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Mapping critical Australian sea lion habitat to assess ecological value and risks to population recovery

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NESP Marine and Coastal Hub partners

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Executive summary

This pilot study aimed to assess the reliability and feasibility of state-of-the-art animal-borne cameras, combined with high-resolution GPS and tri-axial accelerometer/magnetometer devices, to map and identify benthic habitats used by the endangered Australian sea lion (*Neophoca cinerea*). Cameras and tracking instruments were deployed on eight adult female sea lions during a single foraging trip (2-6 days), four at Seal Bay (Kangaroo Island) and four at Olive Island (off Streaky Bay, western Eyre Peninsula, South Australia). Each deployment recorded approximately 8 hours of footage (range 6.7 to 12.8 hours), capturing nearly 80 hours in total and covering 560 km of seabed at depths between 5 and 110 metres.

The footage provided new information on sea lion habitat use, foraging behaviours, and prey species. The sea lions utilised six benthic habitat types: macroalgae reef, macroalgae meadow, bare sand, sponge/sand, invertebrate reef, and invertebrate boulder habitats. Sea lions from Olive Island primarily used macroalgae reef (37%), bare sand (36%), and sponge/sand (21%), while those from Seal Bay favoured invertebrate reef (38%), bare sand (16%), sponge/sand (15%), and invertebrate boulder habitats (13%). Using machine learning-based Random Forest models, habitat maps were developed over a broad area of the shelf adjacent to each colony, spanning more than 5,000 km².

Each deployment yielded valuable and unique information, refining our understanding of sea lion habitat use and behaviour. The animal-borne instruments facilitated the discovery and mapping of hundreds of kilometres of previously unmapped seabed, including previously unknown rocky reefs and kelp forests. This innovative and cost-effective approach allows for the exploration of large areas of unmapped shelf waters, locating crucial sea lion habitats both inside and outside marine reserves, while complementing traditional benthic survey methods.

Although some sea lions foraged within marine reserves, most of the habitat used in this study was outside protected areas. Moving forward, sea lion video data will be invaluable for managing populations, marine park planning, and broader benthic habitat surveys. The cameras provide robust observational data to inform the locations of Biologically Important Areas (BIAs), assisting in the delineation of protection zones critical to sea lion survival. Feeding rate data will help distinguish between transitory and foraging habitats and enable the ecological value of different habitats to be estimated. This will enhance the quantitative assessment of the effectiveness of marine park zoning in safeguarding key foraging habitats.

Sea lion video data can be used to validate existing benthic habitat models and provide valuable georeferenced observations that would otherwise be expensive to obtain. Repeat surveys will allow for the evaluation of ecological and habitat changes over time. Improved information on diet and consumption rates will aid in developing ecosystem models to assess the impacts from ecological change and prey depletion due to fisheries and climate change, and the potential impacts of emerging industries, such as offshore renewables.

As part of the project's engagement and participation initiatives, six Far West Coast Aboriginal rangers contributed to the fieldwork on Olive Island. Presentations about the project were also delivered to students at Yalata Anangu School and Ceduna Area School. The project team also took part in the NAIDOC Family Day community event held at Koonibba Oval in Ceduna.

1. Introduction

Over the last 40 years, populations of the endangered Australian sea lion, *Neophoca cinerea*, have declined by over 60% (Goldsworthy et al. 2021). While management actions introduced over the last 15 years have reduced impacts from fishery bycatch in lobster and demersal gillnet fisheries off South Australia (Goldsworthy et al. 2022), continued declines in some populations suggest other threats remain. These could include marine pollution, disease, climate change, interactions with aquaculture, habitat degradation, prey depletion and human disturbances (Page et al. 2004, Goldsworthy et al. 2009, DSEWPC 2013, Marcus et al. 2014). Across the Australian sea lion's range, there are marked differences in the abundance and trends of populations, even between adjacent colonies (Goldsworthy et al. 2021), suggesting that the impacts of certain threats vary at small spatial scales. Understanding fine-scale differences in habitat-use between Australian sea lion populations is therefore key to assessing the impacts of different threats to the species. Our knowledge of the benthic habitats that are critical to Australian sea lion populations is currently limited.

