



Feasibility study for the use of laser rangefinders in estimating flight heights of Manx shearwaters and European storm-petrels

ProcBe WP3 Deliverable 3.1

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Executive summary

In order to support the expansion of offshore wind in the UK and meet the Government’s Net Zero targets as well working towards addressing the biodiversity and climate crises it is essential to reduce uncertainty around the potential impacts of offshore wind. The [Offshore Wind Evidence and Change programme](#) (OWEC) has provided funding to address the consent risk for Offshore Wind (OW). The most recent leasing rounds for OW will increase the likelihood of overlap with species that have not been a focus of impact assessments in the past. Procellariiforms, specifically Manx shearwater, European storm-petrel and Leach’s storm-petrel have not been a common species of concern for OW in the UK, but this is likely to change with Round 4, ScotWind and floating wind developments. The possible impact pathways between these species and OW are poorly understood and the purpose of the Procellariiform Behaviour and demographics project (hereafter ProcBe) is to improve understanding and reduce uncertainty around some of these potential impact pathways. One of the work packages, work package 3 (hereafter WP3), is being led by the JNCC and is seeking to improve understanding of shearwater and storm-petrel flight heights, including in adverse weather conditions. Current estimates of flight height are mainly produced using boat-based observations and Digital Aerial Surveys (DAS). Although these have the potential to provide good estimates they cannot collect data in adverse weather conditions, such as high winds and sea states due to restrictions on methodologies (European Seabirds at Sea, ESAS) and it is expected that seabirds, particularly, will display different flight behaviour in such conditions.

Novel technologies for collecting flight height data are becoming more common, methods such as radar, LiDAR and laser rangefinders. WP3 of ProcBe will make use of one of these technologies, laser rangefinders (LRFs), to try and collect data from land and at-sea in a wide range of weather conditions. To inform data collection a literature review was undertaken in addition to conversations with a range of experts in the use of LRFs. The results of the review and discussions were used to inform the design of both a trial and calibration exercise to explore the precision and accuracy of the LRFs and field-based data collection. Data collection locations were selected through expert advice, proximity to breeding colonies and based on the availability of, or access to vessels that would run in adverse weather conditions (ferries and small boats which would be available to hire).





Background

Procellariiforms and offshore wind

This project was initiated in response to a funding call by the Offshore Wind Evidence and Change programme which is funded by The Crown Estate. This programme seeks to support the growth of the offshore wind industry and the UK's net zero ambitions by funding research projects that contribute a wide-ranging base of data and evidence to resolve gaps in evidence and understanding of cumulative impacts on protected seabird populations, a high-level priority of the OWEC programme.

The basis of the project is to address evidence gaps for Procellariiforms (namely Manx shearwater (*Puffinus puffinus*), European storm-petrel (*Hydrobates pelagicus*) and Leach's storm-petrel (*Hydrobates leucorhous*)) in light of the planned development of offshore wind in new areas of the UK which overlap with the breeding, foraging and migratory distributions of these species. The recent leasing rounds for Round 4, Round 5 and ScotWind will see the expansion of OW into the Celtic and Irish Seas as well as around the northwest coast of Scotland (Figure 1). Previously, the majority of developments have not overlapped with high densities of Procellariiforms, they have therefore rarely been considered in impact assessments and the interactions between these species and OWF has not been well-studied (Project Erebus Environmental Statement: Chapter 11 Offshore Ornithology). In addition to the novelty of these species as a consent risk, there is also a challenge in terms of understanding at-sea distribution, flight behaviour and general demography of these difficult to study species.

This challenge has been highlighted in a number of fora and projects. In 2022, the Offshore Wind Strategic Monitoring and Research Forum (OWSMRF), a developer-led strategic research forum for which JNCC is the secretariat, identified Procellariiforms as a priority group of species likely posing consent risk for future offshore wind development. The forum focussed on two species commonly found in the UK, Manx shearwater and European storm-petrel. Main outputs included a series of recommendations for research to fill key knowledge gaps around population size, demographic rates and at-sea distribution (Baker et al. 2022). Also in 2022, the Marine Directorate commissioned a review to assess the risk of collision and displacement of petrels and shearwaters from offshore wind developments in Scotland (Deakin et al. 2022). This review covered the same species as the OWSMRF work as well as Leach's storm-petrel of which the UK population breeds exclusively in Scotland. The review assessed the vulnerability of these species to Offshore Wind farms and associated structures and activities (Deakin et al. 2022). These pieces of work were developed in isolation, highlighting the importance of these species for future offshore wind research.



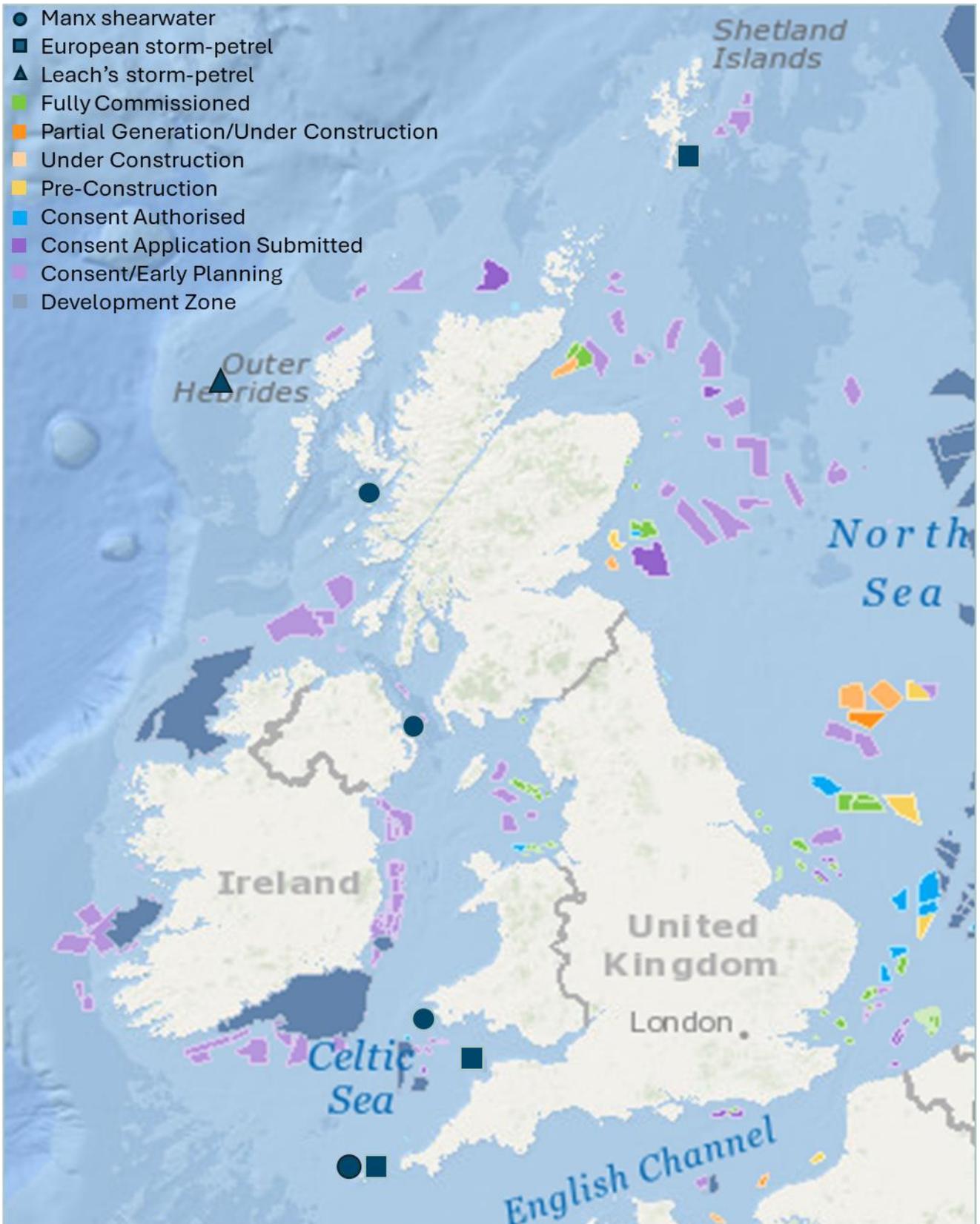


Figure 1. Map showing the extent of Offshore Wind Farms in the UK ranging from Fully Commissioned to Development Zones overlaid with Manx shearwater, European storm-petrel and Leach's storm-petrel SPA colonies (see key) (Map accessed at <https://map.4coffshore.com/offshorewind/>). ProcBe confirmed study sites are also highlighted and include Mousa, Rum, St. Kilda, Copeland Islands, Skomer, Lundy and the Isles of Scilly.



Purpose of this report

This report is the first stage of Work Package 3 under ProcBe. Section 1 consists of an evidence review: a literature review and discussions with various experts. This section sets out what research has already been carried out using LRFs, compares the different types and models of LRFs available and their possible limitations. Chapter 2 details the experimental design and analysis of data from the ProcBe calibration trial. Chapter 3 then applies the collated evidence and the experience gained in the trial to set out the proposed methods and locations for land- and boat-based data collection for the three years of this project.

Section 1 - Review of evidence

1. Flight height data

Flight height data are pivotal to make estimates about the potential risks of seabird collision with wind turbines. Collision Risk Modelling (CRM) is an essential part of the Offshore Wind impact assessment process and works by using a variety of flight parameters, including flight height, flight speed and density to estimate flux (numbers of transits through a particular windfarm) (Band 2012). Other behavioural variables such as commuting and foraging flight patterns and percentage time spent flying at night are also considered in modelling approaches. Flight height data have thus far been collected using visual observations (boat platform- and land-based), Digital Aerial Surveys, radar, Light Detection and Ranging (LiDAR), laser rangefinders and bird-borne telemetry data (Johnston et al. 2023). The most common method used to assess collision risk in impact assessments, and which is currently endorsed by the UK Statutory Nature Conservation Bodies (hereafter SNCBs) is the Band model (Band 2012). In this model, data on bird density should be accompanied by an estimate of the proportion of birds flying within a risk height band (this should be specific to the turbine height, dimensions, etc., for a proposed windfarm) (Band 2012).

In previous studies flight heights have been categorised to a series of vertical bands based on visual observations from either boats, land, or platforms. These bands were assigned using trained observers estimating heights of flying birds using fixed objects of known height or trigonometry to ground-truth (Johnston et al. 2014). In the study by Johnston et al. (2014) continuous distributions of flight height were estimated for each species, and then fitted with a flexible curve. Further detail on methods is available in the published work (2014).

There are four different Band model options available which differ in the characteristics of flight height data used. The “basic” model uses one figure for flight height, the proportion of time spent flying within the rotor swept zone (and therefore at risk of collision). There are then options for either site-specific (option 1), or generic values (option 2) for the flight height proportion. The “extended” model takes into the account the varying risk of collision across the entire rotor swept area as the risk of colliding is not uniform (there is more risk at the centre of the rotor than at the edges of the turbine blades). This model requires more



detailed information on flight height distribution to accurately apply the risk and therefore a flight height distribution is required. The extended model also has two options, use of generic (option 3) or site-specific data (option 4). Mortality estimates derived from these models (of birds predicted present within a site) can then be applied to a relevant population scale and estimates of annual mortality can be calculated to assess the population-level impacts of Offshore Windfarm development.

Flight height data varies with species, both in terms of the number of studies producing estimates and the confidence in these estimates (Furness et al. 2013; Johnston et al. 2014; Wade et al. 2016). A study using flight height data, collected visually from boats in and around OWFs, found that Manx shearwater flight height distribution did not overlap with the rotor swept zone of turbines, with no birds observed within the rotor-swept area (10 sites, 6,801 birds) (Figure 2) (Johnston et al. 2014). The study modelled flight height distributions for a further 24 species and found that distributions varied considerably between species with some overlapping the rotor swept zone (see Figure 2a & b for comparison between Manx shearwater and Lesser black-backed gull (*Larus fuscus*)). Data collection from boats or platforms can only be carried out under certain conditions, usually in sea states <4 and it has been suggested in the literature, and anecdotally, that Procellariiforms, including Manx shearwater, fly at higher altitudes and alter flight behaviour as wind speed increases (Ainley et al. 2015; Gibb et al. 2017; Guilford pers. comm; Spear and Ainley 1997b in Johnston et al. 2014). The majority of species will adapt their flight pattern in adverse weather conditions such as high winds and will fly in even extreme weather conditions, therefore the input parameters, e.g. flight height and speed, for models such as Band are not standard and using data collected in a restricted range of weather conditions will lead to bias in outputs (Ainley et al. 2015; Johnston et al. 2014; Lempidakis et al. 2022; Spear and Ainley 1997a & b).

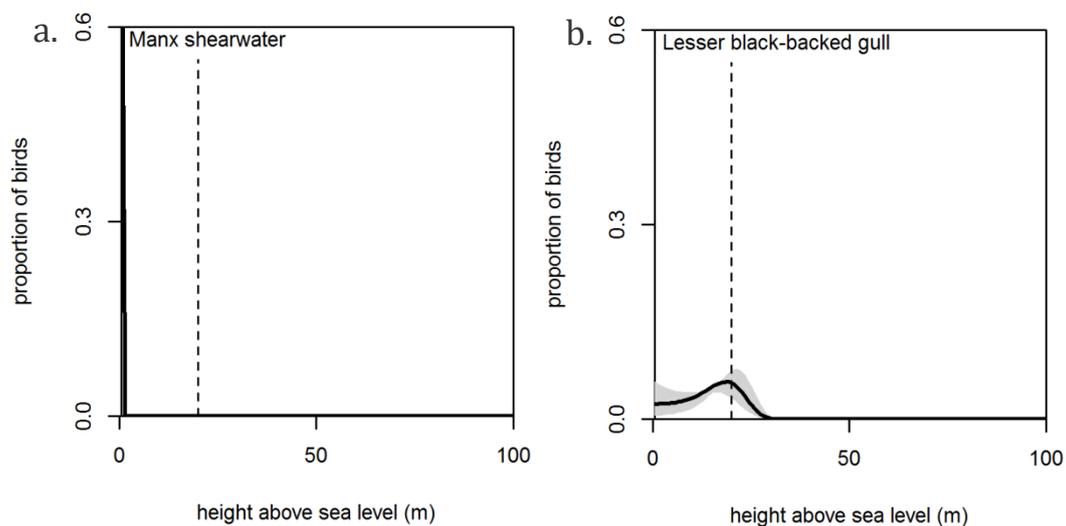


Figure 2a & 2b. Modelled flight height distribution (black line) and associated 95% bootstrap confidence intervals (grey area) for Manx shearwater (a) and Lesser black-backed gull (b) (from Johnston et al. 2014 supplementary materials), the vertical line represents a height of 20m above sea level.



A review of available data and associated confidence in the proportion of time seabird species spend at altitudes overlapping with turbine height provided the highest possible level of uncertainty for European storm-petrel and Leach's storm-petrel (very high) and the second highest level of uncertainty for Manx shearwater (high) (Wade *et al.* 2016). This review highlighted that there are a number of factors which may contribute to the low number of studies on these species including that they are uncommon or rarely recorded, they may be difficult to detect, they may be more active in sea states incompatible with surveying, or they may be absent from renewables sites due to their distribution (Wade *et al.* 2016). Several or all of these factors apply to Manx shearwaters and storm-petrels in the UK. Until recently, Offshore Wind development had been focussed on the North Sea whereas the majority of the UK storm-petrel and shearwater populations are located around the west coast of Scotland and in the Celtic and Irish Seas. Because of this, monitoring occurring at proposed sites or post-construction may not have encountered these species in any great numbers.

Boat-based detection of all seabirds is likely to decrease with distance from the observer beyond 100 m, with some evidence that the probability of detection declines faster for smaller species such as storm-petrels which, given their wing length of 12cm, are very difficult to detect in anything but very calm conditions (Barbraud and Thiebot 2009; Bolton 2021).

Detection using Digital Aerial Survey, at least historically, has been challenging, but upgrades in the camera equipment used in surveys now means that providers of DAS suggest they regularly record storm-petrels during surveys in offshore environments. It is however, currently uncertain how representative observed occurrence is with true encounter rates as no validation of this has been carried out. In some surveys low or zero observations in EIAs have been attributed to storm-petrels being absent rather than being missed even where the foraging, breeding and migration routes of European storm-petrels overlap with the study area. One such example is the DAS surveys for the EREBUS Offshore Windfarm which did not observe any storm-petrels (HiDef 2021) (Project Erebus Environmental Statement Chapter 11: Offshore Ornithology. Available at: [Public register - Customer Portal \(naturalresources.wales\)](https://public-register-customer-portal.naturalresources.wales)). There is not currently any validation of such surveys to prove absence is truly absence of presence or that they were just not picked up during the surveys. Using DAS data to estimate flight heights has been carried out for some time but recent evidence has demonstrated that the current method for estimating flight heights from single-camera DAS data is biased and does not account for uncertainty in seabird body size (Boersch-Supan *et al.* 2024). In addition, it had not been possible to deploy Global Positioning System (GPS) tags onto storm-petrels due to ethical constraints on the size and weight of tags in proportion to their body mass. The first deployment of lightweight GPS tags for European storm-petrel in the UK was completed between 2014-2017 on Mousa, with subsequent studies in Ireland (Bolton 2021; Critchley *et al.* 2020; Wilkinson 2021).

Anecdotal evidence (captured by video and visual estimations) suggests that Manx shearwater in particular fly at greater heights in high winds and sea states with further evidence from other shearwater species (Ainley *et al.* 2015; Guilford pers. comm). This behaviour cannot be captured by current survey methods, where operations are restricted by these weather conditions (Guilford pers. comm). Some flight height data have been collected from GPS tagging which provided evidence of birds flying up to 17.5 m (Davies *et al.* 2021.) Evidence suggests that shearwaters are more likely to be recorded flying in the morning (dawn to 10:00) and then to a lesser extent in the afternoon and early evening which is likely to be linked with commuting flight (Guilford *et al.* 2008). Commuting flight was generally associated with high-speed and direct flight whereas foraging behaviour was also high-speed but more tortuous (Freeman *et al.* 2013).



In order to improve our confidence in the flight behaviour of Manx shearwater and storm-petrel it will be necessary to collect data in adverse weather conditions. There are a number of ways that this can be done, with advantages and disadvantages for each which will not be explored in this report. Most, if not all, of the currently used methods are likely to be impacted by sampling or measurement errors (Humphries *et al.* 2023). This project will focus on the use of laser rangefinders (LRFs) as these have been used to produce data on seabird flight height both on-land and at-sea. This research, WP3 of the ProcBe project, will complement the work being carried out by other work packages which will use animal-borne loggers to collect empirical data on flight heights. By using different methods, it is hoped that the ProcBe project will collect data from a variety of locations around the UK (boat-based and land-based for LRF, at-sea for tags) and a large number of individuals (tagging will be restricted to a small number of birds, whereas the LRF will allow for large sample sizes). Both methods, particularly tagging, will allow data to be collected in weather conditions that current methods (e.g. ESAS and DAS) do not allow for. Results can be compared between methods to produce robust estimates of flight heights for these species.

1.1 Literature review: Search terms

To explore the existing studies that have used laser rangefinders to collect data on seabird flight heights a literature search was carried out. The search engines used were Google Scholar and Scopus so as to cover published research articles and grey literature. Three search term series were used for each search engine:

1. laser rangefinder; flight height*, seabird*, boat-based
2. optical rangefinder; flight height*, seabird*, boat-based
3. optical rangefinder; flight height*, Manx shearwater, boat-based

The results delivered from Scopus were limited with three, seven and zero results for the three searches respectively. Google scholar produced significantly more results, so just the top 30 results were selected from each search. The abstracts were then used to rule out irrelevant studies. A number of review articles were picked up in the searches, any relevant studies identified by these reviews that were not found through the original search were also included. Once the relevant studies were identified the reference list was also interrogated to pick up any studies that may have been missed during the literature search.

