GPS short-range download (SRD) receiver methods are a good option for studies where the birds remain at, or return to, a known and accessible location. The devices can store data for up to two years and data can be transmitted to receivers via Bluetooth, UHF or VHF. They are lightweight, accurate down to 5 m and relatively cheap (Additional file 1: Table S1). Examples include behavioural studies using Druid NANO's on Pacific Black Duck (*Anas superciliosa*) [28], and Latham's Snipe (*Gallinago hardwickii)* in the Australian Capital Territory (in 2023 and 2024), where high-resolution full migration tracks were obtained from two birds that had migrated to Japan and Russia and returned to their non-breeding grounds where the receiving tower (Edge Intelligence Gateway) had been erected (L. Gould unpubl. data).

Automated radiotelemetry such as the Motus Wildlife Tracking System (Motus) and ATLAS networks are successfully being used in many locations around the world. However, they are limited to studies within the vicinity of a receiver network. Motus is an international collaborative research network led by Birds Canada that uses coordinated automated radio telemetry to facilitate research and education on the ecology and conservation of migratory animals [16, 29]. The network is extensive and spans many countries, mostly concentrated in the northern hemisphere. The limitations of these receiver networks are that there is inconsistent spatial coverage (particularly outside North America) and receivers require ongoing maintenance to ensure they are working properly. However, the data collected in areas where it is deployed are extensive and improving all the time [16]. ATLAS has been deployed in several countries and includes shorebird studies in the Dutch Wadden Sea where multiple UHF receivers were used to track several different bird species such as Red Knots (*Calidris canutus)*, Sanderlings (*Calidris alba)*, Godwits (*Limosa spp.),* and Terns (*Sterna spp.)* [1]. Receivers can be moved around the landscape, but some knowledge of bird movement is required to maximise effectiveness. A key limitation of these continental-scale programs is that building the receiver network is very time intensive and expensive, particularly if the aim is to track the birds for their whole migration.

Data management platforms

There are a number of platforms available to manage data. Some are manufacturer proprietary software systems (e.g., Druid) and others subscribe to a multi-user data management platform (e.g., CLS ARGOS) whereby device manufacturers pay a fee to access on behalf of customers (e.g., Lotek, Microwave Telemetry). Proprietary software is linked to the devices being sold by any given manufacturer. For example, Druid (GPS Bluetooth tags) uses an application called Ecotopia to collect, store and analyze data. The Motus network, mentioned above, uses coordinated automated radio telemetry to facilitate research and education on the ecology and conservation of migratory animals [29].

Iridium is another satellite-based system which has coverage of 100% of the planet. Iridium describes both the satellite network and the company that delivers the service (www.iridium.com). Most devices that use Iridium are over 50 g and are, therefore, unsuitable for use on small and medium migratory shorebirds. They do produce one GPS device which weighs only 5 g, however, it is non-solar powered and has a lifespan of 36 days or less (depending on programming) so it was omitted from the review as there are superior options.

The data sharing platform Movebank (www.movebank.org) is a freely accessible system that enables researchers to manage, share, analyse and archive animal movement and biologging data. The Movebank database supports the import of animal tracking data based on almost any method—GPS, ARGOS Doppler locations, radio and acoustic telemetry, solar geolocators, bird rings and natural markers—along with associated attributes and measurements from other on-animal sensors. Once imported, the user can view tracks, manage deployment information and use all the other Movebank features [15].

Movebank are working in partnership with both ARGOS and (more recently) Motus. Once fully operational, Motus users will have the option to automatically transfer a processed version of their data to Movebank, to use Movebank's sharing, analysis and archiving features while maintaining their complete dataset with Motus [15]. Movebank also collaborates with ARGOS to offer free data management and analysis tools specifically for Argos users.

Device attachment

The range of options for attaching devices to migratory shorebirds under 200 g is limited due to their small size and large changes to body weight associated with long distance migration. Attachment methods include implanted devices (rarely used now due to animal welfare considerations) and external devices. External attachments appropriate for shorebirds include gluing, full body (chest) harnesses and leg loop harnesses [21]. The choice of attachment method is largely determined by the shape and behaviour of the bird, the potential impact on the bird and the length of the study. Different methods are outlined below (Table 1). Attachment materials also add to the overall weight of the device and may cause physical injury or impede natural behaviour, which could put the bird at risk of reduced breeding success and/or death.

