Distribution, abundance and movements of sei whales and southern right whales in the Falkland Islands

Technical Report for DPLUS126

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Acronyms

AIC	Akaike’s Information Criterion
ARM	Area restricted movement
BC	Body condition
BL	Body length
BS	Behavioural state [see southern right whale telemetry]
CDC	Complete dive cycle
CMP	Conservation Management Plan
CMR	Capture-mark-recapture [photo-identification]
CV	Coefficient of variation
DPLUS082	Darwin Plus project 082: Conserving Falklands' whale populations: addressing data deficiencies for informed management
DPLUS126	Darwin Plus project 126: Advancing Falklands and region-scale management of globally important whale populations
DD	Dive duration
DMD	Dive maximum depth
DV	Distinctiveness Value
ESW	Effective strip width [abundance surveys]
FC	Falklands Conservation
FI	Falkland Islands
FICZ	Falkland Islands Interim Conservation and Management Zone
FIG	Falkland Islands Government
FIWG	Falkland Islands Wintering Ground [for southern right whales]
FOCZ	Falkland Islands Outer Conservation Zone
GEBCO	General Bathymetric Chart of the Oceans
GPS	Global Positioning System
IMMA	Important Marine Mammal Area
IUCN	International Union on the Conservation of Nature
IWC	International Whaling Commission
KBA	Key Biodiversity Area
LC	Location quality class [see telemetry work]
LIMPET	Low Impact Minimally Percutaneous Electronic Transmitter [sei whale satellite tag]
MCDS	Multiple covariate distance sampling
MDV	Maximum depth value
NARW	North Atlantic right whale (*Eubalaena glacialis*)
PQ	Photographic Quality
PSLME	Patagonian Shelf Large Marine Ecosystem
PV	Peninsula Valdés [southern right whale calving ground in Argentina]
QD	Qualifying Dive
QGIS	Quantum Geographic Information System
SAG	Surface Active Group [terminology used for right whales]
SD	Standard deviation
SEV	Surfacing Event

SO	Sampling occasion [see photo-identification analysis]
SRW	Southern right whale
SST	Sea surface temperature
SWA	South-west Atlantic
TA	Target Area for photo-identification
TAD	Time at depth
TDCT	Total dive cycle time
TIV	Time in view [aerial surveys]
UAV	Unmanned aerial vehicle or ‘drone’
WC	Wildlife Computers

Non-Technical Summary of Key Findings

Chapter 1: Introduction

- This report presents the findings of a Darwin Plus funded project (DPLUS126) led by Falklands Conservation in collaboration with multiple local and international project partners. The project was titled "*Distribution, abundance and movements of sei whales and southern right whales in the Falkland Islands*," and aimed to collect a range of novel datasets on sei whales (*Balaenoptera borealis*) and southern right whales (*Eubalaena australis*) to address knowledge gaps relevant to achieving evidence-based conservation management of whale populations. The report consists of standalone chapters that each provide the results from different research components of the DPLUS126 project.
- The project fieldwork was carried out predominantly in the nearshore (<5 km) waters along the north-east coast of the Falklands between Cape Pembroke and MacBride Head, including the shallow sea inlet of Berkeley Sound. However, the aerial surveys covered an expanded study area which extended west to Pebble Island and to 30 km offshore.
- All of the fieldwork described in this report was conducted with the appropriate research permits issued by Falkland Islands Government to cover non-invasive baleen whale work (R11/2017 and R20.2023), and invasive components including biopsy sampling and satellite tagging (R14/2020 and R32.2023).

Chapter 2: Whale occurrence during boat surveys

- 68 boat surveys were carried out between Cape Pembroke and MacBride Head from March 2022 to May 2024, resulting in totals of 456.8 hr and 6,031 km of survey effort. A total of 40 surveys were completed in the sei whale season, versus 28 surveys in the southern right whale season. The total amount of active search effort collected in weather conditions deemed favourable (Beaufort sea state ≤4, swell of ≤2.5 m, and visibility of >5 km) for the visual detection of large whales was 195.8 hr / 4,291.8 km, with peak effort occurring in March/April and in July/August corresponding with the seasonal peaks of the two target whale species.
- A total of 889 cetacean sightings comprising 3,107 individuals was recorded, with seven species confirmed. Peale's dolphins (*Lagenorhynchus australis*), sei whales, and southern right whales were the most frequently recorded and the most numerous species.
- Sei whales were sighted predominantly in groups of 1 to 5 animals (up to 15 animals). Their relative abundance in Berkeley Sound was reasonably consistent between February and April, declined during May, and was zero between June and September, confirming the strong seasonality documented during previous work. Sei whales were widely-distributed across Berkeley Sound from the area immediately east of Long Island to the mouth of the Sound. Foraging was confirmed as the primary driver of sei whale occurrence, evidenced by observations of surface feeding and defecations at the surface.
- Southern right whales occurred mostly in groups of 1 to 4 animals (up to 11 animals) and were recorded between April and September. Their relative abundance was similar in July and August (a strong seasonal peak shown in June was likely a falsely inflated result due to little survey coverage occurring in that month). Southern right whales were distributed primarily along exposed coasts between Volunteer Lagoon and MacBride Head, but were also regular in the inner part of the main channel of Berkeley Sound. Data collected during DPLUS126 have highlighted the importance of the north-east Falkland Islands as a persistent wintering ground for southern right whales, which use the area for mating and socialising.

- The boat data, in addition to the datasets collected in Chapters 3 to 8, have been used to identify spatial hotspots of whale occurrence in the Falkland Islands. The Falkland Islands Inshore Key Biodiversity Area (KBA) was established for sei whales in 2021, but in 2024 this area was also recognised as a IUCN Important Marine Mammal Area (IMMA) for sei whales and other marine mammals. A KBA assessment for the southern right whale was completed in 2024 and the species has been added as a qualifying feature to the existing KBA. Further, the North-east Falklands Right Whale Wintering Area IMMA was recognised in 2024. Web links to the information for these spatial sites are provided in Section 2.4.4.

Chapter 3: Unmanned aerial vehicle study

- Calibrated unmanned aerial vehicles (UAVs or 'drones') are increasingly used to collect overhead images of whales from which their body sizes can be calculated from the image pixel dimensions, the focal length of the camera lens, and the UAV altitude (i.e. 'photogrammetry'). The body length estimates produced from the UAV imagery can then be assigned to an age class using existing data on the length-at-age of the species originating from similar UAV work on well-studied populations, whaling catches, or cetacean stranding data. Furthermore, UAV photogrammetry can also produce estimates of whale body volume, as a proxy for energy stores and body condition (BC), providing information on growth rates, seasonal variation in BC, and energetics. BC influences both survival and reproductive success.
- A pilot UAV study was carried out in the Falklands over a six-week period during July and August 2023, resulting in seven days of data collection and a total of 37 UAV flights completed over southern right whales.
- Images of sufficient quality to measure body length (BL) were acquired for 66 individual whales, and their BL ranged from 9.78 to 13.71 m (n=66, median=11.73), with a mean of 11.70 m (SD=0.94). The 66 whales were assigned as 26 (39.4%) adults, 37 (56.1%) juveniles, and three (4.5%) yearlings. Therefore, the proportion of mature to immature animals in the Falklands was 39.4% versus 60.6%. The highest density of measurements was around the 12 m threshold applied to distinguish between juveniles and adults, and therefore uncertainty remains over the exact ratio of immature to mature animals using the Falkland Islands wintering ground.
- Images of sufficient quality to measure BC were available for 49 whales, of which 19 (38.8%) were adult, 28 (57.1%) were juvenile, and 2 (4.1%) were yearlings. The BC measurements ranged from 0.04 to 0.32 for yearlings, -0.13 to 0.26 for juveniles, and -0.19 to 0.36 for adults. These measurements span the equivalent of a body volume (BV) 19% below to 36% above the average BV for a SRW of a given size. Individuals classified as yearlings (i.e. born during the previous calving season) had the highest BC, having been only recently weaned.
- The relative proportions of immature and mature animals determined by the UAV study have already been used in the KBA assessment for southern right whales. It is recommended that UAV work continues in the Falklands to establish a higher sample size of both BL and BC data to further clarify the age composition and health of right whales in the Islands.

Chapter 4: Sei whale telemetry

- Seven SPLASH10-F-333B satellite tags were deployed on sei whales in Berkeley Sound during 2022 (n=5), 2023 (n=1), and 2024 (n=1), with the aim of understanding more about their habitat use, spatial movements, and dive behaviour. The tags transmitted from 10 to 56 days, with a mean of 27.4 (SD=15.2) days and a median of 25 days.
- Two animals remained within Berkeley Sound for the entirety of their tag transmission durations (16 and 27 days respectively). Three whales moved south after departing Berkeley

Sound: (1) one moved to the west coast of the Falkland Islands where its tag ceased transmitting; (2) one spent six continuous weeks inside Berkeley Sound before moving south to the southern entrance of Falkland Sound; and (3) one had moved east of the Sea Lion Island group when the tag stopped transmitting. Within Berkeley Sound, whales exhibited erratic movements consistent with foraging behaviour.

- Two whales moved away from the Falkland Islands into international waters. The tag of one animal sent very few transmissions following its deployment, but after a week of no signal it transmitted a handful of positions from deep waters (>2,500 m) approximately 850 km east of the Falklands and 300 km north-west of the Shag Rocks at South Georgia. The final tagged whale moved around the north coast of the Falklands before commencing a concerted north-easterly movement away from the islands into the deep waters (>6,000 m depth) of the Argentine Basin; its tag ceased transmitting when it was ~1,375 km north-east of the Falklands.
- The five whales for which more than 50 tag positions were received in the Islands exhibited preferential use of the innermost shelf, with tag locations having shallow mean water depth (<50 m) and occurring in close proximity to the coast (<5.0 km). Within Berkeley Sound, sei whales foraged in shallower water depths found closer to shore as the season progressed from March to May. The duration of dives in Berkeley Sound also became longer in each consecutive month.
- Overall, the diving behaviour of sei whales in the Falkland Islands may be characterised as shallow and short duration. The majority of dives were to ≤15 m depth and only 15.6% of them exceeded 20 m depth. Whales spent the vast majority of their time (mean=82.7%, SD=7.5, range=74.7–95.0%) at depths of 0–10 m. The clear majority of sei whale dives (87.4%) had durations shorter than 5 min, and very few exceeded 13 min (the longest was 15.1 min). Over 86% of dives in Berkeley Sound were square-shaped, consistent with foraging behaviour.
- Their shallow dive behaviour potentially increases the exposure of sei whales to vessel strike. This is especially the case in Berkeley Sound which is a habitat of high overlap between foraging whales and shipping activity. Consequently, it is recommended that a vessel speed limitation is introduced as mandatory inside Berkeley Sound at night and also during the day unless a dedicated whale lookout is used, with 10 knots recognised globally as a speed within which vessel strikes are less likely to cause serious injury to, or mortality of, large whales

Chapter 5: Southern right whale movements

- Ten satellite tags (five SPOT location-only and five SPLASH location and dive behaviour) were deployed on southern right whales along the coast between Volunteer Point and MacBride Head during July 2022. The transmission duration of the 10 tags ranged from 27 to 261 days, with a mean of 137.8 days. The resulting location data were modelled and locations assigned to three behavioural states (BS) interpreted as high-use (BS1), intermediate use (BS2), and transitory (BS3) habitats. Locations associated with BS1 occurred at shallower depth and closer to shore than BS2 and BS3, while those for BS2 occurred at shallower depths and closer to shore than BS3. Seventy percent (n=865) of modelled locations occurring ≤150 km from the Falkland Islands comprised BS1, representing high-use habitats.
- The 10 tagged whales continued to use Falklands' nearshore waters for between 1 and 57 days (mean=30.1 d, median=34.0 d) following tagging, with six whales spending prolonged periods in the Falklands of 33–57 days, moving back and forth particularly along the exposed north coast between Volunteer Point and Foul Bay, and in the relatively sheltered inlet of Berkeley Sound. The satellite telemetry demonstrated that the nearshore waters along the north and north-east coasts of the Falkland Islands comprise a high-use habitat for right whales during winter.

- Six of the tagged whales subsequently moved to Peninsula Valdés (PV), a well-documented major calving ground for the south-west Atlantic population. The six Falklands–PV movements included all three of the whales genetically-sexed as females (plus an additional suspected female), but only two of the five confirmed males. The tags of two animals stopped working at PV; the remaining four animals spent residencies of 35 to 84 days at PV and departed in October. Individual whales may therefore use more than one winter breeding area within the same breeding season.
- Of the eight whales whose tags transmitted beyond 17 October, seven spent time using outer Patagonian Shelf habitats at latitudes from 37 to 55°S and with water depths of ~70–140 m and were still using those areas when their tags ceased transmitting. Patagonian Shelf waters are known to be used extensively by right whales, and it is likely that these areas comprise important feeding habitats.
- The telemetry results have already informed the delineation of an IUCN Important Marine Mammal Area for wintering right whales in the Falkland Islands, and have been used to plan a winter aerial abundance survey aimed at establishing the local population size to support an IUCN Key Biodiversity Area application.

Chapter 6: Southern right whale dive behaviour

- Transdermal archival SPLASH10-373A satellite tags were deployed on five southern right whales in the Falkland Islands during July 2022, to understand more about their dive behaviour. The tags of the five animals transmitted for 101 to 136 days, with a median of 114 days.
- The deepest dive recorded was 631.8 m, which is the deepest recorded for the species to date. However, the majority of dives occurred in the 10–20 m depth bin. Most dives had durations in the 5–10 min bin, with few exceeding 15 min. All five whales spent the clear majority of their time (72 to 87%) in the upper 20 m of the water column, and individuals spent between 54 and 69% of their time in the upper 10 m of the water column.
- Square-shaped dives were the dominant dive shape recorded and were interpreted as foraging dives. They occurred at lower swim speed than U-shaped or V-shaped dives, which is consistent with slow speeds used while filter-feeding. More square-shaped dives and fewer U- and V-shaped dives were recorded in areas of intermediate habitat use (BS2) than expected, which is consistent with BS2 comprising foraging behaviour. There were fewer square-shaped dives than expected in Antarctic and Wintering Ground habitats, and more than expected in Deep and Patagonian Shelf habitats which supports the use of the latter habitats for foraging.
- The collection of southern right whale dive data is relevant to better understanding: (1) their foraging ecology; (2) the nature of their interactions with potentially adverse human activities including vessel collision and entanglement in fishing gear, and (3) their availability at the surface for detection during abundance surveys, and therefore the calculation of appropriate correction factors to account for the proportion of submerged animals. The results of this study indicated that right whales using the winter breeding area in the Falkland Islands spend the majority of their time in the uppermost 10 m of the water column where they are potentially exposed to vessel collisions, and it is recommended that management measures are implemented to reduce this likelihood during the right whale season. Recommendations are also made with respect to mitigating potential fishing gear entanglements, specifically with respect to fixed gear deployed in nearshore areas which are a documented major source of whale entanglements globally.

Chapter 7: Aerial abundance surveys

- Aerial surveys aimed at estimating the abundance of southern right whales were carried out in the coastal waters of the north-east Falkland Islands from Pebble Islet to Port Harriet during June 2023, July 2024, and August 2023. During each survey a series of transects was flown from the coast to 30 km offshore. Five cetacean species were recorded, and the number of sightings of right whales and Commerson's dolphins (*Cephalorhynchus commersonii*) was sufficient to generate robust abundance estimates.

- Right whale sightings were most widespread from the coast to the outer limits of the survey area during June 2023, intermediate in July 2024, and least widespread in August 2023 when almost all detections occurred close to the coast. Surface active groups (comprising mating and socialising) were found significantly closer to shore than other sightings.

- The resulting uncorrected (for the proportion of submerged animals) abundance estimates were 399 (CV=0.25), 345 (CV=0.26) and 229 (CV=0.46) southern right whales in June 2023, July 2024, and August 2023 respectively. These estimates currently comprise the best available data regarding the number of right whales using the Falkland Islands wintering ground at a given time during the peak season, and are considered significant in a regional and global context.

- The distribution of Commerson's dolphins was heavily skewed towards the western part of the study area in the waters west of Cape Dolphin, and especially to the north of West Falkland. The resulting uncorrected (for the proportion of submerged animals) abundance estimates were 1,661 (CV=0.43), 4,698 (CV=0.30) and 2,579 (CV=0.56) Commerson's dolphins in June 2023, July 2024 and August 2023 respectively. The results indicate that the waters around the Islands host upwards of several thousand animals and therefore comprise a considerable regional, and thus global, stronghold of the species.

- The completion of the aerial surveys over two years (rather than in the same year as had been planned) was an unfortunate consequence of adverse weather in July 2023, and means that the resulting seasonal trends in abundance are also potentially affected by unknown inter-annual variation in cetacean numbers. However, the estimates for both species will be used to inform Key Biodiversity Area applications, and form baselines against which to assess future abundance estimates.

Chapter 8: Sei whale mark-recapture

- Cetacean photo-identification studies rely on the acquisition of high-quality images of the naturally-occurring markings that can be used to recognise individuals, providing valuable information including population size (abundance), movements, habitat use, social affiliations, survivorship and life history parameters. Fundamental to such analyses is the use of a capture-mark-recapture (CMR) method, whereby an individual is marked (i.e., its first photographic capture) and subsequently recaptured (i.e., photographed again) at a later time and/or place.

- A CMR analysis was carried out on images of sei whales taken in Berkeley Sound in 2017, 2019, 2020 and 2021, comprising a total of 59 sampling occasions (i.e. survey dates where images were acquired). To meet the underlying CMR assumption that all individuals have an equal probability of being captured within a sampling occasion, only individuals with a Distinctiveness Value (DV) of 3 (moderately marked) or 4 (highly marked) were included as 'marked animals' in the CMR analysis. Images were cropped to the dorsal fin area and then assessed against a set of photographic quality (PQ) criteria. The CMR analysis was limited to only images of good (PQ2) or excellent (PQ1) quality in order to ensure that the marks used to recognise individuals were visible.

- Following quality control to remove low quality (PQ3 and PQ4) images from the dataset, a total of 368 sei whale individuals (of all DV) remained across 57 sampling occasions. Using only high quality (PQ1 and PQ2) images, the number of captures of individual sei whales across the four years ranged from 1 to 7, with the clear majority (72.3%) of animals captured once only. A continuous increase in the number of new animals identified over time was evident, indicating that the population of sei whales using Berkeley Sound has not yet been fully catalogued.
- The resulting abundance estimates were in the region of 100–150 animals for 2017, 2019 and 2020, and higher values of around 200–300 animals for 2021, depending on the model used. These estimates relate solely to sei whales photographically captured within Berkeley Sound, and do not represent the total number of animals using the entirety of the Falkland Islands.
- It is clear that the distribution range of the sei whale population that visits Berkeley Sound to forage during the summer and autumn extends much further than Berkeley Sound and includes the entirety of the Falkland Islands and very likely the wider south-west Atlantic region. Therefore, the use of a closed model for CMR analysis is not supported by knowledge of the ecology and distribution of the species. However, the use of an open robust model, while more appropriate ecologically, was restricted by the low number of photographic recaptures both within and between years. The results indicate that the CMR study would need to have higher resolution (i.e. more sampling occasions per year), incorporate a greater timespan (i.e. more years), or cover a wider geographic area, in order to increase the number of photographic recaptures and thus improve the accuracy and precision of the resulting abundance estimates. As a first step, there has been photo-identification effort carried out in 2022, 2023 and 2024 which could be processed and added to the CMR analysis in the coming years, to determine whether the longer timeframe improves these results.

Chapter 1: Introduction

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1.1 Project overview

This Technical Report describes fieldwork carried out during a Darwin Plus funded project (DPLUS126) titled "*Advancing Falklands and region-scale management of globally important whale populations*" which was carried out from 1 July 2021 until 30 September 2024. The project built on the research of sei whales (*Balaenoptera borealis*) and southern right whales (*Eubalaena australis*) carried out during a previous Darwin Plus project (DPLUS082: Weir, 2022), and sought to address several of the remaining knowledge gaps on their occurrence in the Falkland Islands deemed most relevant to their conservation and management. In particular, DPLUS126 included the ambitious goal of carrying out the first deployments of satellite tags on baleen whales in the Falkland Islands to track the movements of sei and southern right whales around the Islands and across the wider south-west Atlantic.

DPLUS126 was led and implemented by Falklands Conservation, with a range of local and international project partners contributing to their specific areas of expertise including:

- **The Cooperative Institute for Climate, Ocean, and Ecosystem Studies – University of Washington (Alexandre Zerbini)**: Satellite tag deployments on sei and southern right whales.
- **British Antarctic Survey (Jennifer Jackson)**: Satellite tag deployments and southern right whale photo-identification.
- **Aarhus Institute of Advanced Studies (Fredrik Christiansen)**: Unmanned aerial vehicle (UAV) assessment of southern right whale body condition.
- **Sea Mammal Research Unit (Phil Hammond)**: Aerial abundance estimates.
- **Happy Whale (Ted Cheeseman)**: Sei whale photo-identification matching with citizen science data.
- **Falkland Islands Government (Mike Jervois)**: Input on sei whale Species Action Plan and the development of management recommendations for baleen whales.

This report outlines the methods used and results achieved during the baleen whale fieldwork components of DPLUS126, which included:

- Boat-based surveys to assess the spatio-temporal occurrence of baleen whale species (**Chapter 2**). MANAGEMENT RELEVANCE: identifying key sites for whales that could be incorporated into marine management and used to assess their overlap with, and mitigation of, human activities;
- Unmanned aerial vehicle study of southern right whales (**Chapter 3**). MANAGEMENT RELEVANCE: clarifying the age cohorts and body condition of individual southern right whales, to better understand why the species occurs in the Falklands and the health of the local population;
- Sei whale telemetry study (**Chapter 4**). MANAGEMENT RELEVANCE: understanding how sei whales utilise the Falklands' foraging grounds in terms of their spatial movements and their use of the water column (i.e. dive behaviour), which provides new information on their potential overlap with human activities and exposure to specific threats (e.g. ship strike);

- Southern right whale movements (**Chapter 5**). MANAGEMENT RELEVANCE: understanding how right whales utilise the Falkland Islandss wintering ground and the wider south-west Atlantic, with regard to movements, habitat use, and links with other geographic regions;
- Southern right whale dive behaviour (**Chapter 6**). MANAGEMENT RELEVANCE: understanding how right whales behave in the Falklands wintering ground and the wider south-west Atlantic, with regard to their foraging ecology and potential exposure to vessel strike;
- Aerial abundance estimate of southern right whales in the Falkland Islands (**Chapter 7**). MANAGEMENT RELEVANCE: needed to inform a Key Biodiversity area assessment for that species; and
- Producing the first capture-mark-recapture abundance estimate for sei whales in Berkeley Sound (**Chapter 8**). MANAGEMENT RELEVANCE: increase knowledge of the number, and fidelity, of sei whales in that site, which is the highest area of marine human activities in the Falklands with the potential to impact on the species through, for example, acoustic disturbance or vessel collision.

Some of the resulting data have already been translated into management outputs relevant to whales in the Falklands as part of DPLUS126, including a Conservation Management Plan for the sei whale and a Key Biodiversity Area application for the southern right whale.

1.2 Study area

1.2.1 The Falkland Islands

The Falkland Islands are located approximately 500 km east of the southern Patagonian coast of South America, at latitudes of 51°S to 53°S and longitudes of between 57°W and 62°W (Figure 1.1). The Islands are situated in shallow (<200 m depth) waters that form an eastwards extension of the Patagonian continental shelf. The two main islands of East and West Falkland are divided by a channel of water named Falkland Sound, and their coastlines are indented by a number of large bays and inlets. Falkland Islands Government (FIG) declared the Falkland Islands Interim Conservation and Management Zone (FICZ) in October 1986, comprising an area of 300 km radius centred on Falkland Sound (Figure 1.1). In 1990 the Falkland Islands Outer Conservation Zone (FOCZ) was declared in the area between the FICZ and the 200 nautical mile economic zone boundary (Figure 1.1).

The Falklands are situated approximately 500 km north of the Antarctic Convergence, and the surrounding waters are cold temperate. Average monthly sea surface temperature (SST) in the waters around the Islands ranges from 10–12°C in January (peak austral summer) to 4–6°C in July (peak austral winter).

1.2.2 Research sites

The sei whale work focussed on Berkeley Sound, a large sea inlet located on the east coast of East Falkland, while the southern right whale work occurred in an expanded area that included the north coast of East Falkland (Figure 1.2).

Berkeley Sound is a shallow habitat with depths ranging from ~60 m at the mouth to ~15 m in the innermost part of the main sound to the east of Long Island. It is heavily used on a seasonal basis as an anchoring and transshipment area by vessels associated with the fishing industry, including reefers, tankers, jiggers, longliners and launches. Falklands Conservation has researched sei whales in Berkeley Sound since 2017 (Weir, 2017, 2022), and the site is known to be of high importance as a seasonal feeding area for sei whales between December and May. Topographic features of Berkeley Sound referred to in the text of this report are shown in Figure 1.3.

Southern right whales use Berkeley Sound but previous work has shown that the species is also found in high numbers along the coastline from Volunteer Lagoon north to MacBride Head (Figure 1.4) during winter (Weir, 2022). That area consists of sandy beaches interspersed by rocky coastline with numerous kelp beds and is exposed to the open Atlantic Ocean. In particular, the waters in proximity to MacBride Head can be choppy due to strong tidal currents around the headland in addition to wind.

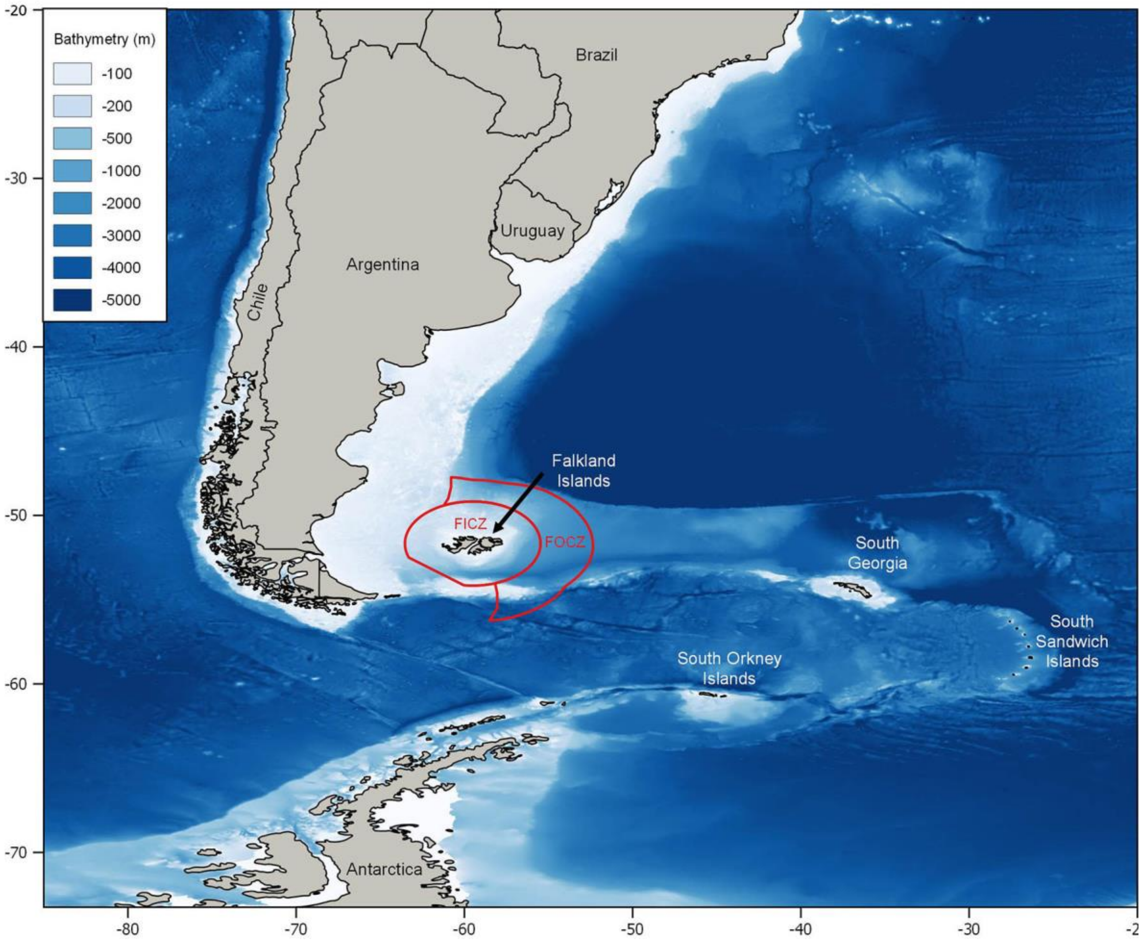

Figure 1.1. Geographic position of the Falkland Islands off South America, showing bathymetry and the locations of the Falkland Islands Interim Conservation and Management Zone (FICZ) and Falkland Islands Outer Conservation Zone (FOCZ).

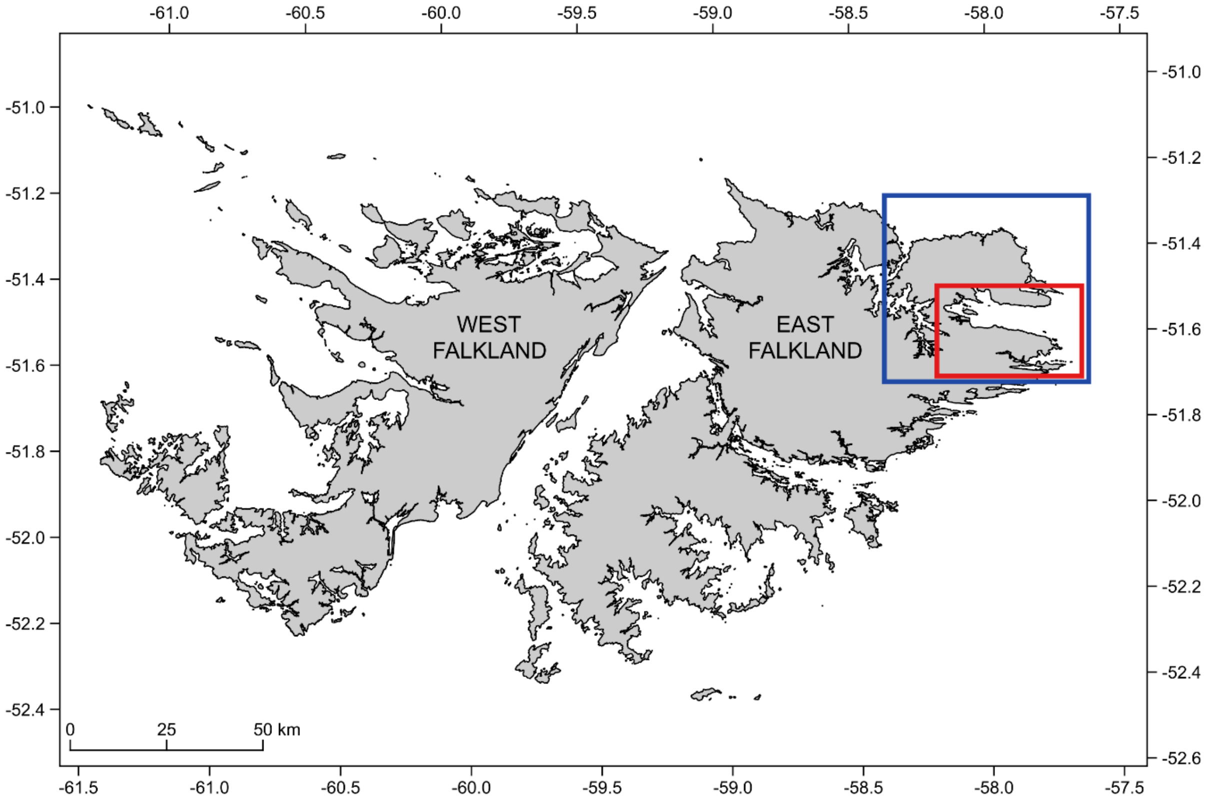

Figure 1.2. The study areas for the sei whale work (red box) and the southern right whale work (blue box) on the north-east coast of East Falkland.

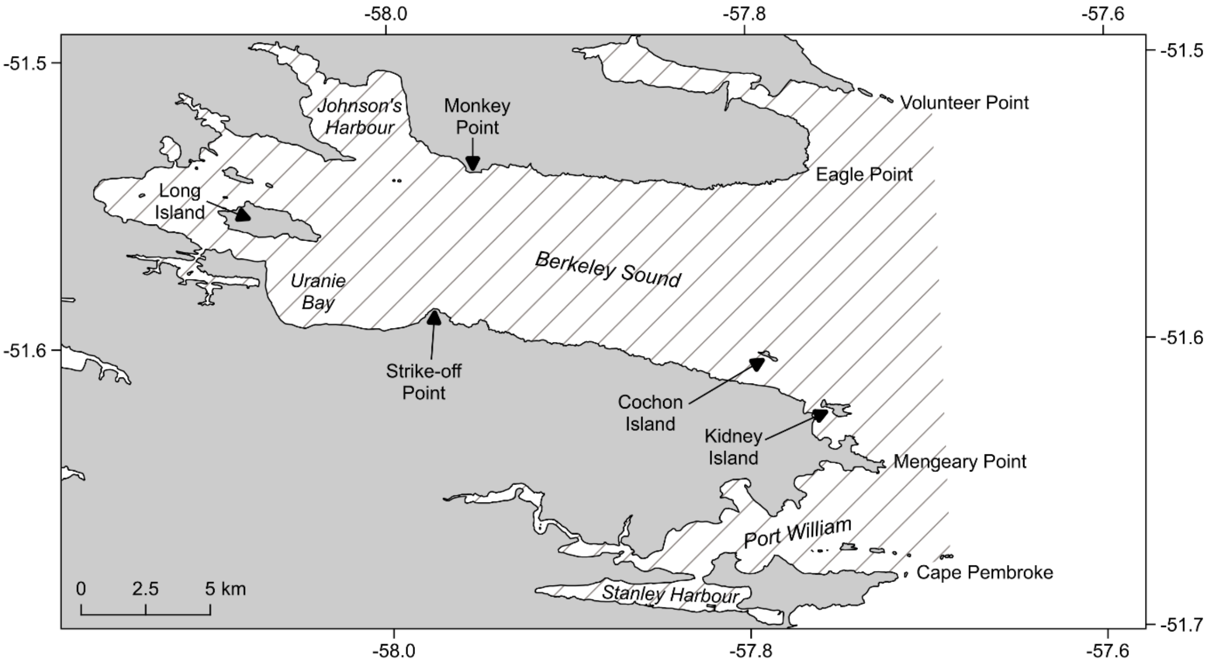

Figure 1.3. The Berkeley Sound study area (hatched area) with topographic features labelled. See Figure 1.2 for the location of Berkeley Sound relative to the rest of the Islands.

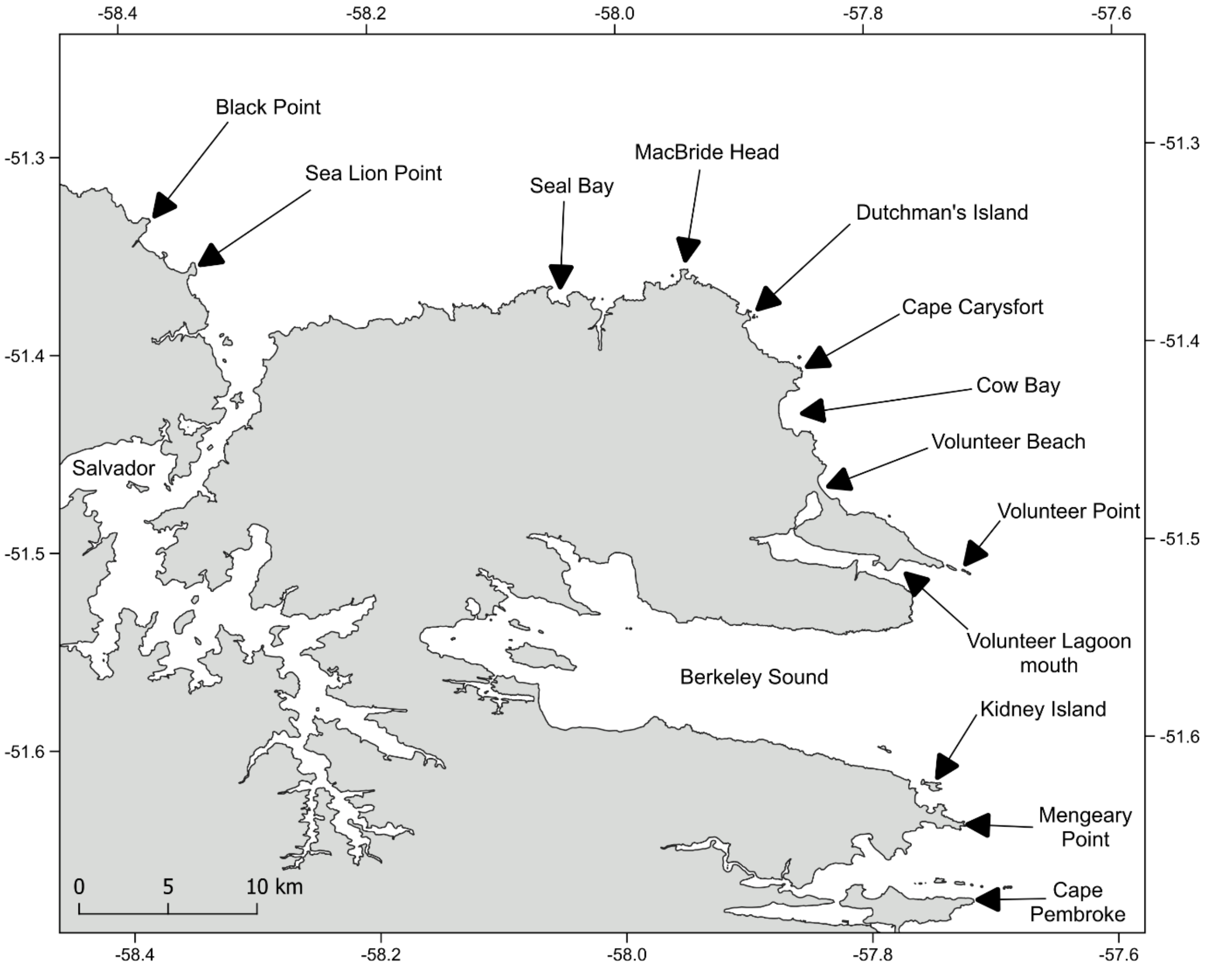

Figure 1.4. The southern right whale study area with topographic features labelled. See Figure 1.2 for the location of this area relative to the rest of the Islands and Figure 1.3 for details of Berkeley Sound.

1.3 Focal species

1.3.1 Sei whale

The sei whale is a species of large baleen whale reaching average lengths of around 15 m and a maximum of around 19 m (Weir and Prieto, 2024). The species is characterised by a slender body, a prominent erect dorsal fin positioned two-thirds of the way along the back, a light chevron marking extending over the back behind the blowholes, a slightly downturned arched jawline, and a distinctive forward-angled and upsweeping pale "brush mark" extending upwards from the lower flank approximately midway between the blowholes and the dorsal fin (Figure 1.5).

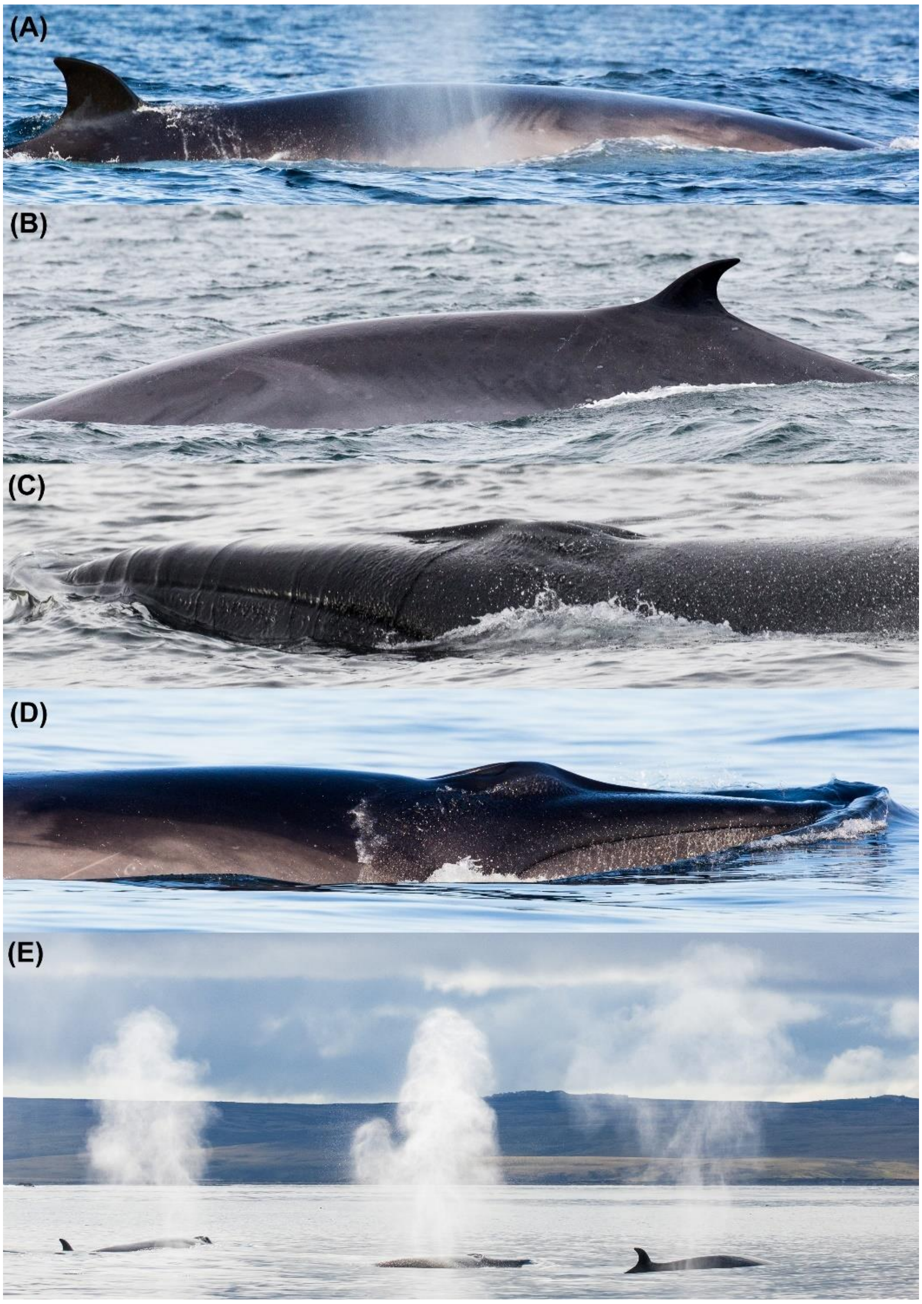

Figure 1.5. Identification features of sei whales photographed in the Falkland Islands: long backs with prominent dorsal fins (A, B and E); pale chevron behind the head (A, D), pale forward-sweeping 'brush marking' extending upwards from the lower flank halfway between the blowholes and the dorsal fin (A, B), slightly downturned jawline (C); tall columnar blows (E). From Weir and Prieto, 2024.

Sei whales are distributed worldwide from polar to tropical waters, but their densities appear to be highest across mid-latitude temperate areas in water temperatures of 8°C to 18°C (Horwood, 1987). In many geographic areas they are considered to be primarily oceanic in habitat, being found along the continental slope or in deep ocean basins (Horwood, 1987). However, in the Falkland Islands, and elsewhere around the southern tip of South America, they also routinely occupy neritic and nearshore habitats (Weir and Prieto, 2024). Despite their widespread occurrence, sei whales are categorised by the International Union for Conservation of Nature (Cooke, 2018) as having Endangered (EN) global conservation status, due to heavy exploitation by commercial whaling operations that occurred particularly during the 1960s and 1970s.

In the Falklands, sei whales are present in coastal waters between (at least) November and June, but with a strong seasonal peak during February and March (Weir, 2017, 2018, 2022; Weir et al., 2019). The underlying driver for this strong seasonal occurrence is the use of Falklands' waters as a feeding ground, evidenced by observations of surface feeding on squat lobster krill (*Munida gregaria*) and amphipods (*Themisto gaudichaudii*), and of regular defecations by whales (Weir, 2017, 2022; Weir et al., 2019). Like most large baleen whale species, the sei whale undertakes seasonal migrations between winter subtropical areas where mating and calving occur, and summer temperate and polar feeding areas (Horwood, 1987). The locations of feeding and breeding areas remain poorly understood globally. However, in the south-west Atlantic a link has been shown between the Falkland Islands feeding ground and a wintering area located off Brazil (Weir et al., 2020).

1.3.2 Southern right whale

The southern right whale (SRW) is a stocky baleen whale reaching around 14 to 15 m body length on average. Although of a similar overall body length to the sei whale, right whales have a considerably wider girth and total body mass. The species is characterised by its robust body shape, lack of a dorsal fin, large head with a strongly arched jawline, and the unique pattern of roughened patches of skin called 'callosities' on their heads which become infested with crustaceans and appear cream or yellow in colour (Figure 1.6). The majority of SRWs of both sexes are black in colour, often with irregular white patches on their belly. However, a small number of (mostly male) calves are born white with black mottled spotting, and become pale grey with black mottling (or 'brindle') as adults (Schaeff et al., 1999).

SRWs are distributed across temperate and polar waters of the Southern Hemisphere, including well-documented winter mating and calving areas located along the coasts of South America (particularly in Argentina and Brazil), South Africa, southern Australia and New Zealand (Cooke and Zerbini, 2018). The pelagic foraging grounds occupied by SRWs during the austral summer are far less well known, but are thought to be concentrated at latitudes of 40–50°S. Although the global population remains well below the estimated pre-exploitation size of 55,000 to 75,000 animals, in many regions SRWs are steadily recovering from centuries of severe exploitation during the early whaling era (<1920s: IWC, 2001). Consequently, their global conservation status has been categorised as Least Concern (LC) since 2008 (Cooke and Zerbini, 2018).

Whaling data, occasional sightings, and recent satellite-tracking work indicate that some southern right whales use the pelagic waters around the Falklands during summer and autumn (Townsend, 1935; Zerbini et al., 2016, 2018; Weir and Stanworth, 2020), presumably for foraging and during their seasonal migrations between foraging and breeding areas. However, the species also uses Falklands' waters during winter. A wintering aggregation of SRWs in nearshore waters was first well-documented during 2017 and has been present every year since (Weir, 2021, 2022; Weir and Stanworth, 2019). The whales often engage in surface active behaviour (SAGs, usually sexual in nature: Wilding Brown and Sironi, 2023), with frequent observations of mating (Weir 2021, 2022), and the presence of gunshot song (a male reproductive display: Crance et al. 2019) throughout the winter months (Cerchio et al. 2022) strongly supporting reproductive behaviour.

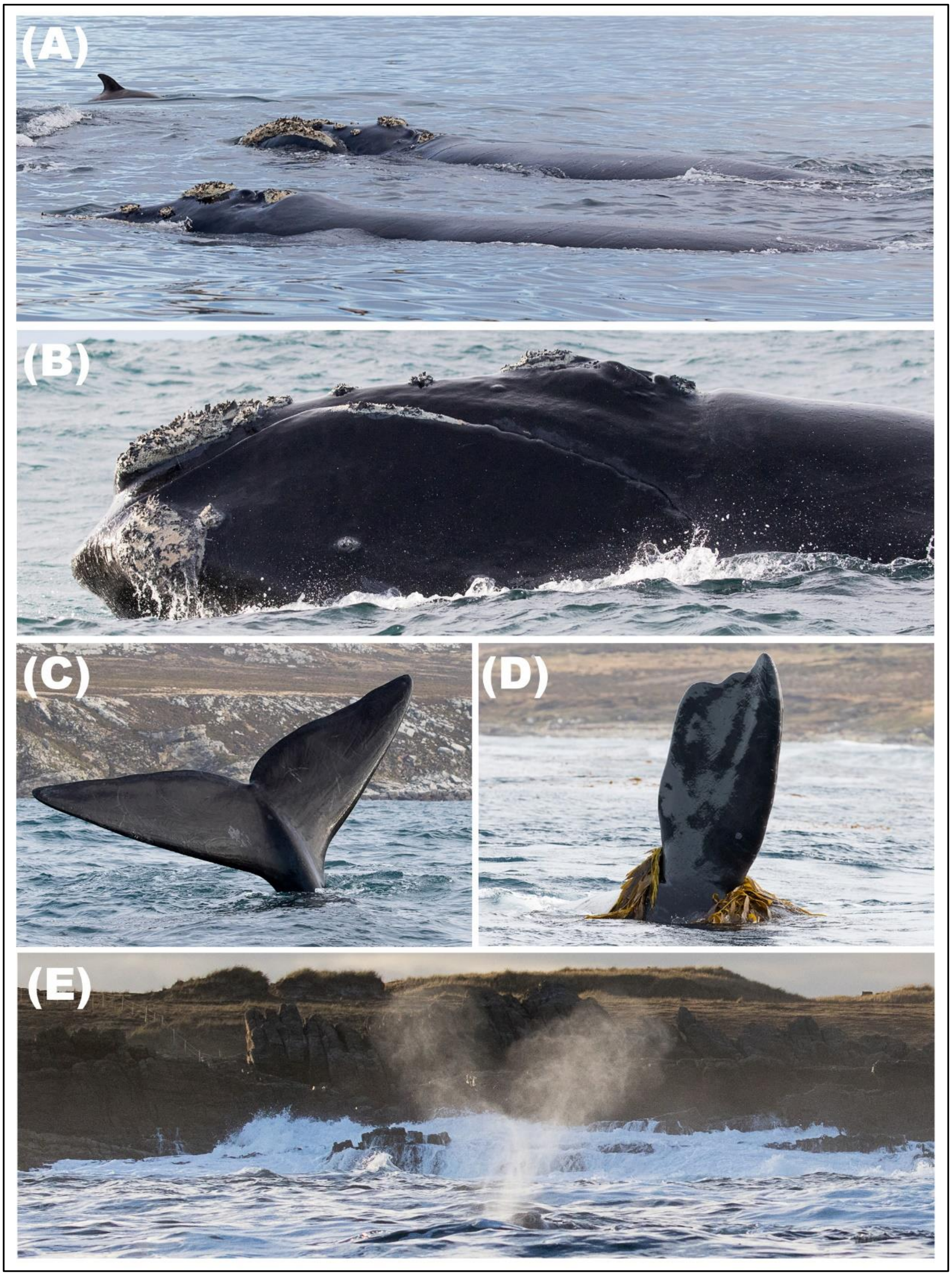

Figure 1.6. Identification features of southern right whales photographed in the Falkland Islands: robust black coloured body with no dorsal fin (A); strongly arched jawline (B); yellowish callosity pattern on the head (A,B); tail flukes often lifted when diving (C); broad paddle-shaped flippers (D); and a characteristic V-shaped blow (E).

To date, no calves-of-the-year have been confirmed in the Falklands, despite survey effort occurring during August and early September when calving occurs elsewhere in the south-west Atlantic

(Rowntree et al., 2013). The composition of SRWs using the Falklands wintering area comprises both adults and juveniles, with a sex ratio biased towards males (Jackson et al., 2022). Genetic analysis has revealed that the SRWs using the FIWG are part of the wider south-west Atlantic population (Jackson et al., 2022), for which the major contemporary calving and nursery grounds are located at Peninsula Valdés in Argentina and Santa Catarina in Brazil (Cooke and Zerbini, 2018). However, an adult female from a South African calving ground was also recently documented in the Falklands (Vermeulen et al., 2023), suggesting that the Islands represent an important strategic location for understanding the movements, connectivity, and behaviour of SRWs across the wider South Atlantic region.

1.4 Report format

The remainder of this report comprises chapters relating to specific individual components of the DPLUS126 fieldwork comprising the small boat survey work (Chapter 2), the unmanned aerial vehicle study of SRWs (Chapter 3), telemetry work on sei whales (Chapter 4) and SRWs (Chapter 5), the diving behaviour of SRWs (Chapter 6), the aerial abundance survey for SRWs (Chapter 7), and the sei whale mark-recapture estimate (Chapter 8). Each fieldwork component is presented as a standalone chapter, with input and coauthorship of the relevant project partners.

1.5 Research permits

All of the work described in this report was conducted with the following permits issued by Falkland Islands Government:

- R11/2017: *Monitoring of baleen whales in the Falkland Islands.* Covering non-invasive work including visual surveys, photo-identification, acoustic monitoring, and faecal sampling.
- R14/2020: *Population structure, foraging ecology and movements of baleen whales in the Falklands*. Covering biopsy and satellite tagging work.
- R20.2023: *Cetacean research in the Falkland Islands*. Covering non-invasive work as a follow-on from R11.2017.
- R32.2023: *Invasive research on baleen whales in the Falkland Islands*. Covering biopsy and satellite tagging work, as a follow-on from R14.2020.

Copies of these permits are available on request from Falklands Conservation or Falkland Islands Government.

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Chapter 2: Spatio-temporal occurrence of sei and southern right whales during boat surveys

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2.1 Introduction and aims

Previous targeted work on the spatial distribution, temporal occurrence and ecology of sei whales and southern right whales in the Falkland Islands has included a pilot study of sei whales in Berkeley Sound during 2017 (Weir, 2017), a sei whale study on the west coast of the Islands during 2018 (Weir, 2018), three years (2019 to 2021) researching sei whales in Berkeley Sound and Falkland Sound (Weir, 2022), and two targeted winter seasons for southern right whales (SRWs) in the north-east Falklands during 2019 and 2020 (Weir, 2022). Over this timeframe, baleen whale research in the Islands has evolved to incorporate a range of novel technologies and address additional research questions aimed at acquiring the most pertinent knowledge to inform the conservation and management of whales. For example, tissue samples have been collected from whales during boat surveys to assess population structure and genetic diversity, while faecal samples are collected to identify prey species (Weir, 2022). In the current study, much focus of the boat survey work was on deploying satellite tags on whales (see Chapters 4 and 5) and collecting whale body measurements (see Chapter 3). However, across the years the collection of standardised data on the occurrence, group sizes and distribution of whales in the Falklands remains pivotal to answering the fundamental questions of where, when and why they occur. This in turn is critical to informing effective management of whales, for example through the identification of key habitats that could be incorporated into marine management and taken forward for global designations such as IUCN Important Marine Mammal Areas or Key Biodiversity Areas, and for assessing the spatial and temporal overlap between whales and potentially adverse human activities.

The collection of robust spatio-temporal datasets on marine predators such as cetaceans, pinnipeds, sharks and seabirds is particularly challenging, due to the highly mobile and wide-ranging nature of those species and the fluctuations in oceanography and prey availability that can influence predator occurrence over ocean-wide scales (Block et al., 2011). Consequently, it is usual for the numbers and distribution of marine predators in an area to show inter-annual and intra-annual variation, requiring long-term multi-year datasets in order to establish robust baselines against which to monitor change and identify the drivers of such changes (e.g. Ramp et al., 2015; Szesciorka et al., 2020). DPLUS126 facilitated the collection of three more years of targeted data on the spatio-temporal distribution of sei whales and SRWs in the Falkland Islands. While the data collected during DPLUS126 was subject to caveats regarding weather limitations and the multi-faceted nature of the boat survey work (meaning that focus was split across several research goals requiring different methodologies), the data provide additional years of information on group sizes, seasonality and spatial distribution that add considerably to the existing available datasets.

This chapter provides an analysis of the boat-based data collected on both whale species during the 2022 to 2024 seasons as part of DPLUS126 and as a comparison to similar analyses carried out for the 2019–2021 data (Weir, 2022).

2.2 Materials and methods

2.2.1 Study area

Small boat surveys were carried out between 2022 and 2024 in the north-east Falklands, predominantly comprising the waters between Cape Pembroke and MacBride Head. The study area for each species differed; between January and May the survey work was focussed on sei whales in the Berkeley Sound region, while between June and early September the work targeted southern right whales in an extended area that primarily covered the Volunteer Point to MacBride Head coastline but also included some surveys of Berkeley Sound. See Figures 1.2 to 1.4 for more information on the study areas for each species.

While the desired routes were determined prior to each survey and planned to optimise spatial coverage, the exact route taken on each boat survey was determined in practice by factors including prevailing weather conditions and whale encounters.

2.2.2 Data collection

A 7.5 m rigid-hulled inflatable boat with twin 90-hp engines was used for the whale survey work, with survey speeds typically in the region of 11 to 14 knots. For reasons of both safety and productivity (it was difficult to work effectively with cameras and sampling equipment once spray began to come over the bow), small boat surveys were only planned for days where low wind speeds (≤12 knots) were forecast. Weather conditions were therefore the primary constraint to the number of surveys carried out per month. Additionally, surveys in some months (particularly May and June) were limited by the presence of coastal fog.

During each survey, two to three observers searched continuously forward and to both sides of the boat for visual cues (e.g., blows, backs, footprints, water disturbance) that might indicate the presence of whales. The boat position was continuously logged at 1-min intervals using a handheld Garmin GPS, with all other data collected during the survey being recorded using a digital voice recorder and subsequently linked to the GPS via correlated timestamps. Effort status was continuously logged as: (1) Active Search effort (while observers were actively scanning the sea surface in search of cetaceans); or (2) Cetacean Encounter effort (while working with cetaceans and not actively searching for new animals). Periods where the observers were not actively engaged in either of those "on effort" activities (e.g. during lunch breaks or safety drills) were considered as “off effort” and no data were logged. For every period of effort, the start and end times were recorded, along with environmental data and effort status. A new set of data was recorded whenever conditions changed, for example when changing from Active Search to Cetacean Encounter effort. Standardised environmental data were recorded throughout the survey in order to assess the quality of the effort data with regard to detecting the target cetacean species. Those data comprised Beaufort sea state, swell height (m), visibility (km), precipitation, and sun glare (see Weir, 2017, 2018 for definitions).

Whenever cetaceans were observed, the following standardised information was recorded: sighting start and end times (recorded directly from the GPS to ensure accurate correlation with positional data), effort status, species identification, group size (minimum, maximum, best estimate), group composition (adults, juveniles, calves, unknown age), and overall behaviour.

When conditions allowed, the boat was diverted to approach baleen whale sightings to implement activities associated with the other DPLUS126 project research goals, particularly photo-identification, satellite tag deployments, and unmanned aerial vehicle measurements of whales. When an approach was made, a second time and distance were logged when the boat was within 200 m of the animal(s) and used to reflect actual animal location. On occasions where whales were not approached (e.g. due to time constraints or adverse weather), the time, vessel heading, relative bearing, and estimated distance to the sighting were recorded, in order to subsequently calculate an accurate sighting position.

2.2.3 Data analysis

Effort and sightings data were entered into standardised Excel databases as soon as possible after each survey. The analysis positions for sightings were determined as: (1) the boat position at initial sighting if animals were within 300 m; (2) the boat position at encounter start time for whales approached in closing mode; or (3) when animals were at distances exceeding 300 m from the boat in passing mode, the sighting position was recalculated based on angle and estimated distance from the boats GPS position using an Excel worksheet (MacLeod, 2011). The best visual estimate of group size was used throughout analysis.

All mapping was carried out in Quantum Geographic Information System (QGIS: V3.28; https://qgis.org) using the WGS 84 / UTM zone 21S projection.

The relative abundance of whales was calculated as both the number of sightings, and the number of individuals, recorded per km of active search effort. This represents a measure of relative abundance and is not a calculation of density or absolute abundance (Evans and Hammond, 2004). Relative abundance was calculated using only effort and associated sightings data collected in conditions considered to be favourable for the visual detection of whales. Favourable conditions were defined for this report as Beaufort sea state ≤4, swell of ≤2.5 m, and visibility of >5 km.

The sighting positions used for relative abundance mapping were the uncorrected boat positions at the time of each initial sighting, since the sightings needed to match with the associated effort in each grid cell. One consequence of this approach is that the actual positions of the animals may have been located in an adjacent grid cell. The relative abundance maps were produced at 4 km grid cell size. Only grid cells in which >1 km active search effort was achieved were included in the maps, to minimise falsely-inflated relative abundance values when sightings were recorded in grid cells where very small amounts of survey effort had occurred.

2.3 Results

2.3.1 Overview

A total of 68 boat surveys was carried out for DPLUS126 fieldwork between March 2022 and May 2024, resulting in totals of 456.8 hr and 6,031 km of survey effort (Table 2.1). Of that, 206.7 hr and 4,527 km of effort comprised active search effort, while 250.1 hr and 1,505 km of effort was spent in encounters with cetaceans. The cetacean encounter effort was split between multiple species as shown in Table 2.2), but with sei whales and SRWs being the focus of the vast majority of the encounter effort.

Effort was not split evenly between the sei whale season (Feb–May) and the southern right whale (SRW) season (Jun–Sep). A total of 40 surveys were completed in the sei whale season, versus 28 surveys in the SRW season (Table 2.1). This was largely the consequence of DPLUS126 having three years of sei whale work (2022–2024) but only two years of SRW work (2022 and 2023).

Table 2.1. Summary of boat-based effort collected on 68 survey dates in 2022–2024.

Year	Month	No. of survey dates	All survey effort (search and encounter)		Active Search effort		Active Search effort in favourable weather		Encounter effort	
			hr	km	hr	km	hr	km	hr	km
2022	Mar	5	37.3	543.4	19.8	405.6	18.2	369.8	17.4	137.9
	Apr	7	48.7	648.9	19.5	420.6	19.0	409.1	29.1	228.3
	May*	1	4.2	70.4	2.4	60.8	2.4	60.8	1.8	9.6
	Jul	9	60.2	742.5	27.8	615.1	27.3	603.4	32.4	127.4
	Aug	8	43.7	563.9	20.2	451.2	17.4	391.2	23.5	112.8
2023	Feb	1	7.1	100.2	3.6	82.2	3.1	71.2	3.5	17.9
	Mar	5	30.5	447.5	15.1	329.1	15.1	329.1	15.4	118.4
	Apr	4	30.4	451.1	13.9	325.9	13.7	321.2	16.5	125.3
	Jun	1	6.7	55.6	2.2	43.4	2.2	43.4	4.5	12.1
	Jul	6	38.5	457.6	16.8	350.4	16.8	350.4	21.7	107.2
	Aug	2	9.3	181.4	7.1	169.6	6.9	166.6	2.3	11.8
	Sep	2	15.3	288.9	10.0	266.7	10.0	266.7	5.3	22.2
2024	Feb	2	11.3	138.9	4.6	92.6	3.6	71.3	6.7	46.3
	Mar	6	48.1	565.4	18.1	362.3	16.3	326.7	30.0	203.1
	Apr	6	42.4	452.4	14.0	299.6	12.6	267.5	28.4	152.9
	May	3	23.4	323.1	11.7	251.7	11.3	243.4	11.7	71.4
2022	Total	30	194.0	2,569.1	89.7	1,953.3	84.3	1,834.4	104.2	615.9
2023	Total	21	137.8	1,982.3	68.7	1,567.4	67.8	1,548.6	69.1	414.9
2024	Total	17	125.1	1,479.8	48.3	1,006.1	43.8	908.9	76.8	473.7
All	Total	68	456.8	6,031.2	206.7	4,526.8	195.8	4,291.8	250.1	1,504.5

* One survey carried out in May 2022 was on a launch rather than FC’s research boat.

Table 2.2. Distribution of cetacean encounter effort according to species, from boat surveys carried out on 68 survey dates during 2022–2024.

Species common name	Species scientific name	Effort	
		Hr	Km
Single species groups			
Sei whale	*Balaenoptera borealis*	125.8	921.6
Southern right whale	*Eubalaena australis*	86.5	359.0
Humpback whale	*Megaptera novaeangliae*	0.1	0.1
Killer whale	*Orcinus orca*	1.7	11.8
Peale's dolphin	*Lagenorhynchus australis*	18.4	124.5
Commerson's dolphin	*Cephalorhynchus commersonii*	11.5	61.9
Multi-species groups			
Sei whale + dolphins		0.6	4.4
Southern right whale + dolphins		5.0	17.9
Humpback + dolphins		0.1	0.2
Peale's + Commerson's dolphins		0.4	3.0
Total		***250.1***	***1,504.5***

A total of 889 cetacean sightings comprising 3,107 individuals was recorded during the 2022–2024 survey work. The Peale's dolphin was the most common cetacean species encountered in the study area (Table 2.3). Three other delphinid species were recorded (Table 2.3), comprising Commerson's dolphin, a single dusky dolphin (*Lagenorhynchus obscurus*) known to be resident in the study area (Weir and Black, 2018), and three sightings of killer whales. All remaining sightings were of baleen whales, with sei whales and southern right whales comprising the most numerous species (Table 2.3). Only a single humpback whale was recorded in the study area during the boat surveys. This was surprising, considering the increased sightings of this species during 2021 (Weir, 2022), and the fact that humpbacks were seen from shore during December/January in some years (Weir, pers. obs.). It appears that humpbacks are most likely to be seen within the study area slightly earlier in the year (Nov–Jan) than the boat survey work was carried out.

As would be expected, the vast majority of cetacean sightings occurred while the survey was engaged in active search effort, with smaller numbers of sightings recorded while off effort or while already working with cetaceans (Table 2.4).

2.3.2 Spatio-temporal distribution of Active Search effort

The total amount of active search effort collected in weather conditions deemed favourable (Beaufort sea state ≤4, swell of ≤2.5 m, and visibility of >5 km) for the visual detection of large whales was 195.8 hr / 4,291.8 km (Table 2.1). The majority of that effort occurred in sea conditions with no whitecaps (Beaufort sea state 0–2: 60.7%), low swells of ≤1.0 m (78.2%), and in excellent visibility exceeding 20 km (90.9%: Figure 2.1).

Most of the 2022–2024 active search effort occurred in March/April and in July/August (Figure 2.2; Table 2.1), representing the peak periods for sei whales and SRWs respectively. Inter-annual variation was evident in the amounts of survey coverage achieved each month (Figure 2.3). For example, the May coverage was far higher in 2024 due to the use of a local coxswain that year which allowed the sei whale work to continue over a longer field season. The coverage achieved during the SRW season (Jul to Sep) primarily reflected weather conditions in each of the years.

Table 2.3. Summary of all cetacean sightings recorded during 68 boat surveys in the north-east Falklands in 2022–2024. The numbers of animals comprise summed survey totals that likely include re-sightings of some individuals.

Species	2022		2023		2024		2022–2024	
	Sightings	Animals	Sightings	Animals	Sightings	Animals	Sightings	Animals
Sei whale	92	208	40	118	97	283	229	609
Southern right whale	134	378	67	205	4	6	205	589
Humpback whale	1	1	0	0	0	0	1	1
UNID large baleen whale	14	16	2	3	7	14	23	33
Killer whale	1	1	1	3	1	7	3	11
Peale's dolphin	159	649	113	415	99	445	371	1,509
Dusky dolphin	0	0	1	1	0	0	1	1
Commerson's dolphin	23	92	16	88	17	174	56	354
Total	*424*	*1,345*	*240*	*833*	*225*	*929*	*889*	*3,107*

Table 2.4. Summary of cetacean sightings by effort status during 68 boat-based surveys in the north-east Falklands during 2022–2024. The numbers of animals comprise summed survey totals that likely include re-sightings of some individuals.

Species	Active Search (all)		Active Search (favourable weather)		Cetacean Encounter effort		Off effort		Group size		
	Sightings	Animals	Sightings	Animals	Sightings	Animals	Sightings	Animals	Mean	Range	SD
Sei whale	178	484	172	469	45	111	6	14	2.7	1–15	1.8
Southern right whale	163	437	161	435	31	110	11	42	2.9	1–11	2.0
Humpback whale	1	1	1	1	0	0	0	0	1	–	–
UNID large baleen whale	20	30	20	30	2	2	1	1	1.4	1–8	1.5
Killer whale	2	4	2	4	1	7	0	0	3.7	1–7	3.1
Peale's dolphin	301	1,182	280	1,108	41	189	29	138	4.1	1–32	2.8
Dusky dolphin	1	1	1	1	0	0	0	0	1	–	–
Commerson's dolphin	39	249	38	234	7	28	10	77	6.3	1–30	6.4
Total	*705*	*2,388*	*675*	*2,282*	*127*	*447*	*57*	*272*	*3.5*	1–32	3.0

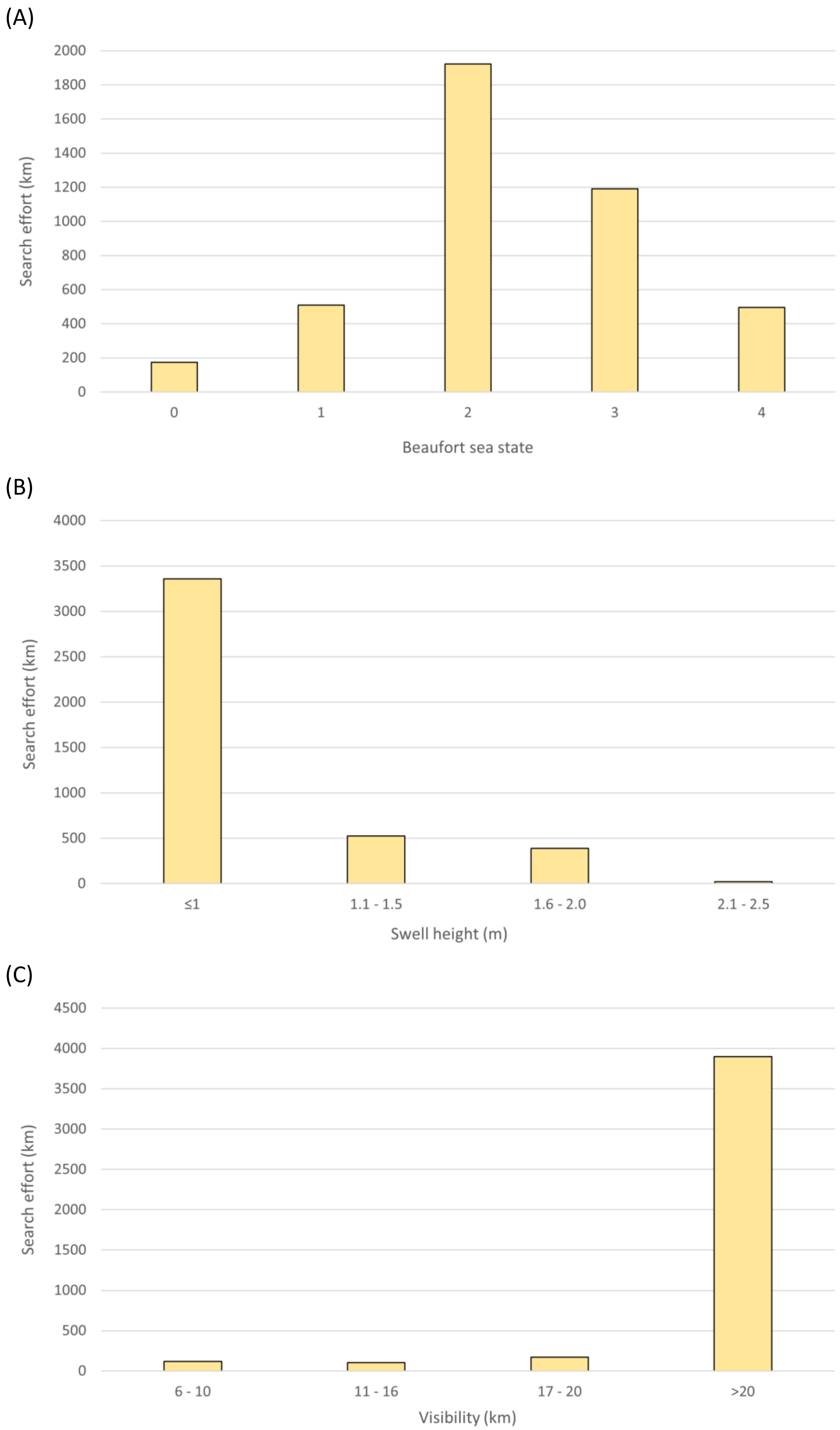


Figure 2.1. Environmental data during 4,291.8 km of active search effort collected in favourable weather conditions (i.e. after data collected in Beaufort sea state >4, swell of >2.5 m, and visibility of <5 km had been removed): (A) Beaufort sea state; (B) swell height; and (C) visibility (km).

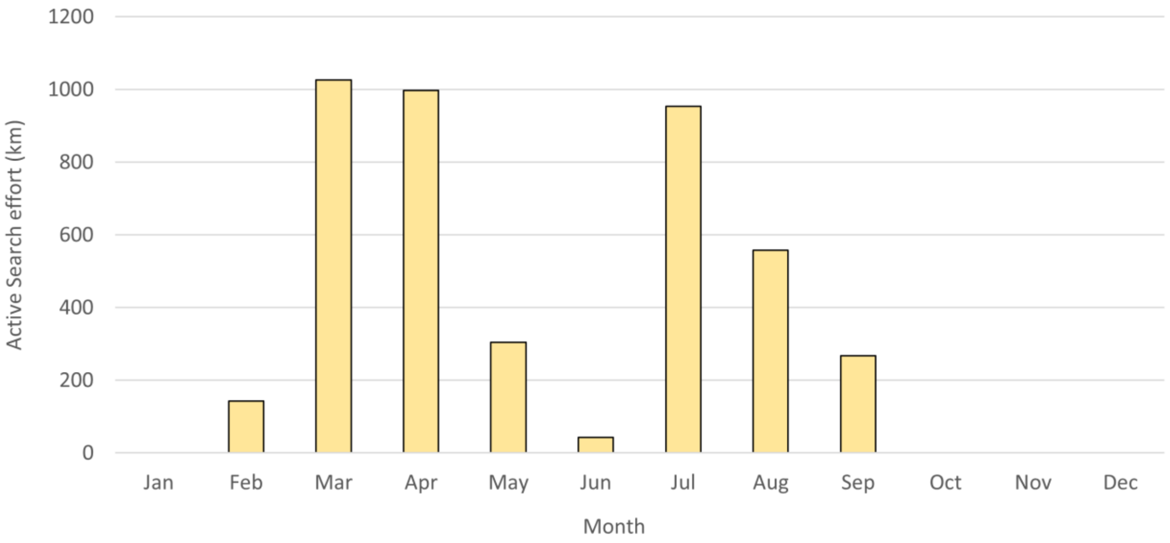


Figure 2.2. Monthly distribution of 4,291.8 km of active search effort collected in favourable weather conditions, 2022–2024.

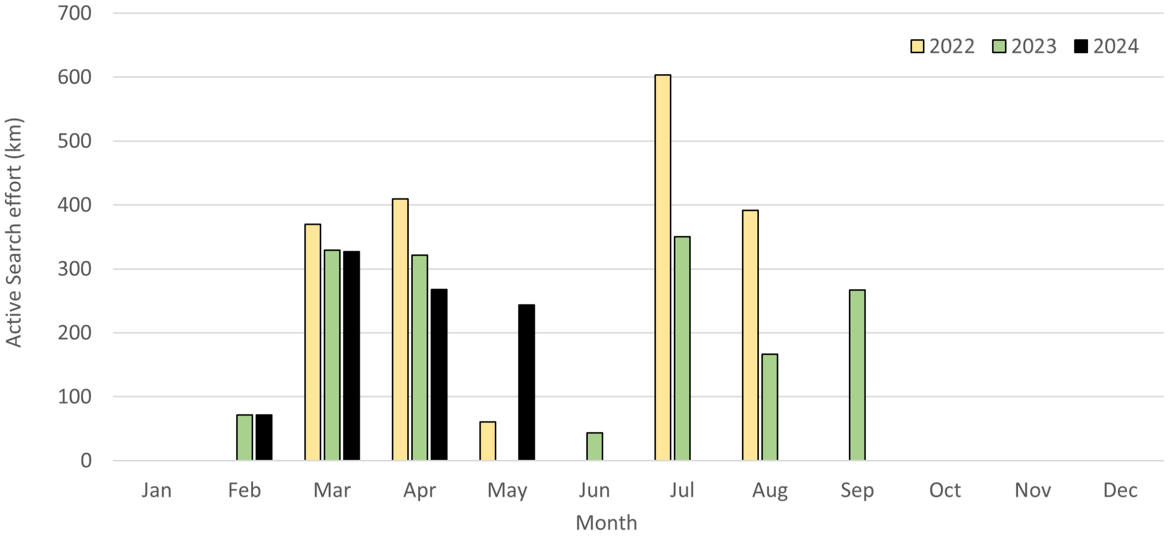
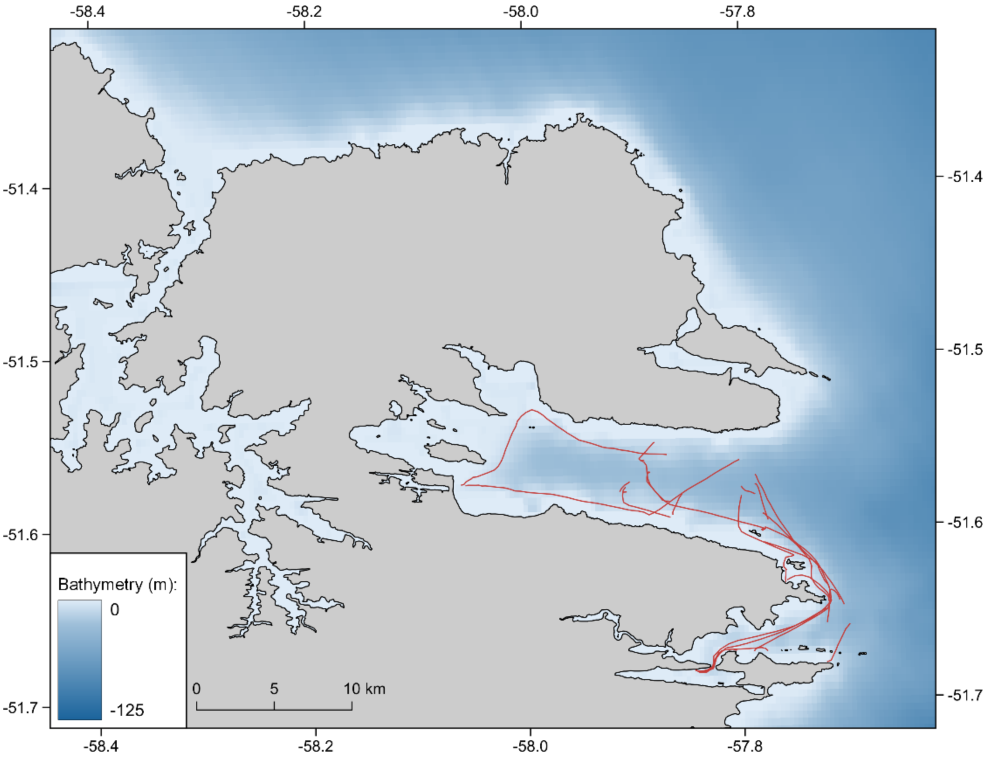


Figure 2.3. Monthly distribution of 4,291.8 km of active search effort collected in favourable weather conditions, shown for each of the three survey years.

Between February and May the spatial distribution of active search effort was predominantly limited to the Berkeley Sound area (Figure 2.4), where weather conditions and whale distribution were favourable for working with sei whales. A few runs to Cape Carysfort were carried out late in that period (April and May: Figure 2.4) during years when sei whales had departed earlier from Berkeley Sound.

During July and August, the emphasis of the survey work swapped to SRWs with most active search effort distributed along the exposed coastline from the Volunteer Lagoon mouth to MacBride Head (Figure 2.4). However, some surveys of Berkeley Sound were also completed in those months to assess SRW occurrence in that area. In early September, SRWs became scarcer and the survey coverage was extended westwards along the north coast of East Falkland as far as Port Salvador entrance and Black Point in an effort to locate whales (Figure 2.4).

(A) February



(B) March

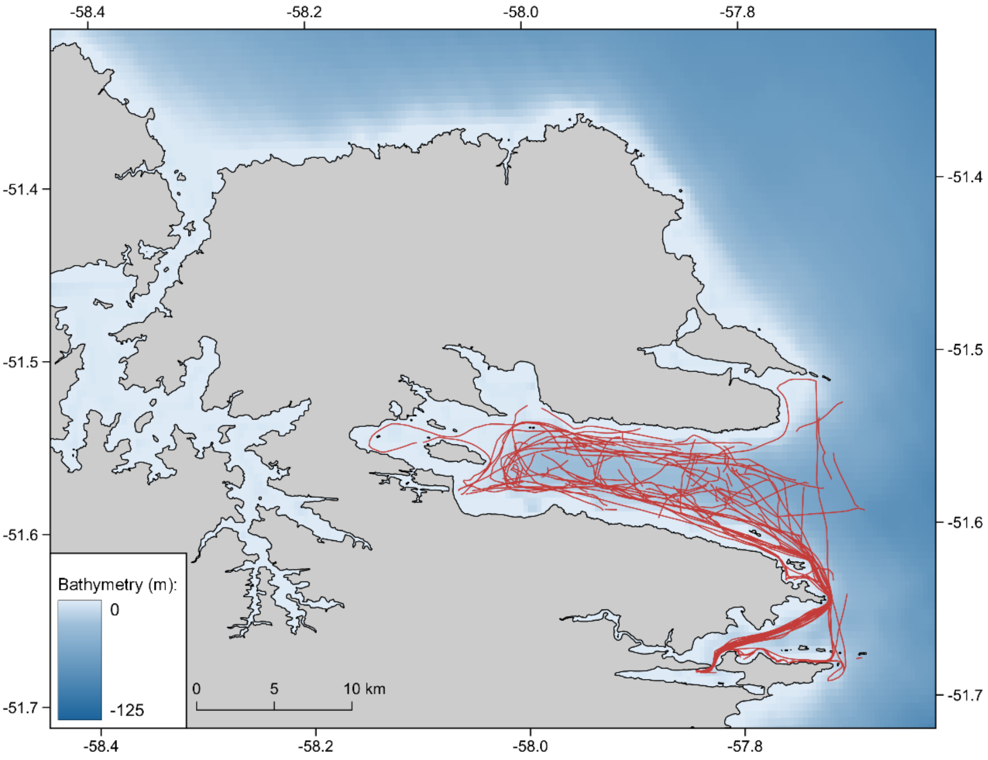
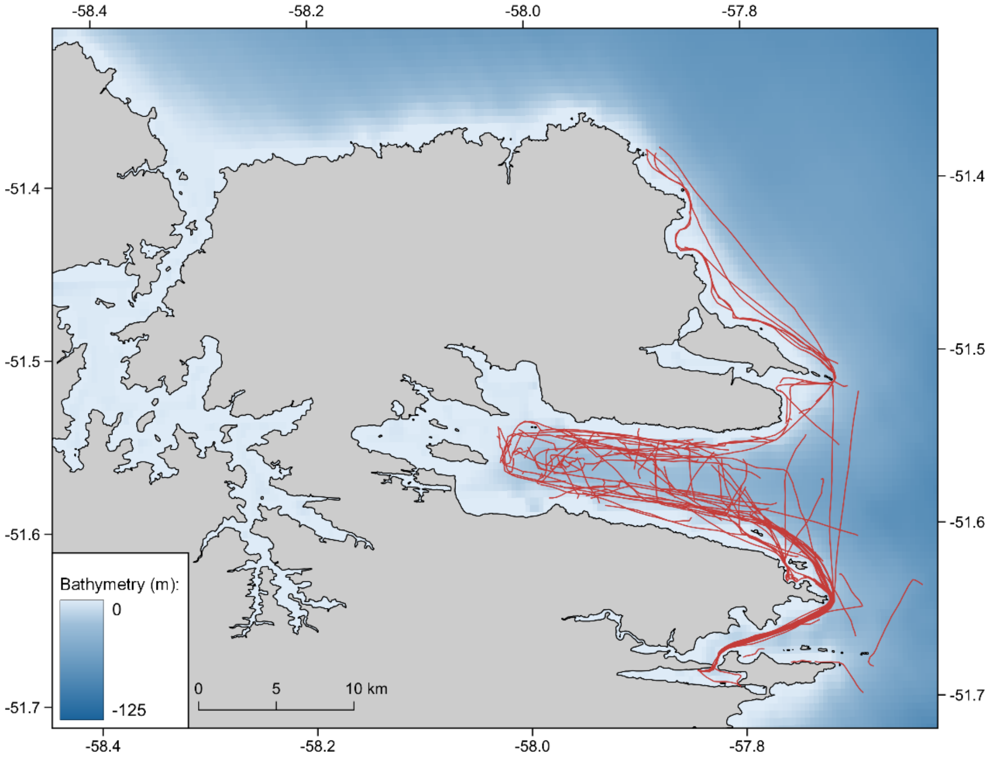


Figure 2.4. Spatial distribution of 4,291.8 km of active search effort collected in favourable weather conditions in the north-east of the Falklands, 2022–2024: (A) February; (B) March; (C) April; (D) May; (E) June; (F) July, (G) August and (H) September.

(C) April



(D) May

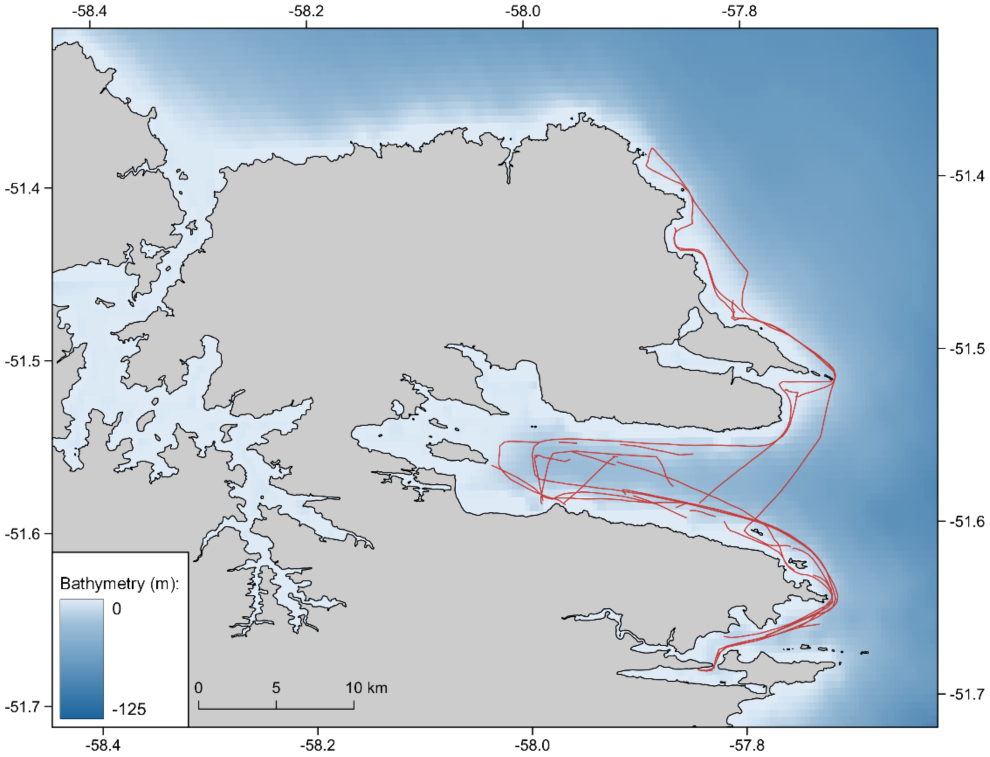
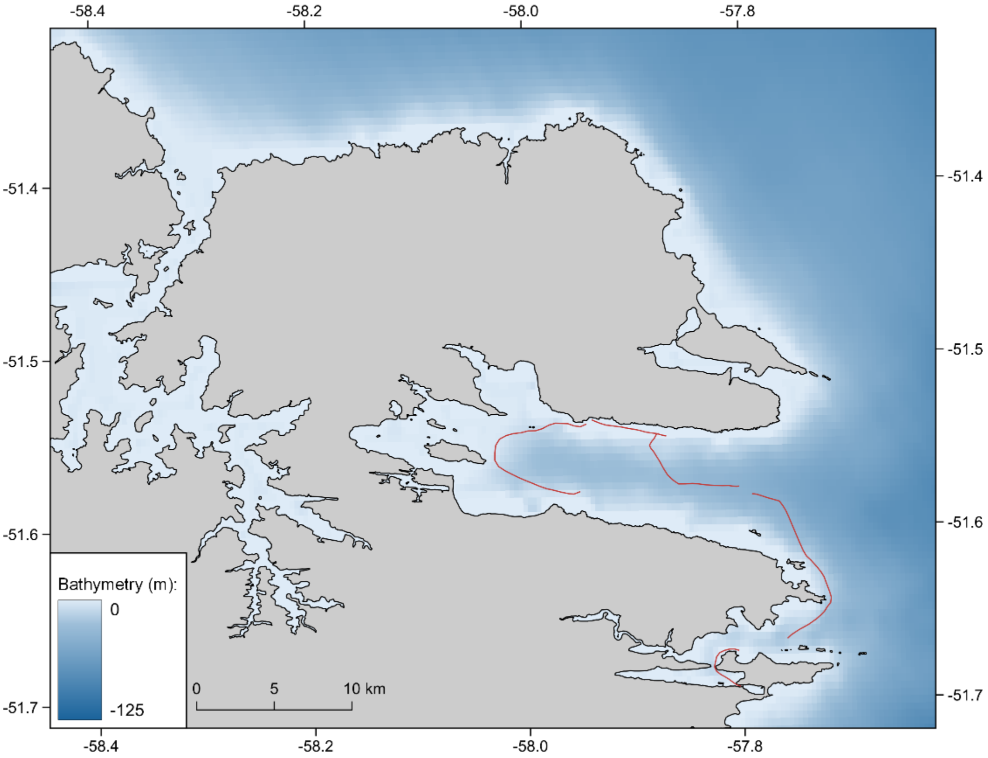


Figure 2.4. Contd.