1.2 How does a rangefinder work?

Laser rangefinders use a laser beam to measure the distance from the observer to a target and has many applications, including forestry, construction and recreational activities such as golf. LRFs have been incorporated into binoculars and can measure distance, altitude and direction (Thaxter *et al.* 2016). LRFs can measure azimuth (i.e. the horizontal angle or direction of a compass bearing), elevation angle and distance to estimate a target's three-dimensional position (Cole *et al.* 2019; Thaxter *et al.* 2016). Over time, modifications have been made to enable estimation of flight speeds and bird tracks to be reconstructed when combined with a computer (for data recording and to record time) (Pennycuick 1982; Tucker and Schmidt-Koenig 1971 in Pennycuick 1982). This modified equipment, specifically used to quantify animal space and habitat use, is known as an ornithodolite, which is a term that



describes the functionality to measure speed. The Vector Ornithodolite is a laser rangefinder incorporated into a pair of Vector 21 binoculars and is one of the most common tools used for estimating flight heights and speeds of seabirds. It is the only integrated system of this kind (as far as could be determined by this work) (Cole *et al.* 2019; Pennycuick *et al.* 2013). One of the main differences between a LRF and an ornithodolite is that the data collected by an ornithodolite is automatically fed into a computer or GPS device rather than being read directly from the device itself (Thaxter *et al.* 2016). Although the Vector device has the capacity to measure flight speed, we will not be using this function within the study, and we will only be using the laser rangefinder capability (work packages 1 & 3 will be using tagging data to make estimates of flight speeds).

1.3 Types of rangefinders in the literature

Our review found that only two devices have been regularly used to estimate flight heights for seabirds, the Vectronix Vector (21 Aero or 21 models) and the Nikon Forestry Pro. It is important to select the most appropriate specification of rangefinder for the study.

There are a number of reasons why the Vector 21 Aero Rangefinder (Vectronix) is such a popular choice for ornithologists collecting flight height data on seabirds. Firstly, it is a military-grade piece of equipment, it has a very high-quality laser and as such can collect data from targets at a very large distance (between 2 - and almost 5 km) from the observer (Cole *et al.* 2019; Skov *et al.* 2018; Thaxter *et al.* 2016). This particular model also has an inclination angle of 90° which allows the collection of flight height data for birds flying above the user or at heights very close to the user, which other Vectronix models do not allow (see website for other models <https://safran-vectronix.com/mission/handheld-equipment/>). The rangefinder can be connected to a computer or GPS to allow data to be downloaded directly. This allows users to collect data continuously, and a computer programme ensures data are stored in a usable format (Pennycuick 1982; Pennycuick *et al.* 2013; Thaxter *et al.* 2016).

However, there are also some features of the Vector that make it challenging to use. Because of the magnetic compass built into the rangefinder, calibration issues can arise when working on a metal platform, such as boats (Largey 2021; Skov *et al.* 2018). This can be corrected but it has been suggested that the Vector will have to be calibrated more often than other simpler rangefinders. Calibration can be done during data collection using nearby objects of known height, but this relies on such objects being available, which they might not be on a moving boat (Harwood and Berridge pers comm; Skov *et al.* 2018). This issue may only be relevant when using the magnetic compass function of the Vector, i.e. azimuth, and therefore should not be a concern when collecting just height, distance and inclination angle measurements. The rangefinder itself is also quite heavy and may need to be mounted on a tripod for operation, this could be suitable for land-based work but on an unstable platform like a boat this can be challenging (Thaxter *et al.* 2016). Issues with 'clutter' have also been reported, although not consistently across different studies which may be linked to the specific make/model being used, where the target is missed and the laser instead bounces off a nearby object, such as the sea or clouds (Cole pers. comm. Largey & Masden pers. comm). Depending on the device and/or the object that was hit in error it should be relatively straight forward to distinguish between fixes from the intended target and those that missed, although again this has not been reported consistently between different studies (Cole pers. comm. Largey & Masden pers. comm). The Vector 21 Aero is also very expensive and has now been discontinued from production, it is unclear whether manufacturing of a comparable model will be undertaken.



The other rangefinder found in the literature that has been used for seabird flight height estimation is the Nikon, Forestry Pro (Harwood *et al.* 2018; Perrow *et al.* 2017). This model is more basic than the Aero and is designed for forestry or leisure. It is significantly cheaper, smaller and lighter which makes it more manageable on a less stable platform as it does not require a tripod. This rangefinder did not appear to have the same issues with 'clutter' as the Aero, this may be because the laser is not as powerful but means there will be fewer erroneous data points that may have bounced off the sea or other features (Harwood/Berridge pers comm). It has a far inferior range, with the distance at which large seabirds were recorded at being around 150 m (maximum distance for a gannet 226m). For smaller seabirds such as Atlantic puffin (wingspan 0.55m) (*Fratercula arctica*) the furthest successful record was 88m. One record was collected for Manx shearwater at a distance of 109.6m. Preliminary data from ProcBe work indicates it is possible to collect data at further distances, up to 300-400 m away. It does not automatically download records and is only able to store 200 data points which are deleted as more are collected, the data log can be transferred by USB. This means that the observer needs to read off the records between data points which would make collecting continuous data for reconstructing movement tracks very difficult.

A further model that was not used in published literature but has been used to gather flight height data for seabirds is the TruPulse 360B (Armitage and Robinson, pers comm.). This model was used to gather flight height for seabirds, including Manx shearwater, opportunistically from ferries, for Manx shearwater data were gathered at a distance of 100-200 m (Armitage and Robinson, pers comm.).



Table 1 Table comparing the advantages and disadvantages of two different models of laser rangefinders identified in the literature review for estimating seabird flight heights.

	Vector 21	Forestry Pro II, Nikon	TruPulse 360B
Range on Product Specification (max)	10 km	1.6 km	2 km
Range in practice (greatest distance a bird successfully recorded)	Cole <i>et al.</i> 2019 reported a whooper swan (<i>Cygnus cygnus</i>) at 2.742 km and a flock of geese at 5.498 km	Previous model used by Harwood <i>et al.</i> (2018) found that the maximum range was around 150m	No evidence found in literature
Inclination	90°	90°	90°
Cost	£20k+	£450	~£1600
Platform	Land and boat based	Land and boat based	Land and boat based
Calibration	Needs to be regularly calibrated (using objects of known height), particularly if on a metal platform as this interacts with the compass	Needs to be calibrated once	Needs to be calibrated once
Data output	Can be connected to a GPS/computer and automatically downloaded	Can store up to 200 readings or outputs need to read off the device as soon as taken (possible issues for doing bird tracks)	Data can be downloaded via Bluetooth to a computer
Usability	Needs to be used on a tripod which makes it difficult to use on an unsteady platform (i.e. boat in adverse weather)	Small and light, does not need a tripod so easy to use on an unsteady platform	Small and light, does not need a tripod so easy to use on an unsteady platform
Resolution	Rounds to the nearest metre	Round to the nearest 10 cm	Round to the nearest 10 cm
Accuracy	Allows high accuracy at far greater range potential issue with "clutter" and false readings for some makes/models but not observed with the Vector 21 used for ProcBe	Short range, no reported issues with clutter	Short range, no reported issues with clutter



1.4 Use of laser rangefinders for estimating seabird flight heights

1.4.1 Boat-based flight height data collection

There are relatively few studies that have used a LRF to estimate seabird flight heights. Five studies were identified that collected flight height data using a laser rangefinder from boats. Two of those studies used a basic Nikon Forestry Pro (Harwood *et al.* 2018; Perrow *et al.* 2017), three used the Vector 21 Aero (Borkenhagen *et al.* 2018; Fijn and Collier 2022; Mendel *et al.* 2014).

Both of the studies using the Nikon Forestry Pro used the LRF to either compare with or calibrate visual observations (Harwood *et al.* 2018; Perrow *et al.* 2017). Perrow *et al.* (2017) observed flight heights of Sandwich terns (*Sterna sandvicensis*) by tracking individuals from a boat (206 tracks in total). When calibrating the visual height observations with the LRF, they found that measurements were largely comparable, but that there was some discrepancy which was nearly always >1 m and <5 m (Perrow *et al.* 2017). This study did not discuss calibration of the device, the sampling strategy or any specific challenges associated with the device.

The second study which used the Nikon Forestry Pro by Harwood *et al.* (2018) compared the data collected using the LRF with visual observations made at the same time. This study used land-based calibration using a drone at a variety of distances and heights (up to 150 m horizontal distance and 100 m altitude) prior to the data being collected at-sea. The calibration work highlighted that although there was an overall agreement between the flight heights measured by the LRF and from the UAV, no readings could be obtained when the drone was < 15 m directly above the operator, < 10 m altitude at 5 m distance and that it was difficult to achieve readings at altitudes of > 75m at a distance of 100 m or >20 m at 125 m distance (Harwood *et al.* 2018). The mean difference between rangefinder and UAV heights was -0.4 ± 1.3 (SD) m, when the readings were limited to 100 m distance and 50 m height the mean difference was reduced to -0.04 ± 0.70 (SD) m (Harwood *et al.* 2018). It was therefore suggested that data collected could be truncated to a maximum distance of 100 m distance and 50 m altitude to provide more reliable results. Boat-based data collection did produce some erroneous results of flight heights below sea level, but this is likely to be caused by movement of the boat on the water.

Agreement decreased between heights collected with the Nikon Forestry Pro and by observer estimates relative to the body size of the bird, with a larger disparity between larger species' estimated flight heights (Harwood *et al.* 2018) (black-legged kittiwakes (*Rissa tridactyla*) and common gulls (*Larus canus*) vs Northern gannets (*Morus bassanus*) but irrespective of body size, observers tended to underestimate heights with increasing altitude, even when heights were relatively low (<5m) (Harwood *et al.* 2018). It was also noted that the underestimation of flight heights may be influenced by the tendency to record heights at the lowest point of the flight path of gannets (Harwood *et al.* 2018). Discrepancy between the results of this study (median altitude 3.5 m) and a study which used GPS to measure flight heights of gannets (median altitude 11.5 m) in the same region may have been influenced by bird behaviour and weather conditions (Cleasby *et al.* 2015; Harwood *et al.* 2018). The potential sources of error identified in this study are directly applicable to the ProcBe study (e.g. recording values at different stages of the flight path, weather conditions).

No records above 55 m altitude were collected for any species, and most records were within 100 m horizontal distance of the observer. Data collection using the Nikon rangefinder was somewhat challenging as obtaining fixes required a relatively high degree of user aptitude (R.



Berridge and A. Harwood, pers. Comm.). The study made a number of recommendations for future work, including:

- Using a UAV of comparable size to the desired target;
- To undertake calibration at-sea to provide a more accurate measure of error and under more challenging conditions;
- Using the most appropriate device for the data collection required, for example if collecting data at >50 m altitude or more than 100 m distance.

Three studies collected flight height data from boats using the high performance, military-grade Vector 21 Aero (Borkenhagen *et al.* 2018; Fijn and Collier 2022; Mendel *et al.* 2014). None of these studies reported any calibration. Two of the studies recorded flight heights twice in quick succession, they were only included in analysis if they were either very similar or ≤ 5 m of each other (Borkenhagen *et al.* 2018; Mendel *et al.* 2014). The study by Mendel *et al.* (2014) and Fijn and Collier (2022) completed boat-based surveys according to ESAS methods and Borkenhagen *et al.* (2018) used a transect method.

Borkenhagen *et al.* (2018) collected data from 15 species and recorded 2,508 measurements up to altitudes of 431 m above sea level. In good conditions they were able to measure targets the size of lesser black-backed gulls up to 500m away but found that data collection was biased against very high or very low flight heights and so supplemented the Vector measurements with visual observations of very low flying birds which were within 2m of sea level (these were assigned to 1m above sea level). Flight heights for lesser black-backed gulls were compared with GPS data (GPS loggers programmed to ensure altitude accuracy of around ± 10 m with heights continuously recorded every second for 35s, at 5-minute intervals, 24 hours a day) and demonstrated similar flight height distributions. The GPS recorded a wider range of flight heights, whereas the proportion of LRF records within the rotor swept zone was almost twice as high as from GPS loggers. When the results of this study were compared with the work by Johnston and Cook (2016) who modelled the proportion of birds flying between 20 and 120m using boat-based and DAS, they found the LRF results differed. LRF data for Sandwich terns and gannets were higher than boat-based data but lower than DAS results, although DAS results are likely to be biased and do not account for variation in bird body size (Boersch-Supan *et al.* 2024). The discrepancy between LRF and DAS estimates could be based on uncertainty in DAS methods related to image quality, variation in bird body size and bird behaviour which reduce the accuracy of estimates (Boersch-Supan *et al.* 2024; Borkenhagen *et al.* 2018; Johnston and Cook 2016). The LRF study also found that a much higher proportion of birds flew within the 20 m – 120 m range (black-legged kittiwake, lesser black-backed gull, herring gull (*Larus argentatus*) and great black-backed gulls (*Larus marinus*)) (see Borkenhagen *et al.* 2018).

Mendel *et al.* (2014) collected data on six seabird species using the Vector 21 Aero. For each bird at least two measurements were recorded, and data were only used if the measurements were very similar. Between 16 and 637 data points were collected for each species with lesser black-backed gull being the most abundant. The median flight height for this species was not provided but appears to be similar to what was found by Borkenhagen *et al.* (median = 21 m).

Fijn and Collier (2022) measured flight heights for Sandwich terns from a boat, with data collected during different behavioural states, foraging, searching and in transit. 1,460 data points were collected with a mean flight height of 13 ± 12.8 m (median 12m, range: 1-319m) which was similar to the data collected by Borkenhagen *et al.* (2018) who recorded 49 Sandwich tern flight heights (median 14 m, range 4-66 m). Compared with the results of the



Perrow *et al.* (2017) study which used the Nikon Forestry Pro the Fijn and Collier (2022) study found the flight heights were around half as high as had been previously estimated (mean =22.3 m, range: 2-113 m, n = 364).

1.4.2 Platform-based flight height data collection

One study was identified that used the Vector 21 Aero from a wind turbine platform. The LRF was calibrated from the platform based on fixed structures, the nacelle of neighbouring turbines. This study did not use selective tracking of individuals, a radar was used to pick up flying birds and then a second observer picked them up using binoculars and took a series of measurements using the Vector (Skov *et al.* 2018). Tracks were recorded with flight height measurements taken every 3-5 seconds; distances were reconstructed up to 1.5-2 km. The data recorded can be used to develop flight height distributions for use in the extended Band model or non-site-specific flight heights can be estimated from other published data using a non-linear smoothing algorithm as detailed in Johnston *et al.* (2014).

This study highlighted a number of challenges with using this LRF:

- The Vector 21 Aero uses a programme to write the data onto a GPS, the data on the GPS needs to be adjusted to ensure the baseline altitude of the observer is correct.
- The Vector is sensitive to metal interference, in this case the turbine, and calibration needed to be carried out regularly against structures of known height, these data were then used to spatially adjust the location of records, however, inaccuracy can be considered within the range of ± 10 m.

1.4.3 Land-based flight height data collection.

Four studies that used LRFs to assess birds flight heights from land were identified. Three of the studies used the Vector 21 Aero but only one study detailed completed calibration of the device. The fourth study did not specify the make or model of rangefinder used or the experimental design used (Hatch and Brault 2007).

Skov and Heinänen (2015) collected data between 2-3 km range with readings taken every 10-15 seconds to reconstruct tracks from the same individual bird. Flight height data were used empirically, in their raw form as mean values, in CRM, rather than using modelled flight altitudes.

Kahlert *et al.* (2012) used the Vector to estimate the flight heights of migrating sea ducks during daylight hours. No sampling strategy was specified. They found that there was a bias towards lower flight heights as birds flying at very high altitudes were hard to detect. As with other studies, a radar was used to help improve detection rates (Kahlert *et al.* 2012).

Largey (2021) explored how the Vector could be used to measure flight heights of seabirds and included calibration experiments on static and moving objects as well as on flying birds.

Variation in the accuracy of the Vector's vertical measurements was tested through comparison between objects of known, fixed height (a building and a wind turbine nacelle) and a hand-held Real Time Kinematics (RTK) GPS. This allowed measurements to be taken where only the distance to the object was varied (fixed height structure) and where both the height and distance were varied (UAV). Distances between the observer and the fixed targets were varied with 20 fixes taken at every distance interval. For data collected where height and distance were varied, the UAV was flown at 10 m vertical height intervals between 10 m-



120 m and records were collected at horizontal distances between 20 m and 300 m. 10 records were collected at each horizontal distance interval. For both the fixed and non-fixed measurements at each interval a GPS was used to record the latitude, longitude and altitude, to an accuracy of <1-3 cm.

For the objects of known fixed height, measurement precision decreased with increasing distance, which may be caused by attenuation in the laser beam over the greater distances. When using the UAV at varying height, accuracy and precision in altitude measurements decreased with increasing horizontal distance. This study has highlighted that with increased altitude of the target and increased distance between the operator and the target the precision of the LRF measurements decrease. For any target there will be an optimum combination of inclination and distance which will be related to object size, and which cannot be known before data collection.

A further experiment within this study used a moving UAV to test how well the Vector performed in a similar scenario to when collecting data from flying birds. The detection capability of the Vector was affected by the movement characteristics of the UAV, its speed, tortuosity and height. The presence of clutter may also reduce the ability to detect a target as the device cannot discriminate between the target and non-target objects. Reduction in detection caused by flight characteristics, such as speeds greater than 11.32m/s or for turning angles greater than 80°, can make tracking a bird in flight challenging and can cause precision to be irregular and reduced. Overall the Vector tends to underestimate flight heights but produces more accurate data over other methods such as visual observations or literature-derived values. It was noted that the experience of the operator may influence the resolution of the data, which was highlighted by another study using a similar Vectronix model (Dunbar 2010 in Largey 2021). Differences in the shape and form of the target are also likely to impact the detectability. Overall, the ability to collect data using the Vector successfully is likely to be highly site, target and context specific.

1.4.4 Use of laser rangefinders for estimating seabird distances and speeds

Cole *et al.* (2019) used the Vector 21 to assess space use of seabirds within Ramsey Sound. The Sound was scanned every 15 minutes to reduce bias, with fixes taken at the beginning and end of dives, highlighting that readings can be taken from birds on the sea surface. This study carried out calibration based on an object of known height, with multiple readings taken at increasing intervals. Variance in vertical measurements increased with horizontal distance and is within 1-2 m height variation at a 2 km range (Cole *et al.* 2019). Azimuth error was identified as the most likely source of positioning error, and that target characteristics (size, colour) and experience of the observer also influenced the ability to obtain a reading of the target (Cole *et al.* 2019). This study also analysed data collected from migrating birds passing Ottenby Bird Observatory in Sweden. The Vector was able to detect birds as small as 5.5 g at 1 km distance, with the maximum distance recorded at 5.5 km (a flock of geese).

1.4.5 Calibration of laser rangefinders from literature review

Calibration of a device is important to assess the ability of the rangefinder to accurately and precisely detect a target over a series of heights and distances. The accuracy of the device is assessed by comparing how close the measurement is to the "true" value, whereas precision refers to how close the measured values are to each other. The majority of the calibration exercises discussed in this review relate to the accuracy of the devices used. Calibration can



be carried out using either static targets of known height, e.g. a turbine nacelle or building, or a smaller moveable target such as a drone (Cole *et al.* 2019; Harwood *et al.* 2018; Largey 2021; Skov *et al.* 2018). Calibration conducted using a large target such as a building would need to be completed carefully to avoid collecting data from different points on the structure which could contribute significant error. A number of studies identified in the review did not carry out calibration or information was not provided in the methods (Borkenhagen *et al.* 2018; Fijn & Collier 2022; Hatch and Brault 2007; Kahlert *et al.* 2012; Mendel *et al.* 2014; Skov and Heinänen 2015). Calibration is important as it can help direct experimental design by highlighting any inaccuracies as well as allowing the detection limits to be identified.

In the literature, two studies used drones to calibrate rangefinders, which were static at the point the data was collected (Harwood *et al.* 2018; Largey 2021). Drones allow the horizontal distance from the observer and vertical distance to be precisely defined at any one time and can be pre-programmed or controlled by a pilot. Previous studies have recommended that the size of drone used for calibration should be as close to the target species as possible to ensure the most reliable calibration of the device (Harwood *et al.* 2018). The same study also suggested that if data collection was planned at-sea then doing calibration at-sea would improve precision by allowing the specific challenges of boat-based data collection to be accounted for e.g. swell (Harwood *et al.* 2018). Calibration at-sea could be done using a drone of using fixed objects, although the latter would be challenging depending on the location and availability of objects of known height by which the rangefinder could be calibrated, for example, in the study by Skov *et al.* (2018) a wind turbine was used.

Two further studies used a fixed target of known height, either a turbine nacelle or building where a specific target area was identified to collect readings from (1m² area) (Cole *et al.* 2019; Skov *et al.* 2018). It was not clear how error conveyed by potentially collecting readings from different points on a building used for calibration was dealt with in a third study (Largey 2018) Readings were taken at increasing horizontal distances, with a number of readings taken at each interval. Calibration showed that the precision of the height measured by the Vector decreased with respect to increase in longitudinal distance (Cole *et al.* 2019; Largey 2021).

Calibration may be required to be carried out multiple times dependent on the device and the platform. Issues have been identified with the magnetic compass within the Vector LRF when used on a metal platform and therefore regular calibration is recommended (Skov *et al.* 2018 and Harwood/Berridge pers comm).