As harnessing is commonly used to attach tracking devices to migratory shorebirds, it is appropriate to go into more detail about these. The main types of harnesses used include full body harnesses (or chest harnesses) and leg-loop harnesses. The former uses a central breast strap and sometimes a neck loop. Weak links may be included in the harness to ensure it detaches after a period of time. Leg-loop harnesses loop around the legs and avoid the chest and wings [30].

Materials used for harnesses include Microfilament Dacron, Microfilament nylon, beading elastic, surgical silicon tubing and Tubular Teflon [21]. Tubular Teflon is often the preferred material for larger heavier birds because it is not abrasive, but it is a heavier material heavy and the overall weight of the harness plus device may exceed allowable thresholds for small birds [21]. Teflon, nylon and Dacron are not elastic and an assessment needs to be made about the best fit to take into account bird weight loss or gain [21]. If it is too tight it may impact on the bird's welfare, and if it is too loose the

Table 1 Types of harness attachment methods used on migratory shorebirds

Type	Method	Suitability for Migratory Shorebirds
Abdominal implantation	Transmitter is surgically implanted into the intraperitoneal cavity of the abdomen by a veterinarian	Invasive and questionable in value given animal welfare implications Requires specialist skills
Glue-on	Fur or feathers are clipped as close to the skin as possible to allow adhesion of a transmitter to the skin Some studies have glued onto tail feathers but this only works for larger birds like seabirds	These are a very simple attachment method but have a very limited time frame of weeks or months depending on the timing of body moult. They are, therefore, only suitable for short-term studies [21]. This method has been commonly used for manual radio-tracking studies, and more recently for attaching GPS devices as part of studies on a variety of shorebirds in the Wadden Sea [1]
Harnessing	Transmitter is attached to the animal via a harness made from (usually) synthetic materials that are soft, which helps reduce abrasion to the skin. Knotting of material (and sometimes also gluing) or metal crimps are commonly used for securing the harness material to the transmitter. Considerations for choice of material include the addition to overall weight, the shape of the harness—whether it is round or flat and potential impacts on the bird, such as rubbing or restriction of movement	Harnesses affix devices to birds for relatively long periods of time and are therefore useful for studies of full migration Most tracking devices have attachment points in the form of holes or hooks which can be adapted to different styles of attachments Can have adverse impacts on the bird depending on type of harness and material used so need to be carefully chosen

device may slip. Some materials may be more irritating, causing excess preening which can increase the likelihood of beak capture [21]. Surgical silicone is a more permanent option, in a similar fashion to Teflon [31] and as with other permanent attachments consideration needs to be given to the long-term welfare of birds carrying devices attached in this way.

There is limited evidence in the literature for the efficacy of certain harness types, as this is difficult to test on wild migratory birds (the target of most deployments). A recent study of 48 Long-billed Dowitchers (*Limnodromus scolopaceusleg*) fitted with 2 g Argos transmitters via leg loop harnesses using medical-grade silicone tubing did not observe any tagging-related mortality [32]. Buck et al. [33] investigated radiotracking backpack and leg loop harnesses and found that success for long-term deployment on juvenile birds depended on the combination of the attachment method device and material, e.g., elastic and leg loops, and ribbon for backpacks. Biles et al. [34] and Clewley et al. [35] found acute impacts from using Teflon harnesses to attach biologgers to Black-legged Kittiwakes (*Rissa tridactyla*) using both thoracic (chest) and leg loop harnesses (noting that the effects were worse using thoracic harnesses). On the other hand, Jirinic [36] tested adjustable leg loop harnesses suitable for small and medium sized birds (under 200 g) using Teflon ribbon on 90 birds and found no adverse effects one year later, a similar finding to Mallory and Gilbert 2008 [30] in their study of sea birds.