Australian sea lions are Australia's only endemic pinniped, and the only marine mammal species identified as a priority species in the current, Australian Government Threatened Species Action Plan. Australian sea lions breed at ~80 sites in South Australia (SA: ~48 sites) and Western Australia (WA: ~32 sites), with SA sites accounting for 82% of the total population (Goldsworthy et al. 2021). Previous studies have revealed that Australian sea lions are benthic predators with a broad diet (>200 species) (Peters et al. 2015, Berry et al. 2017, Goldsworthy et al. 2019). They maximise bottom time (Costa and Gales, Fowler et al. 2006) and, therefore, mostly restrict their foraging effort to the continental shelf (Goldsworthy et al. 2007, 2022). Combined movement and stable isotope analyses have highlighted that Australian sea lions have strong individual and colony-specific foraging specialisations ('inshore' and 'offshore' foraging ecotypes), with long-term fidelity to natal foraging locations (Lowther et al. 2011, Lowther and Goldsworthy 2011). Australian sea lions also have a unique 18-month breeding cycle, that is both asynchronous (different colonies breeding at different times) and aseasonal (no relationship with seasonal climatic patterns; Higgins 1993, Shaughnessy et al. 2011, Goldsworthy et al. 2021). They have a strong philopatry (natal site-fidelity) to foraging locations, particularly adult females, which limits the dispersal of animals and genetic flow between colonies (Campbell et al. 2008, Lowther et al. 2012, Ahonen et al. 2016). This means that populations of Australian sea lions have a highly sub-divided genetic structure across their range (Campbell et al. 2008, Lowther et al. 2012, Ahonen et al. 2016). Identifying and protecting benthic habitats that are critical to different Australian sea lion populations is therefore essential to ensuring their long-term viability. Identifying critical habitats can also highlight potential threats to populations, which may be mitigated through management actions. Additionally, identifying and mapping critical benthic habitats for Australia sea lions allows assessment of the extent to which key habitats are protected by state and commonwealth marine reserves.

Previously, insights into habitat preference and use by Australian sea lions has come from National Geographic crittercam deployments at several sites between 2008 and 2012 (Fragnito 2013). The data were valuable but were limited by the instruments' large size, which likely inhibited the sea lion's natural foraging behaviour, small file capacity, limited battery power, and high failure rate. However, technical advances since 2012 have led to improved instrumentation (smaller solid-state units, more battery capacity and longer recording times).

This proof-of-concept pilot study sought to evaluate the potential of recently developed animal-borne cameras to identify and map critical benthic habitats of Australian sea lions.

The aims of this project were to use animal-borne video and movement data from Australian sea lions to:

1) Identify key sea lion habitats, assess their ecological value and further understand their unique relationship with, and dependency on, benthic ecosystems.

2) Provide new information on the movement and habitat-use of sea lions to inform species risk assessments, including threats from fisheries interactions.

3) Evaluate the extent to which existing management measures (marine reserves) provide protection of key sea lion habitat.

4) Provide novel datasets that would aid and complement other MaC Hub projects mapping continental shelf seabed habitats across southern Australia.

The project was developed in consultation with the Far-West-Coast Aboriginal Corporation (FWCAC). The FWCAC is the Native Title prescribed body corporate for six distinct Aboriginal cultural groups, including the Mirning, Wirangu, Kokatha, Yalata and Maralinga Tjaratja (Oak Valley) Peoples, and the descendants of Edward Roberts. Australian sea lions are spiritually important to Mirning and Wirangu Peoples, and a key outcome of the project was to provide an opportunity to facilitate connections to Sea Country, involve Aboriginal Rangers from FWCAC in field work, and to share stories and knowledge through community events and school visits.

2. Methods

2.1 Study sites and deployment of bio-logging instruments

Data were collected between December 2022 and August 2023 from eight adult female Australian sea lions, four from Olive Island Conservation Park (32.721°S, 133.968°E) on the western Eyre Peninsula and four from Seal Bay Conservation Park (35.994°S, 137.317°E) on Kangaroo Island, in South Australia (Figure 1).