1.4.6 Recommendations from experts

Conversations with experts have also produced recommendations for calibration which echo those found in the literature. If possible, calibration should be carried out from the platform that data collection is planned from as well as trying to match the behaviour and size of the target species. This is something that could be done using a drone that is a similar size and use it both at static heights and distances but also whilst the drone is moving (E. Masden, pers. Comm.).

Through review of the literature and discussion with experts a number of potential issues need to be considered when planning and executing a calibration exercise; e.g.

- Accuracy of the drone GPS/altimeter. We need to have a high precision GPS/altimeter on the UAV, either in built or mounted (A. Harwood and R. Berridge, pers. Comm.)
- Match-up of computers if attempting to take readings from a moving drone.



1.4.7 What makes a good laser rangefinder?

There is a wide range of LRFs available with a significant difference in quality and cost. There are a number of features that may affect the quality of the data collected (Thaxter *et al.* 2016). The features that will contribute to this variation include:

- Beam aspects (laser quality) – the type of pulses, wavelength and sharpness will impact the ability of the user to ‘hit’ a target;
- Optics – quality of the lens and magnification;
- Aperture – opening size of the receiver optic (which can impact the amount of data collected, and LRF’s performance at greater distance and precision at shorter distances);
- Function/interpretation of measurements by the device – analysing outliers, display of results to user, number of pulses to increase sample size (Thaxter *et al.* 2016).

1.5 Potential biases and influencing variables

Based on the existing evidence there are a number of sources of uncertainty and bias that must be considered both during data collection and analysis.

1.5.1 Environmental conditions

As environmental conditions are likely to have an impact on the flight behaviour of both species, particularly wind and sea state, the aim of this research is to collect data in a variety of conditions; however there will be limitations to this. Firstly, it is not possible to use the laser rangefinder in ‘high moisture’ conditions such as rain or fog as this can affect the ability of the laser to reach the target (Borkenhagen *et al.* 2018; Cole pers comm.; Largey 2021; Masden pers comm.; Skov *et al.* 2018). High winds are unlikely to have a direct impact on the device but may make it difficult for the observer to gain fixes, particularly if the device is hand-held rather than being tripod mounted, glare and changes in contrast, e.g. a cloudy or clear sky, are also likely to impact the ability of the device to obtain a fix (Cole *et al.* 2019). This is also likely to be the case when sea state is high. This is a particular challenge as it will not be possible to account for changes in the platform height during boat-based data collection, therefore data on sea state and swell will be essential to collect so that their influence could be accounted for in the analyses (Harwood and Berridge pers comm.).

Despite the potential challenges that adverse weather may present to data collection, it is highly likely to also influence the behaviour of the birds and is one of the main reasons for carrying out this project (Harwood *et al.* 2018). Previous work has demonstrated that wind strength and direction have an impact on flight behaviour of a number of species including Manx shearwaters (Shepherd *et al.* 2016; Kempton *et al.* 2022). When modelling flight height distributions, wind speed and direction can be integrated into one variable, the zonal and meridional components, the impact of wind on flight behaviour will also vary depending on where the measurements are collected from (land or at-sea) (N. Gillies, pers. Comm.). Collecting accurate environmental variables will be vital to account for the impact of weather conditions on encounter rates and flight behaviour during modelling and analyses.



1.5.2 Sampling bias

It has been reported that some laser rangefinders can have a bias against collecting data at low flight heights and that therefore the rangefinder overestimates flight heights because of sampling bias (Borkenhagen *et al.* 2018; Skov *et al.* 2018). In contrast, other studies have found that the rangefinder appears to underestimate flight height due to a difficulty in taking measurements at very high heights and above the operator (Largey 2021). The studies that found the device to overestimate flight height were both platform-based studies (boat and offshore-turbine based) and therefore may have been affected by the ability to use the rangefinder below -30° inclination which is the limit of the model of rangefinder being used (Largey 2021). As the ProcBe study aims to have a significant component of boat-based data collection, with the aim to use platforms on ferries which are likely to be relatively high, this is something that we will need to consider when planning our data collection and analyses. It will be essential to ensure that we have the most accurate measure of platform height possible. For boat-based work it has been recommended that using a plumb line is likely to be the best way of estimating height above sea level as where a boat sits in the water will vary depending on weight, although this might not be possible for all boats, and we would have to rely on information provided by the operator (Harwood and Berridge pers comm.). An alternative that should be readily available is the use of a buoy or a bird sat on the water to calibrate observer height, which will also account for the eye height of the individual. These measurements could be taken at the start and end of the boat journey and opportunistically throughout where buoys or birds are seen (see Figure 18 in section 3.1.1). There will be some error in these measurements as some buoys are quite large and it is not clear which part of the buoy the readings are taken from, but this error is likely to be small compared to other errors with this method.

Manx shearwaters have a very specific and unique flight behaviour. As they go through the shear-soar cycle the profile of the bird changes as well as the colour (black upperparts and white underneath), this may influence the ability of the observer to get a fix on the bird (E. Masden, pers. Comm.) It has been demonstrated to be easier to achieve fixes with larger birds, although success was not directly proportional to size of bird or surface area in view (Skov *et al.* 2018)). There may also be a spatial bias in terms of where the birds are observed from, whether the birds are approaching from the rear, side or front of the boat.

1.5.3 Bird behaviour

We need to consider how bird behaviour may affect flight heights, particularly how birds might react and change their behaviour in response to the presence of a boat (Burger *et al.* 2019; Collet *et al.* 2015; Fliessbach *et al.* 2019; Le Bot *et al.* 2018). Depending on which rangefinder is being used there may be biases to consider relating to distance of the birds from the boat as behaviour may vary depending on proximity to the vessel. Using the Nikon, for example, means that birds may only be recorded close to the vessel compared with the reported superior range of the Vector rangefinder (see comparison in Table 1). Manx shearwaters are not considered to be a species that is consistently attracted to boats as they do not generally scavenge, although this may vary by region (Bicknell *et al.* 2013; Camphuysen 1993). Pelagic vessels that go out to specifically find and/or attract species of shearwater and storm-petrels typically use 'chumming' which takes advantage of the heightened olfactory sense that these species have to attract birds to the boat. Even if on our data collection trips the boats do not use this technique there may be a learned response which may impact the flight behaviour of these species.



Some seabirds exhibit different flight behaviour depending on whether they are foraging and commuting for example, gannets (Harwood *et al.* 2018). GPS data collected from Manx shearwaters on Skomer has highlighted that birds were most likely to be in flight between dawn and 10:00 am, then to a lesser extent in the late afternoon and early evening (Guilford *et al.* 2008). High precision fixes showed that speeds were bimodal, either sitting on the water or flying. Flight behaviour could be separated into erratic and directional flight, which are indicative of searching for food and travelling respectively (Guilford *et al.* 2008). Timing of data collection and the behaviour being observed may impact flight height and should be considered during data collection and analysis.

When using the Nikon Forestry Pro Harwood and Berridge (pers. Comm.) recommended that when taking a flight height measurement the bearing of the bird from the boat should also be recorded to help improve understanding of bird behaviour in relation to the boat and allow accurate positioning of the flight height record. However, this is an issue with the Vector 21 as bearing and azimuth do not appear in the view finder at the same time as the horizontal and vertical height distances. R. Berridge (pers comm.) suggests recording birds considered to be associated with the vessel in any data gathered.

1.5.4 Observer effects

Discussion with experts has provided vital insight into the challenges associated with using the laser rangefinders themselves, both the more basic and advanced models. It has been noted that there is a level of natural ability when using the devices, but that also user experience is important with those that are used to using binoculars regularly being more likely to be successful (Cole *et al.* 2019; Harwood and Berridge pers. comm.; Largey 2021). A number of factors may vary by observer: sampling volume, sampling frequency and measurement accuracy. In a controlled environment, such as the calibration trial, sampling volume will not change between individuals as we will be collecting a pre-determined number of data points, but the speed at which data are collected and the accuracy might change. In the field the number of fixes (sampling volume), the frequency at which readings are collected and the accuracy achieved may vary by individual Bias in accuracy and frequency (amount of time taken to collect readings) can be accounted for during data analysis of calibration data when modelling the effect of operators using mixed effect models.

1.5.5 Clutter and false readings

There has been conflicting advice given to us by experts who have used both the Vector 21 Aero in terms of the issue of clutter and how readings from background objects such as the sea can be distinguished from 'correct' readings from the desired target (Largey, Masden pers comm). Other users of a different model of the Vector have not experienced the same problem and found that either false readings were easy to distinguish or that readings could not be taken at all if they missed the intended target, i.e. readings were not possible from the water surface (Cole pers comm). The issue of clutter was not identified for the Nikon Forestry Pro (Harwood and Berridge pers comm.).



1.6 Summary

Two LRFs were identified in the literature review that have been used to collect flight height data on seabirds, the Nikon Forestry Pro and the Vectronix Vector (21 and 21 Aero models). The devices are at two ends of the spectrum in terms of cost, measurement limits (distance, height and angle) and usability (possible issues with clutter and interference). Based on the outcomes of this review it is clear that there are benefits and opportunities in using both devices as long as the biases and limitations of the devices are understood and accounted for when analysing and interpreting the data. ProcBe will make use of the most recent Nikon, the Forestry Pro II and an earlier model of Vector, the Leica Vector 1500 during the calibration exercise and in field-based data collection.

2. Section 2 – ProcBe Calibration trial

The first stage of the ProcBe laser rangefinder work was to carry out a calibration study to explore the accuracy and precision of the devices intended to be used for data collection on Manx shearwater and European storm-petrel. This study will allow us to estimate the error associated with each device and explore the limitations of their use so that we can be more confident in the data collected in the field.

Training and calibration were carried out over two days in April 2024 (24th and 25th), day one provided an opportunity for staff to be trained by an expert before the calibration is carried out so that users can get used to the device and gain a solid grounding in how it works. Training and calibration took place at Loch of Strathbeg, an RSPB reserve in northeast Aberdeenshire. RSPB reserve staff have access to multiple drones, are licensed to fly them and agreed to assist us with this project.

Calibration took place in three stages in order to assess the precision and accuracy of the different rangefinders and quantify the error associated with the measurements. The first stage used an object of known fixed height to assess accuracy of distance measurements. The second stage used a drone at varying heights and distances to assess potential error in vertical height and the impact of interaction between vertical height and distance on measurements. The final stage used a moving drone flying at a known height to assess the ability of the LRFs to detect a moving object.

2.1 Equipment

2.1.1 Vector 1500 (Vectronix) laser rangefinder

The Vector 21 Aero LRF is the most commonly used device in the available literature to measure seabird flight heights. This particular model has been discontinued and JNCC were unable to buy one, and without a comparable model available, efforts were made to lease or



borrow one. JNCC successfully agreed to borrow a Leica Vector 1500, a different model, from Swansea University and a researcher who used this device has agreed to train JNCC staff in its use.

Readings from the Vector LRF can be taken in three potential ways:

- The LRF can be connected to a laptop which, with the appropriate software and programme, can write the results straight from the device into a .csv file.
- The LRF can be connected to a GPS device where data can be stored. None of the experts we have spoken to have used this method and it is unclear how this might work.
- Readings can be taken straight off the device and dictated to a data recorder. Experts have advised us that two of five possible measurements appear on the screen when a reading is taken, straight line distance to the target, inclination angle, hypotenuse, height and azimuth. For our study we will be collecting horizontal distance and height measurements.

In the experimental stage of this project, we will be attempting to collect data at-sea where it will not be possible to use a laptop. We have been unable to speak to anyone that has used the GPS methods and therefore we will use the third option, reading out the data to a recorder.

2.1.2 Nikon Forestry Pro II laser rangefinder

The previous version of this device, the Nikon Forestry Pro, was used in several studies and is a much simpler to use device.

The Nikon LRF readings can either be taken directly from the device and be dictated to a data recorder or the device can store up to 250 measurements. Once 250 measurements are taken, subsequent readings will replace the preceding records. As the device is not able to synchronise with the UAV it is likely that to ensure the measurements can be matched up to the specific heights and distances required for the calibration exercise, calling out the readings is the most appropriate method. An advantage of this device is that the laser can be targeted continuously which means that getting a reading from a moving target is significantly easier than when using the Vector.

2.1.3 TruPulse

After discussions with staff from Scottish Power Renewables it was agreed that staff would attend the calibration trial and bring their LRF to share knowledge ahead of SPR using it for offshore surveys and allow comparison between three different devices. The TruPulse 360B, which SPR had used for onshore ornithology surveys, is a small, handheld device similar to the Nikon which combines a compass, LRF and inclinometer.

2.1.4 Unmanned Aerial Vehicles (UAVs)

Two different models of UAV were used for training and calibration. A Mavic Air 2 (253.0 x 77.0 x 183.0 mm) is a medium size drone with inbuilt GPS that is accurate to a few metres, which was mainly used for training to maximise the amount of time that users have to get used to the equipment.

The second drone was a DJI Mavic 2 Pro (322 x 242 x 84 mm) which has a more sophisticated, high accuracy RTK (real time kinematics) GPS which uses a number of satellites to provide



positional accuracy of a couple of mm. This drone, at its longest point is comparable to a Manx shearwater, 32.2 cm drone length compared with shearwater body length of around 34cm. This drone was more appropriate for the calibration study as precision in height and distance measurements was vital. In this calibration exercise the altitude measure provided by the drone GPS was taken as a measure of "true" height against which the LRF measures were compared.

2.1.5 Anemometer

Weather variables, particularly wind conditions and pressure, are likely to impact the flight behaviour of seabirds. Using a device to collect real-time weather data throughout data collection would allow us to match up flight height readings with weather variables. Previous studies have used a Gill Windsonic anemometer (Largey 2021; Shepherd *et al.* 2016) which measures wind speed and direction. A Kestrel anemometer that measures wind speed and direction in addition to other variables such including temperature and pressure was recommended to us and the Kestrel 5500 was selected as it gave more variable recording options than other models.

2.2 Training and calibration

2.2.1 Stage 1

The first stage of the calibration used a telescopic pole with a flag mounted on the end which provided a target of known, fixed height. It was measured whilst flat on the ground prior to being erected and secured. A series of tape measures (100m each) were laid out from the pole in a straight line with a peg being inserted in the ground at 10m intervals. The terrain was somewhat uneven and with tussocky grass which made getting the tape flat to the ground challenging at times, but the measurements should be accurate enough for the calibration to work. The measurements of each 10m interval based on the tape measure were calibrated using the high-accuracy RTK GPS drone.

This stage of calibration focussed on testing the accuracy and precision of the LRF with varying distance as it has been demonstrated that both distance and height can affect the accuracy of the rangefinder. Varying the distance only based on a static object of known height controlled for error caused by changes in height (Largey 2021). This stage of the calibration study was vital as the height reading is calculated based on the distance to the target and the inclination angle (see Figure 3). Performing two calibrations allowed the errors in each reading distance and height (in this instance used as a proxy for inclination as we could not get all three measurements within the viewfinder of the device at the same time), and the interaction between the two to be assessed. Readings were taken over a series of distances with a minimum of 10 readings taken at each distance band starting from 10 m and increasing to as far as the rangefinder could reliably get a reading (for example see Figure 4). Based on previous studies, around 12 distance intervals were deemed appropriate depending on visibility and feasibility at the site (up to 5 km as completed by Cole *et al.* 2019 and Largey 2021). As measures of vertical height are calculated by the devices based on horizontal distance and angle, the distance between the drone and the LRF must be measured accurately in order for the accuracy and precision of measurements of vertical height to be assessed at increasing distances.



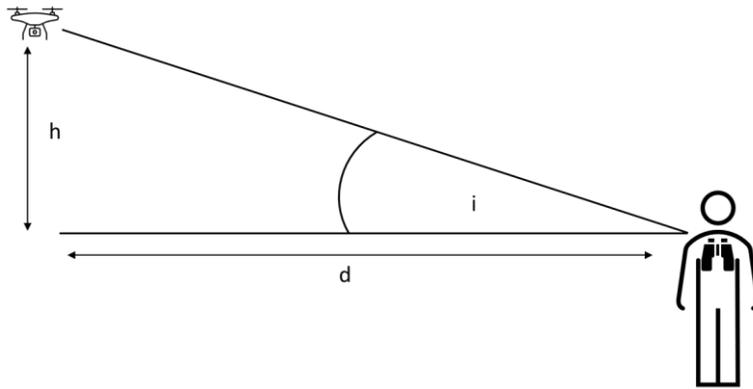


Figure 3. The laser rangefinder measures horizontal distance (d) and angle of inclination (i) to allow calculate of vertical height (h) which is subsequently adjusted based to take account of the eye height of the observer.

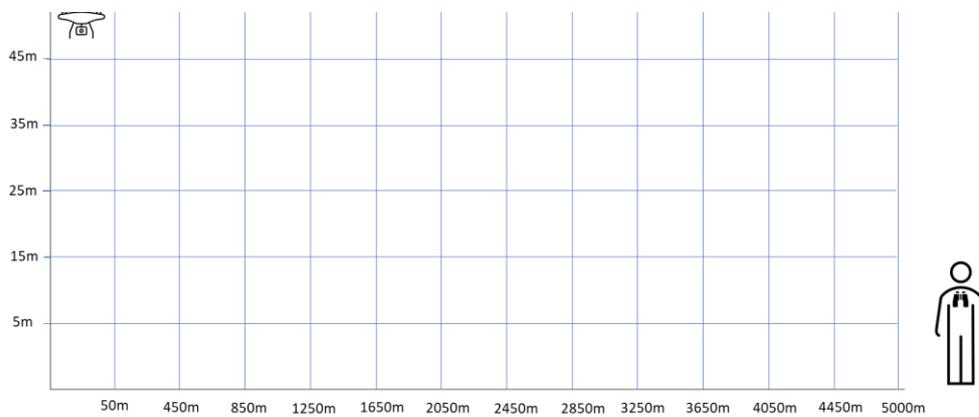


Figure 4. Example distance and height bands for the calibration study using the rangefinder.

2.2.2 Stage 2

A second calibration was carried out using a UAV to test the accuracy and precision of the LRF when height, then both height and distance are varied (see Figure 4). This stage of the calibration is limited by the legal limits on flying a drone, the accuracy of the UAVs in-built GPS and the length of time we had with the drone.

The UAV can fly to a maximum height of 110 m so was programmed to fly at a series of vertical height bands between 10 m and 110 m at 10 m intervals (11 different height bands) with each height band being flown at a series of distances between 25 m and 300 m which varied between devices based on their performance (height and distance combinations shown in Figure 5). The UAV was then flown at a series of increasing distances (10 m to 350 m varying between devices) at height intervals of 25 m, 50 m and 100 m. It was hoped that by choosing a wide variety of different height and distance combinations the relationships between height, distance and the combination of both could be investigated.

The Vector has a reported range of up to 5 km therefore the distance increments need to be larger than for the Nikon and TruPulse which have a reported range of up to 1.6 km (although



it may be less for a small object such as a UAV). The UAV has an inbuilt, high-quality GPS which can measure height/distance within a few cm of accuracy, with the distance between the operator and UAV measured using the in-built UAV GPS which measures distance from take-off point, the LRF operators stood on or very close to the take-off point (around 1-2 m away). 10 attempted fixes were taken for each height and distance position (for example, 10 attempts at recording readings were taken at a height of 10 m and distance of 50 m, then at a height of 20 m and a distance of 50 m etc).

Some of the height and distance combinations were repeated over the two days. For the Nikon, different individuals used the device while for the Vector only one individual carried out the calibration. The TruPulse was not able to collect data at this combination of measurements as the distance was beyond the range at which it could consistently collect data.

Linear mixed models (LMMs) were fitted to assess the potential effects of UAV distance and height from the observer on LRF height measurement error. Device (Nikon, TruPulse or Vector), UAV distance and UAV height were modelled as interacting fixed effects, with random intercept observer and distance-by-height group effects to account for non-independence of repeated measurements by observers and at each distance and height band combination. Models were fitted in R 4.4.0 (R Core Team, 2024) using the 'lmer' function from the lme4 package (Bates *et al.* 2015), and predictions and their 95% intervals were modelled using the predictInterval function from the merTools package (Knowles & Frederick, 2024).

For stages one and two, as well as height measures, the number of successful and failed recording attempts were recorded to assess the effort required at each height and distance. A total of ten attempts were made and where a reading was not returned this was noted.

2.2.3 Detection bias

As the height and distance of the drone increase, the accuracy of measurements may be affected, but there is also likely to be an additional challenge in terms of the ability of the LRFs to achieve a fix as the target becomes relatively smaller. We measured this during our trial by recording how many successes and failures were recorded within the ten attempts to achieve a measurement, as well as the total time taken to record the ten attempts. It is hoped that by determining the distance and height thresholds at which the device is recording more failures than successes we can assess how each device might be used in the field and where the limitations might lie.