Leg-loop harnesses suitable for long-legged shorebirds are generally not suitable for compact species like Red Knots, which have no external knee and require full body harnesses [37]. Full body or chest harnesses also have limitations when used for migratory birds where body mass (and shape) fluctuates regularly, and long-billed birds may be at risk of getting their beaks caught in the harness when preening (51). Chan et al. [37] found through an indoor experimental study of Red Knots, that 10 of 20 birds had to have their harnesses removed due to the impacts of the harness, and of these, six got their beaks caught whilst preening. In contrast, a study of 74 Giant Hummingbirds was undertaken by Williamson and Witt in 2021 [38] who field tested a three loop lightweight backpack harness with three types of tracking devices (geolocators, GPS tags and satellite transmitters) found no evidence of adverse effects after two years. It is likely that some species tolerate certain harness types better than others, which needs to be assessed on a case-by-case basis.

Beading or jewellery-making elastic has the advantage that it expands and contracts with changes in body size, although it is less durable than materials like Teflon and surgical silicone. A current study on tracking of Latham's Snipe has fitted birds with Druid tags and elastic leg-loop harnesses, and recorded three birds still carrying the tag and harness 12–14 months later (L.Gould, unpubl. data).

Overall, published literature on harnessing for shorebirds is limited to a small number of papers which focus on different bird species, and many known tracking studies have not yet been published.

Discussion

There are numerous examples of bird tracking projects around the world which have yielded some incredible insights into movement and behaviour (noting that many tracking studies are yet to be published). For example:

- Grey Plover studies have shown that PTT satellite tags can provide important knowledge on migration strategies by revealing the use of different regions during the annual cycle and detailed quantitative data on population connectivity and migration timing [9].
- Studies on the Eurasian Curlew (*Numenius arquata*) using GPS data loggers have revealed spatio-temporal migration patterns throughout the East Atlantic Flyway [39].
- Black-tailed Godwit studies in Western Europe using satellite transmitters and geolocation have revealed different migration patterns to four distinct regions and locations of individual migratory routes [40, 41].
- VHF radio tracking surveys to monitor the movement and habitat use of 51 Dunlins (*Calidris alpina*) and 44 Great Knots during northward migration [42].

Although there are numerous devices on the market, there are only a small number appropriate for tracking migratory shorebirds under 200 g. The decision of which device to choose depends on the purpose of the research and the hypotheses or questions being answered, the behaviour and welfare of the target species and (often) resource constraints of the research. For example, for tracking local movements of birds with a high level of site fidelity and where tags don't have to be carried long distances, 3.6 g GPS tags (using Bluetooth or radio receiver stations) are likely to be appropriate as the heavier weight is less of an issue if the bird doesn't need to carry the device for migration. This is providing that the < 3% body weight requirements are adhered to and that harness materials are chosen to reduce the risk of a bird carrying the device unnecessarily for long periods of time (e.g., beading elastic or the inclusion of weak links).

For birds that are more mobile, travel long distances and are less predictable the 2 g PTT device is preferable. It is also beneficial to be able to access remotely downloaded data enabled by PTT's, rather than requiring the recapture of birds or requiring birds to be within a known and accessible location. There is also the potential to deploy multiple types of devices on the same bird species for different purposes. For example, using heavier 3.6 g GPS units for tracking local movements and using the 2 g PTT devices for tracking long-range movements.. Automated GPS radio telemetry could be used in a similar context with likely similar results and cost, particularly if the study is being carried out in an area with an existing receiver network.

Animal welfare is paramount when selecting a device. Geen et al. [44] (50) found that the literature often provides conflicting evidence regarding the impacts of tracking devices on birds. Some show that there are no effects on body condition, phenology and breeding while others have shown they can have an overall negative effect on survival. The high variability is thought to be associated with the differences in bird morphology and behaviour, life stage, device type, method of attachment, attachment duration, and device weight as a proportion of bird mass. Other studies such as Barron 2010 [22] found that the effects were independent of attributes of the individual birds. Outside of these dedicated studies and reviews, detailed information, or even general observations about potential tag effects are missing from the vast majority of tracking studies [7, 22].