Sea lions were sedated with Zoletil® (~1.3 mg/kg, Virbac, Sydney, Australia), administered intramuscularly via a syringe dart (3.0ml syringe body with a 14-gauge 25mm barbed needle, Paxarms New Zealand Ltd), delivered remotely by a dart gun (MK24c Projector, Paxarms New Zealand Ltd). After a light level of sedation was attained (~10min), sea lions were approached and anaesthetised using Isofluorane® (5% induction, 2-3% maintenance with medical-grade oxygen), delivered via a purpose-built, gas anaesthetic machine, using a Cyprane Tec III vapouriser (The Stinger™ Backpack anaesthetic machine, Advance Anaesthetic Specialists, NSW). Instrument attachment and sea lion measurement took ~20min, then the Isofluorane was switched off and the animal was ventilated with pure oxygen until its movements indicated imminent recovery.

All bio-logging instruments were pre-adhered to neoprene patches, that were then glued to the pelage (fur) on the dorsal midline of sea lions, using a two-part quick-setting epoxy (Selleys Araldite® 5 Minute Epoxy Adhesive). Each sea lion was instrumented with an archival underwater camera (CATS Cam, 135 x 96 x 40mm, 400g), positioned at the base of the scapula, and an Argos-linked GPS logger with an integrated time-depth recorder (SPLASH-10, Wildlife Computers, 100 x 65 x 32mm, 200g), positioned posterior to the camera (Figure 2). In addition, a tri-axial accelerometer/ magnetometer (Axy-5 XS, TechnoSmArt, 28 x 12 x 9mm, 4g) was positioned at the crown of the head (Figure 2). Instrumented sea lions were recaptured via the same procedure after a single foraging trip (~2-6 days). Instruments were removed by cutting them from their neoprene patches to avoid damage to the pelage (the neoprene patch left on the sea lion would be shed during the next moult period).