(E) June



(F) July

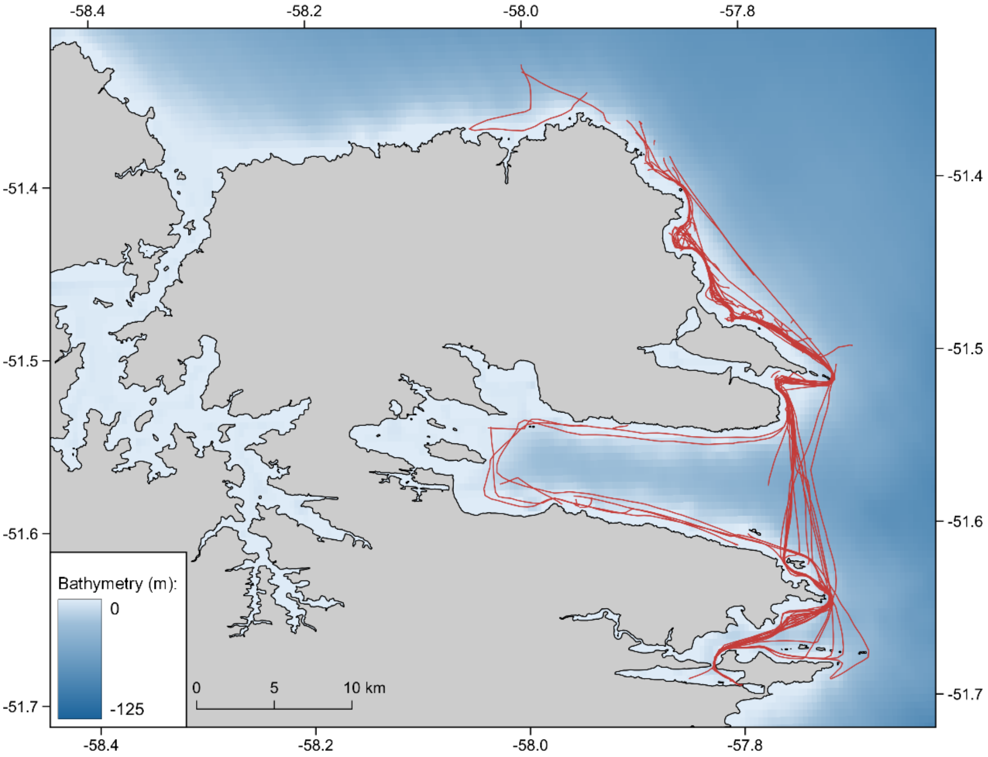
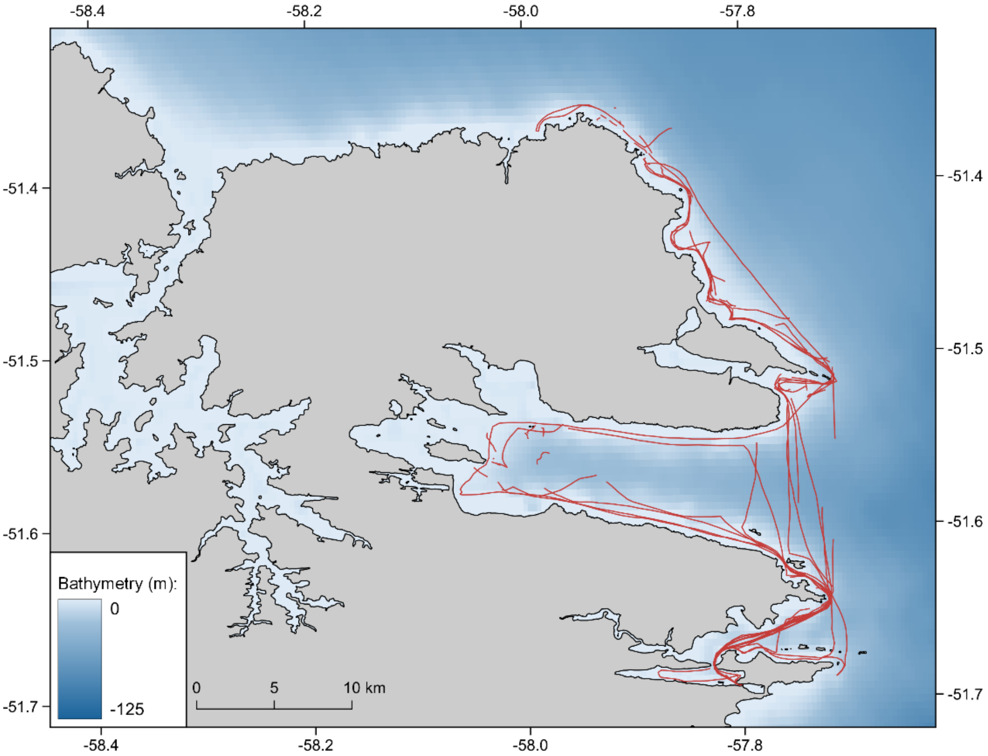


Figure 2.4. Contd.

(G) August



(H) September

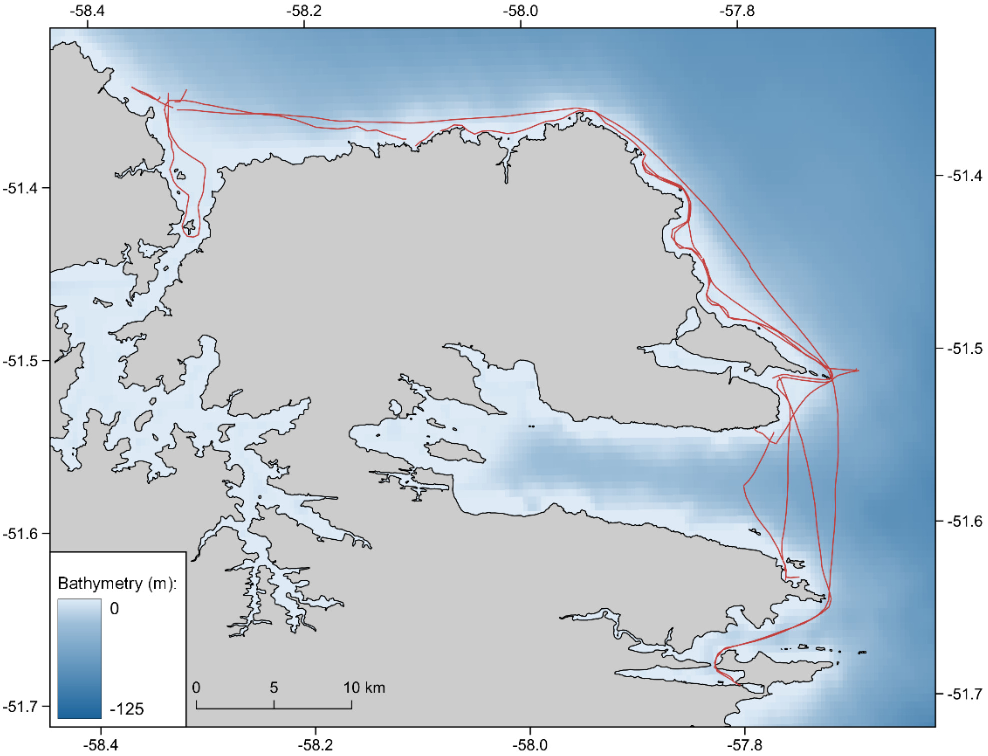


Figure 2.4. Contd.

2.3.3 Sei whales

2.3.3.1. Group size

Sei whales were recorded in groups of 1 to 15 animals (Figure 2.5), with a mean of 2.7 animals (SD=1.8, n=229, median=2.0 animals). The majority of sightings comprised single animals (28.8%), pairs (29.3%), and small groups of 3 or 4 animals (29.3%). Kruskal-Wallis tests revealed no significant difference in the group size recorded by month (H=2.66, df=3, p=0.45: Figure 2.6), or by year (H=6.01, df=2, p=0.05: Figure 2.7).

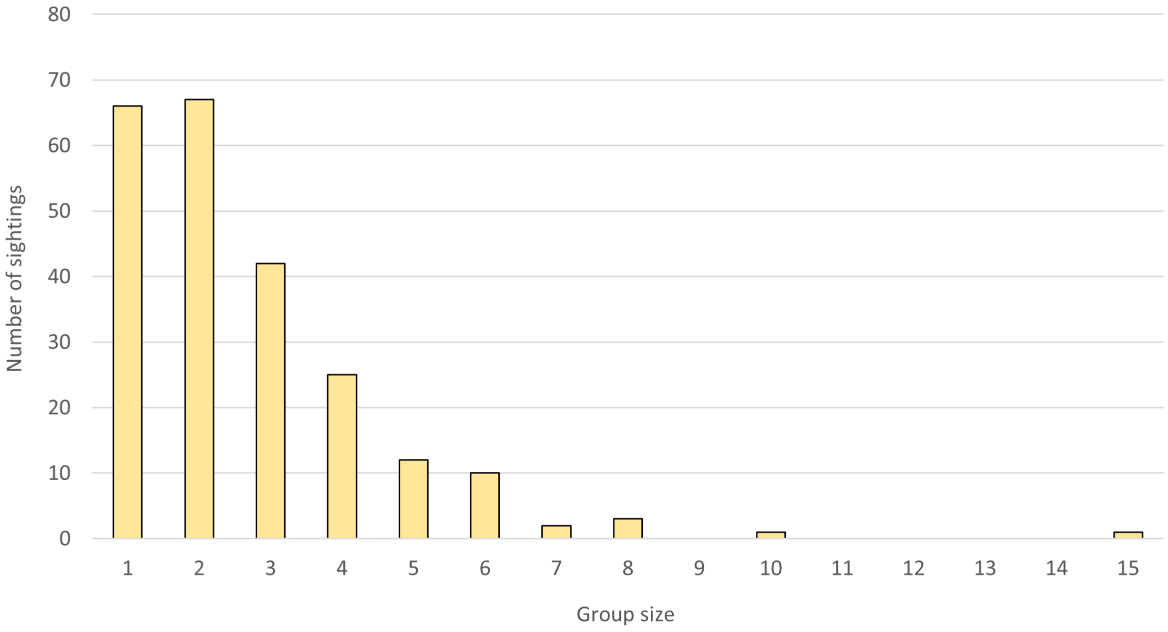


Figure 2.5. The frequency distribution of sei whale group sizes recorded during boat survey work, 2022–2024.

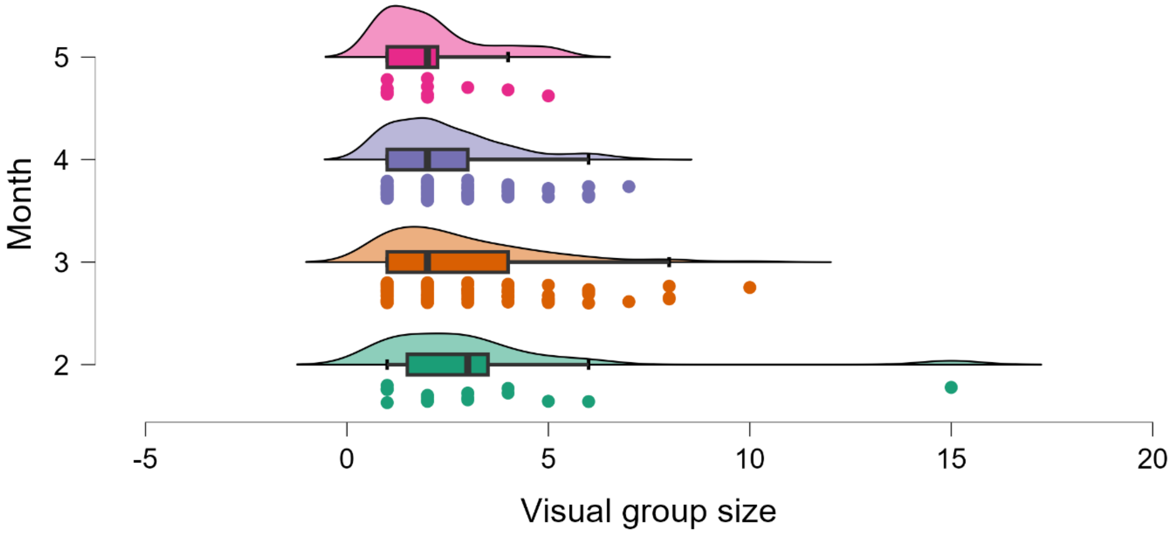


Figure 2.6. Raincloud plot showing the distribution of sei whale group sizes according to month.

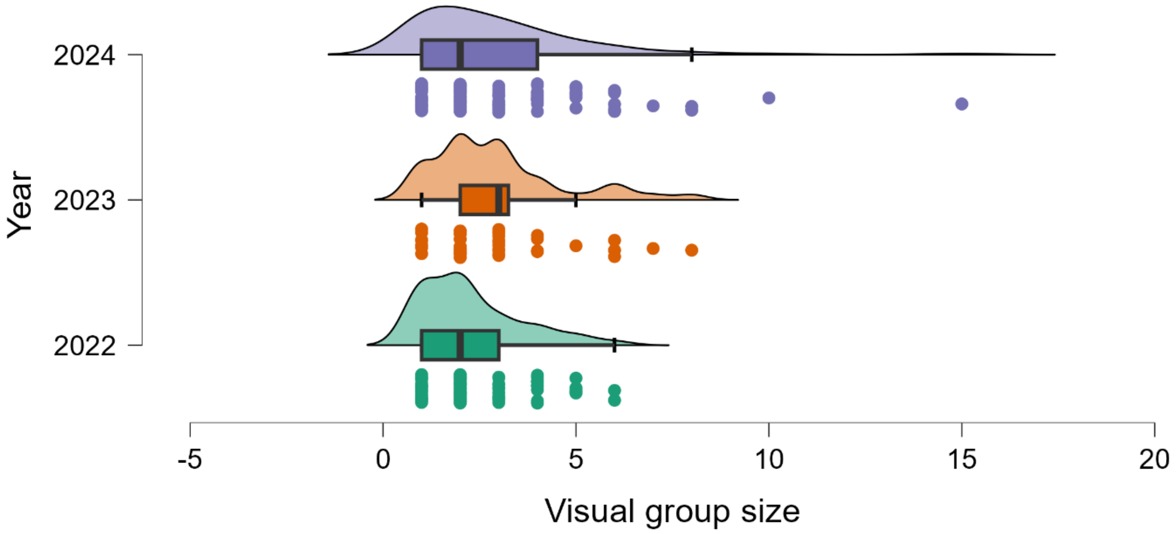


Figure 2.7. Raincloud plot showing the distribution of sei whale group sizes according to year.

2.3.3.2. Temporal occurrence

Of the total 229 sei whale sightings (609 animals) recorded from 2022 to 2024, 172 (469 animals: Table 2.4) were recorded in association with active search effort in favourable weather conditions and were used for the calculation of relative abundance. Sei whale relative abundance was reasonably consistent between February and April, declined during May, and was zero between June and September (Figure 2.8). However, it should be noted that only a small amount of survey effort was available for June following the removal of data collected in adverse weather; sei whales are still present during that month in some years.

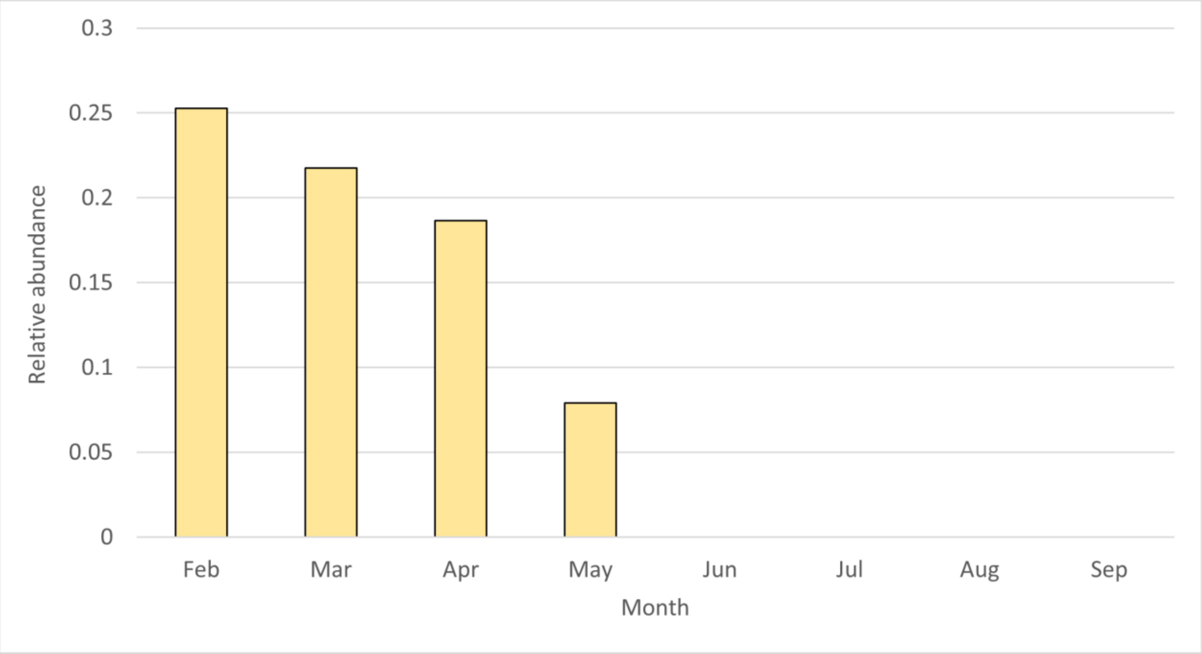


Figure 2.8. Monthly relative abundance (individuals/km using active search effort in favourable weather only = 4,291.8 km), of sei whales, 2022–2024.

2.3.3.3. Spatial distribution

Both sightings and encounter effort indicated that sei whales were distributed throughout Berkeley Sound from the mouth to the inner area between Uranie Bay, Long Island and Johnson's Harbour (Figure 2.9). It should be noted that because of more favourable (sheltered from swell) weather conditions inside Berkeley Sound and the primary focus of DPLUS126 on tagging (which requires calm weather and close approaches), there was less survey effort at the entrance to the Sound or near exposed headlands such as Mengeary Point compared with previous years. Sei whales generally used the central areas of the Sound where the water was deepest, and their occurrence was lower within 1 km of the shoreline where the water depth was shallower (Figure 2.9). The distribution of encounter effort showed that sei whales typically moved around erratically within the Sound, presumably while foraging (Figure 2.9).

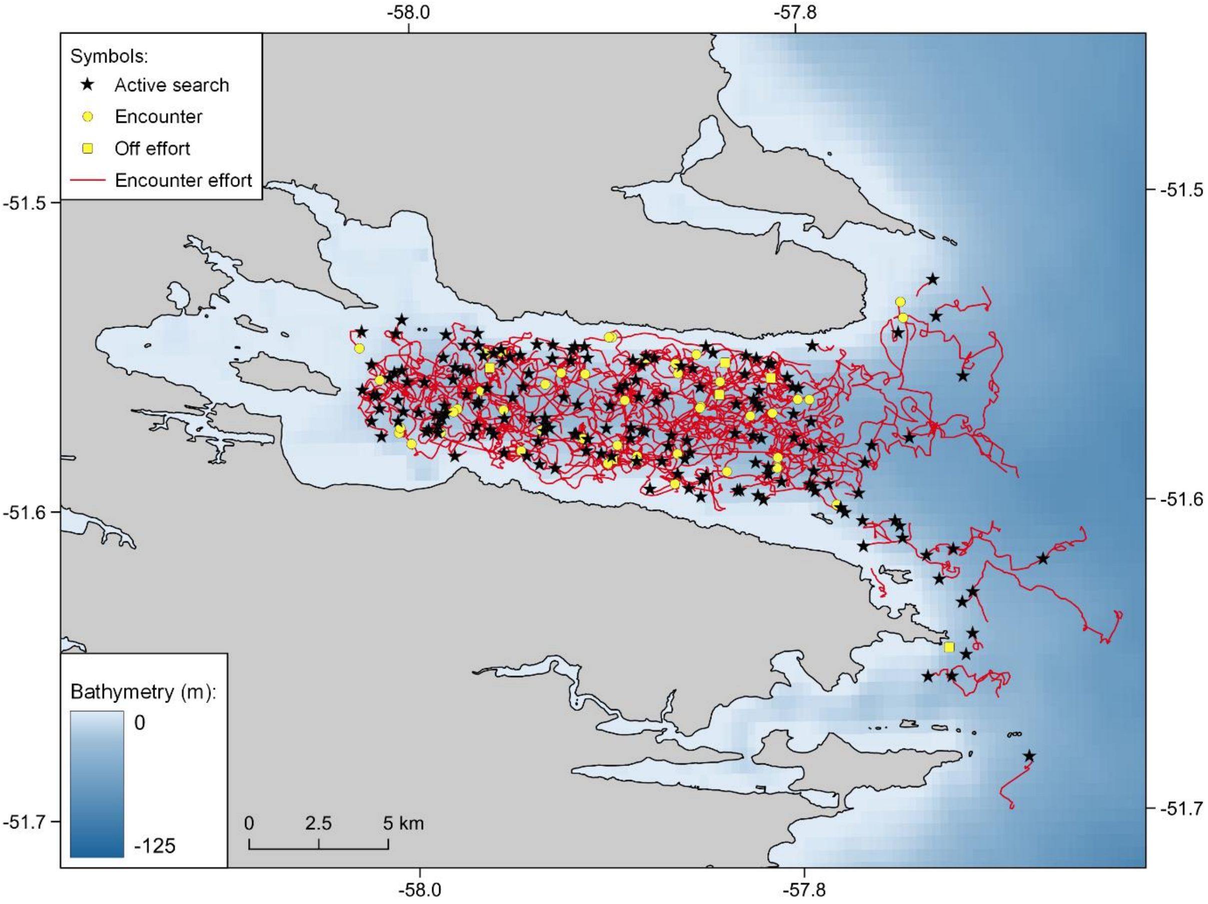


Figure 2.9. Spatial distribution of all sei whale sightings (n=229) and encounter effort recorded during boat surveys in the Falklands, 2022–2024. Sighting locations have been recalculated to reflect animal positions rather than the location of the boat.

When survey effort was accounted for, the relative abundance of sei whales for February to May combined was reasonably similar throughout Berkeley Sound (Figure 2.10), adding further support for the widespread distribution of the species within the Sound. The grid cells of highest relative abundance were located along the south side of Berkeley Sound; however, this likely results at least partly from the fact that boat surveys departed from Stanley and usually surveyed the south side of the Sound first. Therefore, the tall blows of sei whales inside the Sound were more likely to be spotted from the south side. The actual distribution of the whales (Figure 2.9) shows use of the entire Sound.

There was relatively little survey effort carried out during February, and sei whales were primarily located in the outer half of Berkeley Sound during that month (Figure 2.11). In March and April they were widely distributed across the Sound (Figures 2.12 and 2.13), while in May the overall numbers were lower but the species was still distributed across inner, central and outer parts of the Sound (Figure 2.14).

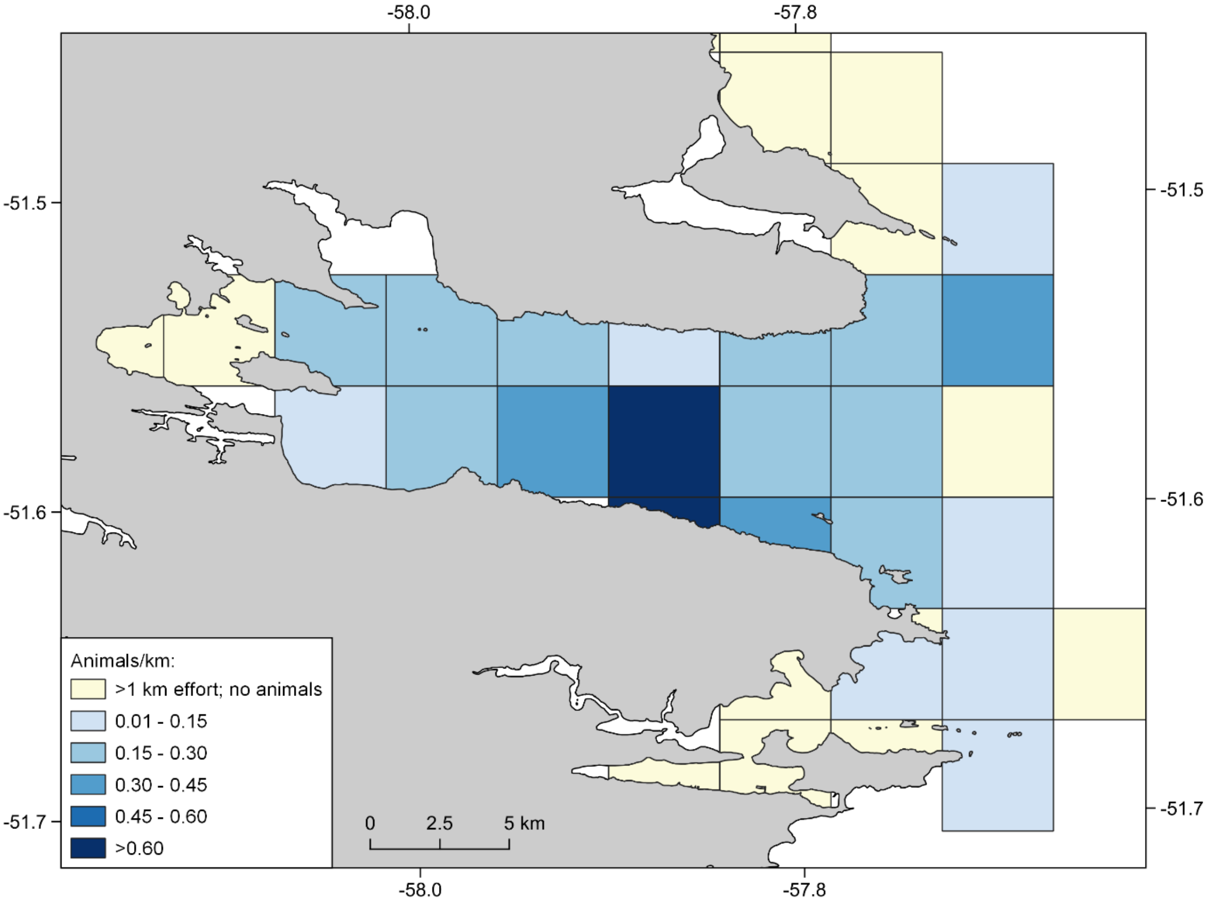


Figure 2.10. Relative abundance (animals/km) of sei whales in 4 km grid cells calculated using active search effort in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) from February to May, 2022–2024.

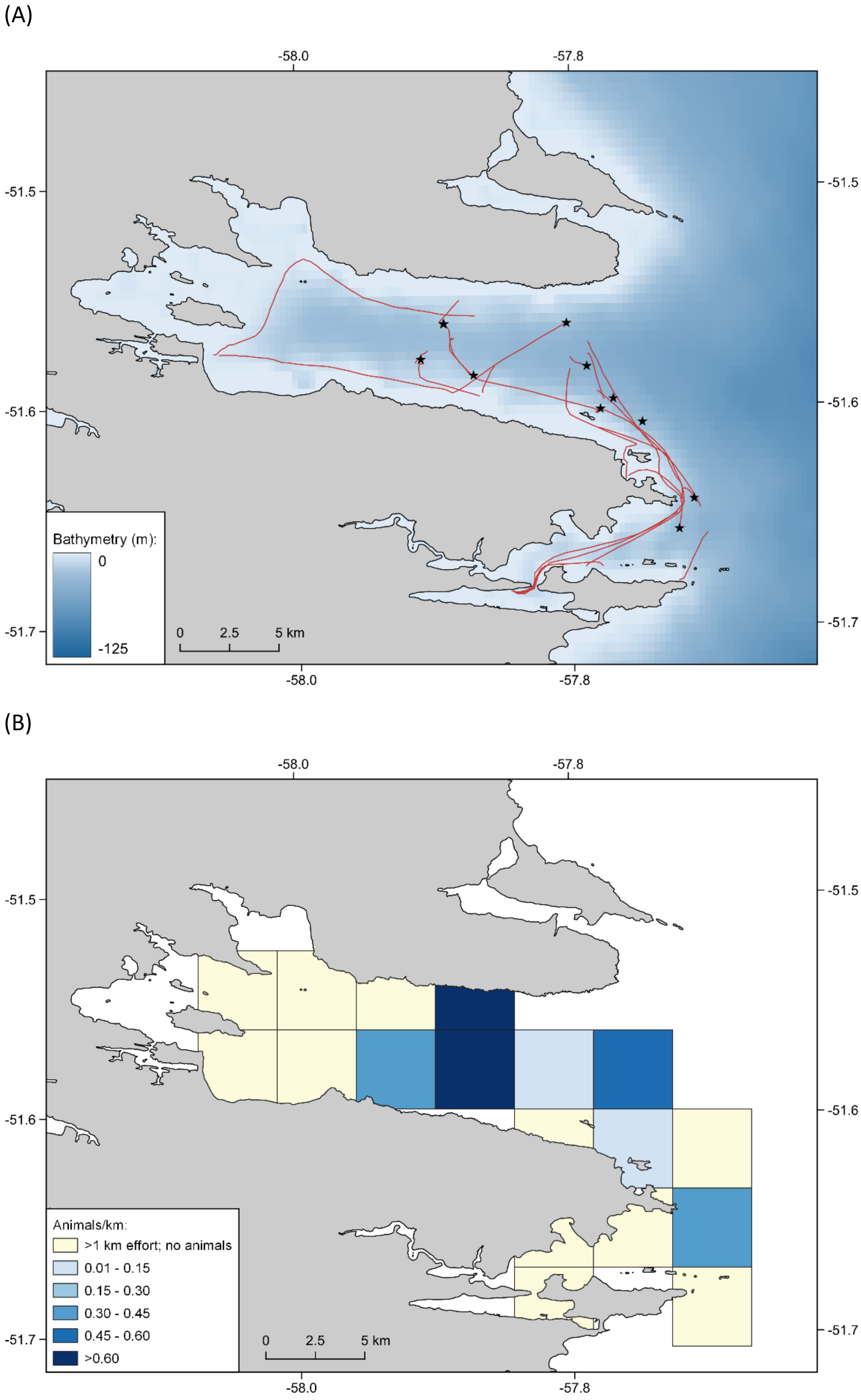


Figure 2.11. Spatial distribution of sei whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during February: (A) active search effort (red lines) and associated sei whale sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

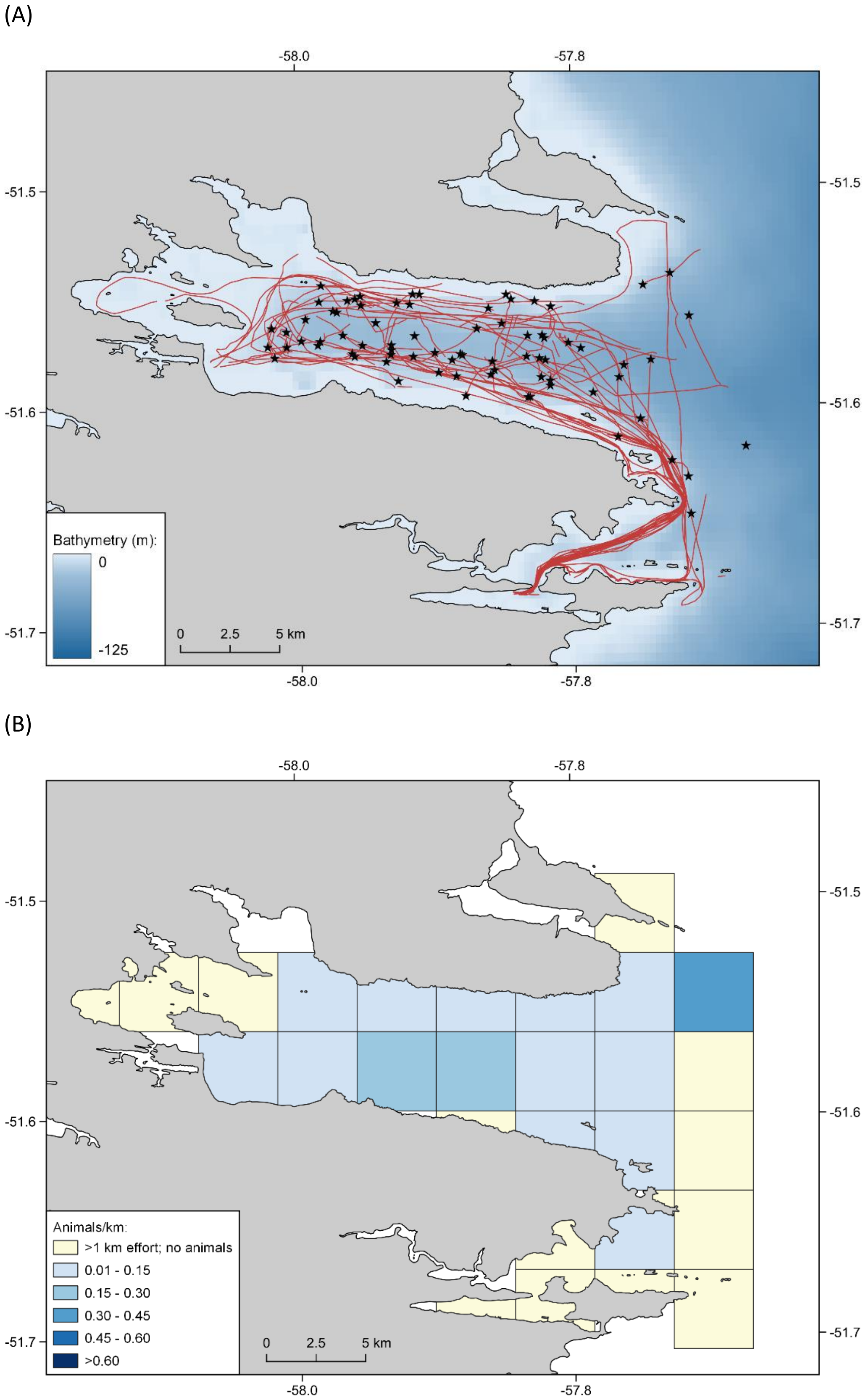


Figure 2.12. Spatial distribution of sei whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during March: (A) active search effort (red lines) and associated sei whale sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

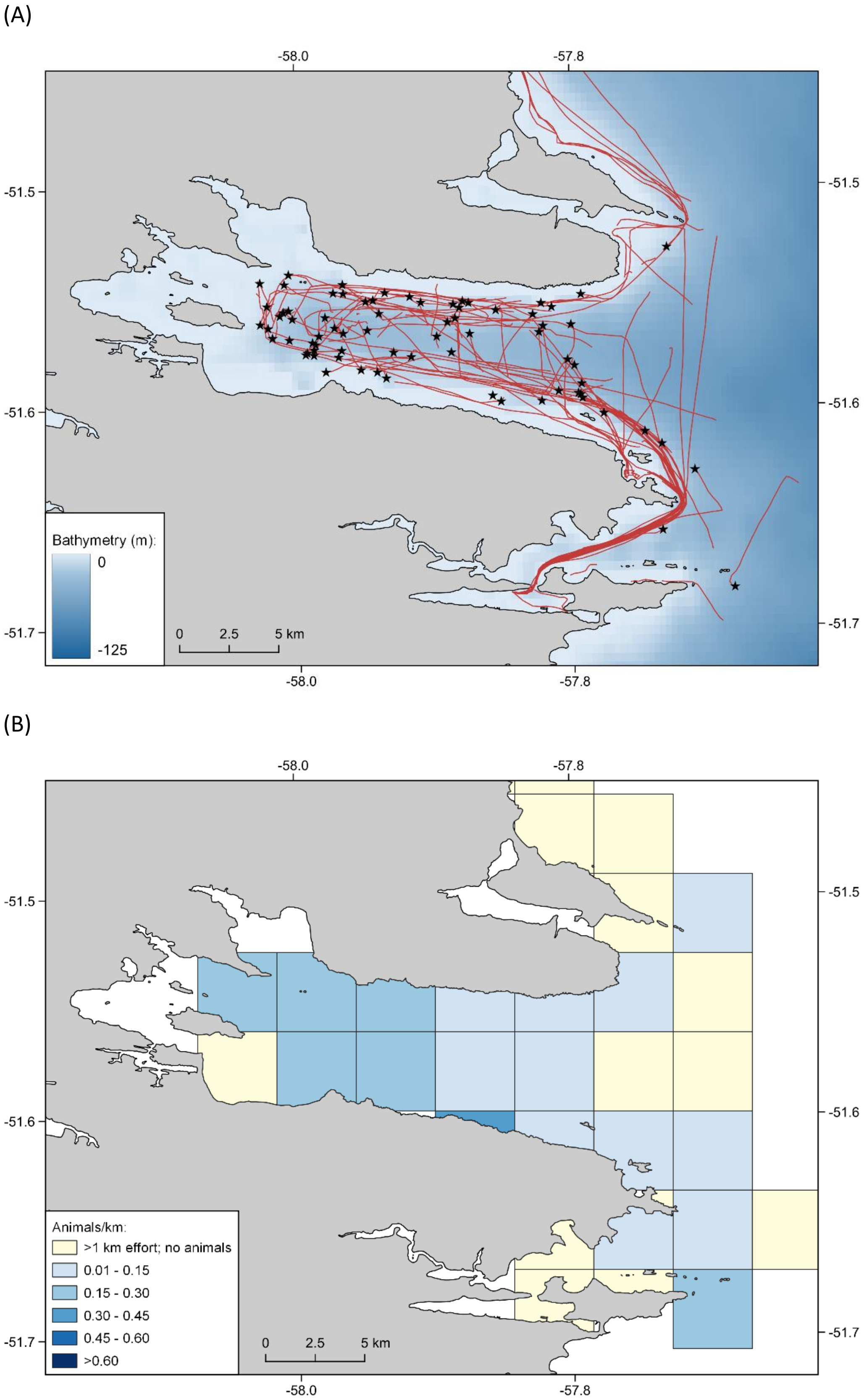


Figure 2.13. Spatial distribution of sei whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during April: (A) active search effort (red lines) and associated sei whale sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

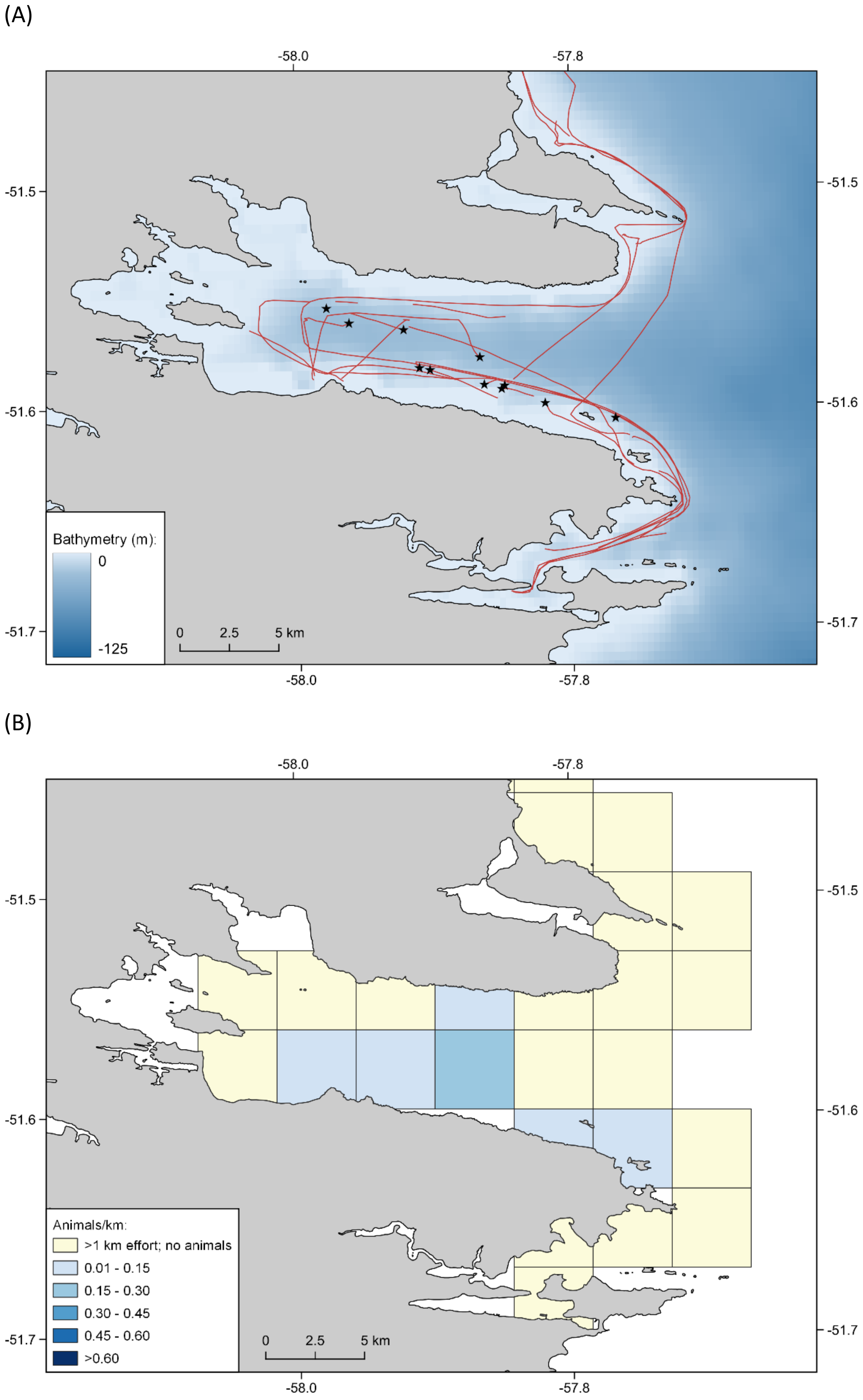


Figure 2.14. Spatial distribution of sei whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during May: (A) active search effort (red lines) and associated sei whale sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

2.3.4 Southern right whales

2.3.4.1. Group size

SRWs were recorded in groups of 1 to 11 animals (Figure 2.15), with a mean of 2.9 animals (SD=2.0, n=205, median=2.0 animals). Most sightings comprised single animals (28.3%), pairs (29.8%), and small groups of 3 or 4 animals (23.4%). Kruskal-Wallis tests revealed no significant difference in the group size recorded by month (H=3.64, df=5, p=0.60: Figure 2.16), or by year (H=2.95, df=2, p=0.23: Figure 2.17). As in earlier studies, no newborn SRW calves were observed during boat surveys, with all animals comprising juvenile/subadult and adults only.

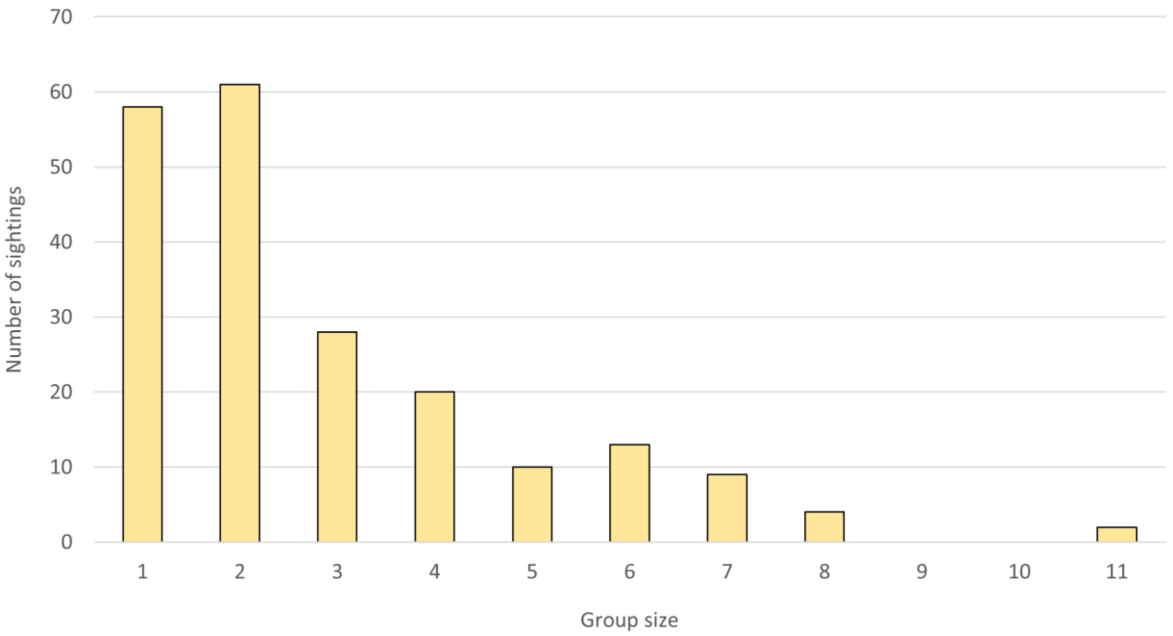


Figure 2.15. The frequency distribution of southern right whale group sizes recorded during boat survey work, 2022–2024.

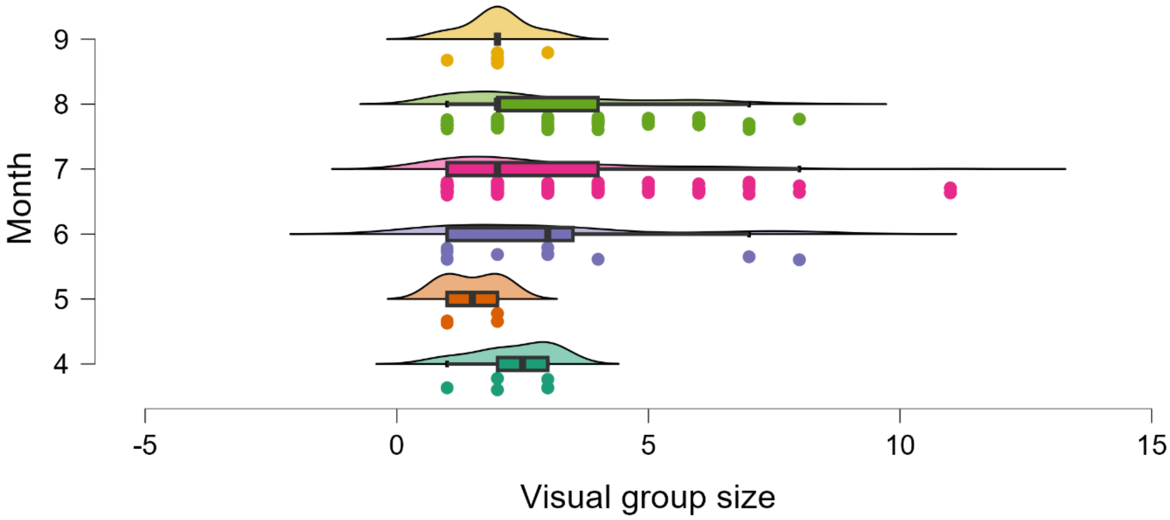


Figure 2.16. Raincloud plot showing the distribution of southern right whale group sizes according to month.

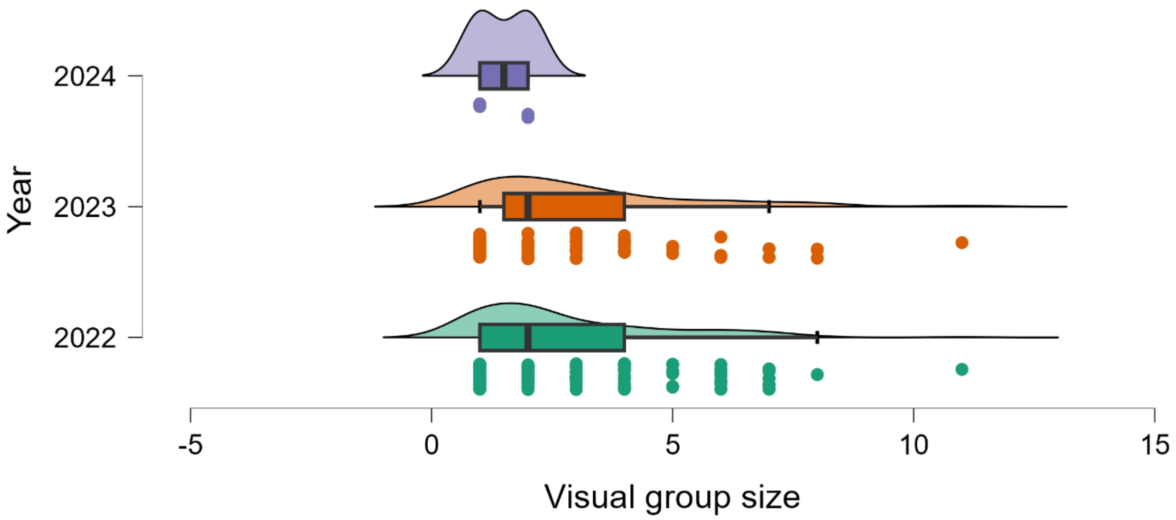


Figure 2.17. Raincloud plot showing the distribution of southern right whale group sizes according to year.

2.3.4.2. Temporal occurrence

Of the total 205 SRW sightings (589 animals) recorded from 2022 to 2024, 161 (435 animals: Table 2.4) were recorded in association with active search effort in favourable weather conditions and were used for the calculation of relative abundance.

SRW relative abundance was low during April and May, showed a strong peak in June, was at similarly high levels in July and August, and declined in September (Figure 2.18), confirming the strong winter seasonality of this species in the coastal waters around the Islands. It should be noted that the very strong peak in relative abundance shown for June is likely an artefact of the relatively small amount of survey effort in that month.

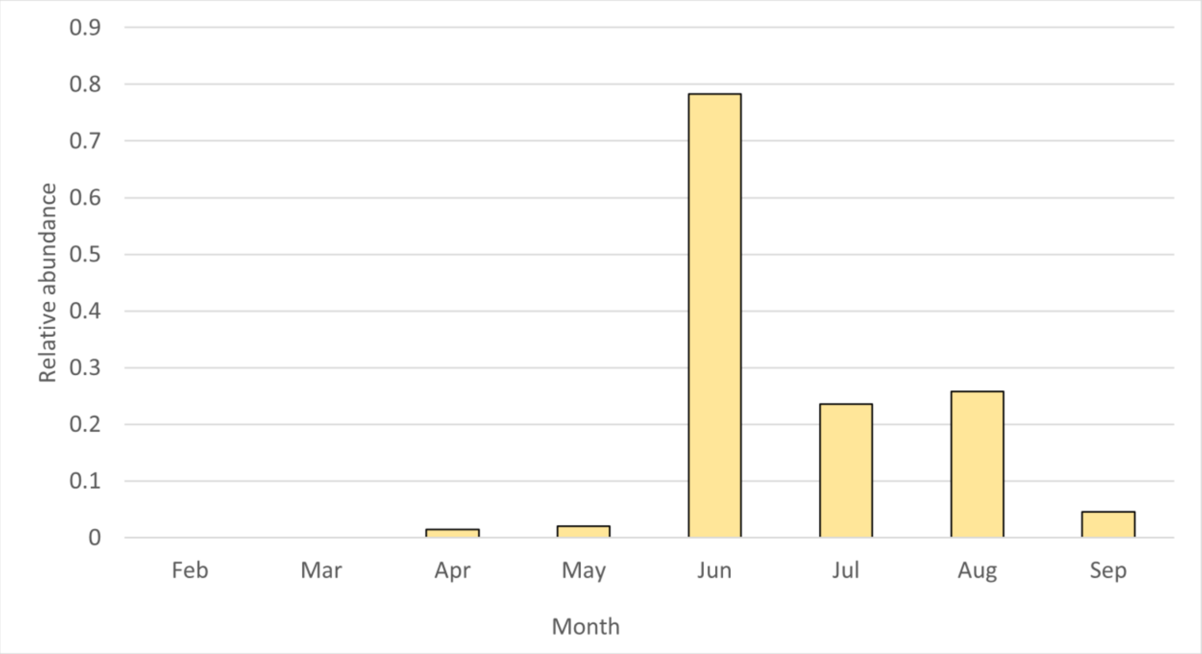


Figure 2.18. Monthly relative abundance (individuals/km using active search effort in favourable weather only = 4,291.8 km), of southern right whales, 2022–2024.

2.3.4.3. Spatial distribution

SRWs had a notably different distribution from that of sei whales, with little occurrence through the centre of Berkeley Sound; rather, within Berkeley Sound they were distributed primarily nearshore along the coasts (Figure 2.19). SRWs were also encountered within Port William and in the exposed areas off Mengeary Point and Kidney Island (Figure 2.19). However, the majority of sightings and encounter effort for SRWs occurred between the Volunteer Lagoon mouth and MacBride Head (Figure 2.19) where most of the winter survey effort was carried out. This was apparent particularly when the relative abundance was calculated to take effort into account, with the highest density grid cells occurring in the waters from Volunteer Point to MacBride Head but with moderate densities also apparent in inner Berkeley Sound (Figure 2.20).

SRWs were not recorded inside Berkeley Sound during April and May; the few sightings of the species that occurred in those months were on exposed coasts at Mengeary Point, Eagle Point, and between Volunteer Point and Dutchman's Island (Figures 2.21 and 2.22). Only a single June survey was carried out during DPLUS126 (on 29 June 2023), during which an aggregation of SRWs was present in Port William and several sightings were also recorded in Berkeley Sound (Figure 2.23). July and August represent the peak period of SRW occurrence in the study area (Weir, 2022), and during those months the species was widely distributed but with highest relative abundance from Volunteer Lagoon to MacBride Head and in the inner part of Berkeley Sound (Figures 2.24 and 2.25). By early September, SRW occurrence decreased and only sporadic sightings were recorded between Volunteer Lagoon and Black Point (Figure 2.26).

2.4 Discussion

2.4.1 Data interpretation constraints

The total number of boat surveys achieved during DPLUS126 was lower than in DPLUS082 due to the different nature and goals of the survey work. DPLUS082 specifically aimed to establish a baseline dataset on the spatio-temporal occurrence of baleen whales at two sites and therefore required a good spatial and temporal spread of survey effort across multiple months and years (Weir, 2022). In contrast, the fieldwork for DPLUS126 was planned in shorter intensive periods timed for the expected seasonal peaks in whale occurrence, with the primary goals of deploying satellite tags and collecting unmanned aerial vehicle (UAV) imagery of whale body measurements.

The weather conditions encountered in the Falklands during DPLUS126 were also worse overall than were recorded in DPLUS082, further limiting the opportunities for boat surveys and reducing the sample size of the dataset. Many surveys that did go ahead took advantage of 'weather windows' in mornings or afternoons, rather than accomplishing full days at sea that would allow for better spatial coverage. Additionally, the nature of the work in DPLUS126 meant that more time was spent with groups of whales during that project than might have been spent during DPLUS082, since deploying satellite tags usually meant spending significant time making slow and careful approaches to sufficient proximity to the whales to attempt a tag deployment. Similarly, the UAV work resulted in a lot of time spent with the boat stationary while the UAV made multiple flights over whale groups to measure all individuals.

Detailed comparisons of the distribution and seasonality of whales recorded during the two projects therefore requires some caution in interpretation.

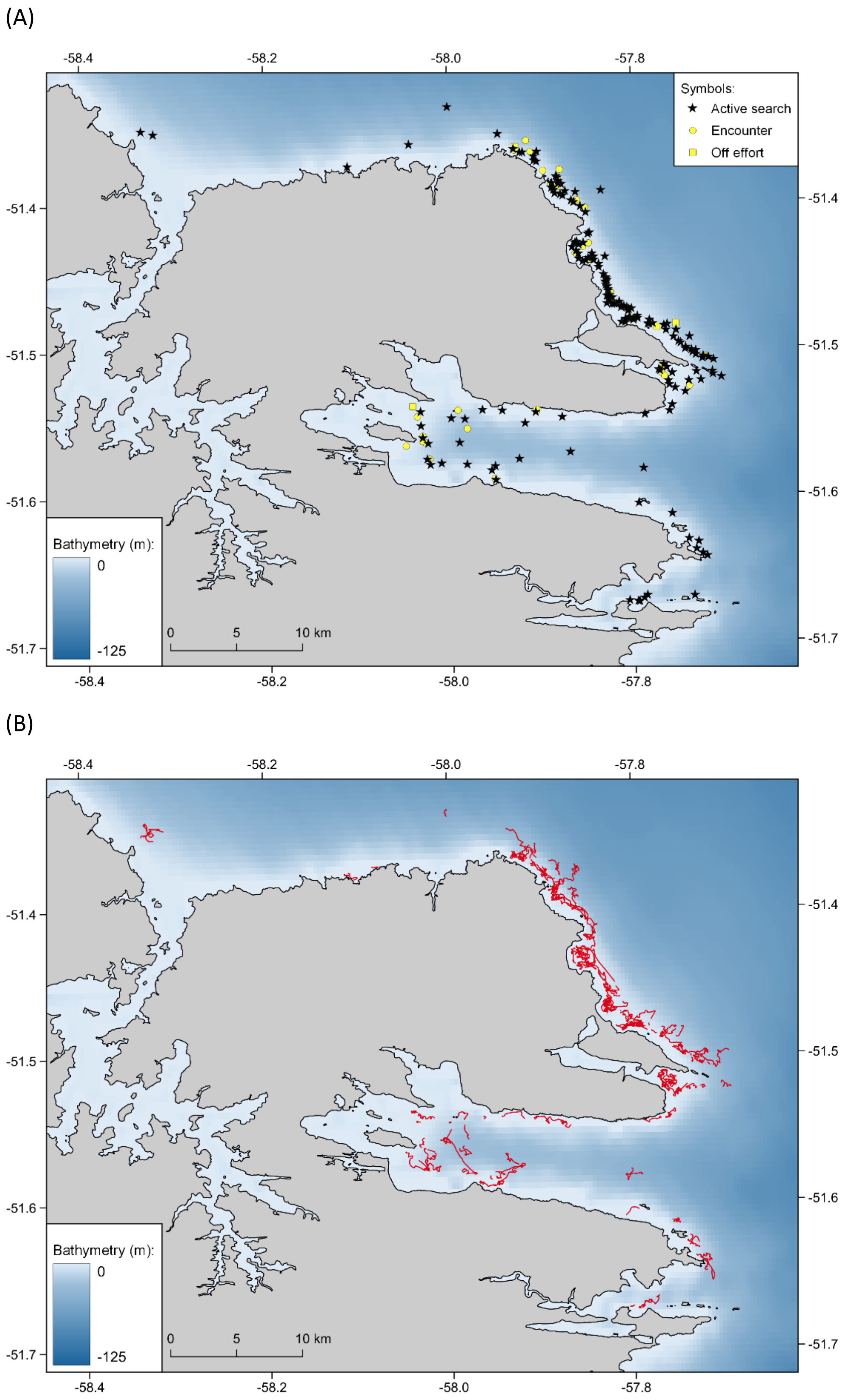


Figure 2.19. Spatial distribution of southern right whales during boat surveys in the Falklands, 2022–2024: (A) sighting locations (n=229), recalculated to reflect animal positions rather than the location of the boat; and (B) encounter effort.

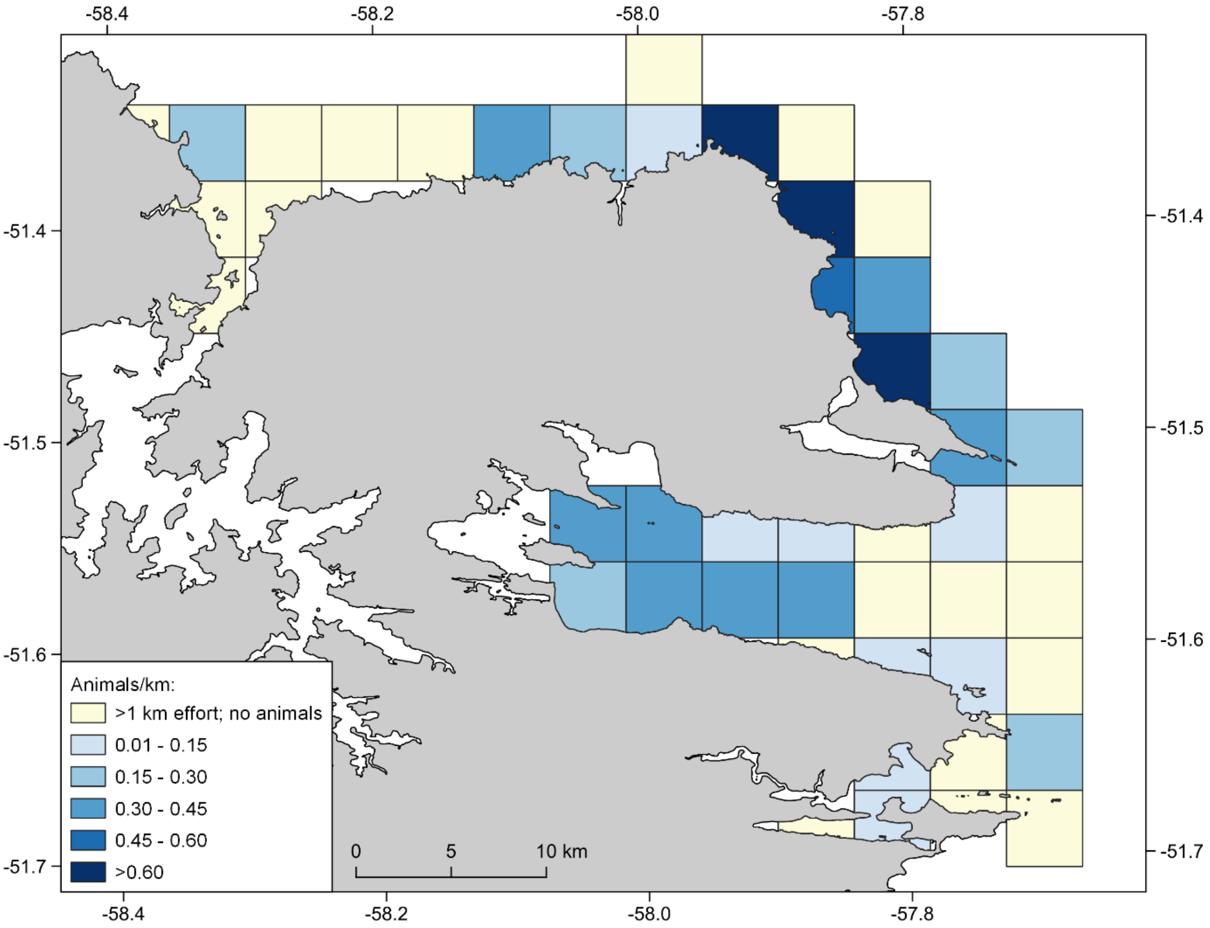


Figure 2.20. Relative abundance (animals/km) of southern right whales in 4 km grid cells calculated using active search effort in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) from June to September, 2022–2023.

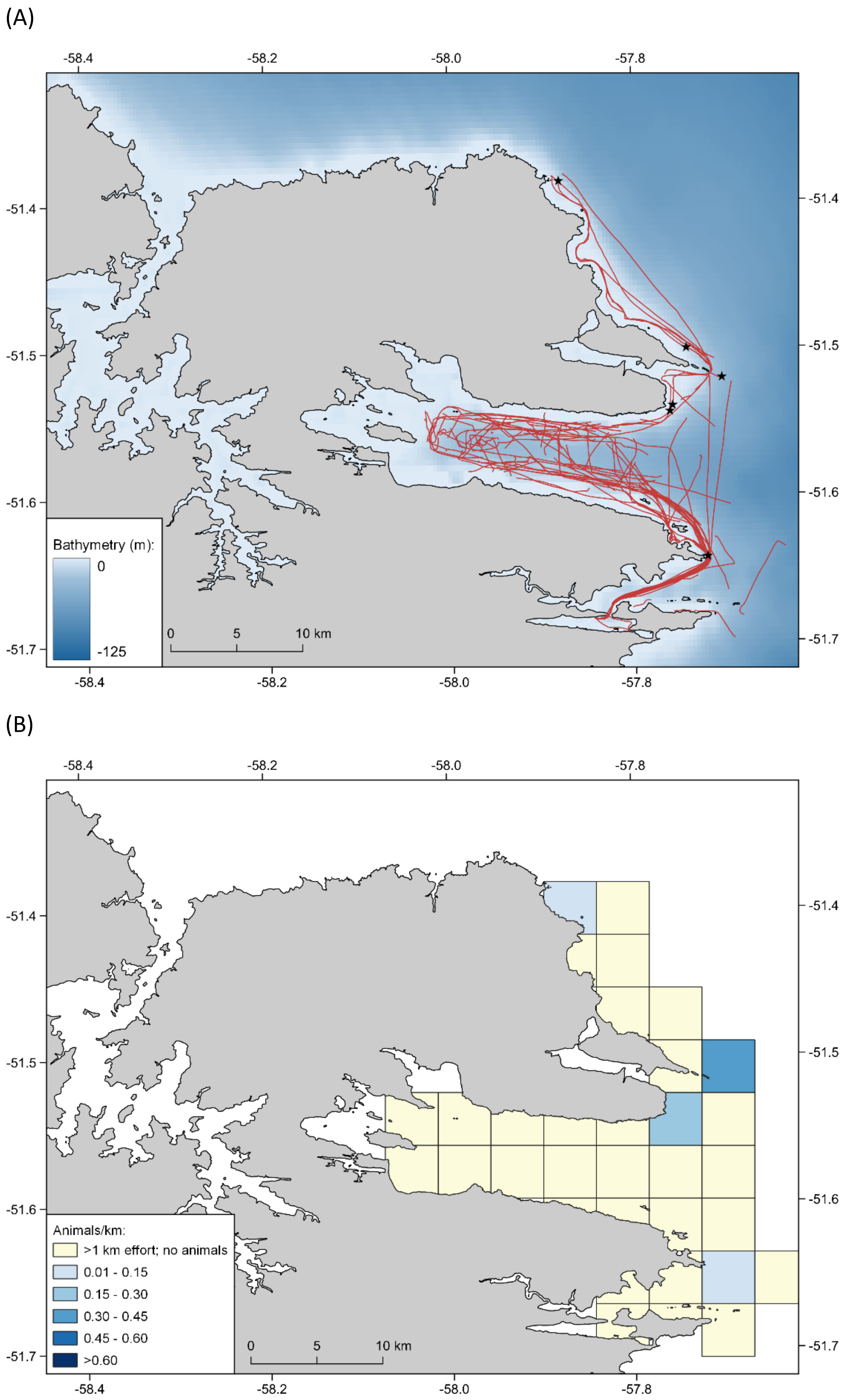
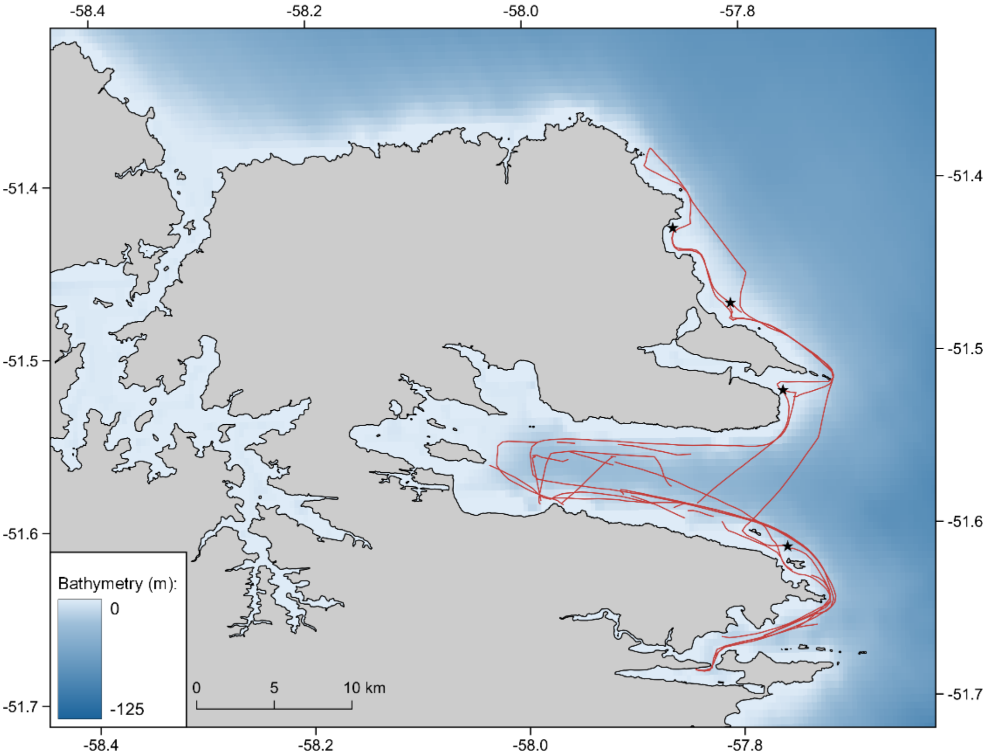


Figure 2.21. Spatial distribution of southern right whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during April: (A) active search effort (red lines) and associated SRW sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

(A)



(B)

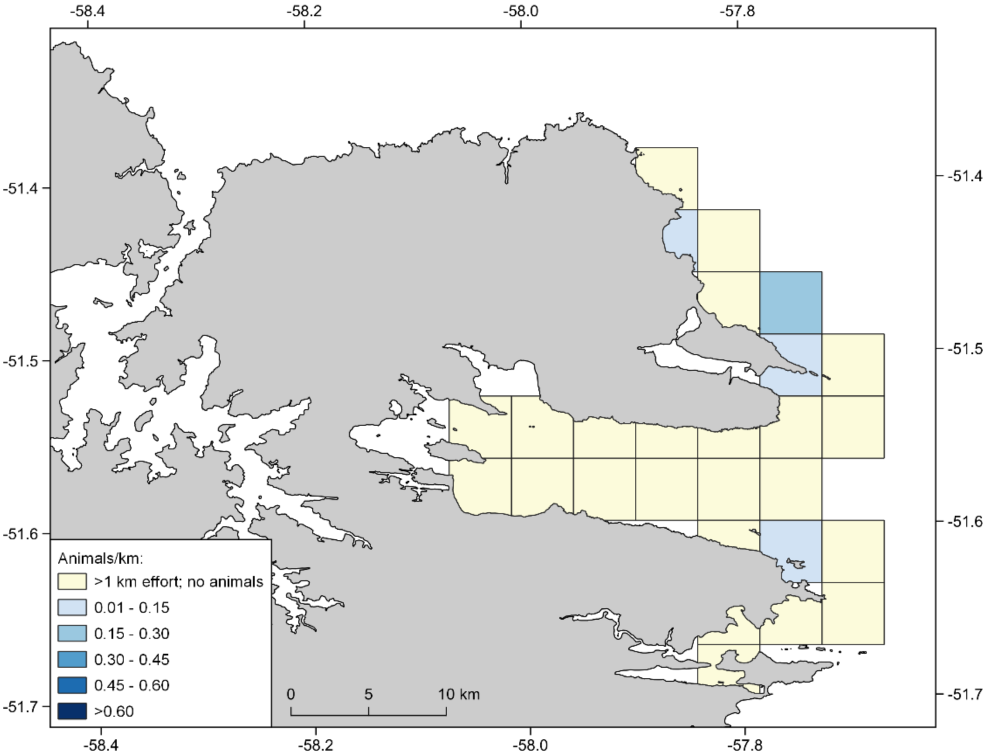


Figure 2.22. Spatial distribution of southern right whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during May: (A) Active Search effort (red lines) and associated SRW sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

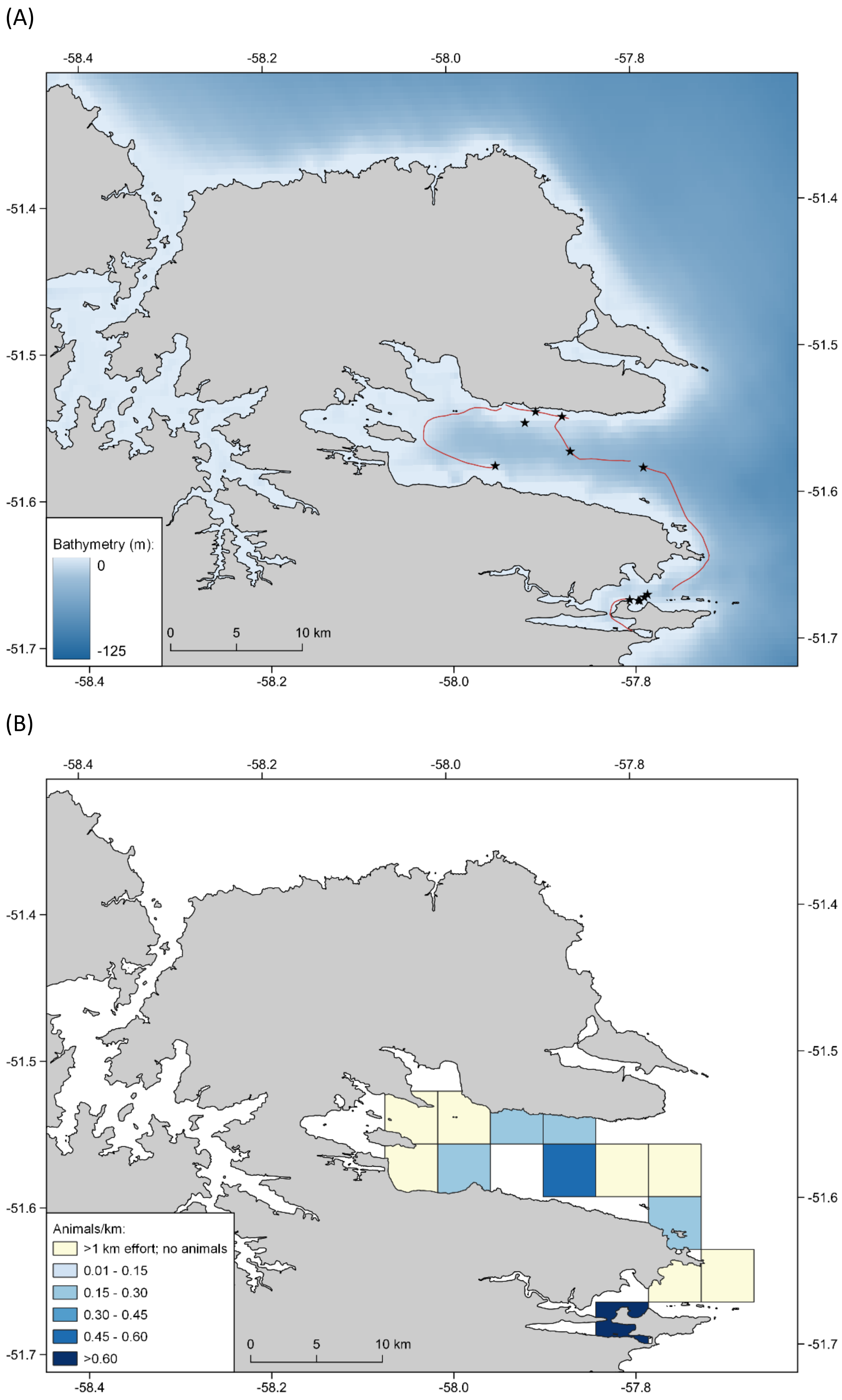


Figure 2.23. Spatial distribution of southern right whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during June: (A) active search effort (red lines) and associated SRW sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

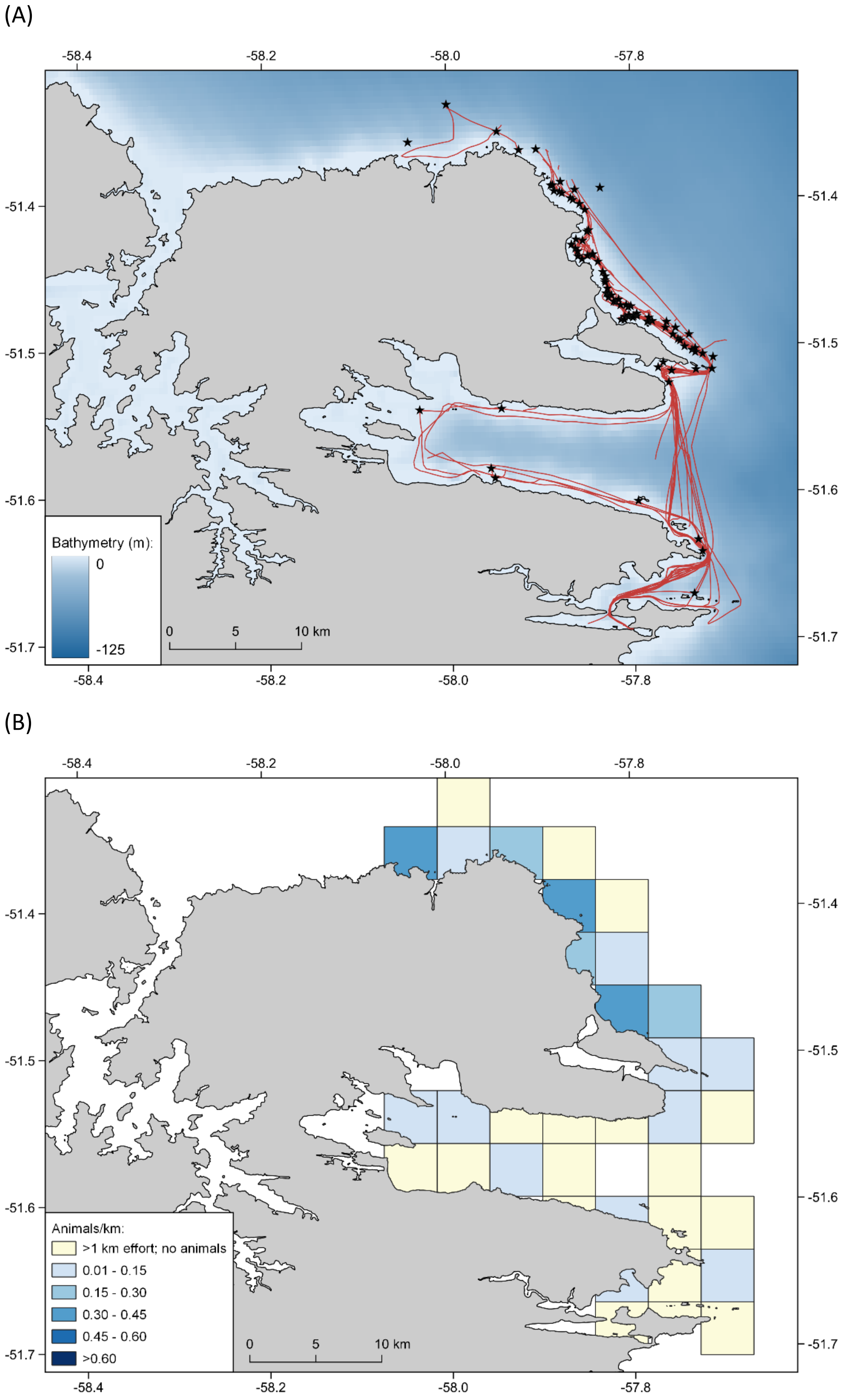


Figure 2.24. Spatial distribution of southern right whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during July: (A) active search effort (red lines) and associated SRW sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

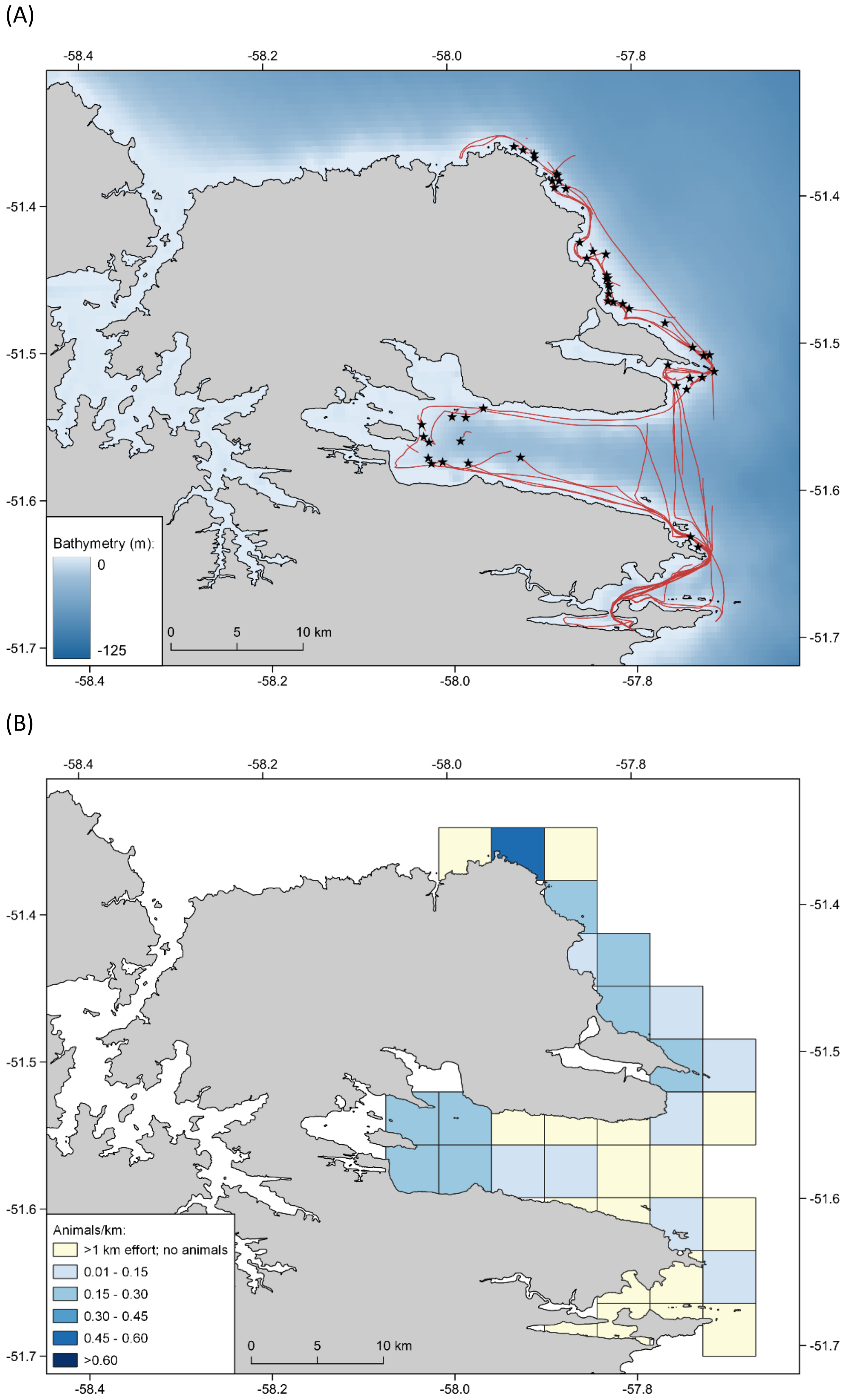


Figure 2.25. Spatial distribution of southern right whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during August: (A) active search effort (red lines) and associated SRW sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

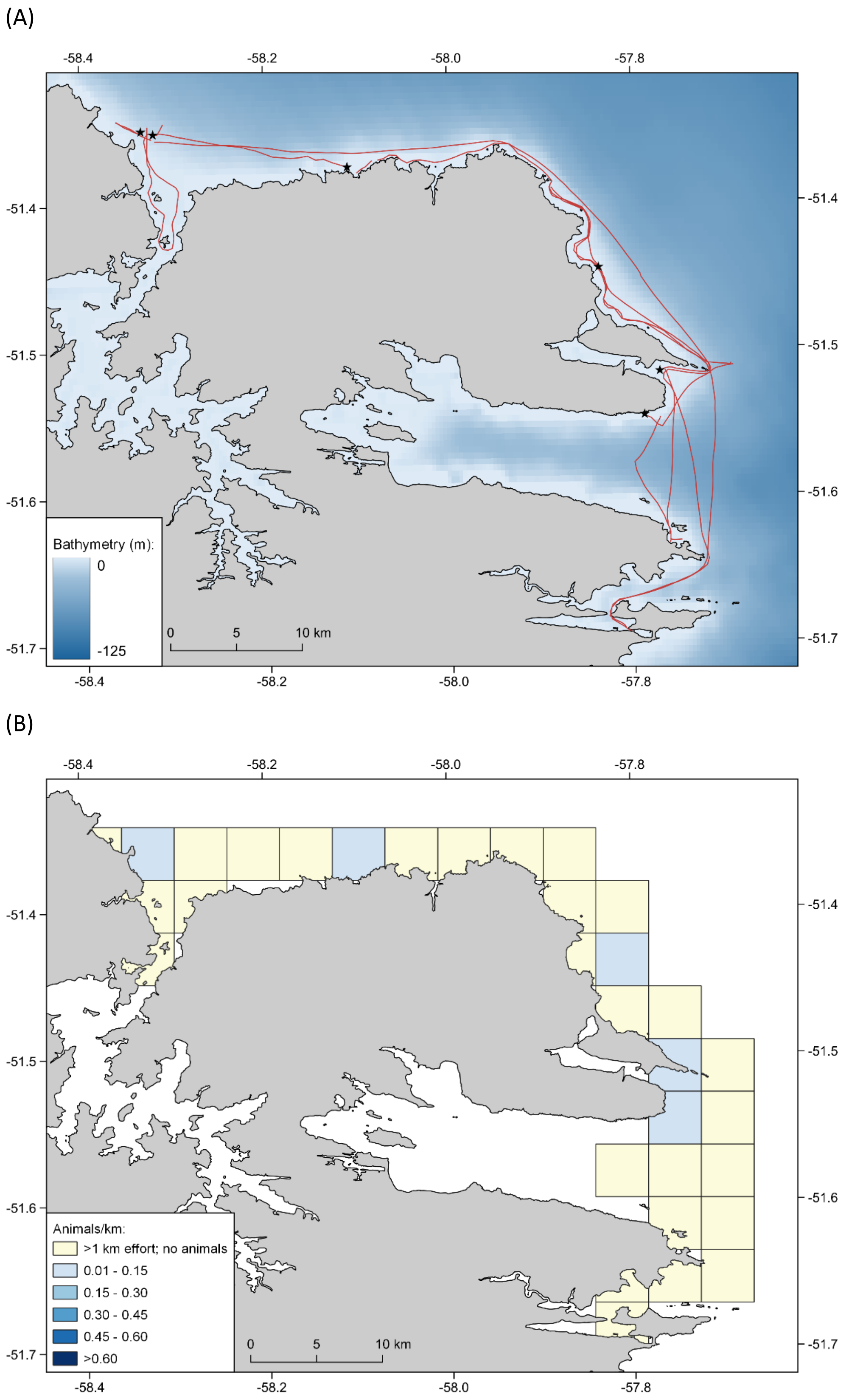


Figure 2.26. Spatial distribution of southern right whales recorded during boat surveys in favourable weather conditions (sea state ≤4, swell ≤2.5 m, and visibility >5 km) during September: (A) active search effort (red lines) and associated SRW sightings recalculated to reflect animal positions (black stars); and (B) relative abundance (animals/km) in 4 km grid cells.

2.4.2 Sei whales

Overall, a far lower number of sei whale sightings (n=229) was recorded during the three years of DPLUS126 compared with the three years of DPLUS082 (n=566: Weir, 2022). This likely reflects differences in the survey methods and coverage as outlined in Section 2.4.1, and does not necessarily indicate reduced whale numbers using the Berkeley Sound region over the 2022–2024 period compared to 2019–2021. In fact, with the exception of February, the monthly relative abundance of sei whales recorded in Berkeley Sound over both periods was broadly comparable: ~0.25 individuals/km in March and April 2019–2021 versus ~0.20 individuals/km in March and April 2022–2024, and ~0.1 individuals/km in May 2019–2021 versus ~0.08 individuals/km in May 2022–2024 (see Figure 2.15 in Weir, 2022). The seasonal pattern of occurrence recorded during DPLUS126 matched well with that evident in DPLUS082 (Weir, 2022) despite the overall lower amount of survey coverage. The February to April period was again shown to be a period of consistent use of Berkeley Sound by sei whales, and again, no sightings of sei whales were recorded from July to September (the austral winter), despite there being ample survey coverage for southern right whales in those months. These patterns are consistent with the use of Falklands' inshore waters as a seasonal feeding ground during summer and autumn, with sei whales moving away from the Islands during the winter when they likely migrate to lower latitudes for reproductive behaviour (Weir et al., 2020).

The mean group size of sei whales using the Berkeley Sound region over the 2022–2024 period was higher (mean=2.7 animals) than that recorded in 2019–2021 (mean=2.1 animals: Weir, 2022), and the proportion of sightings comprising single animals was much lower (28.8% vs 45.4%). The lowest mean group size in both studies occurred during March which is one of the months of highest relative abundance of sei whales in Berkeley Sound, and both studies recorded larger mean group sizes at the start and end of the sei whale season than during the peak months of March and April. The underlying drivers for these differences are currently unclear, but potentially relate to foraging behaviour efficiency, larger groups forming in relation to the onset of the breeding season in May/June (shown by the start of singing behaviour associated with reproduction: Cerchio and Weir, 2022), or predation pressure if larger groups form when there are fewer whales overall in an area. Recent investigations of stranded sei whales in the Falkland Islands suggest that predation pressure from killer whales may be increasing in the region (Falklands Conservation, unpublished data), and three sightings of killer whales were recorded during DPLUS126 compared to none in DPLUS082.

Both studies demonstrated the widespread distribution of sei whales across Berkeley Sound, particularly in March and April during their peak seasonal occurrence when they are found throughout the Sound and move in convoluted patterns. While surface feeding was rarely observed in Berkeley Sound during the survey work, evidence of subsurface feeding was readily apparent from the frequent defecations at the surface which contained the remains of crustacean prey including squat lobster krill (*Munida gregaria*). Shoals of squat lobster krill were also seen only very rarely during the DPLUS126 survey work, and consequently were assumed to be distributed deeper in the water column. However, the spatio-temporal occurrence of potential prey species in the Falklands, and their relative importance as preferred prey for sei whales, remain poorly known and require investigation to better understand sei whale occurrence.

2.4.3 Southern right whales

DPLUS126 built on the baseline dataset for SRWs established during DPLUS082 (Weir, 2022), and confirmed that the wintering aggregations of SRWs found coastally in the Falklands are persistent across multiple years. To date, there have been four full winter seasons of targeted SRW research carried out in the Islands (2019, 2020, 2022 and 2023: Weir, 2022; this study), together with some partial seasons in 2017 and 2021 (Weir, 2017; Falklands Conservation, unpublished data). In combination, this work has highlighted the importance of the north-east Falkland Islands as a newly-documented wintering ground for SRWs in the southern hemisphere (Weir and Stanworth, 2019), and has directly supported the recognition of the region as an IUCN Important Marine Mammal Area[1] and a proposal to have the SRW added as a qualifying species to the existing Falkland Islands Inshore Key Biodiversity Area.

The underlying driver for the SRW wintering aggregations in the Falklands appears to be social and reproductive behaviour. Feeding has not been conclusively documented in the coastal waters during winter, and defecations are very rarely observed and only by animals engaged in surface-active behaviour and clearly not feeding (Weir, pers. obs.). The presence of surface-active groups is considered indicative of mating behaviour, and frequent observations have been recorded of mating amongst pairs and groups (Weir and Stanworth, 2019; Weir, 2022; Falklands Conservation unpublished data). Additionally, two years of acoustic monitoring in Berkeley Sound recorded numerous calls and gunshot song (Cerchio et al., 2022); the latter is considered to be a form of male reproductive advertisement. No neonate calves have been confirmed to date in the Falklands, and the region is currently considered to comprise a mating-only breeding area. However, the presence of juveniles (see Chapter 3) suggests that SRW occurrence in the site encompasses more than solely mating behaviour for reproductive purposes, potentially including social behaviour and rest.

SRWs use the Falkland Islands wintering ground between mid-May and early September, and numbers usually peak during July (Weir, 2022). However, both sightings and acoustic monitoring indicate that a regular occurrence can commence as early as March in some years (Weir, 2022; Cerchio et al., 2022). DPLUS126 further confirmed the strong winter seasonality of the species, recording SRWs between April and September, with numbers peaking between June and August (see Figure 2.18).

The DPLUS126 SRW surveys were able to extend over a wider area of coast compared to those carried out for DPLUS082, due to the greater fuel efficiency and sea handling of the new research boat purchased for the project. The 2019 and 2020 survey work rarely extended north of Cow Bay (Weir, 2022), whereas in 2022 and 2023 the surveys routinely continued north to MacBride Head and occasionally extended further west along the north coast of the Islands as far as Salvador (see Figure 2.4). The boat work for DPLUS126 confirmed the findings of DPLUS082 that SRWs aggregate especially along the exposed coast from the Volunteer Lagoon mouth northwards, and with the extended boat capacity that area of high use was shown to continue all the way to MacBride Head. It should be noted that survey effort along the north coast between MacBride Head and Salvador occurred primarily in September and does not reflect the numbers of SRWs using that area during the peak months from June to August. This was because overall whale numbers decreased markedly in the study area during September, such that there was sufficient time to extend the survey coverage along the north coast in order to locate whales to work with. Both the telemetry work (Chapter 5) and the aerial surveys (Chapter 7) indicate that the north coast of East Falkland is very heavily used by SRWs during the peak season, but is a remote and challenging area to reach by small boat unless the prevailing weather conditions are excellent.

Berkeley Sound was not surveyed as regularly during the SRW season as it was during the sei whale season, but SRWs were also regularly sighted in the Sound and especially in the innermost area between Long Island, Strike-off Point and Monkey Point. Similar distribution was found during boat surveys and acoustic monitoring in DPLUS082, and suggests that the use of Berkeley Sound by SRWs is also persistent across years.