Although the lower weight of modern tracking devices helps reduce negative effects on birds (depending on the device shape), attachment harnesses may still induce changes in survival and behaviour. Harnesses remain the only viable attachment method for many species [43]. Geen et al. [44] found that effects of devices were significantly related to the attachment method and relative device mass, and that there were relatively few reported effects of tail and leg attachments. However, they also found that reports of negative effects were limited to a small number of studies. This lack of information is problematic as welfare issues are likely to be inadvertently repeated. Researchers should be encouraged to explicitly provide this information in such a way that is easily accessible to other researchers (50).

Generally when selecting a device (and associated attachment method), the precautionary principle should apply. The lightest and smallest device possible for the purpose of the study should be the starting point, and the method of affixing the device to the bird has the lowest risk of potentially adverse impacts (both style and material used). There is more leeway for birds that are only going to be tracked for a short amount of time (e.g., 3 months) than for those being tracked for migration studies over many years providing harness material is appropriate as mentioned. Price is also an important consideration, because research studies ideally require a high number of birds to be tracked to get enough data to draw robust conclusions. Figure 2 shows a very simple decision tree for selecting a device for a 150 g shorebird.

Currently there is no single method that can achieve everything. There are always trade-offs between weight, cost, animal welfare, data accuracy and data accessibility. In general terms, lighter devices are preferable, GPS gives more accurate data than doppler and GPS is becoming more common in small tags. In terms of attachment, elastic type materials (e.g., elastic thread and silicone tubing) is likely to be more suitable than non-elastic, and may have less impact on bird movement. Automated data collection via gateways (or other