Although it is likely to get more challenging with distance, if the same observer is collecting data for an extended period the level of challenge may be mitigated by experience as the observer gets better. Equally, fatigue may play a role, this is potentially confounded by the fact that detection is likely to be more difficult at distance. Measurements started closer to the observer and so the UAV got further away as possible observer fatigue increased.



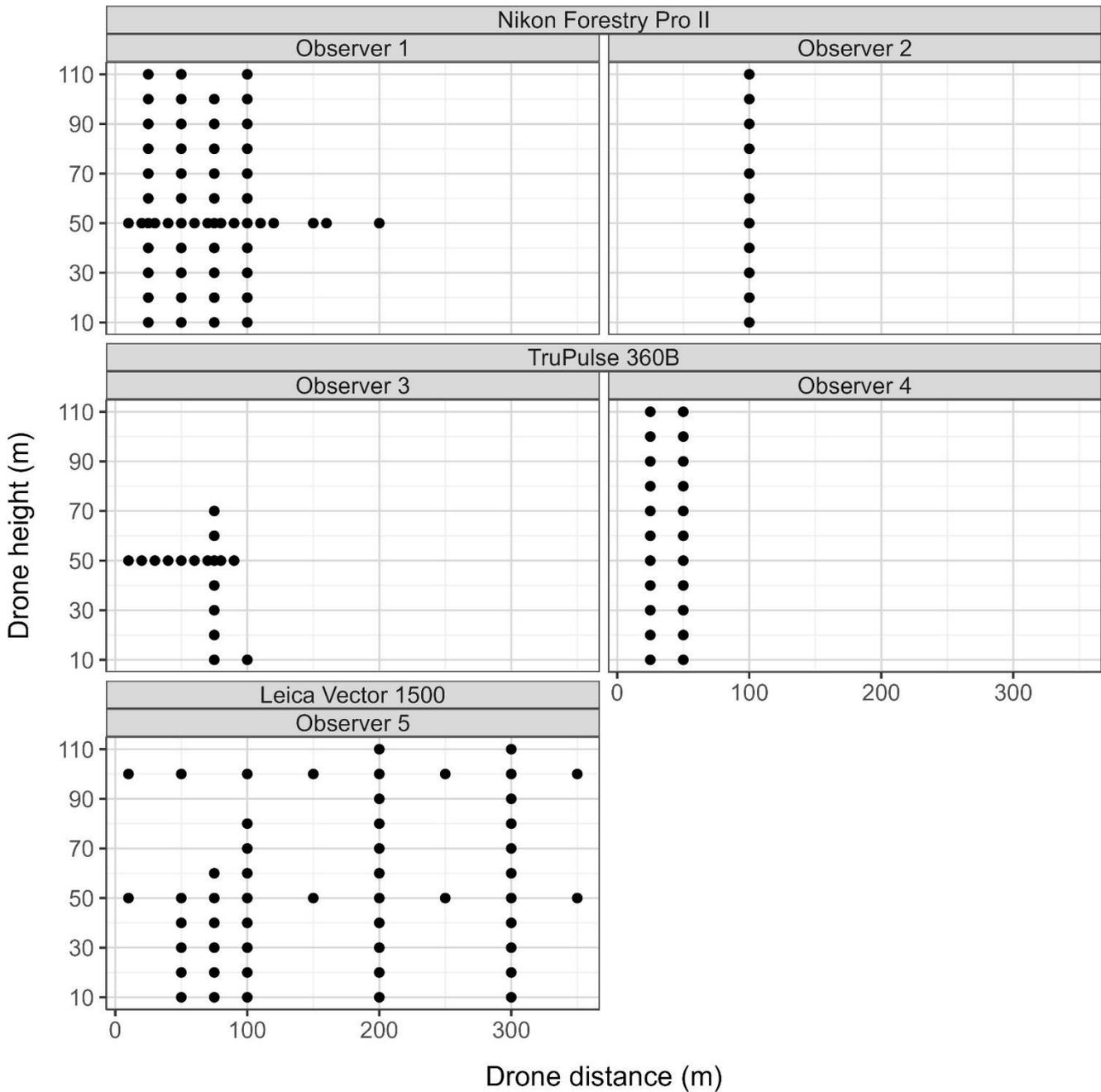


Figure 5. Drone distance and height bands recorded for each LRF device by observers during the calibration trial.

2.2.4 Observer effects

There are different ways in which the observer using the LRF may impact data quality; sampling frequency or volume and measurement accuracy. Accuracy can be evaluated by comparing the results of multiple different observers using the same device on the same target, whereas sampling frequency or volume can be assessed based on the number of fixes an individual can achieve in a given time or how long it takes to achieve a given number of readings. We have data to assess both of these components of observer effect.



Data were collected by two individuals using the same device and recorded the time each combination of heights and distances took to collect at every height and distance combination.

2.2.5 Stage 3

A final trial calibration exercise was carried out on a moving UAV. In previous work this has been done by syncing the clocks within the Vector and the UAV so that timestamps between the devices and therefore the altitude readings from the LRF and UAV GPS can be synced. This was not possible for this calibration study as it proved too difficult to source the laptop and cable connection/input required equipment. For this study the drone was flown at a fixed height with the speed and distance varied to provide a proxy for a bird in flight. The three devices then collected data for a set period of time to allow comparison between the number of readings collected between devices.

The purpose of this stage of the calibration is not only to replicate the nature of the fieldwork by using a moving target, but also an opportunity to explore the potential bias of sampling volume. From a boat or from land there will be restrictions on the area it is possible to sample. From land this may be a 180° area, or maybe more depending on the location whereas for a boat that is moving it is likely to be smaller. Using a moving target that can provide a variety of angles for the observer to collect from it somewhat replicated conditions in the field. It may be more challenging to collect data in certain portions of the total observable area. Therefore the drone was flown across a variety of paths, e.g. across the field of vision, left to right, at different distances from the observer and different speeds. This stage of the calibration was not essential to assess the accuracy and precision of the devices but provided a good training exercise.

2.2.6 Data treatment

All rangefinder devices estimated target height based on the height that the measurement was taken from, see Figure 3, for all stages of the calibration, every measurement taken was adjusted based on the eye height of each individual observer.

Some data were identified during analysis that appeared to show a notable increase in error, i.e. difference between measured LRF height and UAV GPS height, uniformly across all three devices. Mean height difference at the 25 m height category was 1.94 m for the Nikon, 1.93 m for the TruPulse and 2.7 m for the Leica Vector 1500, compared with an average of 0.7 m, 0.3 m and 0.5 m respectively across all other height categories. All devices were recording measurements at the same time therefore this difference was not caused by environmental conditions, and it seems unlikely to be observer error as the data was consistently different across all devices. It seems most likely that this error was caused by the drone position being incorrect, potentially being flown at the wrong height. These data were removed before analysis.

Three other data points were removed from analysis that were clearly not readings recorded from the drone, rather from clouds or other objects (e.g. 5500.9 m height recorded when the drone was at 50 m height).

Sample sizes for each height and distance combination were recorded for each device and can be seen in the Appendix of this document (Table 5). This table shows the total number



of attempts made at each height and distance increment alongside the number of successful fixes achieved.

2.2.7 Stage 1 Results

The tape and pole were used to assess the accuracy and precision of the three devices on an object of known height across increasing distances. Each of the devices was operated by the same individual throughout the 'object of known height' trial. They moved away from the pole at 10 m increments, taking 10 readings at each distance up to a maximum distance of 150 m. Part way through the trial it became clear that the pole was bending in the wind, away from the observers, and therefore the distance from the observer ranged by around 2-3 m. Although the data collected in this stage of the calibration may provide some insight into the different devices, the error conveyed by the wind moving the pole cannot be accurately quantified and was not uniformly exerted throughout the exercise. It has therefore been decided to carry out a further calibration on a different fixed object later this year so that this can be explored ahead of any decisions on future data collection.

Height measurement error (see Figure 6) was defined as the difference between LRF "observed" and "true" UAV heights, with positive and negative values indicating that LRF observations overestimated or underestimated height, respectively.

Of the data that were collected across all three devices overall the TruPulse was the most precise across all distances, the device underestimated height between 1 m – 2m but was remarkably consistent throughout. The Nikon produced height estimates that were closest to the "true" value, bearing in mind the unquantified error associated with the wind. The overall precision was high but decreased with increasing distance (from 90 m onwards). Surprisingly the Vector appeared to be the least accurate and, consistently underestimating height up to 4.5 m which is almost 50% of the true height (9.6 m). This may in part be caused by the device rounding measurements to the nearest metre, but this is unlikely to be the source of all of the error in the measures. Although it was potentially less accurate it was by far the most precise with highly repeatable readings (see Figure 7).



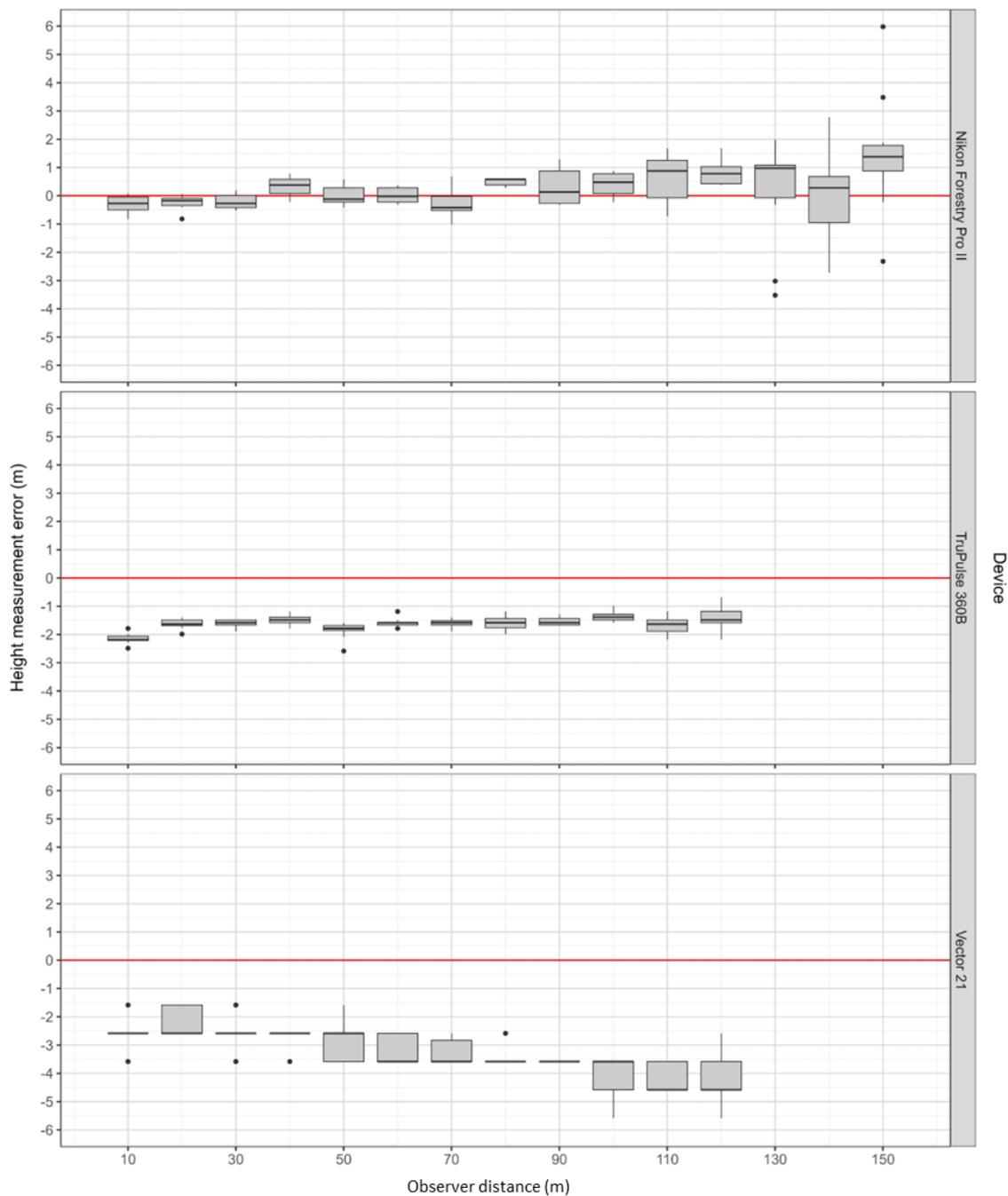


Figure 6. Error in height measurements of three laser rangefinders, Nikon Forestry Pro 2, TruPulse 360B and Vector 1500 with increasing distance when compared to true height of an object of known fixed height, a telescopic pole with mounted flag.

A short calibration of the in-built drone UAV was carried out to make an assessment of how accurate the drone GPS was in comparison to a known horizontal distance, which was measured using the tape. As the stakes we used to mark the 10 m increments were not very visible to the drone an individual walked along the tape and stood directly over the measured 10 m interval, the drone then hovered just above the individual, as directly above as possible. The drone distance measurements were then taken as well as the real-time error in both the x- and y-axes. The error associated with the RTK GPS measurement was recorded at each distance increment and ranged between ± 7 mm and 11 mm.



2.2.8 Stage 2 Results

2.2.8.1 Effect of height and distance

As expected, the Vector had the greatest range, recording readings from the UAV up to 300m from the observer, followed by the Nikon and then the TruPulse. Analysis of the data suggested that both the TruPulse and Vector devices were reasonably accurate across the tested range of distances and heights; height measurements were generally within 1m of the true UAV height (Figure 7, 8), although there did appear to be a tendency for the Vector to consistently, slightly underestimate height, regardless of UAV distance or height (Figure 7). Given the consistency of the underestimation the error may be easier to account for at the data validation stage rather than if the error appeared more random or changed depending on observer or weather variables etc. Furthermore, while height measurements appeared relatively consistent across varying height and distance for both the TruPulse and the Vector, variation in height measurements recorded on the Nikon increased with distance between the UAV and the observer (Figure 7).

As described above, the same observer generally operated each device for the majority of the calibration exercises, however, this was not the case for every height and distance combination. As we will discuss further later in this report, there may be an effect of observer on the accuracy of data collected. As well as using the pooled data for analysis and modelling we have also carried out the same analysis for the primary observer i.e. the observer that collected the most data points for each device across the two days.

Overall, model results indicate that both the TruPulse and Vector devices were reasonably accurate across the tested range of distances and heights. Estimated height measurements were generally within 1m of the true UAV height (Figure 8b), although model estimates were associated with non-negligible error across the range of distance and height values (Figure 8 a,c).



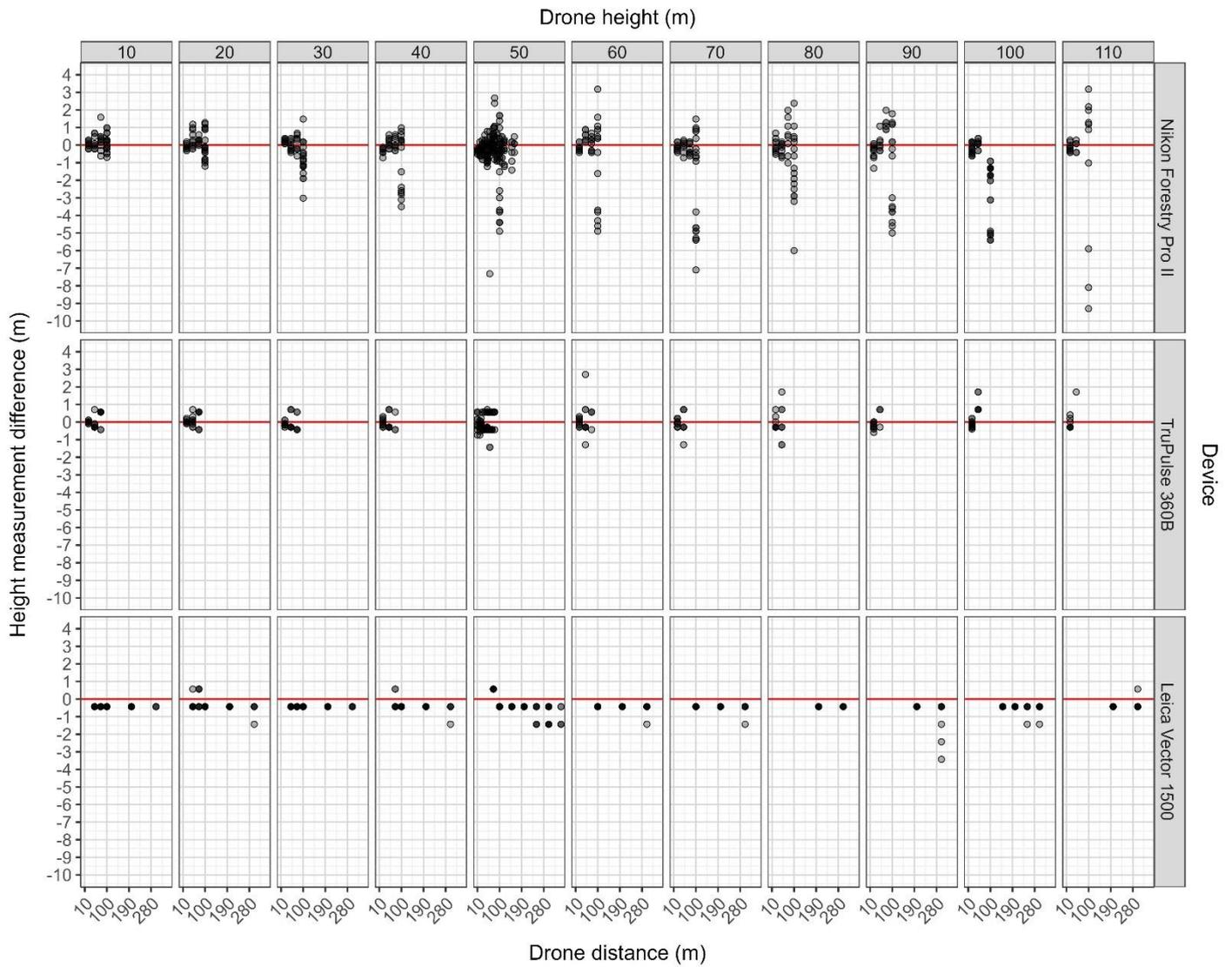


Figure 7. Difference between UAV height measurements and estimates from of three laser rangefinders, Nikon Forestry Pro 2, TruPulse 360B and Leica Vector 1500 with increasing distance (primary x-axis) and height (facets). Positive and negative values indicate that LRF observations overestimated or underestimated height, respectively.