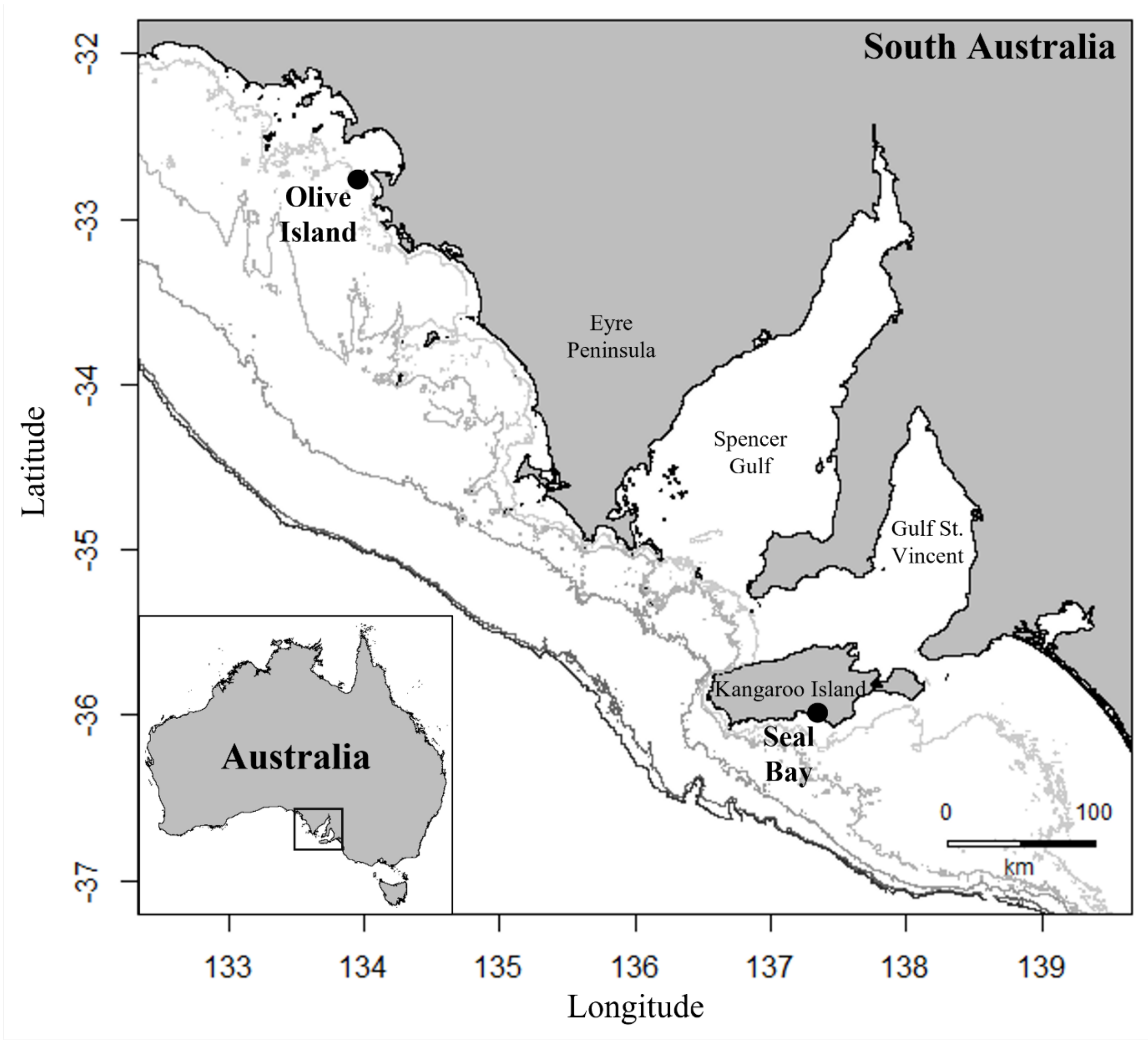

Figure 1 Location of colonies for deployment of animal-borne cameras, Argos-linked GPS loggers/time-depth recorders and accelerometers/magnetometers on 8 adult female Australian sea lions from Olive Island, western Eyre Peninsula (32.721°S, 133.968°E) and Seal Bay, Kangaroo Island (35.994°S, 137.317°E) in South Australia. Isobaths represent depth contours at 50, 75, 100, 150 and 200m (light to dark grey).

Figure 2 Deployment of bio-logging instruments on adult female Australian sea lions from Olive Island and Seal Bay in South Australia, showing attachment of animal-borne cameras (base of the scapula), Argos-linked GPS loggers/time-depth recorders (posterior to cameras) and tri-axial accelerometers/magnetometers (crown of head).

2.2 Data collection and processing

High-definition colour video (forward-facing) (Figure 2) was collected while sea lions were at sea, at depths greater than 5 metres, during daylight hours. Batteries in the cameras allowed up to 13 hours of filming, which enabled coverage for up to three days at sea.

Argos-linked GPS loggers collected Fastloc® locations when sea lions surfaced by capturing signals from orbiting satellite constellations. Locations obtained from four or fewer satellites were not included in analyses and erroneous locations (identified by unrealistic swimming speeds, >6ms^{-1}) were removed in the *R* programming environment, using a speed filter (McConnell et al. 1992, Sumner 2011). Time-depth recorders (TDRs) measured depth every second.

Tri-axial accelerometer/ magnetometer data were used to dead-reckon at-sea movement, in combination with the GPS data, using the methods outlined in Angelakis et al. (2023). Accelerometers measured head movement (G-force), for-surge (anterior-posterior), sway (lateral) and heave (dorsal-ventral) axes at 25 Hz and 8-bit resolution (maximum and minimum acceleration value ±4 G). Magnetometers measured the earth's magnetic field intensity in microteslas (μT) for roll (longitudinal), pitch (transverse) and yaw (vertical) axes at 2Hz.

2.3 Identifying and mapping benthic habitats and foraging behaviour

Analysis of sea lion-borne video was conducted using the open-source Behavioral Observation Research Interactive Software (BORIS, v. 7.12.2). Benthic habitats were classified in line with the Collaborative and Annotation Tools for Analysis of Marine Imagery and Video (CATAMI) classification scheme (Figure 3), which provides a national (Australian) framework for classifying marine biota and substrata (Althaus et al. 2013). The duration of time sea lions spent in different benthic habitats was recorded.

Benthic habitat data for each sea lion was then geo-referenced by time-matching and amalgamation with their dead-reckoned foraging paths. Georeferenced benthic habitat data was then combined with oceanographic/environmental data (sea surface temperature, chlorophyll-a, bathymetry, distance from the coastline and distance from the continental slope) to build random forest models. Random Forest models (*randomForest* package in *R*) (Breiman 2001, Liaw and Wiener 2002), were used to predict benthic habitats for 'absence' locations, where no sea lion-borne video data were available. These models enabled the broad-scale mapping of the benthic habitats used by Australian sea lions on the continental shelf off southern Australia.