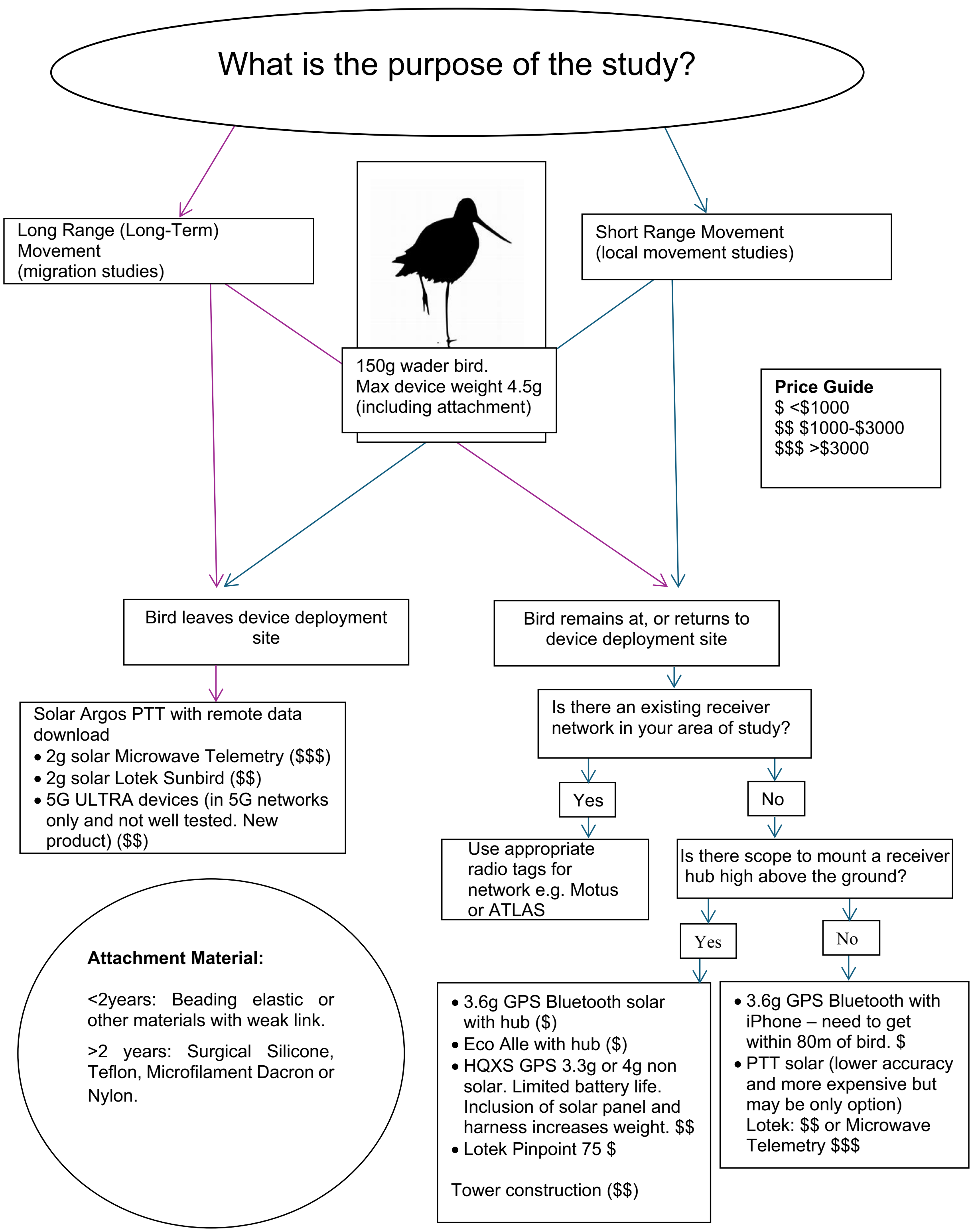

Fig. 2 Simple decision tree for selecting an electronic tracking device for a 150 g Shorebird

sensor technologies) is promising for studies in areas where birds remain or re-visit, particularly studies constrained by budget.

Fortunately, technology is improving all the time with devices getting more accurate, smaller and lighter. As an example, the International Cooperation for Animal Research Using Space (ICARUS) program developed a small, light, accurate, low-cost solar GPS device [35]. Unfortunately, this has been halted indefinitely because it relies on a Russian module of the International Space Station and impacted by the Ukraine–Russia war, [45] but this program demonstrates the progression in tracking technology. Another example is a collaboration between the United States Geological Survey (USGS) and National Aeronautics and Space Administration (NASA) on a Next Generation Wildlife Tracking project to develop low-cost, modular hardware and custom software which will allow scientists to tailor tag implementations to their unique needs. The project has developed a tag architecture and prototype with satellite communications capability using the commercial Globalstar service, aimed at meeting the needs of researchers studying migratory birds [36]. These are not yet commercially available, but the program provides another example of how the sector is rapidly developing. It is critical that researchers stay up to date and contribute to current base of knowledge as technology and methods are continually being updated [7].

It is also important to have a clear understanding of the application of telemetry-derived data and the purpose of undertaking studies with potentially high impacts on tracked animals, that is, whether the research improves the plight of these species [3]. It is often the case that species are studied with no stated hypothesis or clearly articulated conservation outcomes [20]. Addressing this shortfall should be the starting point to ensure that actions that are potentially impacting on a species have a clear reason for doing so.

Conclusion

There is a lack of comparative information about tracking devices for migratory shorebirds under 200 g in the literature, and as a result a review was undertaken to bridge this gap. Ideally, the perfect device for tracking small migratory shorebird birds would be light, small, flat, have high spatiotemporal resolution, longevity, remote download, easy to attach and not too expensive so that a large enough sample size can be obtained. This does not yet exist, but there are options, which if carefully considered, will achieve research aims, while minimizing impacts on bird welfare.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40317-024-00368-z.

Additional file 1: Literature review by topic

Additional file 2. Table S1 Description, advantages and limitations of technology used for obtaining movement data from migratory shorebirds under 200g

Additional file 3. Table S2 Comparison of technology available for tracking migratory shorebirds under 200g as of November 2023

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Author contributions

LG undertook the device review in consultation with BH, HM and AM. BH, HM and AM undertook substantial revisions and contributed knowledge in appropriate sections throughout. AM secured funding from the Woodlands and Wetlands Trust. All authors read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate

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Competing interests

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