Table 2. Mixed effects linear regression model outputs for model of height measurement differences between the UAV "true" height measurement and LRF height estimates (1368 height measurements)

Fixed effects:

	Est.	S.E.	t val.	d.f.	p
(Intercept)	-2.49	1.24	-2.01	2.48	0.16
distance	0.02	0.01	4.39	132.85	<0.01
height	0.01	0.01	2.21	131.26	0.03
device_TrnPulse	2.43	1.80	1.35	2.76	0.28
device_Vector	2.21	2.10	1.05	2.28	0.39
distance:height	-0.00	0.00	-4.75	132.38	<0.01
distance:device_TrnPulse	-0.03	0.01	-2.00	132.25	0.05
distance:device_Vector	-0.02	0.01	-4.32	133.21	<0.01
height:device_TrnPulse	-0.02	0.01	-1.72	130.98	0.09
height:device_Vector	-0.01	0.01	-1.04	130.38	0.30
distance:height:device_TrnPulse	0.00	0.00	2.78	137.18	0.01
distance:height:device_Vector	0.00	0.00	4.21	132.41	0.00

Random effects:

Group	Parameter	Std. Dev.
Observer	(Intercept)	0.56
Group ID	(Intercept)	1.65
Residual		0.52

Grouping variables:

Group	Number of groups	ICC
Observer	155	0.10
Group ID	5	0.82



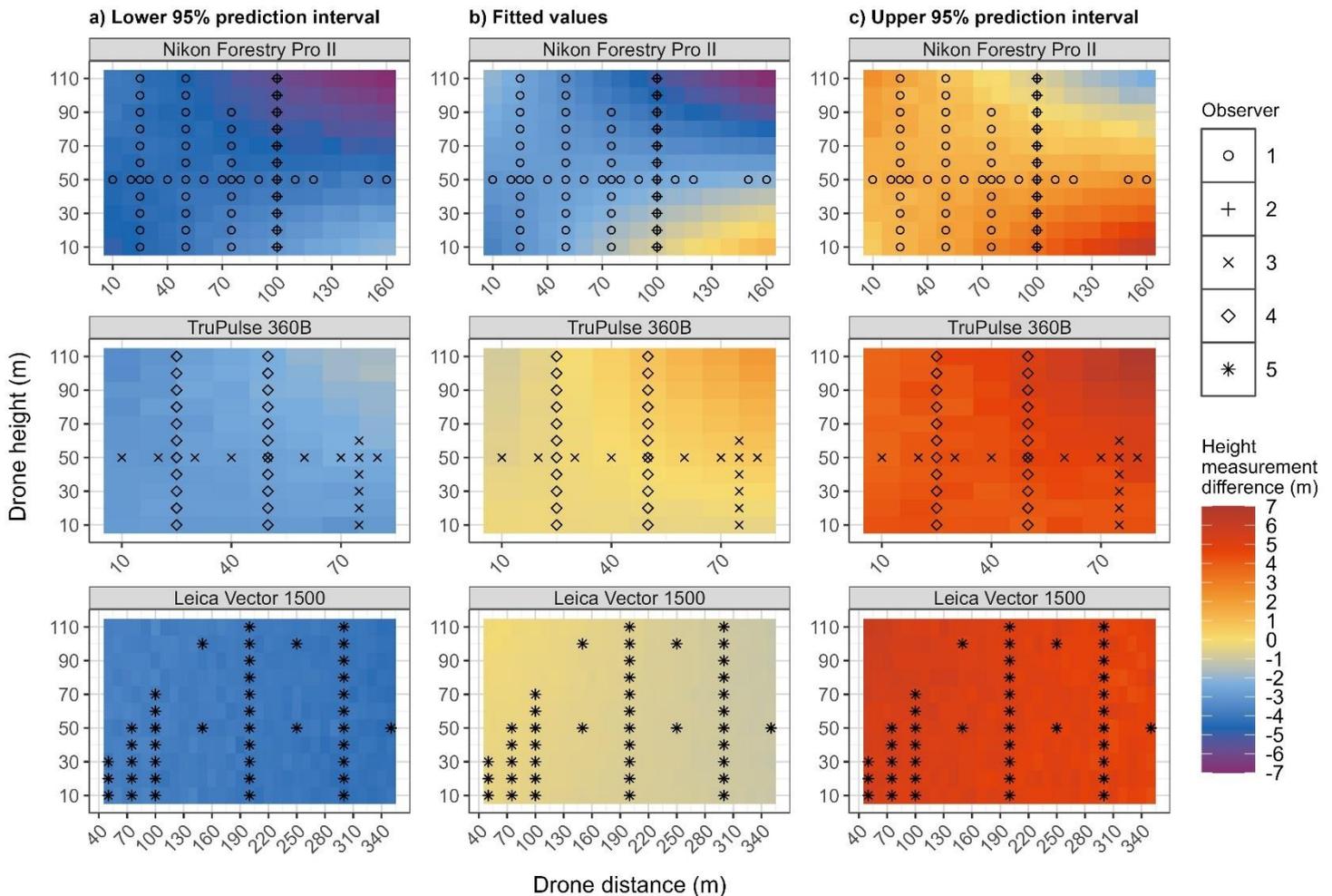


Figure 8. Predicted effects of UAV distance (m) and height (m) from the observer on LRF height measurement error (b) for the three laser rangefinders, with associated (a) lower and (c) upper 95% prediction intervals. Positive and negative values indicate where model predictions estimate that LRF observations overestimated or underestimated height, respectively. Points denote distance and height values where calibration data were recorded for each device, with symbol shape indicating the observer. Note the different horizontal scales.

Model estimates for the Nikon, however, show substantial variation across the distance-height parameter space, with model predictions suggesting very poor measurement accuracy, particularly at high distance and height combinations where estimates suggest that the device is substantially underestimating height. However, it is important to note that there was very sparse data in these higher distance bands and were likely impacted by the substantially lower height estimates recorded by one of the two observers (see Section 2.3.4 for details), and so estimates here are likely to be unreliable.

2.2.8.2 Detection bias results

To assess the potential effects of UAV distance and height on the capacity to record a height measurement with each LRF device, detection bias, a general linear model (GLM) was fitted, with device, distance and height fitted as fixed interacting effects (see Table 3). Initial attempts to fit a more complex mixed effects model structure that could include random observer effects faced issues with convergence and parameter estimation, and so for current



purposes we reverted to a simpler general linear model. However, this model frequently poorly predicted observation fix rate.

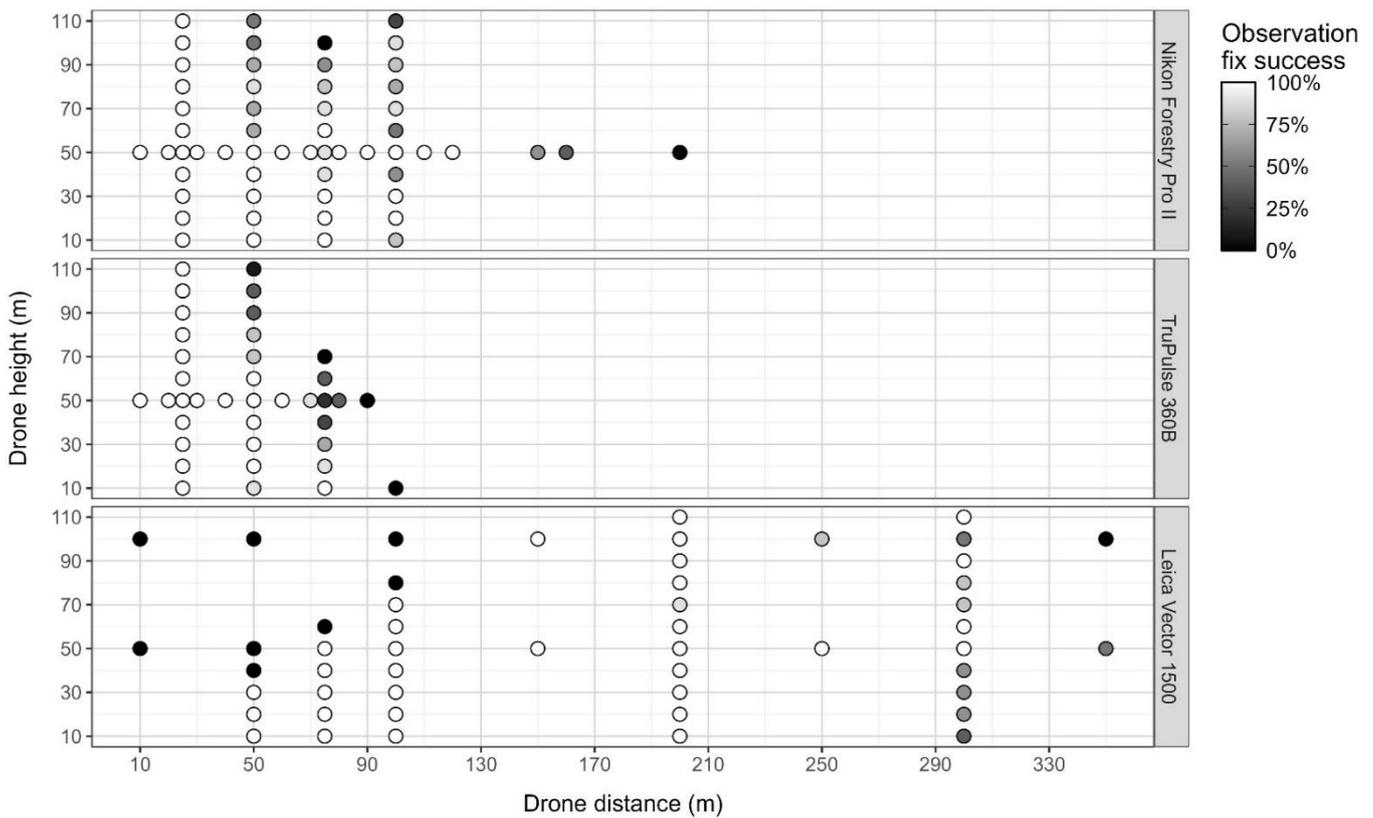


Figure 9. Measured observation fix rate by varying drone distance and height for the three laser rangefinders.

Figure 9 highlights how well the Vector performs at detecting the target, particularly at the further distances. The device struggles to deal with acute positive and negative angles which is demonstrated but the 0% fix rate at the closer and higher height and distance combinations. The Nikon and TruPulse perform comparably at the 25 m and 50 m distances, but beyond this the TruPulse declined very quickly in its ability to achieve fixes. The Nikon continued to perform well out to 110 m distance and beyond this there were not many more distance increments attempted.



Table 3. Generalized linear model outputs for a model of fix success of LRFs on a UAV, the model has a binomial structure based on success and failure of each LRF to gain a reading of height (link function: logit; number of observations: 171)

Fixed effects:

	Est.	S.E.	z val.	p
(Intercept)	10.26	1.2	8.55	<0.01
distance	-0.06	0.01	-5.74	<0.01
height	-0.09	0.01	-6.33	<0.01
device_TruPulse	9.56	3.29	2.90	<0.01
device_Vector	-6.41	1.31	-4.90	<0.01
distance:height	0.00	0.00	3.79	<0.01
distance:device_TruPulse	-0.15	0.04	-3.71	<0.01
distance:device_Vector	0.05	0.01	4.76	<0.01
height:device_TruPulse	-0.03	0.04	-0.84	0.40
height:device_Vector	0.02	0.02	1.50	0.13
distance:height:device_TruPulse	-0.00	0.00	-0.20	0.84
distance:height:device_Vector	-0.00	0.00	-1.95	0.05

2.2.8.3 Observer effects results

The Nikon Forestry Pro 2 was used by two observers at a fixed distance of 100 m and varying height between 10 m and 110 m. The different observers collected the data on different days but had similar levels of experience using the device.

It was not clear until the second day of data collection commenced that the weather, specifically the background against which the drone was flying (contrast), may have had an important impact on the ability of the devices to get successful readings. We did not have time to investigate the impact on background/contrast on the detection capabilities of each device empirically. Anecdotally, when the Lecia Vector 1500 was being used and was unsuccessful at achieving readings with a cloudy, low contrast, back drop, the UAV was moved so that there was blue sky behind it (same height and distance) and fixes were successfully achieved. When data analysis began and the impact of observer was explored for the Nikon LRF, there initially appeared to be a difference between observers, with the data collected by observer one appearing more accurate overall as height increased (See Figure 10). The difference between the observed and “true” height values for observer one remained consistently within $\pm \sim 3$ m, whereas as height increased the difference between observed and “true” values for observer two increased to almost 10 m (Figure 10). Observer 2 also consistently recorded values below the “true” height, underestimating height. This difference in accuracy could be caused by a number of factors.

When the impact of cloud cover is considered, a clear correlation between observer and cloud cover is observed, with Observer 2 experiencing cloudier conditions which may have impacted their ability to obtain accurate readings (See Figure 11). Given the correlation between the observer and cloud cover variables, we are unable at this stage to definitively state which



variable is causing the reduction in accuracy and whether this is simply a correlation or if there is causation between the factors. It would seem logical that the change in contrast would have more of an impact in the ability to achieve a reading, rather than affecting the accuracy of the readings themselves, but this cannot be defined based on the data we have. If possible, we hope to explore this relationship further in the next stage of data collection where we will control for weather conditions.

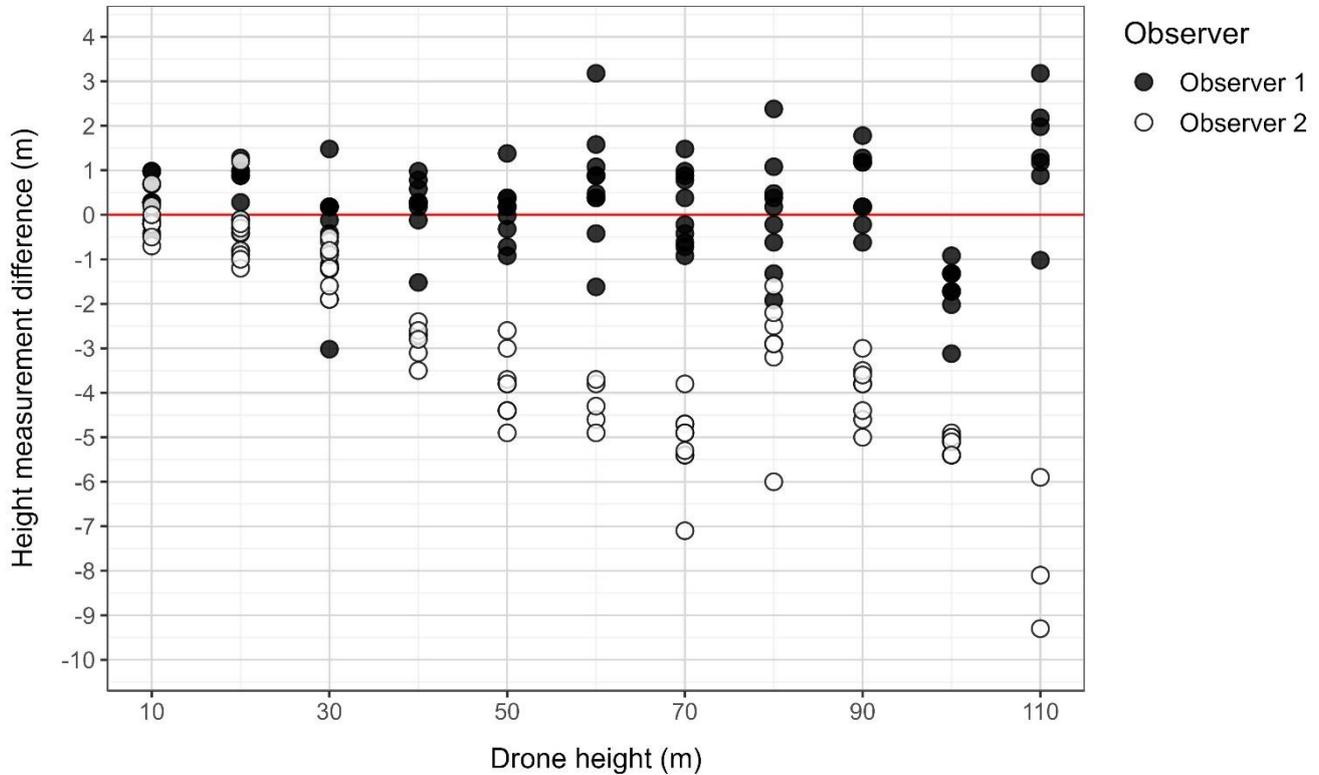


Figure 10. Observed differences in altitude estimates between the Nikon Forestry Pro 2 laser rangefinder and the UAV in-built RTK GPS when operated by observer 1 (top panel) and observer 2 (bottom panel) over increasing heights. The colour of the circles indicates the percentage cloud cover.



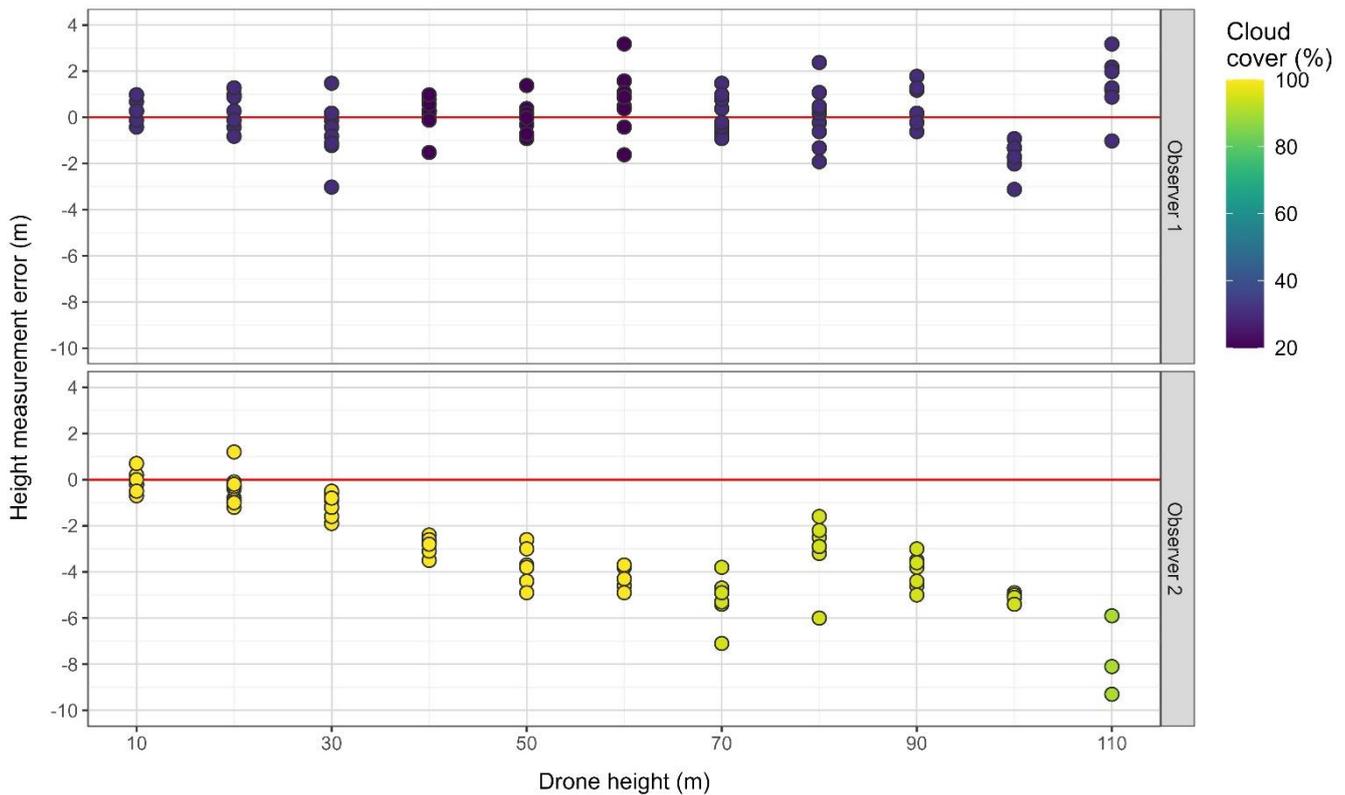


Figure 11. Observed differences in altitude estimates between the Nikon Forestry Pro 2 laser rangefinder and the UAV in-built RTK GPS when operated by two observers over increasing heights.

When comparing the data from Observer 1 & 2 the accuracy of the measurements is very similar and accurate for both in the first 30 m, it is after this that the disparity becomes evident, and increases as the distance also increased. This suggests that the source of error may be being amplified as distance increased rather than being evenly distributed across all measurements, which is what we might expect if the error was caused by environmental conditions.

If contrast and/or environmental variables were not the cause of the disparity between the two observers, a couple of potential sources of error have been identified. User ability may be a factor, however both observers had used the device a similar number of times before doing the calibration exercise and are both very experienced in using telescopes and binoculars for long periods of time. It has been reported that the Nikon is very sensitive to tilt and observer 2 may not have been holding the device completely perpendicular to the horizon which would lead to an error in the LRFs calculation of height. A final potential source of error is that Observer 2 was wearing glasses whereas Observer 1 was not. Although neither the glasses themselves nor the eyesight of the observer is likely to cause error in of itself, the glasses may have had an impact on the angle the device was being held at. As the device uses angle and distance to calculate the height of a target, even a small error in angle can have a large impact on LRF measurements of height, which would increase as distance increases (see Figure 12). Both LRF tilt and changes in the way the device is held when the observer wears glasses could contribute to an error in height measurement.