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[1] https://www.marinemammalhabitat.org/factsheets/north-east-falklands-malvinas-right-whale-wintering-area-imma/

2.4.4 Conclusion

The boat survey data collected during DPLUS126 were incidental to the core project goals of deploying satellite tags and collecting UAV imagery. However, the standardised approach used means that the DPLUS126 work added considerable additional information to the data collected for DPLUS082, confirming broadly similar patterns of distribution and temporal occurrence of the two baleen whale species over multiple years. Both sei whales and SRWs utilise Berkeley Sound, the area of highest vessel activity in the Falklands; SRWs additionally use Port William intensively during some years and occasionally enter Stanley Harbour itself. The period of high use of Berkeley Sound by both species combined extends from (at least) December through to the end of August, as shown by boat survey work, aerial surveys, and acoustic monitoring (Weir, 2022; this study). The overlap in time and space between whales and areas of high vessel activity warrants management to minimise acoustic disturbance to critical behaviours including feeding (sei whales) and breeding (SRWs and sei whales), and to limit the likelihood of vessel strike causing injury or mortality. An additional potential threat that has recently emerged is the commencement of a small-scale experimental crab fishery along the east coast of the Falklands, including in Berkeley Sound and Port William. The potential for whale entanglement in this fishery should be fully evaluated, particularly ahead of any expansion of operations.

The data collected during DPLUS082 and DPLUS126 have already been used to inform several global initiatives relevant to the conservation and management of both species, including:

- The Falkland Islands Inshore Key Biodiversity Area (KBA)[2] – established in 2021 for sei whales, this area spans the waters from the coast to the 100 m isobath around the Islands. A proposal to add the SRW as a qualifying feature to this KBA was submitted in December 2024, and was confirmed by the IUCN on 22 January 2024.
- The Falkland Islands Inner Shelf Waters Important Marine Mammal Area (IMMA)[3] – established in 2024 as a foraging ground for sei whales and other marine mammal species, with similar boundary to the KBA.
- The North-east Falklands Right Whale Wintering Area IMMA – established in 2024 for SRWs, and extending 8 km from the north coast of East Falkland.

These areas recognised by the IUCN as globally important spatial sites supporting high densities of baleen whales (and other species) serve as useful spatial tools that can be used to inform the development of marine management areas in the Falklands and to highlight where mitigation is required to minimise the impacts of human activities on whales.

2.5 Acknowledgements

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[2] https://www.keybiodiversityareas.org/site/factsheet/49174

[3] https://www.marinemammalhabitat.org/factsheets/falkland-islands-malvinas-inner-shelf-waters-imma/

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Chapter 3: Size composition and body condition of southern right whales

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3.1 Introduction and aims

Baleen whales are long-lived and wide-ranging capital breeders, with a migratory cycle that reflects differing spatio-temporal requirements for foraging and reproduction. Many baleen whale populations undertake seasonal movements between low-to-mid latitude breeding grounds and productive mid-to-high latitude feeding areas, although the drivers of such migrations are complex (Corkeron and Connor, 1999) and migratory behaviour varies according to factors including species, age, sex, reproductive status, and region (Horton et al., 2022). As capital breeders, the energy resources accumulated as body (blubber) reserves, or body condition, during intensive feeding periods are subsequently used to support migration and periods of fasting on the breeding grounds, and, in the case of mature females, for the energetically-costly behaviours of gestation and lactation. Understanding the relationships between an individual's demographic parameters, body condition, and foraging behaviour, underpins population dynamics (Weimerskirch, 2017). The ability of an individual to acquire sufficient energy reserves for self-maintenance, activity (i.e. locomotion), and reproduction, directly influences its survival and reproductive success, or fitness. The factors influencing foraging efficiency are therefore important in explaining changes in population size. For example, variation in the reproductive rate of North Atlantic right whales (*Eubalaena glacialis*) has been linked to changes in prey availability related to oceanic conditions in some of their main feeding areas (Meyer-Gutbrod et al., 2015).

Knowledge of population dynamics (primarily recruitment, growth trajectory and mortality rate) is integral to the management of baleen whales, and has long been used by international bodies such as the International Whaling Commission (IWC) to determine sustainable quotas for exploitation and to identify and manage key threats (Punt and Donovan, 2007). Conservation assessments also rely on population dynamics, with age-structured or size-structured population modelling used to estimate the global population sizes and trajectories of several baleen whale species in IUCN Red List assessments (e.g. Cooke, 2018). These approaches have traditionally used life-history parameters (e.g. length-at-age curves, age at sexual maturity, annual pregnancy rate) obtained during the scientific sampling of dead whales during the modern whaling era of the 1900s. However, the advent of long-term field studies of some populations is providing similar demographic information for live animals, using non-invasive techniques such as photo-identification to recognise individual animals and monitor their survival, determine inter-calving intervals, and identify their age at first reproduction. Recent technological advances, including tagging and biopsy sampling, have also provided insights into foraging efficiency and hormone levels which influence individual fitness. One recent development has been the use of calibrated unmanned aerial vehicles (UAVs or 'drones') to collect top-down images from which the morphometric measurements of whales can be estimated by measuring pixel dimensions and then scaling them to real size using the focal length of the camera lens and the UAV altitude. The body length estimates generated by this approach can be assigned to an age class using the length-at-age curves originating from similar work on well-studied populations, whaling catches or stranding data (Leslie et al., 2020), particularly when the sex of the individual is also known. UAV photogrammetry has also been used to produce the first estimates of the body mass of free-ranging whales, as a proxy for energy stores and body condition (Christiansen et al., 2019). Repeated measurements of the same individuals over time, has produced novel information on energetics including seasonal and annual variation in body mass (Christiansen et al., 2019), and calf growth rates and associated maternal loss of body volume (Christiansen et al., 2018).

The southern right whale (*Eubalaena australis*: SRW) has been the focus of several UAV photogrammetry studies across its Southern Hemisphere distribution range, primarily at their mid-latitude subtropical and temperate calving grounds located at Peninsula Valdés (PV) in Argentina (Christiansen et al. 2019), South Africa (Vermeulen et al., 2023), Australia (Christiansen et al., 2023), and New Zealand (Johnston et al., 2022). These calving areas are used between May and December by mature female SRWs for parturition and lactation, but are also visited by other age-sex cohorts including mature animals of both sexes for mating, and by non-breeding whales including juveniles (Wilding Brown and Sironi, 2023). Recently, it has become apparent that SRWs also aggregate on some higher latitude subantarctic wintering grounds, with characteristics including mating and socialising behaviours, no confirmed calving, and a higher representation of subadult age classes. Such areas include the sub-Antarctic waters around Campbell Island (52.5°S) in New Zealand (Torres et al., 2017), and the Falkland Islands in the south-west Atlantic (Weir, 2022; Weir et al., 2024). These areas are located close to subantarctic feeding grounds, and provide novel opportunity to collect UAV photogrammetry data on whales that have potentially not yet undertaken extensive energy-intensive movements to winter calving areas. They also potentially provide data on under-represented age cohorts on the calving areas, including yearlings and subadults.

Here we assess the size and body condition of SRWs on the Falkland Islands wintering ground (FIWG) using UAV photogrammetry, with the aims of clarifying the drivers of occurrence on the FIWG and collecting a baseline dataset on their body condition. The FIWG was only identified as a high-use habitat for wintering SRWs during 2017 (Weir, 2017), and currently has little recognition in conservation management efforts either within the islands or regionally. For example, the FIWG is not acknowledged within the International Whaling Commission Conservation Management Plan (IWC-CMP)[4] for south-west Atlantic SRWs. One useful tool for recognising globally-important sites for conserving biodiversity is the IUCN Key Biodiversity Areas (KBAs) approach, which assesses the population using a site against a set of standard criteria and thresholds. Proposing the FIWG as a KBA requires knowledge of the number of mature individuals and reproductive units of the trigger species using the site. Therefore, a primary driver for the UAV study was to better understand the ratio of immature and mature animals using the FIWG in order to highlight the site as a globally-important SRW wintering area that warrants recognition in local and regional management initiatives.

3.2 Materials and methods

3.2.1. Study area

The Falkland Islands (52°S, 59°W) are located approximately 500 km east of southernmost South America in the south-west Atlantic Ocean. They are situated in the subantarctic zone which extends between the Antarctic Convergence and the Subtropical Front (~46 to 60°S) and have biogeographical links with Antarctica, subantarctic Tierra del Fuego, and the wider Magellanic marine province (Spalding et al., 2007; Convey, 2020).

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[4] https://iwc.int/management-and-conservation/conservation-management-plans/south-atlantic-southern-right-whale

SRW surveys occurred in the nearshore (<5 km) waters located on the north-east coast of East Falkland, from the Cape Pembroke peninsula to MacBride Head including the large inlet of Berkeley Sound (Figure 3.1).

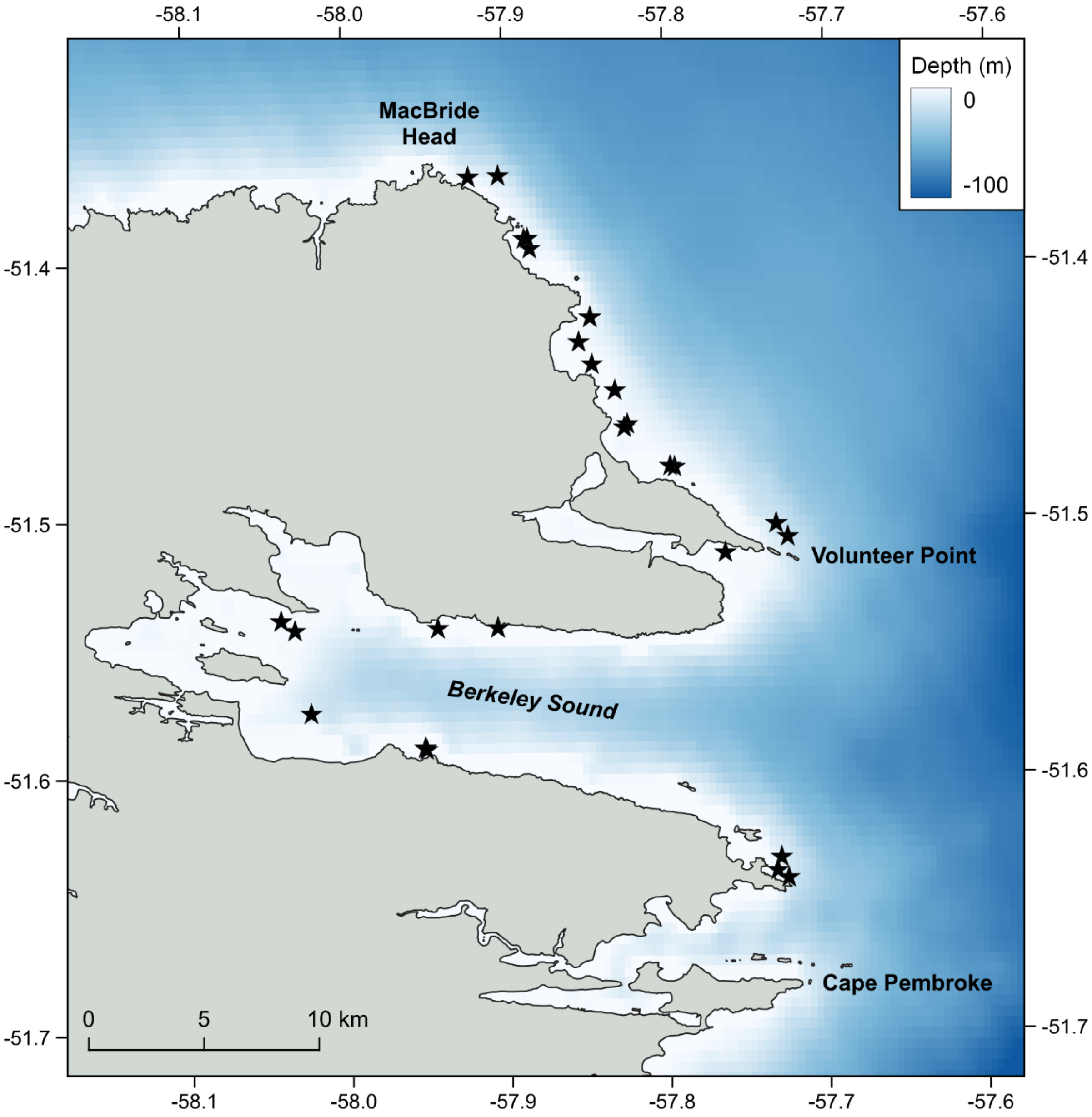

Figure 3.1. Location of the study area, showing the initial sighting locations of southern right whale individuals and groups where unmanned aerial vehicle flights occurred.

3.2.2. Data collection

A 7.5 m rigid-hulled inflatable boat with twin 90-hp engines was used during SRW surveys, with the position logged continuously at 1-min intervals using a handheld Garmin GPS. When SRWs were located, they were approached to sufficient distance to acquire basic information on group size and composition, and behaviour. When weather conditions were favourable to both fly and safely recover the UAV (<15 knots of wind, swell <2 m), a DJI Inspire 2 UAV (60.5 cm diameter, 4.0 kg, www.dji.com) was launched from the boat to collect body morphometric data for individual whales. The Inspire 2 was equipped with a 16 megapixel DJI Zenmuse X5S micro four-thirds camera with an Olympus M.Zuiko 25mm f1.8 lens, and was flown at a mean altitude of 27.1m (SD=3.8, range=18.2–44.6 m).

The altitude was recorded using a LightWare SF11/C laser range finder (Lightware Optoelectronics, weight: 35 g) fitted to the UAV.

The UAV was positioned over surfacing SRWs and short video clips were recorded when whales were close to the surface and exhibiting behaviour from which suitable images could be extracted for measurement. Optimal imagery included periods when the animal was angled as straight as possible along its horizontal and vertical body axes, and when the body outline was clear and not obscured by white water. The number of flights for each SRW encounter undertaken was determined by the group size and behaviour, weather, and decisions by the UAV operator regarding when sufficient good quality imagery had been acquired for all animals. Flight imagery was allocated to particular SRW encounters using timestamps on the recordings, which were matched with the timestamps of GPS data, biopsy samples and visual estimates of group size and behaviour.

3.2.3. Data analysis

Each video clip was examined and individual whales were identified and allocated reference numbers based on established methods for recognising SRW individuals using their callosity pattern and body pigmentation (Payne et al., 1990). The best available image of each individual in each encounter was then identified for body measurement by scrolling through the video frame by frame. Best images were selected as: (1) whales that were positioned with a straight body (without rolling, arching or pitching): (2) images that were well focussed and exposed; and (3) images where the outline of the animal from the rostrum to the tail notch was clearly visible. Each image was scored for its quality (1=good quality, 2=medium quality and 3=poor quality) based on several attributes: camera focus, straightness of body (horizontally), degree of body roll, degree of body arch, body pitch (vertically), body length measurability, and body width measurability (Christiansen et al., 2018).

All measurements and grading were undertaken by a single researcher, thus minimising potential inter-observer bias. The total body length (BL, distance from tip of rostrum to the end of tail notch) and width (at 5% increments) of each whale was measured in pixels using a custom written script (Christiansen et al., 2016) in R 4.4.1 (R Core Team, 2024; Figure 3.2). Pixel measurements (Distance.pix) were converted to meters (Distance.m) by scaling:

$$Distance.m = \left(\frac{Distance.pix}{Image.width.pix} \times Sensor.width.mm\right) \times \frac{Altitude.m}{Focal.length.mm} \quad (1)$$

The corresponding height (dorso-ventral distance) at each width measurement site was predicted, using the published mean height-width ratio of SRWs (Christiansen et al., 2019). From the body length, width and height data, the body volume of each whale was estimated, using the segmented elliptical model of Christiansen et al. (2019):

$$BV_{s,i} = BL_i \times 0.05 \times \int_0^1 \pi \times \frac{W_{A,s,i}+\left(W_{P,s,i}-W_{A,s,i}\right)\times x}{2} \times \frac{H_{A,s,i}+\left(H_{P,s,i}-H_{A,s,i}\right)\times x}{2}\, dx \quad (2)$$

$$BV_{Total,i} = \sum_{s=1}^{20} V_{s,i} \quad (3)$$

where s is the section of the body between two adjacent width/height measurement sites (S=20 in total), BL_i is the body length of whale i, $W_{A,s,i}$ and $H_{A,s,i}$ are the anterior width and height measurements of body segment s for individual i, and $W_{P,s,i}$ and $H_{P,s,i}$ are the posterior width and height measurements of segment s for individual i, respectively. The snout (0–5%BL from the rostrum [hereafter just '%BL']) and tail end (85–100%BL) were modelled as elliptical cones (Christiansen et al. 2019). The body condition (BC) of each whale was calculated, using the formula of Christiansen et al. (2018):

$$\mathrm{BC_i} = \frac{\mathrm{BV_{obs,i}}-\mathrm{BV_{exp,i}}}{\mathrm{BV_{exp,i}}} \quad (4)$$

where $BV_{Obs,i}$ is the observed body volume of whale *i*, in m^3, and $BV_{Exp,i}$ is the expected (or predicted) body volume of whale *i,* in m^3, given by the log-log relationship between body volume and BL, in m, of SRWs (Christiansen et al., 2022a)

$$\log(BV_{Exp,i}) = -4.115 + 3.016 \times \log(BL_i) \tag{5}$$

This BC metric represents the difference in relative BV (expressed as a proportion) of an individual whale compared to the expected (or average) BV of whales, based on the healthy breeding SRW population at the Head of Bight, Australia (Christiansen et al., 2022a). For example, a whale with a BC of 0.20 (or 20%) has a BV that is 20% higher than the average (expected) BV of a whale of the same BL, while a whale with a BC of -0.20 (or -20%) has a BV that is 20% lower than the average (expected) BV of a whale of the same BL. The BV of a whale with BC 0 (or 0%) is the same as the average (expected) BV of the sample population, while accounting for its BL (structural size).

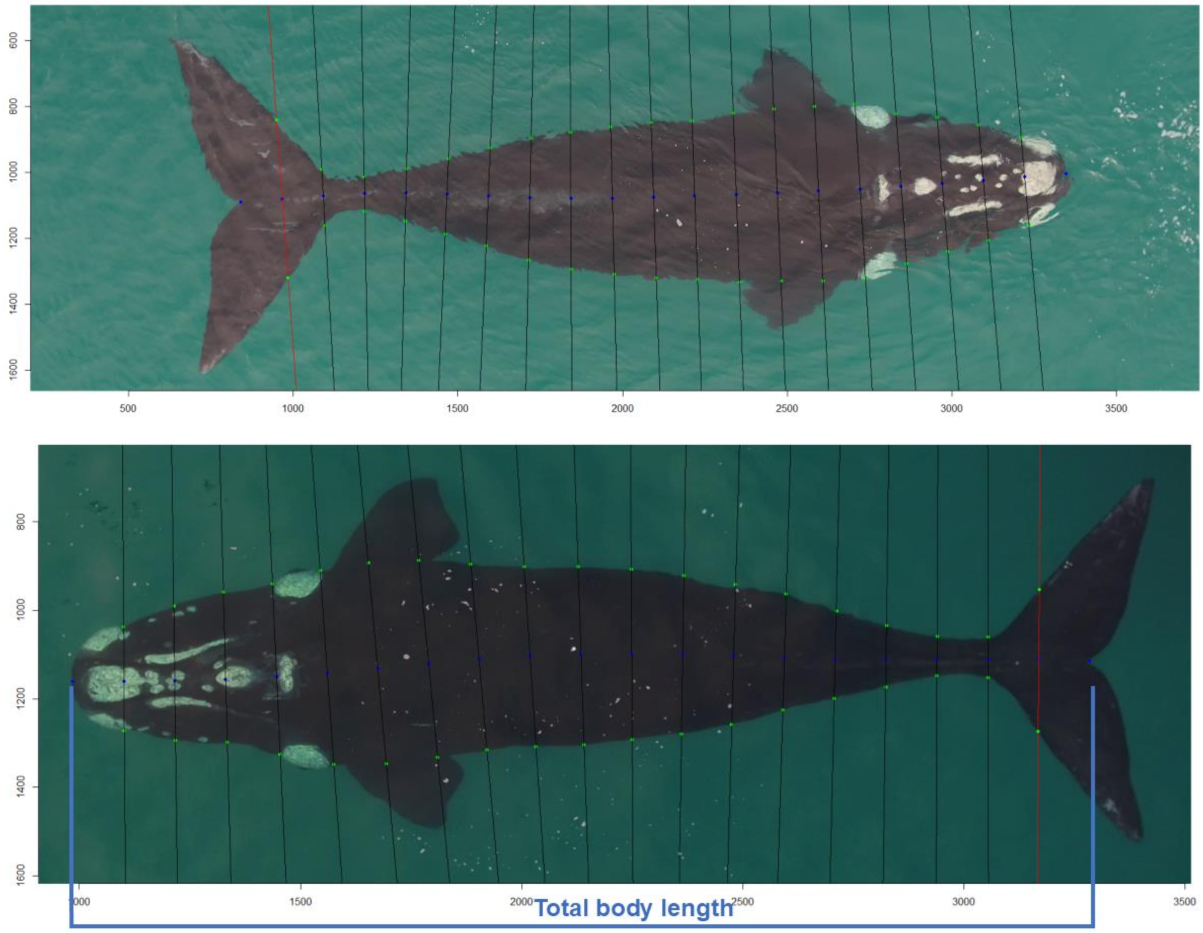

Figure 3.2. Two examples of the measurements of body length and width (at 5% increments) of individual whales using the custom written script (Christiansen et al., 2016) in R 4.4.1.

Using the best available quality image of each individual SRW, the animals were categorised as yearlings, juveniles and adults (presumed sexually mature animals that were not late-pregnant or lactating) based on their BLs and using established thresholds applied to SRW photogrammetry studies (Christiansen et al., 2020, 2022a): yearlings <10.0 m; juveniles ≥10.0 and <12.0 m; adults ≥12.0 m. However, it is important to note that there is individual variation around the BL and age at which individual baleen whales become sexually mature (Chittleborough, 1955), which means that some larger juveniles might have been classified as adults, and some smaller adults might have been classified as juveniles.

BL and BC summary statistics were collated for each age cohort. For the BL data, images that received a score of 3 (poor) for either length.measurability, arching or pitch were removed. For the BC data, images that were given a score of 3 in any attribute were removed, as were images that received a score of 2 for both arch and pitch, pitch and roll, or arch and roll. To avoid pseudo-replication, only a single image of each individual was retained, with the image of the highest picture quality being selected, or the one taken first.

3.3 Results

UAV fieldwork was carried out on seven dates between 11 July and 9 August 2023, with most effort occurring during a single week of good weather between 11 and 17 July. There was a total of 37 UAV flights over the seven days, acquiring 10.5 hr of video footage. The UAV flights occurred over 26 SRW sightings of individuals or groups (Table 3.1). Analysis of the callosity patterns indicated that 73 individual whales were present in the UAV videos. Between six and 25 individuals were measured per date. Of the 73 whales, most (n=61) were imaged by the UAV on only a single date, 10 animals were imaged on two dates, and two animals were imaged on three dates each (Table 3.1). No dependent calves were either observed in the Falklands during the 2023 season or captured in the UAV imagery.

3.3.1. Age composition

Images of sufficient quality to measure BL were available for 66 individual SRWs. The measured BL ranged from 9.78 to 13.71 m (n=66, median=11.73), with a mean of 11.70 m (SD=0.94). The 66 whales were assigned as 26 (39.4%) adults, 37 (56.1%) juveniles and three (4.5%) yearlings (Figure 3.3A). Therefore, the proportion of mature to immature animals in the Falklands was 39.4% versus 60.6%. However, the highest density of measurements was around the 12 m threshold applied to distinguish between juveniles and adults (Figure 3.3B), indicating that the exact ratio of mature to immature animals has uncertainty.

3.3.2. Body condition

Images of sufficient quality to measure BC were available for 49 individual SRWs. Of those, 19 (38.8%) were adult, 28 (57.1%) were juvenile, and 2 (4.1%) were yearlings.

Using the combined dataset, BC measurements ranged from -0.19 to 0.36 (n=49, median=0.01), with a mean of 0.02 (SD=0.13). When assessed according to reproductive group, the BC values ranged from 0.04 to 0.32 for yearlings, -0.13 to 0.26 for juveniles, and -0.19 to 0.36 for adults (Figure 3.4). The BC of adult whales was significantly higher than that of immature (juvenile and yearling combined) whales (Mann Whitney U-test: W=414.0, p=0.007).

Table 3.1. Summary of UAV flights (n=37), estimated visual group size, and the number of whales measured during 26 SRW encounters in July and August 2023.

Date	Sighting Ref.	No. of flights	Visual group size estimate	No. whales in UAV imagery	No. whales measured	Whale UAV IDs
11 July	20230711_3	1	6	6	6	1–6
11 July	20230711_13	1	3	2	2	7,8
11 July	20230711_17	2	3	2	2	9,10
12 July	20230712_6	3	8 to 10	8	5	11–18
12 July	20230712_7	1	5 to 7	4	3	11,12,17,19
12 July	20230712_8	1	6 to 7	4	3	13,15,20,21
13 July	20230713_19	1	1	1	1	22
13 July	20230713_20	1	2	2	2	23,24
13 July	20230713_21	2	4 to 6	6	5	11,12,19,24,25,26
15 July	20230715_2	1	4	3	2	27,28,29
15 July	20230715_3	1	2	1	0	29
15 July	20230715_4	1	2	2	2	27,28
15 July	20230715_5	3	10 to 12	12	10	14,17,18,27,28,30,31,32,33,34,35,36
17 July	20230717_3	2	2	2	2	35,37
17 July	20230717_4	1	1	1	1	38
17 July	20230717_5	4	7 to 8	7	6	32,39,40,41,42,43,44
17 July	20230717_8	1	4	4	3	45,46,47,48
24 July	20230724_1	1	3	3	3	23,49,50
24 July	20230724_6	2	6 to 8	6	5	6,12,51,52,53,54
24 July	20230724_12	1	4	4	4	37,55,56,57
24 July	20230724_13	1	7 to 8	7	6	4,37,57,58,59,60,61
24 July	20230724_15	1	5	5	5	62,63,64,65,66
24 July	20230724_16	1	2	2	2	19,67
9 August	20230809_1	1	3	3	3	68,69,70
9 August	20230809_3	1	2	1	1	71
9 August	20230809_5	1	2	2	2	72,73

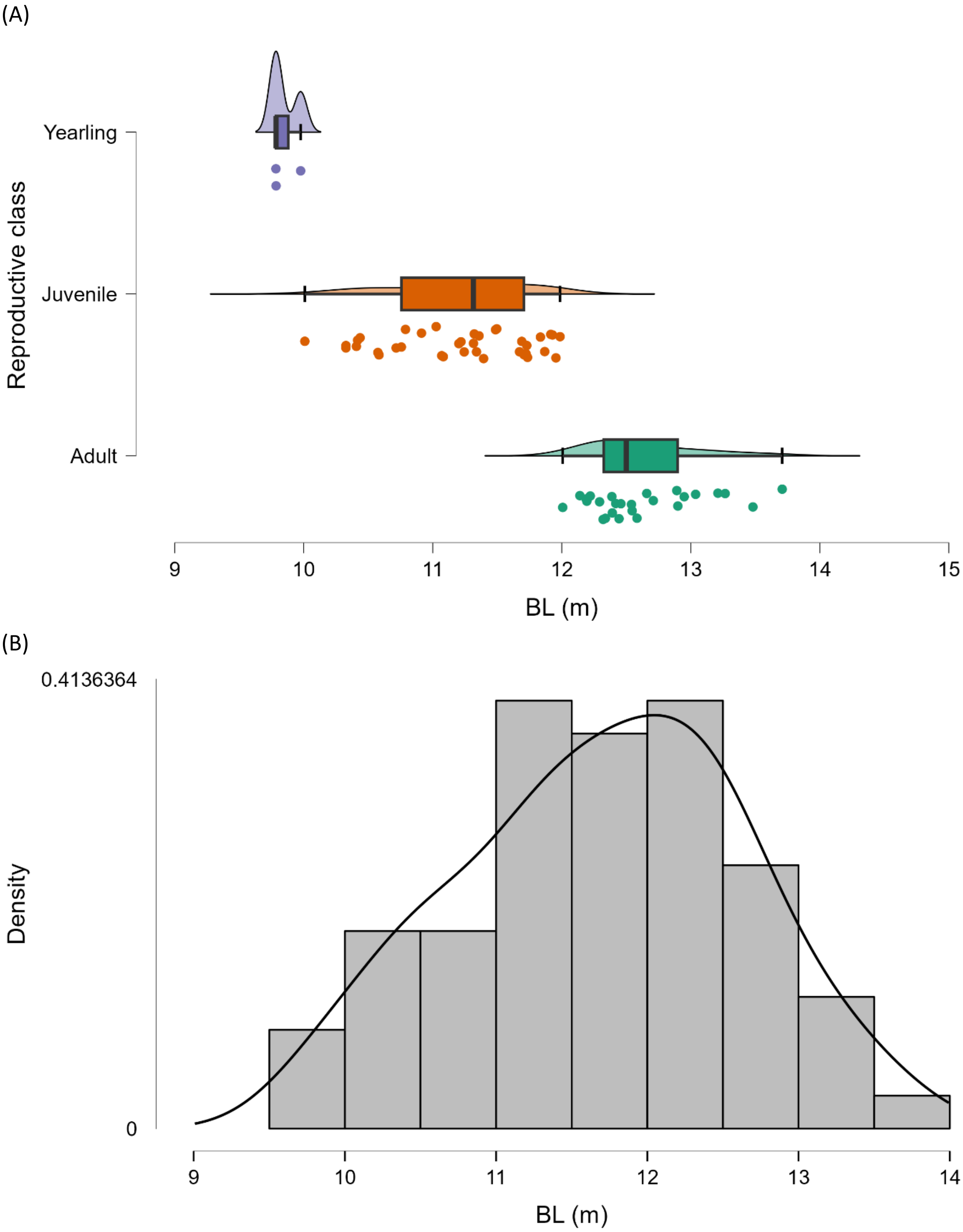

Figure 3.3. The body length (BL) of SRWs (n=66) measured in the Falkland Islands: (A) raincloud plot of each age cohort; and (B) density distribution.

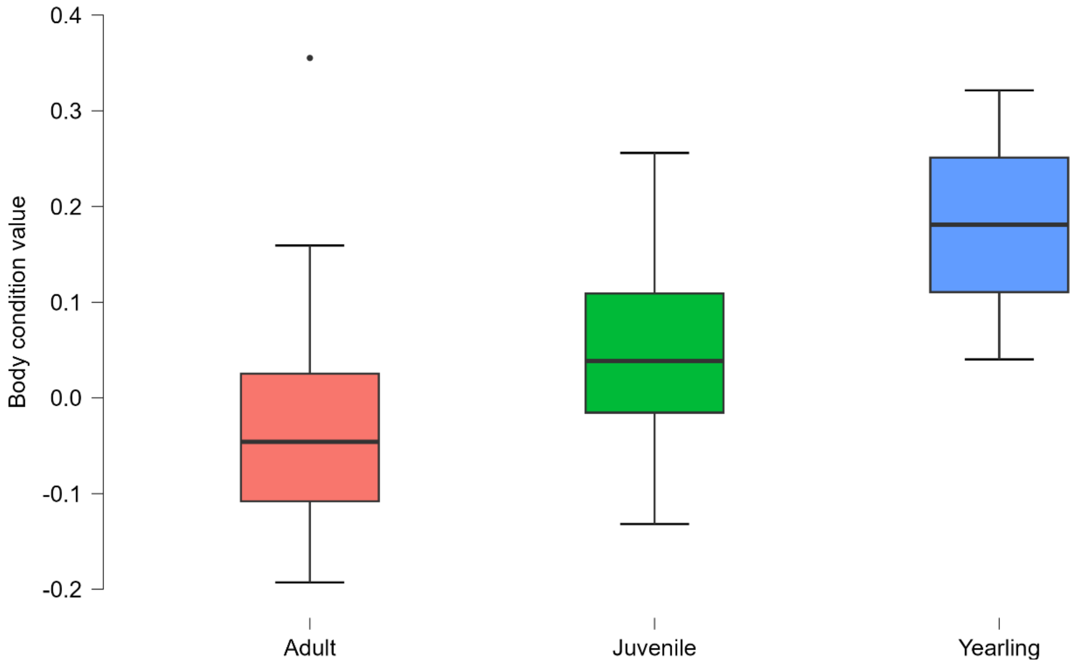

Figure 3.4. Box plots of the body condition of yearling, juvenile and adult southern right whales measured in the Falkland Islands, where a value of zero indicates the average body condition of an individual.

3.4 Discussion

This study was the first attempt to measure body size and condition for a whale species in the Falkland Islands, and the resulting dataset, although small, provides a useful baseline for better understanding the age cohort of south-west Atlantic SRWs that visit the islands during winter.

3.4.1. Age composition

With the exception of adults accompanied by calves of the year in the SRW calving areas (which can be reasonably assumed to comprise mature female and calf pairs), the ageing and sexing of SRWs at sea is challenging. There is no reliable method to sex a baleen whale at sea unless the ventral surface is viewed or a skin sample can be collected for genetic sexing. While field studies may have tracked some individual whales since birth and therefore have accurate age estimates, studies of sufficient longevity and precision to accurately age individuals of long-lived species such as SRWs are relatively rare. More usually, whales encountered at sea can only be assigned to an age class by estimating their overall BL and comparing it with existing age-length datasets, or by comparing the relative sizes of animals within a group. For baleen whales, estimating the total BL at sea by eye is difficult because usually only part of the animal is visible at the surface. The use of an UAV facilitates more standardised and accurate approaches to measuring BL, allowing comparative photogrammetry studies to occur globally (Álvarez-González et al., 2023).

Baleen whales exhibit a growth spurt between parturition and weaning, after which their growth rate slows down. For example, SRW calves have a mean BL of 4.75 m (SD=0.25) at birth (Christiansen et al., 2022b), around 35% of their mother's BL (Christiansen et al., 2022a). They grow rapidly at rates of 3.2 cm d^{-1} (SD = 0.45), with calves from females that are larger and in better BC growing faster (Christiansen et al., 2018). Weaning usually occurs within one year of birth, and the BL at weaning has been measured at 8.9 to 9.9 m (Christiansen et al., 2022b). Consequently, the BL of a calf at a particular age varies, and, additionally, there is overlap in BL between large dependent calves and weaned yearlings. Similarly, the age and BL of SRWs at sexual maturity varies between individuals, and perhaps also according to parameters such as sex and population. Published data for females indicates that 11.9 m is the minimal BL for a lactating mother (Christiansen et al., 2020), and 12 m has been considered representative of SRW BL at sexual maturity by several studies (e.g. Tormosov et al. 1998; Christiansen et al., 2018, 2020). However, as acknowledged in this and other studies, the use of a fixed BL threshold may miscategorise the age class of some larger immature animals and smaller sexually mature whales.

An additional caveat to the allocation of SRW BLs to age classes arises from the fact that the vast majority of available data on age-related BL and sexual maturity has been published for females and their calves (e.g. Tormosov et al., 1998; Christiansen et al., 2018), with relatively little information available for male SRWs. This resulted in the BLs used to categorise SRWs as yearling, juvenile and adult in the Falklands primarily resulting from data collected on females. However, female SRWs, like some other baleen whale species, may potentially reach larger body sizes than males (Tormosov et al., 1998). This is especially relevant to the Falklands dataset, since there appears to be a bias towards males; of 82 individuals sexed genetically in the Islands, 65 (79.3%) were male (Jackson et al., 2022a). If the BL at sexual maturity of a significant proportion of SRW males is smaller than 12 m, the percentage of mature animals (39.4%) calculated during this study may be underestimated.

The difference in BL between large immature and small sexually mature SRWs is sufficiently small (and overlapping) that reliably distinguishing between them by eye during boat surveys is virtually impossible (Torres et al., 2017). This was one of the primary drivers for the UAV study in the Falklands. However, the peak in the density distribution of UAV-measured BLs in the Falklands around the 12 m BL threshold used to distinguish between juveniles and mature animals, means that the relative occurrence of different age classes using the FIWG remains somewhat unclear and the value of 39.4% mature animals reported here should be considered in that context.

Regardless, it is clear that the FIWG hosts a variety of SRW age classes similar to another subantarctic wintering aggregation at Campbell Island in New Zealand (Torres et al., 2017), with both juveniles and adults well represented in the sample. Juveniles are also represented on the calving grounds (Christiansen et al., 2020), and in surface active groups, for reasons that potentially include socialising with conspecifics and the learning and practicing of behaviours that become important as an adult, particularly reproduction (Wilding Brown and Sironi, 2023). It has also been suggested that as SRW populations grow in size, different age-sex cohorts may change their habitat use on the core calving grounds, for example with mother-calf pairs remaining in the preferred habitat while solitary animals and mating groups are displaced to peripheral habitats (Sueyro et al., 2018). Consequently, those peripheral habitats used mostly by solitary juveniles and adults for socializing, courtship, and mating are becoming more important for the reproductive cycle of the species (Wilding Brown and Sironi, 2023). The apparent increase in SRW activity at the FIWG since 2017, the observations of surface active groups, and the novel UAV dataset on size distribution, in combination, suggest that the FIWG might represent one area of increasing use for breeding SRWs.

3.4.2. Body condition

Body condition assessments measure the energy reserves that a whale has relative to the structural components of its body (usually expressed as BL), and therefore BC influences both survival and reproductive success. Most published studies of SRW BC have focussed on mother-calf pairs at calving grounds, given both their coastal accessibility and the clear morphological changes expected as mothers invest their energy reserves in lactation resulting in decreased body condition and calves exhibit rapid post-parturition growth in body size (Christiansen et al., 2018, 2022b). The BC of female SRWs is known to affect both foetal and calf growth rates, and the calving interval (Christiansen et al., 2020), and consequently directly influences population dynamics.

The BC values measured for SRWs in the FIWG spanned -0.19 to 0.36, the equivalent of a BV 19% below to 36% above the average BV for a SRW of a given size. As might be expected, individuals classified as yearlings (i.e. born during the previous calving season) had the highest BC, having been only recently weaned. Average juvenile body condition values in the FIWG (~5.0%) were considerably higher than those reported by Christiansen et al. (2020) for juveniles using three calving grounds in Argentina (-2.9%), Australia (-2.4%) and New Zealand (-1.2%). This may be because juveniles on the FIWG were measured earlier in the year than those on the calving grounds and had been weaned more recently.

The BC values of mature whales (males and non-lactating females combined) recorded in the FIWG (-3.0%) were far lower than those recorded in Argentina (11.2%) and New Zealand (2.2%) but higher than in Australia (-7.8%: Christiansen et al., 2020). The lower BC of mature SRWs in the FIWG compared with those recorded at PV was unexpected, because genetic analysis has confirmed that both wintering areas are used by the south-west Atlantic population (Jackson et al., 2022a) and because: (1) whales were measured in the FIWG early in the breeding season when their stored energy reserves should be optimal; (2) satellite-tracking of 16 SRWs in the FIWG has shown that a high proportion (75%) migrated to PV within the same breeding season (Weir et al., 2024; see Chapter 5); (3) depending on their location in the preceding months, individuals should have expended lower energy reaching the FIWG than if continuing to PV; and (4) the FIWG is located at higher latitudes than PV and therefore closer to rich feeding areas in the subantarctic and Antarctic (for example around the Scotia Sea). The third of these points relies on the assumption that SRWs visiting the FIWG have most likely been foraging in the regions east and south of the Falkland Islands, such that they would be migrating past the Islands en route to PV, and is based on the premise that SRWs of all age-sex cohorts foraging on the Patagonian Shelf in the months preceding the winter breeding period would preferentially travel direct to PV rather than to the FIWG. However, there is increasing evidence that the FIWG comprises a wintering destination in its own right for a component of the south-west Atlantic population, with the isotope signals of tissue samples collected in the Islands suggesting that animals using the FIWG have foraged in both low and high latitude habitats during the autumn (Jackson et al., 2022b).

It is possible that some of the differences in BC between mature non-lactating SRWs at PV and on the FIWG result from the measurements being collected in different years in the two areas, with inter-annual variation in BC noted for some baleen whales related to differences in prey availability or quality (Soledade Lemos et al., 2020). This could be investigated in future by comparing only BC measurements recorded at the two sites within the same year. Similarly, since a proportion of SRWs travel from the FIWG to PV within the same breeding season (Weir et al., 2024), there is potential to carry out comparisons of the BC of the same individuals before and after their transits across the Patagonian Shelf. It would also be useful to incorporate information on the sex of the measured animals. Results of the genetic sexing of the biopsy samples collected from some of the SRWs measured on the FIWG during 2023 should be available in future, but were unfortunately not available in the timeframe of this report.

3.4.3. Conservation and management

The process of proposing a site as a KBA requires the provision of datasets to demonstrate that the site meets the stated thresholds for a number of criteria. Most applicable to baleen whales, are criterion A (Threatened biodiversity), B (geographically restricted biodiversity) or D1 (global persistence of demographic aggregations). As a widely distributed species with Least Concern global status, D1 is the criterion most applicable to the aggregation of SRWs using the FIWG. Therefore, the site must be shown to support an aggregation representing ≥1% of the global population size, over a season, and during one or more key stages of its life cycle (criterion D1a). Both the global population size and the size of the population using the site, must be expressed as the number of mature individuals (i.e. those capable of reproduction). Since baleen whale abundance surveys cannot readily identify the percentage of mature animals, other approaches are needed to generate that value. Similar situations arise for the IUCN Red List assessments, and Taylor et al. (2007) therefore generated a set of percent mature estimations from the demographic data available for 58 cetacean species including the SRW. The estimated percent mature values for the SRW included 58% using present-day data, and 83% once the global population has recovered post-whaling and is stable. The value of percent mature (39.4%) generated during the UAV study in the FIWG was considerably lower than the 58% of Taylor et al. (2007). Applying the 39.4% and 58.0% percent mature estimations to an abundance estimate of 399 SRW recorded in the FIWG during June 2023 (see Chapter 7 of this report) yields final estimates of mature animals using the site of 156 and 231 respectively. Both of these values are sufficient to recognise the FIWG as a KBA under criterion D1a, but this comparison emphasises the direct conservation relevance of understanding the age classes of SRWs in the FIWG. Given that the density of BLs in the FIWG was highest around the 12 m threshold used to distinguish between immature and mature whales, there remains uncertainty about the exact age classes using the site and it is therefore recommended that UAV work continues in the FIWG to establish a higher sample size of both BL and BC data. This is especially the case for BC measurements, which require images of higher-quality and therefore have lower sample size in the FIWG compared to BL.

The UAV data have been incorporated into an application to the IUCN for the FIWG to be recognised as a KBA for hosting a globally-important winter SRW aggregation (Weir, 2024). Despite the global importance of the Falkland Islands for the species, the region has not been recognised as a winter breeding site in the IWC-CMP for south-west Atlantic SRWs. SRWs are wide-ranging species that face anthropogenic threats including vessel strike, entanglement in fishing gear and acoustic disturbance, and regional management initiatives aimed at reducing the impacts of such threats on regional populations should include all parts of the distribution range in order to be effective.

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Chapter 4: Movements and diving behaviour of sei whales on a coastal foraging ground in the Falklands

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4.1 Introduction and aims

Although the sei whale is among the most widely-distributed mammal species on earth, relatively little is understood of its movements and ecology (Prieto et al., 2012). In many parts of its global range, the species commonly occupies oceanic habitats that are logistically difficult and costly to work in. Furthermore, the sei whale is a challenging study subject compared with many other baleen whale species, being seldom observed in many areas, relatively avoidant of boats, unpredictable in behaviour, and bearing comparatively few of the natural markings that facilitate the recognition of individuals of other species (e.g. the tail pigmentation patterns of humpback whales, *Megaptera novaeangliae*). For these reasons, contemporary field studies of sei whales are scarce compared to other baleen whales such as blue (*Balaenoptera musculus*), fin (*B. physalus*), and humpback whales (Prieto et al., 2012).

In recent decades, telemetry has become a widely used component of baleen whale field studies (e.g. Guzman and Félix, 2017; Panigada et al., 2024), providing data on the movements of individual whales over large distances and timeframes of months to years. Telemetry data are usually obtained through the deployment of satellite tags on whales, attached either to the dorsal fin using barbs or in the blubber layer using consolidated tags (Andrews et al., 2019). Such tags may provide a wealth of information on whale migration routes, habitat use, and movements on feeding and breeding grounds, that can be used to identify and manage their critical habitats and overlap with anthropogenic threats (e.g. Aschettino, et al., 2020). The battery lifespan of the currently available tag technology presents a trade-off between the volume of data collected and the duration of tag transmission. Consequently, the tags used on whales are usually programmed either to collect location-only data over long time-frames to investigate ocean-wide movements, or to collect simultaneous location and dive data over a shorter time-frame to investigate habitat use and foraging ecology.

To date, only two satellite telemetry studies, both in the Azores in the North Atlantic, have been published for sei whales due to the low level of global research focus on this species. Consolidated location-only satellite tags were deployed on three sei whales in the Azores in 2005, only one of which yielded data and revealed a long-range movement of over 4,000 km to the Labrador Sea (Olsen et al., 2009). Consolidated location-only tags were deployed on a further 14 sei whales in the Azores during 2008 (n=8) and 2009 (n=6), although only four tags in each year produced data (Prieto et al., 2014).

Those tags again revealed migrations to the Labrador Sea and provided data on the foraging movements of sei whales on their high latitude oceanic feeding grounds.

Similarly, only two published studies have detailed sei whale use of the water column, both relating to dive behaviour in oceanic habitats. Time-depth transmitters were deployed on two whales offshore of Japan in 2013, revealing overall mean dive depths of 14–18 m and a deepest recorded dive of 57 m (Ishii et al., 2017). Six whales tagged on the continental slope off Brazil dove primarily in the top 15 m of the water column and for up to 10 min duration (Baracho Neto et al., 2019). However, the deepest dive recorded was 577 m, which indicates the capacity of sei whales to undertake much deeper foraging dives.

The southern tip of South America is one geographic region where sei whales are regularly encountered in nearshore habitats that make them more accessible to scientists (Weir and Prieto, 2024). The species is frequently sighted in mid-latitude foraging areas that include gulfs and fjords in the southern half of Chile (Acevedo et al., 2017; Häussermann et al., 2017), the Beagle Channel and Strait of Magellan (Reyes Reyes et al., 2016; Acevedo et al., 2017), the southern half of Argentina especially Golfo San Jorge (Belgrano et al., 2007; Iñíguez et al., 2010), and the waters around the Falkland Islands (Weir, 2021, 2022; Weir et al., 2020). In the latter area, targeted research of sei whales has been carried out annually since 2017 using approaches including photo-identification, faecal sampling, genetic sampling, short duration suction-cup tagging, acoustic monitoring, and abundance surveys (Weir, 2017, 2022; this report), providing new insights on the ecology of the species in a coastal neritic feeding area. However, almost all activities have taken place in spatially restricted study areas located <5 km from the shoreline, and less is understood about their wider movements and potential exposure to human activities around the Islands or further from the coast. Additionally, it became apparent during those studies that sei whales spend large amounts of time engaged in subsurface foraging behaviour as indicated by frequent defecations at the surface (Weir, 2018, 2022), their erratic movements between surfacings (Weir et al., 2018; see Chapter 2), and subsurface lunges revealed by suction-cup tagging (Segre et al., 2021). For these reasons, DPLUS126 included a satellite tagging component, with the aim of deploying 10 tags on sei whales to understand more about their movements, habitat use and foraging behaviour on the Falklands feeding ground. The objectives of the study were to investigate:

1. How individual sei whales move around the Islands and their fidelity to particular higher-use areas within the Islands;
2. Whether nearshore waters were used more intensively than more pelagic habitats in the Falklands, or whether animals regularly moved between inshore and offshore areas; and
3. How sei whales use the water column while foraging the Falklands, and implications for vessel collision risk.

While it was not expected that the tags used in the study would have transmission durations exceeding approximately three months, a further objective was to learn more about linkage with other geographic areas in the south-west Atlantic if tags were still transmitting when animals moved away from the Islands.

4.2 Materials and methods

4.2.1. Study area

The sei whale tag deployment area comprised Berkeley Sound, a large inlet situated north of Stanley on the north-east coast of East Falkland (Figure 4.1). Water depths in Berkeley Sound are shallow, ranging from approximately 60 m at the mouth and decreasing westwards to ~15 m in the innermost regions used by sei whales comprising Uranie Bay, east of Long Island, and the mouth of Johnson's Harbour.

The waters of the Falkland Islands are described as two zones: the Falkland Islands Interim Conservation and Management Zone (FICZ) comprising an area of 300 km radius centred on Falkland Sound, and the Falkland Islands Outer Conservation Zone (FOCZ) comprising the waters between the FICZ and the 200 nautical mile economic zone boundary (see Figure 1.1).

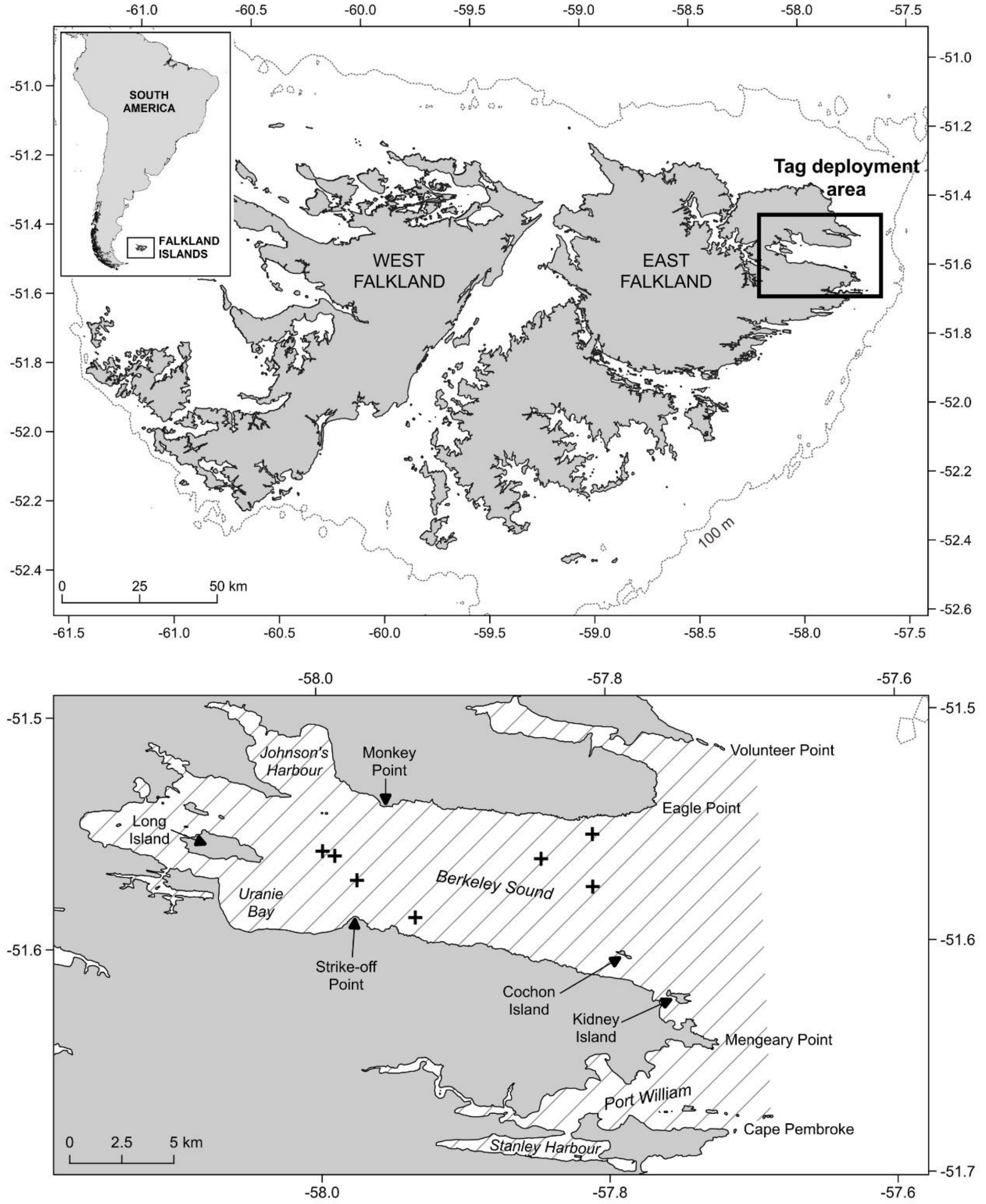


Figure 4.1. The study area, showing the tag deployment locations (crosses) on seven sei whales. The hatched area depicts the area between Volunteer point and the Seal Rocks off Cape Pembroke which was defined as Berkeley Sound in this study.

4.2.2. Tags and tag programming

The 10 tags acquired for sei whale tracking were SPLASH10-F-333B tags produced by Wildlife Computers (WC), which provide Argos locations, Fastloc-GPS (Global Positioning System) locations, and dive depth information. The tags were deployed in the Low Impact Minimally Percutaneous Electronic Transmitter (LIMPET) configuration, using 6-petal darts. Prior to deployment, all darts were sterilised via ethylene oxide in a commercial gas sterilisation unit, after which they were kept in individual sterilisation pouches until use. Since ethylene oxide sterilisation was not possible onsite, if a pouch was opened but the tag was not subsequently deployed on a whale then the darts were re-sterilised in 10% bleach (sodium hypochlorite), followed by a dip rinse in ethyl alcohol and air dry, after which they were wrapped in tinfoil and stored in individual plastic zip-lock bags.

The tags were programmed to transmit Argos data daily throughout the deployments from 08:00 to 16:00 and 18:00 to 06:00 UTC (i.e., periods when adequate satellite coverage was available). The maximum number of Argos transmissions was set to 400 per day. The tags transmitted Fastloc positions throughout the day on a sampling interval of 30 min. The limit for Fastloc attempts was set to 6 per hour and 200 per day.

Dive depth was sampled at 1 second intervals. Dive data were collected in two formats: (1) behavioural dive profile dataset, comprising detailed records of each qualifying dive (QD) and associated surface event (SEV); and (2) binned datasets that summarised dive data in 14 predetermined bins.

The behavioural dive profile dataset contained the start and end time (determined by the wet/dry sensor), maximum depth (m), duration (s), and dive shape of each QD and the duration of each SEV. A dive was defined as a QD if the tag submerged to ≥5 m depth and for >1 min duration. The depth reading to determine the start and end of a dive was set at 2 m.

A 'surface event' (SEV) was defined as each period in between QDs and was automatically allocated to two categories by the WC software:

- Shallow = duration of time (s) spent at depths <2 m (including at the surface); and
- Deep = duration of time (s) spent below 2 m depth but without meeting the thresholds for a QD. Consequently, this category could include both: (1) dives of 2 to 5 m depth; and (2) dives >5 m depth but of shorter duration than the 1 min QD threshold.

The maximum QD depth, total QD duration and total SEV duration were each recorded as two values by the tag; the average values for each of those parameters were used for analysis.

QD shape was classified according to three categories defined by WC and assuming that the bottom of the dive is any depth reading ≥80% of the maximum reading observed for the dive:

- Square-shaped dives, where bottom time was >50% of the dive duration;
- U-shaped dives, where 20–50% of the dive duration was spent at the bottom; and
- V-shaped dives, where bottom time was <20% of the dive duration.

A diel status category was allocated to the start time of each QD and SEV within the behaviour dataset using times extracted from https://www.timeanddate.com/sun/falkland/stanley The time between sunset and the start of nautical twilight was categorised as dusk, and the time between the end of nautical twilight and sunrise as dawn.

The binned dataset contained histogram summaries of dive data in 12-hr intervals, including (Table 4.1):

- Dive maximum depth (DMD): count of QDs in each depth bin (m);
- Dive duration (DD): count of QDs in each duration bin (min); and
- Time at depth (TAD): percentage time spent in each specified depth bin (using all available dive data).

Table 4.1. Values selected for 14 histogram bins to record sei whale dive behaviour.

Parameter	Bin													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Dive maximum depth	2	5	10	15	20	25	30	40	50	75	100	125	150	>150
Dive duration	1	2	3	4	5	6	7	8	9	10	11	12	13	>13
Time at depth	2	5	10	15	20	25	30	40	50	75	100	125	150	>150

The bins were selected to provide highest resolution in the 0–50 depth range, reflecting the nearshore habitats that we expected sei whales to use for foraging and taking into account the surface skim-feeding behaviour documented for the species which could potentially result in long periods spent at shallow depths. The 12-hour intervals selected for the histograms broadly corresponded with local periods of daylight and darkness in the Falklands over the austral summer and autumn period of the tag deployments (Table 4.2).

Table 4.2. Start times selected for 12 hr histogram bins and associated diel status in the Falklands.

Time histogram bin commenced		Diel status in Falklands
Coordinated Universal Time (UTC)	Local time (UTC-3)	
10:00	07:00	Day
22:00	19:00	Night

Finally, because the behavioural dive profile and binned datasets did not always overlap exactly in time (due to transmission gaps and prioritisation settings) and were not always continuous, the Wildlife Computers portal automatically assigned a single maximum depth value (MDV) to each 12-hr period which was the result of examining all sources of data received from the tag.

4.2.3. Tag deployments

Three periods of sei whale tagging effort were carried out: (1) 14 March to 19 April 2022; (2) 23 February to 18 April 2023; and (3) 19 February to 26 May 2024. The tagging was carried out with a research licence issued by Falkland Islands Government (R14/2020) and followed best practice guidance for tagging cetaceans (Andrews et al., 2019). In 2022 and 2023, an experienced whale tagger (RP) travelled to the Falklands to deploy the tags. During the 2023 season, training in tag deployments was also provided to CW, who subsequently carried out tagging attempts in 2024. The tagging platform was a 7.5 rigid-hulled inflatable boat operated by Falklands Conservation.

Two different systems were used to deploy the tags: (1) a Dan Inject CO_2 rifle; and (2) a Barnett recruit recurve crossbow with a 150 lb draw weight. Unfortunately, it was discovered early in the first tagging season that the Dan Inject rifle that had been shipped to the Falklands had only a 16 bar pressure rather than the 25 bar pressure that had been ordered. The Dan Inject rifle was fitted with the appropriate 25 bar manometer ahead of the 2023 season. A float system comprising a small piece of styrofoam attached to the tag by thin monofilament line was used to recover tags that missed a whale during a deployment attempt and fell into the sea. If the tag successfully attached to a whale, a galvanic timed releaser resulted in the float attachment subsequently corroding and releasing from the tag.

Tagging was attempted only on adult sei whales that were not accompanied by calves and that appeared to be healthy. During tagging attempts, the boat was carefully manoeuvred alongside sei whales to a distance of ≤5 m, and the tag was aimed into the dorsal fin of a surfacing animal. A photo-identification image of the tagged whale was simultaneously collected using a Canon 5DIII camera with a 100–400 mm lens. Following each successful tagging event, the team attempted to re-approach to collect follow-up images of the tag in situ, and to acquire a biopsy sample for genetic analysis and animal sexing. The tagged whales were allocated names to make the tracking maps more relatable for the general public; some of those names were selected by school children and some were assigned by project staff.

4.2.4. Data analysis

4.2.4.1. Location data

Some initial manual cleaning of the Argos data was carried out to remove positions with a quality rated as Z (invalid location; n=5) and those with a latitude or longitude of > 4 deviations from the mean (n=20). The remaining tag locations (n=5,419) were mapped using Quantum Geographic Information System (QGIS, v. 3.28). Water depth was extracted for each ARGOS location using QGIS and a gridded bathymetric file obtained from General Bathymetric Chart of the Oceans 2023 (GEBCO Compilation Group, 2023). Water depths were assigned a standard default value of 5 m if they were situated in sufficient proximity to the coast that the resulting GEBCO values were on land rather than in water, or for shallow depths <5 m. Similarly, distance values <500 m from the coast were assigned a default value of 500 m. Statistical comparisons of habitat parameters were carried out using JASP (JASP Team, 2023).

4.2.4.2. Dive data

Dive data recorded within 24 hr of the tag deployment were removed from analysis to limit the potential impacts on dive behaviour from the tagging events. We followed the methods of Shearer et al. (2019) in checking tag records systematically for errors that indicated failure or drift in the tag sensors. One erroneous depth sensor reading was identified from the tag of Keppel on 30 April. Although behaviour messages from the tags undergo their own checking mechanism while being processed in the WC portal and the data contained within them should be correct, as a precautionary approach all dive data from the period 3 hr either side of the erroneous reading were deleted from the analyses. Additionally, the data were checked for depth/duration combinations that resulted in unrealistically high swim speeds.

No histogram data were available from Ninja's tag. The tag of Volde transmitted only two DMD histograms and three DD histograms. Due to the small sample size, data from those tags were not included in the analyses. Since the focus of the analysis was on dive behaviour within the FICZ, histogram data from Keppel's tag were only included for dates between 24 April and 5 May 2024 before the whale passed into the FOCZ and on to international waters.

4.3 Results

Seven tags were deployed on sei whales during 2022 (n=5), 2023 (n=1), and 2024 (n=1). The deployment locations are shown in Figure 4.1 and deployment information is summarised in Table 4.3. Of the seven tags, two were deployed via crossbow, three were deployed using the Dan Inject at reduced power (16 bar), and two were deployed using the Dan Inject at optimal power (25 bar). A further five tags missed the target and fell into the water (Table 4.3); three were subsequently recovered using the flotation system, and two (PTT226742 and 226743) were lost.

Only three of the tags (Ninja, Star and Keppel) were deployed optimally on the dorsal fin (Figure 4.2). One additional tag placement (Volde) was considered good but was slightly lower on the dorsal fin than might be optimal for transmitting with the satellites. The tag on Neptune was attached to the flank below the dorsal fin (Figure 4.2), and was considered suboptimal in terms of both the likelihood of the tag emerging consistently above water to communicate with satellites, and the likely longevity of the attachment (since the darts were situated in blubber rather than in the connective tissue of the dorsal fin). Finally, the tags deployed on Moe and Eclipse were both attached to the leading edge of the dorsal fin and consequently with only a single dart embedded in the connective tissue while the other dart had not penetrated (Figure 4.2). Because of the high water drag experienced at the front of the dorsal fin and the single dart attachment, those tags were not expected to remain on the animals for a long duration. However, their position high on the fin did optimise communications with the satellites, and those tags consequently provided a much higher number of Fastloc positions (Table 4.3). The transmission duration of the seven tags ranged from 10 to 56 days (Table 4.3), with a mean of 27.4 (SD=15.2) days and a median of 25 days. Biopsy samples were obtained from four of the tagged animals; those have not yet been analysed.

Table 4.3. Summary of sei whale tag deployments in the Falkland Islands, 2022 to 2024.

Whale name	PTT	Date/time of tagging		Deployment method	Date of final location	Tag duration	Number of locations	
		Date	Time (UTC)	(DI=Dan Inject)		(days)	Argos	Fastloc
Successful deployments								
Neptune	226746	28 Mar 2022	12:27:41	Crossbow	4 May 2022	37	808	6
Ninja	226740	28 Mar 2022	13:14:49	Crossbow	7 Apr 2022	10	9	5
Star	226739	08 Apr 2022	14:39:42	DI 16 bar	3 Jun 2022	56	1,309	245
Volde	226745	08 Apr 2022	18:01:10	DI 16 bar	24 Apr 2022	16	41	8
Moe	226747	12 Apr 2022	14:13:54	DI 16 bar	7 May 2022	25	775	423
Eclipse	226741	9 Mar 2023	15:57:48	DI 25 bar	5 Apr 2023	27	726	406
Keppel	226744	24 Apr 2024	14:17:34	DI 25 bar	15 May 2024	21	504	147
Unsuccessful tagging attempts								
–	226746	18 Mar 2022	17:08:11	DI 16 bar	–	–	–	–
–	226746	23 Mar 2022	14:18:22	DI 16 bar	–	–	–	–
–	226739	8 Apr 2022	13:52:23	DI 16 bar	–	–	–	–
–	226742	2 Apr 2023	16:22:33	DI 25 bar	–	–	–	–
–	226743	24 Apr 2024	13:44:30	DI 25 bar	–	–	–	–

4.3.1. Distribution and movements

Of the seven sei whales that were tagged, two animals (Volde PTT226745 and Eclipse PTT226741) remained within the vicinity of Berkeley Sound for the entirety of their tag transmission durations (16 and 27 days respectively: Figures 4.3 and 4.4). Those animals moved continuously and erratically around within the Sound, consistent with likely foraging behaviour. The movements of the remaining five animals included areas outside of Berkeley Sound and are briefly described below.

Neptune (PTT226746): Following tagging on 28 March 2022, Neptune remained in Berkeley Sound for 11 days before commencing a movement out of the Sound and south along the coast on 8 April. It spent one day in a relatively small spatial area off Kelp Point (Fitzroy), before continuing south past Lively Island to the area between Low Bay and Bleaker Island where it spent approximately 10 days (Figure 4.5). On 20 April, Neptune departed that area and commenced a directed movement westwards along the south coast of East Falkland and across to the south coast of West Falkland where it arrived south of Cape Meredith on 22 April. It then slowly working north-westwards past the west coasts of Beaver and Weddell Islands before reaching the waters west of New Island on 1 May (Figure 4.5). Neptune had moved around to the north-east of Weddell Island and was in Queen Charlotte Bay when the tag stopped transmitting on 4 May 2022.

(A) Neptune (B) Ninja

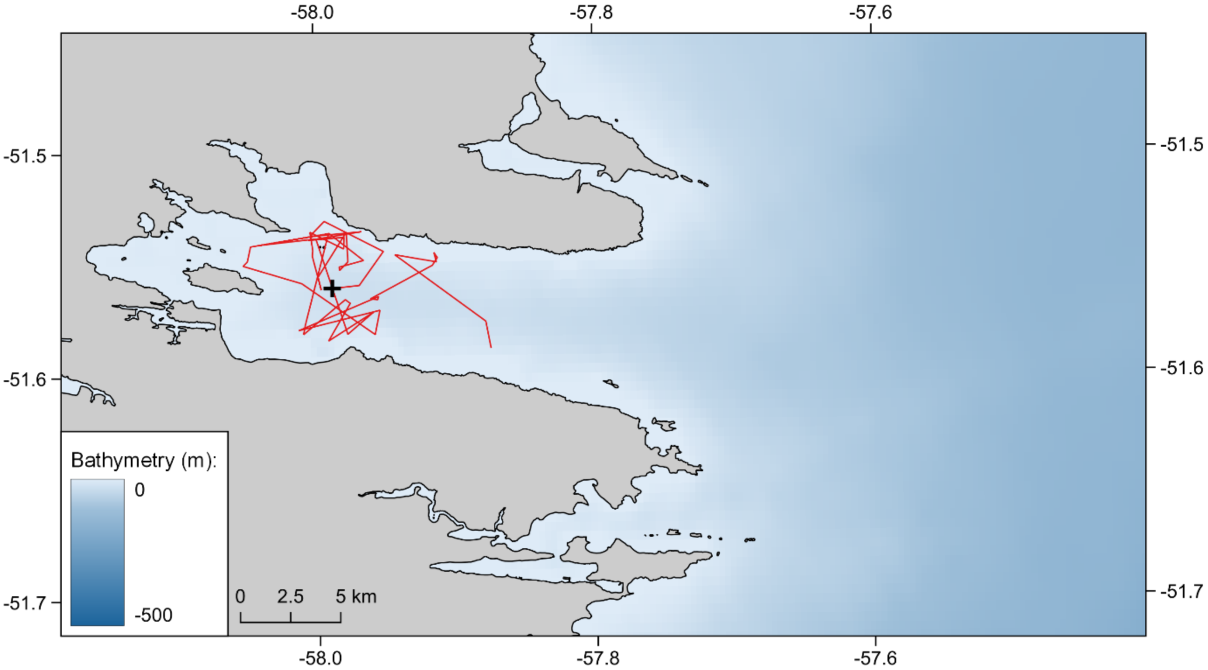
(C) Star (D) Volde

(E) Moe (F) Eclipse

(G) Keppel

Figure 4.2. Photographs of LIMPET tag deployments on seven sei whales in the Falkland Islands, 2022–2024. The white styrofoam floats are visible in many photos.

(A)



(B)

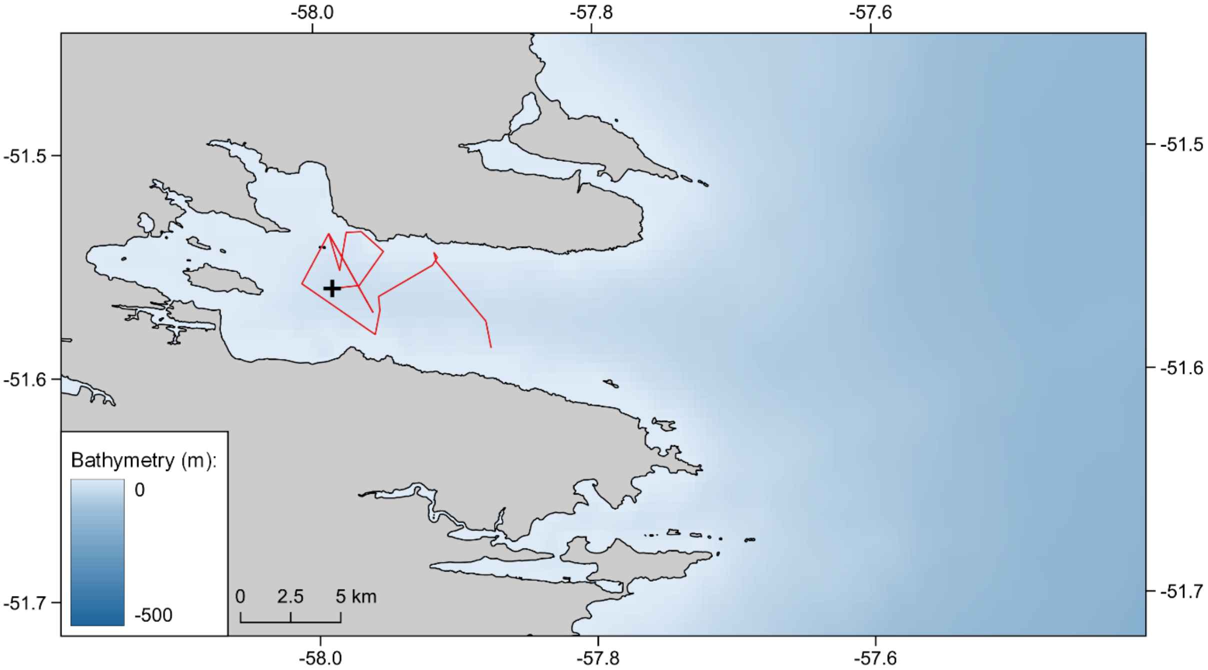
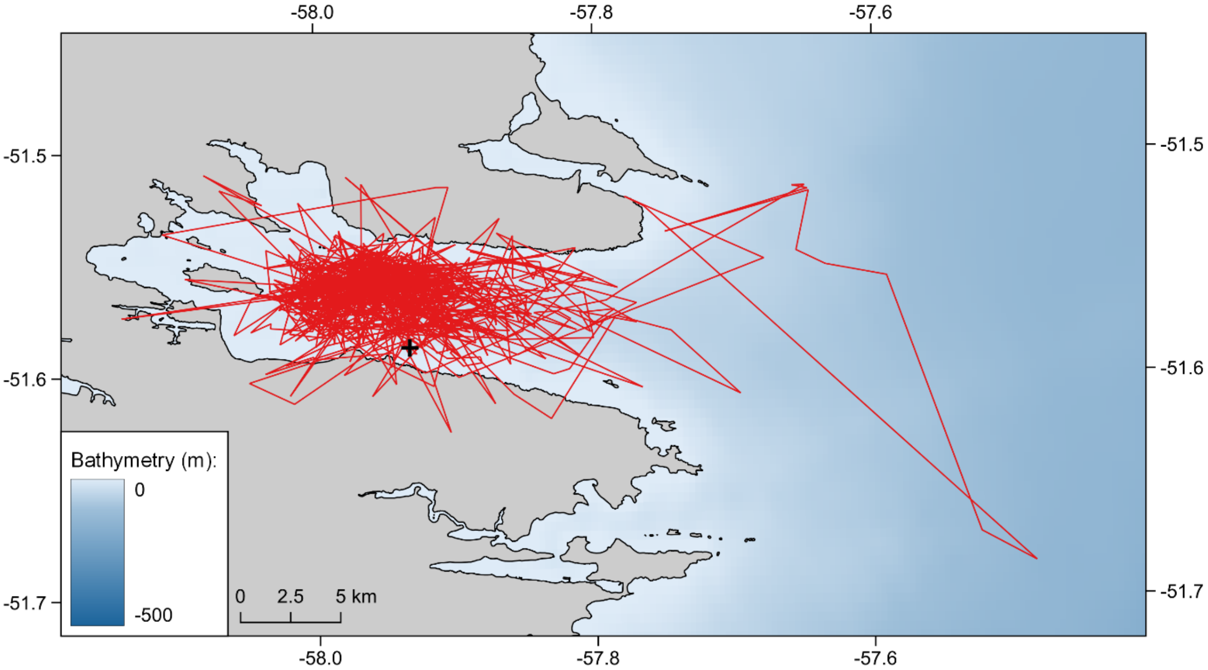


Figure 4.3. Deployment location (cross) and subsequent movements (red lines between satellite locations) of: Volde (16 days): (A) all data; and (B) higher-quality positions (Argos quality 1 to 3, and Fastloc GPS) only.

(A)



(B)

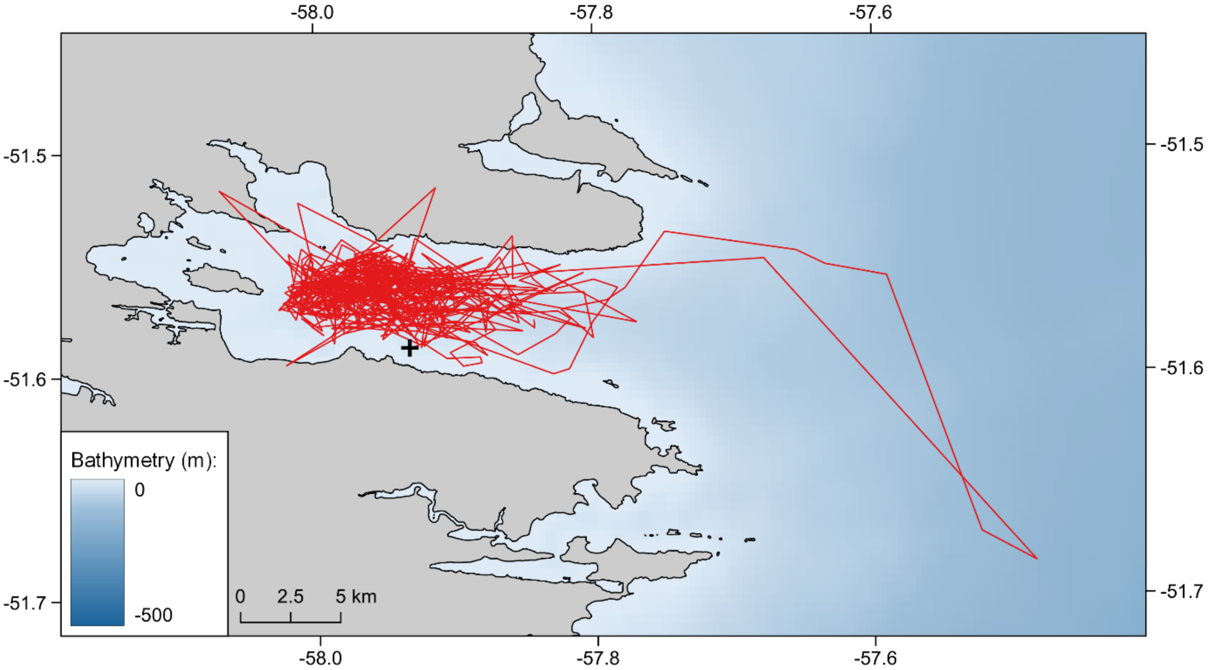


Figure 4.4. Deployment location (cross) and subsequent movements (red lines between satellite locations) of Eclipse (27 days): (A) all data; and (B) higher-quality positions (Argos quality 1 to 3, and Fastloc GPS) only.

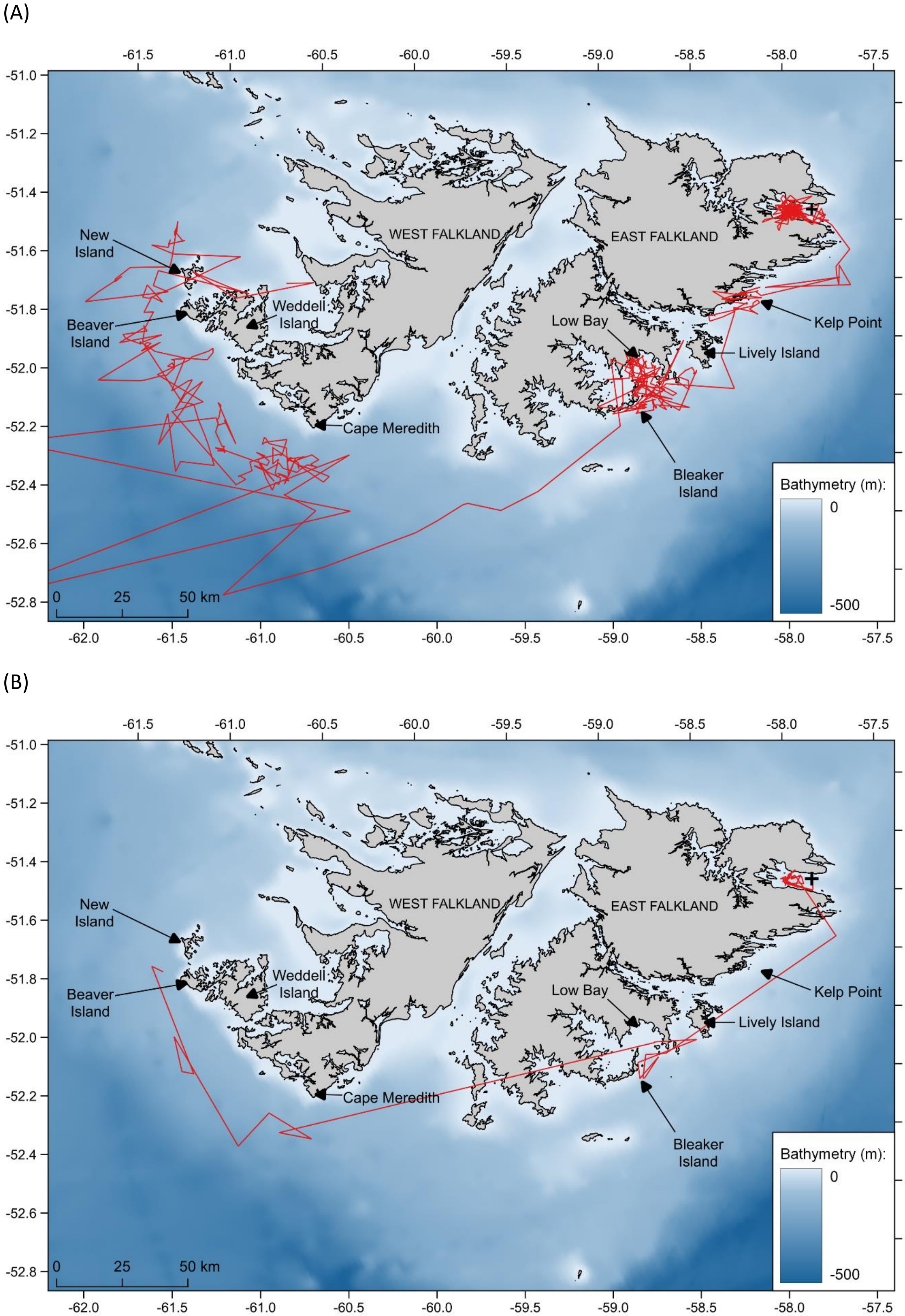


Figure 4.5. Deployment location (cross) and subsequent movements (red lines between satellite locations) of Neptune (37 days): (A) all data; and (B) higher-quality positions (Argos quality 1 to 3, and Fastloc GPS) only.

Ninja (PTT226740): Ninja was tagged on 28 March 2022. Following tagging, a small number of positions were transmitted from Berkeley Sound on 28 and 29 March (Figure 4.6). However, no further transmissions occurred until a week later when a handful of positions received on 6 and 7 April and indicated that the animal had moved a significant distance east and was now located in deep waters (>2,500 m) approximately 850 km east of the Falklands and 300 km north-west of the Shag Rocks at South Georgia (Figure 4.6). No further transmissions were received from the tag.

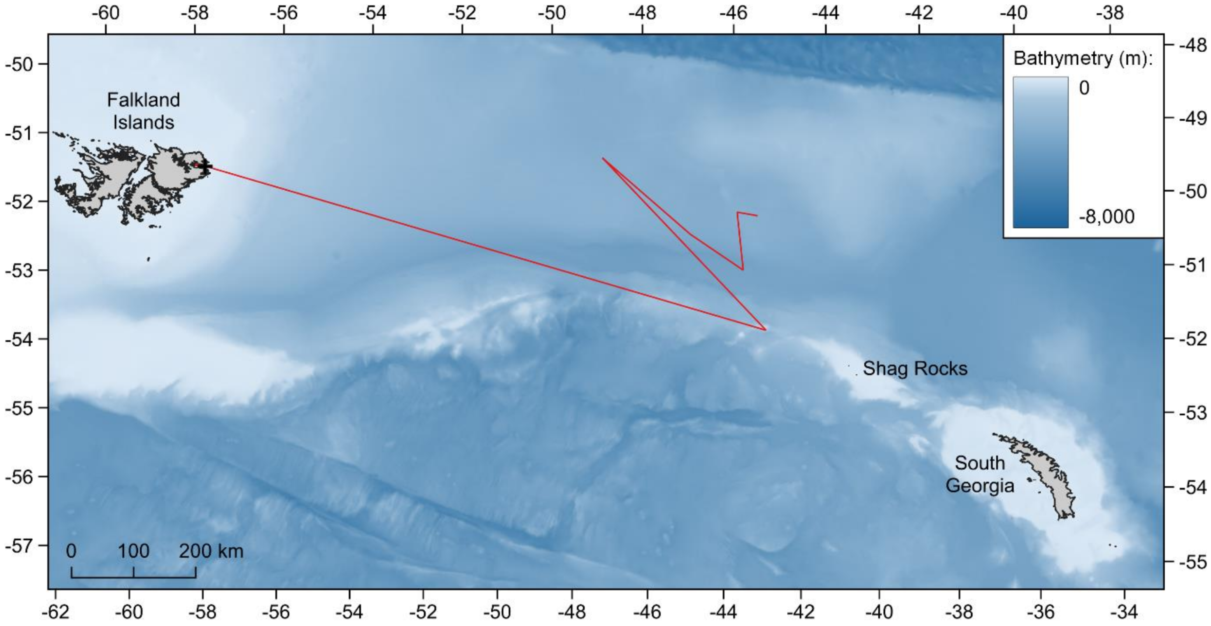


Figure 4.6. Deployment location (cross) and subsequent movements (red lines between satellite locations) of Ninja (10 days).

Star (PTT226739): After being tagged on 8 April 2022, Star used Berkeley Sound continuously for a further six weeks before commencing a distinct southwards movement along the east coast of the Falklands on 20 May (Figure 4.7). It briefly paused that movement on several occasions to spend single days moving around in smaller areas located north-east of Lively Island, in Low Bay, and in the Bay of Harbours. After moving westwards past the Speedwell Island group on 26 May, it arrived off the southern end of Falkland Sound and turned northwards towards the coast between the Arch Islands and Port Edgar (Figure 4.7). Star then began to move east again, passing south of Fox Bay and moving through Eagle Passage at the Speedwell Island group on 27 May, before turning north back along the east coast of the Falklands. On 28 May it revisited Low Bay, where it remained until the tag ceased transmitting on 3 June.

Moe (PTT226747): Moe remained in Berkeley Sound and Port William for 24 days after being tagged on 12 April 2022. It moved out to sea and commenced a southwards movement down the east coast of the Falklands on 6 May. The tag stopped transmitting on 7 May, by which time the whale was east of the Sea Lion Island group (Figure 4.8).

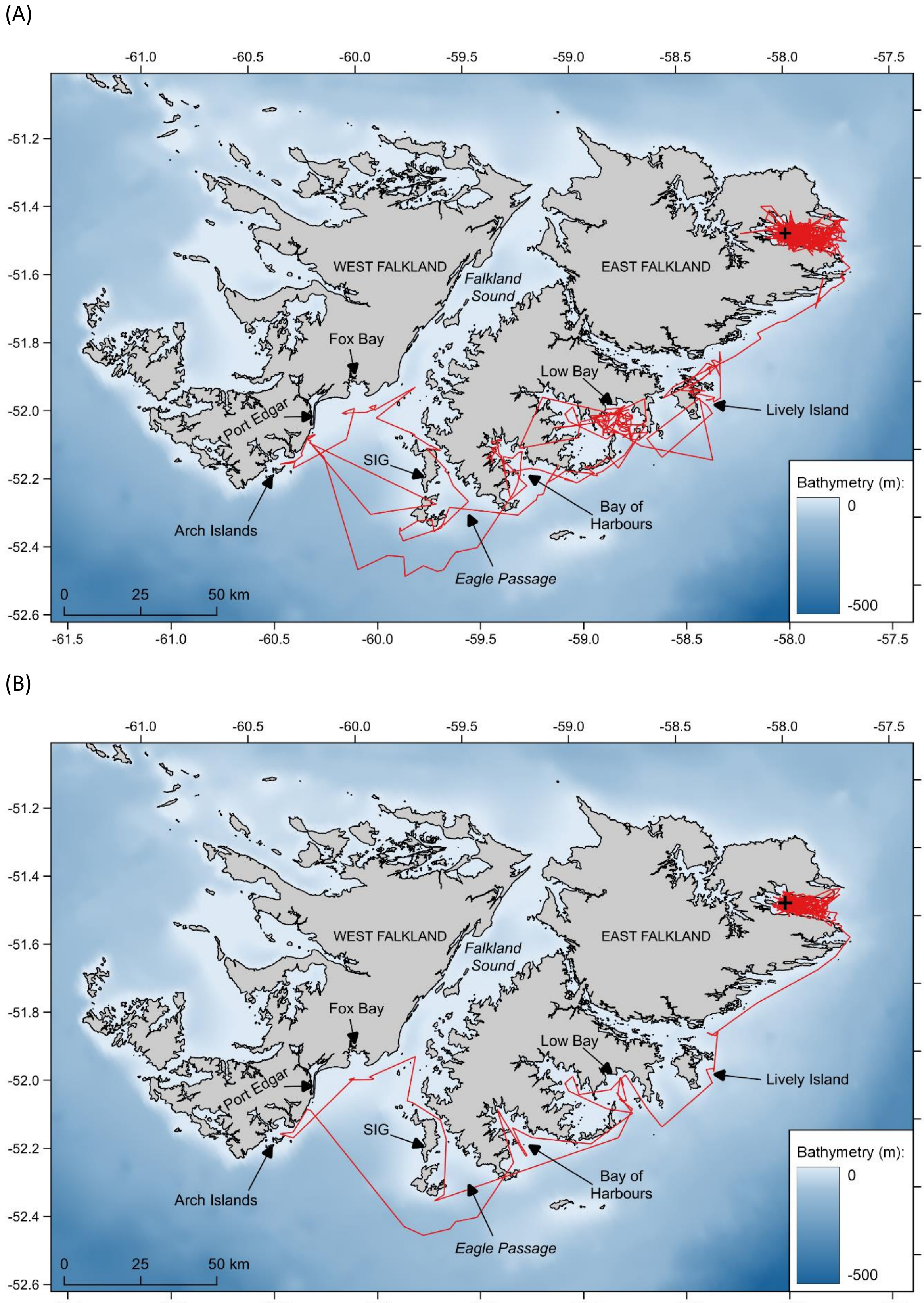


Figure 4.7. Deployment location (cross) and subsequent movements (red lines between satellite locations) of Star (56 days): (A) all data; and (B) higher-quality positions (Argos quality 1 to 3, and Fastloc GPS) only. SIG refers to the Speedwell Island Group.

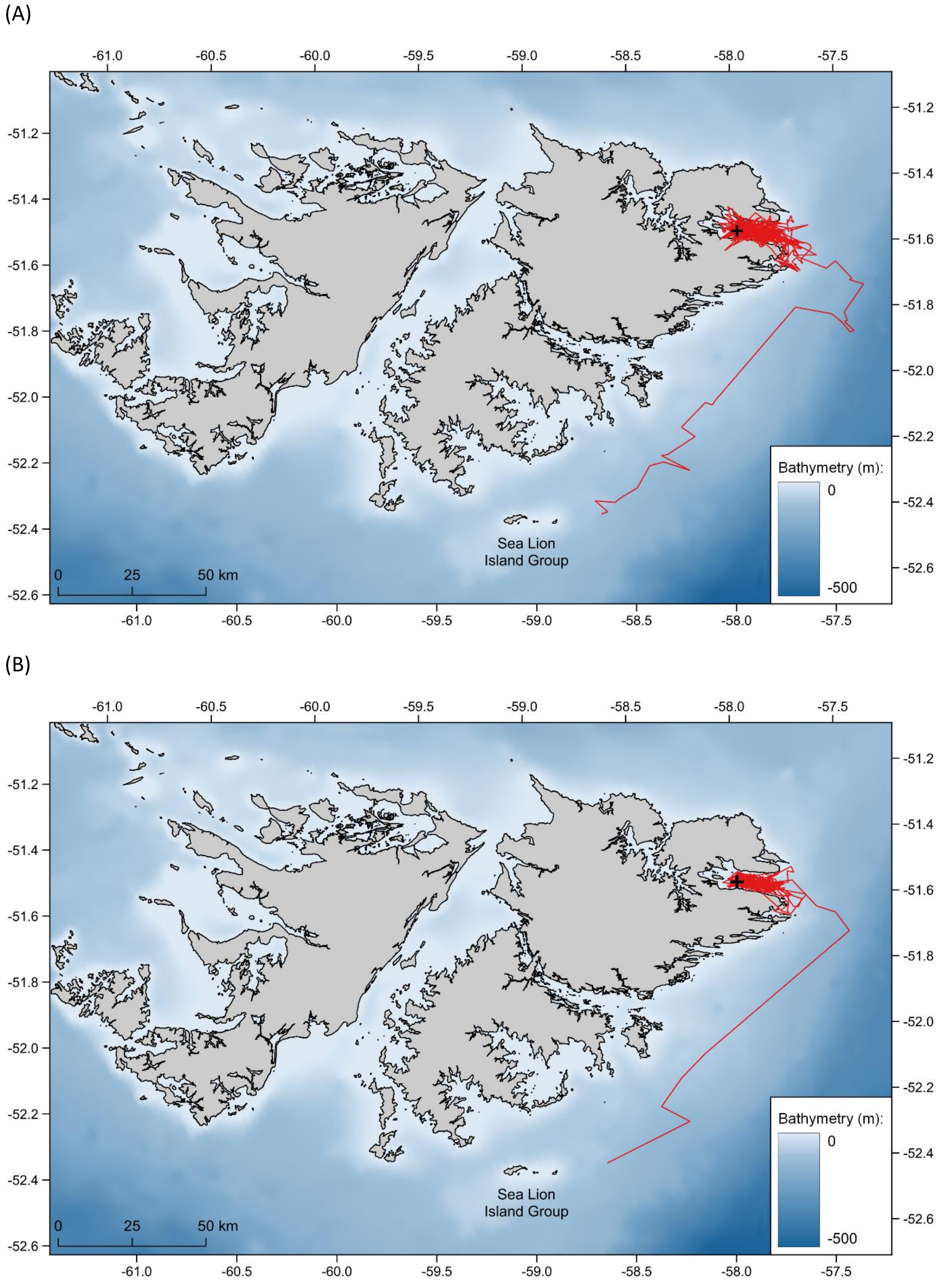


Figure 4.8. Deployment location (cross) and subsequent movements (red lines between satellite locations) of Moe (25 days): (A) all data; and (B) higher-quality positions (Argos quality 1 to 3, and Fastloc GPS) only.