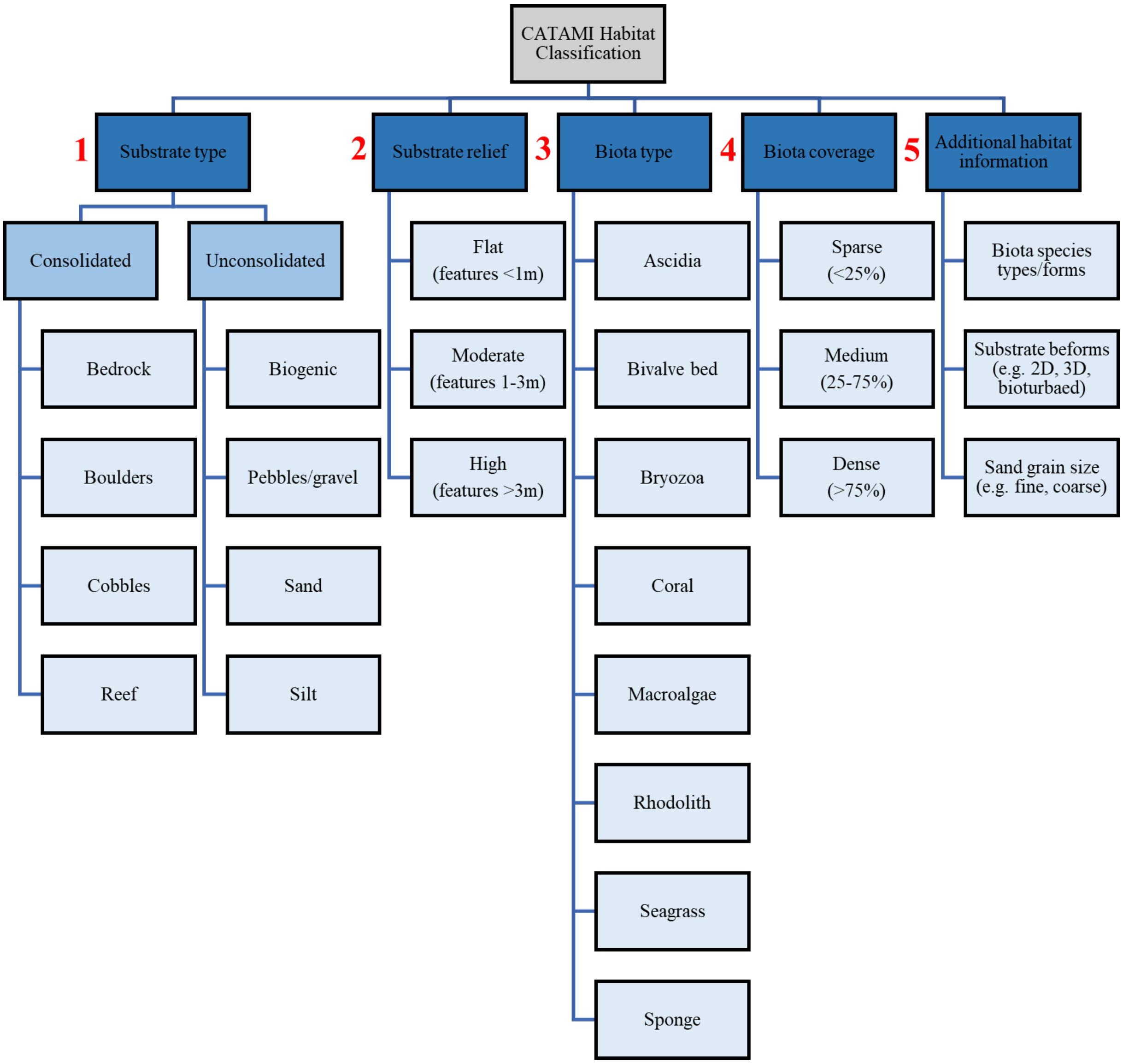

Figure 3 Habitat key used to classify benthic habitat types as identified from animal-borne video attached to 8 adult female Australian sea lions from Olive Island and Seal Bay in South Australia. Numbers in red highlight the stages of habitat classification. Habitat classification was conducted in line with the CATAMI (Collaborative and Automated Tools for Analysis of Marine Imagery) scheme.