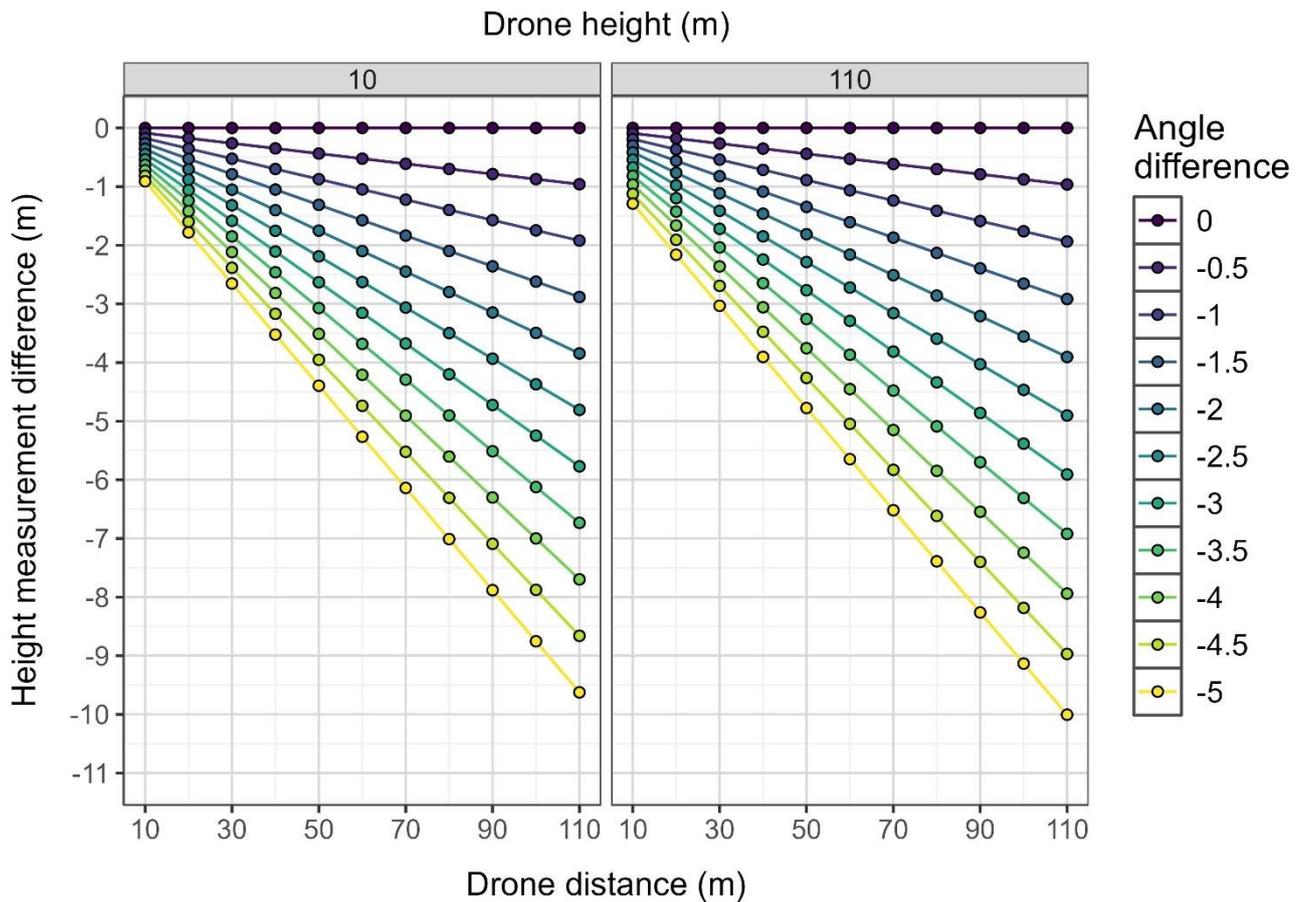


Figure 12. Simulated data showing the impact of inclination angle error on height measurement difference between the UAV “true” height and LRF height estimate over increasing distance and across a range of angle differences.

2.2.8.4 Observer effects: sampling frequency or volume

Based on advice prior to the calibration we aimed to explore the effects of the individual observer on sampling frequency or volume. We did this by recording the amount of time it took to achieve the required readings at each height and distance combination. For the majority of the measurements the time was recorded to the nearest minute. When it came to analysis it was clear that this resolution was not fine enough to give any meaningful indication of sampling frequency, particularly as for the Nikon LRF the speed at which readings were achieved was high. Even though it was certainly more challenging and likely took longer at larger distances, this could not be captured in the analysis and is something we will record more precisely if we carry out any further calibration work and will also try to capture when collecting data from birds in the field.



2.2.9 Stage 3 Results

Time restrictions on the day meant that the opportunity to explore the use of a moving drone was very limited and was taken as more of a training and exploration exercise. The UAV was flown at fixed, undulating and random heights at two different speeds and two different distances. The number of fixes achieved by each device was recorded to make an assessment of usability of the devices on a moving target (see Table 4) (height measurement was not recorded so accuracy was not assessed).

Table 4. Summary of data collected by three LRF devices from a drone moving at a variety of heights, distances, speeds and flight paths

Distance from observer	Speed (m/s)	Height	Time period (s)	Number of fixes		
				Nikon	TruPulse	Leica Vector 1500
80	4	Fixed	30	11	4	4
80	8	Fixed	30	6	4	3
150	4	Fixed	30	6	0	5
150	8	Fixed	30	5	0	3
80	4	Undulating	30	6	5	4
80	8	Undulating	30	7	2	3
Random	Random	Random	60	19	14	5

This was a very simple exercise, and we cannot draw any conclusions about the ability of the devices to accurately measure the height or distance of the UAV, but it was clear that the Nikon was the easiest to use on a moving object. This is likely to be because the laser beam can be kept on continuously and so as soon as the UAV was detected a reading was recorded. The Vector seemed to be the most difficult to use as the laser is operated through a combination of button clicks which means the observer has to be very precise when taking the fix, but there is also a delay between readings, whether they were successful or not reducing the potential number of fixes that can be taken. The TruPulse failed to record any fixes at the further distance (150 m) but was quite successful at the closer distances.

2.2.10 Data limitations

As described previously (section 2.2.6) when the drone was flying at a fixed height of 25 m and across increasing distance the measurements were consistently measured lower by the Nikon, TruPulse and Vector, it seems most likely that the error was in the drone height measurement, that the drone moved during the data collection and the operator did not notice. These data were therefore removed from analyses.

The calibration was carried out over two days, with the pole calibration and a few drone calibrations being undertaken on the first day, once some training had been completed. The operator of each device for the pole calibration was consistent across all distances but was varied across the different drone calibrations; the majority of which was carried out by one 'primary' observer (except for the Vector which had the same operator across all drone



calibrations). This was done to allow for sufficient training opportunities for all attendees, but this has highlighted some issues during analyses.

Although the majority of the drone calibration was carried out on the same day (day 2) there were differences between the weather conditions on the two days. When carrying out the analyses, the weather conditions were considered, particularly cloud cover and wind speed, because, from the experience of the observers during the calibration, differences in background conditions (blue sky or cloud) seemed to have affected the ability of the LRF to get a successful fix.

2.2.11 Model limitations

Initial inspection of model predictions suggested a notable apparent difference in accuracy between the devices, and with increasing UAV distance and height from the observer for the Nikon (Figure 8). However, predicted patterns across the device-distance-height parameter space may not be reliable due to several potentially confounding factors that were identified through the calibration trial data collection, and later in the properties of the resulting data, which could not be fully controlled for in the current models.

Firstly, apparent differences between devices could be confounded by observer effects. Data collected during the calibration trial were generally collected by one primary observer for each device, with no overlap of observers between devices (Figure 8). Therefore, it was not possible to robustly separate the potential impacts of observer and device on the measurement accuracy. Comparisons within devices when data were recorded over the same distance and height bands by two different observers were also limited due to contrasting environmental conditions present during data collection; here, environmental conditions (namely cloud cover) were highly correlated with observer, preventing meaningful comparisons to untangle potential observer effects. Therefore, although random intercept observer effects were included in the model and captured a notable portion of the residual variation (See Table 3), it was not possible to robustly attribute this variation to device, observer or environmental effects. Further data collection across multiple observers, where observer is randomised across device, distance and height measures, and ideally key environmental conditions, would facilitate assessment of these potentially important confounding effects and hence device capacities, particularly as these potential impacts have not been robustly addressed in previous studies. In particular, further data collection may improve predictions of the relationship between distance and height on measurement error for the Nikon, where observed patterns were substantially different between observers (Figure 8) and likely contributed to a poor model fit.

Secondly, inspection of model residuals suggested a degree of heteroskedasticity, where the model residual variance increased with increasing UAV distance; a trend that was primarily driven by Nikon height measurement data. As heteroskedasticity can result in lower estimated variances of regression coefficients, predicted Nikon measurement error uncertainty may be underestimated. While there are modelling methods which can address these issues (for example by fitting models that allow different variance structures; e.g. Largey 2021), this apparent increase in measurement variance with distance is an important feature to consider in the context of overall reliability.

Third, the current model is predicting over parameter space where there was sparse or no data. As such, caution should be taken when interpreting these values.



While the Nikon and TruPulse were both effective at successfully and accurately recording heights at short distances (20m) across all heights measured, this declined with increasing distance, with only the lower height ranges (include these in brackets) consistently achieving a high number of fixes, and relatively few fixes above 100m distance. The Vector, however, struggled at both ends of the distance range, although could successfully and consistently record fixes at greater distances than both the Nikon and TruPulse.

2.3 Lessons learned and next steps

Our data have highlighted some issues in our data collection protocol and therefore we identified some further calibration stages to undertake to improve our understanding of some factors such as weather, inclination angle and observer effects.

It was hoped that by using a primary observer this would control for the effects of observer, however given the other contributing factors this may not have been the best approach. Although it was thought this might have made things more straightforward for the calibration it is clear that the more variation that can be captured the more power the models will have.

The fixed object calibration will be carried out again in calm conditions so that we can have more confidence in the results. At the same time as we do this, we will conduct more exploration of observer effects. We will have two observers and two devices (Nikon and Vector), with each observer using each device in quick succession at each distance interval so that we can control for weather conditions. The TruPulse used during the calibration was loaned and based on the results we will not pursue using it for the rest of the ProcBe work. We will record the time taken to achieve the required number of readings to the nearest second to allow us to explore sampling frequency more effectively. We will also explore the possibility of calibrating the devices from above the target, to investigate the possible limitations of negative inclination angle. As the Vector only provides two measurement readings in the viewfinder at once, we will repeat each set of readings for this device to collect distance, inclination angle and height which will allow us to explore the different measurement errors and limitations.

For the Nikon in particular it would be beneficial to collect more data at the extremes of its height and distance capabilities to provide more confidence in the accuracy of data collected at these ranges.

At this stage of the project it is felt that we cannot definitively assign correction factors to any data collected in the field based on the results of the calibration trial. The analyses have highlighted limitations in the data that would need to be explored before any such adjustments or assumptions can be made. Despite the lack of absolute clarity, we can see that the spread of data collected, therefore accuracy, over increasing distance will mean we have to treat height estimates collected with the Nikon with more caution, particularly beyond 100 m distance. The Leica Vector 1500 showed a much more consistent accuracy across all distances and therefore we can treat data collected using this device with more confidence.



3. ProcBe planning: land- and boat-based data collection

When developing the data collection protocol the first consideration is how and why the data are going to be used. As described earlier in the report the priority for this work package (within ProcBe) is to gain a better understanding of the height at which shearwaters and storm-petrels fly. This includes the maximum height, and also the proportion of time spent at any given height, which can be derived from snapshot flight readings modelled into a distribution curve. Doing this will allow us to ascertain whether these species are at risk of collision with OW turbine blades. Collision risk is currently estimated using Collision Risk Models which require flight height data to be provided in the form of a flight distribution curve (Band options 3 & 4) or a proportion of time spend during the collision risk zone (i.e. Band options 1 and 2) (Band 2012; Johnston *et al.* 2014). A flight distribution is a collation of data points which can be used to assess the proportion of time spent at specific flight heights, allowing the amount of time a particular species may spend flying within the rotor swept zone to be estimated and therefore the potential opportunity for collision.

This section of the report takes the evidence and experience collated in section 1 & 2 to design the methods to be undertaken during the ProcBe project to improve estimates of flight heights for shearwaters and storm-petrels. This is particularly important given the expansion of OW as estimates of flight heights for shearwaters and petrels have high uncertainty and have only been collected in a narrow range of weather conditions which will impact the confidence in which we can assess risk.

Given the paucity of data on shearwater and storm-petrel flight heights, all data collected during this study will improve our understanding and reduce uncertainty. Collecting maximum flight heights will inform on the potential risk for these species to overlap with the rotor swept zone of turbines. To create a distribution of all possible flight heights, representative data should be collected, and for Manx shearwater in particular which has a distinctive flight pattern, ensuring the entire shear-soar cycle is recorded is vital (i.e. the proportion of time birds spend at different points in the shear-soar cycle as a percentage of time they spend on the wing). For Manx shearwater this is represented by Figure 13 which demonstrates how the altitude changes over time and the portion of the shear-soar cycle where birds could potentially be at collision risk height.

Flight data will be collected using the LRF and will be randomised as far as possible using a simple sampling strategy to reduce any biases and provide data that is representative of the entire population, across a range of environmental conditions and which is collected from both land and sea. These data can either be used raw, to plot flight height distribution, or can be assigned to flight height bands, within a range of heights or expressed as a proportion (see Figure 14).

Two methods for data collection using a LRF have been identified in the literature that can provide data for a flight height distribution. Single data points can be collected from individual birds as they pass the observer, the readings should either be taken at random across the flight path of the individual, if that is not possible then any opportunistic reading should be taken if it is challenging to successfully achieve a result. A method for data collection has been identified that would provide a random sample which can be deployed either from land or a boat. A bird would be selected and followed by the observer, as soon as the target is selected the assistant will start a timer, when a pre-identified random number of seconds has passed a reading would be taken. This method relies on the ability of the observer to follow the target. It is currently questionable whether this is realistic in practice in the field. An alternative that may also help to account for bias in data collection is to record the time between when a target bird is identified, and a reading is achieved. I.e. a reading is just taken as soon as is



practically possible to get a fix. This may be at a random point in time to a degree, however we can't account, at this stage, for the fact that fixes on the individual bird may be easier at some points in the shear-soar cycle than others.

Alternatively, flight tracks can be taken, with multiple readings taken per individual bird as it passes the observer. Taking tracks from individual birds can provide a lot of information other than height, such as speed (although this is out of scope of this work at this time). Tracks do have the potential to introduce bias as some birds may behave differently to others and taking more readings from one individual may not be representative. If tracks are taken, individual variation can be accounted for during analysis of track data by using e.g. mixed models (Harwood and Berridge pers comm.). Although the different methods can provide different types of datasets, only empirical data can be used as an input to current CRM, including Band (Band 2012; Skov *et al.* 2018; Skov and Heinänen 2015).

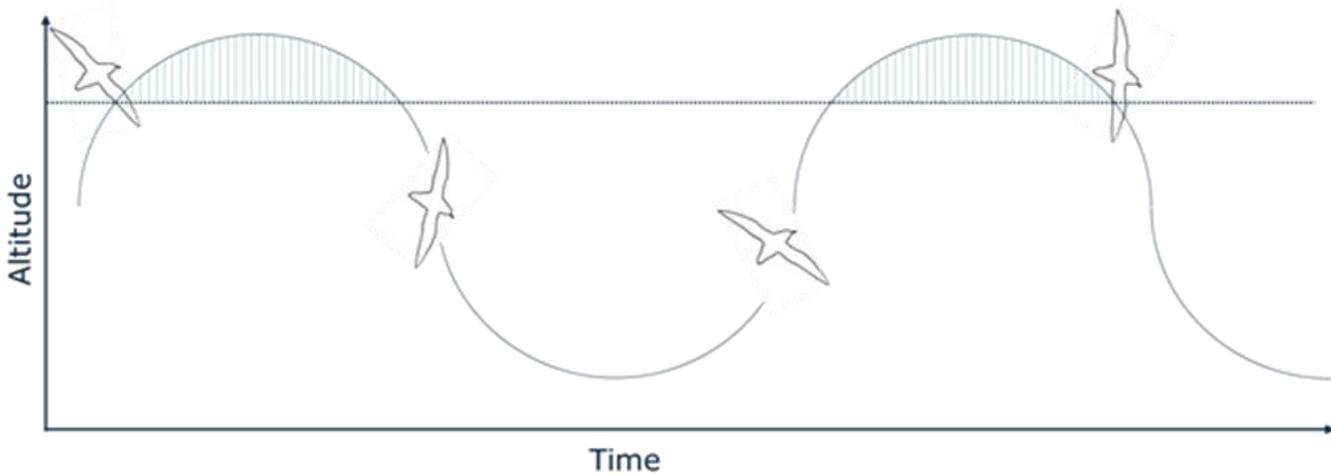


Figure 13. Manx shearwater shear-soar cycle flight behaviour and how the proportion of time above a threshold flight height (horizontal line) might be calculated.

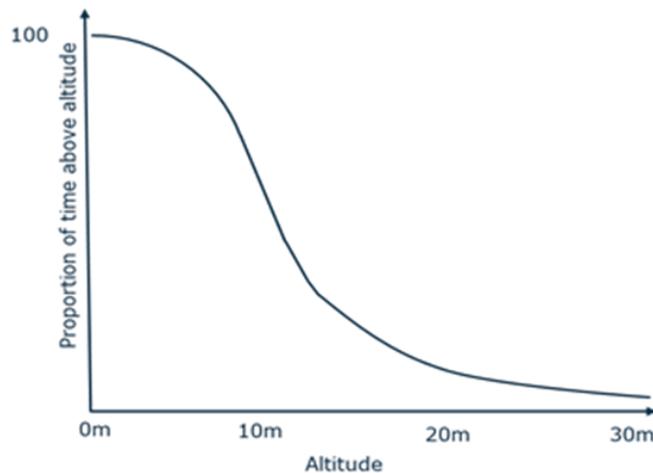


Figure 14. Example graph of the proportion of time a bird spends at increasing altitudes.



Table 5. Example of potential proportional data for the time spent flying above a certain height.

Flight height (m)	Proportion of time spent above a given height
>25	1
>20	2
>15	10
>10	50
>5	90
>0	100

It is likely that environmental conditions, particularly wind speed and direction, will impact the flight height of seabirds and therefore this research will also seek to explore the relationship between environmental conditions and flight behaviour. Where possible data collection will be carried out across a broad range of weather conditions, which may require us to be quite reactive to changes in weather. An anemometer will be used to make regular recordings of weather conditions and analysis of flight heights in relation to environmental variables will be carried out.

It is recognised that shearwaters and storm-petrels may display different flight behaviour at night, particularly when returning to colonies which may be quite high (e.g. Rum). This part of the ProcBe project will not address nocturnal flight height as the laser rangefinders cannot be used in the dark. Data collected from tagging carried out in other work packages of ProcBe may be able to provide data on nocturnal flight height.

3.1 Data collection – Year 1

Manx shearwaters return to UK waters in March and the last fledglings depart at the end of September, therefore there is plenty of opportunity to collect flight height data during the breeding season. During the breeding season the highest densities of Manx shearwaters can be found in the Irish Sea, around south-west Wales, south-west Ireland and inshore waters around western Scotland, particularly during the chick rearing period (July-August, see Figure 15, 16 & 17) (Dean *et al.* 2013; 2105; Stone *et al.* 1994; Waggitt *et al.* 2020). Based on information from experts and existing at-sea distribution (e.g. European Seabirds At Sea database, Marine Ecosystem Research Programme (MERP) data) and tracking data, (see Figure 16), it has been identified that July and August are likely to be the best time to attempt data collection as not only will breeding birds be foraging (both adults will be provisioning a chick) but immature birds will be prospecting breeding colonies (Dean *et al.* 2013 & 2015 Waggitt *et al.* 2020). Therefore, these months should be a priority time to plan and carry out data collection, although as Manx shearwaters are such abundant breeders in the UK sufficient numbers of birds should be available throughout the breeding season. Time of year may also impact the behaviour of birds, in addition to weather being more unpredictable at certain times of year, particularly autumn.

European storm-petrels return to the UK to breed in spring and depart in September/October. Monthly maps show that they occur in highest densities between July and September, particularly off the northwest coast of Scotland, around the entire west coast of Ireland and off the southwest coasts of Wales and England (MERP) (Waggitt *et al.* 2020). Distribution maps are not available for Leach’s storm-petrel but given that they breed exclusively in Scotland it is likely that during the breeding season they are distributed around the north



coast of Scotland. European storm-petrels are recorded regularly and in large numbers on pelagic trips off the coast of the Isles of Scilly (see Figure 16) in late summer (particularly August/September). Distribution maps also highlight their abundance off the south and west coasts of Ireland, particularly between July and September (Waggitt *et al.* 2020). It is likely that the best chances of encountering high numbers of storm-petrels and gathering flight height data will be on pelagic trips in these regions (departing Isles of Scilly and Cork).