Keppel (PTT226744): Following tagging on 24 April 2024, Keppel remained in Berkeley Sound for three days before commencing a movement north along the Falklands coast. Between 27 April and 3 May it spent time along the north coast of East Falkland between MacBride Head and Cape Dolphin (Figure 4.9). Keppel arrived back off the mouth of Berkeley Sound on 4 May 2024. On 5 May 2024, the animal began a concerted north-easterly movement away from the Falklands, passing into the FOCZ on 6 May and out of the FOCZ into international waters on 7 May from where it continued into the deep waters (>6,000 m depth) of the Argentine Basin (Figure 4.10). Keppel consistently moved north-eastwards apart from a brief pause on the 9/10 May where it moved erratically within a small (~20 km) area for 24 hr and may have been engaged in behaviour such as foraging or socialising. The tag ceased transmitting on 15 May, at which point it was located ~1,375 km north-east of the Falklands.

4.3.2. Habitat

4.3.2.1. Overall

The five sei whale individuals for which more than 50 locations were available generated a combined total of 5,349 Argos and Fastloc positions. Using only the most accurate Argos locations (Quality 1–3: accuracy of <1.5 km) and Fastloc GPS, the number of positions available from the four animals combined was reduced by 60% to 2,115 (Table 4.4). In particular, the number of available locations for Neptune was reduced by 93%, likely due to the low position of the tag on the body of that whale (see Figure 4.2A) which provided less time for obtaining fixes from multiple satellites during surfacings. Both datasets indicated that four of the sei whales almost exclusively used shelf waters around the Falklands following tagging, with tag locations having shallow mean water depth (<50 m) and occurring in close proximity to the coast (<5.0 km: Table 4.4, Figure 4.8) indicating preferential use of the innermost shelf. However, Keppel also used oceanic habitats far from shore, consistent with its movement away from the Falkland Islands (Figure 4.10). Keppel was tagged later in the season than the other whales (Table 4.3) which likely explains this difference in habitat use and movements.

Table 4.4. Water depth and distance from shore for two categories of location accuracy for five satellite-tracked sei whales. High-quality positions were defined as the combined total of Argos accuracy 1–3, Fastloc GPS and recorded deployment positions.

Individual	n	Water depth (m)		Distance from shore (km)	
		Mean (SD)	Range	Mean (SD)	Range
All Argos, Fastloc and deployment positions:					
Eclipse	1,133	19.3 (10.2)	5–134	1.8 (0.9)	0.1–14.1
Moe	1,199	23.0 (23.0)	5–246	2.3 (3.0)	0.1–28.9
Neptune	815	59.7 (72.7)	5–379	7.4 (14.1)	0.1–203.2
Star	1,555	15.7 (14.3)	5–143	1.7 (1.7)	0.1–24.9
Keppel	652	1,585.5 (2,518.9)	5–6,184	206.7 (325.6)	0.1–1,376.7
High-quality positions:					
Eclipse	650	20.7 (10.0)	5–134	2.0 (1.0)	0.1–14.1
Moe	596	21.7 (14.9)	5–157	2.1 (2.0)	0.1–25.9
Neptune	53	42.6 (56.7)	5–241	4.4 (6.5)	0.1–28.6
Star	636	16.2 (13.2)	5–123	1.7 (1.4)	0.1–14.4
Keppel	185	960.3 (2,086.3)	5–6,177	112.5 (237.1)	0.1–1,258.7

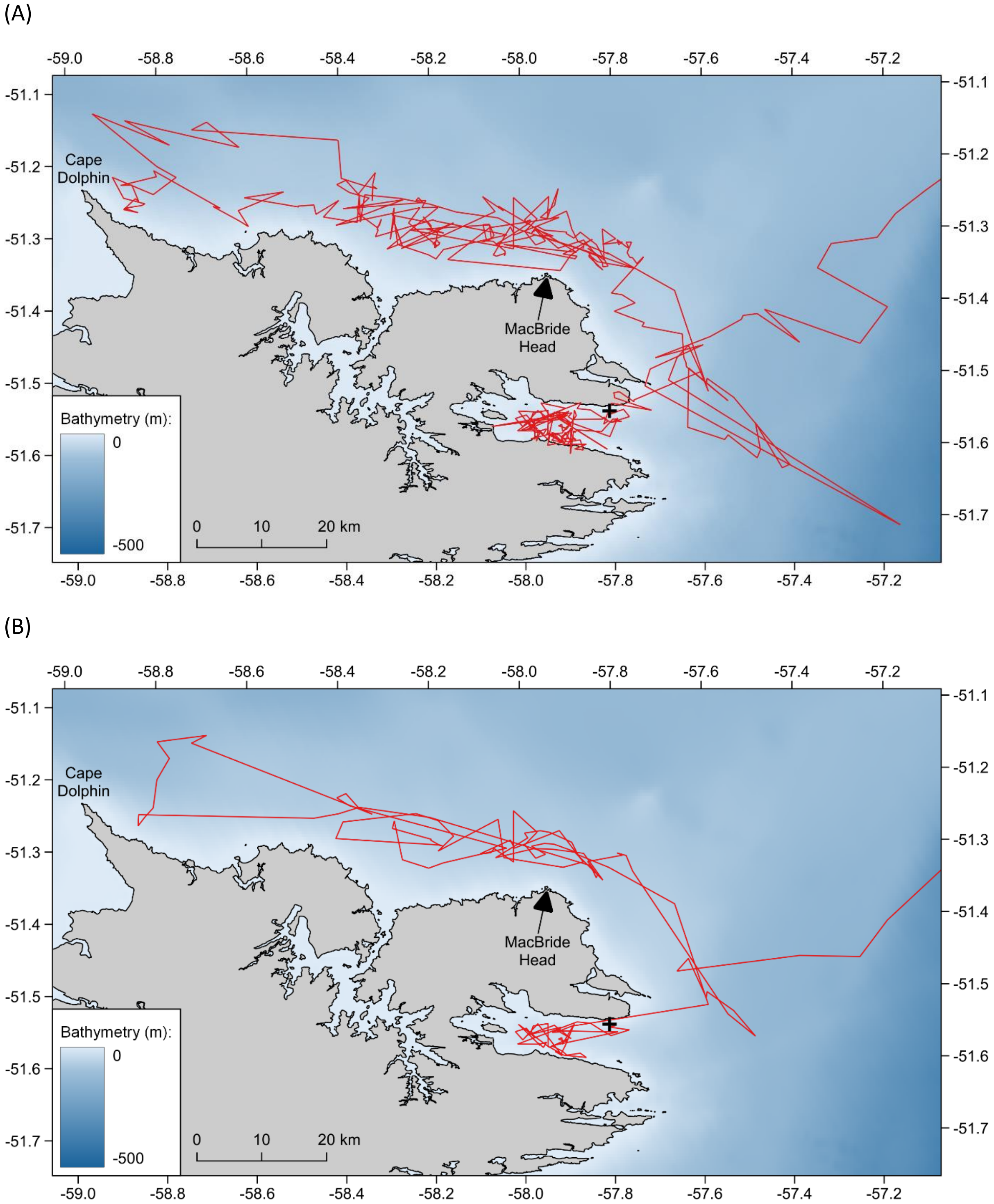


Figure 4.9. Deployment location (cross) and subsequent movements (red lines between satellite locations) of Keppel (21 days): (A) in the coastal waters of the Falklands; and (B) longer-range movement in the south-west Atlantic. (A) all data; and (B) higher-quality positions (Argos quality 1 to 3, and Fastloc GPS) only.

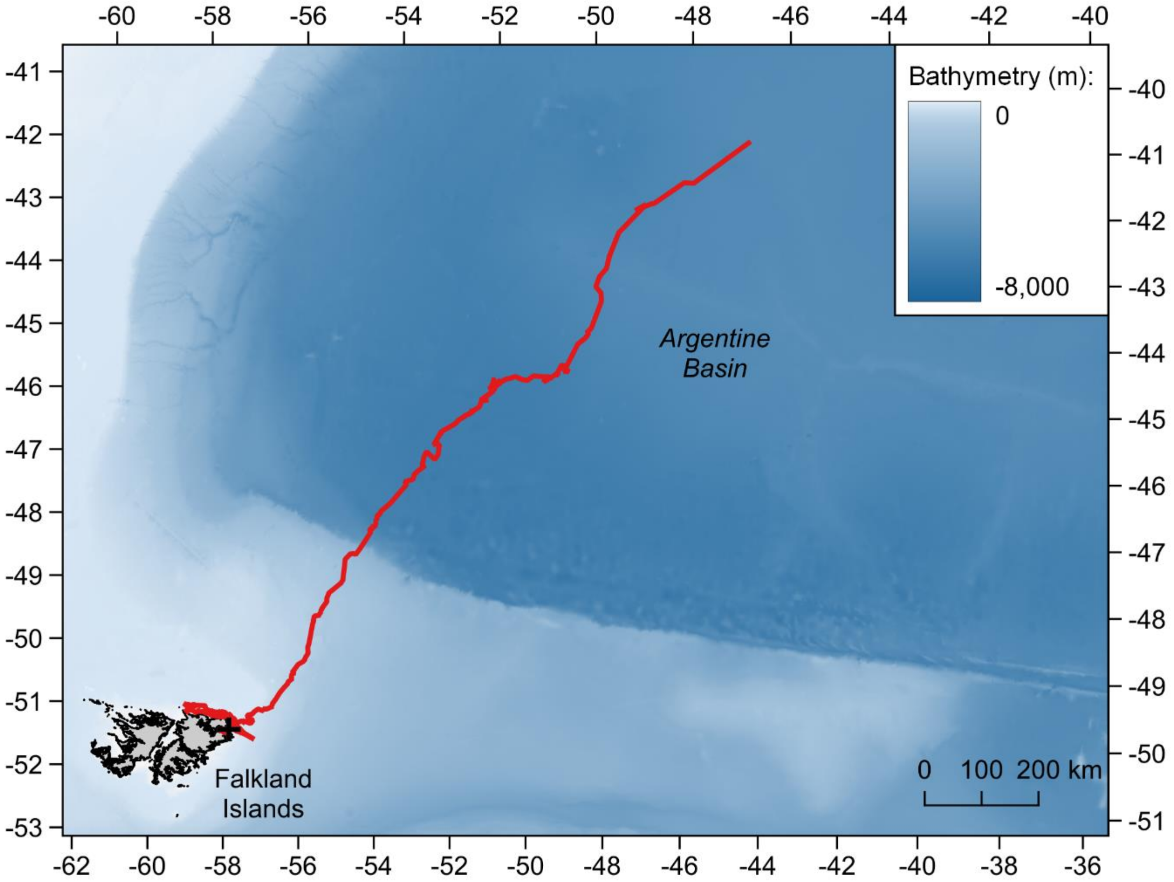


Figure 4.10. Deployment location (cross) and subsequent movements (red lines between satellite locations) of Keppel (21 days) showing longer-range movement into the Argentine Basin.

4.3.2.2. Berkeley Sound

Using the higher-quality dataset for Berkeley Sound only, a significant difference was apparent between individuals for both water depth (Kruskall-Wallis test, H=106.0, df=4, p<0.001) and distance from shore (Kruskall-Wallis test, H=110.5, df=4, p<0.001). Post hoc Dunn tests revealed highly significant (p<0.001) differences between the water depths at locations used by Eclipse–Neptune, Eclipse–Star and Moe–Star, and moderately significant (p<0.01) differences between Eclipse–Keppel, Moe–Keppel and Moe–Neptune. Eclipse and Moe used slightly deeper habitats within Berkeley Sound than the other whales (Figure 4.11). Post hoc Dunn tests revealed highly significant (p<0.001) differences between the distance from shore at locations used by Eclipse–Star and Moe–Star, with Star occurring closer to shore than the other whales (Figure 4.11). Moderately significant (p<0.01) differences were apparent for Eclipse–Keppel, Eclipse–Neptune, Moe–Keppel and Moe–Neptune, with Eclipse and Moe occurring further from shore within Berkeley Sound than the other whales Figure 4.11).

Within Berkeley Sound there was a significant difference between months for both the water depth (Kruskall-Wallis test, H=23.9, df=2, p<0.001) and distance from shore (Kruskall-Wallis test, H=38.9, df=2, p<0.001) of tag locations. Post hoc Dunn tests revealed highly significant (p<0.001) differences between the water depths and distances from shore of locations used by sei whales in March versus May, and moderately significant (p<0.01) differences between March–April and April–May. Sei whales foraged in progressively shallower water depths found closer to shore within Berkeley Sound as the season progressed from March to May (Figure 4.12).

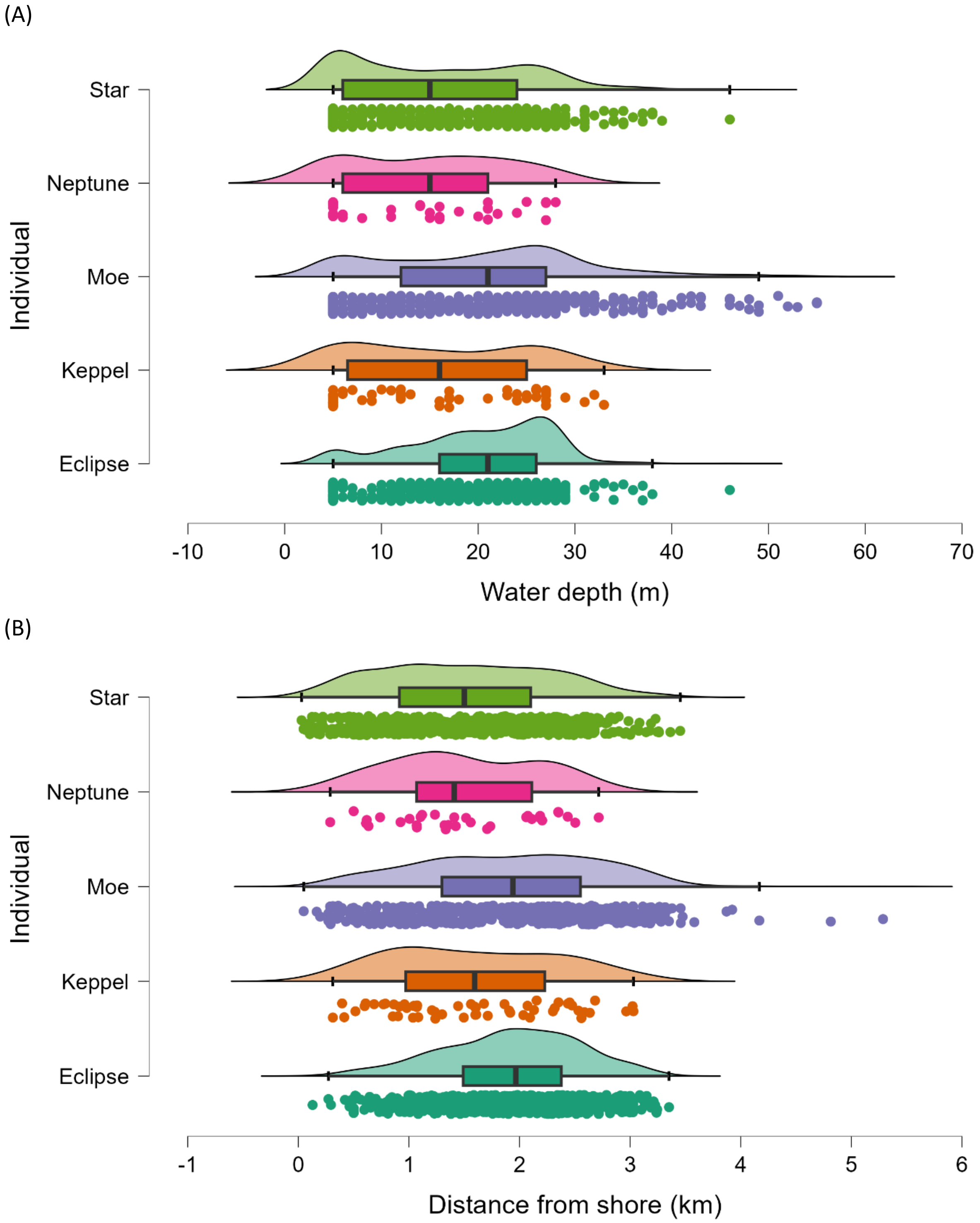


Figure 4.11. Raincloud plots showing the 1,883 higher-quality locations for five satellite-tracked sei whales in Berkeley Sound by: (A) water depth; and (B) distance from shore.

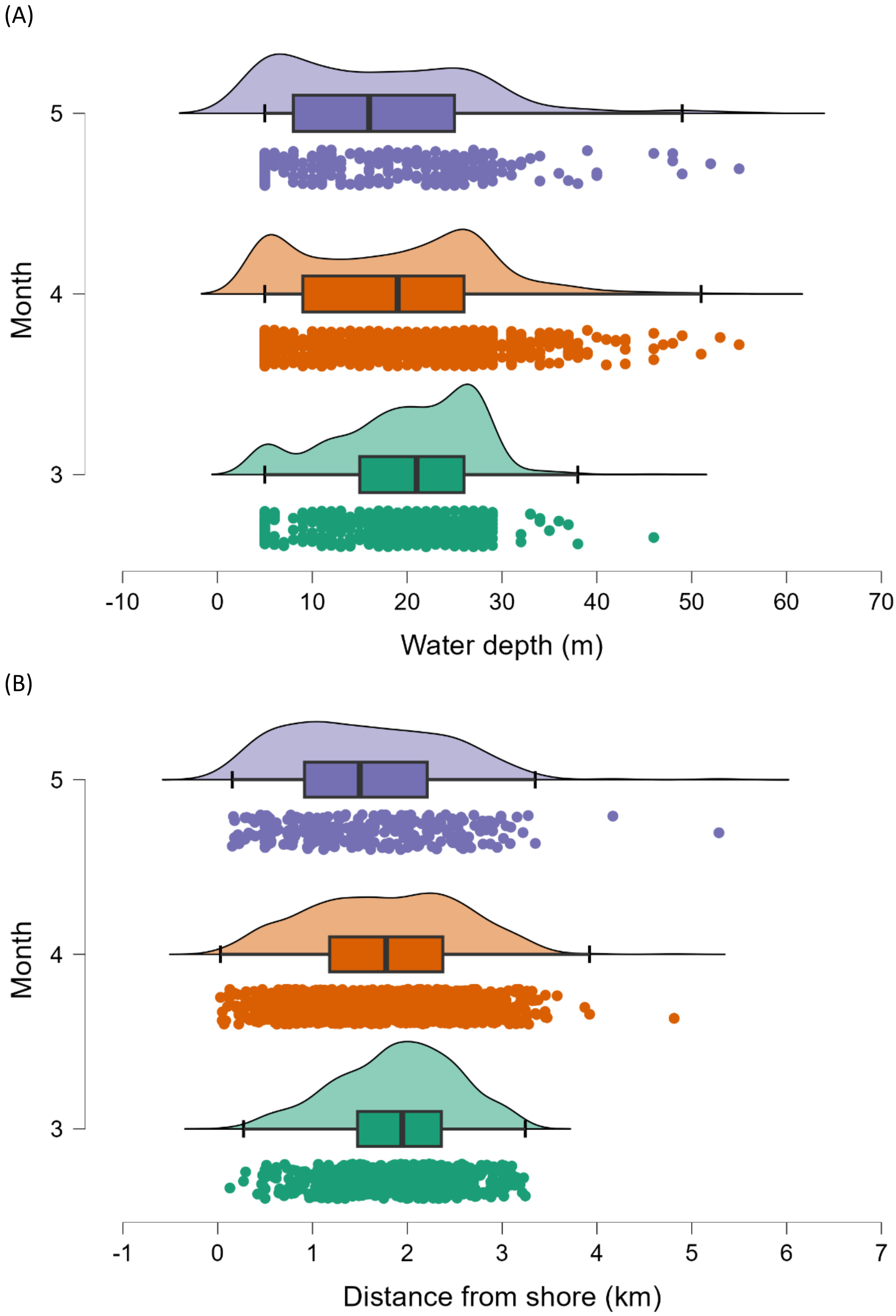


Figure 4.12. Raincloud plots showing the monthly distribution of 1,883 higher-quality locations for five satellite-tracked sei whales (combined dataset) in Berkeley Sound by: (A) water depth; and (B) distance from shore.

4.3.4. Dive behaviour

4.3.4.1. Maximum depth value

The maximum dive depth value (MDV) recorded within a 12-hr period for tagged sei whales within the FICZ ranged from 5.0 to 137.5 m, with a mean of 31.3 m (n=281, SD=21.6, median=26.0 m). Within Berkeley Sound, the MDVs recorded within a 12-hr period ranged from 9.0 to 45.0 m, with a mean of 24.5 m (n=197, SD=6.0, median=25.0 m). Of the ten 12-hr MDV summaries received from Keppel's tag between 6 and 12 May 2024 after departing the FICZ (in water depths >800 m), the deepest MDV recorded was 61.5 m and all other maximum depths were ≤31.5 m.

4.3.4.2. Histogram data

4.3.4.2.1. Dive maximum depth

The 165 DMD 12-hour histogram summaries comprised a total count of 19,397 QDs for sei whales in the FICZ (Table 4.5). Overall, the DMDs achieved by sei whales during QDs in the FICZ were most frequently ≤15 m (67.2% of the total dives recorded in the histogram bins), and only 15.6% of them exceeded 20 m (Figure 4.13A). These results were broadly similar for each of the five individual sei whales, with the highest percentage of QDs for each animal having DMDs in the 5–15 m range (Figure 4.13B). The two whales (Neptune and Keppel) that had the highest proportions of DMDs in depths exceeding 50 m were also those that exhibited the greatest spatial movements within the FICZ, with both animals moving into deeper shelf areas further from coast than the other whales (Figures 4.5 and 4.9). Nevertheless, the clear majority of QDs for those whales was also very shallow (Figure 4.13).

Table 4.5. Number of qualifying dives (QD: ≥5 m depth and ≥1 min duration) in the dive maximum depth (DMD, m) histogram dataset, recorded for five sei whales using the FICZ.

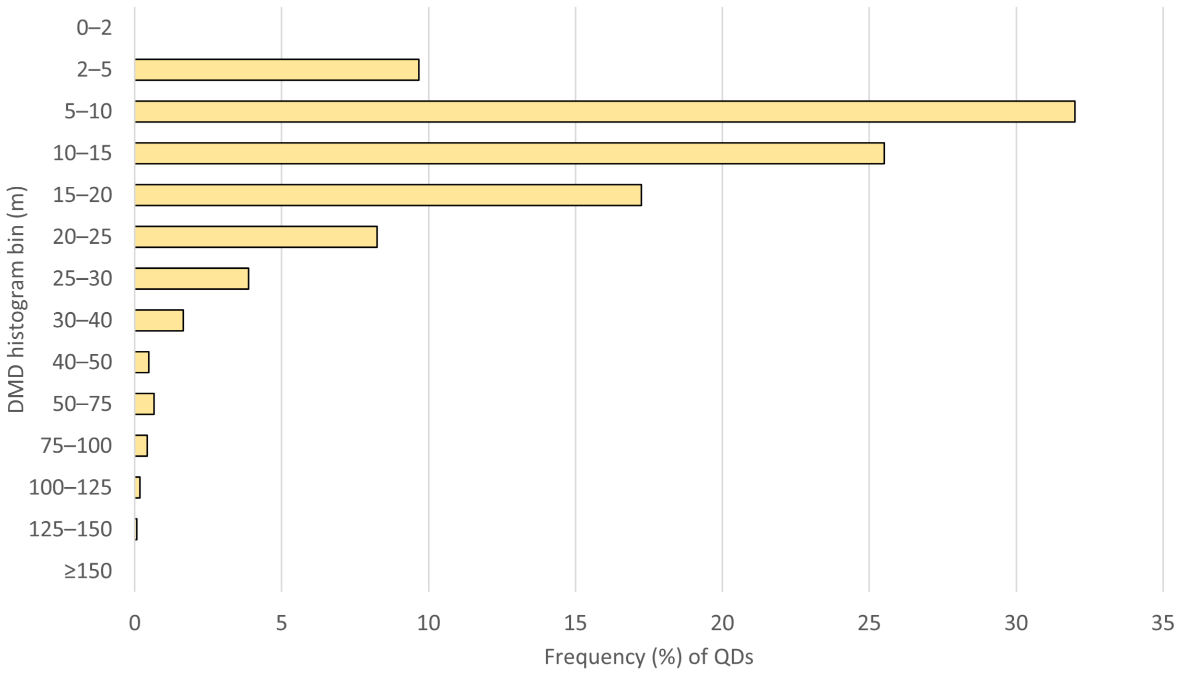
Animal	No. of 12-hr DMD histogram summaries						Total no. of QDs
	Total	By diel status		By month			
		Day	Night	March	April	May	
Eclipse	22	10	12	21	1	0	2,286
Keppel	5	3	2	0	2	3	288
Moe	20	10	10	0	13	7	1,955
Neptune	59	30	29	5	53	1	7,984
Star	59	31	28	0	29	30	7,028
Total	*165*	*84*	*81*	*26*	*98*	*41*	*19,397*

Totals of 9,061 and 10,336 QDs were recorded in the DMD 12-hour histogram summaries allocated to day and night respectively. During the daytime, the highest proportion (38.1%) of QDs in the DMD 12-hour histogram summaries occurred in the 5–10 m bin, while at night the proportion of QDs was broadly similar across the 5–10 m (26.6%) and 10–15 m (28.8%) bins (Figure 4.14).

4.3.4.2.2. Dive duration

The 162 DD 12-hour histogram summaries comprised a total count of 18,812 QDs for sei whales in the FICZ (Table 4.6). The majority (87.4%) of QDs recorded in the DD histogram data had durations shorter than 5 min, and more than half (59.1%) were in the 1–3 min histogram bins (Figure 4.15A). Only 52 QDs (0.3% of the total) exceeded 10 min duration, and very few QDs (n=9; 0.05%) exceeded the 13 min QD duration of the maximum bin (Figure 4.15A). Four of the individual whales had similarly distributed proportions of QDs across the DD bins with the highest proportion of QDs in the 1–2 min bin followed by the 2–3 min bin; however, the highest proportion of QDs for Moe was in the 3–4 min bin, followed by the 1–2 min bin (Figure 4.15B).

(A)



(B)

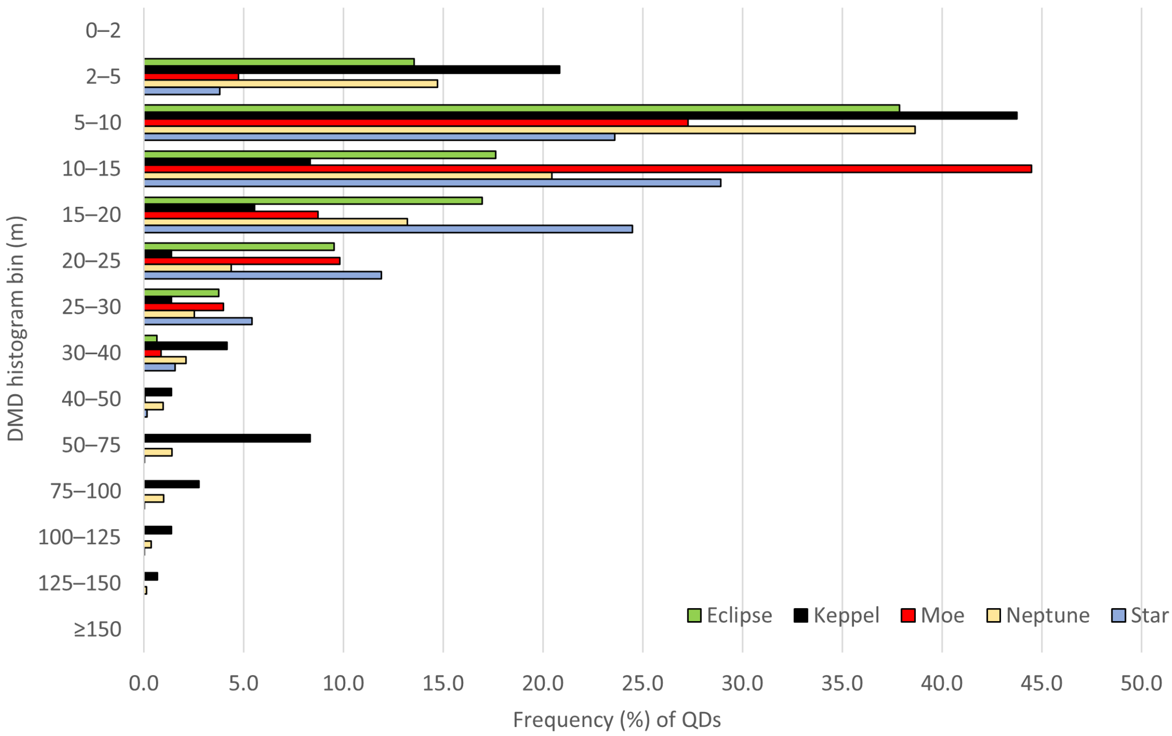


Figure 4.13. Frequency (%) of qualifying dives (QDs, n=19,397) in each dive maximum duration (DMD) histogram bin for five sei whales using the FICZ: (A) combined dataset; (B) for each whale separately. Note that there are no data in the 0–2 m bin because 2 m was set as the starting value to define QDs (see Methods).

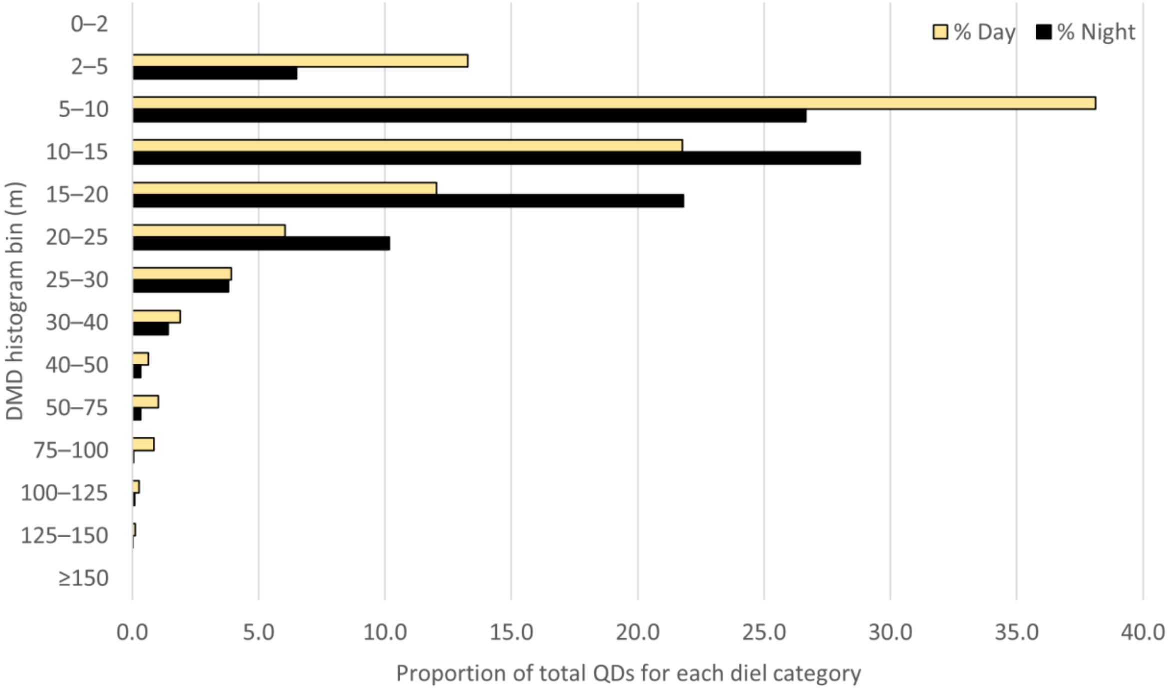


Figure 4.14. Proportion of qualifying dives (QDs, n=19,397) for five sei whales using the FICZ by diel status in each dive maximum duration (DMD) histogram bin of the total QDs recorded in day and at night. Note that there are no data in the 0–2 m bin because 2 m was set as the starting value to define QDs (see Methods).

Table 4.6. Number of qualifying dives (QD: ≥5 m depth and ≥1 min duration) in the dive duration (DD, m) histogram dataset, recorded for five sei whales within the FICZ.

Animal	No. of 12-hr DD histogram summaries						Total no. of QDs
	Total	By diel status		By month			
		Day	Night	March	April	May	
Eclipse	20	10	10	18	2	0	2,079
Keppel	9	3	6	0	4	5	377
Moe	19	7	12	0	16	3	1,838
Neptune	60	29	31	5	53	2	8,126
Star	54	23	31	0	24	30	6,392
Total	*162*	*72*	*90*	*23*	*99*	*40*	*18,812*

Totals of 7,802 and 11,010 QDs were recorded in the DD 12-hour histogram summaries allocated to day and night respectively. The proportion of QDs occurring in each of the DD 12-hour histogram bins was very similar between the daytime and the nighttime datasets, although a slightly higher proportion of nighttime dives occurred in the shorter DD bins (<3 min) and a slightly higher proportion of daytime dives occurred in the longer duration (>4 min) DD bins (Figure 4.16).

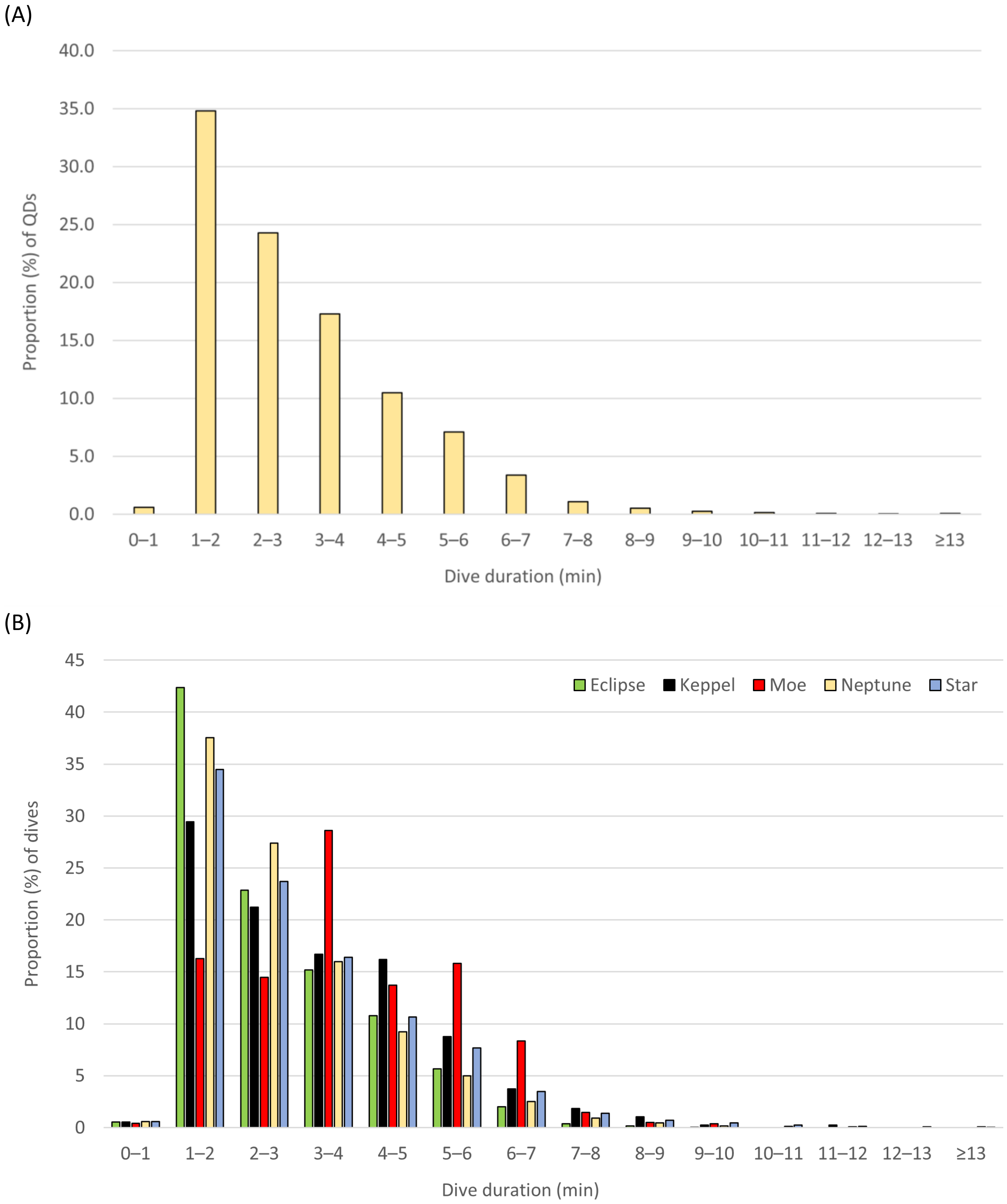


Figure 4.15. Frequency (%) of qualifying dives (QDs, n=18.812) in each dive duration (DD) histogram bin for five sei whales using the FICZ: (A) combined dataset; (B) for each whale separately. Note that there are few data in the 0–1 min bin because 1 min was set as the starting value to define QDs (see Methods).

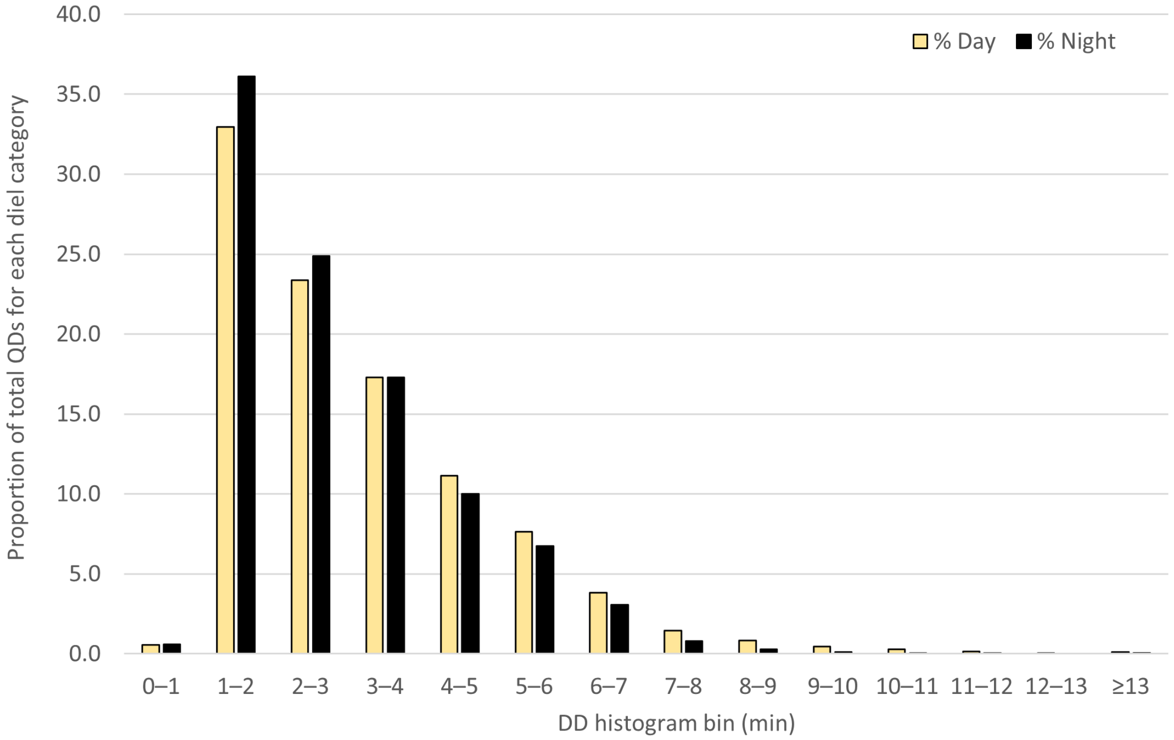


Figure 4.16. Frequency (%) of qualifying dives (QDs, n=18.812) in each dive duration (DD) histogram bin for five sei whales using the FICZ by diel status. Note that there are few data in the 0–1 min bin because 1 min was set as the starting value to define QDs (see Methods).

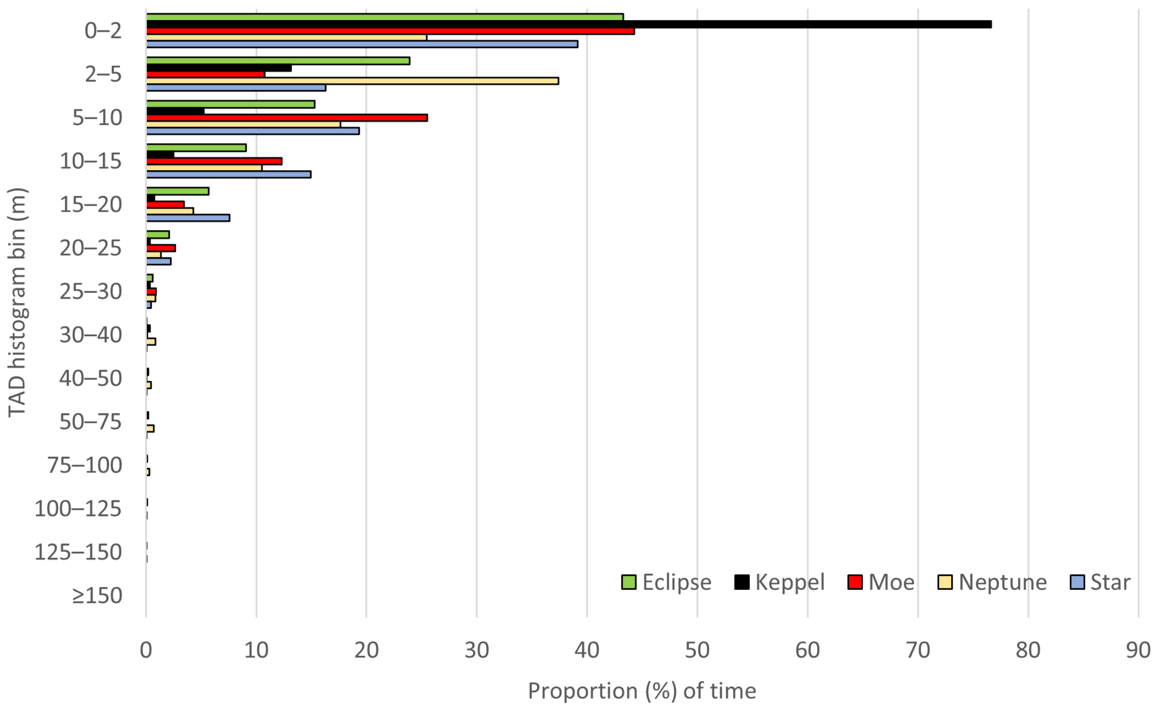
4.3.4.2.3. Time at depth

There was a total of 170 TAD 12-hour histogram summaries available for the five sei whales in the FICZ, with most available for Neptune and least for Keppel (Table 4.7). Plots of the total proportion of time that each whale spent in each histogram depth bin are shown in Figure 4.17A, where it is apparent that Keppel's tag showed a far higher proportion of time (76.6%) spent in the 0–2 m depth bin than the other four whales (25.4–44.3%). The reason for this is unclear but there was no indication of depth sensor issues for Keppel's tag on the included dates, and so this result is presumed to have a behavioural context. While there was inter-whale variation in use of the water column (Figure 4.17A), all five whales spent the vast majority of their time (mean=82.7%, SD=7.5, range=74.7–95.0%) in the 0–10 m depth bins. Overall, sei whales using the FICZ spent relatively little time (3.5%) at depths deeper than 20 m (Figure 4.17 B).

Table 4.7. Number of 12-hour histogram summaries of time at depth (TAD) for five sei whales using the FICZ.

Animal	No. of 12-hr DMD histogram summaries					
	Total	By diel status		By month		
		Day	Night	March	April	May
Eclipse	30	15	15	26	4	0
Keppel	8	4	4	0	4	4
Moe	21	10	11	0	17	4
Neptune	56	27	29	4	51	1
Star	55	28	27	0	23	32
Total	*170*	*84*	*86*	*30*	*99*	*41*

(A)



(B)

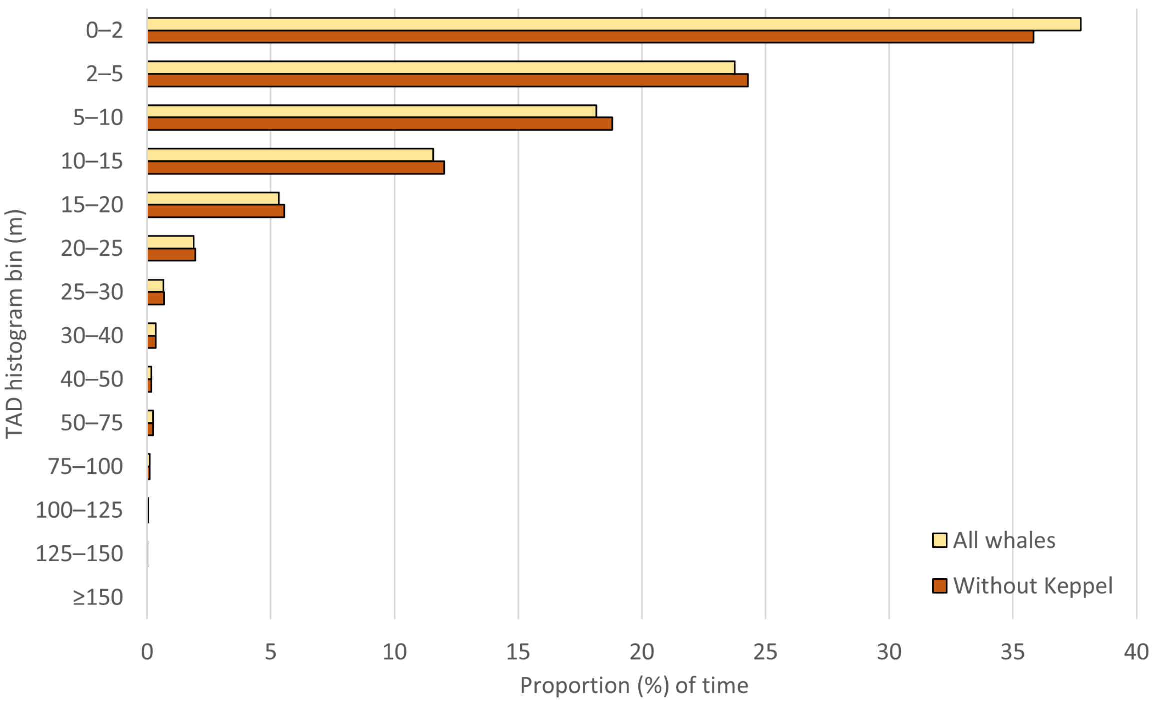


Figure 4.17. Proportion (%) of time spent at depth (TAD) in 14 histogram depth bins for: (A) each individual sei whale; and (B) combined dataset with and without the inclusion of tag data from Keppel (since that whale spent far more time in the uppermost water column than the other animals).

The daytime and nighttime distribution of TAD for the five whales combined (Figure 4.18), indicated that sei whales spent very similar proportions of the day and night using each depth bin.

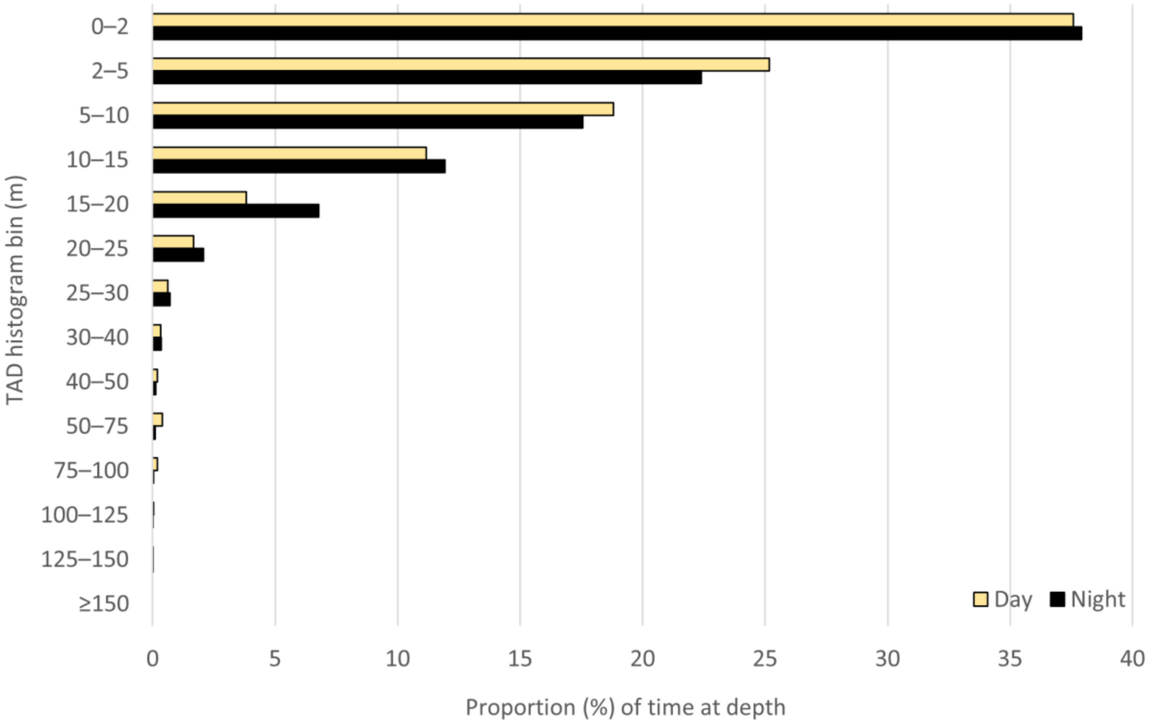


Figure 4.18. Proportion (%) of time spent at depth (TAD) in 14 histogram depth bins by sei whales for daytime and nighttime datasets.

Since the use of the water column by sei whales has management relevance with regard to better understanding vessel collision exposure in the Falklands, TAD was assessed again using only a subset of histogram data for the dates that sei whales were inside Berkeley Sound (a busy shipping area). A total of 118 TAD 12-hour histogram summaries were available for the five sei whales in Berkeley Sound. The results were similar to the FICZ dataset shown in Figure 4.17B, with the clear majority of time (39.3%) spent close to the surface in the shallowest depth bin of 0–2 m, and 78.0% of time spent in the 0–10 m depth bins (Figure 4.19).

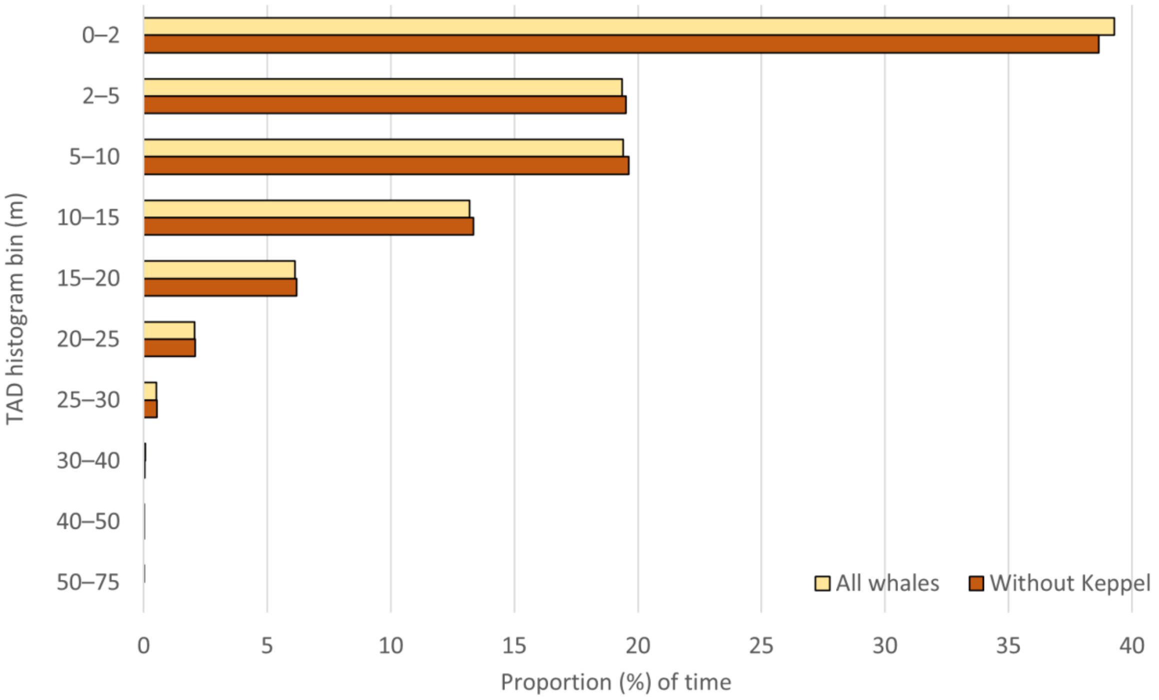


Figure 4.19. Proportion (%) of time spent at depth (TAD) in 14 histogram depth bins in Berkeley Sound for five sei whales, with and without the inclusion of Keppel (since that whale spent far more time in the uppermost water column than the other animals).

4.3.4.3. Behaviour dataset

A total of 9,262 QDs was recorded by the seven sei whales in the behaviour dataset within the FICZ (Table 4.8), while a total of 7,954 QDs was recorded by six sei whales in the Berkeley Sound behaviour dataset (Table 4.9). In combination, sei whale QDs in the FICZ had a mean dive depth of 13.8 m (SD=8.1) and a mean dive duration of 3.2 min (SD=1.7: Table 4.8). Three animals dove to over 100 m depth within the FICZ, with the deepest QD logged at 131.5 m (Table 4.8). All five of the sei whales for which sample size exceeded 300 QDs performed dives that exceeded 10 min duration, and the maximum QD duration recorded within the FICZ was 15.1 min (Table 4.8). In Berkeley Sound, sei whale QDs reached a mean depth of 13.7 m (SD=6.3) and had a mean duration of 3.1 min (SD=1.7: Table 4.9). The highest values recorded for QDs in Berkeley Sound were 49.5 m depth and 15.1 min duration (Table 4.9). The depth to which a sei whale could dive in Berkeley Sound was naturally constrained by water depth within the inlet, with maximum water depths at the entrance to the Sound being ~58 m. The data from the tags of Ninja and Volde were omitted from the subsequent analyses due to their low sample size.

The dive depth (Kruskal-Wallis test, H=326.3, df=4, p<0.001) and duration (Kruskal-Wallis test, H=458.1, df=4, p<0.001) of QDs differed significantly between individuals. Pairwise comparisons using Dunn’s post hoc test showed that the QDs of all pairs of whales reached significantly different depths except for Eclipse–Neptune, Eclipse–Keppel, Keppel–Moe and Keppel–Neptune (Table 4.10). All pairs of whales had significantly different QD duration except for Eclipse–Star and Keppel–Star (Table 4.10). To some extent these differences may reflect the different habitats and/or months of individual tag deployments. Therefore, the depth and duration of QDs was examined again using only the Berkeley Sound dataset when the five whales were foraging in the same spatial area between March and May.

Table 4.8. Summary of the 9,262 qualifying dives (QDs) recorded for seven tagged sei whales within the FICZ.

Whale	Number of QDs								QD depth (m)				QD duration (s)			
	Total	By shape			By diel status											
		Square	U	V	Dawn	Day	Dusk	Night	Mean	SD	Median	Range	Mean	SD	Median	Range
Eclipse	1,795	1,614	137	44	56	858	151	730	12.4	6.8	10.0	5.0–33.0	3.0	1.6	2.6	1.0–10.7
Keppel	322	250	40	32	15	135	18	154	16.0	16.9	9.0	5.0–131.5	3.4	2.1	2.7	1.0–11.3
Moe	1,700	1,508	154	38	103	629	126	842	13.1	6.0	12.0	5.0–34.0	3.8	1.6	3.8	1.0–11.0
Neptune	1,215	961	188	66	43	463	71	638	13.3	11.2	11.0	5.0–123.5	2.7	1.5	2.3	1.0–13.9
Ninja	5	5	0	0	0	0	0	5	5.4	0.6	5.0	5.0–6.0	2.9	1.0	2.8	1.9–4.5
Star	4,200	3,520	529	151	260	1,237	271	2,432	14.8	7.0	14.0	5.0–109.5	3.1	1.8	2.7	1.0–15.1
Volde	25	22	2	1	4	6	0	15	15.7	4.6	18.0	5.0–25.0	3.2	1.2	3.4	1.2–4.9
Total	9,262	7,880	1,050	332	481	3,328	637	4,816	13.8	8.1	12.0	5.0–131.5	3.2	1.7	2.8	1.0–15.1

Table 4.9. Summary of the 7,954 qualifying dives (QDs) recorded for six tagged sei whales within Berkeley Sound. No dive behaviour data were received for Ninja in Berkeley Sound.

Whale	No. of QDs								QD depth (m)				QD duration (s)			
	Total	By shape			By diel status											
		Square	U	V	Dawn	Day	Dusk	Night	Mean	SD	Median	Range	Mean	SD	Median	Range
Eclipse	1,795	1,614	137	44	56	858	151	730	12.4	6.8	10.0	5.0–33.0	3.0	1.6	2.6	1.0–10.7
Keppel	112	88	15	9	0	22	6	84	17.1	7.1	18.0	5.0–49.5	3.2	1.5	3.0	1.0–7.2
Moe	1,677	1,487	154	36	99	620	126	832	13.0	6.0	12.0	5.0–34.0	3.8	1.6	3.8	1.0–11.0
Neptune	650	539	94	17	28	249	26	347	11.6	5.0	11.0	5.0–45.0	2.3	1.0	2.1	1.0–7.5
Star	3,695	3,129	468	98	229	1,075	233	2,158	14.9	6.2	15.0	5.0–41.0	3.0	1.7	2.6	1.0–15.1
Volde	25	22	2	1	4	6	0	15	15.7	4.6	18.0	5.0–25.0	3.2	1.2	3.4	1.0–4.9
Total	7,954	6,879	870	205	416	2,830	542	4,166	13.7	6.3	13.0	5.0–49.5	3.1	1.7	2.8	1.0–15.1

Table 4.10. Pairwise comparisons of dive depth (white cells) and dive duration (grey cells) of QDs by five sei whales in the FICZ. Significant results are highlighted in bold.

Whale	Eclipse	Keppel	Moe	Neptune	Star
Eclipse	–	0.01	**<0.001**	**<0.001**	0.08
Keppel	0.20	–	**<0.001**	**<0.001**	0.07
Moe	**<0.001**	0.26	–	**<0.001**	**<0.001**
Neptune	0.27	0.06	**<0.001**	–	**<0.001**
Star	**<0.001**	**<0.001**	**<0.001**	**<0.001**	–

The depths (Kruskal-Wallis test, H=401.8, df=4, p<0.001) and durations (Kruskal-Wallis test, H=569.4, df=4, p<0.001) of QDs undertaken by five sei whales within Berkeley Sound differed significantly between individuals (Figure 4.20A). Pairwise comparisons using Dunn's post hoc test showed that the QDs of all pairs of whales had significantly different dive depths except for Eclipse–Neptune, with Keppel having the deepest QDs (mean=17.1 m, SD=7.1) while Eclipse (mean=12.4 m, SD=6.8) and Neptune (mean=11.6 m, SD=5.0) had the shallowest (Figure 4.20A). All pairs of whales had significantly different dive duration except for Eclipse–Star (Table 4.11), with Neptune having the shortest QD duration (mean=2.3, SD=1.0) and Moe the longest (mean=3.8, SD=1.6: Figure 4.20B).

Table 4.11. Pairwise comparisons of dive depth (white cells) and dive duration (grey cells) of QDs by five sei whales in Berkeley Sound. Significant results are highlighted in bold.

Whale	Eclipse	Keppel	Moe	Neptune	Star
Eclipse	–	**0.04**	**<0.001**	**<0.001**	0.98
Keppel	**<0.001**	–	**<0.001**	**<0.001**	**0.04**
Moe	**<0.001**	**<0.001**	–	**<0.001**	**<0.001**
Neptune	0.15	**<0.001**	**<0.001**	–	**<0.001**
Star	**<0.001**	**0.001**	**<0.001**	**<0.001**	–

A significant correlation was found between the dive depth and duration of QDs for the five whales combined using both the FICZ dataset (Spearman's rho=0.38, p<0.001) and the Berkeley Sound dataset (Spearman's rho=0.37, p<0.001). Significant correlations between dive depth and duration were also apparent for the five whales individually in both datasets (Table 4.12), with effect sizes varying from weak (Moe) to moderate (Eclipse).

Table 4.12. Spearman rho correlations between the dive and depth of QDs for five sei whales in the FICZ and Berkeley Sound.

Whale	FICZ	Berkeley Sound
Eclipse	0.56***	0.56***
Keppel	0.45***	0.21*
Moe	0.19***	0.19***
Neptune	0.23***	0.31***
Star	0.40***	0.42***

Significance: p<0.5*, p<0.01**, p<0.001***

Within Berkeley Sound, there were significant differences in the depths (Kruskal-Wallis test, H=244.4, df=3, p<0.001) and durations (Kruskal-Wallis test, H=109.7, df=3, p<0.001) of QDs according to diel status (Table 4.13). Pairwise comparisons showed that the QD depths and durations in all diel status categories differed significantly from one another, except for the depth of QDs between dawn and night (Table 4.14). Dives during the daytime were shallower but had longer duration than the other diel categories (Figure 4.21), while dives at dusk were the shortest but also had the greatest depth (Table 4.13). It should be noted that the sample sizes of QDs during day and night were considerably larger than those for dawn and dusk (Table 4.13).

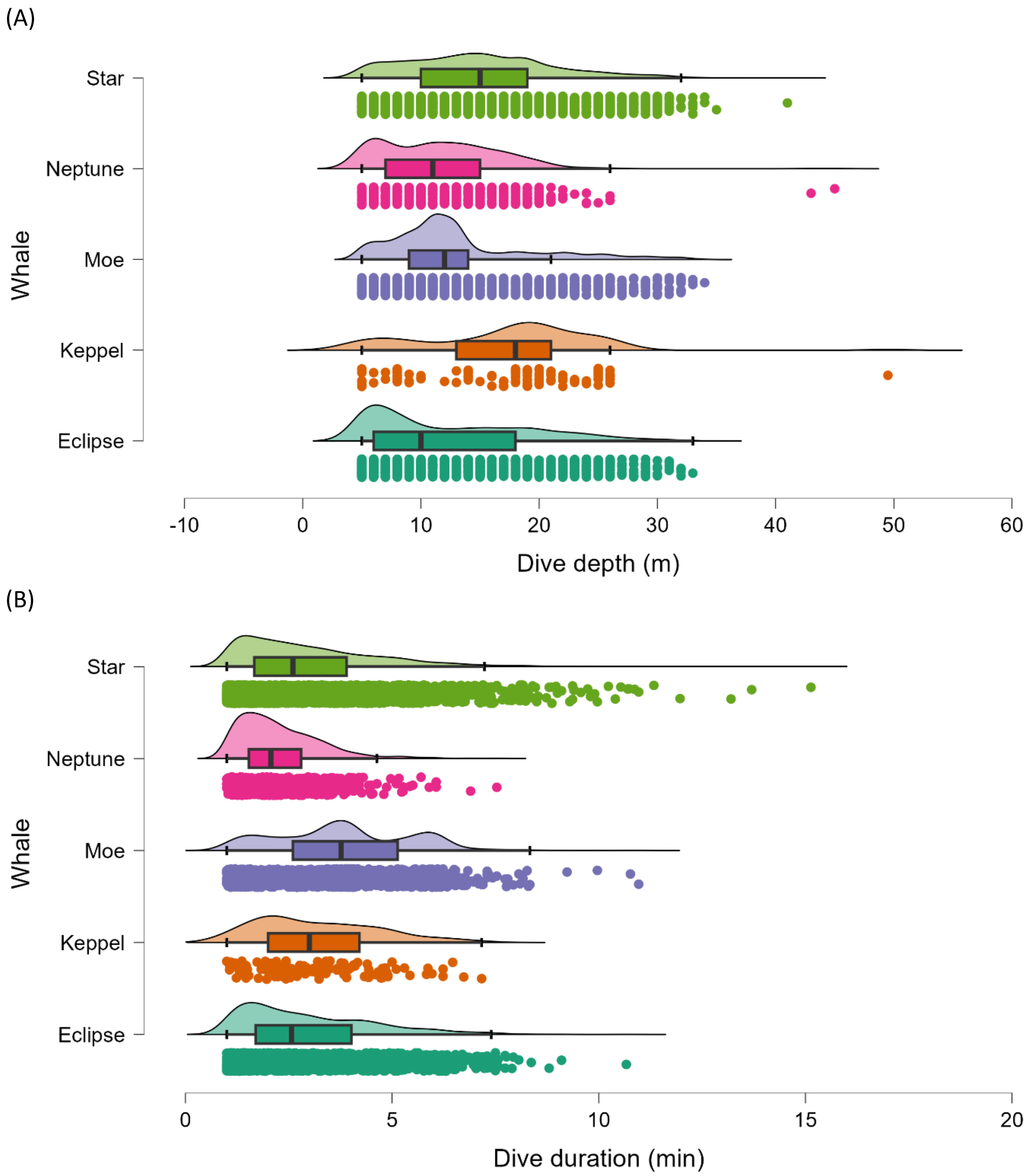


Figure 4.20. Raincloud plots of qualifying dives (QDs) of five sei whales in Berkeley Sound by individual whale: (A) QD depth; and (B) QD duration.

Table 4.13. Summary of the depth and duration of QDs by five sei whales in Berkeley Sound according to diel status.

Diel status	Depth (m)				Duration (min)			
	Mean	SD	Median	Range	Mean	SD	Median	Range
Dawn	14.6	7.2	13.0	5.0–32.0	3.2	1.6	2.9	1.0–8.1
Day	12.6	6.8	11.0	5.0–49.5	3.4	1.8	3.1	1.0–15.1
Dusk	15.6	6.0	16.0	5.0–32.0	2.9	1.7	2.4	1.0–12.0
Night	14.1	5.8	13.0	5.0–33.0	3.0	1.5	2.6	1.0–11.0

Table 4.14. Pairwise comparisons using Dunn's post hoc test of dive depth (white cells) and dive duration (grey cells) of QDs by five sei whales in Berkeley Sound. Significant results are highlighted in bold.

Diel status	Dawn	Day	Dusk	Night
Dawn	–	**0.02**	**0.002**	**0.03**
Day	**<0.001**	–	**<0.001**	**<0.001**
Dusk	**<0.001**	**<0.001**	–	**0.04**
Night	0.80	**<0.001**	**<0.001**	–

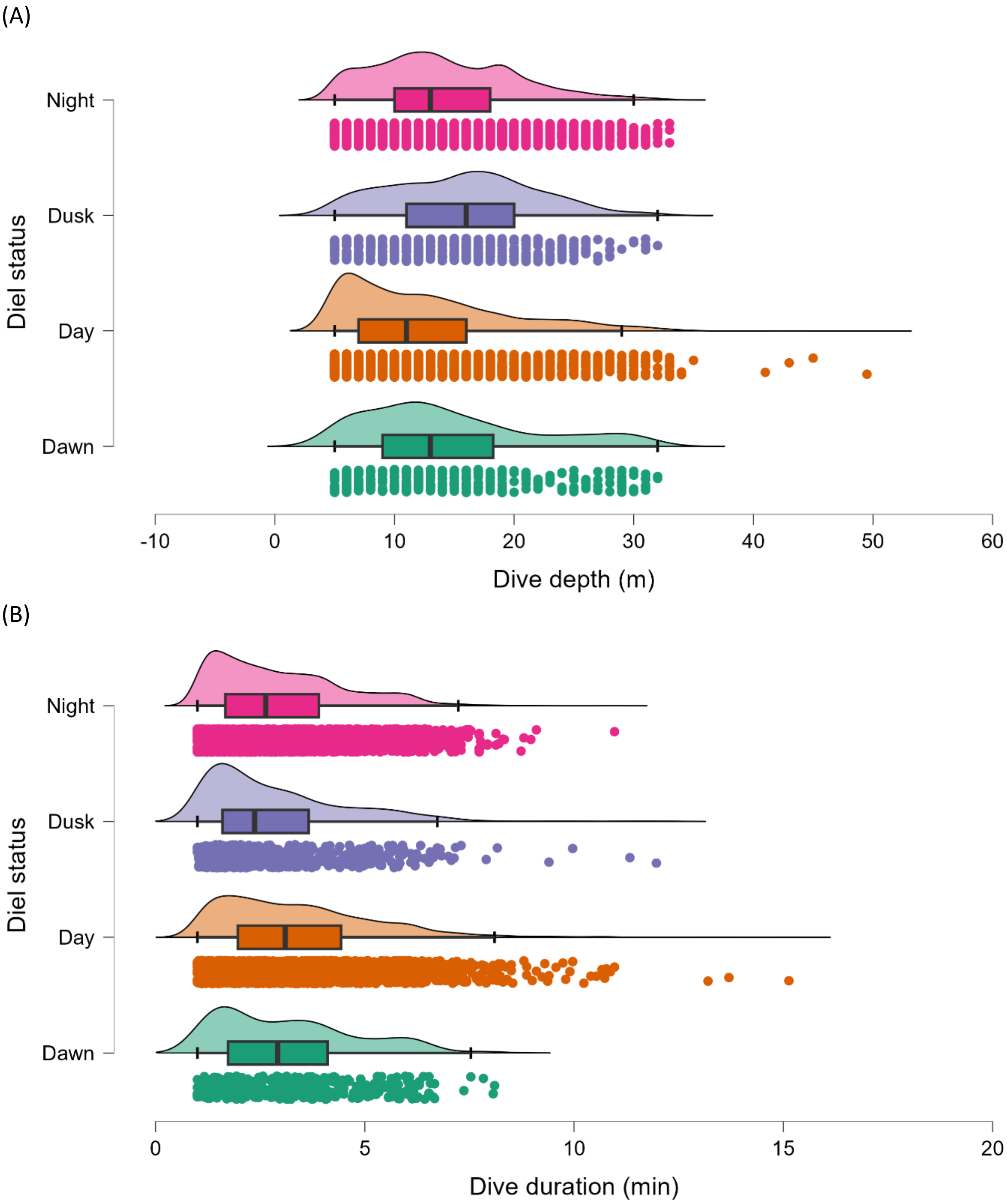


Figure 4.21. Raincloud plots of qualifying dives (QDs) of five sei whales in Berkeley Sound by diel status: (A) QD depth; and (B) QD duration.

The depth (Kruskal-Wallis test, H=139.59, df=2, p<0.001) and duration (Kruskal-Wallis test, H=82.7, df=2, p<0.001) of QDs undertaken by five sei whales within Berkeley Sound differed significantly between months (Figure 4.22). Pairwise comparisons using Dunn's post hoc test revealed highly significant (p<0.001) differences between QD depth in March–April and in March–May, with March having shallower QDs (mean=12.4 m, SD=6.5) than the other months (Figure 4.22). There was no significant difference (p=0.76) in QD depth between April and May. Pairwise comparisons showed that the duration of QDs in Berkeley Sound varied significantly (p<0.001) between all months, becoming progressively longer in each consecutive month (Figure 4.22).

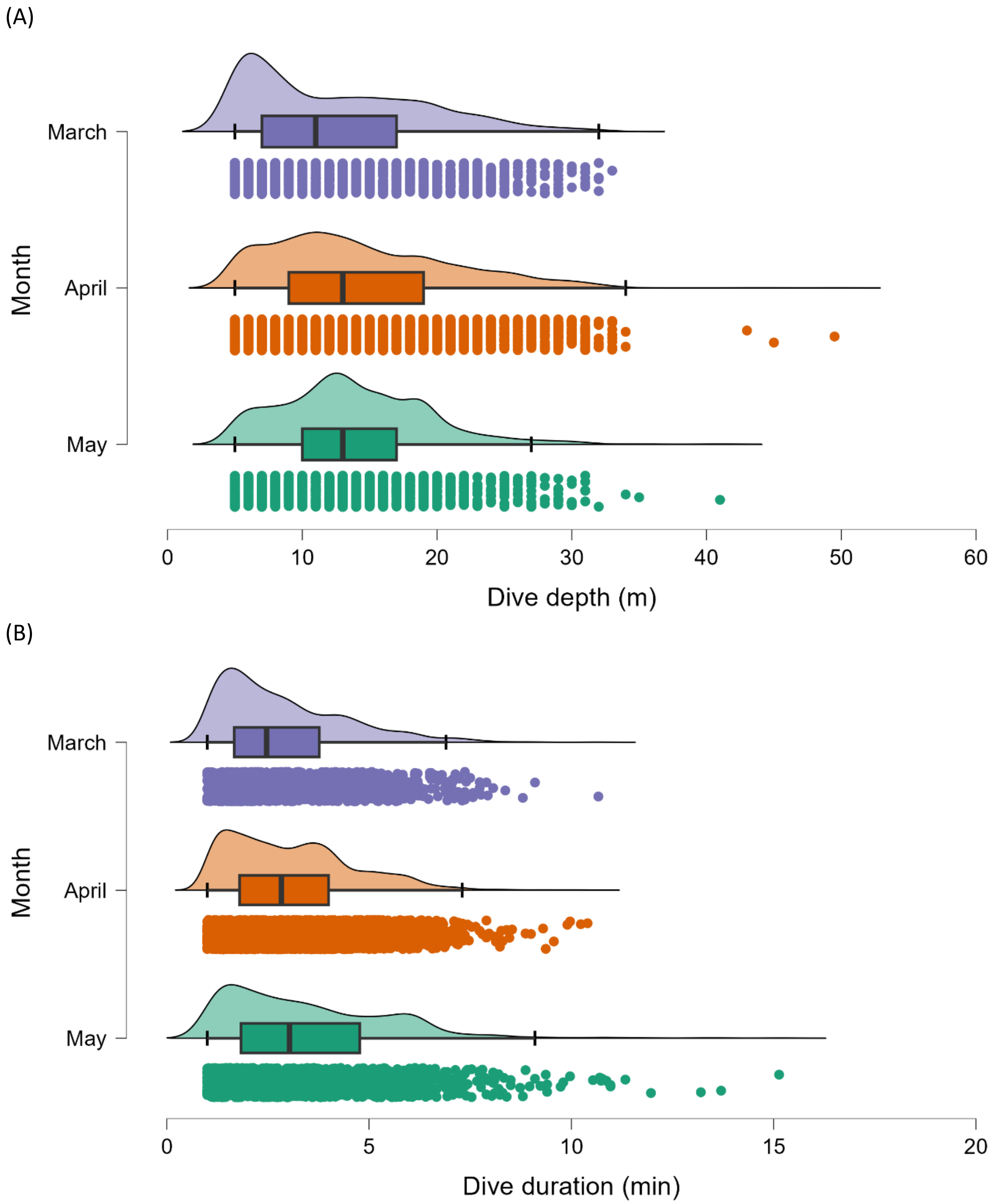


Figure 4.22. Raincloud plots of qualifying dives (QDs) of five sei whales in Berkeley Sound by month: (A) QD depth; and (B) QD duration.

Of the 7,929 QDs recorded in Berkeley Sound for the five sei whales combined, the vast majority (86.5%) were square-shaped and only 2.6% were V-shaped (Table 4.15). Square-shaped dives comprised 79% to 90% of the total QDs of each individual whale in Berkeley Sound, while V-shaped dives comprised only 2.1% to 8.0% of the total QDs of each whale (Table 4.16).

Table 4.15. Summary of the depth and duration of sei whale QDs (n=7,929) in Berkeley Sound by dive shape.

Parameter	Dive depth (m)			Dive duration (min)		
	Square	U	V	Square	U	V
N	6,857	868	204	6,857	868	204
Median	12.0	16.0	18.5	2.9	2.0	3.7
Mean	13.2	16.7	19.4	3.2	2.4	4.1
Std. Deviation	6.3	5.4	6.2	1.6	1.4	2.2
Minimum	5.0	7.0	7.0	1.0	1.0	1.0
Maximum	34.0	49.5	43.0	15.1	11.0	13.2

Both the depth (Kruskal-Wallis test, H=446.3, df=2, p<0.001) and duration (Kruskal-Wallis test, H=245.0, df=2, p<0.001) of QDs differed significantly according to dive shape (Figure 4.23). All pairwise comparisons of QD depth and duration differed significantly (p<0.001) in depth and duration. Square shaped dives occurred at shallowest depth, U-shaped dives had the shortest duration, while V-shaped dives were both the deepest and the longest (Figure 4.23). These characteristics were also true of the QDs of each individual whale, with the exception of Keppel for whom V-shaped dives were the shallowest (Table 4.16).

Significant correlations were apparent in dive depth and duration for each dive shape: square: n=6,879, Spearman's rho=0.41, p<0.001; U: n=870, Spearman's rho=0.37, p<0.001; and V: n=205, Spearman's rho=0.45, p<0.001.

Both the depth (Kruskal-Wallis test, H=403.2, df=4, p<0.001) and duration (Kruskal-Wallis test, H=577.9, df=4, p<0.001) of square-shaped QDs differed significantly between animals. Pairwise comparisons using Dunn's post hoc test showed that all combinations were significantly different from one another, except for Eclipse–Neptune (p=0.17) with regard to QD depth, and Eclipse–Keppel (p=0.15), Eclipse–Star (p=0.39), and Keppel–Star (p=0.23) with regard to QD duration.

Both the depth (Kruskal-Wallis test, H=28.7, df=4, p<0.001) and duration (Kruskal-Wallis test, H=10.2, df=4, p=0.04) of U-shaped QDs differed significantly between animals. Pairwise comparisons revealed highly significant (p<0.001) differences in the depth of U-shaped QDs for Eclipse–Neptune, Moe–Neptune, and Neptune–Star. A moderately significant difference (p<0.01) was apparent for Keppel–Neptune, while the remainder of pairwise comparisons were not significant.

Table 4.16. Summary of the depth and duration of QDs (n=7,929) in Berkeley Sound by dive shape for five individual sei whales.

Parameter	Eclipse			Keppel			Moe			Neptune			Star		
	Square	U	V	Square	U	V	Square	U	V	Square	U	V	Square	U	V
n	1,614	137	44	88	15	9	1,487	154	36	539	94	17	3,129	468	98
% of total	89.9	7.6	2.5	78.6	13.4	8.0	88.7	9.2	2.1	82.9	14.5	2.6	84.7	12.7	2.7
Depth (m)															
Median	9.0	16.00	17.0	19.0	18.0	14.0	11.0	17.0	21.0	11.0	13.0	17.0	14.0	16.0	19.0
Mean	11.9	17.1	17.6	16.7	19.8	16.6	12.4	17.7	20.8	10.9	14.5	18.5	14.5	16.6	20.1
SD	6.7	5.2	5.3	6.9	8.9	5.0	5.7	5.6	6.3	4.6	5.1	7.4	6.2	5.1	6.3
Min	5.0	7.0	7.0	5.0	12.0	10.0	5.0	8.0	10.0	5.0	7.0	10.0	5.0	8.0	9.0
Max	33.0	29.0	32.0	26.0	49.5	26.0	33.0	32.0	34.0	24.0	45.0	43.0	34.0	33.0	41.0
Duration (min)															
Median	2.6	2.1	3.6	3.0	2.0	3.7	3.8	2.4	4.6	2.1	1.9	3.1	2.7	1.9	3.5
Mean	3.0	2.4	3.7	3.1	2.9	4.6	3.9	2.7	4.7	2.2	2.1	3.6	3.1	2.4	4.2
SD	1.6	1.3	1.6	1.3	1.7	1.9	1.6	1.3	2.2	0.9	1.0	1.7	1.7	1.5	2.4
Min	1.0	1.0	1.0	1.0	1.1	2.4	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.1
Max	10.7	7.2	7.5	6.5	6.2	7.2	10.8	6.8	11.0	6.9	5.7	7.5	15.1	11.0	13.2

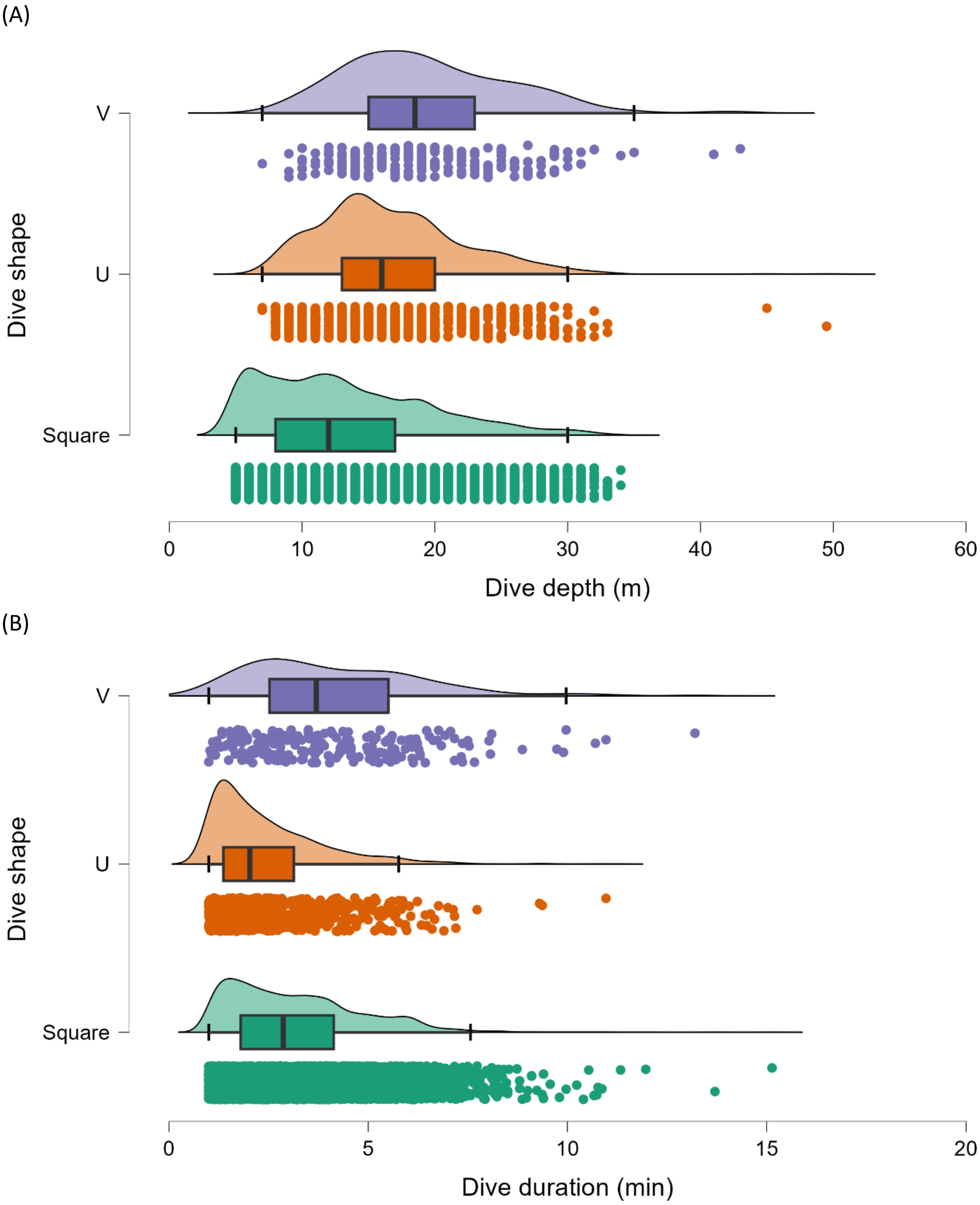


Figure 4.23. Raincloud plots of qualifying dives (QDs) of five sei whales in Berkeley Sound by dive shape: (A) QD depth; and (B) QD duration.

4.4 Discussion

4.4.1. Tagging success

Very few telemetry studies have focussed on sei whales worldwide (Olsen et al., 2009; Prieto et al., 2012; Baracho Neto et al., 2019), and this study was the first to deploy satellite tags on sei whales using a neritic feeding ground. Of the 11 satellite tags purchased for DPLUS126, seven were successfully deployed on whales. There were five failed attempts where tags missed contact with the animal and fell into the sea. Additionally, two of the tags that were successfully deployed on animals (Ninja and Volde) provided only minimal amounts of data before they ceased transmitting. These results highlight the array of difficulties encountered while attempting to deploy satellite tags on sei whales in the Falklands, which included:

- *Sei whale behaviour*. The species is naturally skittish as a study subject compared to many other baleen whale species. Sei whales were difficult to approach to sufficient proximity for confident tagging attempts, and on the few occasions where animals surfaced close then it was usually with the whale slightly angled away from the boat. These resulted in suboptimal deployments, where one tag barb penetrated more deeply into the fin than the other.

- *Prevailing weather and sea conditions*. Adverse weather conditions in the Falklands greatly hindered the number of days spent at sea (especially during 2023), which was a challenge when international personnel were critical to fieldwork but only present in the islands for a limited amount of time. Much survey time took place in marginal weather that made tagging very difficult. Furthermore, conditions were often overcast and it was rarely possible to track whales when they were subsurface in order to stay alongside them and predict where they might surface.

- *Suboptimal equipment*. The incorrect model of Dan Inject was erroneously shipped to the Falklands by the supplier ahead of the 2022 season, and given the logistics of shipping equipment to the Islands then it was not possible to have a replacement sent in time. Consequently, tagging attempts in 2022 used equipment that was too low-powered, resulting in misses and poor penetration in the dorsal fin.

- *Tag choice*. Tags in the LIMPET configuration were selected for deployment on sei whales, because their penetration into the animal is limited compared with consolidated implantable tags. This is considered to be appropriate for species with a thin blubber layer such as sei whales and Bryde's whales (*B. brydei*; Constantine et al., 2018) to reduce potential impacts of the tag compared with e.g. right whales *Eubalaena* spp. However, the selection of LIMPET tags meant that placement of the tag was far more critical and required the boat to be perpendicular to, and close to, an animal's dorsal fin for a tag to be deployed. By comparison, the selection of consolidated tags would have provided a much higher variety of feasible distances and angles for deployment attempts, and a larger target area (essentially the entire upper flank of the whale). While the choice of LIMPET configuration therefore greatly increased the difficulties in deploying the tags on sei whales, the decision to use it reflected ethical concerns about the potential negative impacts of the currently available implantable tags on this species.

- *Team inexperience*. Of the four personnel involved with the sei whale tagging in the Falklands (one tagger, one sei whale biologist, and two coxswains), only one (RP) had experience with deploying satellite tags, and only two (RP and CW) had experience of working with sei whales. This team inexperience likely resulted in some missed opportunities, particularly during 2024 when no experienced taggers were available and CW undertook the tagging for the first time and without previous experience of tagging more cooperative species.

Notwithstanding those limitations, the seven tags deployed on sei whales over the project timeframe have provided novel information with management relevance on the use of a neritic feeding ground by the species, including movements around the Islands, site fidelity, habitat use, and dive behaviour, most of which could not be acquired by other methods. The mean transmission duration of 27.4 days for LIMPET tags transmitted on sei whales in the Falklands is similar to the mean values obtained for other species similar in morphology and behaviour, for example fin whales (24.5 days: Keen et al., 2019; 15.5 days: Herr et al., 2022; 23.5 days: Panigada et al., 2024;). Therefore, the tagging work was considered a success overall with respect to both the tag transmission longevity and the research goals addressed.

4.4.2. Sei whale movements

The telemetry data revealed higher fidelity of sei whales to Berkeley Sound than expected, with individuals remaining there continuously for up to 42 days post-tagging. Of the four whales which subsequently departed Berkeley Sound with their tags still transmitting, post-tagging residency within the Sound ranged from 3 to 42 days with a mean of 20.0 days (SD=17.0). In contrast, photo-identification work carried out during 2017 (Weir, 2017) and in 2019/2020 (Weir, 2022) revealed that most individuals (64.6% in 2017, 62% in 2019 and 60% in 2020) were photographed inside the Sound on one date only. However, the photo-identification work occurred on only sporadic survey dates due to the prevailing weather conditions in the Islands, and sei whales are generally poorly-marked and require high quality images for individual identification which are not always possible to obtain (see Chapter 8). Therefore, the photo-identification data provide only an indication of the likely residency of the individuals using Berkeley Sound. Even so, residencies of up to 36 days have been recorded (i.e. BS89 photographed on every survey (n=8) between 24 April and 29 May 2017: Weir, 2017). The telemetry data provided a much more robust indication of site fidelity and revealed that Berkeley Sound, even though only a relatively small sea inlet (25 x 6 km), was intensively and continuously used by individual sei whales during the autumn. The longest residencies were for the whales tagged in late March and early April, while the whale tagged in late April (Keppel) stayed in the Sound for only three days before moving to the north coast of the Islands and subsequently embarking on a migration away from the Islands. March and April are the months of highest sei whale relative abundance in Berkeley Sound (Weir, 2017, 2022; see Chapter 2), and together with the longer period of residency in those months shown by the telemetry data, it appears likely that prey availability for foraging whales has a seasonal peak at that time.

Berkeley Sound has been confirmed as a feeding area for sei whales since the onset of targeted research there during 2017, and demonstrated by frequent observations of defecations containing crustacean prey remains (Jackson et al., 2022), suction-cup tagging showing subsurface feeding lunges (Segre et al., 2021), and occasional observations of surface feeding on squat lobster krill (*Munida gregaria*) and the amphipod *Themisto gaudichaudii* (Weir, 2017, 2022; Weir et al., 2019). The erratic movements of tagged sei whales within Berkeley Sound is also consistent with foraging behaviour, as animals moved continuously around while locating and exploiting prey patches.

A modelling approach is often applied in telemetry studies to identify areas of high-use (i.e. changes of direction within, and long occupancy of, spatial areas referred to as Area Restricted Movement, ARM) that are inferred to support foraging behaviour (Prieto et al., 2014; Panigada et al., 2024). However, such studies usually include telemetry data extending across wide regions and in remote areas where whale behaviour cannot be observed firsthand. In those contexts, modelling provides a robust solution to identifying which habitats are simply travelled through by whales versus which areas comprise high-use habitats used for foraging and potentially are of greater conservation importance (e.g. Garrigue et al., 2015; Panigada et al., 2024). In the context of Berkeley Sound, modelling of the telemetry data has not been carried out because:

1. It is already confirmed to be a high-use feeding site (Weir, 2017, 2022); and
2. The size of Berkeley Sound in its entirety is well within the error margin of the majority of Argos positions acquired from the tags which usually contain mean location errors in the low tens of kilometres (Witt et al. 2010).

Rather, the entire time that tagged whales spent in Berkeley Sound was reasonably assumed to represent foraging behaviour within a high-use habitat.

Of the five sei whales whose tags were still transmitting when they departed Berkeley Sound, three animals (Neptune, Star and Moe, all tagged in 2022) travelled southwards along the east coast of East Falkland. Moe did not visit any of the other inshore bays or inlets along the east coast prior to its tag stopping transmitting. However, Neptune and Star both spent time in the Low Bay–Bleaker Island region at the mouth of Adventure Sound, with Star having returned to that area when its tag ceased transmitting. This area also likely comprises a high-use foraging habitat for sei whales and would merit further research focus.

While Neptune was the only tagged sei whale to move to the west coast of the Falkland Islands, this is considered to reflect the location of the tag deployment site and the limited tag transmission durations rather than preferential use of the east coast by sei whales. In fact, the west coast of the Falklands has been shown to be extensively used by foraging sei whales (Weir, 2018; Weir et al., 2020), with both Queen Charlotte Bay and King George Bay predicted to host high relative densities of sei whales (Baines and Weir, 2020). Unfortunately, Neptune's tag stopped transmitting soon after it arrived at Queen Charlotte Bay, but those areas represent priorities for future tagging work in order to better assess how sei whales utilise the west coast.