3. Results

3.1 Foraging paths and cover of benthic habitats

The cameras attached to eight adult female Australian sea lions (Olive Island: OI1, OI2, OI3, OI4; and Seal Bay: SB1, SB2, SB3, SB4) provided a total of 79 hours and 10 minutes of animal-borne video and included 1,935 individual dives (Table 1). Morphometrics and other details for each adult female are provided in Table 2. Video was recorded across a total of ~560km of the benthos (Olive Island ~223km, Seal Bay ~337km) (Figure 4), filming benthic habitats between 5 and110m depth.

Six broad benthic habitat types were identified from the videos: macroalgae reef, macroalgae meadow, bare sand, sponge/sand, invertebrate reef, and invertebrate boulder habitats. Percent cover of these benthic habitats differed on the foraging paths of sea lions from Olive Island and Seal Bay (Figure 4). The dominant habitat cover for sea lions from Olive Island was macroalgae reef (36.6%, 81.6km), bare sand (35.8%, 79.9km) and sponge/sand habitats (21.2%, 47.3km). The dominant habitat cover for sea lions from Seal Bay was invertebrate reef (38.2%, 128.6km), bare sand (15.6%, 52.5km), sponge/sand (15.3%, 51.6km) and invertebrate boulder habitats (13.2%, 44.3km; Figure 4). Reef habitats included many kelp-dominated (*Ecklonia radiata*) reefs, as well as macroalgae habitats consisting of varying assemblages of different brown, red and green algae taxa (e.g. *Sargassum*, *Cystophora*, *Plocamium* and *Ulva sp*.). In deeper waters, bare sand, sponge/sand and invertebrate reef/boulder habitats dominated (Figure 5). Sponge/sand habitats were dominated by Demospongiae sponges, (e.g., *Callyspongia* and *Echinodictyum sp*.). Invertebrate reef and boulder habitats were also dominated by Demospongiae sponges, as well as bryozoans (Phidoloporidae *sp*.), ascidians (Phlebobranchia and *Pyura sp*.) and soft corals (Alcyonacea and *Dendronephythya sp*.).

The location of reef habitats identified from the video data from the deployments at Olive Island and Seal Bay, highlighted significant high-relief reef systems, especially south of Kangaroo Island (Figure 5). Reef habitats visited by Olive Island females comprised 10.2% (9.2km) flat relief (features <1m), 60.0% (54.0km) moderate relief (features 1-3m) and 29.8% (26.8km) high relief (features >3m). For Seal Bay females, reef habitats were 36.4% (62.7km) flat, 30.8% (53.1km) moderate and 32.8% (56.4km) high relief.

Table 1 Summary of animal-borne video data available for eight adult female Australian sea lions from Olive Island (*n*=4) and Seal Bay (*n*=4) in South Australia.

Animal ID	**Video amount (hh:mm)**
OI1	12:32
OI2	11:42
OI3	12:49
OI4	06:40
SB1	12:01
SB2	11:28
SB3	12:26
SB4	09:32

Table 2 Age, morphometric and reproductive history data (at deployment) for eight adult female Australian sea lions from Olive Island (32.721°S, 133.968°E), and Seal Bay (35.994°S, 137.317°E), in South Australia.

Animal ID	Colony	Length (cm)	Girth (cm)	Weight (kg)	Body condition	Moult stage	Pup age
OI1	Olive Island	166	119	108	Excellent	Moulted	~12-15 months
OI2	Olive Island	165	118	98	Very good	Half moulted	6-12 months
OI3	Olive Island	163	126	94	Good	Pre-moult	Unknown
OI4	Olive Island	160	110	83	Good	Pre-moult	Unknown
SB1	Seal Bay	161	106	80	Good	Moulted	11 months
SB2	Seal Bay	157	108	79	Good	Moulted	10 months
SB3	Seal Bay	164	113	91	Good	Moulted	12 months
SB4	Seal Bay	167	114	95	Good	Moulted	12 months