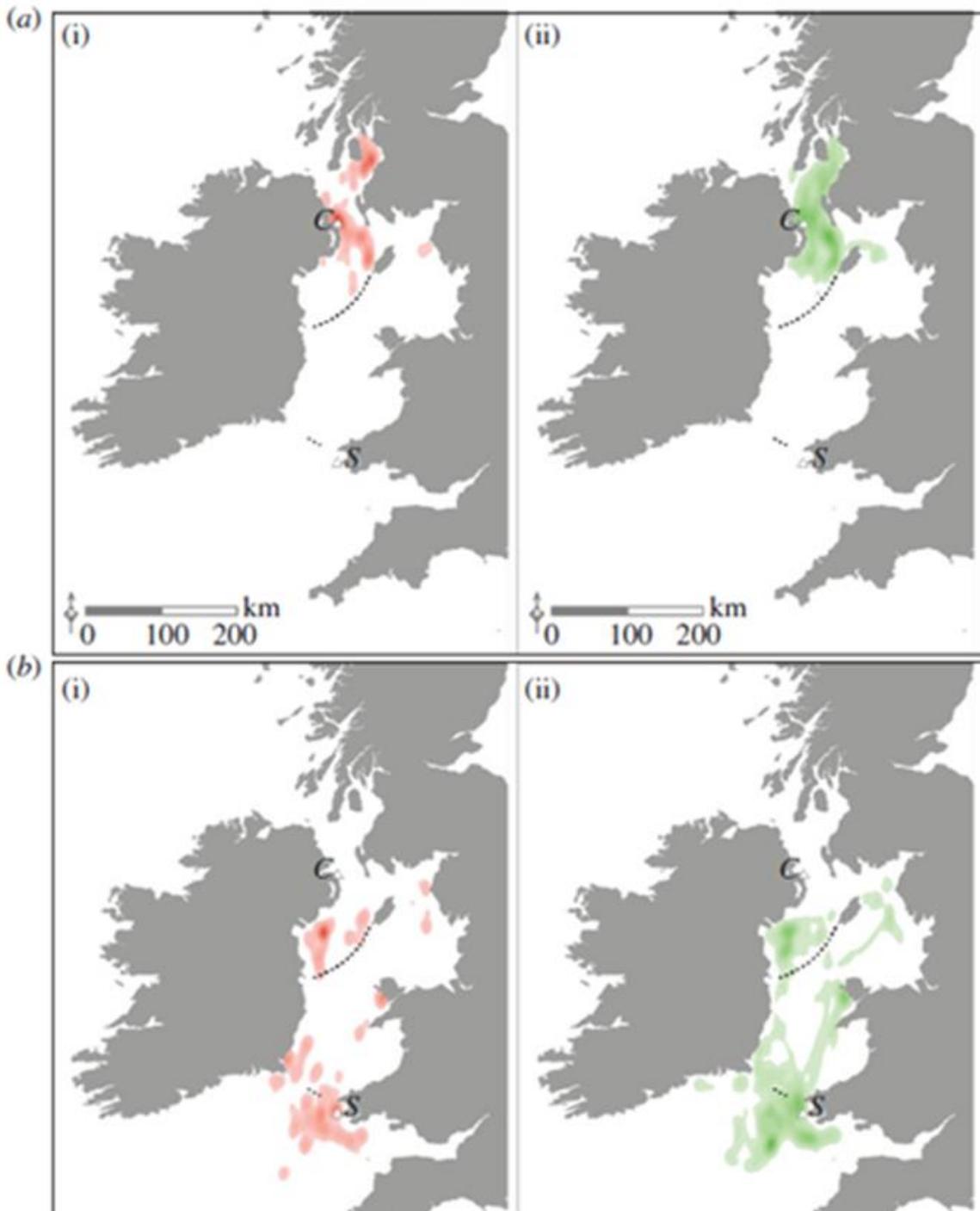


Figure 15. Manx shearwater kernel density distributions for birds from Copeland (a) and Skomer (b) during the breeding season, (i) foraging distribution and (ii) direct flight. Densities shaded from lightest to darkest. Locations of Copeland (C) and Skomer (S) shown. Frontal systems are shown by dark lines. Figure from Dean *et al.* 2013).



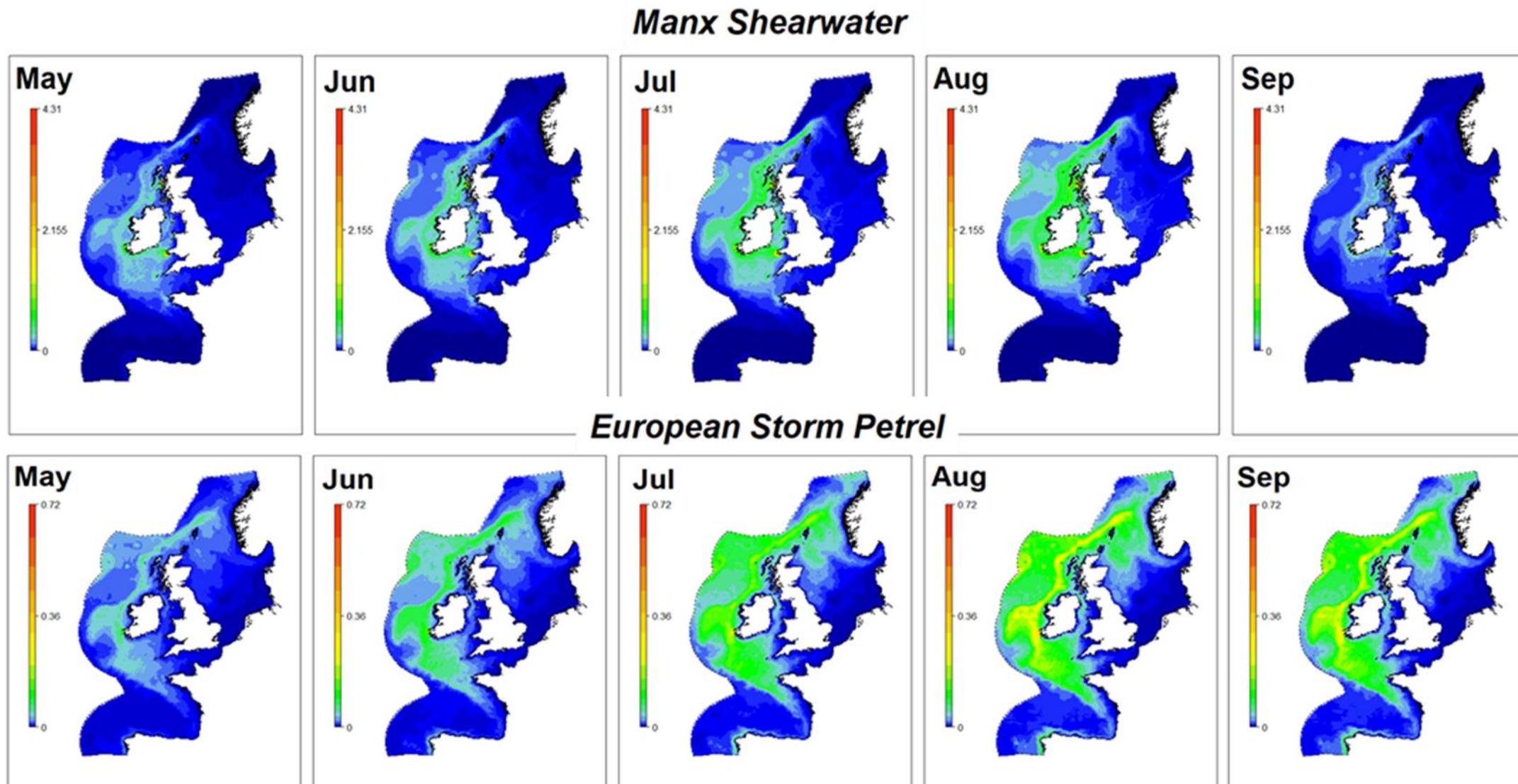


Figure 16. Monthly Manx shearwater (top maps) and European storm-petrel (bottom maps) distribution in UK and Irish waters (maps from the Marine Ecosystem Research programme). Figure taken from Waggitt et al. 2020).



Two types of data collection have been planned across the three years of the project. In year one only land-based work for Manx shearwater will be carried out to ensure that the technique works sufficiently and to establish the practicality of collecting data from boats, this will result in a go-no-go decision before year two. A further benefit of carrying out data collection from both land and sea is to identify whether flight behaviour is different in a more pelagic scenario when compared to near a colony or close to land. It is unlikely that storm-petrel data will be possible to be collected from land as they will not pass close enough to the coast. Discussions with experts resulted in two locations where Manx shearwaters would be visible from land and pass close enough to take measurements.

The Copeland Islands, Northern Ireland, are a small group of islands that were classified as an [SPA](#) in 2009 with Manx shearwater as a feature (last population estimate of 4800 breeding pairs, 2000-2001). The island with the largest Manx shearwater colony is Lighthouse Island, it is relatively flat and at times observers could be at or near to sea level. The island has a relatively large populations of Manx shearwater and at times there can be thousands of birds passing the islands at a range of between 400 m to 5 km. There are a number of advantages of using this site:

This is one of the study sites for one of the partner organisations, OxNav for whom this is a long-term tracking site. OxNav have existing relationships with the island managers and can provide logistical support for travel etc.

JNCC will be able to coordinate data collection with OxNav's tracking work and enable us to work together. As the island is small there is limited capacity for overnight guests but there is an opportunity to stay from the 13th of May for a week, as well as later in the year (end of July/start of August). Although this falls outside of the peak time for observations, as previously stated, this site should still provide ample opportunity to collect data throughout the week and test methods and LRF detection limits.

The island is low-lying therefore any potential issues of clutter and false readings from the sea surface will be significantly reduced and birds are likely to be closer to the coast at this location than the other option, Strumble Head.

Strumble Head, Pembrokeshire, is around 35 km north of the largest breeding colony of Manx shearwaters in the UK, Skomer Island. As birds depart from and return to the colony, they can often pass very close to the headland at Strumble Head, within 5 km and often far closer (Guilford and Padget pers comm). As discussed above the best time of year to observe large numbers of birds passing this point will be July when birds have chicks and therefore both partners will be foraging daily. This site acts as a good vantage point because of its location and its elevation, it is between 90-120 m above sea level. This site already has a sea watching hide constructed and is a popular spot to watch seabirds from. This site has several advantages for data collection:

- It has infrastructure such that it would allow for equipment to be kept dry and provide some shelter for observers.
- It is on the mainland and therefore easier and cheaper to get to without the risk of boat cancellations.
- It is close to very high concentrations of breeding Manx shearwaters.



One potential issue when collecting data from this site is the limitations around use of the Vector LRF at inclination angles $\pm 35^\circ$ (this is the reported limit of the Leica Vector 1500). As discussed previously the limitation of inclination angle was not explored during the calibration but this will be included in future work.

During discussion with experts and after interrogating the literature, issues with clutter were highlighted for certain models of the Vector (21 Aero), particularly when readings are taken looking down on birds, which may be the case at this site. Based on our brief experience of using the Leica Vector 1500 on Copeland clutter did not seem to be a major issue as the LRF did not return any values from the sea surface, but this was not at significant elevation and will need to be explored further. On some of the larger vessels we may be using for boat-based data collection we may also be looking down on birds and therefore doing some data collection at this site will directly inform the practicality and ability to collect data in subsequent years and should therefore still be considered.

As described previously flight characteristics may vary at different times of day and when they are either commuting or foraging. Given that Copeland is a breeding colony and Stumble Head is close to breeding colonies it may be that the highest density of birds is present in the morning and evening when birds are leaving and returning to the colonies. The ability of the rangefinders to detect birds in low light is unclear and therefore this should be considered during data collection and analyses.

It was anticipated that an issue with both sites is that the birds are unlikely to pass close enough to the coast to allow data collection using the Nikon model of laser rangefinder, however, based on our experience of using both devices on Copeland this does not seem to be a problem with the Nikon detecting birds and recording fixes at similar distances to the Leica Vector 1500. It has been noted that in north-westerly winds the birds fly closer to the coast at Strumble Head so if possible, targeting time periods where the wind is in this direction may improve the chances of achieving readings, but this is challenging as plans for travel and accommodation will need to be made in advance.

At this stage of the project it is unclear how much data will be required for us to fully understand the flight behaviour of these species across a wide range of weather conditions. Given how little data we currently have on flight heights during wind and sea state conditions outside of the limits imposed on existing data collection methods we may require substantial sample sizes. We will have to consider the wide range of factors that might affect flight heights, both when we are planning data collection and analysing the data.

As this first year is a trial in the use of the device and the methods of data collection, several methods can be trialled to test which are most effective and provide the best data. This year will also be an opportunity to explore the effects of weather and individual experience/ability on the users ability to record flight heights. It is also suggested that both tracks and single fixes are taken to test the impact of individual on flight height and how comparable the flight height distributions recorded are between methods. As this work package is highly experimental there will be a series of go-no-go decision points and discussions will be had with the Project Expert Group and TCE at various points to discuss progress, issues and potential changes to the work plan.



3.1.1 Land-based data collection protocol

The initial land-based field work is the first time that birds will be the target for data collection, and therefore the protocol is largely a guideline as it will depend on which LRF will be used, how close to shore the birds are flying and the weather conditions.

Based on the literature, the only specific data collection protocol was defined by Skov *et al.* (2018), where flight track data were collected from turbine platforms. Targets were selected by sweeping the field of view and starting recording with the first target detected from the left-hand side and following the target with the remaining clockwise range. This process was repeated in the opposite direction, starting from the right. Once the target is lost, the track was recorded along with any associated parameters such as weather etc. This can be adapted for our own data collection when collecting tracks and depending on the LRF being used. If we are able to collect track data, we propose to use the same methodology as Skov *et al.* (2018).

When collecting single readings per individual we propose to start by sweeping the field of view from the left and then taking a reading from the first bird encountered, before continuing to scan from left to right until the next bird is encountered. There are then two potential options:

- Once a target is selected a reading will be taken at a random time interval that is pre-determined using a random number generator. This method removes any potential bias of taking readings at an “easier” height to record at.
- If it is too challenging to try and record a bird at a specific time, then the lag time and number of attempts between target identification and a successful reading will be taken.

Once the field of view is fully swept to the far right, the same will be done from right to left. Depending on the weather conditions, the distance to the birds and the confidence of the observer one of the two specified methods will be applied. Both methods will be trialled, and the results will be considered to identify the most realistic method to capture data whilst attempting to reduce bias. The capability of each LRF will be assessed during this period of data collection and will be reviewed before a decision is made on further data collection.

Birds are likely to be passing land in the same direction, by scanning both from left to right and right to left this will hopefully reduce bias.

Based on the experiences gained from our first land-based data collection on Copeland (12th – 17th May) some additional considerations and adjustments to the suggested protocol will need to be made.

Firstly, based on the distance and speed the birds were passing at, it was challenging, particularly at the beginning of the data collection period to successfully collect readings from passing shearwaters. We did not attempt to apply the previously suggested randomised protocol at this stage, rather just collected as many readings as possible across the week. The ability of the observer to collect data using both the Vector and the Nikon improved during the week as we became more experienced, particularly when wind speed increased, and birds were passing closer to shore. The increase in wind speed did make it more challenging to collect data, particularly with the heavier Vector, as holding it steady was difficult, when this occurred, we were able to make use of a hide or find a sheltered area. The results from the first data collection period have indicated that when birds are at the distances experienced from Copeland using a randomised time sampling strategy may not be feasible as it may significantly reduce



the number of readings that can be collected. If birds are closer to shore or a boat, this method may still be practicable and should be trialled in other circumstances before it is ruled out.

An issue that was highlighted during the time on Copeland, that applies to all land-based data collection, is accounting for changes in tide height. As flight heights collected using the LRFs are based on the height of the observer relative to sea level, it will be important to account for change across the tidal cycle. Initially, when data was collected from the jetty on Copeland, tide height was measured using a tape measure, however this method will not be possible at all locations. Readings cannot be taken from the sea surface, so buoys were identified as a potential proxy. Buoys will always sit on the surface of the water regardless of the tide height, by taking readings regularly changes in tide height can be applied to the data collected using the LRFs. Figure 18 highlights how recording observer height above sea level (X) can be used to calculate bird height above sea level, either by adding (Y) or subtracting (Z) the height reading taken using the LRF on the target bird.

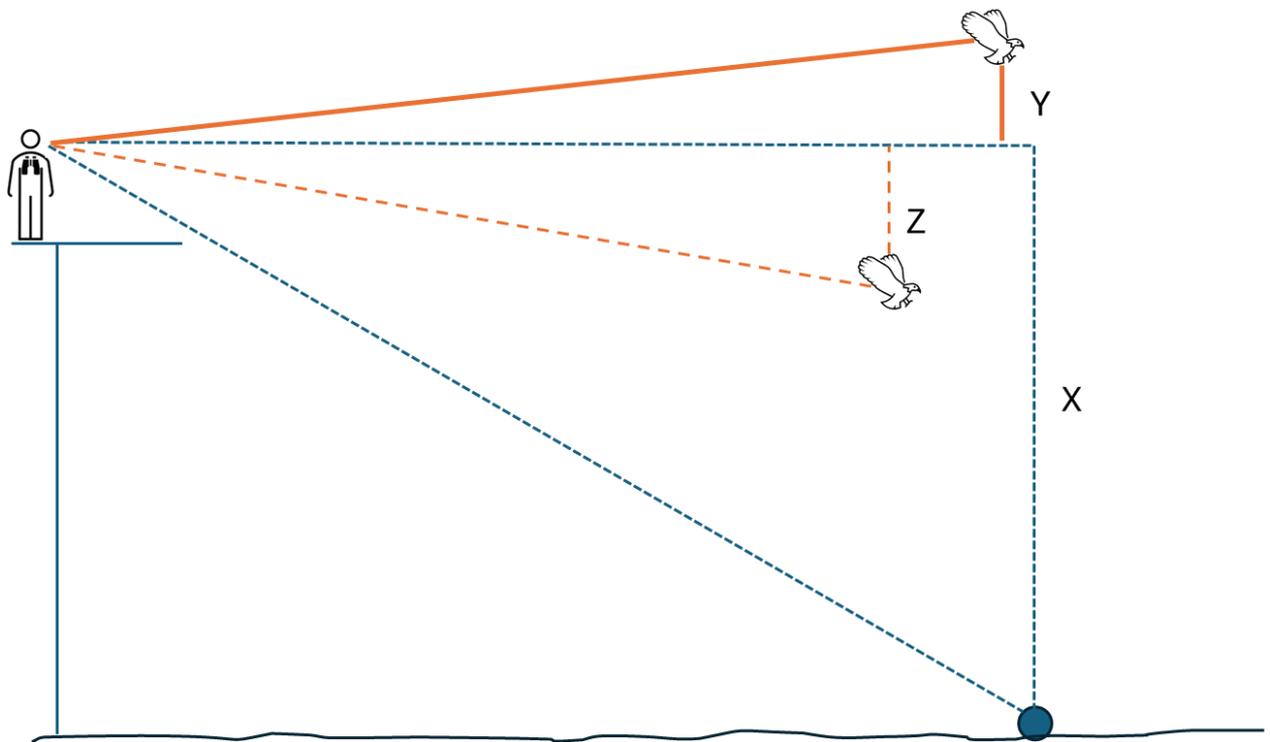


Figure 17. Schematic illustrating the suggested method of calibrating observer eye height across the tidal cycle

3.1.2 Summary of data collection sites and timing

May-Aug 2024 (4 Months) – Trial of Land-based Methods (1st Field Season)

- Targeted 15 days fieldwork at Copeland Islands (Northern Ireland) and Strumble Head (Wales), where large numbers of MSW known to commute on passage within sight of shore.



In year one we have allocated three weeks (15 days) of fieldwork to test and practice using the equipment. It will be very beneficial to accompany OxNav to Copeland and will provide an opportunity to collaborate as well as collecting data from lower vantage points. This may also allow us to explore alternative methods of data collection which have been trialled by the OxNav group, such as using video. Timing of trips to Copeland will have to coincide with OxNav trips and we have agreed to an initial week in mid-May. After this period a review of the data collected, performance of the laser rangefinders and methods can be conducted before further field work is planned. Pending the results of this week a further week will be carried out based at Strumble Head and another week on Copeland. Strumble Head fieldwork can be more flexible as there are fewer constraints in terms of logistics. Based on expert advice and evidence it seems that the highest number of birds are passing in July so this should be the target month for data collection at Strumble Head and potentially for a second week on Copeland if this is possible. If plans can be relatively flexible, coinciding this trip with adverse weather conditions would be a bonus.

The data collected in this initial year will directly inform the following years, such as sample sizes, the detection capability of the different rangefinders, the comparison of data collected using different methods and possible effect of observer.

3.1.3 Data analysis

Flight height data collected will be turned into flight height distributions with associated error, either based on the raw data or as proportion of time spent at certain heights. The methods for this will vary based on the data collected. Data collected using the LRF will be a random sample of flight heights will be absolute values. Where possible we intend to make use of existing distributional models such as the Johnston *et al.* or Johnston and Cook that are already established methods (2014 & 2016).