The Falkland Islands Inshore Key Biodiversity Area (KBA) was recognised by the IUCN in 2021 as supporting a globally important feeding aggregation of sei whales. The KBA extends from the coast to the 100 m depth isobath around the Falkland Islands, comprising habitat considered to host high seasonal densities of sei whales. However, the appropriateness of the seaward limits of the KBA was uncertain, since relatively little survey effort has been carried out beyond ~10 km from the coast. One of the main drivers for the telemetry study was therefore to assess the extent to which sei whales forage in more pelagic areas within the FICZ. The results of the study indicate that although sei whales did use open parts of the FICZ, the vast majority of the satellite positions received for most whales was inside the KBA and supports the existing KBA boundaries (Figure 4.24). The exception was one area used by Neptune, approximately 20 km offshore along the exposed south-west coast of the Falklands, which was deeper than 100 m and therefore outside of the KBA boundary (Figure 4.24). That area has received little research focus to date, but no sei whales were observed there during one boat survey (Weir, 2018) and nor was it predicted by habitat modelling to host notable sei whale densities (Baines and Weir, 2020). Since most sei whale telemetry locations were well inside the KBA, it is not considered appropriate to revise the KBA boundaries at this time based on the movements of a single animal. As more telemetry results become available it should be apparent whether the south-west part of the Falklands is also used by other whales. If so, then an offshore extension to the KBA boundary in that area may be appropriate.

The only animal that moved to the north coast of the Falklands after departing Berkeley Sound was Keppel, which was also the whale tagged latest in the season. Potentially, prey availability in Berkeley Sound was in seasonal decline when that animal was tagged, which might explain its relatively short stay in the Sound. Currently no data are available on the seasonal changes in abundance of sei whale prey species in Berkeley Sound or elsewhere around the Falklands, and this has been highlighted as an important data gap both in understanding sei whale occurrence and other marine predators including dolphins, seabirds and pinnipeds. Keppel used the exposed north coast of East Falkland for a week, which, similar to Neptune's use of the south-west region, was not an area predicted by Baines and Weir (2020) to host high densities of sei whales. These results highlight the need to incorporate longer-term datasets and spatio-temporal variation into habitat modelling, and emphasise the value of telemetry in documenting how whales use parts of the Falklands coast that are particularly remote and challenging to work in by boat.

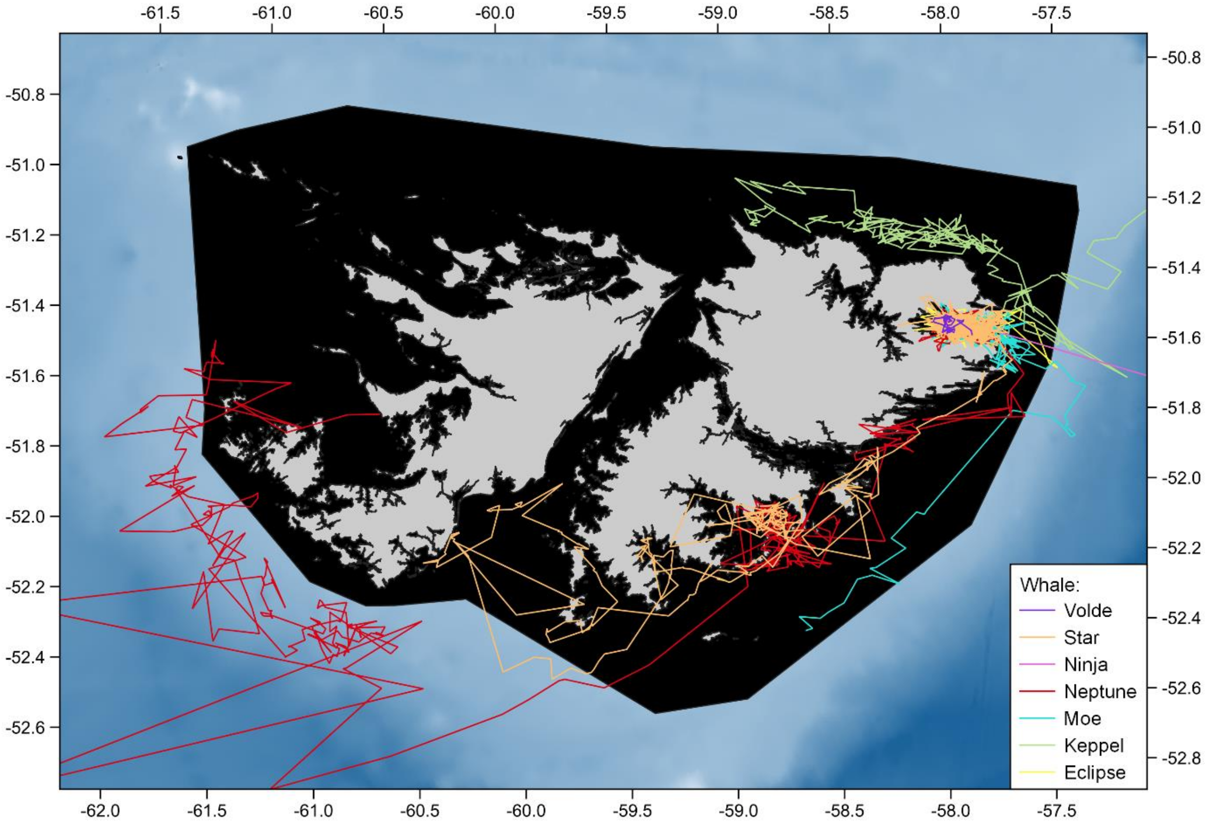


Figure 4.24. The Falkland Islands Inshore Key Biodiversity Area (black area) around the Falklands, with the satellite tracks of the seven sei whales superimposed.

The data obtained from two of the whales (Ninja and Keppel) offer some insight into the longer-range movements of the sei whales that forage in the Falklands during autumn. Ninja's tag did not transmit well (for unknown reasons) and there were only two short bursts of transmissions interspersed by a week-long gap during which the whale swam from Berkeley Sound to an area ~300 km north-west of Shag Rocks at South Georgia. Sei whales were one of the major components of the whaling catches at South Georgia, with approximately 16,000 landed particularly between 1948 and 1965 (Horwood, 1987). However, contemporary sightings of the species around Shag Rocks and South Georgia are uncommon compared to fin whales, humpback whales and southern right whales *Eubalaena australis* (Richardson et al., 2012; Jackson et al., 2020; Biuw et al., 2024). The movement by Ninja was therefore interesting in confirming some linkage between whales that forage in the Falkland Islands and in the wider South Georgia region. At South Georgia, most sei whale catches between 1927 and 1931 occurred from February to April (Matthews, 1938) which corresponds with the movement of Ninja. However, during the later years when sei whales were the main target species for whalers at South Georgia, the seasonal peak in catches occurred earlier, in January (Horwood, 1987). Further tagging of sei whales in the Falkland Islands, especially if longer transmission durations could be achieved, may be expected to reveal more information about movements between the two archipelagos.

Keppel was the only whale for which the tag was still transmitting when the animal commenced a movement away from the Falkland Islands. Data from the Discovery tags used by whalers to understand the movements and population structure of exploited whale stocks, along with a photo-identification match of a distinctive sei whale between the Falklands and Brazil (Horwood, 1987; Weir et al., 2020), indicate that at least some sei whales undertake seasonal latitudinal movements between low latitude wintering areas and higher latitude feeding grounds in the south-west Atlantic. Additionally, the strong and opposing seasonality in the occurrence of sei whales on the Falklands foraging ground (Nov–Jun: Weir, 2022) and in sei whale catches at shore stations in Brazil (Jun–Nov: Paiva and Grangeiro, 1965, 1970), are supportive of potential seasonal movements between the two areas. It was recently discovered that sei whales commence singing during the autumn in the Falklands, a behaviour concurrent with reproductive display and considered to mark the onset of the breeding season in other baleen whales (Cerchio and Weir, 2022). The onset of singing and the subsequent seasonal departure of sei whales from the Islands likely reflects the migrations to their winter breeding areas, and sightings of sei whale calves during winter and spring confirm the presence of breeding off Brazil (Heissler et al., 2016; Wedekin et al., 2018). The movement of Keppel away from the Falklands and towards the offshore waters of Brazil adds to the existing information and supports migrations between the two areas. Although highly speculative, if Keppel had continued on the same course after its tag ceased transmitting, it would have ended up in the vicinity of the Vitória-Trindade Seamount Chain, an area known to be used by breeding sei whales during winter (Heissler et al., 2016).

4.4.3. Dive behaviour

Few previous studies have described the diving behaviour of sei whales, and they primarily occurred in oceanic habitats (Ishii et al., 2017; Baracho Neto et al., 2019). Some information on dive behaviour in the neritic Falklands feeding area was provided by Weir et al. (2018) but focussed on dive duration and cue rate parameters that could be assessed visually during focal follows, rather than on subsurface use of the water column. The maximum dive duration recorded during focal follows by Weir et al. (2018) of 13.6 min was similar to the 15.1 min maximum dive duration recorded using telemetry data in this study. It is also within a similar range of the maximum dive duration of 12.2 min recorded in oceanic habitat (Ishii et al., 2017), suggesting that sei whales primarily undertake relatively short dives regardless of their habitat.

Overall, the diving behaviour of sei whales in the Falkland Islands may be characterised as shallow and short duration. The clear majority of time was spent in the upper 10 m of the water column both in the FICZ and in Berkeley Sound, and QDs rarely exceeded 5 min duration. The majority of QDs recorded by the sei whale tags were square-shaped or U-shaped. Both of these dive shapes are considered indicative of foraging dives by baleen whale species (Fortune et al., 2020; Fonseca et al., 2022), allowing an animal to spend relatively more time at the deepest part of the dive where it is assumed that the targeted prey layer occurs. Therefore, the depths reached on such dives can be inferred to represent the layer within the water column where crustacean prey species are distributed at sufficient densities for sei whales to feed. While most of the dive behaviour recorded in this study was in neritic habitat which might have constrained dive depth and duration, some data were available from the tag of Keppel in deep oceanic habitats seaward of the shelf edge and in the Argentine Basin. Keppel's dives in oceanic habitat continued to be primarily shallow and short in duration, and this was also the case for two sei whales tagged in oceanic habitat off Japan (Ishii et al., 2017). Therefore, while sei whales are certainly physiologically capable of much deeper dives (e.g., Baracho Neto et al., 2019), ecologically it may not often be necessary to undertake them.

The time that sei whales spent in the uppermost water column included shallow foraging dives, the surfacing bouts between foraging dives, and time spent engaged in other behaviours such as rest or socialising. However, sei whales also forage at the surface, and are currently the only balaenopterid species known to regularly engage in skim feeding in addition to surface and subsurface lunging (Segre et al., 2021). Because the satellite tags require a user to define QDs using depth and duration thresholds, it was only possible to quantify the depth and duration of dives exceeding 5 m and 1 min respectively during this study. Therefore, the amount of time that individual whales spent engaged in surface feeding could not be distinguished from other, non-foraging, surface behaviours. This is relevant in a management context, because it means that the total amount of foraging behaviour may be under-estimated and the occurrence of square- and U-shaped QDs does not represent the full repertoire of sei whale foraging behaviour. Further, it has been noted during other studies that some baleen whale species are often easier to approach when surface feeding, since their manoeuvrability is more limited by engulfed prey (Calambokidis et al., 2019). This has also been noted specifically for sei whales during observations in the Falkland Islands (C. Weir, pers. obs.) and by whalers (Horwood, 1987), with feeding animals becoming unusually tolerant of vessels that they would normally avoid. Feeding whales were therefore easier to catch by whalers (Horwood, 1987) and provided the only opportunities for deploying suction-cup tags on whales in the Falklands during 2019 (Segre et al., 2021; Weir, 2022). Consequently, the behaviour of surface feeding whales may also increase their vulnerability to some anthropogenic activities, most notably the increased potential for vessel collisions (Calambokidis et al., 2019). Suction cup deployments appear to represent the only reliable way to currently distinguish between skim-feeding and non-foraging, surface behaviours, for sei whales, but are short in deployment duration and can be difficult to recover in a geographically-remote and windy environment such as the Falklands.

It was anticipated that the amount of time that sei whales spent near the surface might potentially increase during the hours of darkness in relation to the diel migration of prey layers as has been shown for some other baleen whale species (e.g. Friedlaender et al., 2013; Keen et al., 2019). However, there was little evidence of that; in the behaviour dataset the maximum depth of QDs was deeper at night than during the day, while the TAD summary indicated relatively similar depth distributions during the night and day. Little is understood of the vertical distribution of potential sei whale prey in the Falklands, or whether documented prey such as lobster krill undertake diel migrations. However, shoals of lobster krill are relatively rarely observed in the surface layers of Berkeley Sound during boat survey work and it is assumed that their highest densities occur subsurface. A survey of lobster krill in the Beagle Channel found that the pelagic stage did not exhibit diel vertical migration, remaining mostly in the upper (<50 m) layers of the water column (Castro et al., 2021). If this is also the case in the Falkland Islands, then sei whales targeting lobster krill might be expected to exhibit similar dive behaviour throughout the day and night. Targeted prey surveys would be desirable in Berkeley Sound to better understand the spatio-temporal occurrence and vertical distribution of prey and how it influences the dive behaviour of sei whales

4.4.5. Insights for vessel collision risk

All of the tagged sei whales spent the majority of their time within the upper water column at 0–10 m depth. This included 78.0% of time within Berkeley Sound and 82.7% of time in the wider FICZ. The high use of the upper water column potentially increases their exposure to vessel strike. Berkeley Sound (in addition to Stanley Harbour and Port William) comprises the main area of vessel activity in the Falklands, dominated by platforms directly (i.e. reefers, longliners, jiggers, trawlers, fishery patrol) or indirectly (i.e. tankers, launches) related to the fishing industry, which use the area for transhipments and bunkering.

A summary of vessel drafts for some of the categories of vessel that most frequently use the FICZ and Berkeley Sound is provided in Annex 1. They range from 1.0 m for launches to 10.7 m for a large motor research vessel, with most vessels having drafts in the region of 5.0 to 9.0 m (Annex 1). This includes many of the vessels associated with the fishing industry which are the highest users of Berkeley Sound. It also includes cruise vessels, which do not commonly visit Berkeley Sound but do travel round the FICZ while visiting Stanley and some of the islands during the summer tourist season.

The high overlap between the draft of vessels around the Falklands and the preferential use of the upper water column by sei whales, potentially increases their vulnerability to vessel collision. Globally, vessel strikes on sei whales are thought to be under-reported because struck whales may be dislodged from the bow in rough seas and deceased animals are unlikely to wash ashore due to the pelagic distribution of sei whales in many geographic regions (Weir and Prieto, 2024). Nevertheless, at least four sei whales died as a direct result of vessel strike in the USA between 2013 and 2020 (Henry et al., 2020, 2022), while Van Waerebeek et al. (2007) reported four confirmed or suspected cases of strikes in the southern hemisphere, including two mortalities from container ships. In 2009, a cruise ship docked in Puerto Montt in Chile with a freshly dead sei whale across its bow (Brownell et al. 2009). The nearshore occurrence of sei whales in the Falkland Islands likely results in higher spatial overlap with shipping than elsewhere. To date, two minor physical contacts between sei whales and smaller vessels have been reported in the Falklands (Weir, 2017, 2018), highlighting the potential for more serious interactions with larger, faster-moving vessels.

Although a voluntary Falkland Islands Cetacean Code of Conduct has been produced to recommend how marine users can behave around cetaceans to reduce potential negative impacts, no awareness guidance or mandatory mitigation (such as reduced vessel speed) is currently in place in Berkeley Sound to manage the coexistence of vessels and whales. Given the results of this study, it is recommended that awareness documents on whales are included in the standard documentation issued to vessels visiting the wider Stanley Harbour-Port William-Berkeley Sound area. Further, it is recommended that a vessel speed limitation is introduced as mandatory inside Berkeley Sound at night and during the day unless a dedicated whale lookout is used, with 10 knots recognised globally as a speed within which vessel strikes are less likely to cause serious injury to, or mortality of, large whales[5],[6].

4.4.5. Conclusions

The telemetry work has further highlighted the importance of Berkeley Sound as a foraging area for sei whales, providing novel data on residency and foraging behaviour within the site. Almost all dives within Berkeley Sound comprised foraging dives, adding to the existing knowledge that sei whales utilise the region as a seasonal feeding ground. The inability of the current satellite tag technology to separate between surface feeding and other behaviours limits interpretation, but was an expected caveat of this study. However, the telemetry work has provided valuable information on sei whale use of the water column, and highlights the high overlap between the vertical distribution of whales and the drafts of the vessels most often using Berkeley Sound, which raises concerns for potential vessel strike. While the tags provided less information on the use of waters outside of Berkeley Sound than expected, this was predominantly the result of animals remaining within Berkeley Sound for long periods which meant that most tags ceased transmitting within, or shortly after departing, the Sound. The study provided proof of concept, and it is recommended that additional satellite tagging of sei whales in Berkeley Sound is carried out to improve sample size and expand on the findings of the current dataset. Tagging in other parts of the Falkland Islands would also be very valuable in understanding whale movements, although logistically challenging. Two LIMPET tags remain at the end of DPLUS126, and it is intended that they will be deployed during 2025 if the opportunity arises.

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[5] https://www.mmc.gov/priority-topics/vessel-strikes/

[6] https://www.fisheries.noaa.gov/national/endangered-species-conservation/reducing-vessel-strikes-north-atlantic-right-whales

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Chapter 5: Local and regional movements of southern right whales tagged in the Falkland Islands

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5.1 Introduction and aims

Satellite telemetry has become an important tool for studying marine vertebrates, providing unique data on highly-mobile and wide-ranging species, those occupying harsh and remote environments, and throughout both day and night (Cooke, 2008). Telemetry provides an array of data relevant to the conservation and management of marine vertebrates, including information on spatio-temporal movements, identification of home ranges and critical habitats, behaviour, population structure, and overlap with anthropogenic activities (Cooke, 2008; Costa et al., 2010; Williamson et al., 2019). Satellite telemetry is a particularly applicable tool for baleen whale studies, where animals spend most of their lives underwater and inaccessible to researchers, and travel long distances across remote habitats during their annual migrations between feeding and reproductive areas. Moreover, their large body size makes them relatively robust to the invasive attachment and physical weight of a satellite tag.

Southern right whales (*Eubalaena australis*, SRW) have a circumpolar distribution across the Southern Hemisphere. Although classified as globally 'Least Concern' by the International Union for Conservation of Nature (Cooke and Zerbini, 2018), the population of SRWs inhabiting the south-west Atlantic is of conservation concern due to widespread calf mortalities in recent decades (Rowntree et al., 2013). As a result, the International Whaling Commission adopted a Conservation Management Plan for south-west Atlantic SRWs in 2012, aiming to protect habitat for the population and minimise anthropogenic threats to maximise its recovery to pre-exploitation levels.

The vast majority of SRW research globally has focussed on the well-established winter calving grounds located in coastal temperate and subtropical habitats (Cooke and Zerbini, 2018; Harcourt et al., 2019), given their proximity to human habitation, predictable winter whale occurrence, and favourable weather conditions for field research (compared with oceanic and higher latitude habitats). However, the whales spend most of their year, and perhaps the entire year during non-breeding stages of their life cycle, in pelagic foraging habitats located from mid to high latitudes across the Southern Hemisphere (Zerbini et al., 2016, 2018; Harcourt et al., 2019). The distribution and behaviour of SRWs using their pelagic feeding grounds are relatively poorly documented, yet suspected to have a major influence on post-whaling population recovery by affecting the number of calves born annually (Leaper et al., 2006; Seyboth et al., 2016) and calf survival (Rowntree et al., 2013). As a result, increasing conservation emphasis has been placed on understanding the foraging behaviour and movements of SRWs outside of the core calving grounds, primarily through the use of satellite telemetry (Carroll et al., 2020). Satellite tags were first used to track movements of SRWs in South Africa in 2001 (Mate et al., 2011), and have since been widely employed on calving grounds in Argentina (Zerbini et al., 2016, 2018, 2023), South Africa (Vermeulen et al., 2023), Australia, and the Auckland Islands in New Zealand (Mackay et al., 2020), as well as two deployed on a foraging ground (Kennedy et al., 2023).

In the south-west Atlantic, a wintering aggregation of SRWs has been documented in coastal waters off the north-east Falkland Islands, hereafter 'FI', annually since 2017 (Weir and Stanworth, 2019; Weir, 2021, 2022; see Chapter 2). These whales often engage in surface active behaviour, with frequent observations of mating (Weir, 2021, 2022), and the presence of gunshot song (a male reproductive display: Crance et al., 2019) recorded throughout the winter months (Cerchio et al. 2022), strongly supporting reproductive behaviour. To date, no calves-of-the-year have been confirmed in the FI wintering ground (hereafter 'FIWG'), despite survey effort occurring during August and early September when calving occurs elsewhere (Rowntree et al., 2013). The composition of SRWs in the FIWG comprises both adults and juveniles (see Chapter 3), with a sex ratio biased towards males (Jackson et al., 2022a). Genetic analysis has revealed that the SRWs using the FIWG are part of the wider south-west Atlantic population (Jackson et al., 2022a), for which the major contemporary calving and nursery grounds are located at Peninsula Valdés (PV) in Argentina and Santa Catarina in Brazil (Cooke and Zerbini, 2018). However, an adult female from a South African calving ground was also recently documented in the FIWG (Vermeulen et al., 2023), suggesting that the Islands represent an important strategic location for understanding the movements, connectivity, and behaviour of SRWs across the wider South Atlantic region. As one of few permanently-occupied human settlements located south of 50°S worldwide, the FI also offer access to SRWs close to some of their pelagic sub-Antarctic foraging grounds.

This chapter describes the results from the deployment of 10 satellite tags on SRWs in the Falkland Islands during July 2022. The key aims of this work with regard to better understanding the conservation and management related aspects of SRW occurrence in the Falklands included:

1. To assess how long individual SRWs spend in the FI during winter, and therefore better understand whether animals are simply transiting through the Islands or whether the FI comprise a destination where animals remain for a protracted period; and
2. To clarify the core habitats used by SRWs in the FI, given that current information has been limited (by the logistical constraints of small boat work) to the area in proximity to Stanley and to waters within 5 km of the coast.

In addition, the FI were recently highlighted as a high priority area to focus southern right whale tagging effort to address wider information gaps across the southern hemisphere (Carroll et al., 2020). The tag deployments in the FI therefore also provided the opportunity to collect data on the movements of SRWs after they depart the FI, including whether or not they continue on to calving areas and links with foraging grounds.

The results of this study have already been published in an open access peer-reviewed paper on which much of this chapter is based:

- Weir, C.R., Fernandez, S., Jackson, J.A., Miller, A., Sucunza, F., Slesser, H.W. and Zerbini, A.N. (2024). Movements and behaviour of southern right whales satellite-tracked in and beyond a subantarctic archipelago wintering ground. Endangered Species Research, 55: 229–245. https://doi.org/10.3354/esr01371

5.2 Materials and methods

5.2.1. Study area

The study area for deploying the tags comprised the coastal waters located between the Cape Pembroke peninsula and MacBride Head on the north-east coast of East Falkland, but with most tag deployment effort concentrated in the waters from Volunteer Point north to Dutchman's Island (Figure 5.1). That coastline is very exposed to weather and swell, and consists of sandy beaches interspersed by rocky coastline with numerous kelp beds extending out from the shore.

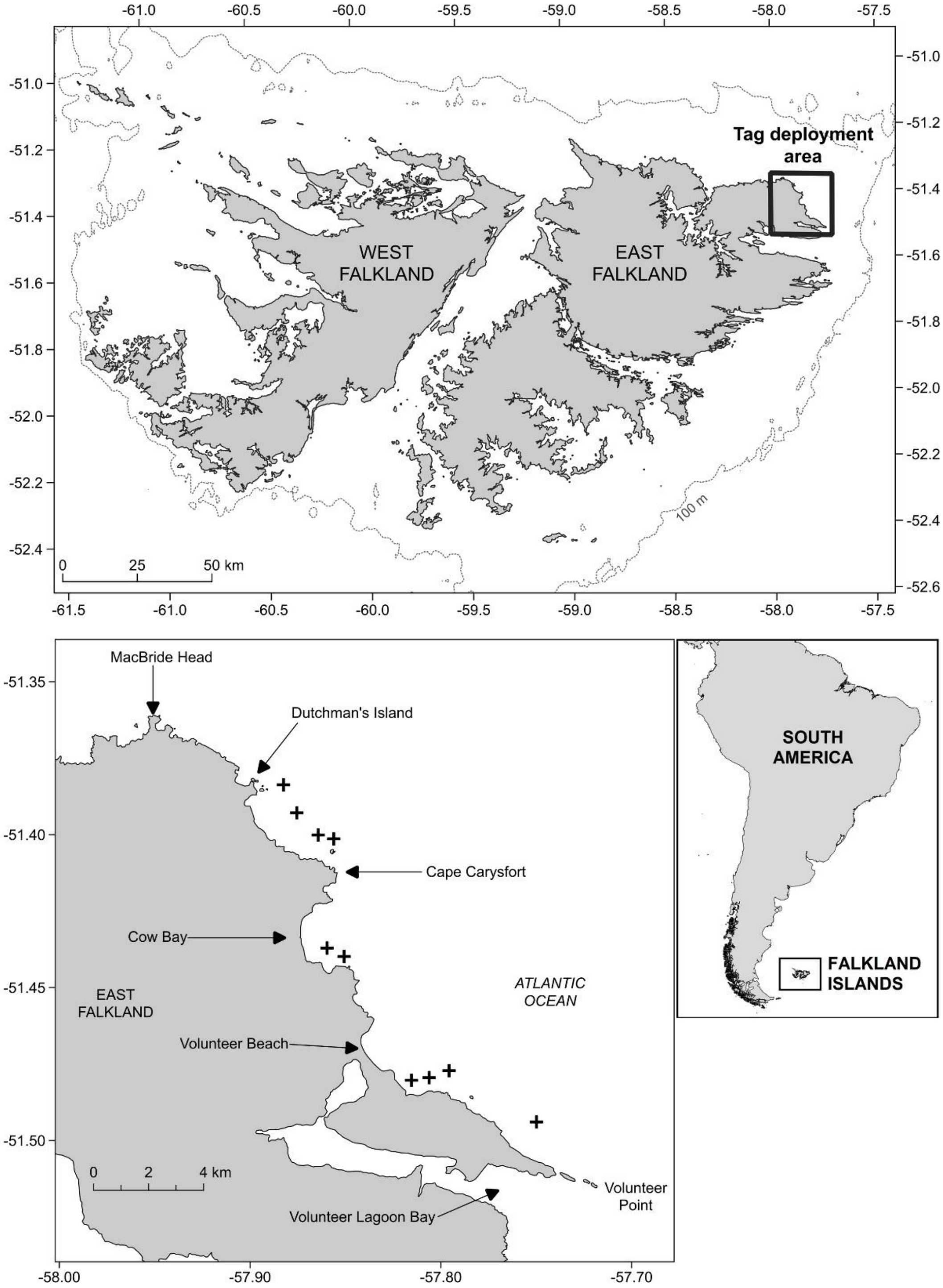


Figure 5.1. The study area, showing the tag deployment locations (crosses) for 10 southern right whales in 2022.

5.2.2. Tag programming

A total of 10 fully integrated consolidated Argos satellite tags manufactured by Wildlife Computers were acquired for the SRW tagging programme:

1. Five SPOT-303F location-only tags, provided collaboratively by the British Antarctic Survey; and
2. Five SPLASH10-373A tags that were purchased for the project as part of DPLUS126.

Tags were sterilised prior to deployment via: (1) ethylene oxide in a commercial gas sterilisation unit, after which they were kept in individual sterilisation pouches until use (SPOT tags); or (2) disinfection in 10% bleach (sodium hypochlorite), followed by a dip rinse in ethyl alcohol and air dry before wrapping in tinfoil and kept dry inside a freezer bag (SPLASH tags).

Tags were programmed to transmit daily from 08:00–16:00 and 19:00–06:00 UTC (SPOT tags) and from 08:00–16:00 and 18:00–06:00 UTC (SPLASH10 tags). Those transmission periods were selected to coincide with Argos satellite passes. The maximum number of transmissions was set to 20/hour (SPOT tags) and 400/day (all tags).

5.2.3. Tag deployments

For the SRW tag deployments, a 7.5 rigid-hulled inflatable boat operated by Falklands Conservation was fitted with a raised bowsprit platform that provided a height above the waterline of approximately 1.5 m (Figure 5.2). Boat surveys were limited to weather conditions comprising ≤12 knots of wind and ≥5 km visibility.

Figure 5.2. The tagging platform fitted to the research boat.

Tagging methods followed best practice approaches (Andrews et al., 2019), using a trained and experienced whale tagger. Prior to tagging attempts, time was spent assessing the animals and acquiring images for photo-identification work using a Canon 5D camera fitted with a 100–400 mm lens. This assessment period allowed the team to check the age composition of SRW groups, identify individual focal animals that might be suitable for tagging, and determine whether the behaviour of the group (and their location) was suitable for small boat approaches.

During tagging attempts, animals were carefully approached to sufficient proximity (≤3 m) to place a tag dorsally behind the blowholes to optimise transmission time during surfacing events. Tags were deployed using a modified pneumatic line thrower (ARTS, Restech) set to a pressure of 17 to 20 bars. Whenever possible, the tagged whales were biopsied for genetics and sex determination using a Barnett BCR Recurve crossbow (150 lb draw weight) fitted with bolts and sterile stainless-steel biopsy tips from CETA-DART. Short video clips of tag deployments were taken with a GoPro camera mounted on the head of the arbalester (Figure 5.3).

Figure 5.3. Preparing to deploy a tag on a SRW in the FI on 8 July 2023. Image is from a GoPro camera mounted on the head of CW while preparing to simultaneously collect a biopsy sample.

5.2.4. Data analysis

5.2.4.1. Genetic sexing

DNA was extracted from skin tissue using a Qiagen DNEasy Blood and Tissue kit. Genomic DNA was visualised on a 2% agarose gel to assess DNA quality, and DNA was quantified using a Nanodrop. Sex determination of the tagged whales was carried out through multiplex PCR amplification of the ZFX/ZFY sex-linked gene (Bérubé and Palsbøll, 1996).

5.2.4.2. Location data

Location data were provided by the Argos System (Argos, www.argos-system.org). A location quality class (LC) is automatically allocated to each Argos location, and has four levels of reported accuracy: LC-3 with a stated error of <150 m, LC-2 with error of 150–350 m, LC-1 with error of 350–1,000 m, and LC-0 with error >1,000 m. Additionally, locations derived from 2 or 3 messages have unknown error estimates and are assigned LC values of B and A respectively, while locations deemed ‘invalid’ by Argos are assigned LC-Z. It is common for most locations in animal tracking studies to comprise lower accuracy LCs of 0, A, B or Z. It is also apparent from combined satellite and GPS tagging that the error levels stated by Argos are often exceeded in animal tracking studies; for example, LC-A and LC-B locations produced mean errors of 3.5 and 14.3 km respectively during sea turtle tracking (Witt et al. 2010), and 31.5 and 36.1 km respectively during pinniped tracking (Costa et al., 2010). To analyse SRW movements and behaviour, implausible locations were removed while retaining as much positional information as possible. Initial manual cleaning of the Argos data was carried out to remove LC-Z positions (n=18). Additionally, positions with latitudes or longitudes greater than 4 standard deviations from the mean latitude or longitude calculated based on the 2 days before and after the date/time of that location were removed (n=58). The remaining tag locations (n=36,694, all tags combined) comprised the 'unfiltered dataset.'

Further preprocessing included the removal of locations that plotted on land using the st_intersects function from the "sf" package in R (version 4.3.3; R Development Core Team 2024). A speed-filter was applied to remove locations that would have required unrealistically high swim speeds (defined as >6 m s^{-1}). Sections of data separated by gaps exceeding 24 hr (i.e. due to pauses in tag transmission) were treated as independent, and sections comprising fewer than 10 locations were removed. The remaining tag locations (n=26,747, all tags combined) comprised the 'filtered dataset.'

5.2.4.3. Behavioural State modelling

The filtered dataset was fitted with a Continuous-Time Correlated Random Walk (CTCRW) model to predict locations at a variety of time intervals using the crawlWrap function from the "crawl" package version 2.3.0 (Johnson et al., 2008) in R. The selected model predicted locations at 6-hr intervals, with the 'modelled dataset' containing 5,188 predicted locations for all tags combined.

Data were modelled with 2- and 3-behavioural state discrete-time hidden Markov models (HMM) using the "momentuHMM" package (version 1.5.5; McClintock and Michelot, 2018) in R. The model with the lowest negative logarithmic probability and distribution of pseudo-residuals was selected. The best model included 3 behavioural states (BS) comprising:

- BS1: slow and non-directional movement indicative of high-use habitats;
- BS2: intermediate speed of movement and rate of directional change; and
- BS3: faster and directed movement, consistent with transitory habitats.

The step length was modelled based on a Gamma distribution with initial values of 5.73 ± 4.07 km, 13.41 ± 8.27 km, and 28.79 ± 9.17 km for BS1, BS2, and BS3, respectively. The turning angle was modelled as a wrapped Cauchy distribution with an initial concentration parameter of 0.03 for BS1, 0.24 for BS2, and 0.76 for BS3. The Viterbi algorithm was used to compute the most likely sequence of those three underlying BS in the track (Zucchini et al., 2017; McClintock and Michelot, 2018).

5.2.4.4. Habitat

Throughout this chapter, the locations of tagged SRWs are described as broad habitat types according to water depth: (1) shelf (<200 m depth); (2) slope (200–1,999 m depth); and (3) oceanic (≥2,000 m depth). Since SRWs primarily use nearshore temperate habitats for winter reproductive behaviour, shelf habitats in South America and the FI were further subdivided into: (1) nearshore (<30 km from the coast); and (2) outer shelf (≥30 km from the coast). We followed the terminology of Wilding Brown and Sironi (2023) in defining the areas where calves are born as calving grounds, areas where mothers provide neonatal care as nursery grounds, and areas where courtship and copulation occur to be breeding grounds.

Both the unfiltered and modelled datasets were mapped using Quantum Geographic Information System (QGIS, v.3.28). Water depth was extracted for each location using QGIS and a gridded bathymetric file obtained from General Bathymetric Chart of the Oceans 2023 (GEBCO Compilation Group, 2023). In both datasets, water depths and distances from shore were assigned standard default values of 5 m and 0.5 km respectively for locations that plotted on land. The distance travelled by individual SRWs was calculated using QGIS for the modelled dataset only.

5.2.4.5. Statistical analysis

Statistical analysis was carried out in JASP (JASP Team, 2024). Pairwise comparisons following Kruskal-Wallis tests were carried out with Dunn's post hoc tests.

5.3 Results

The 10 satellite tags were deployed on SRWs in the FIWG over six days between 6 and 24 July 2022 (Table 5.1), and the deployment locations are shown in Figure 5.1. Most (n=8) whales were tagged within surface active groups (SAGs). The sex of eight individuals was determined genetically, comprising five males and three females (Table 5.1). The sex of one animal (Elizabeth, PTT171985) was also confirmed in the field to be female, based on belly-up behaviour within a SAG and observation of the genital area.

The transmission duration of the 10 tags ranged from 27 to 261 days, with a mean of 137.8 days. The transmission duration of SPOT tags (mean=159.0 days, median=163 days, range=27–261, n=5) was greater than SPLASH10 tags (mean=116.6 days, median=114 days, range=101–136, n=5). The shortest duration tag (27 days) was deployed on an adult female who was the focus of a mating group. All other tag durations exceeded 100 days (Table 5.1), during which animals moved up to 15,375 km (Weir et al., 2024). The number of daily locations provided by SPOT tags (median=30.0) was significantly higher than the number from SPLASH tags (median=25.0; Mann-Whitney test, W = 142715.0, $p<0.001$). Daily positions were received continuously from each tag over its transmission period, with the exception of: (1) Dora on 31 July 2022, from 29 January to 12 March 2023, and on 19 March 2023; (2) Elizabeth from 25 July to 3 August; and (3) Kelpie from 25 July to 30 July, and on 2 August. Mean swim speeds of the 10 SRWs over continuous tag transmission periods ranged from 1.53 km/h to 3.19 km/h (Weir et al., 2024).

5.3.1. Individual whale movements

A summary of the movements of each tagged SRW is provided, and maps shown in Figures 5.4 to 5.13. A map showing the model-predicted locations for all 10 whales is provided in Figure 5.14. Where distances are presented in the following accounts, they are straight-line distances between satellite positions and should only be considered as indicative *minimum* movement distances.

The tagged whales were allocated names by local school children, in order to optimise outreach and make the tracking maps more relatable for the general public.

Table 5.1. Summary of southern right whale tag deployments in the Falkland Islands during 2022. LC refers to Argos location quality class. Argos locations received refers to the unfiltered dataset following initial quality-control to remove LC-Z positions (n=18) and those with latitude or longitude deviations from the mean exceeding 4 (n=58). Sex was determined genetically: M=male; F=female; U=unavailable.

Whale	Tag type	Sex	Transmission dates		Tag durn (days)	Argos locations received				No. of Argos locations per day	
			Start	Final		Total	Good quality (LC-1 to LC-3)	Moderate quality (LC-0)	Unknown quality (LC-A and LC-B)	Mean (SD)	Median
Beatrice	SPLASH	U	06 Jul 2022	28 Oct 2022	114	2,641	291	199	2,151	23.2 (4.0)	23.0
Sandy	SPLASH	M	08 Jul 2022	17 Oct 2022	101	2,868	494	246	2,128	28.5 (5.1)	29.5
Walter	SPLASH	M	08 Jul 2022	10 Nov 2022	125	2,498	320	97	2,081	20.0 (6.0)	20.0
Frosty	SPLASH	M	09 Jul 2022	24 Oct 2022	107	3,084	415	239	2,430	29.0 (9.5)	30.0
Kelpie	SPLASH	U	11 Jul 2022	24 Nov 2022	136	3,492	599	354	2,539	28.0 (6.8)	29.0
Elizabeth	SPOT	F	11 Jul 2022	07 Aug 2022	27	531	93	8	430	34.7 (9.8)	39.0
Elmo	SPOT	F	15 Jul 2022	27 Oct 2022	104	2,692	350	131	2,211	26.0 (7.2)	25.0
Byron	SPOT	M	24 Jul 2022	21 Mar 2023	240	7,828	1,678	863	5,287	32.7 (7.4)	32.0
Pebble	SPOT	M	24 Jul 2022	03 Jan 2023	163	6,018	1,613	689	3,716	37.0 (5.2)	36.0
Dora	SPOT	F	24 Jul 2022	11 Apr 2023	261	5,042	866	424	3,752	23.9 (7.8)	23.0

Beatrice (PTT232647): After tagging in the FI on 6 July, Beatrice remained close to the Falklands coast until 8 July and then moved away from the coast on 9 July and undertook a directed north-westerly movement across the Patagonian Shelf to arrive off Puerto Deseado (Argentina) on 15 July (Figure 5.4). It transited north across the outer Golfo San Jorge, and continued along the coast to arrive at PV on 21 July. It remained in Golfo Nuevo at PV for 77 days until 6 October, when it departed and moved north across the mouth of Golfo San Matias, crossing into Buenos Aires province on 15 October. Beatrice then continued northwards along the coast, before starting to move further offshore on 23 October. It remained in a relatively small area of the Patagonian Shelf (80 to 100 m water depth) located approximately 160 km north-east of Mar del Plata until the tag stopped transmitting on 28 October. Beatrice remained in shelf habitat (<200 m depth) throughout the tag deployment.

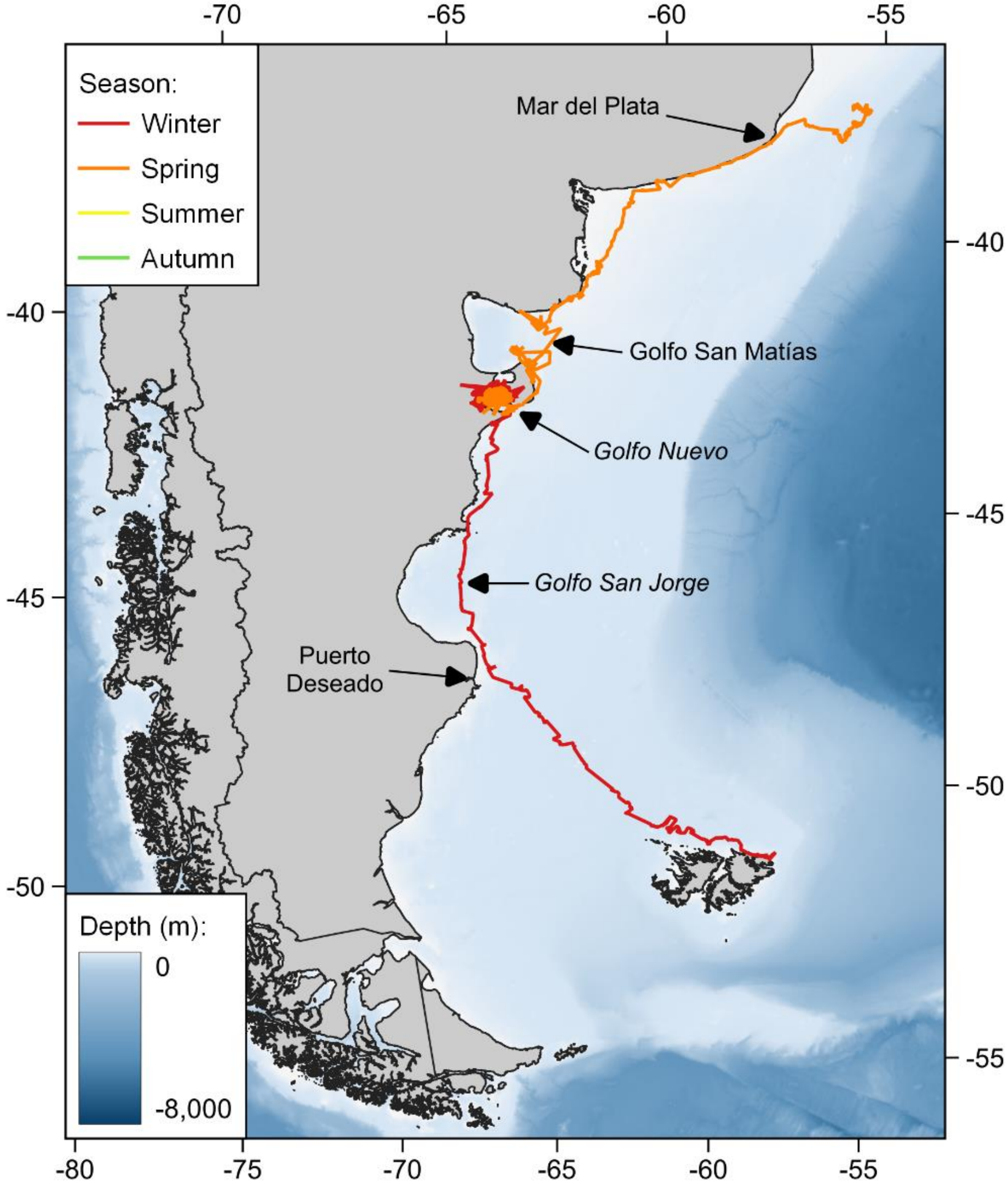


Figure 5.4. The movement of SRW 'Beatrice' following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean).

Sandy (PTT232648): Following tagging on 8 July, Sandy spent 57 days repeatedly moving west and east along the north coast of East Falkland, primarily between Berkeley Sound and Foul Bay, and usually within a few kilometres of the shoreline (Figure 5.5). During the final week of his stay in the FI, Sandy made an exploratory journey southwards through Falkland Sound, but doubled back at the southern end of the channel and moved north again. He continued back around the coast to Cape Bougainville, but then turned away from the FI coast on 3 September, embarking on a defined north-westerly movement in a direct line towards the northernmost point of the Golfo San Jorge where he arrived on 10 September. He then continued northwards along the Argentine coast, entering Golfo Nuevo at PV on 15 September. Sandy remained in Golfo Nuevo for 31 days until 16 October. His tag stopped transmitting on 17 October while he was still on the south side of PV. Sandy remained in shelf habitat (<200 m depth) throughout his tag deployment.

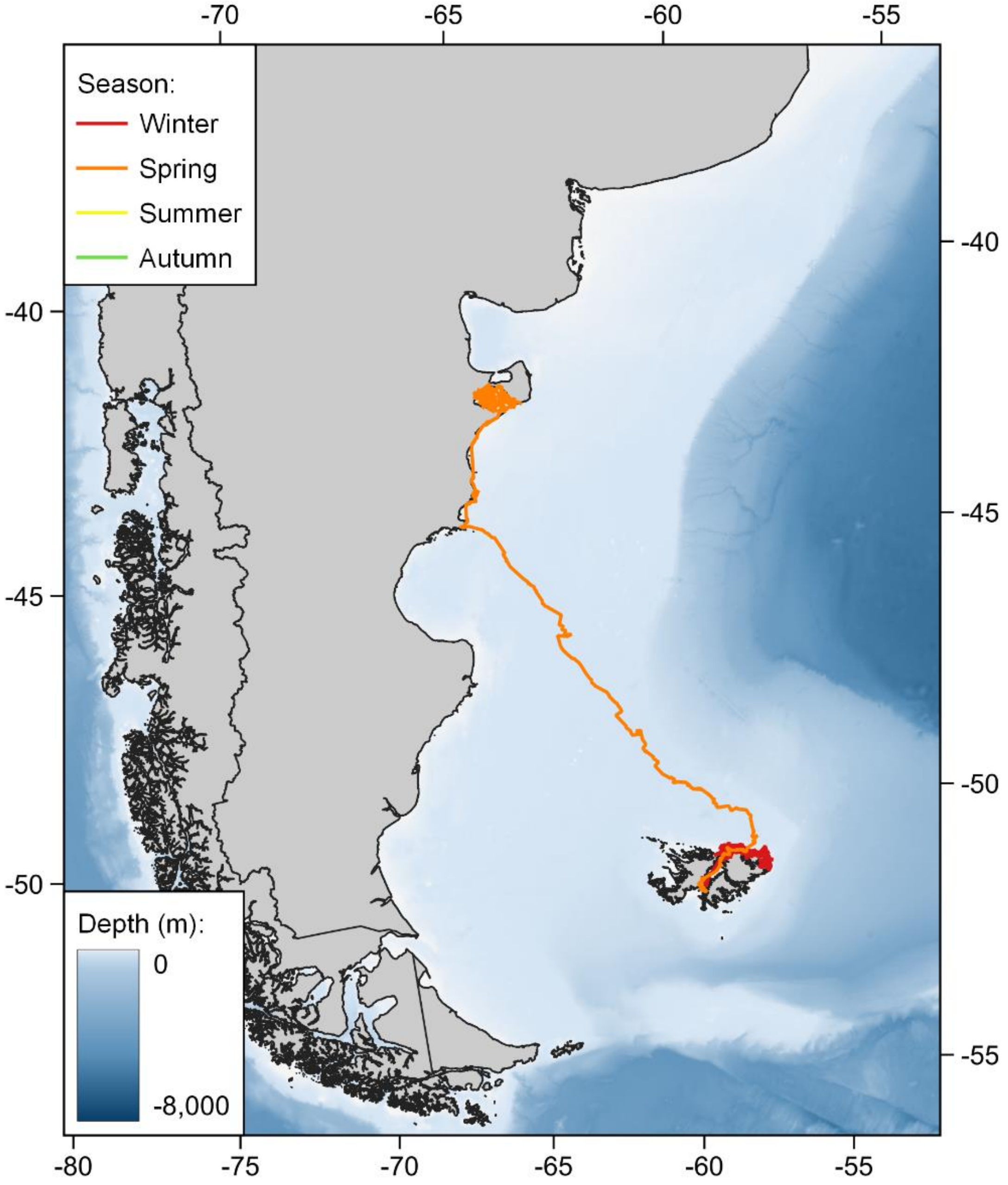


Figure 5.5. The movement of SRW 'Sandy' following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean).

Walter (PTT232646): Following tagging on 8 July, Walter spent two weeks moving back and forth along the north coast of the FI between Salvador and Concordia Bay (Figure 5.6). On 19 July he moved offshore to an area approximately 30 km north-east of the Falklands, and spent the following 16 days making several movements back and forth between that offshore region and the coastline between Volunteer Point and MacBride Head. From the 5 August, Walter moved westwards along the coast towards Cape Dolphin, before moving offshore on 8 August to the north-east of the FI. From 10 August, Walter began a week-long sustained directional movement away from the FI and towards the northernmost point of Golfo San Jorge (Argentina). He remained on the shelf, apart from a few days crossing deeper (200–500 m) waters from 12 to 15 August. He arrived off Golfo San Jorge on 22 August, then turned north and continued along the coast to PV, entering Golfo Nuevo on 28 August. Walter departed Golfo Nuevo on 3 October and, after a few days at the northern tip of PV, moved offshore to an area approximately 90 km south-east of PV, where he remained until 26 October. From the 27 October Walter started to move south along the Patagonian Shelf, pausing intermittently. The tag ceased transmitting on 10 November, at which time he was located east of the southern Golfo San Jorge, approximately 315 km from the nearest coast (Figure 5.6).

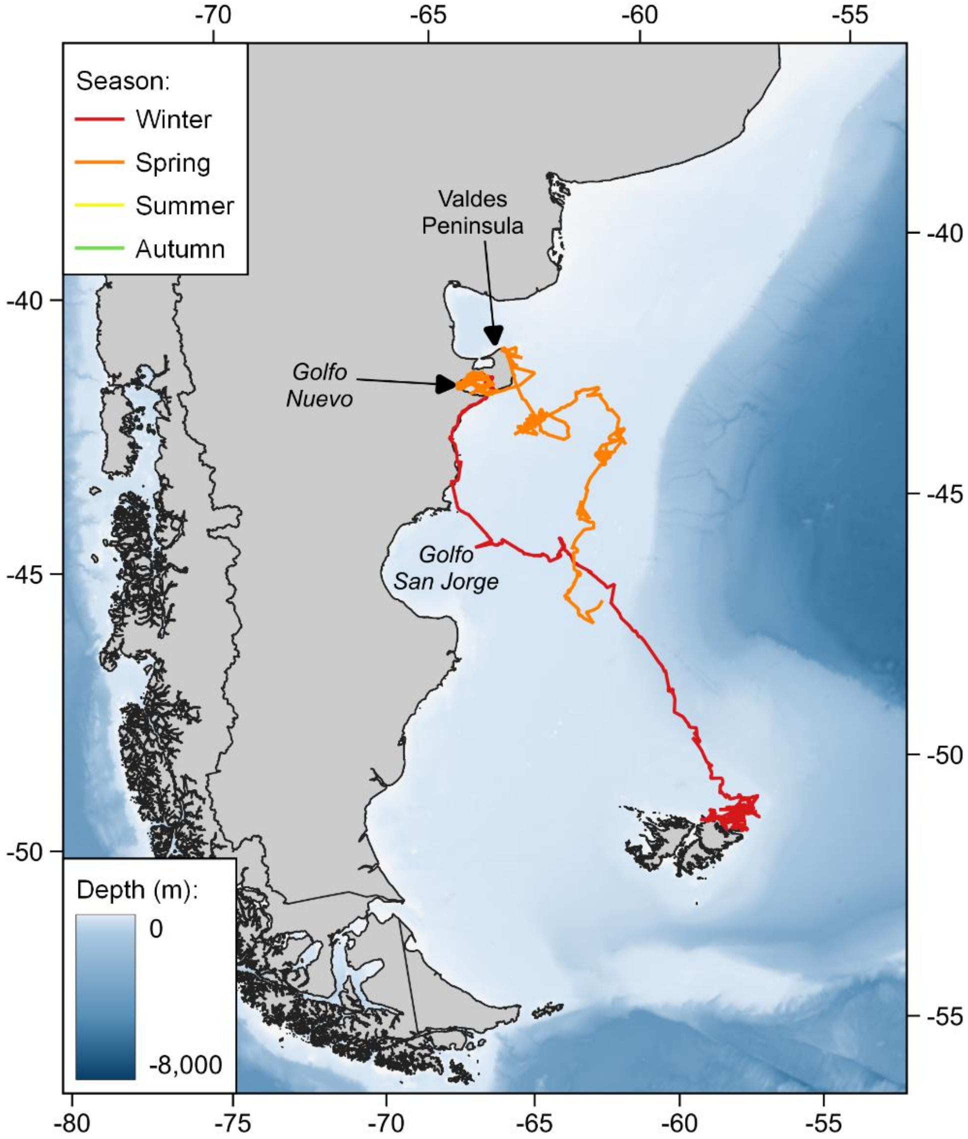


Figure 5.6. The movement of SRW 'Walter' following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean).

Frosty (PTT232645): Following tagging on 9 July, Frosty moved 45 km north-east of the FI where he stayed until 13 July, before commencing a long directional transit towards the South Orkney Islands (Figure 5.7). Approximately 175 km north-west of the South Orkneys on 26 July, Frosty turned west and continued for over 400 km before turning south again on 1 August and spending several days north of Elephant Island. The entire period from 16 July to 5 August was spent in oceanic habitat with water depths of 2,000 to 4,000 m. Late on 5 August, Frosty approached Elephant Island, and followed a deep-water channel south-west towards the main South Shetland Islands group. On 10 August he continued westwards along the north coast of the South Shetland Islands. On 13 August he turned south towards an area of continental slope (~50 to 1,500 m depth) in the Bransfield Strait located south of Low Island (Figure 5.7). He stayed in the latter area for 22 days before moving away on 5 September. On 8 September he moved into oceanic habitat (2,000 to 4,000 m depth), and commenced a northerly movement across the Drake Passage towards the Wollaston Islands (Chile) where he arrived on 15 September. Frosty spent several days in nearshore parts of Tierra del Fuego, before departing from the mainland on 18 September and travelling >1,400 km to the north-east, passing west of the FI. From 1–7 October, Frosty used an area of deep oceanic (~5,000 m depth) waters located west of PV. He then moved a further 400 km north to an area of the outer Patagonian Shelf (80–100 m depth) where he remained from 10 October until his tag ceased transmitting on 24 October.

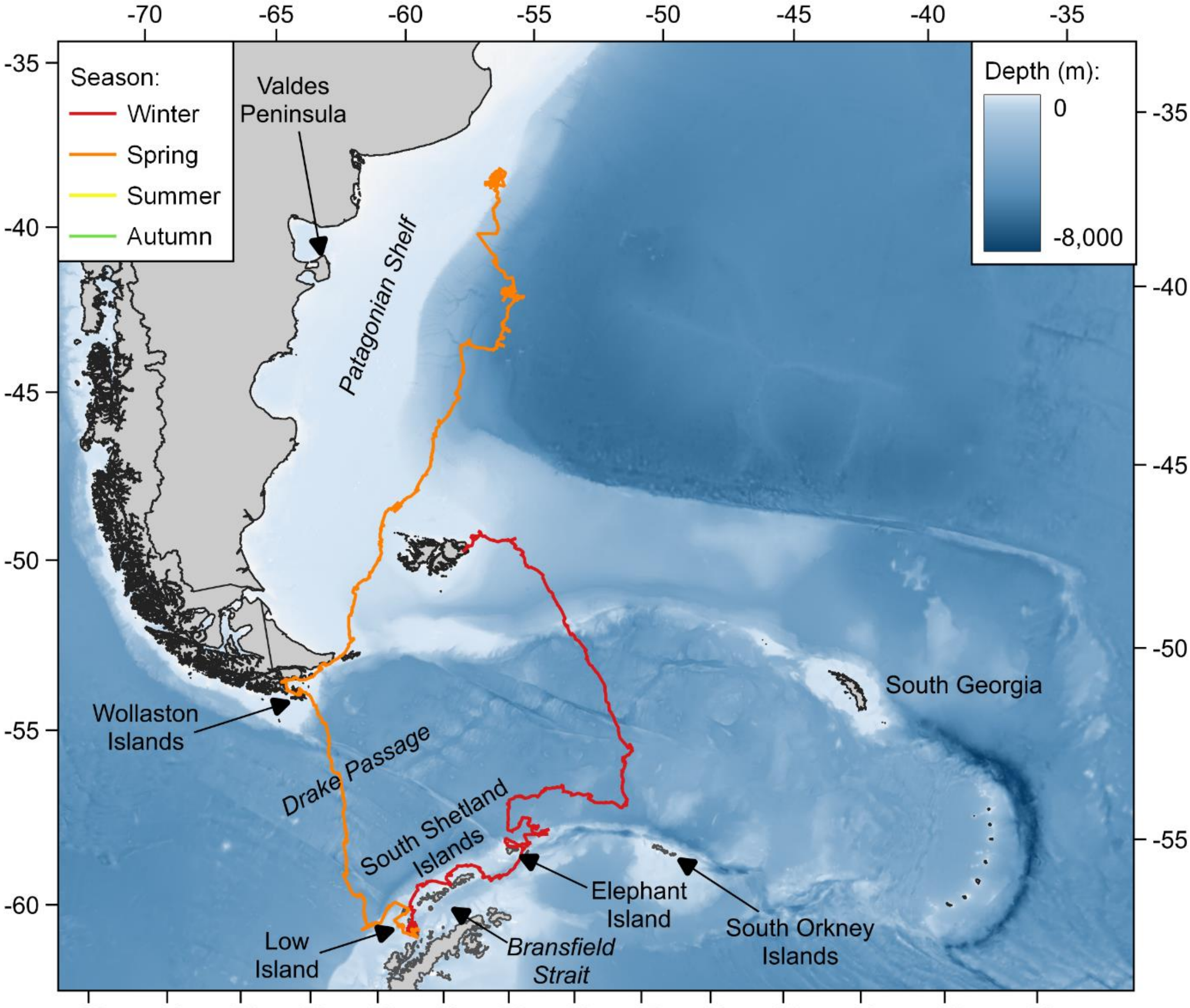


Figure 5.7. The movement of SRW 'Frosty' following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean).

Kelpie (PTT232644): After being tagged on 11 July, Kelpie moved westwards along the north coast of East Falkland reaching Foul Bay on 17 July, where it stayed until at least 24 July (Figure 5.8). Between 24 July and 2 August, the tag transmitted only intermittently and very few positions were acquired; however, those positions were in the Salvador area indicating that the whale was moving back along the north coast. It spent the next three weeks in nearshore waters moving between Berkeley Sound and Salvador, spending most time between MacBride Head and Salvador. On 5 September, after 56 days spent close to the FI coast, Kelpie began a directed movement away from the FI towards PV, including a crossing of slope habitat (200–1,000 m depth) from 6 to 9 September. However, on 11 September it turned northwards and continued along the outer Patagonian Shelf (70–100 m depth). On 18 September, Kelpie stopped moving north and spent prolonged time using relatively small spatial areas within a ~200 km area of the Patagonian Shelf to the north-east of PV. It remained in that area until the tag ceased transmitting on 24 November, with the exception of the period from 30 September to 11 October when it made an exploratory movement eastwards into deep water (>5,000 m depth) before returning to the shelf.

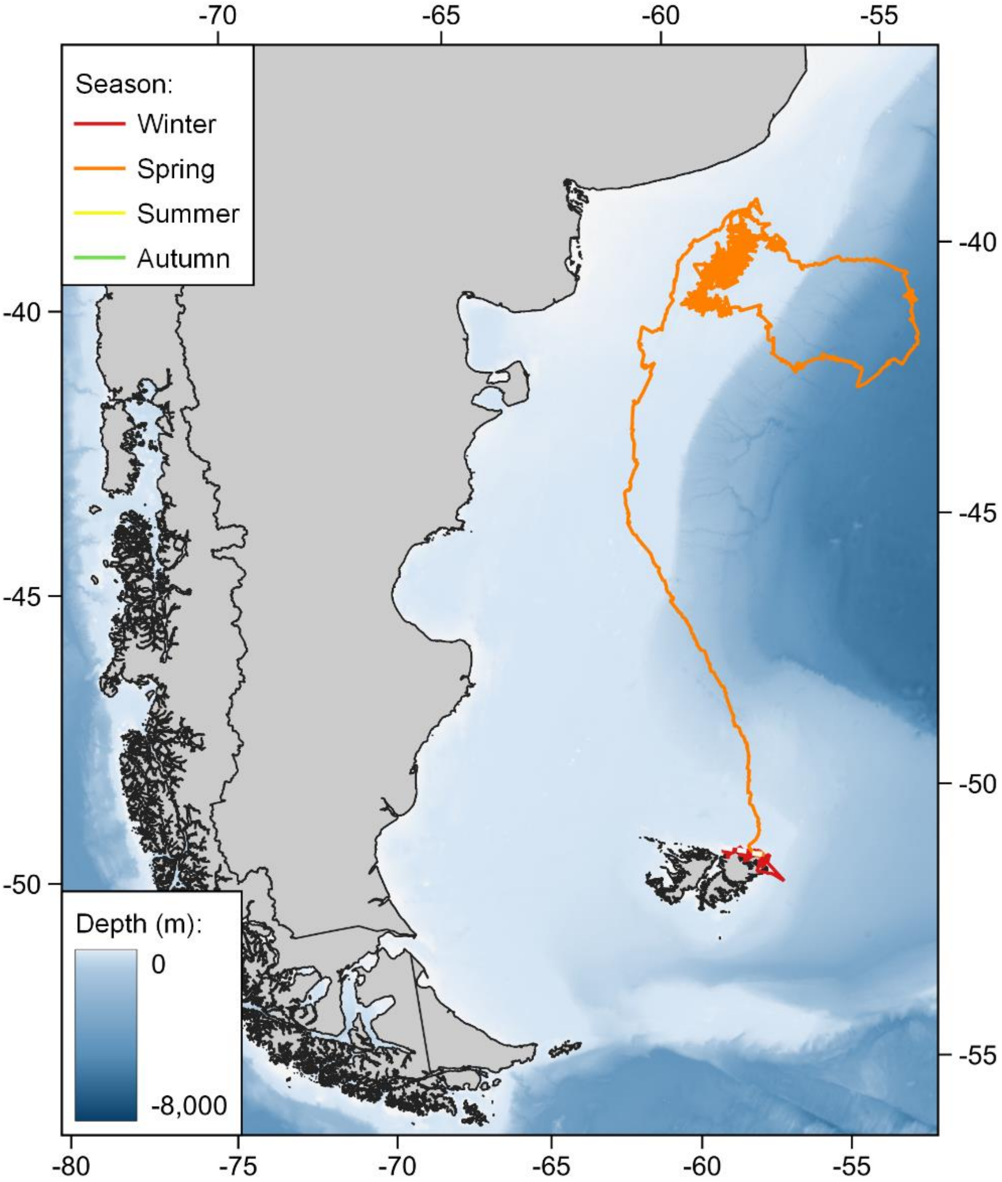


Figure 5.8. The movement of SRW ‘Kelpie’ following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean). Gaps in tag transmission exceeding 24 hr are shown by a dotted line.

Elizabeth (PTT171985): Elizabeth was identified in the field as an adult female, and was tagged within a SAG (with two presumed males) encountered on 11 July. After tagging, she moved ~30 km offshore and travelled around to the north coast of the FI, approaching the coast again off Cape Bouganville (Figure 5.9). She moved along the coast westwards to Cape Dolphin, and then again moved offshore ~30 km before approaching the north coast of Pebble Island. She continued to move west towards Sedge Island, but then on 20 July turned north-westwards and commenced a directional movement towards Golfo San Jorge. Unfortunately, the tag stopped transmitting on 24 July when Elizabeth was around 160 km from Puerto Deseado. The next transmission was not until 4 August, by which time she was located on the coast south of Rawson, and moving towards PV. At the final transmission on 7 August, she was just south of the entrance to Golfo Nuevo. All of the tag locations received for Elizabeth were in shelf waters (<200 m depth).

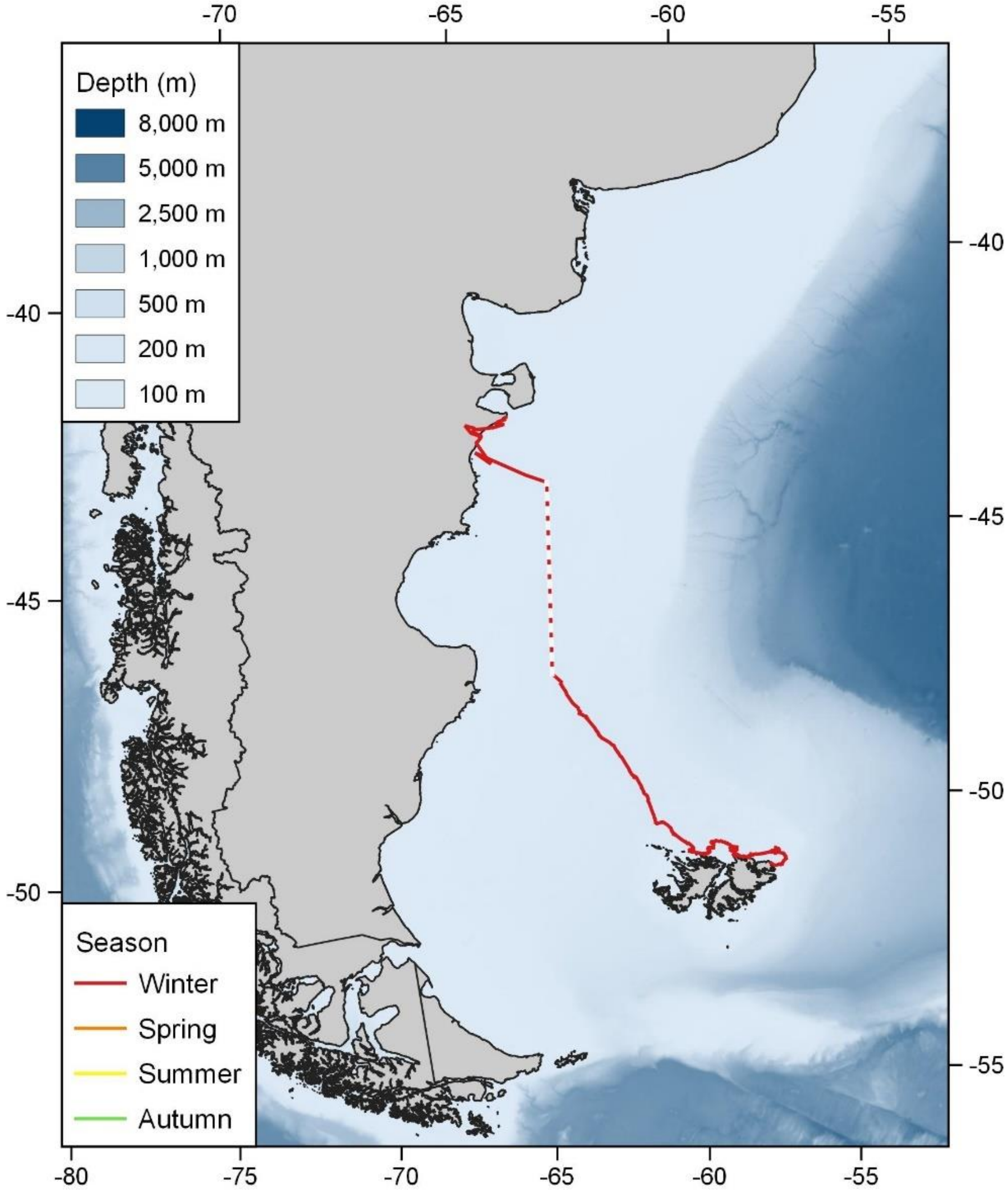


Figure 5.9. The movement of SRW 'Elizabeth' following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean). Gaps in tag transmission exceeding 24 hr are shown by a dotted line.

Elmo (PTT171989): In the three weeks following tagging on 15 July, Emo primarily remained close to the coast between Volunteer Point and the MacBride Head area (Figure 5.10). She made an offshore movement on the 23 and 24 July to around 65 km north-east of MacBride Head, but subsequently returned to the coast. On 8 August, Elmo began moving further west along the north coast of East Falkland, reaching Cape Dolphin on 12 August and then spending time in Foul Bay and San Carlos Water. On 19 August, 35 days after tagging, Elmo began a directional movement away from the FI, heading north-west and arriving at the southern coast of Golfo San Jorge on 25 August. She then travelled close to shore all the way around Golfo San Jorge, and onwards to PV. She entered Golfo San Jorge on 10 September, remaining there for 32 days until the 13 October. She then departed PV and moved offshore, arriving at an area of Patagonian Shelf located 90 km south-east of PV on 16 October. She remained in that area until her tag ceased transmitting on 27 October. Elmo utilised shelf waters (<200 m depth) throughout her tag deployment.

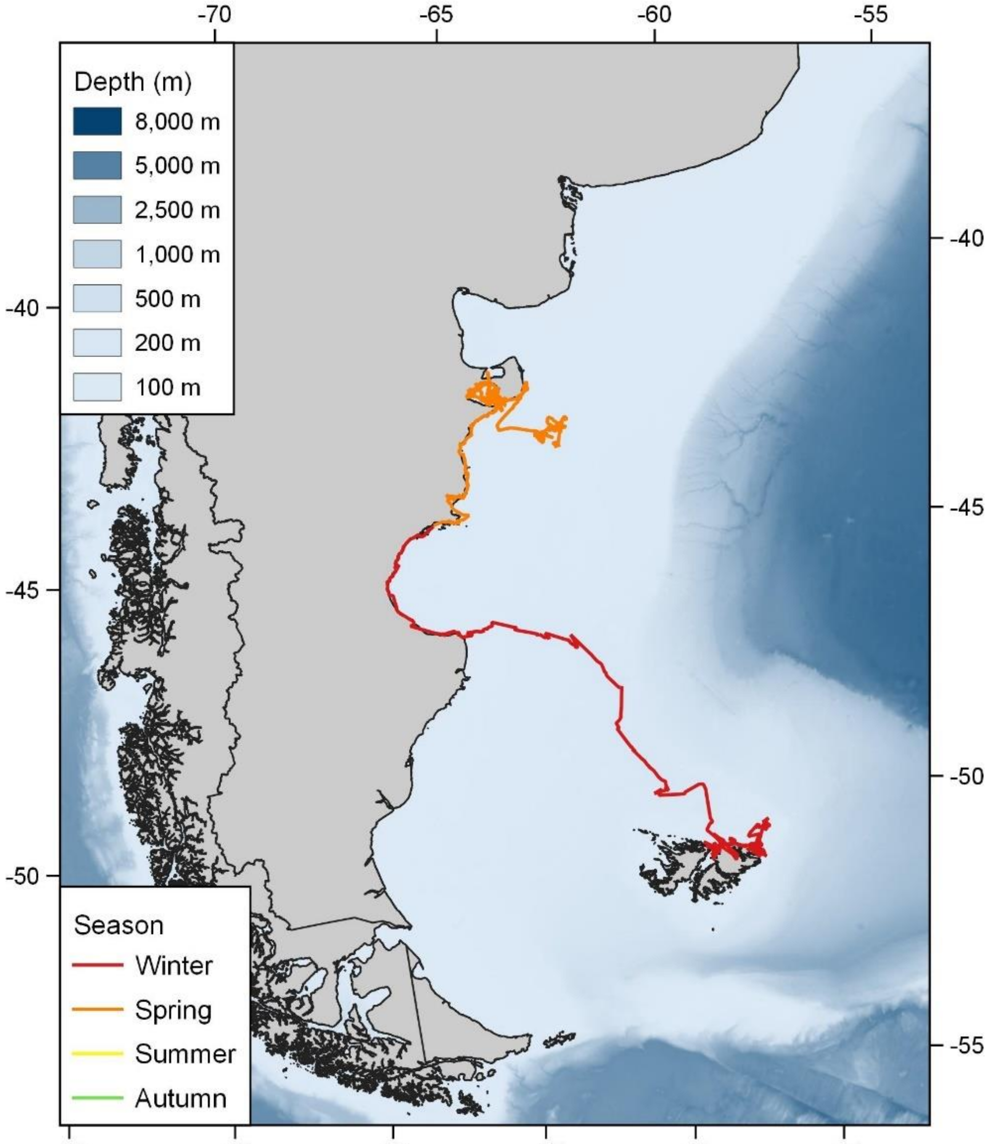


Figure 5.10. The movement of SRW 'Elmo' following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean). Gaps in tag transmission exceeding 24 hr are shown by a dotted line.

Byron (PTT171984): Following tagging on 24 July, Byron spent 40 days moving around the north coast of the FI (Figure 5.11). His movements included two loops to 100 km offshore before returning to the coast, and he used the entire area between Cow Bay and Byron Sound in the northern part of West Falkland (Figure 5.11). On 2 September, Byron commenced an offshore movement away from the FI, initially moving to the slope located north-east of the FI, but then turning south-east on 4 September. He swam towards an area around 75 km north of the South Orkneys (2,000 to 5,000 m depth) where he remained from 17 to 25 September. Bryon subsequently went north-east to arrive off the north coast of South Georgia on 8 October. However, he did not stop at South Georgia, but instead travelled over the slope and into oceanic habitat to an area located ~1,300 km north of South Georgia (~5,000 m depth), where he remained from 29 October 2022 until 1 January 2023. Byron then moved another 450 km to the south (>5,000 m depth), and spent 8 to 27 January in that broad area, before starting to move southwards back towards South Georgia. From 3 to 25 February, the whale moved slowly in an anti-clockwise loop in deep water (2,000 to 5,000 m depth) located to the north of South Georgia. On 26 February he arrived off the mouth of Cumberland Bay in South Georgia, but spent only 36 hours there before moving away to the south and south-east of the Island. On 9 March he commenced a directional movement back into deep waters (>2,000 m depth), arriving at an area located approximately 300 km south-west of South Georgia (~3,000 m depth) on 13 March and remaining there until the tag ceased transmitting on 21 March.

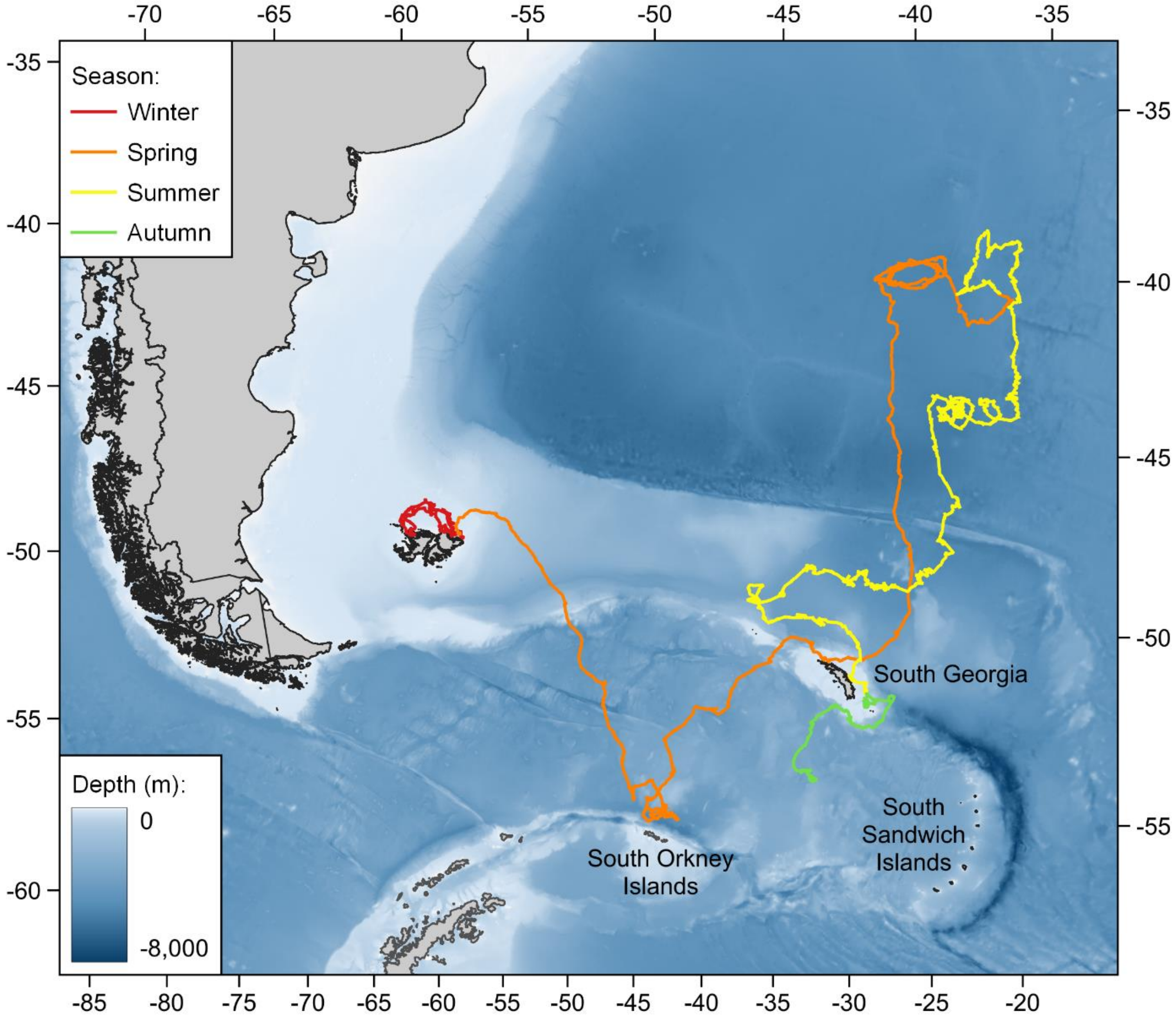


Figure 5.11. The movement of SRW 'Byron' following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean).

Pebble (PTT171986): Following tagging on 24 July, Pebble remained in the area between Berkeley Sound and MacBride Head until 27 July and then went a short distance (<30 km) offshore before moving west, re-joining the coast at Salvador and travelling past Cape Dolphin to the north-east coast of West Falkland where he continued along the north coast of Pebble Island (Figure 5.12). He then swam a loop to the north of Sedge Island and out to sea around 50 km from the coast, before swimming back to Cape Dolphin on 3 August and moving east along the north coast of East Falkland where, from 4 August to 20 August, he spent a lot of time between Salvador and MacBride Head. From 21 August, Pebble spent several days between MacBride Head and Volunteer Lagoon, before entering Berkeley Sound on 24 August and remaining in the Sound for 18 days. On 13 September, Pebble commenced a directional movement to the south-east and away from the FI, crossing the slope and moving into deep oceanic waters (>2,000 m depth). Approximately 70 km north of the South Orkneys, he began to exhibit more variable directions and spent the next period primarily in an area of oceanic habitat to the north of the South Orkney Islands. On 8 October, Pebble commenced a long-distance north-westerly movement to the Patagonian Shelf west of Golfo San Jorge (90–140 m depth) where he remained for two months from 26 October until 24 December. On 25 December, he undertook a short directional movement to the south to another shelf area off Puerto San Julián (100–140 m depth), where he remained until the tag transmissions ceased on 3 January 2023.

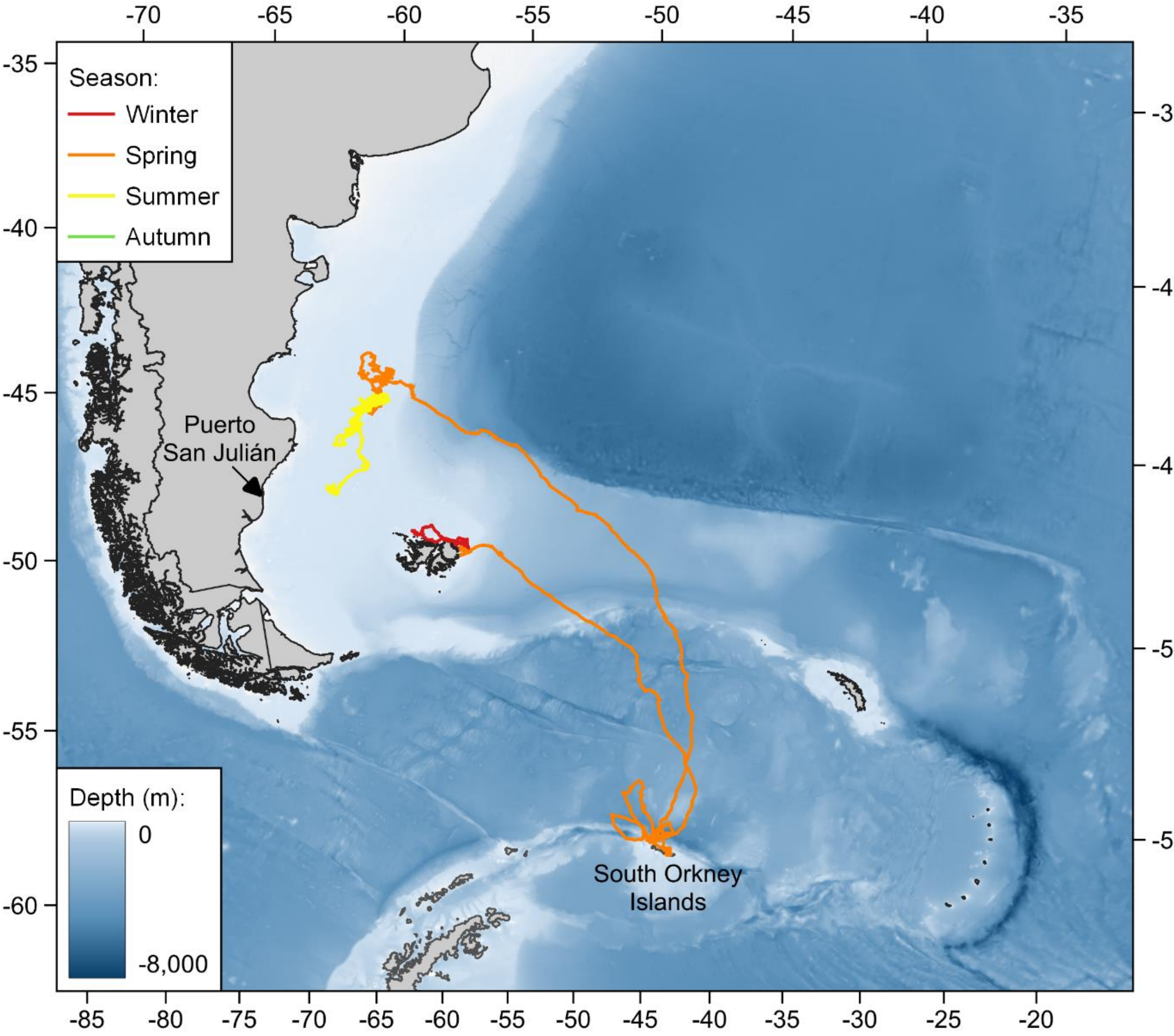


Figure 5.12. The movement of SRW 'Pebble' following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean). Gaps in tag transmission exceeding 24 hr are shown by a dotted line.

Dora (PTT171988): Following tagging on 24 July, Dora remained in the vicinity of MacBride Head before progressing westwards to Concordia Bay on 3 August (Figure 5.13). She then continued past Cape Dolphin and across to the north coast of West Falkland on 6 August, where she proceeded to travel west along the coast past Pebble Island, Saunders Island, Carcass Island and West Point Island. On 9 August, Dora left the FI and moved south-west towards Terra del Fuego, passing 10 km west of New Island and reaching the shoreline south of San Sebastián on 14 August. She spent two weeks in the nearshore waters between San Sebastián and the mouth of the Magellan Strait. On 29 August, Dora began to travel north, taking a straight line across the mouth of the Golfo San Jorge, and reaching Golfo Nuevo on 14 September. She remained in Golfo Nuevo until 5 October, and then entered Golfo San Matías on 13 October. On 21 October, Dora departed Golfo San Matías and began a directional movement away from the coast. From 22 October 2022 until the tag stopped transmitting on 11 April 2023, she stayed entirely on the outer Patagonian Shelf (70–120 m depth) using the area east of PV to east of Golfo San Jorge.

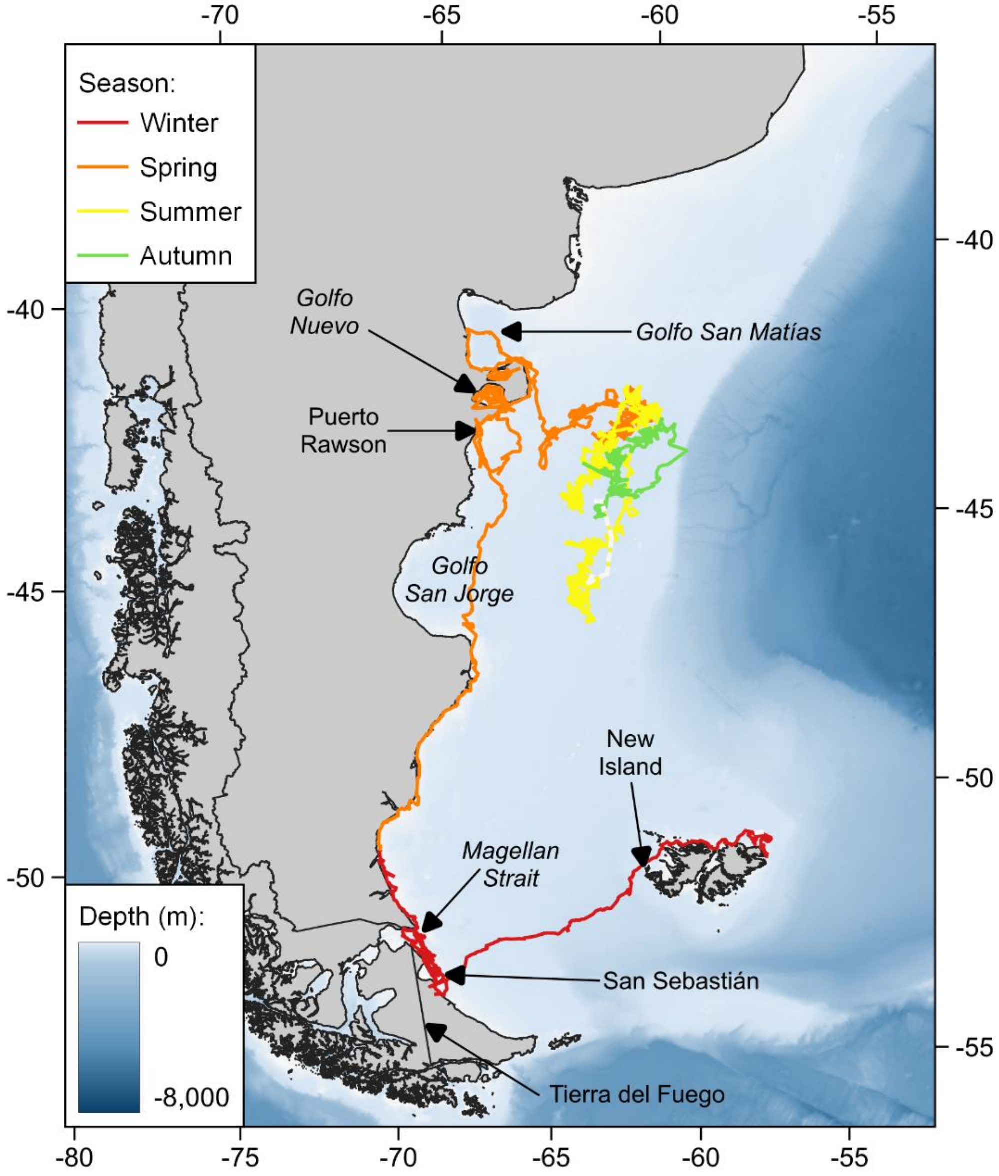


Figure 5.13. The movement of SRW 'Dora' following tagging in the Falkland Islands in July 2022. Tracks exclude Argos positions with an accuracy of Z and those with latitude or longitude errors (> 4 deviations from mean).

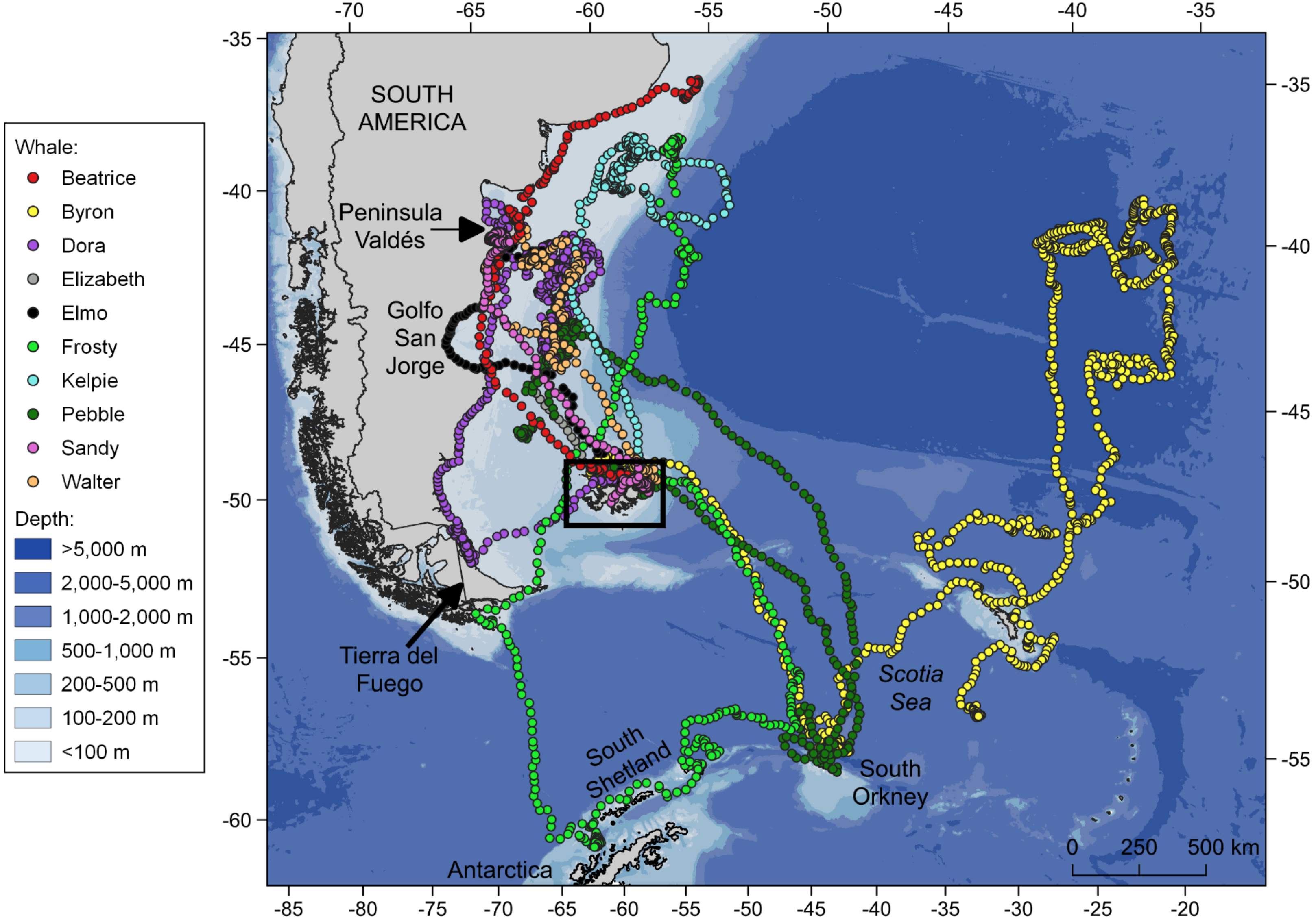


Figure 5.14. Model-predicted locations of 10 individual southern right whales satellite-tagged in the Falkland Islands (black box) during 2022.