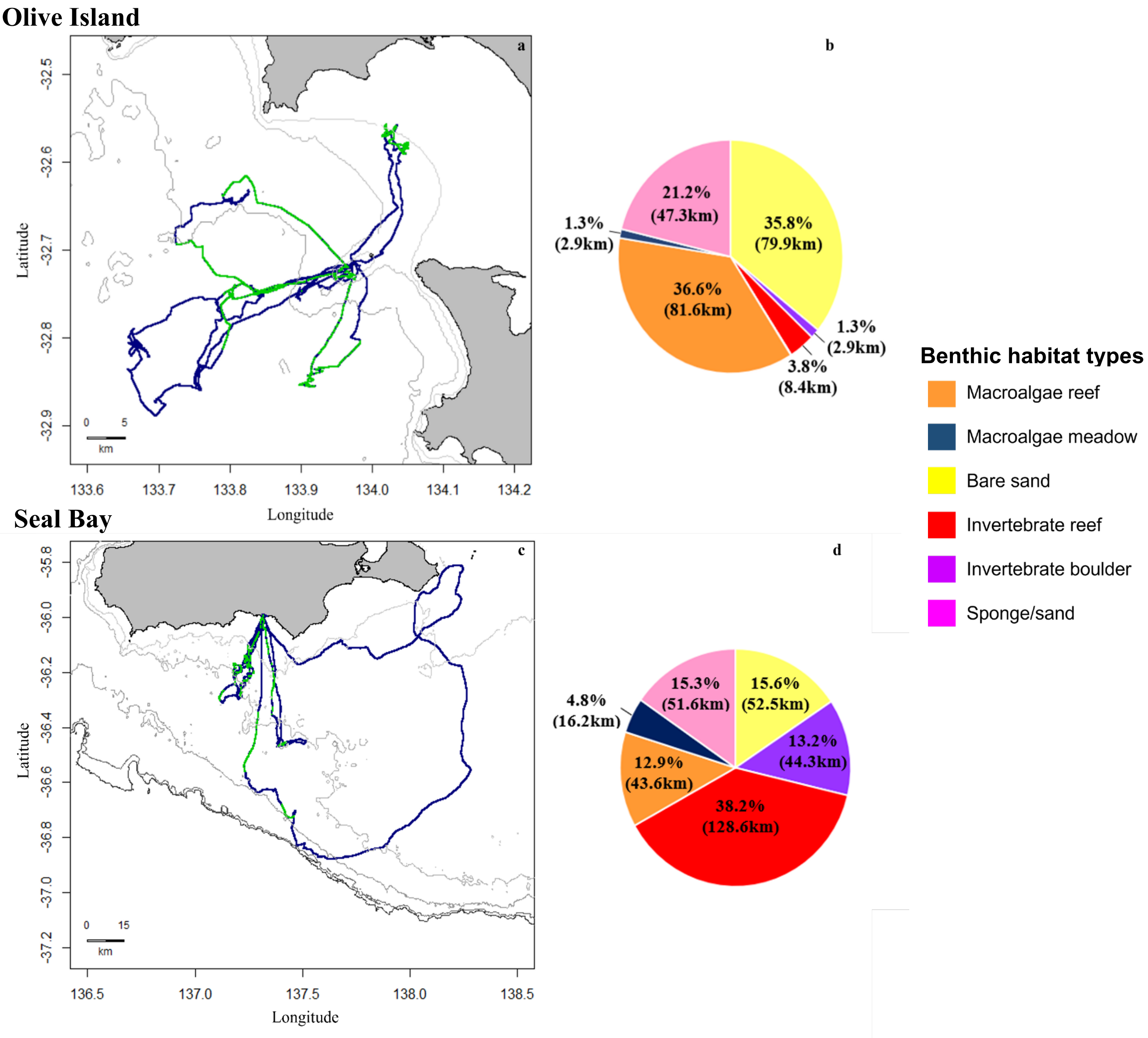

Figure 4 Movement and benthic habitat data for eight adult female Australian sea lions, four from Olive Island, western Eyre Peninsula, and four from Seal Bay, Kangaroo Island, in South Australia. Dead reckoned foraging paths show at-sea movement (blue) and regions where animal-borne video data was available (green) (a and c). Isobaths represent depth contours at 10, 25 and 50m for Olive Island and 50, 75, 100, 150 and 200m for Seal Bay. Pie charts represent the percent cover (km) of different benthic habitat types on foraging paths for sea lions from the respective colonies (b and d).