Based on the type of data being collected, it is likely that linear mixed effect models (LMM) will be the most appropriate statistical analysis method for modelling flight height data and investigating distribution patterns. To allow us to detect patterns in flight height data, fixed variables, such as weather conditions, will be included in models. Including observer identity as a random variable will also need to be considered to control for possible observer effects.

Examples of fixed variables that could be included in models to improve our understanding of flight heights are:

- Wind speed
- Wind direction
- Heading (into or against the wind)
- Pressure
- Platform (land, ferry, rib)
- Location (at-sea, different land-based observation points)
- Time of day
- Bird behaviour



For maximum flight height data, analysis would be done in R using the package lme4 and could look like:

Maximum height ~ wind_variable + (1|observer identity)

For proportional data, it may be appropriate to use a zero-inflated beta regression model using glmmTMB:

Proportion of time ~ wind_variable + (1|observer identity)

After year 1 data collection and analysis has been completed, a go-no-go will be made to decide whether boat-based data collection is possible and or/practical, and whether further land-based data collection is worthwhile.

3.2 Data collection – Year 2

3.2.1 Summary of proposed work

In the second year of data collection both land-based and boat-based field work will be undertaken based on the protocols and lessons learned from year 1. If data collection from the land-based field sites is successful in Year 1 (2024), 15 days of field work from land-based field sites will be carried out in Year 2 (2025) and is likely to be Strumble Head and Copeland once again. As this work package is quite experimental, fieldwork plans need to be quite reactive to the success/failure of the data collection in previous years.

To target Manx shearwater, one of the most accessible, regular ferry routes, in close proximity to the second largest breeding colony in the UK (Rum) are the Small Isles, Barra and South Uist ferry routes, particularly the Oban to Lochboisdale and Mallaig to Lochboisdale routes which pass to both the north and south of Rum (see Figure 19). These routes have been selected based on evidence collated from tracking studies and distribution maps (see figures 15, 16 & 17) as well as expert advice. It is hoped that these routes will encounter birds commuting and foraging as well as close to and at a distance to breeding colonies, but we will only know for certain once data collection starts. It is also likely that behaviour and distribution will be influenced by weather and food availability which are unpredictable, and it is understood that foraging distribution does change over time and between seasons. Given the low resolution of maps produced from tracking data it is unclear whether one or the other of these routes will encounter a higher density of birds, but it may be beneficial to try both routes to identify if one is busier than the other, bearing in mind this might vary in different weather conditions. Another benefit of using these routes is that JNCC already have a working relationship with the ferry operator (Calmac) through the VSAS programme. It is highly likely that throughout the breeding season these routes will encounter high numbers of shearwaters as well as possibly offering the opportunity to compare flight heights between more open waters (between Rum and South Uist and Barra) and more inland waters between Rum and the mainland.



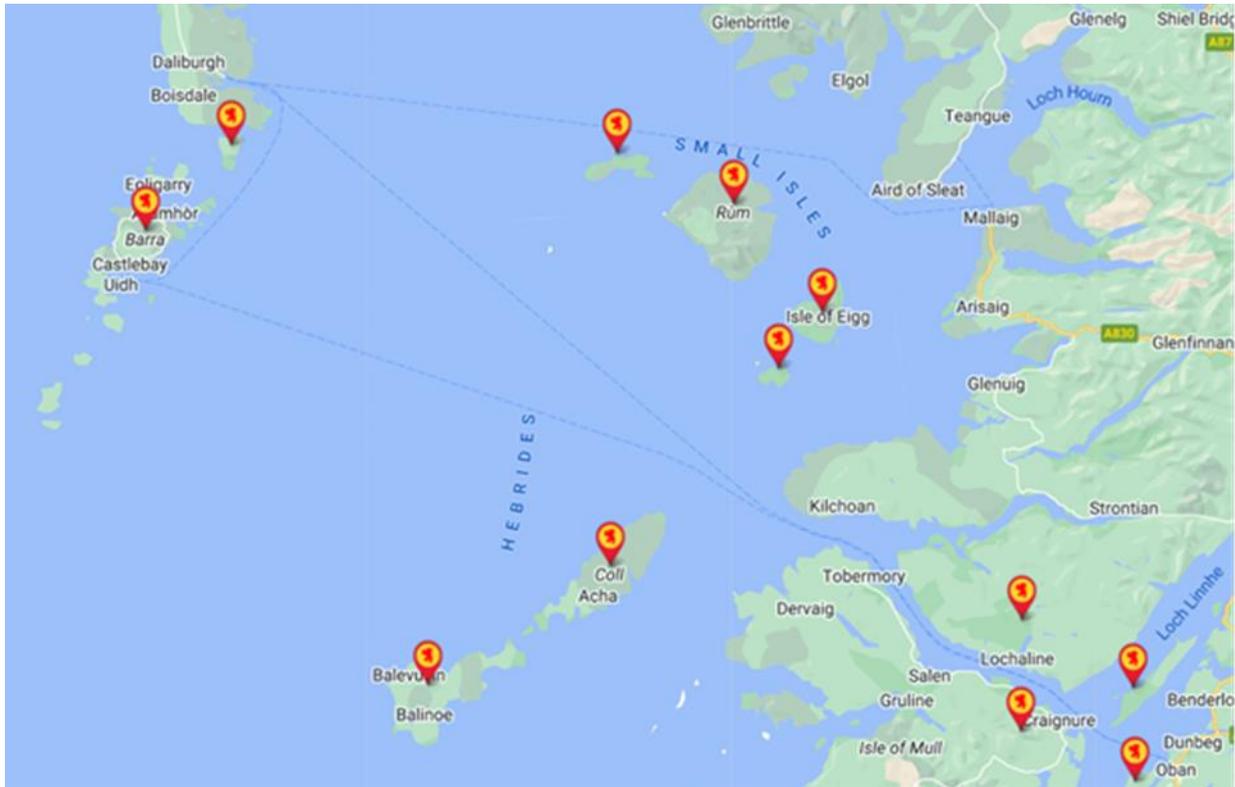


Figure 18. Small Isles, South Uist and Barra ferry routes (taken from <https://www.calmac.co.uk/interactivemap?f=13279>).

To target European storm-petrel, Manx shearwater and possibly Leach’s storm-petrel, a more pelagic approach using a smaller vessel will be needed to ensure overlap with the areas of highest density of birds, see Figure 16. Trips run from St. Mary’s, Isles of Scilly and they encounter several species of shearwater and storm-petrels, around 50-100 European storm-petrels and hundreds/thousands of Manx shearwaters per trip. Scheduled bird watching trips are carried out in August, but trips would be available between May and late-July, with 2/3 weeks in July being recommended. The standard practice on the pelagic trips organised for bird watchers and photographers involved ‘chumming’ whilst at-sea, taking advantage of Procellariiform olfactory senses to attract birds to the boat. Although this would increase the chances of encountering storm-petrels it will affect their behaviour and will therefore be considered with care for our trips. However, it should be considered that birds may associate these vessels with food and the boat is still likely to smell strongly and therefore birds may be attracted anyway.

Previous flight height data collection from boat-based platforms have followed the ESAS protocols with snapshot data collected for flight heights and with heights being assigned to bands. To allow comparability with previous work and ensure that the data collected can be used in current CRM models this protocol should be followed (as per Camphuysen *et al.* 2004), although in our study we will be recording raw flight heights with the LRF.

3.2.2 Boat-based data collection protocol

The data collection protocol will vary based on the platform (ferry or rib/small boat) and can be applied to both devices, although which device is used will depend on the weather conditions and how far away the birds are from the boat. For both devices whenever a reading is taken the direction of travel of the bird relative to the boat, the behaviour (foraging/commuting) and a time stamp should be noted. This is to ensure that as many variables as possible can be



matched to each record of flight height. Weather variables will be recorded every 15 minutes and platform height will be established when on the boat, this could either be done by targeting objects on the sea surface and/or getting information from the crew.

A large proportion of boat-based seabird data collection studies use the European Seabirds At-Sea (ESAS) protocol. Although this method was designed for collecting distribution and density data the protocol can also in-part be applied to collecting flight height data. ESAS methods are detailed in full [here](#), methods for birds on the water are not relevant for this project. Birds in flight are recorded in two ways - continuously and in snapshots. The survey area is 90° from the front of the boat to the right or left and any bird flying within that area and the direction of flight are recorded. In terms of recording flight heights using the LRF the density and frequency of birds will impact the method to be used. The continuous method, which is very similar to that described for land-based data collection will be applied here:

- scanning the field of view, 90° from the front of the boat either left or right, and selecting the first bird encountered;
- taking a reading either at the first opportunity or using the random time sampling method depending on the conditions and proximity of the birds;

The benefit of using the ESAS method is that data will be comparable, in terms of the methods for identifying birds, to previous flight height estimates (although those data were collected in bands).

It may be possible to collect track data from a boat, if this is possible then the same method will be applied with multiple readings taken per bird. If this is done the readings will need to be clustered so that this can be accounted for during analysis.

For both of these methods a factor will be the direction of travel of birds passing the boat, where possible readings should be taken from birds traveling in both directions, if birds are only passing in one direction, then once a target that has been tracked has passed from view the observer should start the process again from the initial start point.

If data has to be read from the device and manually recorded tracks may not be possible, therefore the method would be adapted, and single readings would be taken for each bird passing the boat.

3.2.3 Summary

May-Aug 2025 (4 Months) – Roll out of Land-based Method at two Sites and Trial of Boat-based Methods (2nd Field Season)

2nd Field Season of Land-based LRF fieldwork at Strumble head (for Manx shearwater)

- Targeted 15 days fieldwork at Strumble head collecting flight height data using LRF for Manx shearwater.

2nd Field Season of Land-based LRF fieldwork at Copeland (for Manx shearwater)

- Targeted 15 days fieldwork on Copeland (Northern Ireland) collecting FH data using LRF of MSW.

1st Field Season of Boat-based (Large Platform) LRF fieldwork Mallaig - Small Isles (Scotland (for Manx shearwater)



- First testing of LRF on large platform boat-based work. It is anticipated that this work can be arranged through existing VSAS survey relationships with Calmac Ferry on the Mallaig to Small Isles ferry routes that transit near the large MSW colony at Rum.

1st Field Season of Boat-based (Small Platform) LRF fieldwork Scilly Pelagics (for European storm-petrel)

- First testing of LRF on small platform boat-based work. The purpose of this work at the Scilly's would be to get flight height data on European storm-petrel. Boat operators report large numbers of European storm-petrel being sighted in key breeding season months off Scilly. A potential bonus would be data collected on Manx shearwater that are sighted at the same time.

Based on the outcomes of year 1 land-based work will be expanded to 15 days at both Copeland Island and Strumble Head. If the methods trialled on land are judged to be applicable and produce appropriate data, then data collection will be rolled-out to boat platforms. Prior to boat-based data collection methods for calibration at-sea, if using the Vector, needs to be resolved, as well as assessing the impact of swell on flight height measurements. Once these issues have been resolved then data collection from ferries in Scotland for Manx shearwater, and from small pelagic boats off the coast of the Isles of Scilly can be carried out.

3.2.4 Data analysis

Methods based on year one data analysis to be applied to year 2 data.

3.3 Data collection – Year 3

3.3.1 Land-based data collection.

A go-no-go decision will be taken after year two data collection to decide if further land-based work is required, if it is then further work will be carried out on Copeland or Strumble Head, depending on success of the previous year's fieldwork sites.

3.3.2 Boat-based data collection protocol

Boat-based data collection in year 3 will be informed by the success or issues encountered in year two. Before any data collection is planned or carried out a go-no-go decision will be taken based on previous experiences. The platforms used will also be informed by year two work, ferry routes (Small Isles in Scotland; 15 days) and pelagics (Isles of Scilly; 15 days) will be repeated if year two is successful in addition to further work on other routes between Pembrokeshire and Ireland (see Figure 20; 15 days) for Manx shearwater and pelagics out of Cork (Ireland; 15 days) for storm-petrels. Alternative routes will provide information from different locations and help us account for different behaviours from different colonies.



3.3.3 Summary of proposed work

May-Aug 2026 (4 Months) – Roll out of Boat-based Methods (Large and Small Platforms) – only if necessary.

3rd Field Season of Land-based LRF fieldwork at Copeland (for Manx shearwater)

- Targeted 15 days fieldwork on Copeland (Northern Ireland) collecting flight height data using LRF of Manx shearwater.

2nd Field Season of Boat-based (Large Platform) LRF fieldwork Mallaig - Small Isles (Scotland) (for Manx shearwater)

- Targeted 15 days fieldwork collecting Manx shearwater flight height data on Mallaig to Small Isles ferry routes, Scotland. This aims to collect flight height data from Rum Manx shearwater population.

1st Field Season - Boat-based (Large Platform) LRF fieldwork Milford Haven - Rosslare (Wales) (for Manx shearwater)

- Targeted 15 days fieldwork collecting Manx shearwater flight height data on Milford Haven to Rosslare ferry routes, Wales. This aims to collect flight height data from Pembrokeshire Manx shearwater populations.

2nd Field Season - Boat-based (Small Platform) LRF fieldwork Scilly Pelagics (for European storm-petrel)

- Targeted 11 (out of 15-day period) days fieldwork collecting European storm-petrel (and any MSW data available) flight height data on small pelagic vessel, following proof of concept from Year 2.

1st Field Season - Boat-based (Small Platform) LRF fieldwork Cork Pelagics (for European storm-petrel)

- Targeted 11 (out of 15-day period) days fieldwork collecting European storm-petrel (and any Manx shearwater data available) flight height data on small pelagic vessel, following proof of concept from Year 2, and to supplement the flight height data collected from similar vessel at the Scillies.



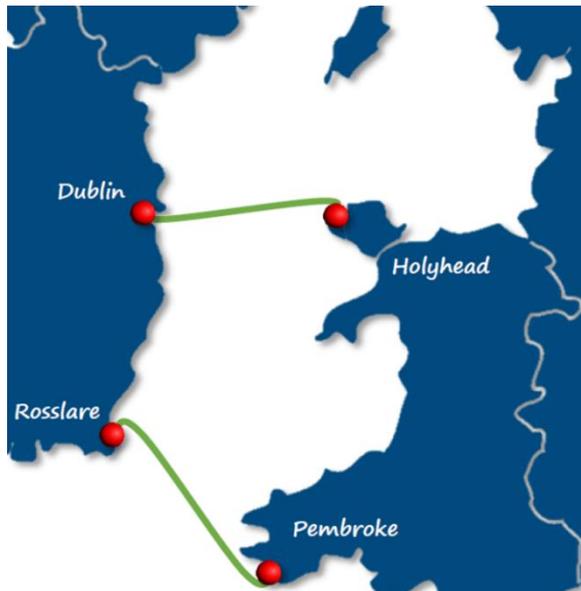


Figure 19. Ferry route from Pembroke to Rosslare and Holyhead to Dublin (image from <https://iwtdg.ie/ferry-surveys/>).

Based on the outcomes of year two land-based work will be followed up, only if further data are required, with a further 15 days at Copeland Island or Strumble Head, depending on success of the previous year's fieldwork sites. Boat-based data collection will be extended, on existing routes and to new ones based on the outcomes of year two data collection and pending the issues and biases previously described being resolved.

3.3.4 Data analysis

Methods based on year one and two data analysis to be applied to year three data.



4. Conclusion

The first deliverable of Work Package 3 of the ProcBe project was to produce a feasibility study to review the existing literature and evidence surrounding the use of laser rangefinders for estimating flight heights of seabirds. The scope of this work package is to provide improved estimates of flight height by collecting data from a variety of locations and across a range of weather conditions. By collecting data in this way we hope to identify whether Manx shearwaters and European storm-petrels may fly at potential risk heights, what proportion of time they spend at these heights, and how this might vary geographically, temporally and if the risk changes in different weather conditions.

A review was carried out that identified a series of projects and articles which primarily used one of two devices, Vector Aero 21 and Nikon Forestry Pro, to collect data from boats, platforms and land. The evidence collated, alongside discussions with a variety of experts, led to the procurement of two devices for this project a Nikon Forestry Pro II and a Vector 1500. A calibration trial was then carried out to establish the limitations of the two devices, as well as a third which was provided by SPR for the purpose of the trial. The results of this trial will be used to inform data collection as well as help to provide confidence intervals on data collected.

Using information gathered from experts and the literature the most appropriate locations, pelagic boat opportunities and ferry routes for data collection from both land and boats were identified for both species of interest. These options were selected as it is hoped they will provide the greatest opportunity of encountering high densities of birds. The first year of data collection will be only land-based to test the devices, refine methods and identify any problems or limitations in a more controlled environment. It will also help in determining the field work plans for the following two years of ProcBe work. The schedule and protocol for data collection was developed based on the results of the literature review and calibration trial and refined during the first season of data collection.



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6. Appendices

Table 6. Sample sizes for height and distances measurement combinations for the three LRFs, Nikon, TruPulse and Leica Vector 1500, number of successful fixes is shown alongside the number of attempts to achieve each reading.

Drone height (m)	Drone distance (m)	Device					
		Nikon Forestry Pro II		TruPulse 360B		Leica Vector 1500	
		Successful fixes	Attempts	Successful fixes	Attempts	Successful fixes	Attempts
10	25	10	10	10	10	-	-
	50	10	10	9	10	10	10
	75	10	10	10	10	10	10
	100	18	20	-	10	10	10
	200	-	-	-	-	10	10
	300	-	-	-	-	4	10
20	25	10	10	10	10	-	-
	50	10	10	10	10	10	10
	75	10	10	9	10	10	10
	100	20	20	-	-	10	10
	200	-	-	-	-	10	10
	300	-	-	-	-	6	10
30	25	10	10	10	10	-	-
	50	10	10	10	10	10	10
	75	10	10	7	10	10	10
	100	20	20	-	-	10	10
	200	-	-	-	-	10	10
	300	-	-	-	-	6	10
40	25	10	10	10	10	-	-
	50	10	10	10	10	-	10
	75	9	10	3	10	10	10
	100	16	20	-	-	10	10
	200	-	-	-	-	10	10
	300	-	-	-	-	6	10
50	10	10	10	10	-	10	
50	20	10	10	10	10	-	
50	25	10	10	10	10	-	-
	30	10	10	10	10	-	-
	40	10	10	10	10	-	-
	50	19	20	20	20	-	20
	60	10	10	10	10	-	-
	70	10	10	9	10	-	-



Drone height (m)	Drone distance (m)	Device					
		Nikon Forestry Pro II		TruPulse 360B		Leica Vector 1500	
		Successful fixes	Attempts	Successful fixes	Attempts	Successful fixes	Attempts
	75	9	10	2	10	10	10
	80	10	10	4	10	-	-
	90	10	10	-	10	-	-
	100	28	28	-	-	20	20
	110	10	10	-	-	-	-
	120	10	10	-	-	-	-
	150	6	10	-	-	10	10
	160	4	10	-	-	-	-
	200	-	10	-	-	20	20
	250	-	-	-	-	10	10
	300	-	-	-	-	17	20
	350	-	-	-	-	5	10
60	25	10	10	10	10	-	-
	50	7	10	10	10	-	-
	75	10	10	4	10	-	10
	100	15	20	-	-	10	10
	200	-	-	-	-	10	10
	300	-	-	-	-	10	10
70	25	10	10	10	10	-	-
	50	7	10	8	10	-	-
	75	9	10	-	10	-	-
	100	19	20	-	-	10	10
	200	-	-	-	-	9	10
	300	-	-	-	-	8	10
80	25	10	10	10	10	-	-
	50	9	10	8	10	-	-
	75	8	10	-	-	-	-
	100	16	20	-	-	-	10
	200	-	-	-	-	10	10
	300	-	-	-	-	8	10
90	25	10	10	10	10	-	-
	50	7	10	4	10	-	-
	75	6	10	-	-	-	-
	100	16	20	-	-	-	-
	200	-	-	-	-	10	10
	300	-	-	-	-	10	10
100	10	-	-	-	-	-	10
	25	20	20	20	20	-	-
	50	10	20	8	20	-	10



Drone height (m)	Drone distance (m)	Device					
		Nikon Forestry Pro II		TruPulse 360B		Leica Vector 1500	
		Successful fixes	Attempts	Successful fixes	Attempts	Successful fixes	Attempts
	75	-	20	-	-	-	-
	100	28	29	-	-	-	10
	150	-	-	-	-	10	10
	200	-	-	-	-	19	20
	250	-	-	-	-	8	10
	300	-	-	-	-	15	20
	350	-	-	-	-	-	10
110	25	10	10	10	10	-	-
	50	5	10	1	10	-	-
	100	10	20	-	-	-	-
	200	-	-	-	-	10	10
	300	-	-	-	-	10	10