5.3.2. Behavioural state

The modelled locations for BS1, BS2 and BS3 occurred at significantly different water depths (Kruskal-Wallis test, H=1363.1, df=2, p<0.001) and distances from shore (Kruskal-Wallis test, H=1963.6, df=2, p<0.001), with all pairwise comparisons being statistically significant (p<0.001). Locations associated with BS1 occurred at shallower depth and closer to shore than BS2 and BS3, while those for BS2 occurred at shallower depths and closer to shore than BS3 (Table 5.2; Figure 5.15). The same results were obtained using only modelled locations ≤150 km from the FI during winter (Table 5.2); locations for BS1, BS2 and BS3 occurred at significantly different water depths (Kruskal-Wallis test, H=407.0, df=2, p<0.001) and distances from shore (Kruskal-Wallis test, H=413.2, df=2, p<0.001), and all pairwise comparisons were statistically significant (p<0.001). Seventy percent (n=865) of modelled locations occurring ≤150 km from the FI comprised BS1, and 99% of those were in nearshore habitat <30 km from the FI coast (70% ≤2 km; 91% ≤5 km; 95% ≤10 km: Figure 5.16).

Based on these results and knowledge of SRW behaviour and habitats, in the remainder of this chapter we interpret BS3 locations as representing travel, while BS1 and BS2 locations represent occupancy of high and intermediate use habitats respectively. The latter categories include the area restricted movement (ARM) inferred by other marine predator studies (e.g. Silva et al., 2013; Patterson et al., 2016) to represent foraging behaviour, as well as behaviours exhibited on the coastal wintering grounds.

5.3.3. Use of the FIWG

Following tagging, the 10 SRWs continued to use FI nearshore waters for between 1 and 57 days (mean=30.1 d, median=34.0 d) before commencing directed movements (BS3) away. The use of the FIWG by confirmed females (mean=20 days, SD=13.5, n=3) was shorter than that of males (mean=38 days, SD=19.8, n=5).

Four whales (Beatrice, Elizabeth, Frosty and Dora) remained in nearshore habitats for ≤16 days following tagging; three of those animals moved slowly westwards (BS2) along the north coast of the FI before departing from the west coast of the islands, while Frosty moved 45 km north-east of the coast within 24 hr of tagging and then departed (Figures 5.4 to 5.13).

The remaining six SRWs spent prolonged periods of 33–57 days using nearshore habitats after tagging, particularly the exposed north coast between Volunteer Point and Foul Bay, and the relatively sheltered inlet of Berkeley Sound (Figures 5.4 to 5.13; Figure 5.16). Shared similarities in their use of the FIWG included: (1) the majority of both unfiltered and modelled locations were located <10 km from the coast and in water depths of <50 m; (2) most animals moved back and forth along this stretch of coast, rather than progressing in one direction along it; and (3) BS1 comprised the vast majority of modelled locations <10 km from the shoreline, with lower amounts of BS2 and almost no BS3 (Figure 5.16). Exploratory movements (BS2) were exhibited by five of the six SRWs while using the FIWG, including offshore loops to ~45 km from the north coast by three whales, an extensive offshore loop to ~100 km north of Pebble Island by Byron, and a southerly movement through Falkland Sound by Sandy. In all cases, the whales subsequently returned to the coast and resumed BS1. Pebble was the final animal to move away from the FI, on 13 September 2022.

Table 5.2. Distance travelled, swim speed, water depth and distance from shore according to modelled behavioural state for 10 satellite-tracked southern right whales, using modelled locations predicted at 6 hr intervals. Distances of 0 m from shore are unfeasible but were retained to represent extreme proximity to the coast given the known error margin of Argos locations. IMMA: IUCN Important Marine Mammal Area.

Behavioural state	n	Distance (km) between locations			Swim speed (km/day)			Water depth (m)			Distance from shore (km)		
		Mean (SD)	Median	Range	Mean (SD)	Median	Range	Mean (SD)	Median	Range	Mean (SD)	Median	Range
Entire south-west Atlantic modelled dataset													
1	1,895	5.7 (4.0)	4.9	0.07–28.0	22.8 (15.8)	19.4	0.3–112.0	121.4 (406.6)	36.0	1–3,379	32.4 (90.2)	3.0	0–578.7
2	2,248	13.1 (8.3)	11.3	0.05–68.5	52.3 (33.3)	45.4	0.2–273.8	1,141.6 (1,970.7)	100.0	1–5,730	467.4 (719.6)	209.7	0–2,490.1
3	1,045	28.4 (9.0)	28.1	8.90–70.9	113.7 (36.2)	112.3	35.6–283.5	2,121.8 (2,022.5)	1863.0	1–5,908	500.7 (626.1)	246.7	0–2,448.6
Locations ≤150 km from the Falkland Islands													
1	865	5.2 (3.7)	4.4	0.07–26.2	20.8 (14.8)	17.5	0.3–104.8	17.1 (25.4)	5.0	1–130	2.6 (5.8)	1.1	0–46.5
2	290	13.4 (8.5)	11.9	0.92–68.5	53.6 (34.0)	47.6	3.7–273.8	91.8 (117.9)	89.5	1–1,056	23.0 (26.0)	13.5	0–148.1
3	81	29.0 7.9)	28.9	13.79–57.2	115.8 (31.8)	115.6	55.1–228.7	198.2 (188.7)	161.0	1–1,257	72.0 (43.6)	74.4	0–146.6
Locations in the North-east Falklands Right Whale Wintering Area IMMA													
1	700	5.0 (3.6)	4.1	0.07–26.2	20.01 (14.7)	16.5	0.3–104.8	13.1 (15.4)	5.0	1–71	1.6 (1.5)	1.1	0–8.5
2	75	10.0 (6.5)	8.5	1.44–30.4	39.9 (26.0)	33.8	5.8–121.8	22.9 (21.6)	14.0	1–84	2.2 (1.8)	1.7	0–7.4
3	5	22.0 (7.9)	18.5	15.3–34.9	88.1 (31.7)	74.0	61.0–139.5	22.6 (27.0)	8.0	1–65	2.6 (3.0)	1.7	0–7.7

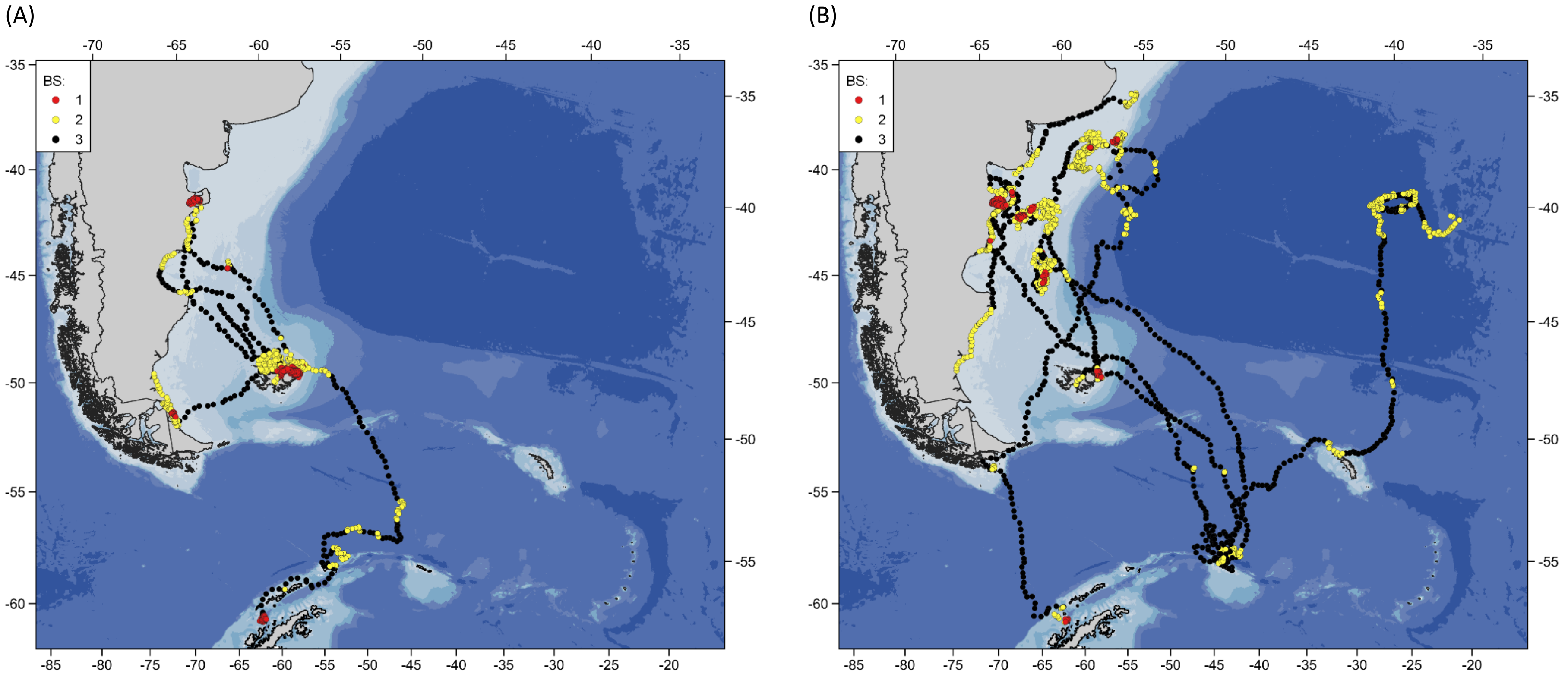
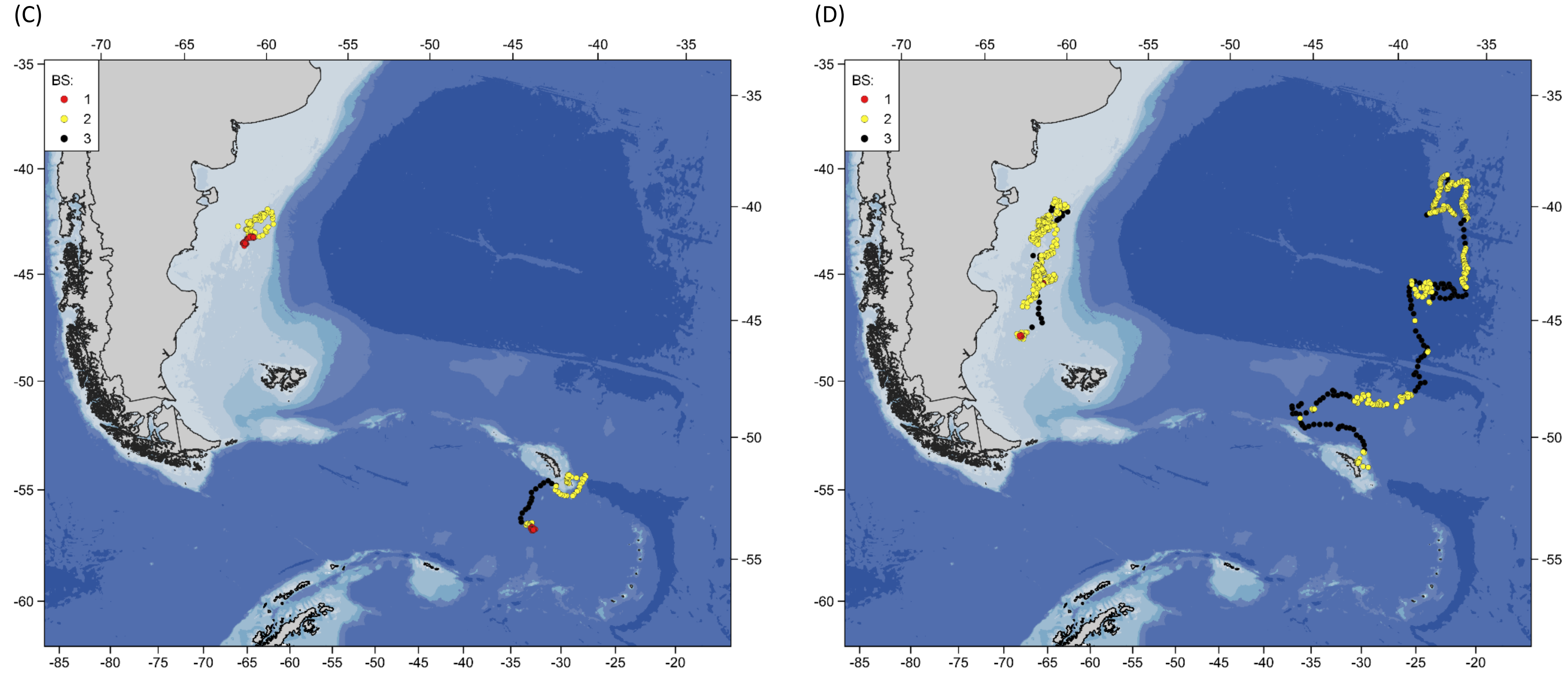


Figure 5.15. Model-predicted locations of 10 southern right whales satellite-tagged in the Falkland Islands according to three behavioural states (BS) generated with discrete-time hidden Markov models (BS1: slow and non-directional movements, indicative of high-use habitats; BS2: intermediate use areas (likely including foraging); and BS3: directed and fast movements, indicative of transitory habitats) in: (A) winter (June to August); (B) spring (September to November); C) summer (December to February); and (D) autumn (March to May).



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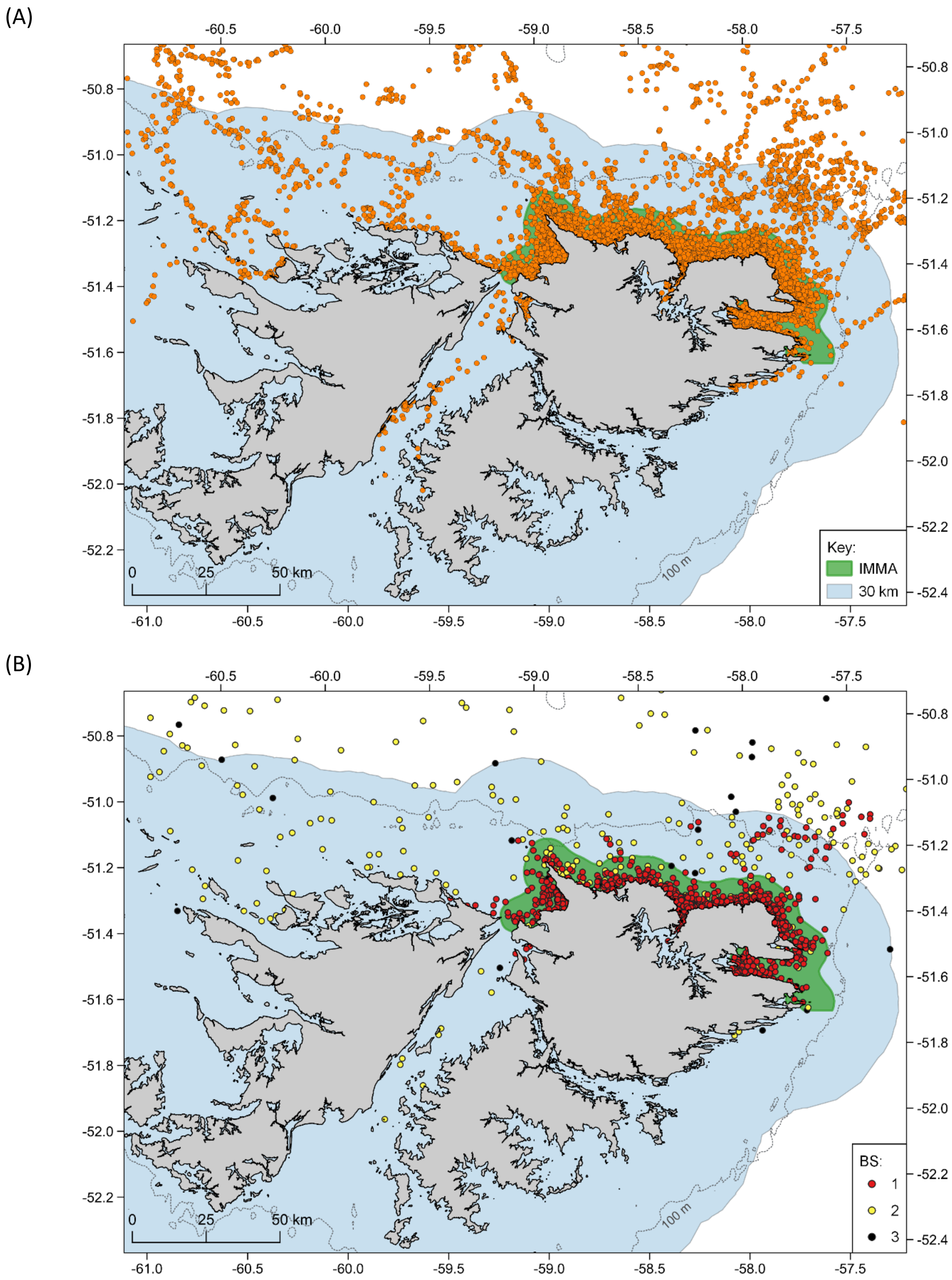

Figure 5.16. Locations of 10 satellite-tagged southern right whales in the waters around the Falkland Islands during 2022 using: (A) the unfiltered dataset; and (B) the model-predicted positions according to three behavioural states (BS) generated with discrete-time hidden Markov models: BS1: slow and non-directional movements, indicative of high-use habitats; BS2: intermediate use areas (likely including foraging); and BS3: directed and fast movements, indicative of transitory habitats). The spatial extents of the 30 km buffer from the coast and the North-east Falklands Right Whale Wintering Area Important Marine Mammal Area (IMMA) are shown.

5.3.4. Links with Peninsula Valdés

Six of the whales tagged in the FIWG subsequently moved to PV. Five whales (Beatrice, Elizabeth, Elmo, Sandy and Walter) travelled north-westwards after leaving the FIWG (Figures 5.4 to 5.13), moving directly across the Patagonian Shelf at speeds of 4.2 to 5.5 km/h (Weir et al., 2024). In contrast, Dora proceeded south-westwards directly towards Tierra del Fuego and spent two weeks close to the coast between San Sebastián and the mouth of the Magellan Strait (BS1 and BS2), before commencing a northwards coastal movement towards PV. Characteristics of whale movements from the FIWG to PV included; (1) most swam across the mouth of Golfo San Jorge rather than around its coast; (2) they slowed down and transitioned from BS3 to BS2 between Golfo San Jorge and the entrance to Golfo Nuevo; and (3) they changed from BS2 to BS1 after entering Golfo Nuevo. The six whales took a mean of 19.7 days (SD=8.9; range=12–36 d; median=18.0 d) to reach the Golfo Nuevo entrance after commencing their movements away from the FI, arriving in late July (Beatrice), August (Elizabeth and Walter), or mid-September (Elmo, Dora and Sandy).

The tags of two animals (Sandy and Elizabeth) stopped transmitting while the whales were still at PV. After residencies of 35 to 84 days exhibiting BS1 and BS2, the remaining four individuals (Beatrice, Walter, Elmo and Dora) departed PV during October.

5.3.5. Use of the Patagonian Shelf

Of the eight whales whose tags transmitted beyond 17 October, seven spent time in BS1 and BS2 on the outer Patagonian Shelf (Figures 5.4 to 5.13). This included: (1) all four of the whales (Beatrice, Walter, Elmo and Dora) that departed PV; (2) one whale (Kelpie) that travelled to the Patagonian Shelf directly after departing the FIWG and remained there almost continuously in BS2 until its tag stopped transmitting in late November; and (3) two whales that initially moved south-east after departing the FIWG, but returned to the Patagonian Shelf in early October (Frosty) and late October (Pebble) respectively.

The Patagonian Shelf areas used in BS1 and BS2 by the seven whales spanned latitudes from 37 to 55°S and had water depths of ~70–140 m (Figure 5.15). All seven animals were still using that habitat when their tags ceased transmitting. Dora exhibited BS2 almost continuously on the shelf east and south-west of PV for six months between October 2022 and April 2023 (Figure 5.13).

5.4 Discussion

The satellite telemetry demonstrated that: (1) the nearshore waters along the north coast of the FI are a high-use habitat for SRWs during winter; (2) the movements of tagged SRWs after departing the FIWG were both diverse and extensive; and (3) there was high connectivity between the FIWG, the PV calving ground, and presumed foraging areas on the Patagonian Shelf (with connectivity also indicated with Chile, Scotia Sea, South Shetland Islands, and Antarctica).

The duration of nine of the 10 tags deployed in the FI exceeded 100 days, with a maximum of 261 days. These durations are consistent with other SRW telemetry studies using recent tag technology (e.g. Kennedy et al., 2023; Vermeulen et al., 2023; Zerbini et al., 2023). The transmission longevity of the SPOT tags exceeded that of the SPLASH tags, but this was expected beforehand since the programming of the SPLASH tags included the collection and transmission of dive profile data which reduced battery life (see Chapter 6).

Similar to other marine megafauna telemetry studies (Costa et al., 2010; Witt et al., 2010), the majority (72.8% for combined tags; 77.7% for SPLASH tags; 69.6% for SPOT tags) of Argos locations received from SRWs tagged on the FIWG were LC-A and LC-B, and the dataset therefore likely contained mean location errors in the low tens of kilometres, particularly with regard to longitudinal accuracy which is often lower than latitude (Witt et al., 2010). This level of accuracy was considered acceptable in the context of the spatial scales considered in our research goals.

The longest distance moved by an individual SRW tagged in the FIWG was 15,375 km (Weir et al., 2024). Since distances were derived from straight-lines between modelled 6-hr locations, they are under-estimated compared with the more convoluted routes taken by whales in real-time. Nevertheless, the distance of 15,375 km swum by Byron over a 239-day period greatly exceeds SRW movements documented in most studies and is similar to one South African whale (15,288 km over 369 days; Vermeulen et al., 2023) but achieved over a much shorter timeframe. The average swim speeds recorded over the tag deployments were within the range of other SRW studies (Weir et al., 2024). The average swim speeds achieved during migrations to calving/nursery areas and directed movements to, and between, foraging areas were much higher than the averaged swim speeds over the total tag deployments, since the latter included time spent in nearshore wintering habitats when spatial movements are limited. Telemetry data from the FIWG and other studies indicate that SRWs can achieve sustained speeds in the region of 4.5 to 6 km h^{-1} during directed movements (Weir et al., 2024), allowing them to cover well over 100 km in a day. These speeds are comparable to those of some migrating balaenopterid species (e.g. blue whales, averaging 5.6 km h^{-1}: Lesage et al., 2017) despite their less streamlined shape, and to other robust species such as humpback whales (*Megaptera novaeangliae*, averaging 3.9 km h^{-1}: Zerbini et al., 2011) and bowhead whales (*Balaena mysticetus*, up to 5.8 km h^{-1}: Mate et al., 2000).

5.4.1. Use of the FIWG

Weir and Stanworth (2019) noted that potential uses of the FIWG by SRWs could comprise: (1) a short-term resting and socialising stop-off for animals migrating from foraging grounds located further east or south towards the South American calving areas; (2) a breeding destination used for courtship and mating; (3) a winter gathering area for sub-adult and non-breeding adults, primarily for social interaction; and (4) recolonisation of a historical winter calving ground. Since then, extensive targeted work on SRWs has occurred on the FIWG, including annual boat surveys and photo-identification (Weir, 2022), genetic analysis (Jackson et al. ,2022a), year-round acoustic monitoring (Cerchio et al., 2022), and the satellite telemetry reported here.

SRW aggregations form in the FIWG primarily between May and September, with numbers peaking during July (Weir, 2022). In some years, whale aggregations begin to form earlier, during March and April (Weir, 2022). Satellite tags were deployed in July to optimise the success of this novel study; however, doing so omitted the early part of the SRW season and likely underestimated the duration of FIWG occupancy. Nevertheless, some individuals remained for two months following tagging, confirming that the FIWG represents a high-use habitat and is not solely transited through by migrating animals. Additionally, photo-identification analysis in the FIWG during 2019 and 2020 documented seven whales seen in both years (Weir, 2022), suggesting that some individual SRWs exhibit longer-term fidelity to the region. In combination, the available evidence indicates that the FIWG comprises a winter destination for a component of the south-west Atlantic SRW population, and according to the International Whaling Commission habitat categorisation (IWC, 2001) it may be considered a breeding habitat in which courtship and mating predominate. However, the FIWG also has (currently unclear) significance for sub-adult whales, and telemetry results support some use on a more temporary basis, both by whales that subsequently migrate to other geographic areas (including both calving and feeding areas: this study) and by non-breeding whales that might be feeding nearby and are briefly attracted to the inshore SAGs (e.g. Vermeulen et al., 2023).

The telemetry work provided valuable insights into the spatial and temporal extent of SRW high-use areas during winter, and therefore the definition of the FIWG. Due to logistical constraints associated with the remoteness of FI, SRW targeted boat work between 2017 and 2023 was mostly confined to areas <50 km from Stanley. Consequently, uncertainty persisted regarding their use of other regions of the FI (Weir, 2021). Apart from the initial tagging locations, that bias is removed from the telemetry dataset which indicated very high use (i.e. BS1) during winter of the entirety of the exposed north coast of East Falkland, predominantly within 10 km of the coast. None of the tagged whales exhibited movements to the southern parts of the FI, except for one brief exploratory excursion (BS2) through Falkland Sound, and there was only sporadic exploration of the waters west of Pebble Island by two whales. Consequently, the north coast of East Falkland seems to represent a genuinely higher use area for SRWs within the FI, although targeted winter survey work in southern regions of the FI is required for confirmation.

The purpose of the short movements (BS2) up to ~100 km north of the FI undertaken by several individuals before returning to the coast, are unclear. These movements could represent foraging excursions, relate to surface active groups forming further from the coast, or have some other underlying driver. At PV, SRWs are sometimes observed foraging during the calving and mating season (D'Agostino et al., 2018, 2023). Dora and Walter exhibited BS1 and BS2 in an area ~20–45 km north-east of MacBride Head before returning to the coast, and that same area was used by a non-breeding adult assumed to be foraging from South Africa during winter 2022 (Vermeulen et al., 2023). Consequently, opportunistic foraging trips to adjacent habitats might be undertaken by whales using the FIWG. However, recent aerial surveys of the FIWG recorded surface active groups forming >25 km from shore during June (Falklands Conservation, unpublished data), indicating that offshore trips may not solely reflect foraging excursions.

Both boat surveys (Weir, 2022) and acoustic monitoring (Cerchio et al., 2022) indicate that most SRWs move away from the FIWG during early September. The telemetry data further confirmed this seasonality; departure from the FIWG by tagged whales was completed in the first half of September.

5.4.2. Movements beyond the FIWG

Genetic data demonstrate that SRWs using the FIWG belong to the wider south-west Atlantic population (Jackson et al., 2022a). Weir and Stanworth (2019) noted that the seasonal peak (July and August) in SRW numbers on the FIWG occurs earlier in the year than at the PV calving ground (late August to mid-September: Crespo et al., 2019), suggesting that some individuals may move to PV after departing the FIWG. The 2022 satellite-telemetry provided confirmation, with six of the SRWs tagged on the FIWG subsequently moving to Golfo Nuevo and remaining at PV for up to 12 weeks.

The FI–PV movements revealed direct links between the FIWG and the PV calving area, and almost all whales undertaking those movements crossed the Patagonian Shelf (<200 m depth) to arrive in the vicinity of Golfo San Jorge rather than taking a shorter route direct to PV. There was no evidence that whales formed SAGs in the pelagic waters between the FI and Argentina, supporting the notion that coastal habitats are critical for SRW breeding behaviour as well as for calving and nursing. These movements indicate that some individuals use two wintering areas within the same breeding season and thus potentially extend their reproductive potential across multiple sites and months. The six FI–PV movements included all three of the whales genetically-sexed as females (plus an additional suspected female: Beatrice), but only two of the five confirmed males. One female also visited the nearshore waters between San Sebastián and the mouth of the Magellan Strait (Chile) on the Atlantic coast of Tierra del Fuego (also a likely wintering ground for south-west Atlantic SRWs: Gibbons et al., 2006), and therefore potentially visited wintering grounds across three countries within one breeding season. In contrast, the animals exhibiting the most extensive spatial movements during this study (Frosty, Byron and Pebble) were all males that did not visit PV. While our sample size is small, the results suggested that even though they all mix on the same wintering ground, differences occur in the FIWG residency duration, and in the subsequent movements and habitat use, of SRWs according to their sex.

Previous satellite tagging work at PV during spring has shown that Patagonian Shelf waters are used extensively by foraging SRWs (Zerbini et al., 2018). The Patagonian Shelf Large Marine Ecosystem (PSLME), is one of the most productive ecosystems in the world and encompasses year-round tidal mixing fronts and seasonal fronts that support important fisheries (Arkhipkin et al., 2013). Most of the whales tagged on the FIWG exhibited lengthy periods of BS2 in the PSLME. However, in contrast to Zerbini et al. (2018) who found that ARM predominantly occurred over the outer continental shelf and slope within the PSLME, the animals tagged on the FIWG used the central shelf (70–140 m depth) and exhibited very little use of Patagonian Slope waters. Further, Zerbini et al. (2018) noted a gap in ARM between 40 and 44°S in the PSLME across four tagging years and suggested that area may have lower habitat suitability, whereas the whales tagged in the FI exhibited ARM throughout those latitudes with the exception of 41.5 to 42.8°S. These differences likely represent both inter-individual and inter-annual variation in the use of foraging areas, reflecting oceanographic shifts affecting prey availability and changes in preference according to whale age, sex and reproductive status. Nevertheless, the PSLME clearly comprises a very important foraging ground for SRWs, being used by whales tagged at wintering grounds in Argentina (Zerbini et al., 2016, 2018), the FI (this study) and South Africa (Vermeulen et al., 2023). Two animals tagged on the FIWG also undertook long journeys south (to the South Orkney Islands and Antarctic Peninsula respectively) before returning to the Patagonian Shelf within the same feeding season, further highlighting the region-wide importance of the PSLME for foraging. In particular, Pebble travelled almost continuously >1,400 km to an area north of the South Orkney Islands, exhibited relatively little ARM behaviour over a two-week period in that area, and then undertook a 2,000 km movement back to the Patagonian Shelf west of Golfo San Jorge where it then remained likely foraging for two months. That animal spent considerable energy on two extensive latitudinal movements for apparently low reward, before finding a productive feeding area on the shelf. SRWs may exhibit maternally transmitted fidelity to certain feeding areas (Valenzuela et al., 2009; Carroll et al., 2015), and it is possible that animals are predisposed to investigate those locations for food before searching elsewhere.

Frosty visited the western end of the Bransfield Strait in the Antarctic Peninsula, close to the known southern limits of the species range (64–66°S: Savenko and Friedlaender, 2022; Kennedy et al., 2023). Remarkably, while other records of SRWs at the southern limits of their range have occurred during summer and autumn (Hamner et al., 1988; Savenko and Friedlaender, 2022; Kennedy et al., 2023), Frosty moved to Antarctica in late winter (mid-August) and remained in a high-use (BS1) area for three weeks apparently foraging.

Weir and Stanworth (2019) proposed that the FIWG may be located on the northward migration route of a component of the south-west Atlantic population that feeds in areas located further south or east of the Islands during the summer, such as in the Scotia Sea, the South Sandwich Islands, or Antarctica. The satellite telemetry work presented here has confirmed links between SRWs on the FIWG and all of those feeding grounds. However, isotope analysis indicates that SRWs sampled in the FIWG span at least two trophic levels (Jackson et al., 2022b), likely representing separate foraging areas located south of the Polar Front and on the Patagonian Shelf respectively (Valenzuela et al., 2009). This suggests that SRWs arrive in the FIWG from both low and high latitude feeding areas rather than the FIWG comprising a preferred destination for a single feeding group (Jackson et al., 2022b). Consequently, the FIWG may provide relatively unique opportunities to study SRWs from different feeding areas while they are still in optimal body condition prior to migrating to the calving grounds.

5.4.3. Conservation and management conclusions

Although the FIWG has been highlighted as an important habitat for SRWs for several years (Weir and Stanworth, 2019; Weir 2021, 2022), and its location is strategic in providing links between calving grounds and foraging areas (a species research priority: Carroll et al., 2020), the region is still not well acknowledged as an important SRW habitat. The growing evidence of the importance of the FIWG as a high-use habitat for SRWs in the SWA should be incorporated into future region-wide conservation efforts, including the International Whaling Commission Conservation Management Plan for the south-west Atlantic population which does not currently include recognition of the FIWG.

Recent studies have referred to the FI as a socialising area (Carroll et al., 2022; Kennedy et al., 2023), a migratory habitat (Carroll et al., 2022), or as an area where SRW numbers peak during summer (Savenko and Friedlaender, 2022). However, the occurrence of song and mating observations demonstrates that the FI supports regionally important winter breeding aggregations (Weir, 2021, 2022). In terms of identifying and managing potential anthropogenic disturbance to the species, recognition that breeding behaviour occurs on the FIWG is important. For example, significant shipping noise in Berkeley Sound during July 2019 coincided with a reduction in detected SRW vocalisations (Cerchio et al., 2022). Whales call to maintain contact when aggregating to feed or locate potential mates, and acoustic masking or reduction in call rate in response to noise can therefore potentially affect critical life-history events with unknown long-term population consequences (Nowacek et al., 2007).

The FIWG telemetry data have already informed the delineation of an IUCN Important Marine Mammal Area for wintering SRWs (https://www.marinemammalhabitat.org/portfolio-item/north-east-falklands-malvinas-right-whale-wintering-area-imma/). Additionally, they have been used to plan a winter aerial abundance survey for SRWs, aimed at establishing local population size to support an IUCN Key Biodiversity Area application (see Chapter 7). These spatial conservation tools will be available to guide future management and mitigation of potentially-adverse human activities on SRWs in the FI, such as hydrocarbon exploration, shipping and marine aquaculture.

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Chapter 6: Dive behaviour of southern right whales tagged in the Falkland Islands

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6.1 Introduction and aims

Baleen whales (suborder Mysticeti) feed by exploiting dense patches of zooplankton and schools of fish which they filter through racks of baleen plates hanging from their upper jaws (Goldbogen et al., 2013). They employ three methods of filter-feeding (Goldbogen et al., 2013): continuous ram feeding (family Balaenidae), suction feeding (gray whales, *Eschrichtius robustus*), and lunge feeding (family Balaenopteridae).

The family Balaenidae comprises four species: bowhead whale (*Balaena mysticetus*), North Atlantic right whale (*Eubalaena glacialis*; NARW), North Pacific right whale (*Eubalaena japonica*), and southern right whale (*Eubalaena australis*; SRW). All are characterised by their stocky body shape with high blubber stores and a strongly arched rostrum housing especially long baleen plates (up to 4 m in the bowhead) with fine bristles. Balaenid whales feed on slow-moving dense crustacean patches using continuous ram feeding, where animals swim steadily at slow speeds with their mouths agape for prolonged periods to strain prey from the water. They can ram feed both at the surface and during dives deeper in the water column. Swimming subsurface with an open mouth alters the hydrodynamic shape of the animal and significantly increases drag (Simon et al., 2009; van der Hoop et al., 2019). Consequently, balaenids swim more slowly when ram-feeding at the bottom phase of foraging dives (mean speed averaged across individuals of <1.0 m s^{-1}) compared to when they forage at the surface (1.1–2.5 m s^{-1}: Simon et al., 2009). Mean speed during the descent and ascent phase of balaenid foraging dives has been measured at 0.6 and 0.6 m s^{-1} respectively for bowhead whales (Laidre et al., 2007) and 1.4 and 1.5 m s^{-1} respectively for NARWs (Baumgartner and Mate, 2003; van der Hoop et al., 2019); both are faster than the speed during the bottom phase when the animal is assumed to be ram-feeding. Balaenids are positively buoyant, and much of their dive ascent comprises gliding rather than active tail strokes (Goldbogen et al., 2013).

Several previous studies of balaenid dive behaviour on foraging grounds have examined dive shape profiles, observing that bowhead and NARWs undertake: (1) V-shaped dives reflecting travel or prey search behaviour; and (2) square and U-shaped dives reflecting foraging where the bottom phase is maximised (Baumgartner and Mate, 2003; Laidre et al., 2007; Simon et al., 2009; van der Hoop et al., 2019; Fortune et al., 2020; Pontbriand et al., 2023). As with other mysticetes (e.g., Derville et al., 2020), it is therefore possible to infer the behaviour of balaenids from their dive profile shape.

Foraging balaenids tend to have longer dive durations than lunge-feeding balaenopterids. For example, the mean dive durations of bowhead whales (mean=10.6 min, max=48 min: Laidre et al.,

2007) and NARWs (mean=12.2 min, max=16.3 min: Baumgartner and Mate, 2003) exceed those of balaenopterids such as fin whales (*Balaenoptera physalus*: mean=6.3 min, max=16.9 min) and blue whales (*B. musculus*: mean=7.8 min, max=14.7 min), despite the latter species having larger body sizes and correspondingly higher theoretical aerobic dive limits (Croll et al., 2001). This has been attributed to the higher metabolic costs incurred by the fast swim speeds associated with subsurface-lunge feeding, which limits the submergence duration (Acevedo-Gutiérrez et al., 2002). Both bowheads and NARWs routinely undertake foraging dives to comparable mean water depths of around 120 m (Baumgartner and Mate 2003; Fortune et al., 2020). However, the maximum dive depths recorded for those species are considerably higher at 720 m (Pontbriand et al., 2023) and 174 m (Baumgartner and Mate 2003) respectively.

Compared with bowhead whales and NARWs, the diving behaviour of SRWs has received relatively little focus although it may be expected to share similarities. Argüelles et al. (2016) deployed suction-cup tags on five SRWs in Argentina, with total tag deployment durations of 4 to 33 min. The whales dove to 75 m depth and ascended from dives at rates of 0.6 to 2.3 m s^{-1}. A brief description of dive behaviour of three SRWs satellite-tagged at Peninsula Valdes (PV, Argentina) was provided by Zerbini et al. (2016), indicating that most dives were to ≤100 m depth but a few dives reached 450 m depth in the Scotia Sea.

Understanding the dive behaviour of whales has direct applicability to their management. For example, the major contemporary anthropogenic threats to the Critically Endangered NARW comprise fishing gear entanglement and vessel strike (Baumgartner et al., 2017). Understanding how much time whales spend at, or near, the surface and in what contexts, is important in assessing vessel collision risk. Similarly, information on how whales use the water column can be used to determine their potential exposure to vessel strike and to different types of fixed and suspended fishing gear (Baumgartner et al., 2017; Dombroski et al., 2021).

During July 2022, we deployed archival satellite tags on five SRWs using a wintering ground in the nearshore waters of the Falkland Islands (south-west Atlantic). This archipelago wintering ground is used between May and September by juvenile and adult SRWs for mating and socialising (Weir and Stanworth, 2019; Weir, 2021; Weir et al., 2024). This chapter describes their diving behaviour in a range of behavioural contexts and habitats, with the overall aims of improving knowledge of their foraging behaviour and habitat use, assessing their exposure to vessel collisions, and informing the availability bias corrections applied to abundance estimates.

6.2 Materials and methods

6.2.1. Study area and tag deployments

The tag deployment area is described in Chapter 5 of this report.

6.2.2. Tag programming

Five transdermal archival SPLASH10-373A satellite tags (Wildlife Computers, Redmond, WA) were deployed on SRWs using the Falkland Islands wintering ground (FIWG) during 2022. The deployment methods, and the programming of tags with regard to location and transmission settings, are described in Chapter 5 of this report.

The tags were programmed to sample dive depth at 1 second intervals. Dive data were collected in two formats: (1) behavioural dive profile dataset, comprising detailed records of each qualifying dive

(QD) and associated surface event (SEV); and (2) binned datasets that summarised dive data in 14 predetermined bins.

The behavioural dive profile dataset contained the start and end time (determined by the wet/dry sensor), maximum depth (m), duration (s), and dive shape of each QD, and the duration of each SEV. A QD was defined as dives ≥10 m depth and >10 s duration. We adopted 10 m as a biologically relevant threshold since the FIWG is used by both juvenile and adult SRW, and this value falls midway between the length of SRWs at weaning and sexual maturity (8.3 vs. 12.5 m: Huang et al., 2009). Maximum depth and duration were each provided as two values, from which an average was calculated. Dive shape was automatically classified according to three categories defined by Wildlife Computers and assuming that the bottom of the dive is any depth reading ≥80% of the maximum reading observed for the dive:

1. square-shaped dives, where bottom time was >50% of the dive duration;
2. U-shaped dives, where 20–50% of the dive duration was spent at the bottom; and
3. V-shaped dives, where bottom time was <20% of the dive duration.

A SEV (i.e., periods between QDs) commenced when the wet/dry sensor indicated that the animal had broken the surface. The duration of each SEV was split into: (1) ‘shallow’ comprising the time that the tag was above the surface; and (2) ‘deep’ comprising the time the tag was submerged but above 10 m depth.

The binned dataset contained summaries of dive data in 6-hr intervals (Table 6.1), broadly corresponding with winter daylight (10:00–22:00 UTC) and darkness (22:00–10:00 UTC) periods in the FIWG. Data were logged in 14 predetermined bins (Table 6.2) including:

1. dive maximum depth (DMD): count of QDs in each depth bin (m);
2. dive duration (DD): count of QDs in each duration bin (min); and
3. time at depth (TAD): percentage time spent in each specified depth bin (using all available dive data).

Table 6.1. Start times selected for histogram bins during SPLASH tag programming and associated diel status in the Falklands.

Time histogram bin commenced		Diel status in Falklands
Coordinated Universal Time (UTC)	Local time (UTC-3)	
04:00	01:00	Night
10:00	07:00	Dawn/Day
16:00	13:00	Day/Dusk
22:00	19:00	Night

Finally, because the behavioural dive profile and binned datasets did not always overlap exactly in time (due to transmission gaps and prioritisation settings) and were not always continuous, the Wildlife Computers portal automatically assigned a single maximum depth value (MDV) to each 6-hr period which was the result of examining all sources of data received from the tag.

Table 6.2. Values selected for histogram bins during SPLASH tag programming to record southern right whale dive behaviour.

Parameter	Bin													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Dive maximum depth	2	5	10	20	30	40	50	75	100	150	200	250	300	>300
Dive duration	1	2	3	4	5	10	15	20	25	30	35	40	45	>45
Time at depth	2	5	10	20	30	40	50	75	100	150	200	250	300	>300

6.2.3. Data analysis

6.2.3.1. Location data

The analysis of the tag location data and the modelling of behavioural state (BS) are described fully in Chapter 5 and in Weir et al., (2024). The three resulting BS were defined as: BS1: slow and non-directional movement indicative of high-use habitats; BS2: intermediate speed of movement and rate of directional change; and BS3: faster and directed movement, consistent with transitory habitats.

The locations of tagged SRWs are described as broad habitat types according to water depth: (1) shelf (<200 m depth); (2) slope (200–1,999 m depth); and (3) oceanic (≥2,000 m depth). Since SRWs primarily use nearshore temperate habitats for their winter reproductive behaviour, shelf habitats in South America and the FI were further subdivided into: (1) nearshore (<30 km from the coast); and (2) outer shelf (≥30 km from the coast). We followed the terminology of Wilding Brown and Sironi (2023) in defining the areas where calves are born as calving grounds, areas where mothers provide neonatal care as nursery grounds, and areas where courtship and copulation occur to be breeding grounds.

Dive data were also considered in respect of four south-west Atlantic (SWA) categories that incorporated habitat, BS, and known SRW behavioural contexts, aimed at distinguishing dive profiles by broad behavioural use:

1. Coastal wintering grounds, defined as nearshore (<30 km) shallow (<200 m depth) habitats used during winter and spring and where BS1 and BS2 dominate, including known wintering grounds in the Falkland Islands, Argentina and Chile;
2. Patagonian Shelf, defined as shelf waters (<200 m depth) excluding category 1, comprising BS1 and BS2 exhibited in the shelf habitats around the Falkland Islands and Argentina;
3. Antarctic, defined as Antarctic waters used for BS1 and BS2, and including shelf, slope and oceanic habitats; and
4. Deep (slope/oceanic), defined as waters exceeding 200 m depth outside of Antarctica used for BS1 and BS2, predominantly comprising international waters.

All BS3 data were excluded from the SWA categories, on the basis that BS3 data represents transits through, rather than preferred use of, a habitat. The Antarctic SWA category was represented only by data from one whale (Frosty), while the Deep category was predominantly represented by data from Frosty and Kelpie.

6.2.3.2. Dive data

We followed the methods of Shearer et al. (2019) in checking tag records systematically for errors that indicated failure or drift in the tag sensors. During that process, it became apparent that the depth sensor of Walter had failed from 4 October 2022; data from that date onwards were therefore removed from all dive datasets.

For the behavioural dive profile dataset a minimum value of mean swim speed (m s^{-1}) for each dive was calculated as: 2 x mean dive depth / dive duration. Normal swimming speeds of 1.0–2.0 m s^{-1} (~2–4 knots) have been reported for balaenids across a range of behavioural contexts, including while undertaking foraging dives. Winn et al. (1995) considered that NARW vertical dive speeds >3 m s^{-1} (~6 knots) were likely to be erroneous. Slightly higher mean speeds of 2.6–2.8 m s^{-1} have been calculated for SRWs making sustained directional movements over several days (Mate et al., 2011; Weir et al., 2024). The fastest sprint speed published for a balaenid is 6.3 m s^{-1} (bowhead: Ford and Reeves, 2008).

A total of 465 (1.3%) of the 36,452 dives in the SRW behavioural dive profile dataset had mean vertical dive speeds of >3 m s^{-1} (of which 234 had mean speeds exceeding the 6.3 m s^{-1} sprint speed) and were considered potentially erroneous based on Winn et al. (1995) and other balaenid studies. Of those dives, 442 were undertaken by Frosty (the remainder were Walter), and the vast majority comprised square (n=393) or U (n=34) shaped dives where significant horizontal movement must also have occurred which implies even higher swim speeds. Those dives (and the subsequent surfacing period) were removed from the dataset.

While maximum dive durations of over 40 min and ~63 min have been recorded for NARW and bowhead whales respectively, such long dives could be artefacts of animals surfacing without exposing the tag (Nieukirk, 1993; Krutzikowsky and Mate, 2000). Our dataset included 26 dives with reported durations of 1.5 to 12.3 hr which were clearly erroneous (21 of those related to Kelpie). Since dives of 30–40 min have been recorded for NARW (Nieukirk, 1993), we used 40 min as the threshold for a viable SRW dive and excluded longer dives (n=60; 0.2%) from the analysis.

The duration of SEVs in the raw dataset (n=36,456) ranged from 0.03 to 681 min (mean=5.8 min, SD=17.6; median=1.7 min). 131 (0.4%) SEVs had durations exceeding 2 hr, including multiple (15–38) SEVs from all five whales. Since SRWs potentially spend prolonged periods using the upper 10 m of the water column while engaged in surface active group (SAG) or surface skim-feeding behaviours, the long duration SEVs were retained for analysis. Laidre et al. (2007) similarly recorded extended periods of >6 hr at the surface for tagged bowhead whales.

Complete dive cycles (CDC) were defined as a dive followed by a corresponding surface interval. The total dive cycle time (TDCT) comprised the sum of the dive duration and its succeeding surface interval (Baumgartner and Mate, 2003).

6.2.3.3. Statistics

Since the datasets were non-normally distributed, non-parametric tests were used to compare samples. Dunn's post hoc tests with Bonferroni corrections were used to test specific pairs following significant Kruskal-Wallis H tests. Chi-square ($\chi 2$) tests were used to determine whether relationships existed between categorical variables. Statistical analysis was carried out using JASP (JASP Team, 2023).

6.3 Results

The five SPLASH tags were deployed between 6 and 11 July on three males (Sandy, Walter and Frosty) and two SRWs of unidentified sex (Beatrice and Kelpie: Table 5.1). The tags of the five animals transmitted for 101 to 136 days, with a median of 114 days.

6.3.1. Maximum depth value

The maximum depth value (MDV) recorded within a 6-hr period for five SRWs during SPLASH tag deployments ranged from 10.0 to 631.8 m with a median of 57.8 m and a mean of 69.4 m (n=2,004, SD=56.0). There was a significant difference in the MDV between seasons (Mann-Whitney test, W=277619.5, p<0.001), with dives reaching deeper MDVs during spring (median=87.8 m) than in winter (median=30.8 m: Figure 6.1).

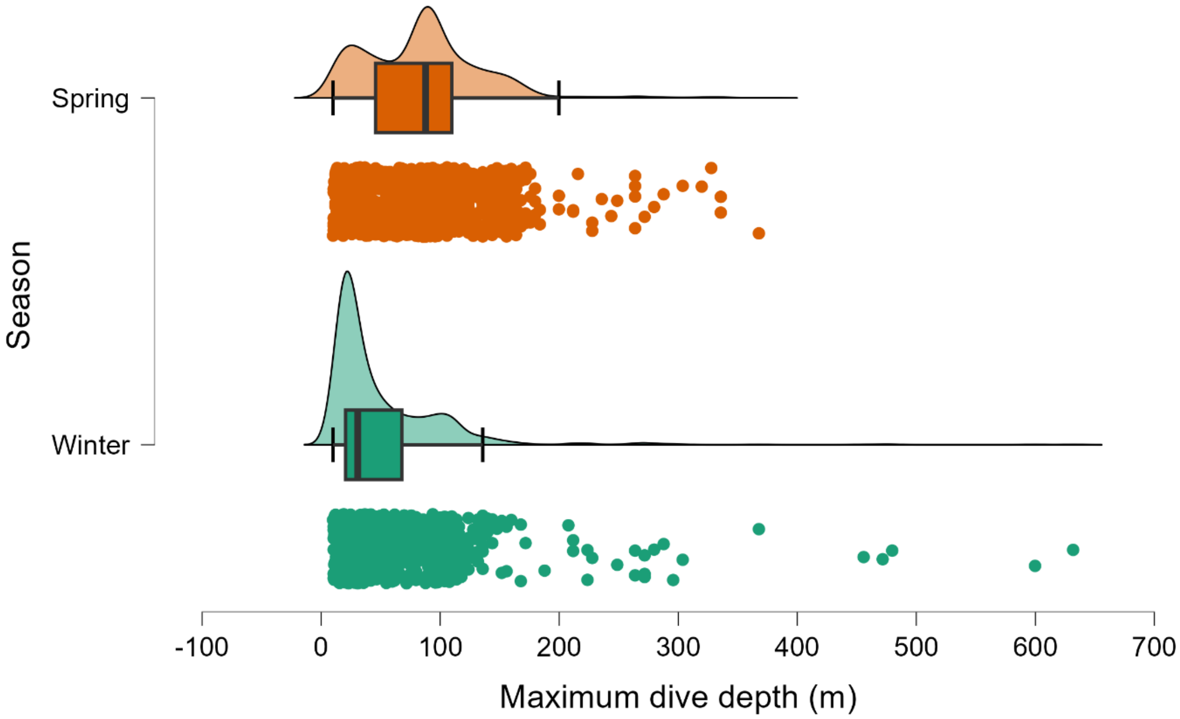


Figure 6.1. The maximum dive depth values recorded within a 6-hr period for five SRWs during SPLASH tag deployments during winter (Jul-Aug) and spring (Sep-Nov).

6.3.2. Histogram data

6.3.2.1. Dive maximum depth

A total of 1,315 6-hour DMD histogram summaries were received for the five SRWs combined, comprising a total count of 39,480 QDs (Table 6.3). Similar proportions of DMD histogram summaries were acquired during day and at night (Table 6.3). Within the FIWG, a total of 329 DMD histogram summaries comprising a total of 9,227 QDs were received (Table 6.3).

The DMD of the majority of QDs occurred in the 10–20 m depth bin (Table 6.4; Figure 6.2), both when considering the full dataset (52% of dives) and particularly within the FIWG (75% of dives). A second peak occurred in the 75–100 DMD bin for Kelpie in the full dataset (Figure 6.3A), likely reflecting repeated foraging dives undertaken by that animal on the Patagonian Shelf from September to November. There were no QDs deeper than the 100–150 DMD bin in the FIWG (Figures 6.2A and 6.3B), which was expected since water depths within 30 km of the north-east coast are predominantly <200 m depth. In the full dataset, 1,939 (4.9%) QDs were recorded in DMD bins greater than 100 m, including 60 QDs (0.2%) deeper than 300 m (Figures 6.2A and 6.3A).

Using the full dataset, there were proportionately more QDs with a DMD of 10–20 m, and fewer QDs with a DMD of 75–150 m, at night than during the day (Figure 6.4A). However, in the FIWG the proportions of QDs in each DMD bin were similar (Figure 6.4B).

Table 6.3. Number of 6-hr histogram summaries and qualifying dives (QDs) for which maximum dive depth (DMD) was logged for five southern right whales tagged at the Falkland Islands wintering ground (FIWG) during July 2022.

Animal	Full dataset (all geographic regions)						FIWG	
	Total		Day		Night			
	No. 6-hr periods	No. QDs	No. 6-hr periods	No. QDs	No. 6-hr periods	No. QDs	No. 6-hr periods	No. QDs
Beatrice	244	6,187	123	3,021	121	3,166	10	483
Frosty	281	8,188	134	3,463	147	4,725	0	0
Kelpie	372	13,265	181	5,700	191	7,565	119	2,638
Sandy	240	6,887	119	3,242	121	3,645	141	4,356
Walter	178	4,953	85	2,058	93	2,895	59	1,750
Total	*1,315*	*39,480*	*642*	*17,484*	*673*	*21,996*	*329*	*9,227*

6.3.2.2. Dive duration

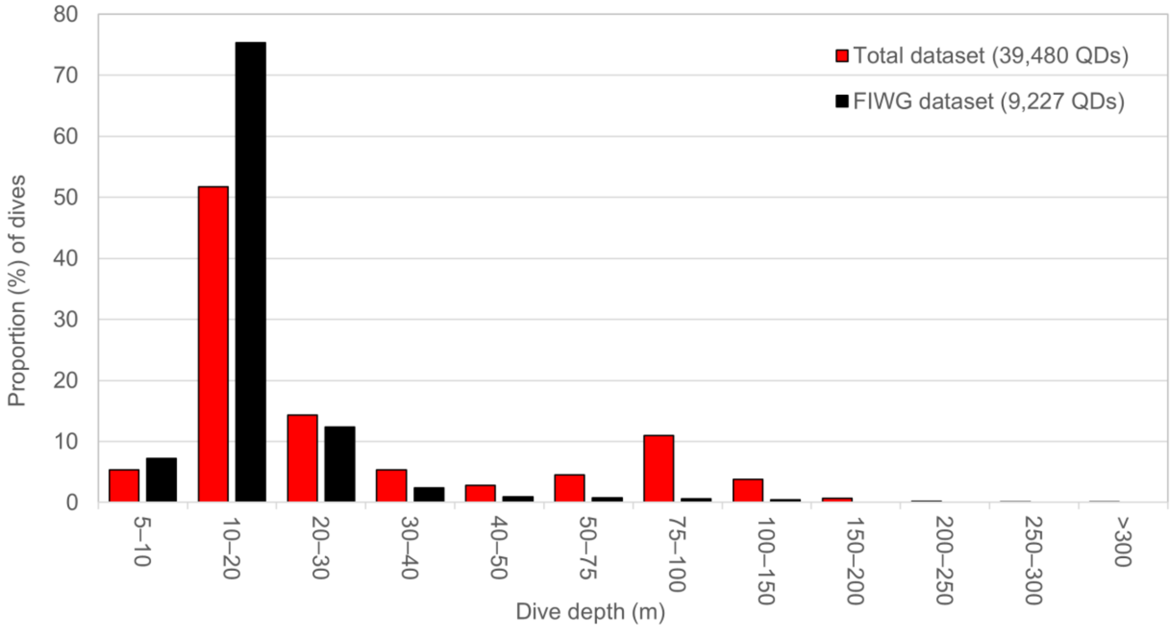
A total of 1,323 6-hour DD histogram summaries were received for the five southern right whales combined, comprising a total count of 39,642 QDs (Table 6.5). A total of 326 DMD histogram summaries comprising a total count of 9,385 QDs were received in the FIWG (Table 6.5).

Table 6.5. Number of 6-hr histogram summaries and qualifying dives (QDs) for which maximum dive duration (DD) was logged for five southern right whales tagged at the Falkland Islands wintering ground (FIWG) during July 2022.

Animal	Full dataset (all geographic regions)						FIWG	
	Total		Day		Night			
	No. 6-hr periods	No. QDs	No. 6-hr periods	No. QDs	No. 6-hr periods	No. QDs	No. 6-hr periods	No. QDs
Beatrice	248	6,181	117	2,757	131	3,424	9	426
Frosty	281	7,978	132	3,283	149	4,695	1	42
Kelpie	354	12,574	180	5,631	174	6,943	117	2,534
Sandy	254	7,486	124	3,444	130	4,042	144	4,609
Walter	186	5,423	84	2,044	102	3,379	55	1,774
Total	*1,323*	*39,642*	*637*	*17,159*	*686*	*22,483*	*326*	*9,385*

In both the full and the FIWG datasets, a clear majority of QDs (39.3% and 41.6% respectively) occurred in the 5–10 min DD bin (Figure 6.2B). This was also true for all five of the tagged individuals (Figure 6.5). Few QDs occurred in the DD bins exceeding 15 min, comprising only 4.6% and 3.2% of the total QDs in the full and FIWG datasets respectively (Figure 6.2B). Fifty-six QDs (0.14% of the total) had DDs exceeding 45 min, of which 50 occurred in the FIWG including 47 of the 48 dives of over 45 min duration recorded by the tags of Kelpie and Sandy (Table 6.6: Figures 6.2B and 6.5B). It is highly likely that these long durations represent errors due to the wet/dry sensor of the tags not detecting the surfacing event following a dive.

(A)



(B)

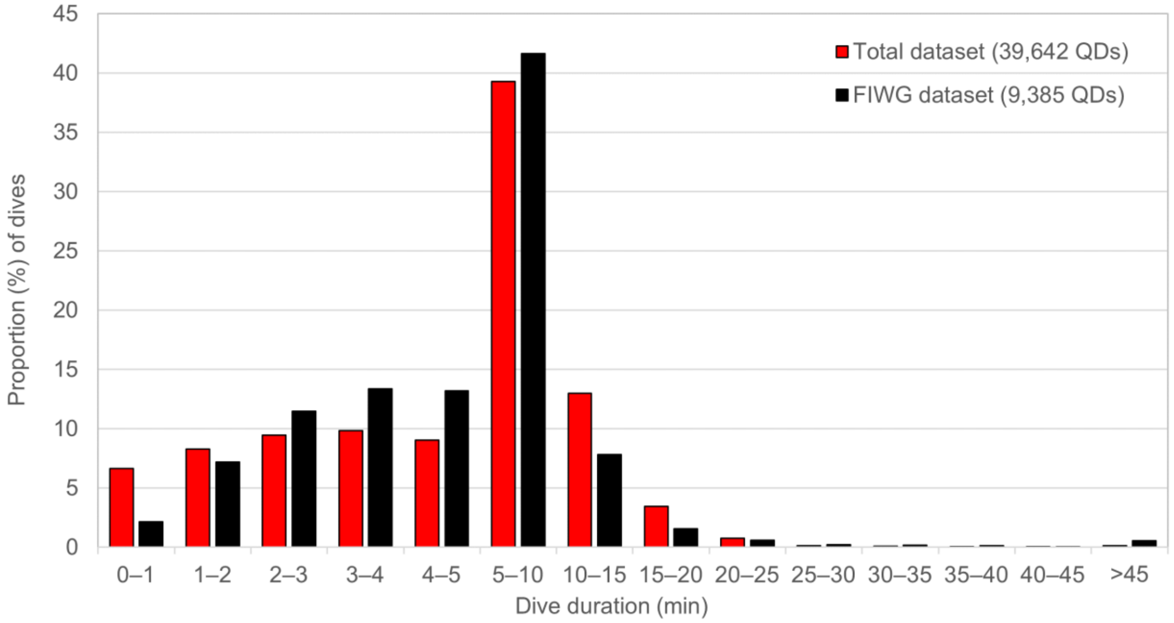


Figure 6.2. Total count of qualifying dives of five southern right whales tagged at the Falkland Islands wintering ground (FIWG) during July 2022 in: (A) dive maximum depth histogram bins; and (B) dive duration histogram bins. Each histogram bin upper limit is inclusive of that value, such that a dive of 3 min duration would be allocated to the 2–3 min bin.

Table 6.4. Total count of qualifying dives in each of the dive maximum depth (DMD) histogram bins for five southern right whales tagged at the Falkland Islands wintering ground (FIWG) in July 2022. Each histogram bin upper limit is inclusive of that value, such that a dive to 10 m depth would be allocated to the 5–10 m bin.

DMD (m)	Total			Beatrice		Frosty		Kelpie		Sandy		Walter	
	All	Day	Night	All	FIWG	All	FIWG	All	FIWG	All	FIWG	All	FIWG
5–10	2,105	884	1,221	398	10	409	–	514	209	420	310	364	134
10–20	20,428	7,534	12,894	3,196	232	3,385	–	6,113	2,076	4,648	3,385	3,086	1,259
20–30	5,660	2,114	3,546	1,153	159	1,473	–	1,708	259	857	559	469	164
30–40	2,095	824	1,271	415	19	717	–	580	51	198	88	185	64
40–50	1,125	500	625	150	11	518	–	273	22	64	12	120	39
50–75	1,802	967	835	272	21	716	–	602	15	74	1	138	32
75–100	4,326	3,261	1,065	253	14	577	–	3,255	6	123	0	118	34
100–150	1,494	1,140	354	305	17	162	–	175	0	480	1	372	24
150–200	273	181	92	45	0	72	–	32	0	23	0	101	0
200–250	70	31	39	0	0	60	–	10	0	0	0	0	0
250–300	42	23	19	0	0	39	–	3	0	0	0	0	0
>300	60	25	35	0	0	60	–	0	0	0	0	0	0
Total	*39,480*	17,484	21,996	*6,187*	*483*	*8,188*	–	*13,265*	*2,638*	*6,887*	*4,356*	*4953*	*1,750*

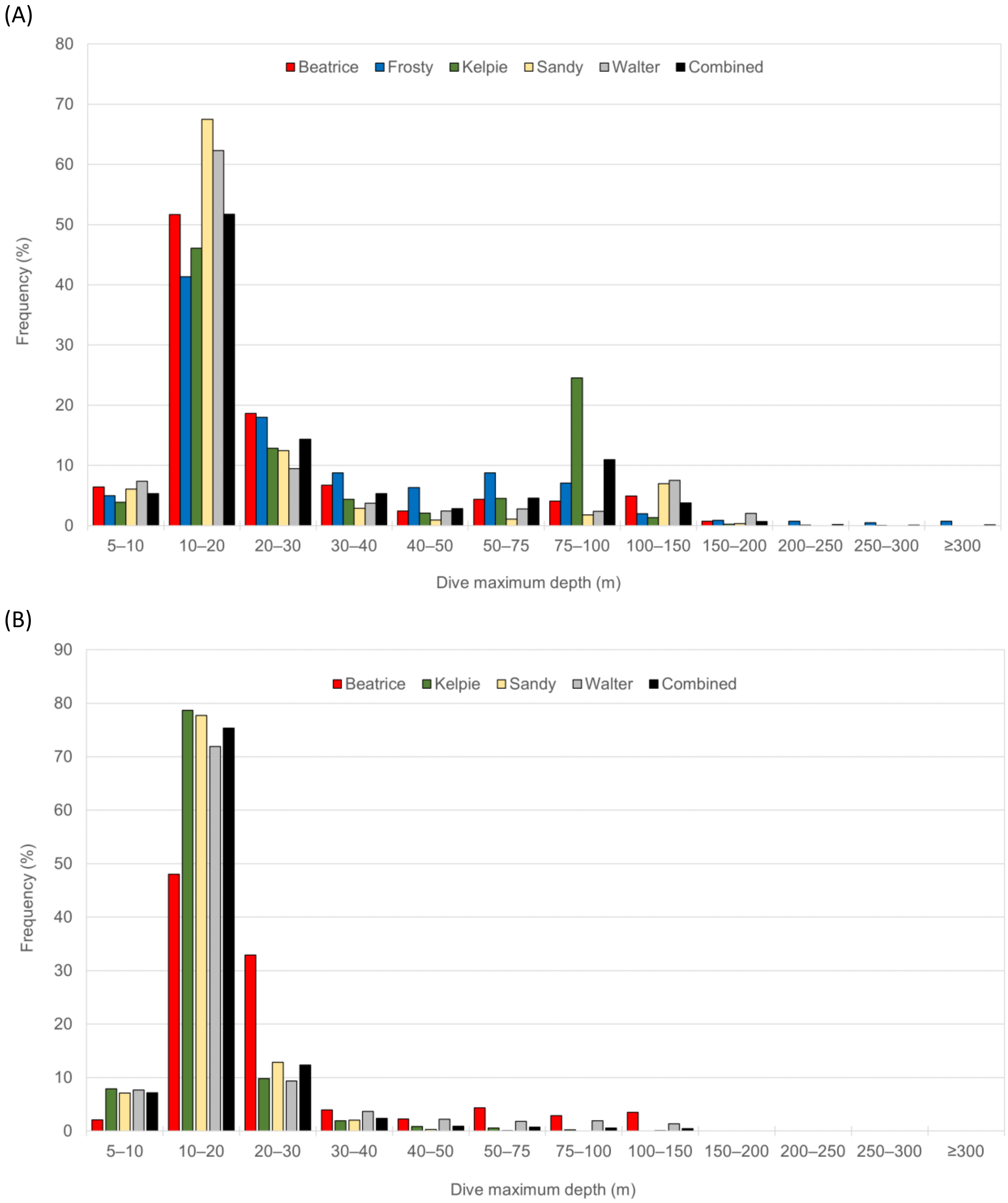


Figure 6.3. Frequency (% of total dives) of qualifying dives in each dive maximum depth (DMD) histogram bin for five southern right whales tagged in the Falkland Islands wintering ground (FIWG) in July 2022: (A) full dataset (n=39,480 dives); and (B) FIWG dataset (n=9,227 dives). Note different scale of the Y-axis.

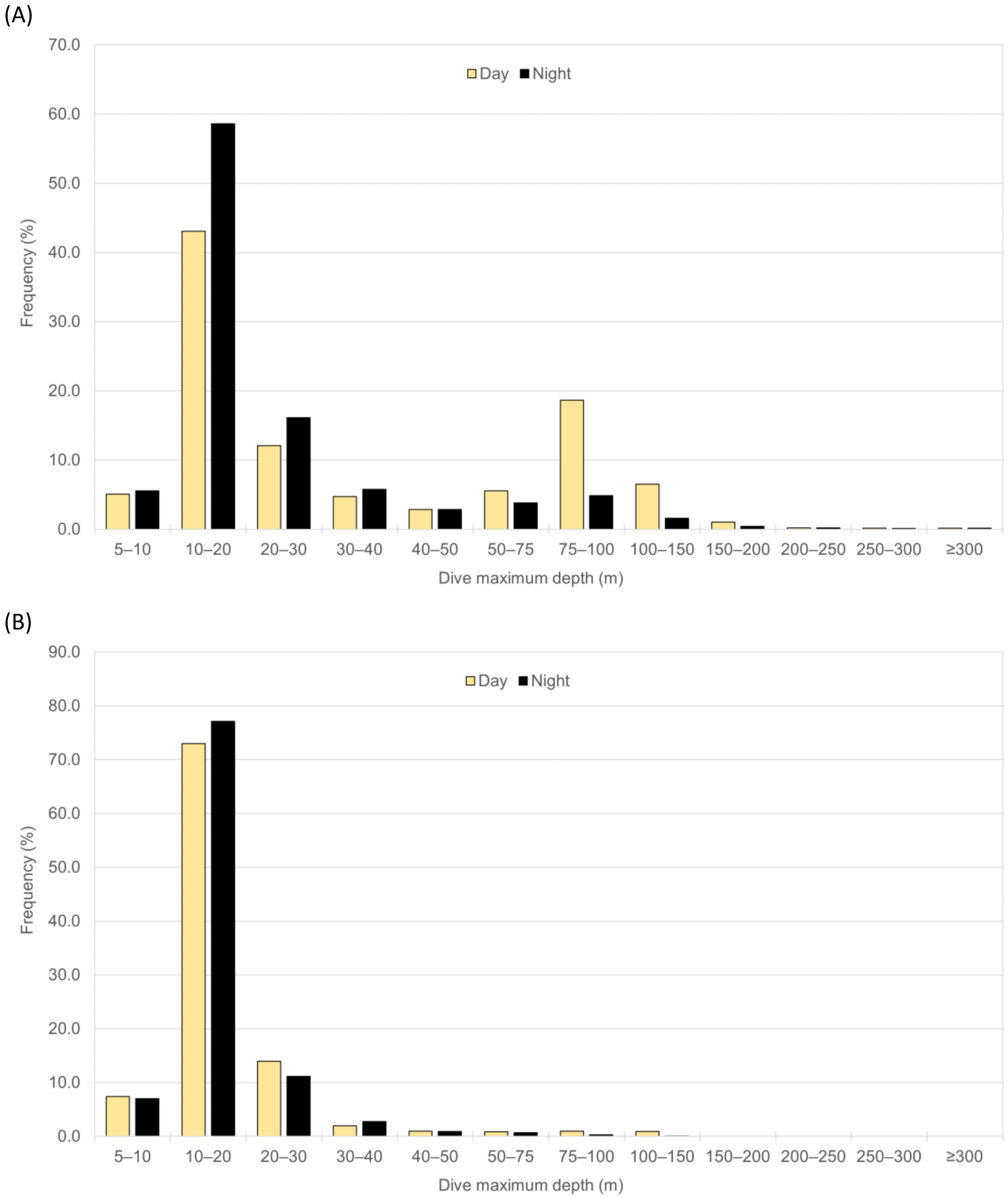


Figure 6.4. Frequency (% of total dives) of qualifying right whale dives in each dive maximum depth (DMD) histogram bin during day and night: (A) full dataset (n=39,480 dives); and (B) Falkland Islands wintering ground (FIWG) dataset (n=9,227 dives). Note different scale of the Y-axis.

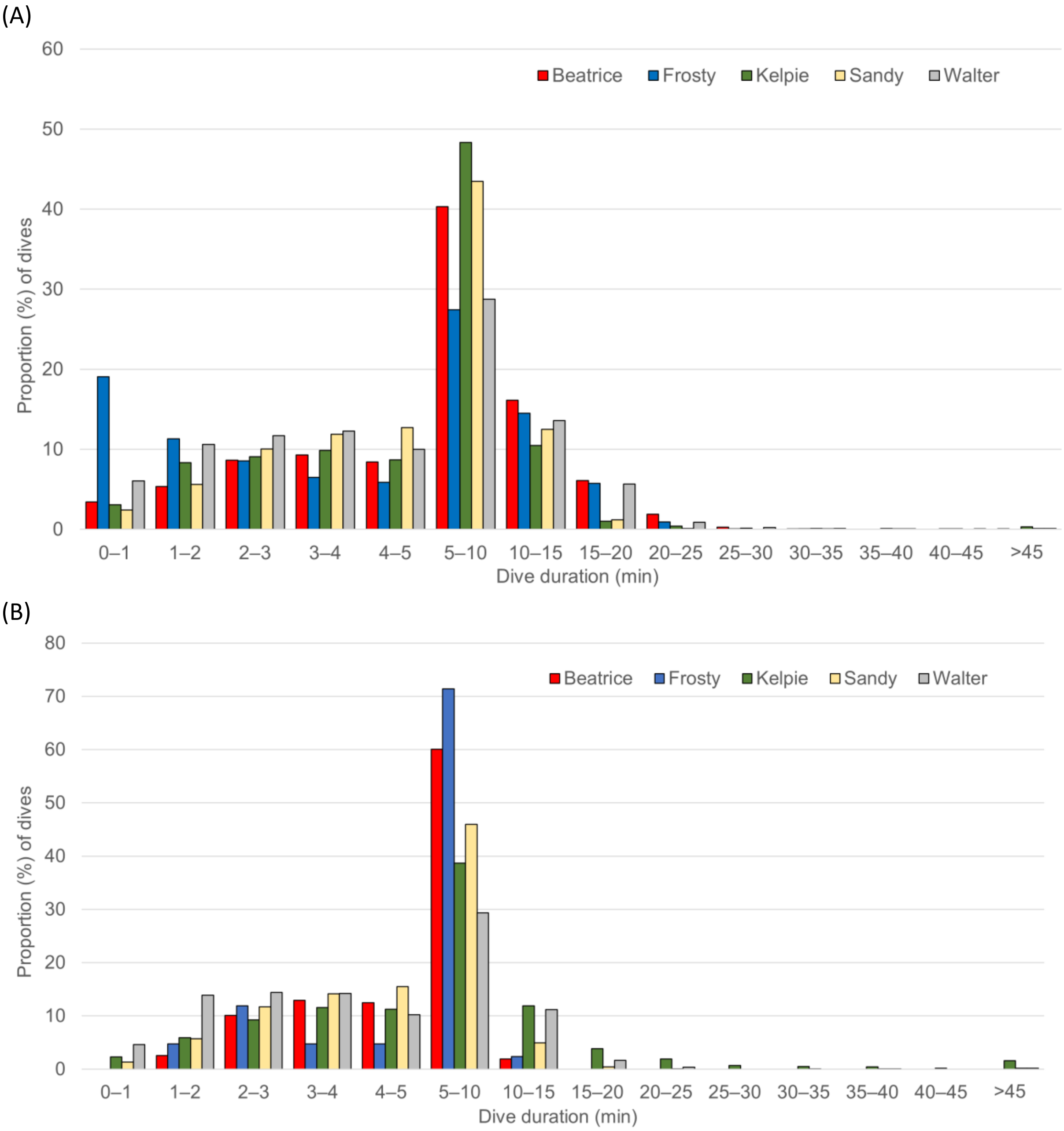


Figure 6.5. Frequency (% of total dives) of qualifying dives in each dive duration (DD) histogram bin for five southern right whales tagged in the Falkland Islands wintering ground (FIWG) in July 2022: (A) full dataset (n=39,642 dives); and (B) FIWG dataset (n=9,385 dives). Note different scale of the Y-axis.

Table 6.6. Total count of qualifying dives in each of the dive duration (DD) histogram bins for five southern right whales tagged at the Falkland Islands wintering ground (FIWG) in July 2022. Each histogram bin upper limit is inclusive of that value, such that a dive of 3 min duration would be allocated to the 2–3 min bin.

DD (min)	Total			Beatrice		Frosty		Kelpie		Sandy		Walter	
	All	Day	Night	All	FIWG	All	FIWG	All	FIWG	All	FIWG	All	FIWG
0–1	2,630	969	1,661	213	0	1,522	0	386	58	180	62	329	82
1–2	3,279	1,179	2,100	331	11	904	2	1,048	150	421	264	575	246
2–3	3,744	1,319	2,425	535	43	681	5	1,143	235	750	540	635	255
3–4	3,889	1,364	2,525	574	55	519	2	1,240	293	890	652	666	252
4–5	3,577	1,300	2,277	521	53	470	2	1,094	285	951	715	541	181
5–10	15,573	7,235	8,338	2,492	256	2,189	30	6,080	981	3,254	2,119	1,558	521
10–15	5,140	2,744	2,396	996	8	1,156	1	1,316	301	935	227	737	198
15–20	1,360	795	565	378	0	460	0	127	97	89	19	306	29
20–25	298	167	131	118	0	74	0	51	48	6	1	49	6
25–30	50	30	20	18	0	1	0	19	18	0	0	12	0
30–35	25	13	12	3	0	1	0	13	13	2	2	6	0
35–40	14	7	7	0	0	0	0	11	11	1	1	2	1
40–45	7	2	5	0	0	1	0	5	4	0	0	1	0
>45	56	35	21	2	0	0	0	41	40	7	7	6	3
Total	*39,642*	*17,159*	*22,483*	*6,181*	*426*	*7,978*	*42*	*12,574*	*2,534*	*7,486*	*4,609*	*5,423*	*1,774*

6.3.2.3. Time at depth

There was a total of 1,293 TAD 6-hour histogram summaries available for the five southern right whales, with the highest number generated by the tag of Kelpie (Table 6.7). Only 316 of the TAD summaries were generated within the FIWG, with the highest numbers relating to the tags of Kelpie and Sandy (Table 6.7).

Table 6.7. Number of 6-hr histogram summaries of time at depth (TAD) for five southern right whales tagged at the Falkland Islands wintering ground (FIWG) during July 2022.

Animal	Full dataset (all geographic regions)			FIWG
	Total	Day	Night	
Beatrice	248	127	121	9
Frosty	277	140	137	1
Kelpie	361	175	186	118
Sandy	234	102	132	130
Walter	173	88	85	58
Total	*1,293*	*632*	*661*	*316*

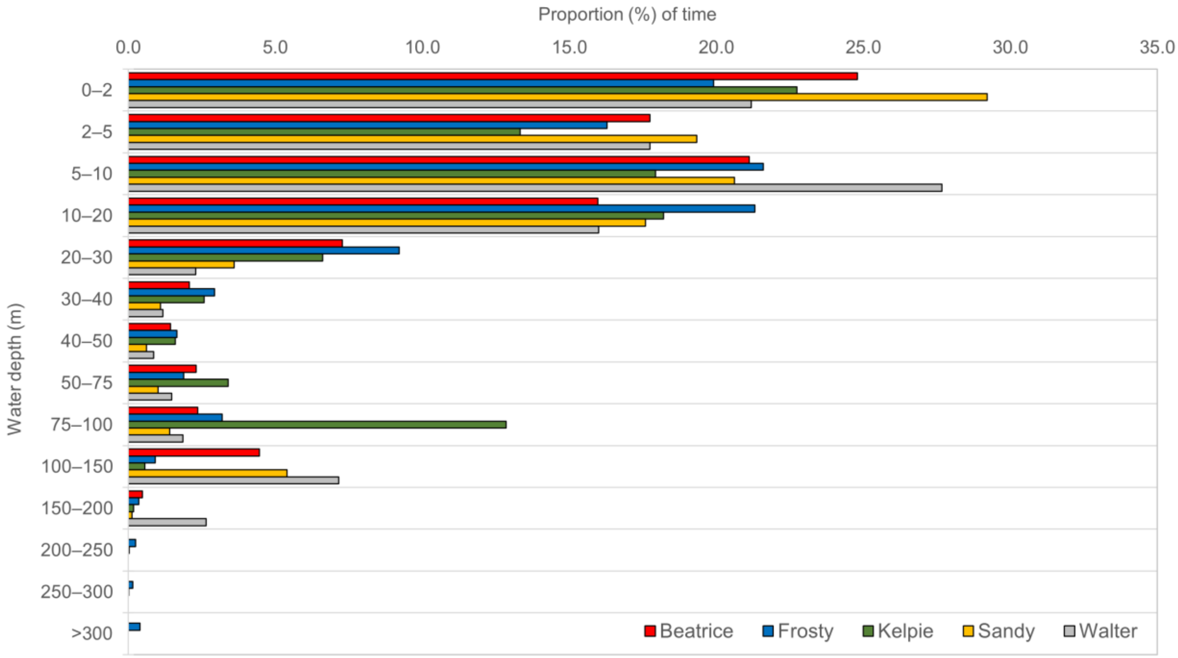
Considering the full dataset, three of the whales (Beatrice, Kelpie and Sandy) spent the highest proportion of their time (23 to 29%) in the 0–2 m depth bin, and less than 10% of their time at depths deeper than 50 m (Figure 6.6A). Conversely, two whales (Frosty and Walter) spent the highest proportion of their time (22 and 28% respectively) in the 5–10 m depth bin, and relatively high proportions of time (17 and 13% respectively) in depths deeper than 50 m (Figure 6.6A). All five whales spent the clear majority of their time (72 to 87%) in the upper 20 m of the water column, and between 54 and 69% of their time in the upper 10 m of the water column (Figure 6.6A).

Only one TAD histogram summary was available for Frosty within the FIWG, and so that animal was not considered further. Of the four remaining whales, two (Kelpie and Walter) spent the highest proportion of their time (31 and 29% respectively) in the FIWG using the 5–10 m depth bin (Figure 6.6B). Sandy spent the highest amount of time (28%) in the 0–2 m depth bin, while Beatrice spent most time (35%) in the 10–20 m depth bin (Figure 6.6B). However, only 9 summaries were available for Beatrice (Table 6.7). Of the three whales for which at least 58 TAD summaries were available within the FIWG reflecting their extended use of the region (Table 6.7), all spent a very high amount of time (>93%) in the upper 20 m of the water column, and between 72 and 82% of their time in the upper 10 m of the water column (Figure 6.6B).

When considering TAD according to habitat type, SRWs spent the majority of their time in the upper 10 m of the water column in nearshore (70%), slope (58%) and oceanic (53%) habitats (Figure 6.7). However, in shelf habitats they spent 48% of their time in the upper 10 m of the water column, and a second peak of use was evident in the 75–100 m depth bin where 16% of time was spent (Figure 6.7).

When the SWA categories were examined, SRWs spent most time in the upper 10 m of the water column while using the Wintering Grounds (70%) and Antarctic (62%), but less time when using the Patagonian Shelf (45%) and Deep (35%) habitat (Figure 6.8). On the Patagonian Shelf, 21% of time was spent in the 75–100 m depth bin, while in Deep habitats the highest amount of time (25%) was spent in the 10–20 m depth bin (Figure 6.8)

(A)



(B)

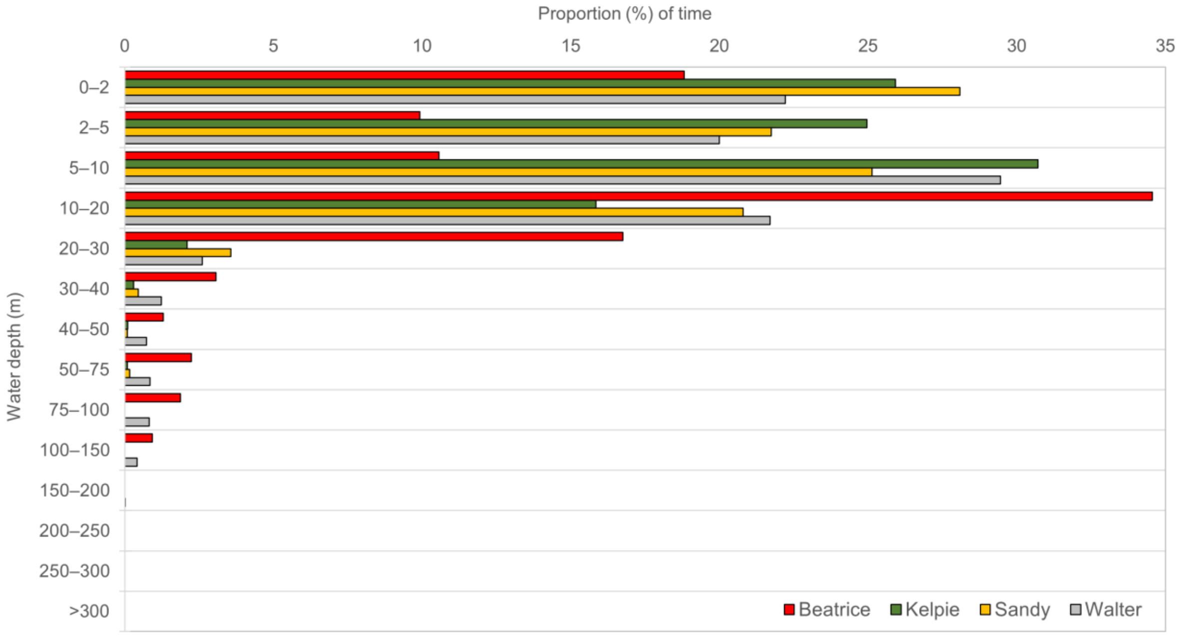


Figure 6.6. Time at depth (TAD) of five southern right whales tagged at the Falkland Islands wintering ground (FIWG) during July 2022: (A) full dataset; and (B) FIWG dataset.

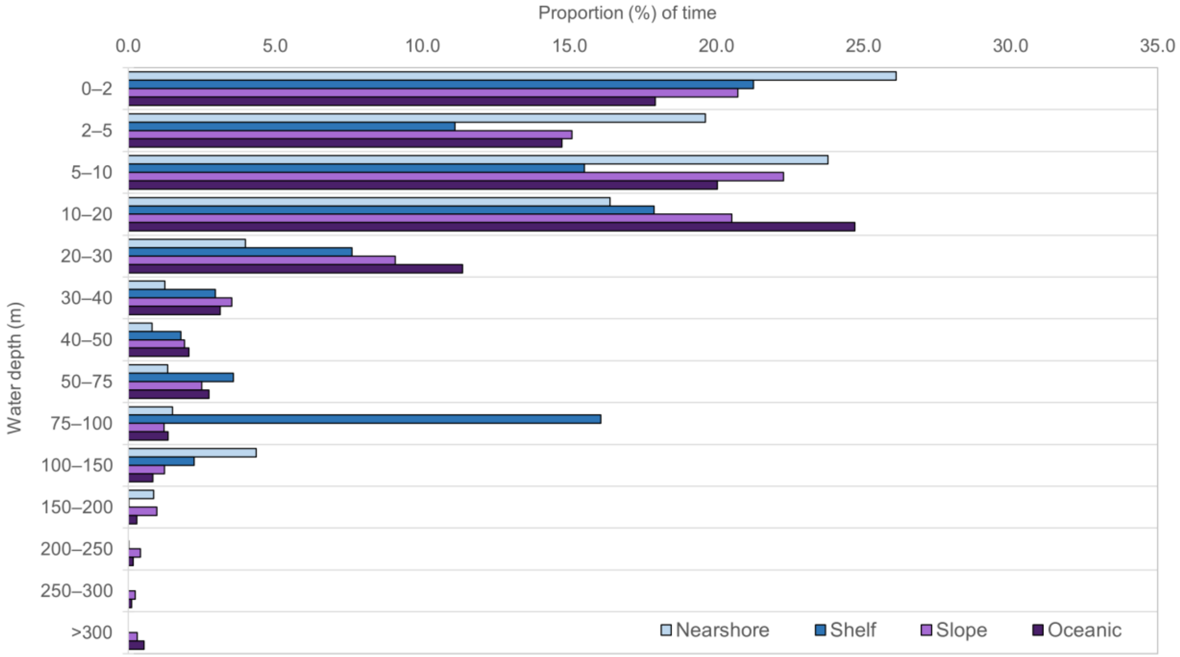


Figure 6.7. Time at depth (TAD) of southern right whales tagged at the Falkland Islands wintering ground (FIWG) during July 2022 according to habitat type: (1) nearshore (<200 m depth, <30 km from the coast); (2) shelf (<200 m depth, ≥30 km from the coast); (3) slope (200–1,999 m depth); and (4) oceanic (≥2,000 m depth).

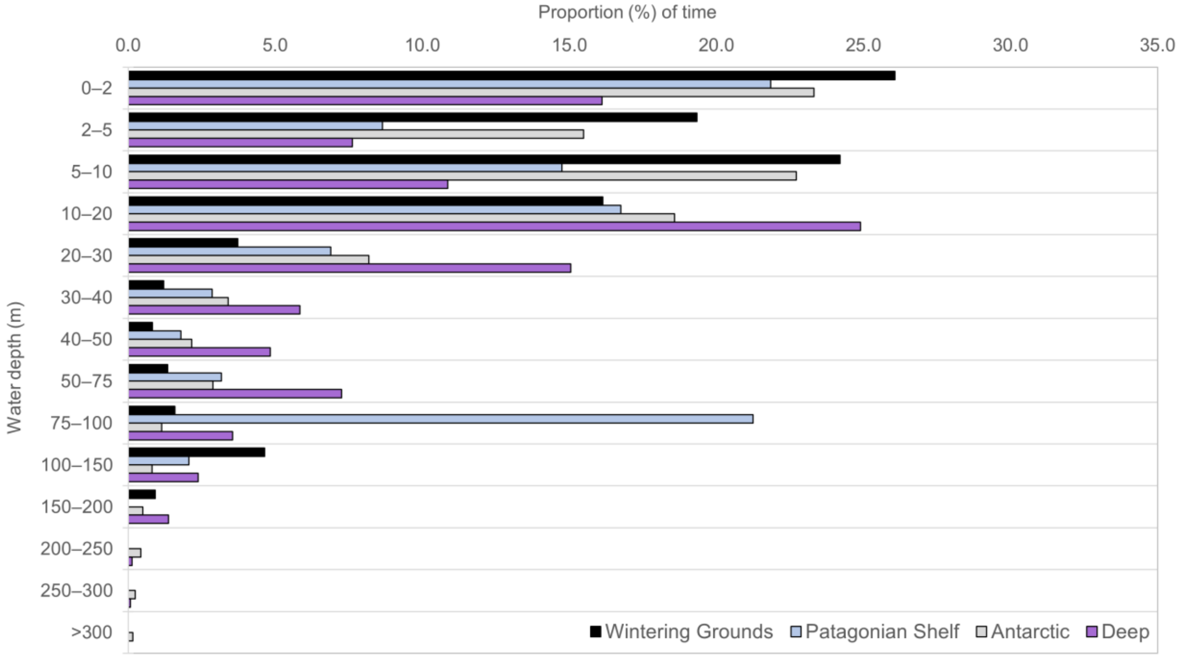


Figure 6.8. Time at depth (TAD) of southern right whales tagged at the Falkland Islands wintering ground (FIWG) during July 2022 according to south-west Atlantic category: (1) wintering grounds (<200 m depth, <30 km from the coast of the Falkland Islands, Argentina and Chile); (2) Patagonian Shelf (<200 m depth, ≥30 km from the coast); (3) Antarctic (all water depths); and (4) Deep (waters >200 m depth outside of Antarctica).

6.3.3. Behaviour dataset

6.3.3.1. Overview

A total of 35,457 CDCs were available for the five southern right whales following data preparation. Mean inter-whale dive depths ranged from 25.5 (SD=29.9) to 38.6 m (SD=33.3) (Table 6.8), and differed significantly (H=1251.7, df=4, p<0.001) with all pairwise comparisons also showing significant differences (p<0.001). The five whales dove to maximum depths exceeding 170 m (Table 6.8), with 22 deep dives of between 400 and 632 m depth undertaken by Frosty. Mean inter-whale dive durations ranged from 6.1 (SD=3.3) to 7.8 min (SD=5.1) (Table 6.8). Only 392 (1.1%) dives had durations exceeding 20 min. Inter-whale dive durations differed significantly (H=442.2, df=4, p<0.001), with post-hoc comparisons indicating highly significant (p<0.001) or significant (p<0.05) differences between all whale pairs except for Frosty–Walter (p=0.18) and Frosty–Sandy (p=1.0). Beatrice had significantly (p<0.001) longer dive durations than all other whales (Table 6.8).

A significant moderate correlation was found between dive depth and duration for the five whales combined (Spearman’s rho=0.43, p<0.001) (Figure 6.9). Significant correlations (p<0.001) between dive depth and duration were also found for the five whales individually, although the effect size varied from small (Frosty: Spearman’s rho=0.19) to large (Beatrice: Spearman’s rho=0.55).

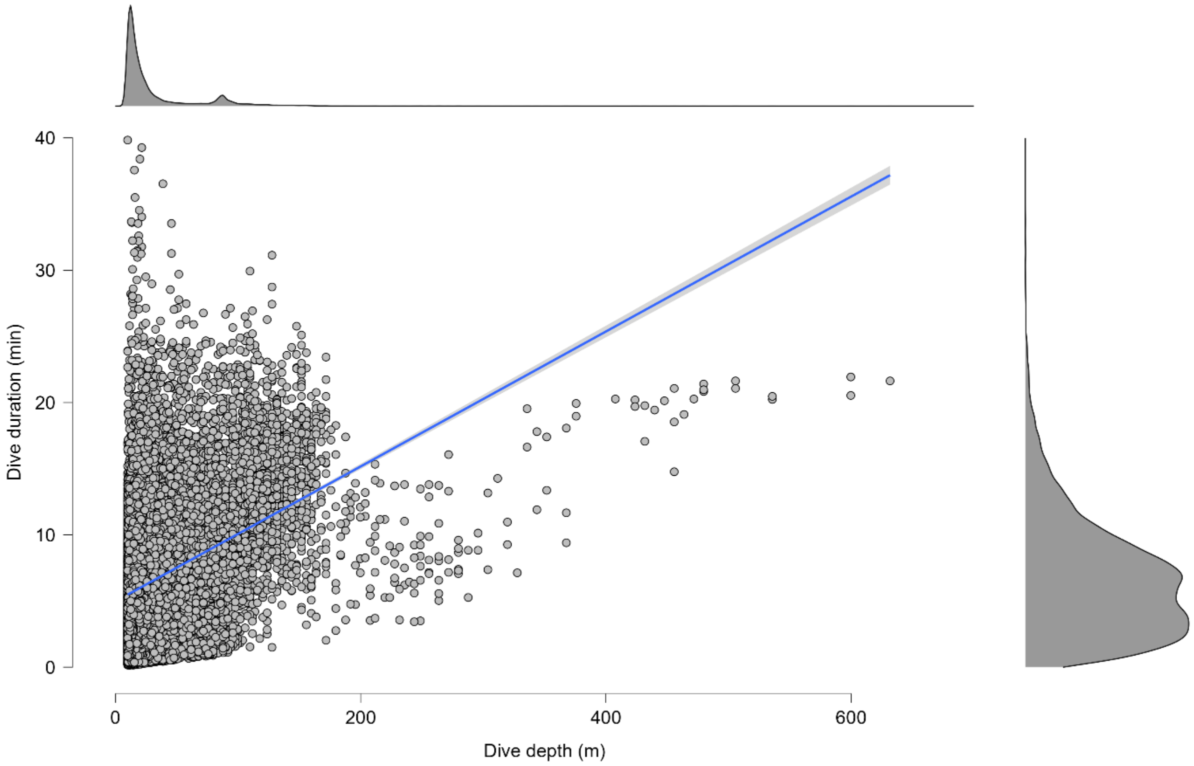
The TDCT ranged from 0.2 to 682.4 min (mean=12.5, SD=18.2, median=9.1) (Table 6.9), of which means of 68.6 (SD=25.9, median=78.0) and 31.4% (SD=25.9, median=22.0) were allocated to dives and post-dive SEVs respectively. Over 79% of post-dive SEVs had durations of <5 min. A total of 35 TDCTs exceeded 240 min (4 hr) due to prolonged SEVs; those included TDCTs from all five individuals. Inter-whale TDCTs differed significantly (H=718.4, df=4, p<0.001), with post-hoc comparisons highly significant (p<0.001) for all pairs except for Frosty–Walter (p=0.02), Frosty–Sandy (p=1.00) and Sandy–Walter (p=0.07).

Significant and strong correlations occurred for TDCT with dive duration (Spearman’s rho=0.72, p=<0.001) and SEV duration (Spearman’s rho=0.68, p=<0.001) indicating that both parameters influenced TDCT (Figure 6.10). These correlations were evident also in the data for each individual whale. Although the correlations between both dive depth (Spearman’s rho=0.09, p=<0.001) and dive duration (Spearman’s rho=0.16, p=<0.001) with the duration of the subsequent SEV were significant, both were very weak effects (Figure 6.11).

Table 6.8. Summary statistics of qualifying dives (≥10 m depth and ≥0.17 min duration) and total dive cycle times (TDCT) recorded during 35,457 complete dive cycles of five southern right whales tagged in the Falkland Islands.

Category	N	Dive depth (m)			Dive duration (min)			TDCT		
		Mean (SD)	Median	Range	Mean (SD)	Median	Range	Mean (SD)	Median	Range
Combined										
All	35,457	32.8 (35.7)	17.5	10.0–631.8	6.6 (4.4)	6.0	0.2–39.8	12.5 (18.2)	9.1	0.2–682.4
Whale										
Beatrice	6,589	29.8 (30.9)	18.0	10.0–179.8	7.8 (5.1)	6.9	0.2–33.5	15.1 (21.6)	10.6	0.2–519.7
Frosty	6,864	33.4 (44.0)	20.0	10.0–631.8	6.6 (5.2)	5.8	0.2–31.3	13.9 (22.8)	9.7	0.2–681.3
Kelpie	10,919	38.6 (33.3)	20.5	10.0–271.8	6.4 (3.8)	6.3	0.2–39.8	9.9 (14.1)	8.5	0.2–682.4
Sandy	6,432	25.5 (29.9)	14.5	10.0–171.8	6.1 (3.3)	5.6	0.2–23.9	12.5 (16.1)	8.9	0.3–351.8
Walter	4,653	32.7 (39.1)	15.0	10.0–207.8	6.4 (4.8)	5.1	0.2–33.5	12.5 (15.4)	8.7	0.3–272.9
Shape										
V	4,595	35.1 (29.1)	23.0	10.0–279.8	6.3 (4.3)	5.4	0.2–33.7	15.2 (25.1)	9.4	0.2–519.7
U	10,933	29.4 (37.8)	17.0	10.0–631.8	4.8 (4.0)	3.8	0.2–38.4	11.3 (18.5)	7.1	0.2–367.6
Square	19,929	34.1 (35.9)	17.0	10.0–431.8	7.7 (4.3)	7.2	0.2–39.8	12.5 (15.9)	9.7	0.2–682.4
Behaviour state										
1	16,679	28.8 (34.1)	15.0	10.0–455.8	6.3 (4.7)	5.2	0.2–39.8	12.9 (20.2)	8.6	0.2–682.4
2	12,583	38.0 (34.2)	21.0	10.0–367.8	6.3 (3.7)	6.1	0.2–31.3	10.4 (12.7)	8.6	0.2–387.5
3	6,077	33.3 (41.6)	20.0	10.0–631.8	8.4 (4.6)	8.3	0.2–33.5	15.4 (21.1)	11.2	0.2–519.7
Habitat										
Shelf	28,576	32.4 (33.1)	17.0	10.0–248.8	6.6 (4.3)	5.9	0.2–39.8	12.3 (17.8)	9.0	0.2–682.4
Slope	3,653	36.9 (51.5)	19.5	10.0–599.8	5.8 (4.6)	5.1	0.2–23.8	12.2 (22.6)	8.6	0.2–681.3
Oceanic	3,228	31.9 (36.1)	22.5	10.0–631.8	8.0 (4.9)	7.6	0.2–31.3	14.1 (15.9)	10.8	0.2–393.6
SW Atlantic context										
Coastal wintering ground	17,323	26.9 (31.5)	14.5	10.0–179.8	6.7 (4.6)	5.7	0.2–39.8	13.3 (18.6)	9.1	0.2–682.4
Patagonian Shelf	8,121	43.7 (34.7)	24.0	10.0–199.8	5.7 (3.3)	5.6	0.2–24.7	9.0 (9.8)	8.1	0.2–255.3
Antarctic	2,555	35.1 (44.2)	19.5	10.0–455.8	4.9 (4.9)	3.0	0.2–31.3	11.7 (27.3)	6.4	0.2–681.3
Deep (slope/oceanic)	1,381	36.7 (29.1)	25.8	10.0–271.8	6.9 (3.8)	6.9	0.2–22.4	10.3 (9.1)	8.9	0.2–121.3

(A) All whales (Spearman's rho=0.72, $p<0.001$, $R^2=0.5184$)



(B) Beatrice (Spearman's rho=0.55, $p<0.001$, $R^2=0.3025$)

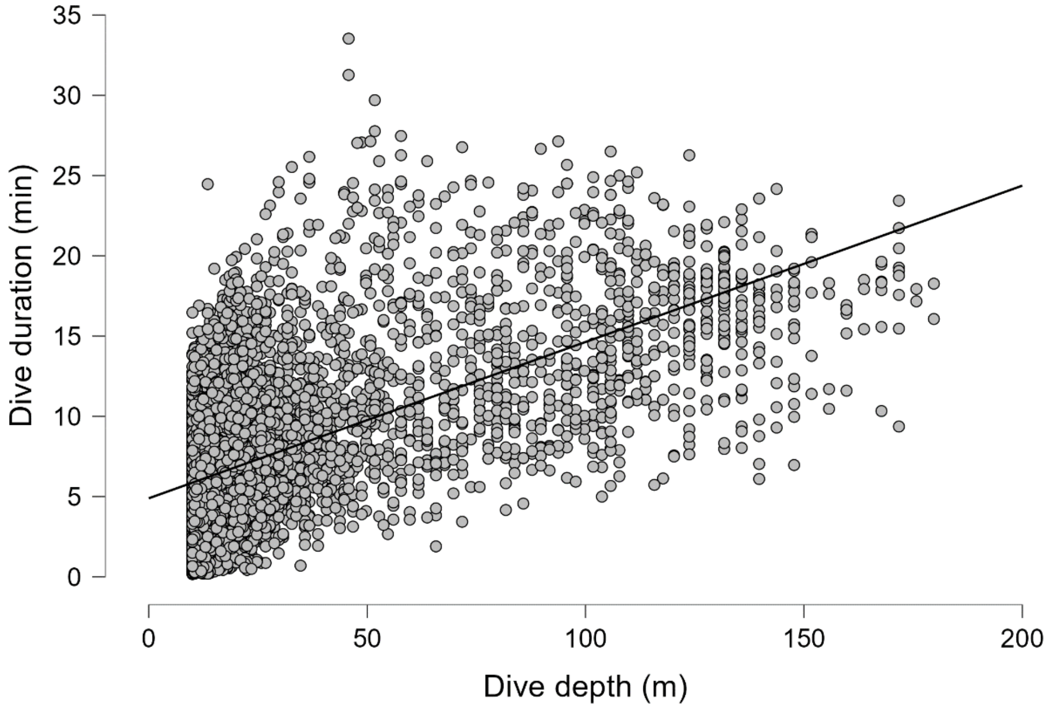
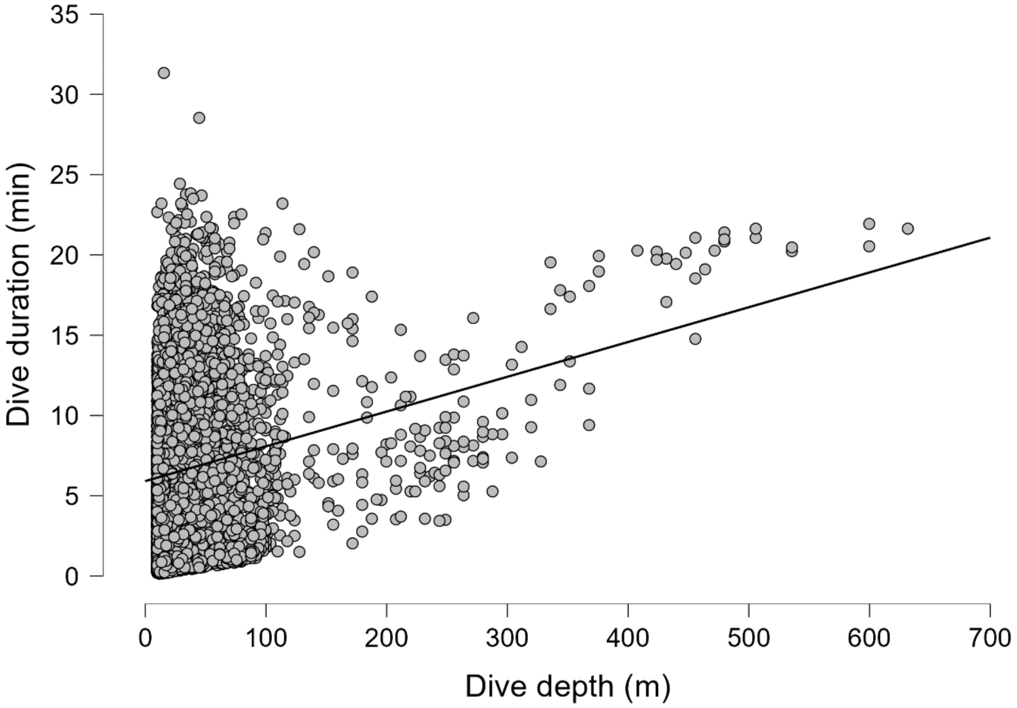


Figure 6.9. Relationship between dive depth (m) and duration (min) for five southern right whales tagged in the Falkland Islands: (A) combined dataset; and (B–F) datasets for each whale. Data in part A are fitted with linear regression lines showing 95% confidence intervals.

(C) Frosty (Spearman's rho=0.19, p<0.001, R^2=0.0361)



(D) Kelpie (Spearman's rho=0.50, p<0.001, R^2=0.25)

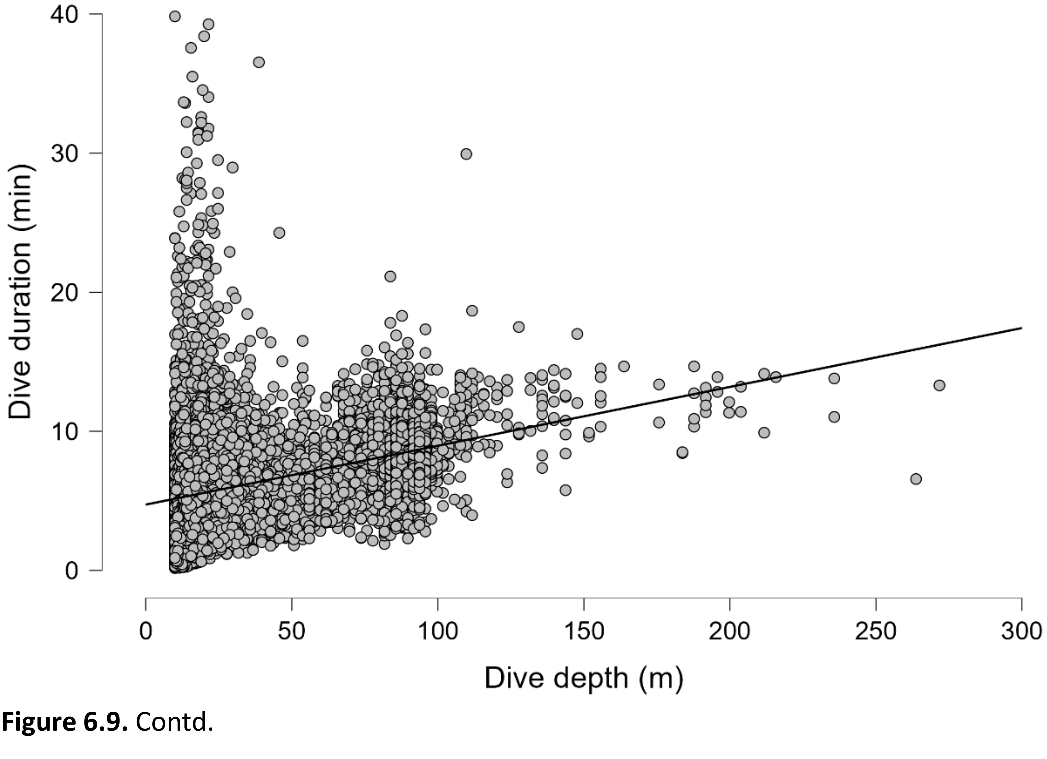
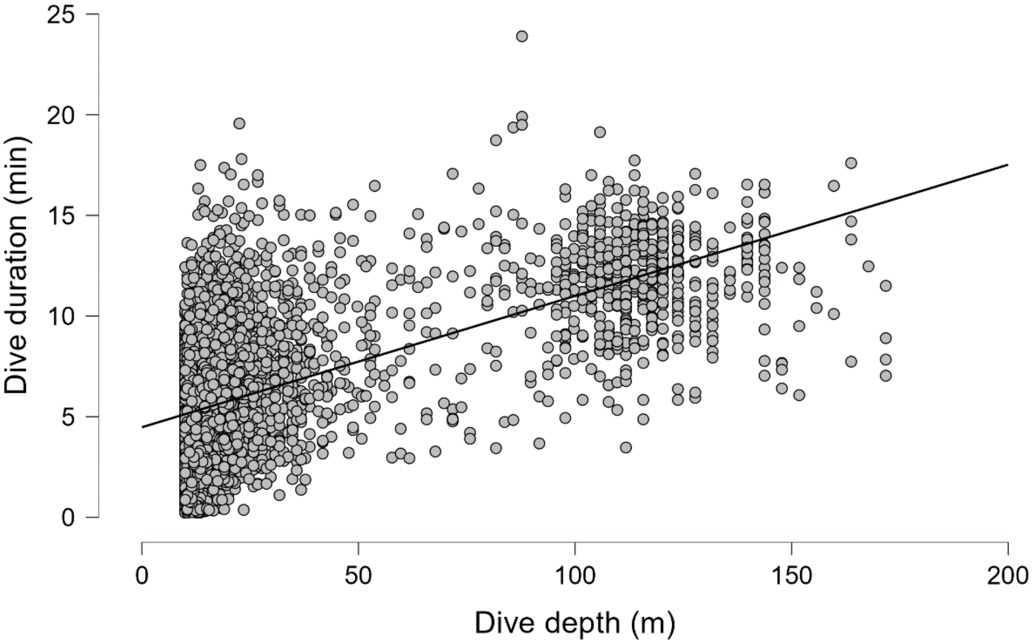


Figure 6.9. Contd.

(E) Sandy (Spearman's rho=0.45, p<0.001, R^2=0.2025)



(F) Walter (Spearman's rho=0.44, p<0.001, R^2=0.1936)

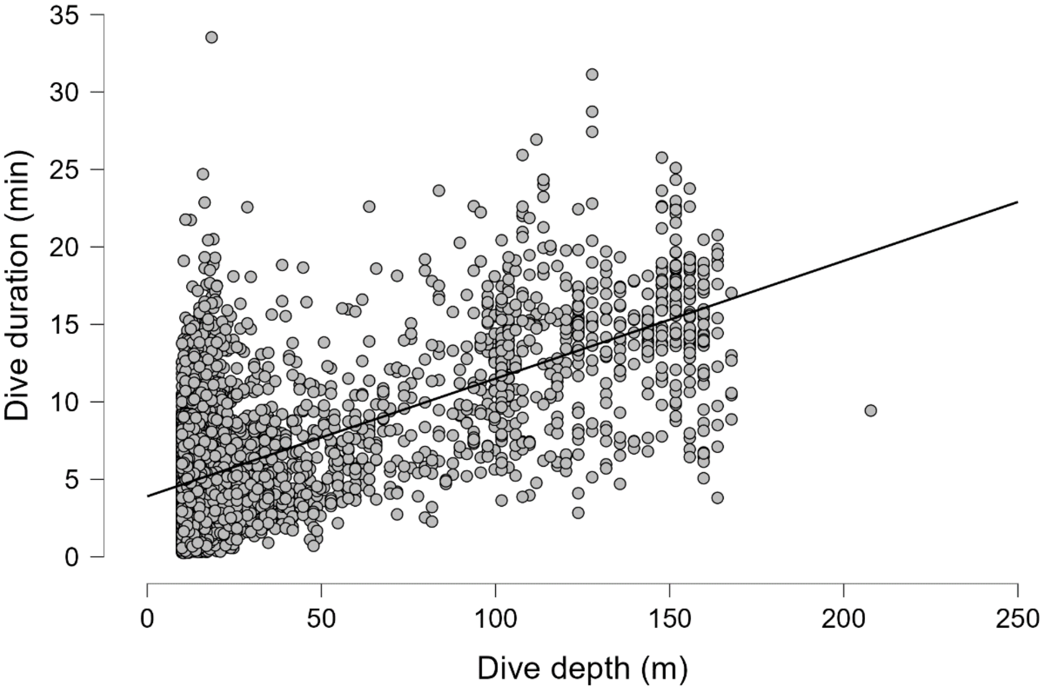
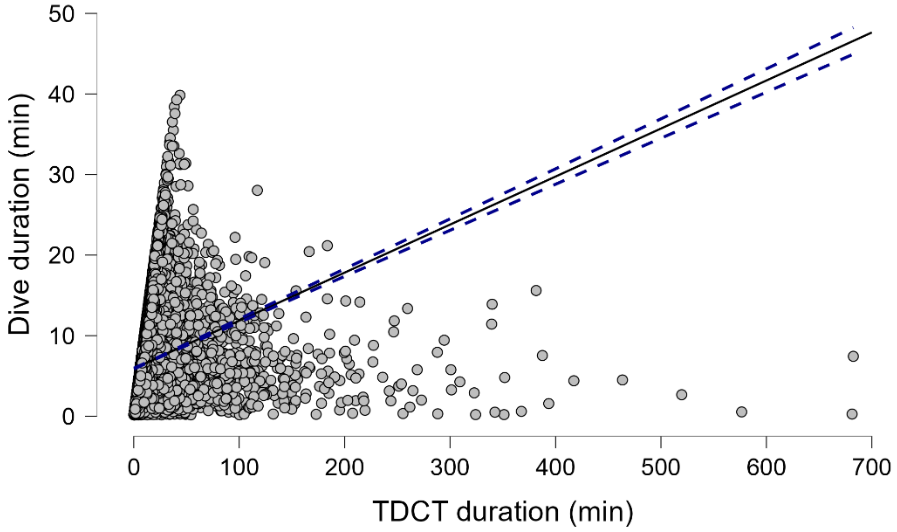


Figure 6.9. Contd.

(A) Dive duration (Spearman's rho=0.72, p=<0.001, R^2=0.5184)



(B) SEV duration (Spearman's rho=0.68, p=<0.001, R^2=0.4624)

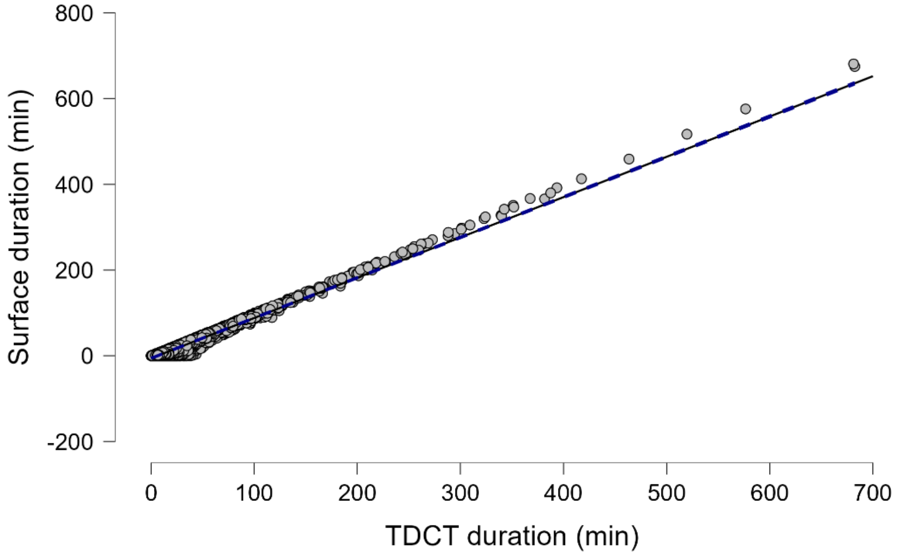
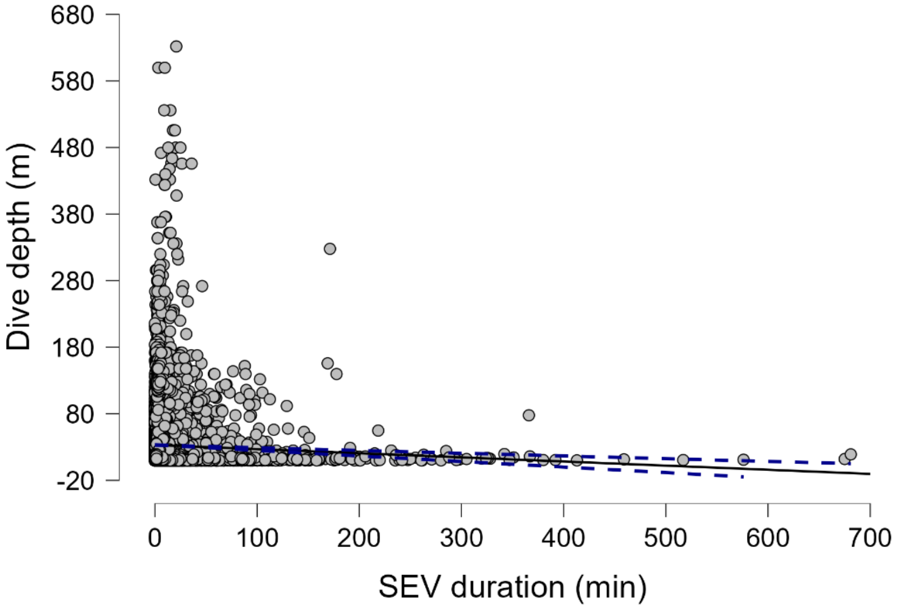


Figure 6.10. Tag data from five southern right whales showing the relationship for total dive cycle time (TDCT) with: (A) dive duration; and (B) surfacing event (SEV) duration. Data are fitted with linear regression lines showing 95% confidence intervals.

(A) Dive depth (Spearman's rho=0.09, p=<0.001, R^2=0.0081)



(B) Dive duration (Spearman's rho=0.16, p=<0.001, R^2=0.0256)

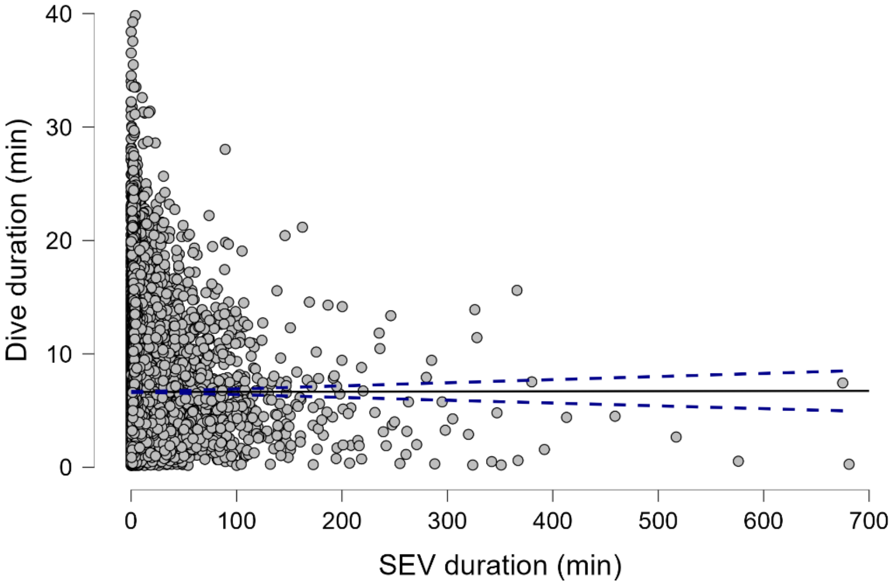


Figure 6.11. Tag data from five southern right whales showing the relationship of surfacing event (SEV) duration with parameters of the preceding dive: (A) dive depth (m); and (B) dive duration (min). Data are fitted with linear regression lines showing 95% confidence intervals.

6.3.3.2. Dive shape

Totals of 19,929 (56%), 10,933 (31%) and 4,595 (13%) dives were categorised as square-, U- and V-shaped respectively (Table 6.8). Both dive depth (H=307.8, df=2, p<0.001) and dive duration (H=4,136.2, df=2, p<0.001) differed significantly according to dive shape, with post-hoc comparisons indicating highly significant (p<0.001) differences between all pairs. U-shaped dives were both shallower and of shorter duration than square- or V-shaped dives (Table 6.8).

Significant (p<0.001) moderate correlations were found between dive depth and duration for each of the three dive shapes (square: Spearman's rho=0.46; U: Spearman's rho=0.47; V: Spearman's rho=0.33).

There was a significant difference in dive speed according to dive shape (H=2,937.0, df=2, p<0.001). Square-shaped dives had significantly (p<0.001) lower speeds (mean=0.17 m s^{-1}, SD=0.22) than both U- (mean=0.32 m s^{-1}, SD=0.37) and V-shaped (mean=0.33 m s^{-1}, SD=0.49) dives, and the latter pair also differed significantly (p<0.001) from each other.

6.3.3.2. Behaviour state

Dive depth (H=1,408.4, df=2, p<0.001), dive duration (H=1,355.8, df=2, p<0.001) and TDCT (H=936.7, df=2, p<0.001) all varied significantly according to BS. Pairings of these parameters all showed highly significant (p<0.001) differences, with dives in BS1 being both the shallowest and shortest, while TDCT was longest in BS3 (Table 6.8).

Square-shaped dives were the dominant dive shape (exceeding 50% of total dives) recorded for all BS, but the proportion was highest in BS2 (63.3%, n=7,968). The proportions of each dive shape recorded in BS1 and BS3 were very similar (Figure 6.12A). There was a significant relationship between dive shape and BS (X^2(4, n=35,339)=426.6, p<0.001). Dives recorded during BS1 and BS3 comprised fewer square-shaped and higher U- and V-shaped than expected, while more square-shaped dives and fewer U- and V-shaped dives were recorded during BS2 than expected.

6.3.3.3. Habitat

Sample size for the habitat analyses had a strong bias towards shelf habitats (Table 6.8).

Dive depth (H=240.7, df=2, p<0.001), dive duration (H=496.5, df=2, p<0.001) and TDCT (H=280.3, df=2, p<0.001) varied significantly according to habitat. The depth of dives in shelf waters was significantly (p<0.001) shallower than dives in either slope or oceanic habitats (Table 6.8), while the latter habitats did not differ significantly from each other (p=0.06). Dive duration and TDCT differed significantly (p<0.001) between all habitat pairings, both being shortest in slope habitats and longest in oceanic habitats (Table 6.8).

There was a significant relationship between dive shape and habitat (X^2(4, n=35,457)=281.6, p<0.001). In shelf habitats, there were fewer V-shaped dives and more square- and U-shaped dives than expected. In slope habitats there were fewer square-shaped dives but more U- and V-shaped dives than expected. In oceanic habitats, there were more V-shaped dives and fewer U-shaped dives than expected.

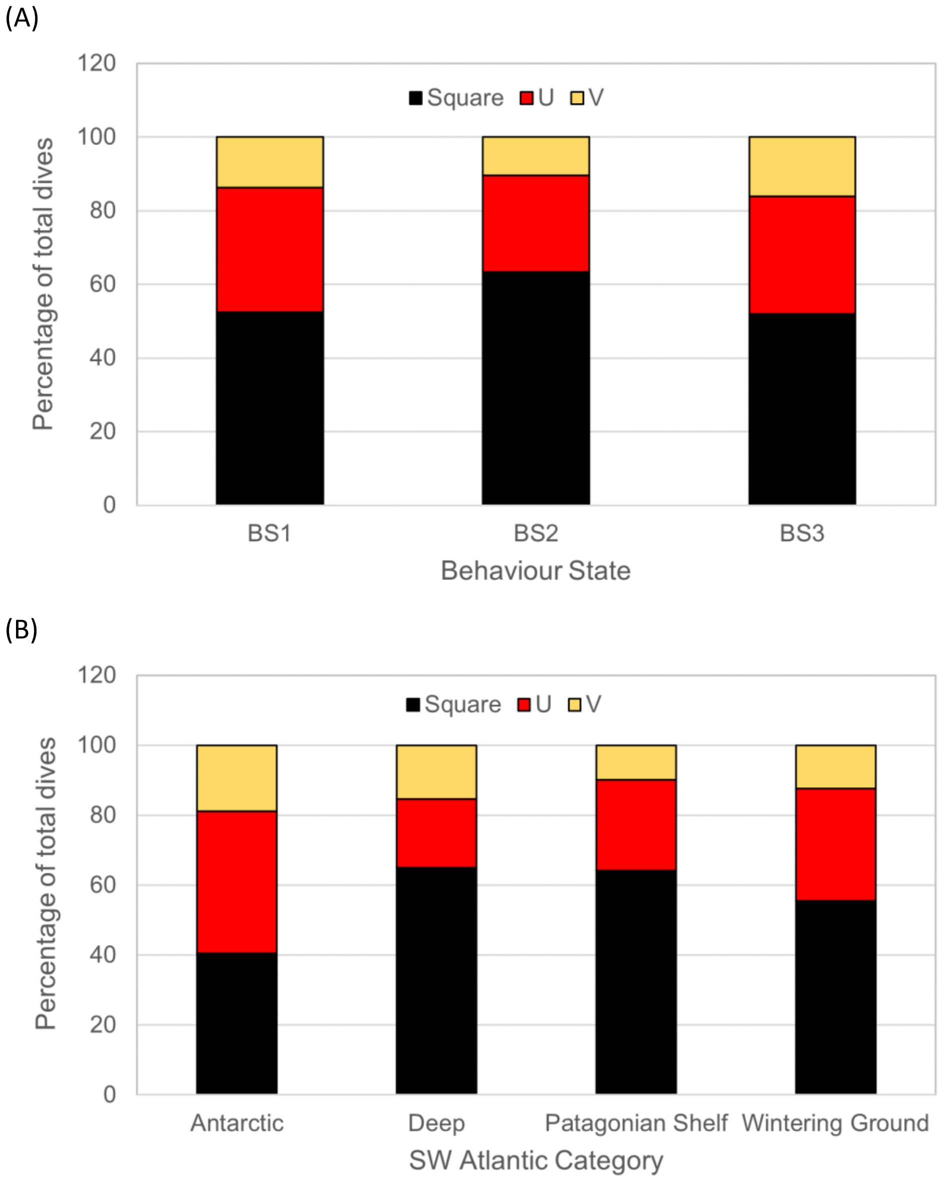


Figure 6.12. Proportions of dive shapes recorded from five tagged southern right whales according to: (A) behaviour state (BS), n=35,339; and (B) south-west Atlantic category, n=29,380. A total of 118 dives were not assigned to a BS due to nuances of the modelling process.

6.3.3.4. SW Atlantic category

The four SWA categories included data from at least three whales, except for the Antarctic which was represented by a single animal (Frosty).

Dive depth (H=2,113.7, df=3, p<0.001), dive duration (H=834.4, df=3, p<0.001) and TDCT (H=748.0, df=3, p<0.001) varied significantly according to SWA category. All pairwise comparisons had highly significant (p<0.001) differences in dive depth (Table 6.8), except for Deep–Patagonian Shelf (p=0.01). Dives on the Wintering Grounds were shallower, while dives in Patagonian Shelf and Deep habitats were deeper, than other SWA categories (Table 6.8). All pairwise comparisons had highly significant (p<0.001) differences in dive duration, with Antarctic dives having shortest duration, while those in Deep habitats were the longest (Table 6.8). All pairwise comparisons had highly significant (p<0.001) differences in TDCT, with dives on the Wintering Grounds being the longest.

There was a significant relationship between dive shape and SWA category (X^2(6, n=29,380)=560.4, p<0.001). There were fewer square-shaped dives than expected in Antarctic and Wintering Ground, and more than expected in Deep and Patagonian Shelf (Figure 6.12B). The opposite was true of U-shaped dives. There were fewer V-shaped dives than expected in Patagonian Shelf habitat, and more than expected in Antarctic and Deep.

6.3.3.5. *Foraging dives*

While BS1 and BS2 are indicative of area restricted movement considered to represent foraging, those BS's were also exhibited by whales using their wintering areas as well as on foraging grounds (Weir et al., 2024). Consequently, the likelihood of dives representing foraging behaviour was optimised by using SWA categories 'Antarctic,' 'Deep' and 'Patagonian Shelf,' which excluded the Wintering Grounds. We also used only square- and U-shaped dives as indicative of foraging. This data subset (n=10,570) was termed the 'foraging dive' dataset.

Within the foraging dive dataset, square-shaped dives were significantly deeper ($W=1.36x10^{+7}$, $p<0.001$; $r_B=0.11$), of longer duration ($W=1.87x10^{+7}$, $p<0.001$; $r_B=0.53$), and had longer TDCT ($W=1.64x10^{+7}$, $p<0.001$; $r_B=0.34$) than U-shaped dives (Figure 6.13), with dive duration having the largest effect.

Foraging dives (U- and square-shaped combined) undertaken at night were significantly shallower ($W=1.99x10^{+7}$, $p<0.001$; $r_B=0.45$), longer in duration ($W=1.85x10^{+7}$, p<0.001: $r_B=0.34$), and had longer TDCTs ($W=1.73x10^{+7}$, $p<0.001$; $r_B=0.26$) than those occurring during daytime (Figure 6.14), with depth having the largest effect.

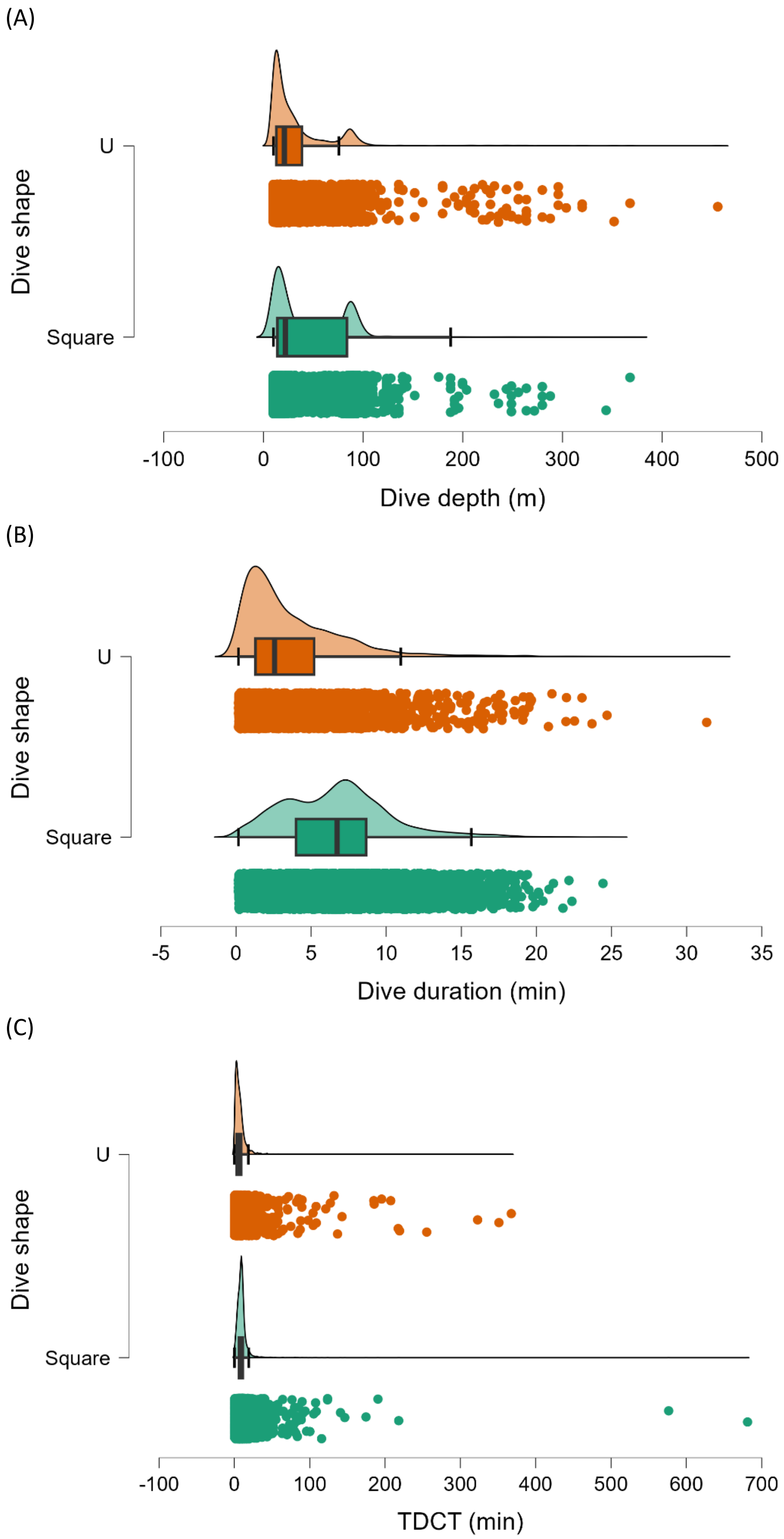


Figure 6.13. Raincloud plots of square- and U-shaped foraging dives (n = 10,570) undertaken by five southern right whales according to: (A) depth; (B) duration; and (C) total dive cycle time (TDCT).

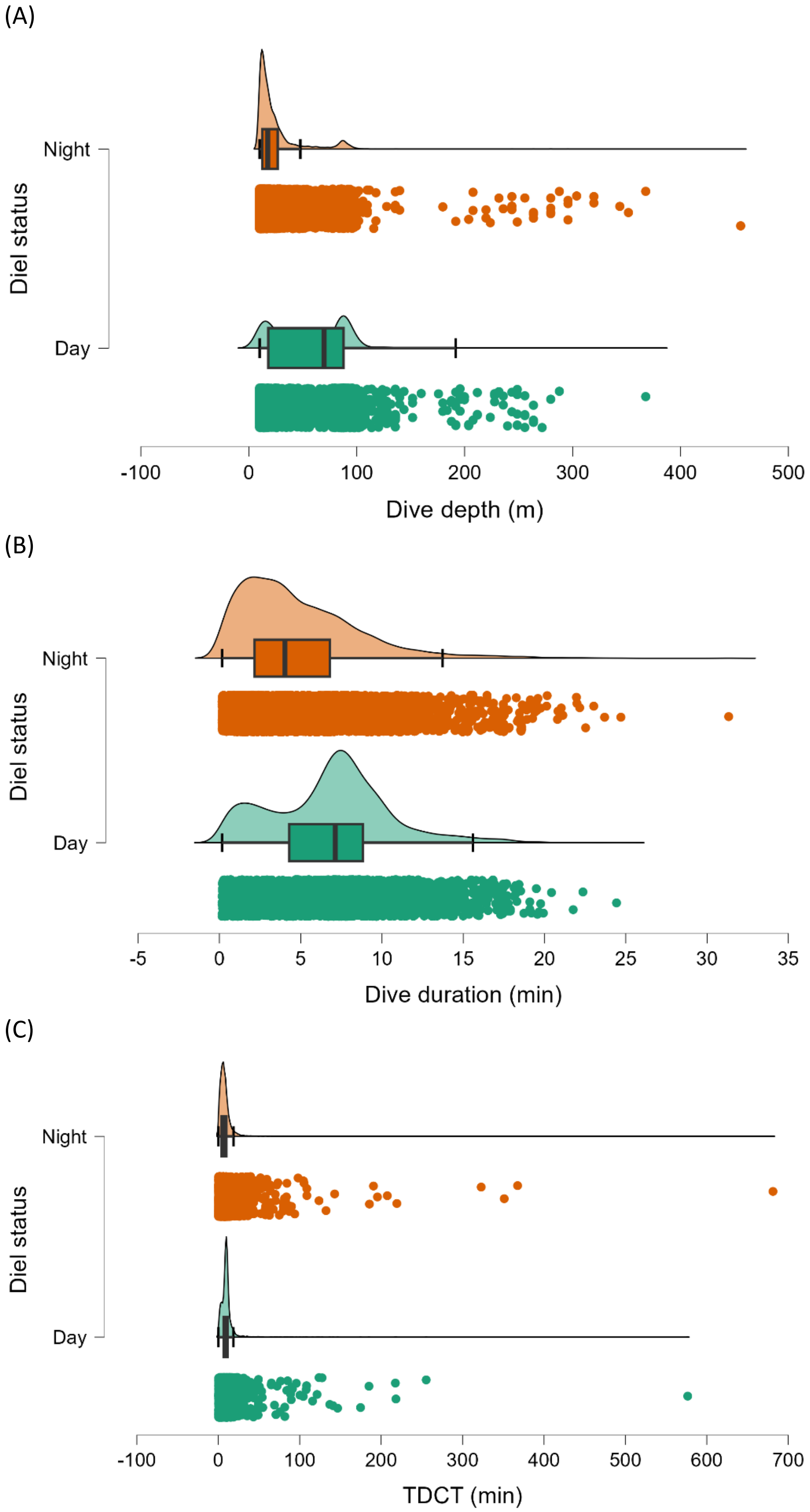


Figure 6.14. Raincloud plots of foraging dives (n = 10,570) undertaken during day and night (defined as broad 12 hr periods) by five southern right whales according to: (A) depth; (B) duration; and (C) total dive cycle time (TDCT).

6.4 Discussion

Compared with other balaenid species, the diving behaviour of SRWs has received little research focus to date, despite widespread research of the species on its calving grounds, including significant satellite-tagging effort in many countries (e.g., Mate et al., 2011; Zerbini et al., 2016, 2018; Mackay et al., 2020; Kennedy et al., 2023). The trade-off between the battery life of tags and the volume of data collected is likely the primary reason why more SRW tagging studies have not utilised tags that additionally collect dive profile information. Most such studies have prioritised the collection of location-only datasets that can potentially produce data on SRW movements for over a year (e.g. Vermeulen et al., 2023), providing a wealth of knowledge on migration routes and the use of offshore habitats. In contrast, the five SPLASH tags used in this study transmitted for approximately 4 months, demonstrating how the increased amount of data recorded and transmitted reduces the transmission longevity.

Nevertheless, the collection of data on diving behaviour is also relevant to the conservation and management of SRWs, in order to better understand both their foraging ecology and the nature of their interactions with potentially adverse human activities including vessel collision and entanglement in fishing gear. This study has provided novel data on the dive behaviour and habitat use of SRWs in the south-west Atlantic, greatly adding to the relatively small amount of information already published for the species (Argüelles et al., 2016; Zerbini et al., 2016). In general, SRWs were found to spend the vast majority of their time in the upper part of the epipelagic zone, between the surface and 20 m depth. The majority of dives were <15 min duration, and the QDs showed a strong peak in occurrence in the 5–10 min DD bin. Zerbini et al. (2016) reported dive information for two SRWs tagged in Argentina and presumably subsequently feeding on the Patagonian Shelf, reporting that a juvenile typically dove to around 100 m and an adult typically dove to depths of less than 100 m. In Golfo Nuevo, three non-calf SRWs dove to maximum depths of 57 to 75 m, although total tag deployment times were <35 min and so the resulting sample size was very small (Argüelles et al., 2016). Neither of those studies reported TAD. Far more detailed information is available on the dive behaviour of the closely-related NARW, although relatively few of those have reported TAD. Baumgartner et al. (2017) reported that 55 NARW tagged on shelf feeding grounds in the USA and Canada spent an average of 49% (range=23–99%) of their time in the upper 10 m of the water column, which is almost identical to the 48% of time reported in this study in shelf habitats where SRWs were assumed to be primarily foraging.

The deepest dive reported in this study reached 632 m depth, which represents the deepest depth reported for SRWs to date; however, dives into the mesopelagic zone were relatively uncommon. While the deepest dive reported for a NARW to date appears to be 174 m (Baumgartner and Mate, 2003), studies of dive behaviour in that species have been limited to suction cup tag deployments on the USA and Canadian shelf and thus the maximum dive depths recorded were constrained by the water depth of the habitat that the whales were tagged in and the short durations of the deployments. Studies of bowhead whales regularly record dive depths exceeding 500 m and to over 700 m where the habitat allows (Heide-Jørgensen et al., 2013; Fortune et al., 2020; Pontbriand et al., 2023), and it's likely that all members of the balaenid family have the capacity to undertake dives to several hundred metres depth.

6.4.1. Habitat and behavioural context

It should be noted that the tag deployment location, time of year, and the four-month longevity of the tag transmissions mean that the dive data recorded by the five tagged whales includes bias towards their behaviour on coastal winter breeding grounds rather than primarily representing the foraging behaviour that most other balaenid dive studies have targeted (e.g. Baumgartner and Mate, 2003; Fortune et al., 2020; Pontbriand et al., 2023). For example, of the 1,020 TAD histogram summaries for which a SWA category could be allocated, 64% were assigned to Wintering Ground. Since the wintering grounds are located in nearshore temperate habitats where the overlap between high-use whale habitats and human activities is highest, this information provides useful insight into the potential for whale collisions and entanglement in fixed fishing gear. However, only subsets of the dataset relate to foraging behaviour and are comparable to the published studies on the foraging behaviour of NARW and bowhead whales.

Differences in SRW dive behaviour in the context of different habitats and behavioural context were evident within the TAD dataset. SRWs in nearshore habitats and in the Wintering Grounds category spent 70% of their time in the upper 10 m of the water column, which might be expected given both the shallow water depths and the scarcity of feeding behaviour associated with SRWs on their winter breeding grounds. The amount of time spent in the upper 10 m of the water column was lower in the other habitats but still around 50%, indicating that SRWs continue to spend significant time near the surface throughout their range. Removal of BS3 (transit) data from the SWA category dataset provides the greatest insight into how SRWs use the water column within higher-use habitats, which likely comprises foraging behaviour in the Antarctic, the Patagonian Shelf and Deep categories. In the latter two categories, more time was spent deeper in the water column, especially on the Patagonian Shelf where significant time was spent in the 75–100 m depth bin. The spatial areas used by the tagged whales on the Patagonian Shelf had water depths in the region of 70 to 140 m (Weir et al., 2024) which suggests that some of these whales may have been foraging relatively close to the seabed. Baumgartner and Mate (2003) noted that NARW performed repeated feeding dives to specific narrow bands of water depth in order to exploit discrete layers of highly concentrated zooplankton prey. The high amount of time in the 75–100 m depth bin found here for SRWs suggests that a similar targeted prey layer was being exploited by the whales using the Patagonian Shelf.

Interestingly, while the mean depths of QDs were shallowest on the Wintering Grounds, the mean dive durations on the Wintering Grounds were longer than when whales were using Antarctic and Patagonian Shelf habitats where they were assumed to be foraging. The relatively longer periods of submergence on the Wintering Grounds might simply reflect whales in a low state of activity (for example lactating mothers that are resting/milling while their calves grow), or they may reflect animals remaining subsurface while engaged in mating or socialising groups (or surfacing in a manner that did not expose the tag).

The predominance of square-shaped and U-shaped dives in the behaviour dataset is consistent with the result of other balaenid studies, and is usually interpreted as representing foraging dives (Baumgartner and Mate, 2003; Laidre et al., 2007; Fortune et al., 2020; Pontbriand et al., 2023). However, our results indicate that square- and U-shaped dives are actually undertaken by SRWs in a wide variety of different habitats and behavioural contexts. While the proportion of square-shaped dives was highest in BS2 and on the Patagonian Shelf, which may be consistent with the expected SRW foraging behaviour in those categories (Zerbini et al., 2016, 2018), the square-shaped QDs also dominated all other BS and most SWA categories including on the Wintering Grounds where little foraging behaviour was expected. This result suggests that the majority of SRW dives include horizontal movement at the deepest part of the dive, regardless of whether the whales are foraging. On the Wintering Grounds, this likely reflects topographic constraints of the habitat to some extent, since QDs were defined with a 10 m depth threshold and SRWs undertaking a QD in shallow parts of the Wintering Grounds may be likely to reach the seabed and travel along it.

The Antarctic was the only SWA category where U-shaped dives were more prevalent than square-shaped dives. This might reflect different foraging behaviour in the Antarctic, where SRWs have been observed feeding close to, or at, the surface on Antarctic krill (*Euphausia superba*: Hamner et al., 1988). In bowhead whales, higher proportions of shorter and shallower U-shaped dives are performed when feeding on near-surface prey aggregations compared to higher proportions of longer and deeper square-shaped dives when feeding near the sea bottom (Fortune et al., 2020). Our results for SRWs were consistent with that finding, with square-shaped dives within the foraging dataset having longer duration and reaching deeper depths than the U-shaped dives. Since the Antarctic dataset originates from only one of the tagged whales (Frosty), there is also the possibility that this individual simply exhibited different dive behaviour from the others. More data would be needed from SRWs in the Antarctic region to demonstrate whether or not the dive behaviour of the species in that region does reflect different foraging conditions or target prey species rather than the behaviour of an individual whale.

Consistent with other baleen whale studies (e.g. Calambokidis et al., 2019; Keen et al., 2019), the foraging dives undertaken by SRWs at night were shallower than those during the daytime. These diel patterns in whale dive behaviour are usually believed to be associated with the vertical migration of their zooplankton prey species (Baumgartner and Fratantoni, 2008), which migrate to the surface at night to feed on phytoplankton and then return to depth during the day to avoid visual predators.

6.4.2. Availability bias

One potentially useful application of whale dive profile information is in the calculation of *availability bias*, or the availability of animals at the surface to an observer (Hammond et al., 2021). During line transect surveys aimed at estimating the abundance of diving animals such as cetaceans, only a portion of the total number of animals present in an area will be visible at the surface when the platform (usually a ship or aircraft) passes by and the resulting abundance estimate will therefore be negatively biased to an unknown extent (Hammond et al., 2021). The calculation of the true abundance of animals in the area requires the application of a correction factor for the proportion of animals likely to be submerged. Obtaining a correction factor for availability bias can be achieved via several methods, for example the use of a double observer team or a 'circle back' method during the survey (Hammond et al., 2021), visual focal follows or unmanned aerial vehicles to estimate time at the surface (e.g., Ganley et al., 2019; Weir et al., 2021; Brown et al., 2023), and telemetry data (e.g., Heide-Jørgensen and Laidre, 2015; Katsumata et al., 2023).

In their analysis of telemetry data from 18 tagged humpback whales (*Megaptera novaeangliae*) in Greenland, Heide-Jørgensen and Laidre (2015) used time spent in the 0–2 m depth histogram bin as indicative of whale availability to an aerial observer, on the basis that the white flippers of North Atlantic humpback whales means that an animal remains visible when slightly submerged. Similar logic could be applied to the SRW, considering its cream-coloured head markings which are also visible to aerial observers when a whale is slightly submerged (Weir, pers. obs.). This would mean that within the FIWG, SRWs were available for 23.4% (SD=3.6, range=18.8–28.1). of the time using TAD data from all five whales, or for 25.4% (SD=3.0, range=22.2–28.1) of the time if only data from the three whales with >50 histogram summaries were available. As noted by Heide-Jørgensen and Laidre (2015), the simplest availability correction factor $\hat{a}$ is the estimated proportion of time an animal is available for detection, which is an estimator of the probability that an animal is available at any randomly chosen instant. This is therefore an appropriate correction factor when the survey is instantaneous. However, since aerial surveys use platforms moving at high speed, they are non-instantaneous and there is a period where the animals are within view of the observers (i.e. time-in-view: TIV). TIV would need to be incorporated into the correction factor for the aerial surveys carried out in the FIWG (see Chapter 7). Furthermore, it would be appropriate to use a subsample of TAD summary data relating only to the extent of the aerial study area, to daylight hours only, and to July and August (when aerial surveys occurred; there were no telemetry data available for June: see Chapters 5 and 7) to calculate a suitable correction factor for the FIWG aerial surveys.

6.4.3. Conservation and management

Vessel strike and entanglement in fixed fishing gear (predominantly ropes in the water column associated with lobster and crab pots, and gillnets) are well-documented causes of injury and mortality for the NARW, contributing directly to its Critically Endangered conservation status (Laist et al., 2014; Knowlton et al., 2022). A 30-year assessment of entanglement rates showed that 83% of the NARW population has been entangled at least once, and 59% of individuals more than once (up to seven times: Knowlton et al., 2012). Understanding dive behaviour can reveal the likely exposure of whales to such risks. For example, Baumgartner and Mate (2003) found that NARW pregnant females and mother-calf pairs spent more time at the surface than other demographic groups, increasing their exposure to vessel strike. Similarly, documenting the amount of time that whales spend in water column strata under different behavioural contexts will inform the likelihood of their entanglement in fixed fishing gear (and other marine activities involving slack ropes in the water column, such as aquaculture moorings), including the ground lines that connect multiple pots or traps at the sea floor, and the end lines between bottom gear and surface marker buoys (Baumgartner et al., 2017). When undertaking foraging dives, NARWs are known to use the entire water column including dives close to the sea floor (Baumgartner et al., 2017).

While the anthropogenic threats to SRWs are not as well documented as for the NARW, vessel strikes and entanglement in fixed fishing gear are also proven causes of serious injury and mortality (Argüelles et al., 2016; Vermeulen et al., 2022). SRWs have been observed in the Falkland Islands with propeller injuries from large vessels, entanglement wounds, and with severe traumatic injuries of unknown origin (Figure 6.15). Additionally, a dead SRW that washed ashore in the Falklands during 2024 had succumbed to a chronic entanglement in fishing gear (Figure 6.16). While these injuries could have originated anywhere across their south-west Atlantic range, the fact that they are being documented in the relatively pristine waters of the Falkland Islands serves to highlight the potential vulnerability of SRWs and the need to specifically incorporate them into marine management as human activities around the Islands increase. This particularly applies to increases in shipping (for example related to fishing and tourism, and the planned expansion of Port Stanley), and to the development of fisheries that utilise fixed fishing gear, especially when those overlap with key whale habitats.

The five SRWs tagged in the Falkland Islands spent the majority of their time within the upper water column at 0–10 m depth. This included 54 to 69% of their time (mean=62%, SD=6.3) in the wider south-west Atlantic/Antarctic region, and 72 to 82% of their time (mean=76%, SD=5.1) within the FIWG. It is likely that the higher amounts of time spent at shallow depths in the FIWG compared to the wider dataset is due to the use of the region for mating and socialising behaviour at the time the tags were deployed, when animals may be more active at the surface compared to when they are foraging. These high amounts of time spent in the upper 10 m of the water column by SRWs overlap with the drafts of large commercial ships considered to comprise a major collision risk to NARWs (Baumgartner et al., 2017). A summary of vessel drafts for some of the categories of vessel that most frequently use the FIWG is provided in Annex 1, and range from 1.0 m for launches to 10.7 m for a large motor research vessel, with most vessels having drafts in the region of 5.0 to 9.0 m. While these are shallower than some of the largest vessels operating globally (i.e. 15 m for medium to large container ships: Calambokidis et al., 2019), there is still high spatial overlap with the depths used most regularly by SRWs. Fortunately, there is little temporal overlap between nearshore SRW wintering aggregations (May–Sep) and the cruise ship season (Oct–Mar) in the Falkland Islands. However, they remain exposed to a range of other vessel types that operate in the Falkland Islands year-round.

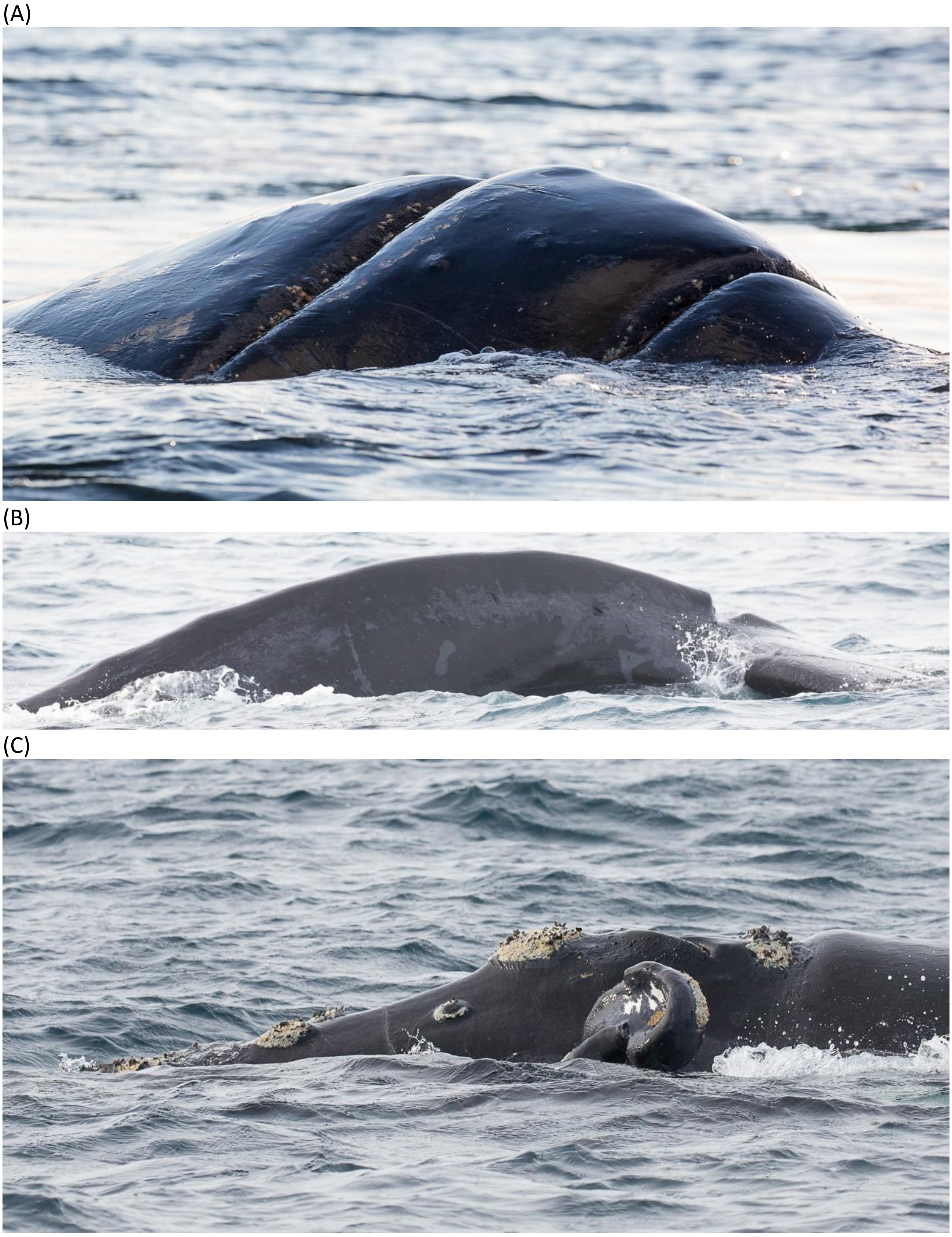


Figure 6.15. Injuries documented on southern right whales in the Falkland Islands: (A) propeller scars from a large vessel; (B) tailstock injury from rope entanglement; and (C) head injury of unknown origin.

Figure 6.16. Dead southern right whale stranded at Pebble Island in May 2024 with fishing gear entangled around the tailstock: (A) the gear wrapped around the animal's tailstock; and (B) close up of the gear embedded in the tissue. Consultation with a North Atlantic right whale entanglement expert (Amy Knowlton) and an experienced vet working on southern right whales (Marcela Uhart) indicated that the injuries to this whale constituted a 'severe entanglement' and likely led to its death. Further, the chronic nature of the injuries indicated that the whale had likely been entangled for several months prior to its death, causing a significant welfare issue and presumably limiting its ability to swim and feed. The fishing gear comprised monofilament gillnet, three different types of rope, and gillnet floats with a total weight of 12.1 kg. Gillnets are not used in the Falklands, and it is presumed that the whale acquired it somewhere along the coast of South America.

In USA and Canadian waters the management actions implemented to reduce NARW vessel strike have included the reduction of vessel speeds within, and the shifting of shipping lanes around, areas of high-use habitat (Laist et al., 2014). Re-routing shipping to avoid SRW aggregations within the FIWG is unlikely to be viable, since Port Stanley comprises the major working harbour in the Islands which the vast majority of vessels utilise. However, seasonal reductions in the speed of large vessels (to ≤10 knots) within the key habitats used by SRW in the Falklands may be sufficient to reduce the risk of serious injury or mortality (Laist et al., 2014; Aschettino et al., 2020). Ten knots has been recognised globally as a speed within which vessel strikes are less likely to cause serious injury to, or mortality of, large whales[7,8]. Such speed restrictions were requested on a voluntary basis by the FIG Maritime Department in 2023 in response to large numbers of SRWs using Port William that year, but could be made mandatory within the FIWG between (at least) June and August. This is particularly recommended with regard to the limited daylight during winter which reduces the relevance of using dedicated whale lookouts to reduce collision. The dives undertaken by tagged SRWs were shown to be shallower at night, and this factor may also increase their vulnerability to vessel strike during the hours of darkness (Calambokidis et al., 2019).

The prevalence of SRW activity in the upper water column also exposes them to entanglement in the vertical ropes used to attach surface buoys to fixed fishing gear such as creel pots. Moreover, in shallow inshore habitats such as the FIWG, the fact that most SRW activity occurs in 0–20 m depth means that they may often also be relatively close to the seabed. For example, SRWs are often observed in extremely shallow habitat during surveys of inner Berkeley Sound, Port William, Volunteer beach and Cow Bay (see Chapter 2). This means that entanglement in the groundlines used between creel pots is also a possibility and is known to occur for NARWs and humpback whales (Johnson et al., 2005). For these reasons, fixed fisheries are not permitted within high-use breeding habitats during the NARW calving season (Dombroski et al., 2021). Until recently, no fishing has been permitted in the inshore waters (<3 nm) around the Falkland Islands. However, an experimental crab pot fishery was recently licenced (the environmental assessment supporting the licence did not include consideration of whale entanglement risk), and a small number of pots are being deployed within the FIWG with a view to a potential longer-term expansion into a commercial fishery. Since SRW wintering aggregations in the Falklands occur primarily between May and September (peaking June to August) and within 10 km of the coastline of the north-east Falklands (Weir, 2021), the simplest and most effective approach to mitigating potential entanglement within such a crab pot fishery would be to disallow the use of fixed-fishing gear within the high-use habitat during the peak months of occurrence. However, as recommended by other studies, should fishing activity be permitted within the FIWG during the peak whale period, gear modifications including ropeless gear, sinking or neutrally buoyant groundlines, and reduced breaking strength ropes would be the best practice options to reduce entanglement risk (Dombroski et al., 2021; Knowlton et al., 2022).

Global evidence indicates that entanglements occur wherever fixed-gear fisheries and large whales overlap (Knowlton et al., 2022), and it should be anticipated that ongoing use of unmodified (and possibly also modified: Pace et al., 2014) fixed fishing gear within key whale habitats in the Falklands will very likely result in future entanglement events. Advanced preparation for responding to such events (i.e. people to inform locally, experts to consult for advice, health and safety considerations

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[7] https://www.mmc.gov/priority-topics/vessel-strikes/

[8] https://www.fisheries.noaa.gov/national/endangered-species-conservation/reducing-vessel-strikes-north-atlantic-right-whales

while responding, available equipment in the Islands) is highly recommended[9,10,11], since the disentanglement of whales is emotive (affecting decision-making), potentially dangerous for both humans[12] and whales, and requires skilled personnel and techniques to achieve optimal outcomes. It is also recommended that the reporting of entanglement events is made mandatory in the Islands, so that the risk can be monitored as fisheries develop.

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[9] For example: https://coastalstudies.org/our-work/marine-animal-entanglement-rescue/

[10] https://scottishentanglement.org/downloads/1073/

[11] https://nammco.no/wp-content/uploads/2020/06/04-nammco-bycels-2020-01-iwc-guidelines-disentanglement.pdf

[12] https://www.bbc.co.uk/news/world-us-canada-40579766

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Chapter 7: Abundance of southern right whales and Commerson’s dolphins during winter aerial surveys

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7.1 Introduction and aims

Southern right whales *Eubalaena australis* have a circumpolar distribution across subtropical to polar waters of the southern hemisphere. Their major winter calving grounds are located along the coasts of the south-west Atlantic (Argentina/Brazil), South Africa, southern Australia, and the Auckland Islands in New Zealand (Cooke and Zerbini, 2018). Additionally, non-calving aggregations form around some subantarctic archipelagos in winter including the Falkland Islands in the south-west Atlantic (Weir and Stanworth, 2020; Weir, 2021; Weir et al., 2024) and Campbell Island to the south of New Zealand (Torres et al., 2017). During other seasons, southern right whales disperse widely across the southern hemisphere ocean basins while foraging, with highest occurrence across mid latitude temperate and subantarctic higher latitude areas, and some animals occurring further south in polar habitat to 65°S (Bannister et al., 1999).

Due to characteristics including their nearshore occurrence in winter, slow swim speed, and high oil yield, the right whales were considered the ‘right’ whale to target during early open boat whaling effort commencing in the 1600s. The species was already severely depleted prior to the onset of modern commercial whaling at the start of the 1900s, with fewer than 300 animals estimated to survive by the 1920s (Jackson et al., 2008). Full protection of the species was implemented in 1935 by the International Whaling Commission (IWC); however, catches of over 3,000 individuals by illegal Soviet Union operations in the mid-1900s further hindered their recovery (Tormosov et al., 1998). The most recent global abundance was estimated at 13,611 individuals in 2009 (IWC, 2013), with the largest populations comprising an estimated 4,029 animals using the south-west Atlantic (SWA) calving grounds in Argentina and Brazil, and 4,411 animals using calving areas off southern Africa (IWC, 2013). Monitoring at the core southern right whale calving grounds indicates that populations are increasing at rates of up to 7% per annum, although the rates of increase are not stable or equal across regions (IWC, 2013; Romero et al., 2022). Consequently, the current global population is likely higher than the 2009 IWC assessment. For example, the abundance of right whales in the SWA population was recently estimated at 4,742 whales (95% CI=3,853–6,013) in 2021 (Romero et al., 2022), and that in southern Africa was estimated at 6,470 individuals (SE 285) in 2020 (Brandão et al., 2023). As a result of expanding population sizes, the species was listed as Least Concern in the 2018 global Red List assessment (Cooke and Zerbini, 2018).

While the pre-exploitation global abundance was estimated at around 70,000 animals in the 2013 IWC assessment, more recent modelling and reconstructed catch histories indicate that pre-exploitation abundance was close to 58,000 animals in the SWA (Romero et al., 2022) and 43,000–47,000 animals in south-west Pacific waters (Jackson et al., 2016). However, all sources agree that the current abundance of southern right whales remains well below pre-exploitation estimates, indicating that recovery is ongoing and that the global abundance is likely to increase significantly before levelling off. The steady recovery of southern right whale populations has been identified as the likely explanation for recent increases in some areas as animals recolonise habitats that whaling data indicate were important historically, for example in Golfo San Matías in Argentina (Arias et al., 2018) and around mainland New Zealand (Carroll et al., 2014). Additionally, increasing numbers may result in a redistribution of certain age-sex cohorts on a breeding ground as carrying capacity is approached, with optimal nearshore habitats being occupied by mother-calf pairs while unaccompanied whales and mating groups are displaced further offshore or into adjacent areas (Crespo et al., 2019).

In some cases, it may be unclear whether seemingly novel occurrences of southern right whales in wintering areas where they had been previously scarce represents: (1) recovery of a matrilineal subpopulation with cultural memory of an area of historical use (Carroll et al., 2014); (2) plasticity in philopatric behaviour leading to rapid recolonisation of an area of historical use (Carroll et al., 2014; Arias et al., 2018); (3) novel colonisation of a historically-unused or low use area, perhaps associated with factors such as changing oceanographic conditions altering habitat suitability or density-dependent age-sex redistribution; or (4) a combination of the above.

The Falkland Islands (51.7°S, 59.4°W), an archipelago located on the south-eastern extremity of the Patagonian Shelf in the south-west Atlantic, are one area where the winter nearshore occurrence of southern right whales appears to have markedly increased in recent years (Weir, 2021). Historical evidence for Falklands' waters having comprised an important wintering ground for southern right whales is lacking. Available whaling records suggest that catches in the Falklands occurred predominantly in pelagic habitat and during the summer and autumn (Weir and Stanworth, 2020), with similar indicated by modern sources of evidence including year-round sighting surveys (Ohsumi and Kasamatsu, 1986; White et al., 2002) and satellite-tracking (Zerbini et al., 2016, 2018). It was not until 2017 that coastal wintering aggregations became apparent (Weir and Stanworth, 2020), and targeted research on the species commenced in the north-east region of the Falklands during 2019 (Weir, 2021; Falklands Conservation unpublished data).

This chapter describes the results of winter aerial surveys carried out in Falklands' coastal waters. The primary objective was to generate an abundance estimate of southern right whales to inform conservation assessments, including the identification of spatial management tools such as Key Biodiversity Areas (KBAs) and Important Marine Mammal Areas (IMMAs). An additional objective was to improve knowledge of right whale distribution in geographically remote parts of the Falklands that are challenging to survey by other means, including the entire north coast of East Falkland, and areas further from the coast to assess the offshore extent of the wintering aggregations. While not a stated aim of the aerial survey work, all other cetacean species were also recorded and the high number of Commerson's dolphin *Cephalorhynchus commersonii* sightings recorded allowed us to also generate abundance estimates for that species. Commerson's dolphins are distributed predominantly in the waters of Argentina and the Falkland Islands, with small numbers occurring in Chile and around the Kerguelen Islands, and the data presented here are interpreted in the context of existing published information for the species.

7.2 Materials and methods

7.2.1. Survey area

The survey area comprised the coastal waters in the north-east Falkland Islands, from Pebble Islet (51.2°S, 59.9°W) at the westernmost limit, to the waters off Port Harriet (51.7°S, 57.8°W) at the south-east limit (Figure 7.1). The western limit was selected based on the logistical constraints of completing two flight days per survey, rather than on an ecological basis.

Locations from satellite tags deployed on 10 southern right whales during July 2022 were used to determine the offshore extent of the study area. A total of 8,545 Argos positions were acquired from the 10 animals within the Falkland Islands Exclusive Economic Zone, of which 80%, 83% and 85% of locations were located within 30 km, 40 km and 50 km of the shoreline respectively (Figure 7.2). Since the proportional increase in the number of positions located between 30 km and 50 km from the shore was relatively minor, a 30 km buffer from the coast was selected as incorporating a significant portion of the right whale telemetry positions while optimising cost and logistical considerations.

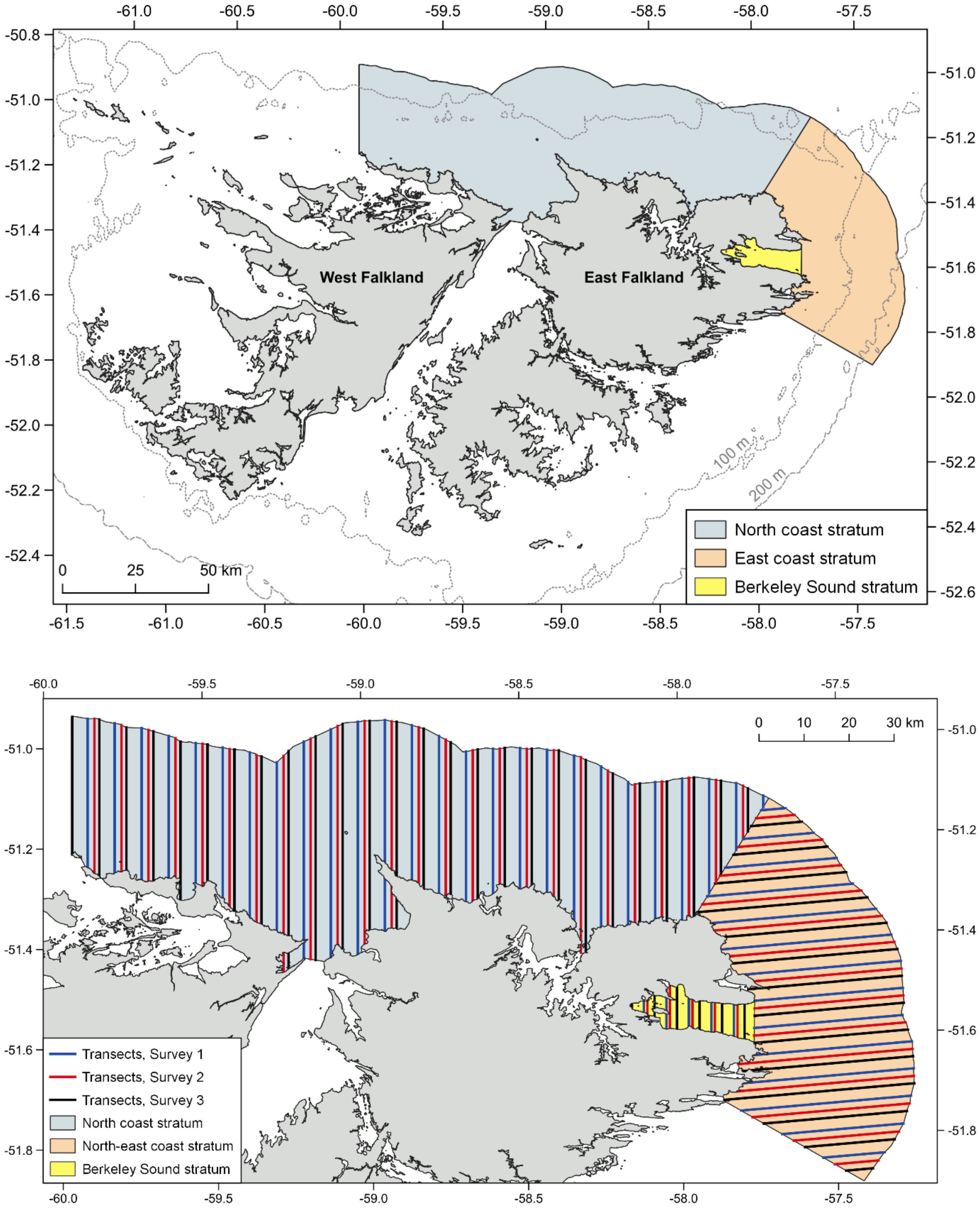

Figure 7.1. Location of the aerial study area in the Falkland Islands, showing the three survey strata used in the survey design, and the locations of three sets of transect lines planned for aerial abundance surveys in June, July and August.

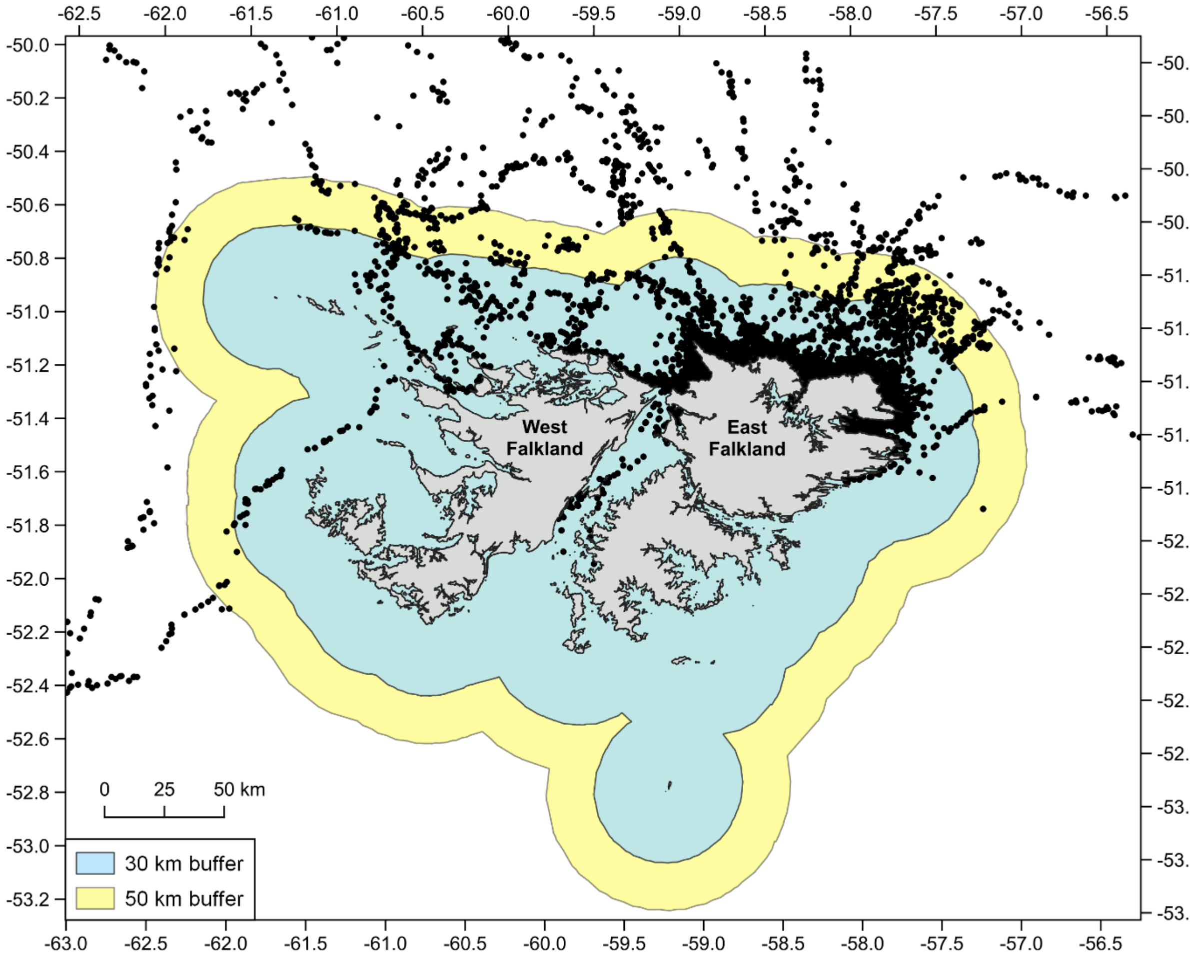

Figure 7.2. The 30 km and 50 km buffer zones around the coast of the Falkland Islands, showing the distribution of Argos positions obtained from 10 southern right whales that were satellite-tagged in July 2022 (see Chapter 5).

The final survey area comprised 7,890 km^2 of shelf habitat of primarily less than 100 m depth, but extended to just beyond the 200 m depth isobath along the east coast of the Falklands where the continental slope occurs closer to shore.

7.2.2. Survey design

Previous boat and acoustic survey work indicated that southern right whales exhibit strong seasonality in the coastal study area, aggregating during the austral winter between June and August (Weir, 2021, 2022). Consequently, three aerial surveys were planned for June, July and August in order to assess temporal changes in whale abundance and distribution over the winter.

The survey design and methodology followed standard line transect distance sampling techniques for estimating abundance (Buckland et al., 2001). The study area was divided into three geographic strata (Figure 7.1; Table 7.1): (1) North Coast (5,273.5 km^2); (2) East Coast (2,446.1 km^2); and (3) Berkeley Sound (170.6 km^2). Transects were generated using a systematic random sampling design in the software Distance 7.5 (Thomas et al., 2010), running perpendicular from the coast in a north-south direction in the North Coast and Berkeley Sound strata, and in an east-west orientation in the East Coast stratum. Transect spacing was 6 km in the North Coast and East Coast strata, and 5 km in the Berkeley Sound stratum. A new design of transects with randomised start points was generated for each of the three surveys to avoid covariance issues.

Table 7.1. Planned and realised aerial survey effort (km) by geographic stratum, survey month, Beaufort sea state, and visibility. Effort collected in visibility of <5 km was removed prior to abundance analysis.

Effort category	June 2023		July 2024		August 2023	
	No. of transects	Total effort	No. of transects	Total effort	No. of transects	Total effort
Planned effort by stratum:						
North Coast	26	874.4	26	897.6	25	867.6
East Coast	14	406.5	14	412.5	14	410.3
Berkeley Sound	5	31.1	6	36.2	5	32.7
Total	45	1,312.0	46	1,346.3	44	1,310.6
Realised effort by stratum:						
North Coast	26	867.2	26	897.9	25	865.6
East Coast	14	405.6	14	412.4	14	409.3
Berkeley Sound	5	29.1	6	35.5	5	31.8
Total	45	1,301.9	46	1,345.8	44	1,306.7
Realised effort by Beaufort sea state:						
0	–	0.0	–	4.1	–	17.4
1	–	9.1	–	99.0	–	241.0
2	–	537.7	–	482.8	–	830.3
3	–	495.3	–	688.5	–	218.1
4	–	259.9	–	71.4	–	0.0
Realised effort by visibility (km):						
<5	–	8.0	–	36.5	–	5.2
5–9	–	2.2	–	83.6	–	4.6
10–14	–	5.7	–	123.4	–	0.4
15–19	–	19.0	–	210.4	–	12.5
≥20	–	1,267.0	–	891.9	–	1,284.0

7.2.3. Data collection

The study was conducted with a research licence (R11/2017) issued by Falkland Islands Government. A Britten-Norman BN-2B Islander operated by Falkland Islands Government Air Service was the only suitable aircraft available in the Falkland Islands. The aircraft was fitted with large bubble windows on either side which provided a view directly downwards onto the trackline. The target altitude and speed were 229 m (750 feet) and 90 knots (167 km hr–1) respectively, to ensure consistency with aerial surveys of large whales elsewhere (e.g., Panigada et al., 2017; Pike et al., 2019). The survey team comprised two observers (one on each side) and a pilot, with communication carried out via a headset intercom system. The same observers were used throughout the three surveys and both were experienced cetacean observers, although only one had previous experience of aerial abundance surveys. Training in methods and species identification from the air were provided to the other observer ahead of the surveys commencing.

With an operational limit of 6–7 hr flying time, each of the three surveys required two days to complete. The dates for each survey were planned as closely together as possible, given constraints of weather and aircraft availability. Surveys only commenced when forecasts indicated that weather conditions would be suitable for visually detecting large whales, comprising Beaufort sea states ≤4 and visibility of at least 5 km. Given a plausible expected overall shift in the distribution of animals in a westerly or north-westerly direction (concurrent with the direction that most tagged animals moved when they finally departed the waters around the archipelago: Weir et al., 2024), each survey was flown starting at the westernmost limit and working towards the east/south.

The surveys were conducted in passing mode; that is, searching effort was not interrupted following a sighting. While flying transects, each observer continuously scanned a 90° quadrant from ahead to abeam with the naked eye. The aircraft's position was logged at 1-sec intervals on a Global Positioning System (GPS). Each observer used a digital voice recorder (DVR) to record data; the DVR recordings were subsequently matched to the GPS tracklog using a timestamp recorded verbally at the start of each survey and at 1-hr intervals thereafter. The data recorded included the start and end time of every transect (indicated by coastline and/or a verbal cue by the pilot), environmental conditions, and cetacean sightings. Environmental conditions (Beaufort sea state, sun glare, precipitation and visibility) were logged at the start of each transect and at every subsequent change in condition. The data recorded for each cetacean sighting included: (1) time of initial sighting; (2) time and angle of declination when the animal(s) passed abeam; (3) species identification and certainty; (4) estimated group size; and (5) initial sighting cue (e.g., blow, body, footprint). For all southern right whale sightings, the observers additionally recorded whether or not the observation comprised a surface active group (SAG) versus a non-SAG, and whether or not a calf born that winter (i.e. <60% of the body length of the accompanying adult: Christiansen et al., 2018) was present. The logging of group composition and behaviour for other, non-target, cetacean species was only carried out when time permitted. A group was defined as animals separated from one another by no more than three body lengths. Declination angles were measured to the centre of each group using handheld Suunto analogue inclinometers (model: PM-5/360 PC). Cetaceans observed while off-effort were also logged, although were excluded from the abundance analysis.

7.2.4. Data analysis

Following each survey, locations were extracted from the GPS tracklog and matched to all DVR data events using timestamps. Data were transcribed into standardised spreadsheets. All data collected in conditions of poor visibility (defined here as <5 km) were removed from the dataset prior to data analysis.

The declination angle (α) to each sighting was converted to perpendicular distance from the trackline (X) using the formula (e.g., Pike et al., 2008):

$$X = ALT(\tan(90-\alpha))\sin(\beta)$$

where ALT is aircraft altitude, α is the declination angle to the sighting, and β is the drift-corrected angle from the aircraft nose to the sighting. Sighting locations were then recalculated for mapping, based on perpendicular distance from the trackline, observation side, and aircraft heading. Sightings were investigated as likely duplicates seen below the aircraft by both observers if the beam time matched (≤1 sec) between the observers, and the declination angles recorded by both observers were >86° (equivalent to 0–16 m from the trackline, given that southern right whales reach average adult body lengths of ~15 m: Tormosov et al., 1998). Two sightings in the July 2024 survey were assigned as probable duplicates seen by both observers, and only one of each retained for analysis.

Mapping was done in Quantum Geographic Information System (QGIS, v. 3.28) software. Water depth and distance from shore were extracted for each sighting location using QGIS and a gridded bathymetric file obtained from General Bathymetric Chart of the Oceans 2023 (GEBCO Compilation Group, 2023). Water depths were assigned a standard default value of 5 m if they were situated in sufficient proximity to the coast that the resulting GEBCO values indicated land rather than water (n=6). Statistical comparisons were carried out using JASP (JASP Team, 2023).

Abundance analysis was carried out using the software Distance 7.5. Simple models with half-normal and hazard rate detection functions but without covariates were first examined to determine the best key function. The model with the best key function was then used to examine whether right truncation of the data at 5%, and at 1 km, 2 km, 3 km and 4 km perpendicular distance was justified. The results of Kolmogorov-Smirnov and Cramer-von Mises goodness-of-fit tests, and visual inspection of model diagnostic plots were used to determine whether or not to truncate the data. Candidate covariates (Table 7.2) were added to the model one at a time to see whether they improved model fit. Covariates were assumed to affect the scale rather than the shape of the detection function, and were incorporated into the detection function through the scale parameter in the key function (Thomas et al., 2010). Since the surveys were consistent in aircraft, observers, and speed/altitude parameters, pooled detection functions were used but the encounter rate, density and expected group size were computed separately for each monthly survey.

Table 7.2. Candidate covariates tested in the detection function models using multiple covariate distance sampling. Sea state was considered as either a factor or a numerical covariate, but not simultaneously.

Covariate	Type	Categories
Sea state (f)	Factor	Low (Beaufort sea state 0–2) and High (BSS 3–4)
Sea state (n)	Numerical	0 to 4, based on sea states recorded using the Beaufort scale
Observer	Factor	CW, AM
Side of Aircraft	Factor	Port or Starboard
Behaviour	Factor	Surface active group (SAG) or non-SAG
Group size	Numerical	1 to 15

Model selection was based on minimum Akaike's Information Criterion (AIC). If more than one model was well supported by the data (within 2 AIC units), the simplest model, i.e., the one with fewest parameters, was selected.

To estimate the expected group size, the size-bias regression method (i.e., a regression of the logarithm of recorded group size against detection probability) was used if the regression was significant at an alpha-level of 0.15 (Buckland et al., 2001). If it was not significant, the mean of the observed groups was used. Default estimators in Distance were used to estimate variance, except in the case of using group size as a covariate in which case a Bootstrap was applied.

The resulting abundance estimates were uncorrected for the number of animals that were submerged when the aircraft passed over and therefore unavailable for detection ('availability bias') and for animals that were available at the surface for detection but simply missed by the observers ('perception bias': Hammond et al., 2021), and therefore were negatively biased (see Discussion).

7.3 Results

Surveys were carried out on 24 and 27 June and on 17 and 18 August 2023. Unfortunately, adverse weather prevented the survey planned for July 2023. Given the importance of July as the expected month of peak right whale numbers (Weir, 2022), that survey was subsequently carried out over 14, 16 and 17 July 2024. Although intermittent snow squalls and fog caused reduced visibility and resulted in effort being suspended for short periods in all months, totals of 99.23%, 99.70% and 99.96% of the planned transect effort were realised in June 2023, August 2023, and July 2024 respectively (Table 7.1).

Five species of cetacean were recorded during the surveys (Table 7.3): southern right whale, sei whale (*Balaenoptera borealis*), humpback whale (*Megaptera novaeangliae*), Peale's dolphin (*Lagenorhynchus australis*), and Commerson's dolphin (*Cephalorhynchus commersonii*). The number of sightings of the southern right whale and Commerson's dolphin were considered sufficient to support robust abundance estimation.

Table 7.3. Summary of cetacean sightings (S) and individuals (I) recorded during winter aerial surveys in the Falkland Islands in 2023/24. Only sightings recorded ‘on transect’ and in visibility of >5 km were used for abundance estimation.

Species	June 2023						July 2024						August 2023					
	On transect		On transect, vis >5 km		Off transect		On transect		On transect, vis >5 km		Off transect		On transect		On transect, vis >5 km		Off transect	
	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I
Southern right whale	51	114	51	114	4	5	52	100	52	100	5	11	25	66	25	66	6	21
Sei whale	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humpback whale	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baleen whale species	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Commerson’s dolphin	43	161	42	159	0	0	96	406	96	406	2	4	53	239	53	239	0	0
Peale’s dolphin	2	13	2	13	0	0	1	5	1	5	0	0	2	7	2	7	0	0

7.3.1. Southern right whales

7.3.1.1. Group size

A total of 143 sightings and 317 individuals were recorded across the three surveys, of which 128 sightings and 280 individuals were logged on-effort and used for the abundance analysis. The group size of on-effort southern right whale sightings ranged from 1 to 9 animals, with a pooled mean across the three surveys of 2.2 animals (n=128, SD=1.65, median=2.0). There was a weakly significant difference in group size between months (Kruskal-Wallis test, H=8.1, df=2, *p*=0.02: Figure 7.3), with Dunn's post hoc comparisons showing significant differences between June and August (*p* =0.03) and July and August (*p* =0.005). SAGs comprised 21.6%, 17.3% and 48.0% of the total on-transect sightings in June, July and August respectively. There was a significant difference between the group size of whales observed in SAGs (n=32, mean=4.2 animals, SD=1.9, median=3.0, range=2–9) versus non-SAGs (n=96, mean=1.5 animals, SD=0.8, median=1.0, range=1–6; Mann-Whitney test, W=177.5, *p*<0.001). None of the individuals observed were identified as being calves of the year.

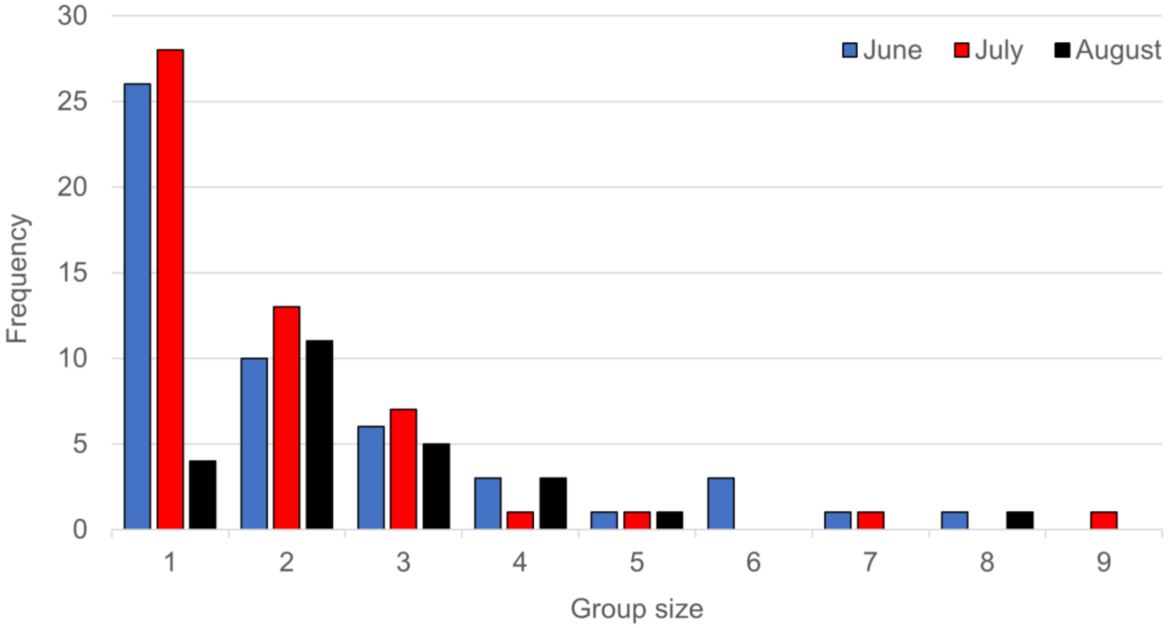

Figure 7.3. Group size of 128 on-transect sightings of southern right whales recorded during three aerial surveys. Note that the July survey was carried out in a different year (2024) to the surveys in June and August (2023).

7.3.1.2. Distribution

Southern right whales were recorded in all three strata during each of the three surveys. Relatively few sightings of the species were recorded in the waters north of West Falkland (Figure 7.4). Their spatial distribution varied markedly between the survey months, with sightings being most widespread from the coast to the outer limits of the survey strata during June 2023 (Figure 7.4A), intermediate in July 2024 (Figure 7.4B), and least widespread in August 2023 when almost all detections occurred close to the coast (Figure 7.4C). Those differences were reflected in the sighting habitat parameters (Figure 7.5; Table 7.4), with highly significant differences found between the water depths (Kruskal-Wallis test, H=32.5, df=2, p<0.001) and distances from shore (Kruskal-Wallis test, H=19.2, df=2, p<0.001) of sighting locations in each survey month. Dunn's post hoc comparisons indicated that all months differed significantly from one another for the water depth of sighting locations, while sightings in June occurred at significantly higher distances from shore compared with July (p<0.01) and August (p<0.001).

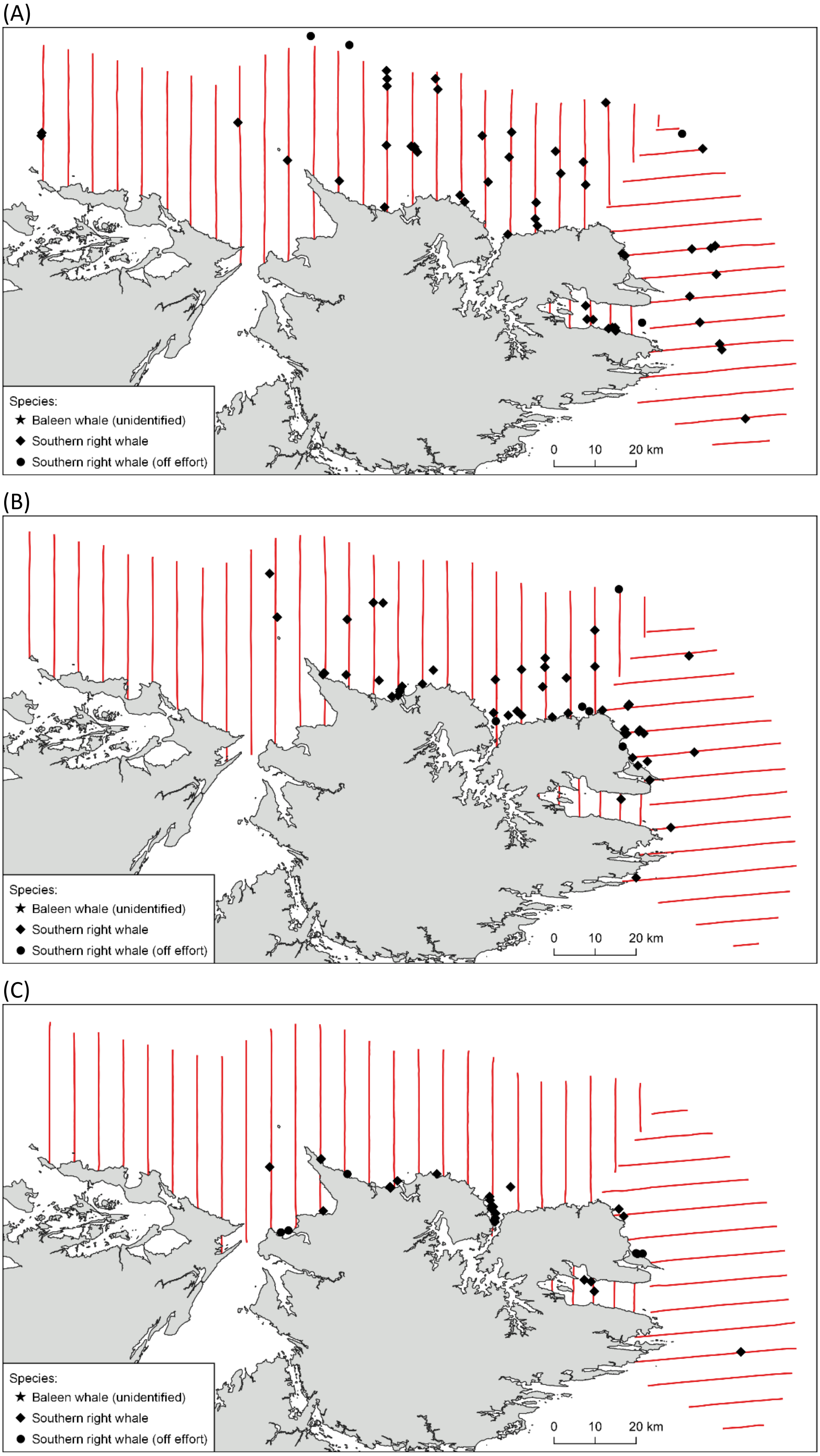

Figure 7.4. Distribution of realised transect effort (red lines) and sightings of southern right whales during aerial surveys in: (A) June 2023; (B) July 2024; and (C) August 2023.

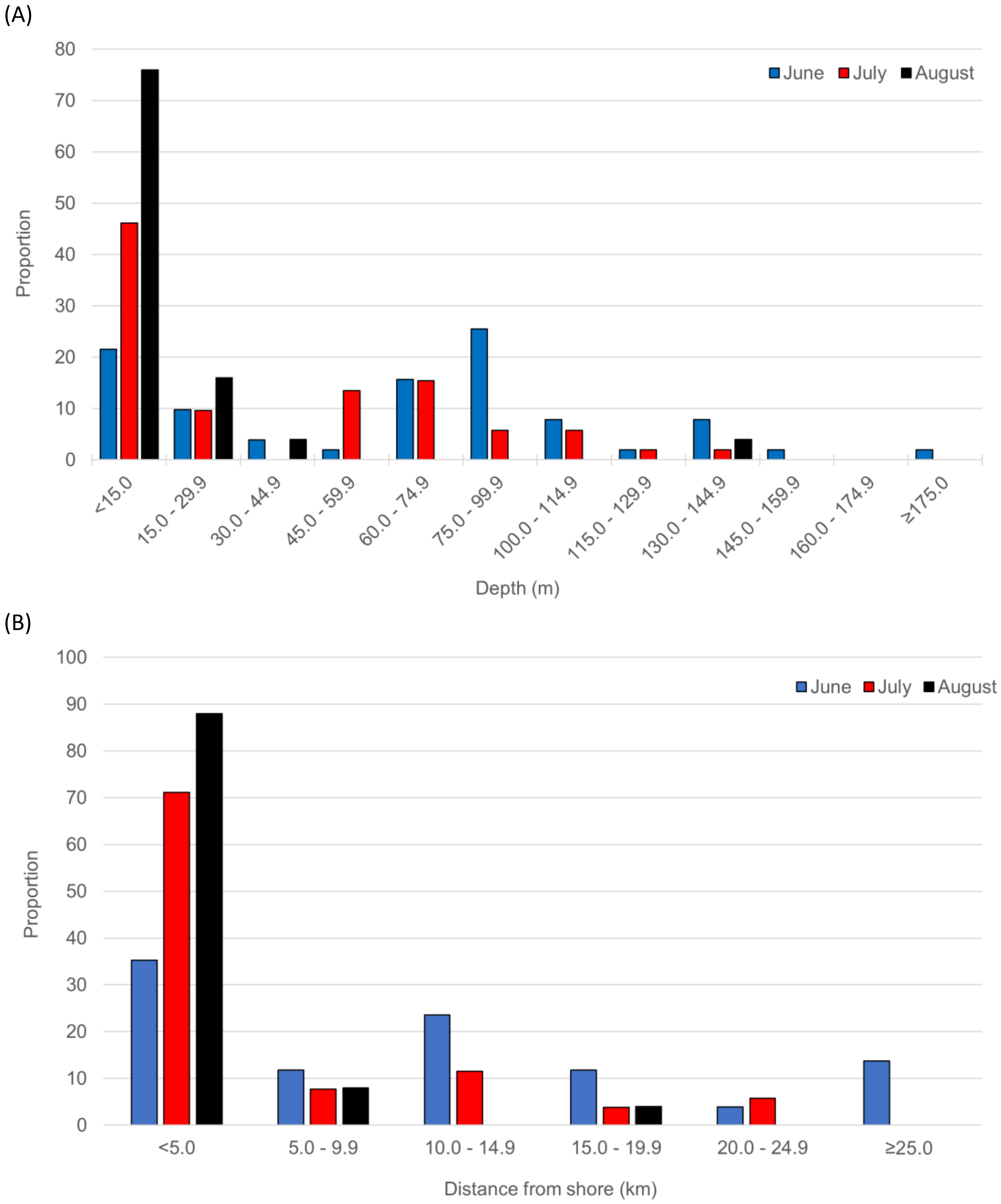

Figure 7.5. Proportion of on-effort southern right whale sightings (n=128) by month during winter aerial surveys by: (A) water depth; and (B) distance from shore.

Table 7.4. Water depths and distances from shore of on-effort southern right whale sightings.

Month	n	Water depth (m)			Distance from shore (km)		
		Mean	SD	Range	Mean	SD	Range
June 2023	51	66.7	45.6	1.0–175.0	10.8	9.4	0.0–30.9
July 2024	52	37.7	37.5	2.0–132.0	5.0	6.4	0.1–24.1
August 2023	25	13.6	28.3	1.0–141.0	2.0	3.6	0.3–16.6
Total	128	44.5	44.1	1.0–175.0	6.8	8.1	0.0–30.9

SAGs (n=32, mean=3.0 km, SD=6.6, median=0.9) were found significantly closer to shore than non-SAGs (n=96, mean=8.0 km, SD=8.2, median=4.9; Mann-Whitney test, U=2259.0, p<0.001). Similarly, SAGs (n=32, mean=19.6 m, SD=36.3, median=5.0) occurred in significantly shallower water depths than non-SAGs (n=96, mean=52.9 m, SD=43.4, median=51.5; Mann-Whitney test, U=2315.0, p<0.001).

7.3.1.3. Uncorrected abundance

A hazard rate model was selected as the detection probability model. None of the truncation options improved the model. The addition of covariates improved model fit, with the final selected model incorporating Observer and Behaviour (Table 7.5). The detection probabilities (P) were near identical between the most supported detection functions (Table 7.5), and the resulting abundance estimates were therefore similar for each of those models. The selected detection function is shown in Figure 7.6. Right whale density varied from 0.029 animals/km^2 in August 2023 to 0.051 animals/km^2 in June 2023 (Table 7.6). The resulting uncorrected abundance estimates were 399 (CV=0.25), 345 (CV=0.26) and 229 (CV=0.46) animals in June 2023, July 2024 and August 2023 respectively (Table 7.6).

Table 7.5. Most supported models (delta AIC <2) for southern right whale abundance. Covariate definitions are provided in Table 7.2.

Key function	Covariate	Delta AIC	Par	ESW (m)	P (CV)	GOF–K-S p
Hazard rate	Observer, Behaviour	0	4	872.1	0.20 (0.09)	0.817
Hazard rate	Observer, Behaviour, Group size	1.40	5	872.8	0.20 (0.09)	0.816
Hazard rate	Observer, Behaviour, Sea state (f)	1.46	5	844.3	0.19 (0.09)	0.792
Hazard rate	Observer, Behaviour, Side	1.87	5	884.2	0.20 (0.09)	0.674

Par, number of parameters; ESW, effective half-strip width; P, probability of detection; CV, coefficient of variation; GOF–K-S p, goodness-of-fit Kolmogorov-Smirnov test probability.

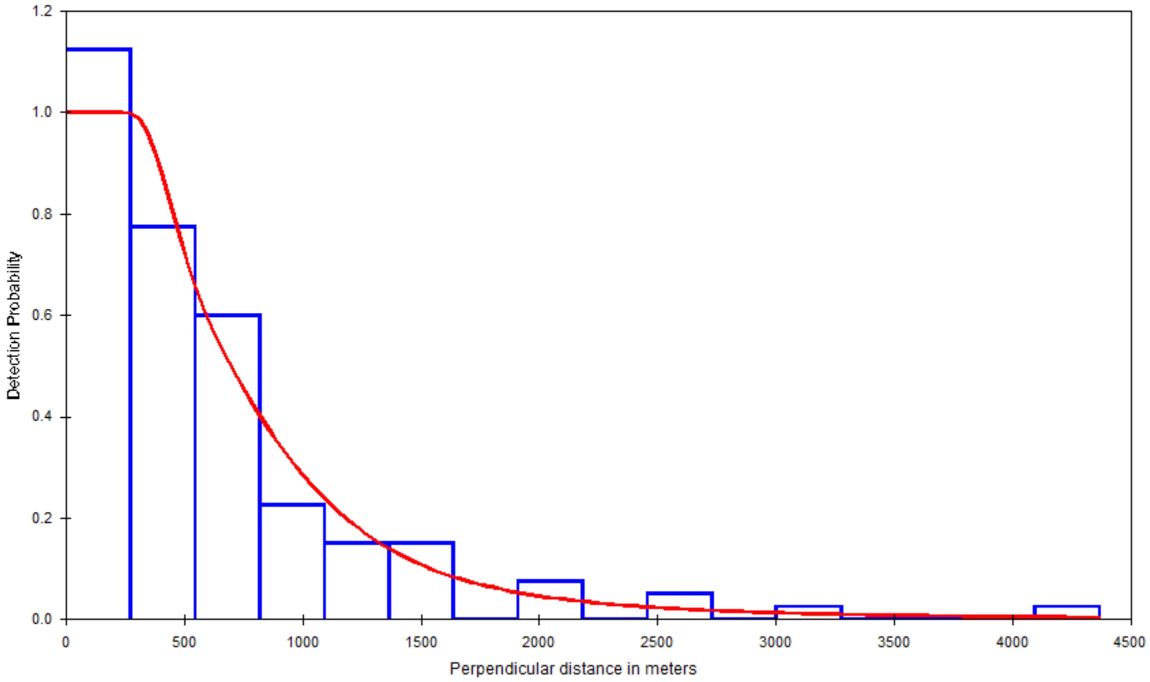

Figure 7.6. Detection function curve for the most supported model using the pooled southern right whale dataset.

Table 7.6. Summary statistics for abundance estimates of southern right whales during three winter surveys using a pooled detection function.

Survey	*L* (km)	*n*	*n/L*	*E(s)*	*D*	*%CV*	*N*	Lower 95% *CL*	Upper 95% *CL*
Jun 2023	1,293.9	51	0.039	2.24	0.051	24.9	399	245	649
Jul 2024	1,309.4	52	0.040	1.92	0.044	25.9	345	208	573
Aug 2023	1,301.5	25	0.019	2.64	0.029	46.2	229	95	555

L, realised effort; *n*, number of sightings; *n/L,* encounter rate (sightings per kilometre); *E(s)*, mean group size; *D*, density (indiv/km^2); *CV*, coefficient of variation of density and abundance; *N*, abundance.

7.3.2. Commerson's dolphins

7.3.2.1. Group size

Totals of 194 sightings and 810 individuals were recorded across the three aerial surveys, of which 192 sightings and 806 individuals were logged on transect in visibility ≥5 km and used for the abundance analysis. The group size of on-transect Commerson's dolphin sightings ranged from 1 to 15 animals (Figure 7.7), with a pooled mean across the three surveys of 4.2 animals (n=191, SD=2.5, median=4.0). There was no significant variation in group size between months (Independent one way ANOVA, F=1.02, df=2, *p*=0.362).

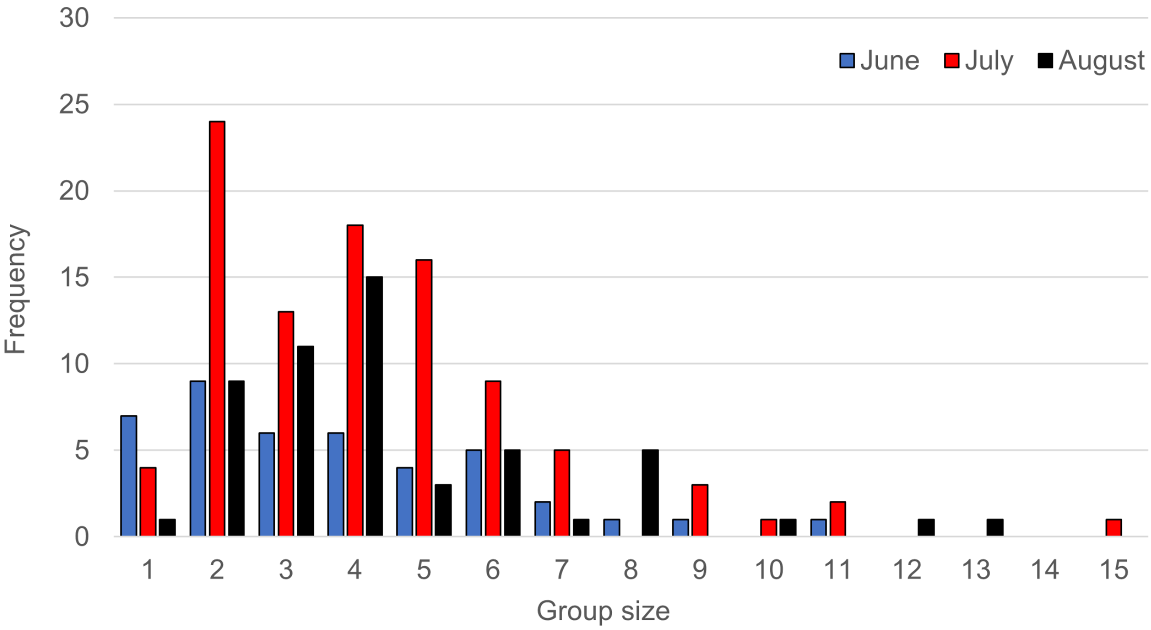

Figure 7.7. Group size of 191 on-transect sightings of Commerson's dolphins recorded during three aerial surveys.

7.3.2.2. Distribution

Commerson's dolphin distribution was heavily skewed towards the western portion of the North Coast stratum, in the waters west of Cape Dolphin and especially to the north of West Falkland (Figure 7.8). Only seven on-effort sightings occurred east of Cape Dolphin in the North Coast stratum. Additionally, there were just two sightings in Berkeley Sound, and no Commerson's dolphin sightings were recorded at all in the East Coast stratum (Figure 7.8).

The water depths of Commerson's dolphin sightings varied significantly between survey months (Kruskal-Wallis test, H=22.8, df=2, p<0.001: Figure 7.9, Table 7.7). Dunn's post hoc comparisons revealed that dolphin sightings during August occurred in significantly (p<0.001) deeper water than both other months, but there was no significant difference between June and July (p=0.297). There was no significant difference between months in the distance of dolphin sightings from shore (Kruskal-Wallis test, H=2.3, df=2, p=0.311: Figure 7.9, Table 7.7).

Table 7.7. Water depths and distances from shore of on-effort Commerson's dolphin sightings.

Month	n	Water depth (m)			Distance from shore (km)		
		Mean	SD	Range	Mean	SD	Range
June 2023	42	38.8	19.0	1.0–88.0	8.2	3.5	0.0–13.2
July 2024	96	46.4	34.2	1.0–125.0	8.5	7.5	0.1–28.9
August 2023	53	65.9	26.9	4.0–138.0	8.8	5.2	0.6–21.3
Total	191	50.1	31.1	1.0–138.0	8.5	6.2	0.0–28.9

7.3.2.3. Uncorrected abundance

A half normal model was selected as the best fitting detection function for the Commerson's dolphin dataset. Right truncation of the data at 400 m improved the model fit, as indicated by Kolmogorov-Smirnov and Cramer-von Mises goodness-of-fit tests. The lowest AIC model included both Observer and Sea (factor) as covariates (Table 7.8). However, two models were well supported by the data (within 2 AIC units) and their detection probabilities (P) were near identical (Table 7.8). Consequently, the simplest model with fewest parameters and only Observer as a covariate was selected as the final model for abundance (Figure 7.10).

The density of Commerson's dolphins varied from 0.210 animals/km^2 in June to 0.595 animals/km^2 in July (Table 7.9). The resulting uncorrected abundance estimates were 1,661 (CV=0.43), 4,698 (CV=0.30) and 2,579 (CV=0.56) animals in June 2023, July 2024 and August 2023 respectively (Table 7.9). Given the marked variation in dolphin distribution with 98% of the on-effort sightings occurring west of MacBride Head, these abundance estimates predominantly relate to the North Coast stratum.

Table 7.8. Most supported models (delta AIC <2) for Commerson's dolphin abundance. All models were right truncated at 400 m. Covariate definitions are provided in Table 7.2.

Key function	Covariates	Delta AIC	Par	ESW (m)	P (CV)	GOF–K-S p
Half-normal	Observer, Sea state (f)	0.0	3	248.7	0.62 (0.05)	0.727
Half-normal	Observer	1.96	2	252.0	0.63 (0.05)	0.726

Par, number of parameters; ESW, effective half-strip width; P, probability of detection; CV, coefficient of variation; GOF–K-S p, goodness-of-fit Kolmogorov-Smirnov test probability.

Table 7.9. Summary statistics for abundance estimates of Commerson's dolphins during three winter surveys using a pooled detection function.

Survey	*L* (km)	*n*	*n/L*	*E(s)*	*D*	*%CV*	*N*	Lower 95% *CL*	Upper 95% *CL*
Jun 2023	1,293.9	41	0.032	3.35	0.210	42.8	1,661	729	3,791
Jul 2024	1,309.4	93	0.071	4.23	0.595	30.4	4,698	2,586	8,537
Aug 2023	1,335.2	50	0.037	4.40	0.327	56.0	2,579	902	7,376

L, realised effort; *n*, number of sightings; *n/L,* encounter rate (sightings per kilometre); *E(s)*, mean group size; *D*, density (indiv/km^2); *CV*, coefficient of variation of density and abundance; *N*, abundance.

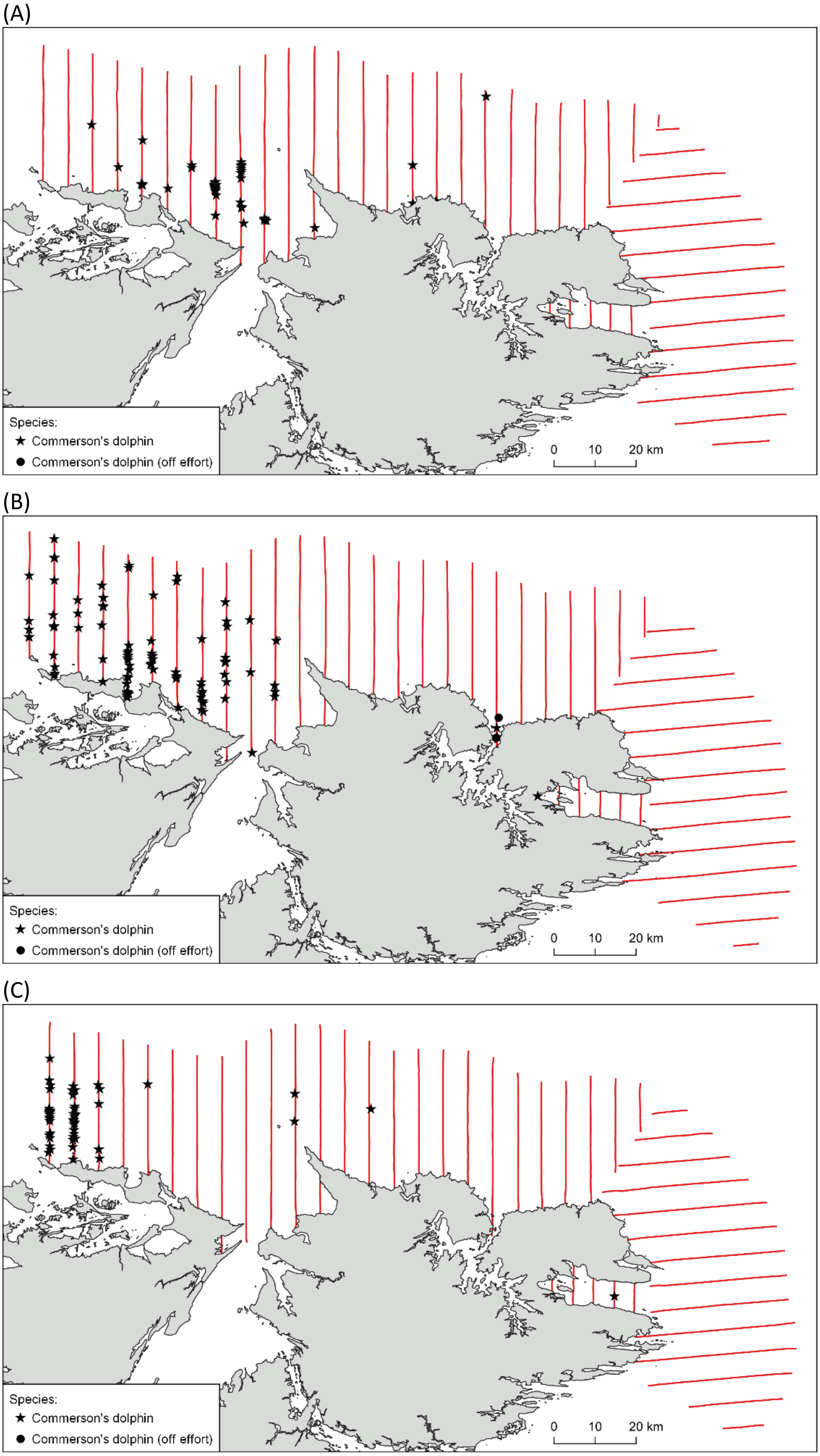

Figure 7.8. Distribution of realised transect effort (red lines) and sightings of Commerson's dolphins during aerial surveys in: (A) June 2023; (B) July 2024; and (C) August 2023.

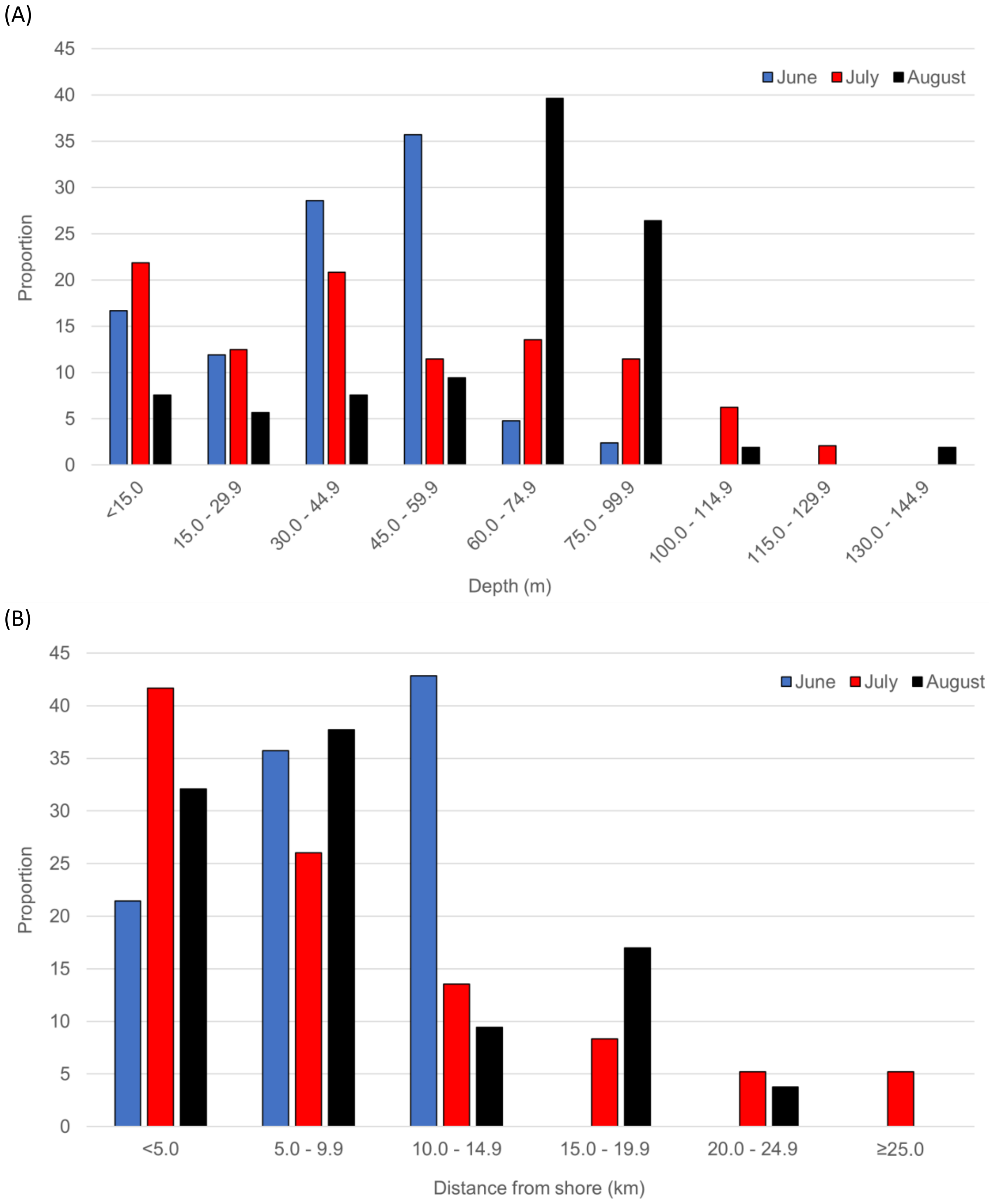

Figure 7.5. Proportion of on-effort Commerson's dolphin sightings (n=191) by month during winter aerial surveys by: (A) water depth; and (B) distance from shore.

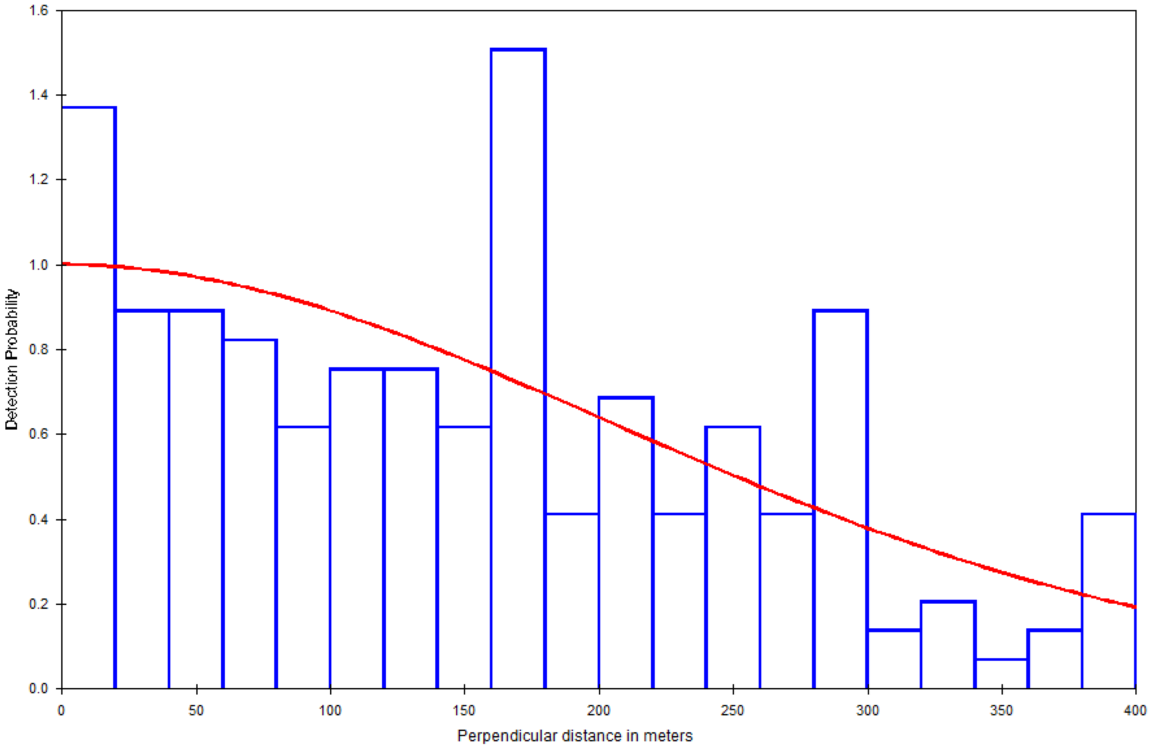

Figure 7.10. Detection function curve for the selected model using the pooled Commerson's dolphin dataset.

7.4 Discussion

Very few surveys aimed at estimating the abundance of cetaceans have been carried out in the Falkland Islands to date. A pilot aerial survey aimed at assessing the abundance of sei whales in Berkeley Sound was carried out from February to May 2017 producing a corrected (for availability bias, but not for perception bias) estimate of 64 animals, but the resulting estimate had very high uncertainty (CV=1.08) resulting from the relatively small spatial extent of the study area and low number of sightings recorded (Weir, 2017). An island-wide (to 10 km offshore) aerial survey was carried out from March to May 2017 aimed primarily at estimating the abundance of Peale's and Commerson's dolphins (Costa and Cazzola, 2018); the resulting estimates of 1,896 (CV=0.33) and 5,789 (CV=0.18) animals respectively were uncorrected for availability and perception bias. The only published abundance estimate, corrected for availability bias, is a boat-based abundance estimate of 916 (CV=0.19) sei whales on the west coast of the Islands during summer 2018 (Weir et al., 2021).

The aerial surveys completed as part of DPLUS126 comprise the first abundance surveys carried out during winter in the Islands, and therefore address an important seasonal data gap on the winter occurrence of cetaceans. While it was expected that a suitable dataset would be acquired for the southern right whale which was the target species, the high number of Commerson's dolphin sightings was not anticipated and allowed abundance estimates to additionally be produced for that species. The estimates presented here are uncorrected for availability and perception bias, and are therefore negatively biased. Perception bias was reduced by using consistent observers throughout the surveys, planning surveys for favourable weather, and removing effort that occurred in visibility of <5 km. However, animals may still be missed for a variety of reasons. The use of a dual-observer platform would allow future abundance surveys to calculate perception bias. However, at present there are no suitable aircraft in the Falklands capable of carrying two sets of observers and sufficient fuel to make such a survey cost-effective.

7.4.1. Southern right whale

A combination of satellite-tracking data (Weir et al., 2024) and genetic analysis (Jackson et al., 2022), indicates that most of the southern right whales occupying the coast of the north-east Falklands during winter originate from the wider south-west Atlantic population whose core winter calving grounds are located in Argentina and Brazil (Cooke and Zerbini, 2018). The recent observation of an adult female from the South African calving area within Falklands' waters during winter (Vermeulen et al., 2023) also raises the possibility that some animals from the south-east Atlantic population may be included in these abundance estimates. Nevertheless, biopsies collected from 82 animals in the Falklands confirmed genetic affinity with whales from Argentina, Brazil and South Georgia and were significantly differentiated from South African animals (Jackson et al., 2022). While acknowledging that there may be some mixing of animals from different breeding populations in Falklands' waters, we therefore consider that the abundance estimates reported here relate primarily to a subset of the south-west Atlantic right whale population that was using Falklands' waters at the time of each survey.

The uncorrected (for availability and perception bias) estimate of ~400 southern right whales using the study area during June 2023, currently comprises the best available data regarding the number of right whales using the Falkland Islands wintering ground at a given time during the peak season. The estimate comprises approximately 3% of the global population of 13,600 individuals estimated during 2009 (IWC, 2013), and is therefore significant in a global context. In the SWA, instantaneous counts during flights at the major SWA calving ground at PV during the peak of the breeding season between 2005 and 2017 comprised around 1,200 adult/subadult animals and 500 newborn calves (Crespo et al., 2024). In that context, the 400 adult/subadult animals recorded in the Falkland Islands is also regionally significant, particularly since the PV flights occurred along the high-use coastal zone while the aerial surveys in the Falkland Islands ran perpendicular to the coast. However, the different methods and timeframes of those studies limit the appropriateness of direct comparisons.

The abundance estimates presented here should not be interpreted as the total number of right whales that use Falklands' waters during winter, for several reasons. Firstly, the surveys comprised only six days of effort in total, and thus do not equate to the total number of whales that pass through the study area given that the residence time of most individuals will be less than the breeding season duration. Secondly, it is acknowledged that right whale aggregations do occur in other parts of the Falklands that were not covered by the aerial surveys, although they remain poorly documented. For example, around 30 animals were observed off Saunders Island to the west of the study area on several dates during July 2023 (Suzan Pole-Evans, pers. comm.), while the prolonged time spent by a tagged whale at Weddell and Beaver Islands during 2024 strongly suggests that breeding aggregations were present in that area (Falklands Conservation, unpublished data). While an island-wide aerial survey was beyond current logistical constraints and finances, it would be desirable in future in order to fully assess the distribution and numbers of right whales around the entire Falklands coast during winter. Finally, the aerial surveys under-estimated the total number of animals in the study area due to factors including group size estimation, perception bias, and availability bias. For example, Bortolotto et al. (2016) found significant differences between humpback whale mean group sizes estimated from ship and aerial platforms in Brazil, with the latter being 19% lower and attributed to the much smaller timeframe available to an observer to assess and estimate group size during aerial surveys.

Prior to the aerial surveys, it was expected that July would represent the month of highest right whale abundance. This was based primarily on the clear peak in relative abundance of right whales recorded in July during boat-based surveys from 2019 to 2021 (Weir, 2022). However, the abundance estimates for June and July were reasonably comparable while a decrease in abundance was apparent during August. Interpretation of this result is problematic because of the caveat that the June and August surveys were completed during 2023 while the July estimate related to 2024. Observations from boat surveys in both years do suggest that the overall numbers around the Falkland Islands in 2024 may have been lower than in previous years (Falklands Conservation, unpublished data). Nevertheless, the June and July abundance estimates were comparable and their confidence intervals largely overlap. Boat work and acoustic monitoring in the north-east Falklands have indicated that the seasonal pattern of right whale occurrence in the Falklands has inter-annual variation, with the main concentration of southern right whales arriving earlier in some years than others (Weir, 2022; Chapter 2 of this report). The high abundance estimated during June 2023 might represent one such year where animals arrived earlier than expected, or might reflect inter-annual variation in animal occurrence (i.e. if 2023 had higher numbers overall than 2024) in addition to inter-month seasonal variation. Additionally, the boat work and acoustic data primarily occurred only in the south-east part of the total aerial survey area, and the seasonal pattern of occurrence might be different across the larger area. Regardless, the aerial work was consistent with all other available data sources in indicating that southern right whales are numerous in Falklands' nearshore waters across the austral winter between June and August (Cerchio et al., 2022; Weir, 2021, 2022; Weir et al., 2024), with the peak numbers in June and July occurring earlier in the winter breeding season than those recorded at the PV calving ground (i.e. usually between late August and mid-September: Crespo et al., 2019). This likely reflects some movement of whales between the breeding areas at the Falkland Islands and PV within the same winter, with telemetry results indicating that a high proportion of whales tagged in the Falklands do subsequently travel to PV, arriving there by mid-September (Weir et al., 2024; Chapter 5).

It is noted that no calves of the year were observed during the aerial surveys, despite the large amount of previously-unsurveyed habitat covered. This supports previous suggestions that the Falklands wintering ground currently comprises a non-calving breeding area, supporting courtship and mating amongst adults (Weir and Stanworth, 2020; Weir, 2021), in addition to presumed non-breeding socialising aggregations of both sub-adults and adults.

While the estimates presented in this Chapter were uncorrected, a correction factor to account for availability bias could be produced from existing or novel datasets. For example, some of the dive information recorded from tagged southern right whales in the Falkland Islands (see Chapter 6) may be applicable for correcting the abundance estimate. An alternative would be to carry out unmanned aerial vehicle (UAV) focal follows of right whales within the study area to assess the proportion of time that animals are visible at the surface. Given the dive durations recorded in the Falklands (see Chapter 6), relatively long duration focal follows would be required to generate a robust dataset in this respect, requiring UAVs with the capacity to fly for at least 30 min duration in order to capture at least two dive cycles.

7.4.2. Commerson's dolphin

The Commerson's dolphin occurs as two subspecies globally. The South American subspecies (*C. c. commersonii*) is endemic to the south-west Atlantic where it inhabits the coastal waters of Argentina, Chile and the Falkland Islands, while the Kerguelen subspecies (*C. c. kerguelenensis*) occurs only around the Kerguelen Islands in the southern Indian Ocean (Crespo et al., 2017; Kraft et al., 2021). Additionally, small numbers of Commerson's dolphins inhabit localised parts of the Pacific coast of southern Chile (Acevedo et al., 2019). The most recent IUCN global assessment allocated a Least Concern status to the Commerson's dolphin, on the basis that it appears to be widespread, abundant, and not in decline in major portions of its range (Crespo et al., 2017).

The Commerson's dolphins found along different areas of the South American mainland comprise a single panmictic population (Durante et al., 2022). While it has been suggested based on distribution, parasites and skull morphology that there is "little mixing, if any" between the South American mainland and Falkland Islands populations (Crespo et al., 2017), recent genetic work concluded that dolphins in those two areas share several haplotypes and do not show high levels of differentiation or sufficient divergence to warrant subspecies status (Kraft et al., 2019). Consequently, the abundance estimates generated for Commerson's dolphins in the Falkland Islands need to be considered in the regional context of the wider south-west Atlantic population.

Relatively few abundance estimates have been published for South American Commerson's dolphins (Table 7.9), and much of their known distribution range has not received adequate survey coverage to understand abundance, ecology, or status. Furthermore, few of the published abundance estimates can be directly compared to one another, given the variation in total survey effort, study area limits, seasonality and methods. Only part of the Chilean distribution range has been surveyed (Table 7.9), producing an estimate of ~1,200 animals in the most recent survey (for which, however, data are almost 30 years old: Lescrauwaet et al., 2000). In Argentina, estimates of 18,100 animals were generated from line transect surveys carried out between 1994 and 2001; density estimates from those surveys were then applied to unsurveyed areas to generate an estimated abundance across the total Argentine shelf to 100 m depth of ~40,700 animals (Table 7.9: Pedraza, 2007). More recently, an abundance of ~22,000 animals was estimated for the Argentine coast using spatial modelling of data collected between 2009 and 2015 (Dellabianca et al., 2016); however, those results had high uncertainty and the use of a vessel platform is problematic given the highly responsive movement of Commerson's dolphins to vessels. Given the variation in methods and the fact that almost all existing abundance estimates for South American Commerson's dolphins are based on data that are several decades old, it is challenging to put the results of the Falklands' aerial surveys into context. Nevertheless, it is clear that the waters around the Islands host upwards of several thousand animals and therefore comprise a considerable regional, and thus global, stronghold of the species, considering that the numbers of the Kerguelen subspecies are likely to be very low (Robineau et al., 2007). This information may be sufficient to support a KBA proposal for the Commerson's dolphin.

Table 7.9. Published large-scale abundance (N) estimates for the South American subspecies of Commerson's dolphin. LTDS=Line transect distance sampling.

Area	Study area size (km^2)	Effort (km)	Dates	Platform	Method	N	CV	95% CI	Study
Chile									
North-east Strait of Magellan	1,330	375	Jan/Feb 1984	Aerial	LTDS	3,211	0.34	–	Leatherwood et al., 1988
	3,600	578	May 1987	Aerial	LTDS	313	–	–	Venegas and Atalah, 1987
	3,600	1,320	Dec 1989	Aerial	LTDS	718	–	–	Venegas, 1996
	3,600	819	Jun 1996	Aerial	LTDS	1,206	0.27	711–2,049	Lescrauwaet et al., 2000
Argentina									
Chubut (including Golfo San Jorge)	80,490	3,519	1994, 1995, 1996, 2000	Aerial	LTDS	1,210	0.43	532–2,753	Pedraza, 2007
North of Santa Cruz	10,465	1,761	1994, 1995	Aerial	LTDS	2,185	0.56	771–6,190	Pedraza, 2007
South of Santa Cruz and Tierra del Fuego	24,380	798	2001	Aerial	LTDS	14,717	0.27	8,495–25,498	Pedraza, 2007
Unsurveyed latitudes (48°21'S to 51°40'S)	–	–	N/A	–	Inferred from density estimates	22,580	–	–	Pedraza, 2007
Argentinean coast to 100 m depth	–	8,535	Nov to Apr, 2009-2015	Vessel	Spatially explicit models	21,933	0.74	6,013–80,012	Dellabianca et al., 2016
Falkland Islands									
Island-wide to 10 km offshore	19,314	4,255	Autumn 2017	Aerial	LTDS	5,789	0.18	–	Costa and Cazzola, 2018; Franchini et al., 2020
North-east coast to 30 km offshore	7,890	1,309	Jul 2024	Aerial	LTDS	4,698	0.30	2,586–8,537	This chapter

It is emphasised that the aerial abundance estimates presented here for Commerson's dolphin were not generated from optimal methods for targeting dolphins. In particular, the surveys were carried out in sea states up to Beaufort 4, where the presence of whitecaps may obscure the splashes and other cues of small cetaceans. It would be useful to carry out the analyses again using only data collected in Beaufort 0–2 and Beaufort 0–3 to determine whether the resulting estimates are significantly impacted, although the inclusion of sea state as a covariate in the current analysis should have accounted for such variation to some extent. Additionally, the altitude at which the surveys were flown during the right whale surveys (229 m) was higher than that generally used in surveys that have specifically targeted Commerson's dolphins, for example 100 m (Lescrauwaet et al., 2000) and 150 m (Leatherwood et al., 1988; Pedraza, 2007), which may potentially have affected the detection of dolphins considering their small body size. The ESW of ~250 m generated for Commerson's dolphins detected during the Falklands' winter aerial surveys was greater than the ESWs recorded in other abundance surveys of the species, for example 166 m in Chile (Lescrauwaet et al., 2000), and 126 to 227 m in Argentina (Pedraza, 2007). This suggests that the detection of animals was not negatively affected by the higher altitude, perhaps because of the bold white body colouration of the species which contrasts markedly against the water colour.

During the 2023/24 winter aerial surveys, the highest densities of Commerson's dolphins occurred in the waters west of Cape Dolphin and particularly to the north of West Falkland including Pebble Island. That area was used in June, July and August which suggests that there is some consistency in its importance for dolphins over the winter both within, and between, years. While the distribution of the high density area appeared to be fully captured within the survey area during June, there were indications that the area of high density extended further west from the survey area in July and especially in August such that only the eastern part of it was surveyed. This implies that the actual number of dolphins in that wider region during the latter part of winter may be considerably higher than the abundance estimates presented here.

This region has not been identified as a high-use habitat for Commerson's dolphins previously. Following year-round boat work to document cetaceans and seabirds in the Falkland Islands between 1998 and 2001, White et al. (2002) described Commerson's dolphins as being highly coastal in nature, with the majority of records occurring in partially enclosed waters and within 10 km (98.8%) of the coast. Consequently, aerial surveys aimed at estimating the abundance of the species in autumn 2017 only covered areas within 10 km of the coast (Costa and Cazzola, 2018). Interestingly, those surveys did not record any Commerson's dolphins on the exposed coast between Cape Dolphin and Pebble Islet (i.e., the corresponding area to that used in the 2023/24 surveys described here). Possibly this might be explained by the seasonal difference in the timing of the two aerial studies, with one carried out during autumn (Costa and Cazzola, 2018) and the other in winter (this study). However, a high density of Commerson's dolphins was recorded in the region during a vessel passage in February 2018 (i.e., austral summer: Weir, 2018), and the year-round surveys of White et al. (2002) recorded dolphins in all grid cells corresponding with the high density dolphin area indicated by the winter 2023/24 aerial surveys. The reasons for these discrepancies remain unclear, but highlight the need to survey areas more than once to account for spatio-temporal variation in occurrence.

The spatial distribution of Commerson's dolphins predicted by habitat modelling has also shown variation between studies, which again may reflect seasonal differences in distribution. For example, the use of generalized additive models based on data collected during summer, autumn and winter predicted some moderate density areas to the north of Pebble Island, but the highest densities were strictly inshore (Baines and Weir, 2020). MaxEnt modelling of the same dataset did predict high densities of Commerson's dolphins at ~15 to 40 km offshore (Baines and Weir, 2020), but did not predict high densities in many of the inshore areas known to be regularly used by the species which reduces confidence in that model. Another habitat modelling study used a Hurdle model approach to predict the occurrence of Commerson's dolphin sightings using a spatially limited boat-based dataset, and compared the results against sightings recorded during the 2017 island-wide aerial survey (Franchini et al., 2020). The boat data used to generate the model did include some survey effort and associated sightings north of West Falkland in an area overlapping with the 2023/24 winter aerial surveys (although only within ~10 km of the coastline). That study did not predict high densities of Commerson's dolphins between Cape Dolphin and Pebble Islet. However, both the data used to generate the model and the data collected during the aerial survey used to validate the model were from autumn (Franchini et al., 2020), and perhaps do not reflect dolphin distribution during other seasons.

The high densities of Commerson's dolphins recorded during the 2023/24 winter aerial surveys merit further investigation, with respect to the drivers of occurrence and additional assessment of their spatio-temporal occurrence, as this relatively small region in the Falkland Islands may represent a regional and global stronghold for the Commerson's dolphin.

There are currently no data available to generate a correction factor to account for availability bias in the Commerson's dolphin abundance estimates. One possibility would be to apply correction factors from similar studies elsewhere, for example those published for Hector's dolphins (*C. hectori*: Slooten et al., 2006*)* which are another small, pale-coloured species of the same genus and might be expected to have similar availability to the Commerson's dolphin. Alternatively, UAV focal follows of Commerson's dolphins within the study area could generate an applicable dataset at relatively low cost if the flights were carried out from land (e.g. Brown et al., 2023), although their applicability to the sightings recorded further from the coast would remain unknown.

7.4.3. Conservation and management conclusions

Previous winter survey work targeting southern right whales was spatially limited to a ~40 km stretch of coast between Stanley and MacBride Head (Weir and Stanworth, 2020; Weir, 2021). Consequently, it was unclear to what extent the wintering aggregations occurred elsewhere (Weir, 2021). This study, along with the results of satellite-tracking carried out in 2022 (Weir et al., 2024), showed that right whales utilise the entire remote north coast of East Falkland intensively during winter, including many of the small bays and the entrance to Port Salvador. One of the primary drivers for the aerial surveys was to generate a dataset on southern right whale abundance that could be used to inform an IUCN Key Biodiversity Area (KBA) Assessment. This requires information on the number of mature individuals using a site (to compare against global population size), and data on spatial distribution to facilitate site delineation. As a direct result of the distribution and abundance information produced by the aerial surveys, the north coast of East Falkland was recently (December 2024) proposed as an IUCN Key Biodiversity Area supporting a winter breeding aggregation of the southern right whale (Weir, 2024). The aerial survey results also add additional support for the site boundaries identified as an IUCN Important Marine Mammal Area for right whales during 2024. These spatial tools identify globally important biodiversity sites, and their recognition will highlight the need to manage potentially adverse human activities on right whales such as shipping, fishing, and hydrocarbon extraction.

The results of the aerial surveys provide a baseline against which to assess future abundance of southern right whales. The distribution of whales during the winter aerial surveys, together with the results of satellite-tracking, suggest that the highest whale densities occur relatively close to the coast in most months, and the best option for the long-term monitoring of the population may be considered in that context. The Falklands' coast is complex and remote, and any monitoring of population size is likely to be costly and logistically challenging. The approach used at PV, incorporating the monitoring from air of a coastal strip extending 1,000 m from the coastline within which instantaneous counts of whales are made (Crespo et al., 2024), may represent a more cost-effective monitoring approach (though using trends in relative abundance rather than absolute abundance), allow a greater spatial extent of coastline to be covered, and provide better indications of the overall number of whales using the Falklands during winter.

The regionally-important southern right whale numbers identified during the aerial surveys further highlight the relevance of the Falkland Islands to the IWC Conservation Management Plan for the south-west Atlantic population which does not currently include recognition of the FIWG as a winter breeding area for the species. In addition, the abundance of Commerson's dolphins recorded during the southern right whale surveys is of regional, and likely global, significance and warrants consideration in local and regional management plans for that species.

7.5 Acknowledgements

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Chapter 8: Sei whale mark-recapture

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8.1 Introduction and aims

Cetacean photo-identification studies rely on the acquisition of high-quality images of the naturally-occurring markings that can be used to recognise individuals (Würsig and Jefferson, 1990; Hammond, 2018). The markings used to catalogue individual animals vary between species, depending on their morphology and behaviour. In all cases, the selected markings need to persist over the timeframe of the study, such that animals can continue to be recognised.

Compared to other baleen whale species, relatively little concerted effort has been made to establish photo-identification catalogues for sei whales (*Balaenoptera borealis*) worldwide. This largely reflects the low numbers of encounters with the species in many regions globally, due to its occurrence in pelagic habitats, unpredictability, elusive behaviour (which makes the acquisition of suitable images difficult), and lack of conspicuous natural markings (Weir, 2017). Horwood (1987) also noted limitations in the availability of natural markings on sei whales. Schilling et al. (1992) identified 47 individual sei whales in the Gulf of Maine during 1986 based on features that included variation in dorsal fin shape, occurrence of small circular scars on either flank, and light pigmentation swathes behind the dorsal fin. A total of 13 sei whales were photo-identified in the Magellan Strait in Chile between 2004 and 2015, using scars or nicks in their dorsal fins (Acevedo et al., 2017). Twelve individuals were photo-identified at Caleta Chome on the Pacific coast of Chile in 2019/20 through scars or distinctive notches in the dorsal fins (Cisterna-Concha et al., 2022). In the Azores, 87 individuals were identified in the waters around São Miguel, but the left and right sides were not always reconciled and allocated to the same animal (Leal, 2021). However, with the exception of Acevedo et al. (2017), those published studies did not include good evidence of the marks used to identify animals (i.e. Schilling et al., 1992; Leal, 2021), and/or the quality of the images provided in the publications were poor (e.g. Cisterna-Concha et al., 2022). The citizen science photo-identification catalogue HappyWhale (Cheeseman et al., 2017) holds images of 364 sei whale collected globally, less than 0.1% of the total number of baleen whale images in that catalogue. Many of those images were contributed by Falklands Conservation.

A population of sei whales uses the inner shelf waters around the Falkland Islands as a seasonal feeding area during the summer and autumn (Weir, 2021; Weir et al., 2019), providing good opportunity to establish a long-term and systematic photo-identification study. Photo-identification has been carried out on sei whales annually in the Islands since 2017, with a focus on Berkeley Sound (Weir, 2017, 2018, 2022a). The catalogues for 2017 to 2021 include almost 700 animals, of which 497 animals have been photographed on both sides. This high number of catalogued sei whales provides a uniquely-large dataset for the species globally.

Over the long-term, the recognition of individuals can provide valuable information relevant to the conservation and management of species, including population size (abundance), movements, habitat use, social affiliations, survivorship and life history parameters (Hammond, 2010, 2018). Fundamental to such analyses is the use of a capture-mark-recapture (CMR) method, whereby an individual is marked (i.e., its first photographic capture) and subsequently recaptured (i.e., photographed again) at a later time and/or place. Establishing photographic capture histories of individual animals is therefore necessary, which relies on the study population having sufficient natural marks to allow for the recognition of individuals (expressed here through animal Distinctiveness Value, DV) and on the Photographic Quality (PQ) of the dataset being high enough to provide certainty in identifying recaptures.

To date, the sei whale photo-identification datasets collected in the Falkland Islands have been informally assessed to provide preliminary information relevant to the conservation and management of baleen whales in Falklands' waters (Weir, 2017, 2018, 2022a), including:

- Calculating the minimum number of whales photographed at the study sites;
- Assessing movements of individual whales between study sites, both within and between years; and
- Understanding the intra-annual residency of individual whales within the study sites.

However, applying CMR analysis methods, the datasets could potentially also provide robust information on abundance and life history parameters, especially survival and recruitment rates (Hammond, 2017).

This chapter provides the results of the first CMR analysis carried out on the sei whale photo-identification dataset collected in the Falkland Islands. The main objectives of the analysis were:

1. To assess the applicability of CMR methods to the sei whale catalogues, in terms of whether the number of captures and recaptures in the Falklands following suitable quality control were sufficient to produce robust results; and
2. To generate the first CMR abundance estimate of sei whales in Berkeley Sound.

8.2 Materials and methods

8.2.1 Data collection

Images of sei whales were collected in Berkeley Sound during small boat surveys carried out during 2017, and each year from 2019 to 2024 (see Weir, 2017, 2022a, for more information on methods). During photo-identification efforts, the boat was carefully manoeuvred to position the photographers parallel with the animal(s) and to travel slowly alongside them. High-resolution images suitable for photo-identification work were taken with Canon 100–400 mm zoom lenses, and either a Canon 7D Mark II DSLR or a 5D Mark III DSLR camera body. The clocks on all camera bodies were synchronised with the GPS to ensure that images could be cross-referenced with particular sightings. Where groups were followed, equal effort was made to photograph every individual in the group. Both sides of the animals were photographed whenever possible. Photo-identification effort was terminated as soon as it was considered that sufficient images had been obtained of each individual, or if the animal was lost or began to display repeated avoidance of the boat.

8.2.2 Cataloguing

Sei whales have a prominent dorsal fin which is usually fully exposed above the waterline when the animal surfaces, providing the opportunity to catalogue the species in a similar way to that well-established for many odontocete species (most commonly bottlenose dolphins, *Tursiops* spp.), using marks along the trailing edge of the fin. Consequently, for this study the Target Area (TA) for photo-identification was the dorsal fin (Figure 8.1). Images of sei whales were cropped to the TA prior to quality-control.

Figure 8.1. The Target Area used for the sei whale photo-identification, showing an original image (top) and the same image cropped to the TA for matching and quality control (bottom).

A single person (CW) worked through every photo-identification encounter, visually-assessing each image and assigning it to a sub-folder for a particular individual where possible based on any unique markings. Left- and right-side images were matched to the same animal whenever possible, using distinctive features. The highest-quality images of the left and right sides of each distinctive individual were then cropped to the TA and used for the cataloguing process. Every individual whale was compared to the existing catalogues and either considered to be a photographic ‘recapture’ of an animal already catalogued (in which case it was allocated the same unique Identification Number), or entered into the catalogue with a new Identification Number if no match with an existing catalogued animal was apparent.

Each catalogue was cross-checked for false positives (i.e. matching images to the same animal that actually originate from two separate individuals) and false negatives (i.e. allocating images from the same animal to two different individuals). False positives can be reduced with care and by using only good-quality images. False negatives are more common in cetacean studies, and can result from: (1) matching images of insufficient quality (including different light conditions that might affect the visibility of scarring); (2) attempting to match individuals that are very poorly-marked; and (3) changes in the natural markings between encounters caused by acquisition or healing of scars or nicks.

8.2.3 Definition of Sampling Occasion (SO)

The Sampling Occasion (SO) refers to the need to define spatial areas and timeframes that are considered to comprise a ‘sample’ for CMR analysis. It is important that the resulting set of SOs comprises representative samples for capture and recapture. For example, it would not be relevant to include survey data from July and August in a sei whale CMR, since sei whales are largely absent from the Falkland Islands in those months.

The identification of SOs for the sei whale CMR study was carefully considered by Weir (2022b), and it was determined that a suitably-representative dataset for use in the initial CMR analysis would be restricted to data collected only in the Berkeley Sound area and only between February and June. The lowest level of SO was identified as Date rather than Encounter, in recognition that sometimes the same individuals are repeatedly encountered on the same date. Consequently, the SO for determining captures and recaptures for CMR analysis was defined as each boat survey date carried out Feb–Jun in Berkeley Sound.

8.2.4 Distinctiveness Value (DV)

The best available image of the TA of every sei whale captured in each SO was assessed and graded for Distinctiveness Value (DV). An underlying assumption of CMR analysis is that the marks used to recognise individuals are unique and are not lost over time. It is also important to define what constitutes an ‘unmarked’ animal.

The range of available natural marks on sei whales, and the likely longevity of those marks, was fully considered by Weir (2023). The highest certainty of marks being both permanent, and readily available for capture/recapture (i.e. consistently above the water), relates to: (1) those marks that occur in the edges of the dorsal fin; and (2) holes in the dorsal fin (Weir, 2023). Additionally, the use of those marks means that an individual sei whale should be equally recognisable from either side and largely negates the need to consider both sides of the individual in the CMR analysis.

For the purposes of this study, a DV was assigned to the best available image of each individual using the definitions in Table 8.1. To meet the underlying CMR assumption that all individuals have an equal probability of being captured within each SO, only individuals with a DV of 3 (moderately marked) or 4 (highly marked) were included as ‘marked animals’ in the CMR analysis. Animals with a DV of 1 (unmarked) or 2 (slightly marked) were combined to form the proportion of ‘unmarked animals’ in the CMR analysis. Note that DV1 animals were recognised and catalogued primarily using the scar patterns on their flanks (see Weir, 2023). Some examples of individual sei whales graded as DV1, DV2, DV3 and DV4 are provided in Figure 8.2.

Table 8.1. Definitions of Distinctiveness Value (DV) allocated to individual sei whales for this CMR analysis. The 'marks' described here are permanent dorsal fin marks that include nicks in the fin edges, holes through the fin, and/or injuries/deformities.

DV	Description	Definition
0	Calf	Known calf of the year. Not included in mark-recapture analysis
1	Unmarked	Animals lacking marks
2	Slightly marked	1 or 2 marks of small size or; 1 moderate-sized mark with no other marks
3	Moderately marked	3 or 4 marks of any size or; 1 moderate-sized mark with at least one other mark; or 1 large-sized mark with no other marks
4	Highly marked	5+ marks of any size or; 2+ moderate-sized marks; ≥1 large-sized mark with at least one other mark; or Physical injury or deformity affecting over one-third of the fin

8.2.5 Photographic Quality (PQ)

The visibility of marks on sei whales relies on the acquisition of high-quality images in which the TA is fully visible and the primary marks used to recognise individuals are easily seen. One approach for determining the appropriate photographic quality (PQ) criteria for CMR analysis is to consider the type of marks and level of distinctiveness to be used, and then determine the image quality threshold necessary to recognise individuals (Urian et al., 2015).

Prior to assigning a PQ value, the best available RAW format images of each animal were imported into Lightroom, cropped to the TA (see Figure 8.1), and digitally-manipulated to adjust the exposure, contrast, and shadows, to optimise the visibility of marks. Consequently, the size of the TA within the original frame was not specifically considered as a PQ criterion.

Scores were allocated for each PQ criterion, adapted from the method of Urian et al. (2013) and defined in Table 8.2. Using this standardised scoring system, an overall PQ value was generated for each image assessed:

- Score of **3 to 4**: Excellent quality (PQ1)
- Score of **5 to 6**: Good quality (PQ2)
- Score of **8 to 9**: Fair quality (PQ3)
- Score of **≥12**: Poor quality (PQ4)

The CMR analysis was limited to only images of good (PQ2) or excellent (PQ1) quality in order to ensure that the marks used to recognise individuals were visible and reduce the likelihood of false positives and false negatives.

(A) DV1 Unmarked

(B) DV2 Slightly marked

(C) DV3 Moderately marked

Figure 8.2. Some examples of Distinctiveness Value (DV) allocated to individual sei whales during the grading for CMR analysis.

(D) DV4 Highly marked

Figure 8.2. Contd.

Table 8.2. Criteria and scoring system used to generate a photographic quality (PQ) rating for sei whale photo-identification images.

PQ Criteria	Definition	Scores
Clarity	Sharpness of the TA, reflecting both focus and resolution following digital cropping	Excellent = 1 Good = 2 Moderate = 6 Poor/blurred = 10
Angle	Angle of the animal relative to the photographer, important for identifying nicks	Perpendicular = 1 Slightly angled (<10º) = 2 Angled (>10º) = 10
Exposure	Not considered, since permanent dorsal fin marks should be visible irrelevant of image exposure	–
Visibility of the Target Area	Extent of the dorsal fin visible within the image	100% visible = 1 75–100% visible = 2 50–75% visible = 6 <50% visible = 10

8.2.6 CMR analysis

A discovery curve is a graphical representation showing the cumulative number of individual animals identified over time, indicating the progress and effectiveness of the identification effort. Discovery curves were plotted with sampling occasions on the X-axis and the cumulative number of marked individuals identified on the Y-axis.

Capture histories were compiled for each identified whale using the subset of images that contained individuals of DV3 and DV4 (“well-marked”) and quality of PQ1 and PQ2. Capture history data were then pooled by month such that CMR analyses could be applied to either pooled or unpooled data. Analyses were carried out in program Mark (White and Burnham, 1999). An open robust design multi-state model (Kendall and Bjorkland, 2001) was applied, using year as the primary session, in order to estimate annual abundance, survival, emigration and re-immigration between years.

Abundance within each year was also estimated using closed population models (Huggins, 1989) that allow for heterogeneity of capture probabilities with respect to behavioural response (i.e. avoidance or attraction to the survey vessel) or time specific variation. The program can be set to identify the most appropriate model by performing chi-square tests comparing each model with the null hypothesis model M(o) and testing goodness of fit.

Abundance estimates were of the number of marked (i.e. DV3 and DV4) animals. The proportion of marked individuals was calculated for each encounter, from which a mean value was calculated. This proportion was used to estimate total abundance from the abundance of marked animals.

8.3 Results

8.3.1. Overview

The CMR analysis was restricted to years 2017 to 2021 for which full datasets had been processed and catalogued. A total of 59 SOs were identified for Berkeley Sound between February and June across those years, as summarised in Table 8.3. A total of 441 sei whale individuals were identified across the 59 SOs using the raw dataset (i.e. images of all PQ and individual whales of all DV).

Table 8.3. Summary of Sampling Occasions (SOs) identified for the Berkeley Sound sei whale CMR analysis.

Year	First SO	Final SO	Total SOs
2017	9 Feb	29 May	22
2019	1 Feb	27 Apr	13
2020	6 Feb	26 Mar	10
2021	15 Feb	1 Jun	14
Total	1 Feb	1 Jun	59

8.3.2. CMR dataset

Following quality control to remove low quality (PQ3 and PQ4) images from the dataset, a total of 368 sei whale individuals (all DV) remained across 57 SOs. The proportions of individuals with each DV category were similar using the raw dataset and using high quality (PQ1 and PQ2) images only (Table 8.4).

Table 8.4. Summary of Distinctiveness Value (DV) allocated to sei whale individuals using all data and using images of high-quality (PQ1 and PQ2) only.

DV	All PQ		PQ1 and PQ2 only	
	N	% of total	N	% of total
0	6	1.4	4	1.1
1	138	31.3	112	30.4
2	138	31.3	115	31.3
3	85	19.3	76	20.7
4	72	16.3	61	16.6
Unassigned*	2	0.5	0	0.0
Total	441	100.0	368	100.0

*Image of insufficient quality to determine DV.

Using only high quality (PQ1 and PQ2) images, the number of captures of individual sei whales ranged from 1 to 7, with the clear majority (72.3%) of animals captured once only (Figure 8.3). Those proportions were similar when only well-marked (DV3 and DV4) individuals were considered, with between 1 and 6 captures per individual and most (70.1%) being captured only once (Figure 8.3).

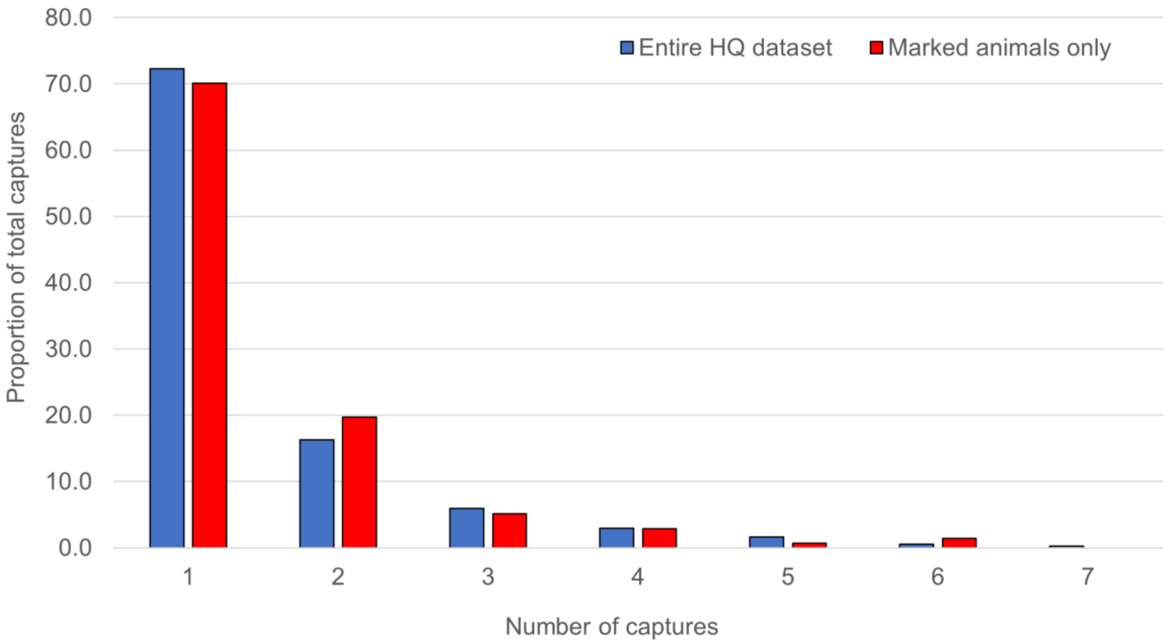

Figure 8.3. The proportion of photographic captures of individual sei whales using the entire high quality (PQ1 and PQ2) dataset and for a subset of well-marked (DV3 and DV4) animals within the high-quality dataset.

The relative proportion of marked animals that was captured on the 57 SOs ranged from 0 to 80%, with a mean of 34.1% (SD=20.0) and a median of 33.3%. In contrast, the relative proportion of unmarked animals captured on the 57 SOs ranged from 20 to 100%, with a mean of 66.0% (SD=20.0) and a median of 66.7%.

8.3.3. CMR abundance analysis

8.3.3.1. Discovery curve

The discovery curve showed a continuous increase in the number of new animals identified over time (Figure 8.4), with no indication of a reduction in the rate of increase, either within years or overall. Only three recaptures were recorded between years, one each between 2017 and 2019, 2017 and 2020, and 2019 and 2020. When the data were pooled by month, there were three recaptures within 2017, two in 2019, one in 2020, and seven in 2021.

Pooled data was input to open population models to reduce the complexity of models and improve parameter estimation (Hargrove and Borland, 1994) since, for example, unpooled data resulted in a CV for abundance in 2021 of 0.36 for unpooled data and 0.06 when data were pooled. The unpooled dataset was used for the closed population modelling in order to maximise the number of recaptures within years.

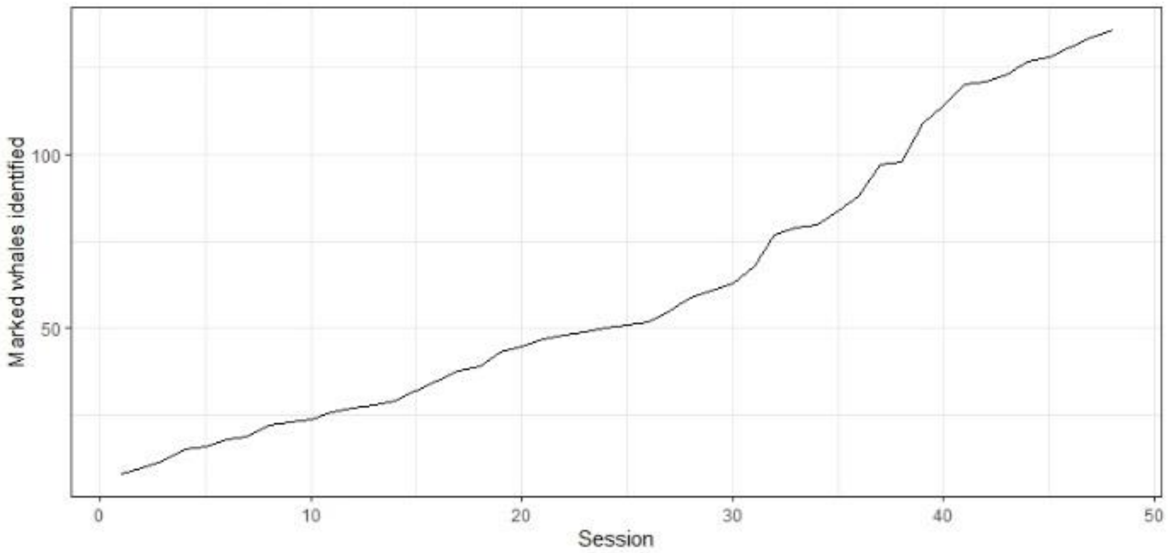

Figure 8.4. The discovery curve of individual sei whales (DV3 and DV4 only) identified over time in Berkeley Sound for the period 2017 to 2021. There were 48 Sampling Occasions in which new animals were identified and added to the curve.

8.3.3.2. Open robust design multi-state model

The abundance was estimated using the Robust model applied to monthly pooled data, with survival (S) constrained to 0.97 for the interval 2017–2019 and 0.98 for the subsequent one-year intervals (Table 8.5). It was necessary to constrain S because the low number of recaptures between years otherwise resulted in an unrealistic estimate for the estimation of S (e.g. S=0.25 for the interval 2017–2019). A lower value was selected for the first interval because it represents survival through two years. A mean value for the proportion of marked animals of 34.1% was applied to estimate the overall abundance of sei whales (Table 8.5). The resulting abundance estimates ranged from 85 animals in 2017 to 182 animals in 2021 (Table 8.5). The estimated emigration and re-immigration parameters (Table 8.6) indicate a high degree of flux in and out of the study area.

Table 8.5. Summary of abundance (N) estimates for sei whales in Berkeley Sound from the robust open model. A 'marked' animal was an individual of DV3 and DV4 while 'overall' is an estimate of all animals following the incorporation of a correction factor for the proportion of marked whales (34.1%).

	Marked animals				Overall		
Year	N	CV	Low 95% CI	High 95% CI	N	Low 95% CI	High 95% CI
2017	29	0.00	29	30	85	85	88
2019	53	0.30	35	103	156	103	303
2020	38	0.13	33	56	112	97	165
2021	62	0.06	58	76	182	171	224

Table 8.6. Survival (S), emigration (Gamma'') and re-immigration (Gamma') parameters estimated by the robust open model for sei whale abundance. Survival was constrained to the values specified.

Year	Survival	Emigration	Immigration
2017	–	–	–
2019	0.97	0.92 (0.77–0.98)	–
2020	0.98	0.84 (0.79–0.89)	0.96 (0.70–0.99)
2021	0.98	1.00	1.00

8.3.3.3. Closed population model

The best fitting closed population models using unpooled data identified time-specific variation in trapping probability, suggesting that whales moved in and out of the study area within each field season. The resulting abundance estimates ranged from 124 animals in 2020 to 306 animals in 2021 (Table 8.7).

Table 8.7. Summary of abundance (N) estimates for sei whales in Berkeley Sound using closed population models. A 'marked' animal was an individual of DV3 and DV4 while 'overall' is an estimate of all animals following the incorporation of a correction factor for the proportion of marked whales (34.1%).

	Marked animals				Overall		
Year	N	CV	Low 95% CI	High 95% CI	N	Low 95% CI	High 95% CI
2017	54	0.29	38	105	159	112	309
2019	45	0.31	31	92	132	91	271
2020	42	0.14	36	59	124	106	174
2021	104	0.16	82	149	306	241	438

8.3.3.4. Model comparison

There were significant differences (i.e. no overlap in the 95% CIs) in the abundance estimates between the two modelling approaches for 2017 and 2021. However, for 2019 and 2020 the point estimates for each of the two modelling approaches lay within the 95% confidence intervals of the other (Figure 8.5). The general trend indicated by the two approaches was similar, suggesting little change in abundance between 2017 and 2020, followed by an increase during 2021.

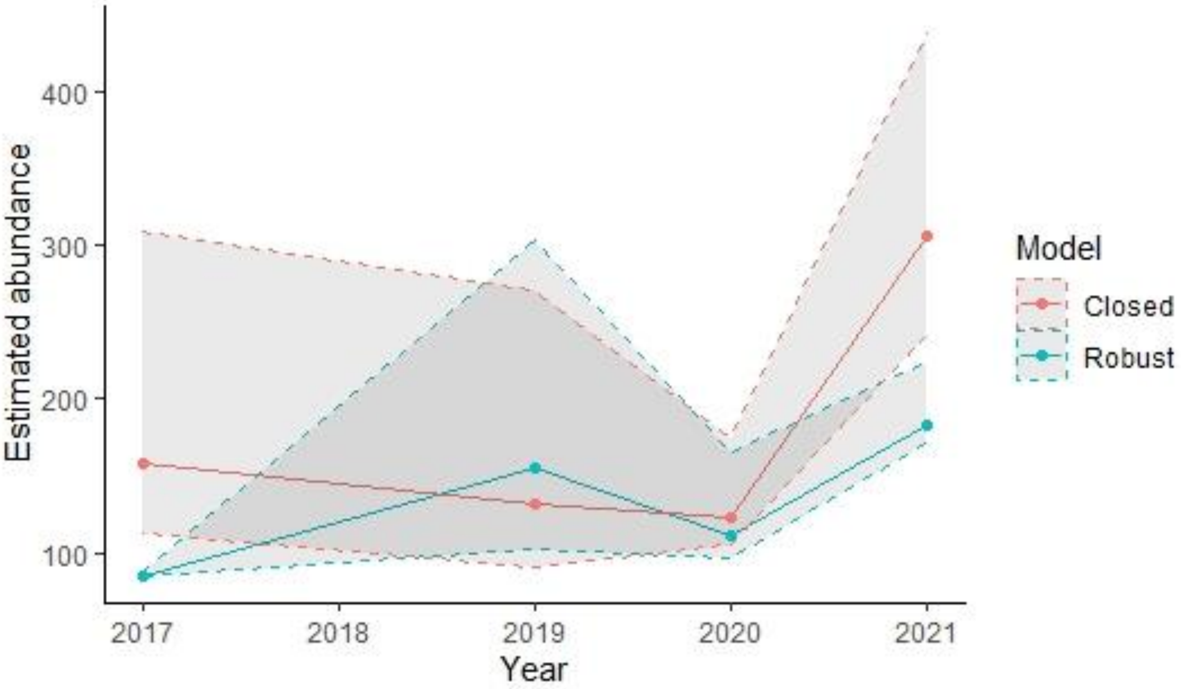

Figure 8.5. Plot of sei whale abundance estimated using robust open and closed models. The shading indicates the 95% confidence intervals.

8.4 Discussion

The CMR analysis presented here included four years of data from Berkeley Sound, and yielded abundance estimates in the region of 100–150 animals for 2017, 2019 and 2020, and higher values of around 200–300 animals for 2021, depending on the model used. The higher number of animals recorded in Berkeley Sound during 2021 was also evident in the boat survey work, with both sightings/km and individuals/km in 2021 being more than double those recorded during 2019 or 2020 (Weir, 2021). Therefore, the CMR analysis results support the findings of the visual survey work that a higher number of sei whales were using Berkeley Sound during 2021.

The abundance estimates relate to sei whales photographically captured within Berkeley Sound. The sea inlet of Berkeley Sound is a relatively small study area, measuring only approximately 25 x 6 km in the core area used by sei whales to the east of Long Island. The full length of the site could easily be covered by a sei whale in just a few hours. For example, one whale tagged in Berkeley Sound in 2019 departed the Sound and swam over 45 km northwards in just under 7 hr of sustained travel (Segre and Weir, 2022). Additionally, the high mobility of the species is reflected by photographic recaptures made between both coasts of the Falkland Islands (Weir, 2022) and between the Falklands and Brazil (Weir et al., 2020), and by the telemetry data collected during DPLUS126 (see Chapter 4) which showed individual whales moving to other parts of the Falklands' coast. Consequently, it is clear that the distribution range of the sei whale population that visits Berkeley Sound to forage during the summer and autumn extends much further than Berkeley Sound and includes the entirety of the Falkland Islands and very likely the wider south-west Atlantic region. Therefore, the use of a closed model for CMR analysis is not supported by knowledge of the ecology and distribution of the species. However, the use of an open robust model, while more appropriate ecologically, had limitations. The robust model uses recaptures between years for the estimation of parameters that characterise open populations, including survival and rates of emigration and immigration. The low recapture rates, both within and between years, limited the effectiveness of the robust model in distinguishing between survival and emigration rates, resulting in unrealistic parameter estimates unless the survival values were constrained. In conclusion, although both models generated similar findings, neither could be considered wholly appropriate for estimating the abundance of sei whales in this study due to the low number of recaptures which limited the precision of the abundance estimates. The results indicate that the CMR study would need to have higher resolution (i.e. more SO's per year), incorporate a greater timespan (i.e. more years), or cover a wider geographic area, in order to increase the number of photographic recaptures and thus improve the accuracy and precision of the abundance estimates.

The high estimates for the emigration parameters in the robust open model indicated a high degree of flux in the population, with whales moving in and out of the study area. The closed population model indicated time-specific variation in capture probability within years, again indicative of movements in and out of the study area within each season. These fluctuations and high levels of mobility are indicative of low levels of site fidelity, perhaps suggestive of opportunistic behaviour by sei whales while moving around the Islands in search of prey. However, this finding contrasts with other results. For example, using images of all quality and animals of all DV ratings, most individuals (65% in 2017, 62% in 2019 and 60% in 2020) were captured on only one date per year in Berkeley Sound; however, one-third of the individuals were recorded on two to eight different dates within a year (Weir, 2017, 2022). Furthermore, the data from satellite tags deployed between 2022 and 2024 indicated that individual whales remained continuously inside Berkeley Sound for up to (at least) six weeks (see Chapter 4), supporting relatively high site fidelity although over only a portion of the timeframes considered in the mark-recapture analysis. The reasons for these discrepancies likely include the low and variable nature of the sampling occasions due to weather, the fact that not all sei whales within Berkeley Sound on a given date were photographed (due to weather, behaviour etc), and the restriction of using the subset of highest-quality data for the CMR analysis which omitted many of the previously-documented recaptures. The latter point is difficult to reconcile, since the use of a more lenient quality data subset would potentially increase the likelihood of false positives and false negatives, and undermine the assumptions of CMR. This is especially the case for sei whales which are naturally poorly marked and require high quality images for reliable individual identification.

Another possibility for improving the CMR estimates would be to reconsider the inclusion of animals in the analysis with regards to their DV. The current study restricted animal inclusion to those of DV3 and DV4 only, representing those individuals with the most highly-marked dorsal fins. One reason for this approach was the principle that animals with marks in their dorsal fins would be recognisable from both sides, thus negating the requirement to acquire and reconcile the left- and right-side images of each individual whale. This also optimises the inclusion of data from encounters when only one side of the animal(s) was photographed. However, the proportion of animals of DV3 and DV4 within the dataset was relatively low. In contrast, almost all sei whales have recognisable scar patterns on their flanks originating from interactions with cookie-cutter sharks (*Isistius* spp.), and these have been used as a primary feature for recognising and resighting individuals in the Falklands in the absence of dorsal fin marks (Weir, 2017, 2022a,b, 2023). The use of flank scar patterns, in combination with dorsal fin markings, would greatly increase the recognition of individuals and result in a larger dataset for CMR analysis. However, it also adds a higher degree of complexity, requiring the use of images where the flank is visible in addition to the fin, higher levels of quality control (since the visibility of flank markings is very variable with light and angle), and requiring either both sides of every animal to be reconciled or separate right- and left-side CMR analyses to be carried out. This would require a significant investment of time and effort compared with using the dorsal fin markings only, noting that even the latter is not a minor undertaking. It also remains unclear how stable the scar patterns are on sei whales over time (Weir, 2023).

To conclude, the CMR analyses on four years of sei whale photo-identification data from Berkeley Sound did not yield robust results due to the low number of recaptures using the high-quality dataset. This was not unexpected, considering that sei whales are boat-avoidant, unpredictable, and poorly-marked species, and consistently obtaining images of sufficient quality for CMR is challenging. The results indicate the need for a larger dataset with a higher number of recaptures. With regard to the long-term monitoring of sei whales in the Falkland Islands, the costs and effectiveness of photo-identification going forwards would need to be considered in the context of other options for assessing population size and trend. In particular, given the remote coastline, the cost and logistical constraints of using larger vessels or aircraft to conduct population monitoring are considerable but are likely to yield robust results over quick timeframes (e.g. Weir et al., 2021). Photo-identification is more cost-effective but extremely time-consuming and the indications from this CMR analysis are that the current programme would need to be considerably upscaled in order for CMR to be effective for population monitoring. That upscaling could take the form of a wider study area (with associated logistics), more intensive sampling frequency (difficult, due to weather), or the addition of more years of data. As a first step, there has been photo-identification effort in 2022, 2023 and 2024 which could be processed and added to the CMR analysis in the coming years, to determine whether the longer timeframe improves these results.

8.5 Acknowledgements

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Annex 1: Vessel drafts in the Falkland Islands

The table comprises a list of the categories of commercial vessels that have recently used the marine waters around the Falkland Islands, together with some specific examples in each category to provide an indication of their sizes and drafts. The table is ordered by vessel category and then by draft within each category. The list is indicative rather than exhaustive. FV = Fishing Vessel.

Vessel category	Vessel name	Draft (m)	Length overall (m)	Gross tonnage
Cargo vessel	Scout	3.0	92.9	2,615
Cruise (passenger) ship	Fram	5.0	113.7	11,647
Cruise (passenger) ship	Plancius	5.0	90.0	3,434
Cruise (passenger) ship	Roald Amundsen	5.3	140.0	21,765
Cruise (passenger) ship	Oosterdam	7.8	285.2	82,820
Cruise (passenger) ship	Star Princess	8.1	245.6	63,786
Cruise (passenger) ship	Zaandam	8.1	237.0	61,396
Cruise (passenger) ship	Norwegian Star	8.2	294.1	91,740
Fishery patrol vessel	Lilibet	3.5	50.0	485
Fishery patrol vessel	Pharos SG	4.2	78.3	1,986
FV (jigger)	Agnes 109	4.0	49.7	604
FV (jigger)	Agnes 110	4.3	66.4	1,336
FV (jigger)	Sky Max 101	4.8	65.2	1,402
FV (jigger)	Zi Da Wang	6.0	74.0	1,278
FV (jigger)	Fu Kuo 1	6.0	65.0	1,164
FV (jigger)	Her Hung 16	6.4	66.6	988
FV (krill trawler)	Antarctic Endurance	7.9	130.0	2,018
FV (longliner)	CFL Hunter	4.2	59.5	1,580
FV (longliner)	Argos Georgia	5.5	53.9	2,004
FV (trawler)	Kestrel	4.2	53.0	775
FV (trawler)	Hermanos Touza	5.1	74.0	1,390
FV (trawler)	Robin M Lee	5.6	70.0	2,036
FV (trawler)	Argos Vigo	5.9	78.0	2,074
FV (trawler)	Golden Chicha	6.0	57.8	1,400
FV (trawler)	Venturer (FK0511)	6.0	84.2	1,931
FV (trawler)	Montelourido	6.5	68.0	1,499
FV (trawler)	Sil	6.5	78.5	2,156
Launch	John Davis	1.0	13.0	13
Launch	John Byron	1.0	11.0	9
Launch	Fitzroy	1.4	16.0	27
Motor vessel - research	Hans Hansen	2.8	23.3	146
Motor vessel - research	Sir David Attenborough	7.4	129.0	15,609
Motor vessel - research	Polar Stern	10.7	117.9	12,614
Passenger landing craft	Concordia Bay	2.2	49.9	483
Reefer	Frio Mugami	5.4	135.0	7,367
Reefer	Zefyros Reefer	5.5	141.0	8,483
Reefer	Sein Honor	5.6	134.0	7,313
Reefer	Frio Aegean	5.8	130.0	6,973
Reefer	Frio Marathon	6.0	146.3	7,089
Reefer	Frio Star	6.0	150.0	9,307
Reefer	Orange Sea	6.0	115.1	6,088
Reefer	Cassiopea	6.5	134.0	7,326
Reefer	Sierra Lara	7.0	117.5	5,110
Reefer	Frio Poseidon	7.1	148.0	9,072
Reefer	Invincible	7.3	152.0	10,532

Vessel category	Vessel name	Draft (m)	Length overall (m)	Gross tonnage
Reefer	Frio Chikuma	7.5	135.0	7,367
Reefer	Cool Girl	8.7	143.0	8,507
Tanker	Jason	7.0	105.5	3,978
Tanker	Seafrost	8.0	151.3	11,013
Tanker	China Spirit	8.8	144.0	11,290