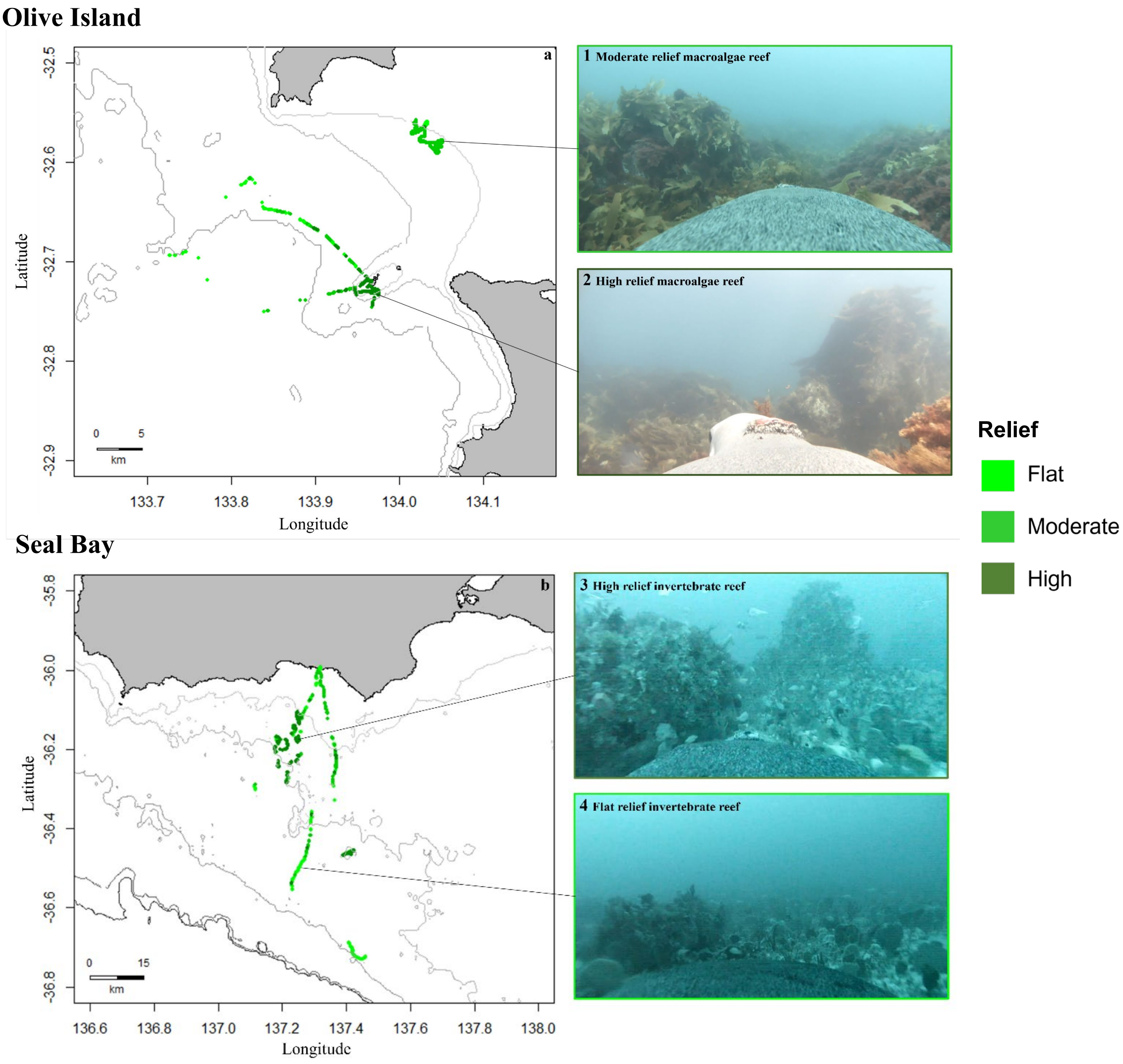

Figure 5 Distribution of reef habitats for a) Olive Island, western Eyre Peninsula, and b) Seal Bay, Kangaroo Island in South Australia. Maps show the distribution of flat (features <1m; light green), medium (features 1-3m; green) and high relief reefs (features >3m; dark green), as identified from animal-borne video data from eight adult female Australian sea lions. Isobaths represent depth contours at 10, 25 and 50m for Olive Island (a) and 50, 75, 100, 150 and 200m for Seal Bay (b) (light to dark grey). Annotated images show examples of a 1) moderate relief macroalgae reef, 2) high relief macroalgae reef, 3) high relief invertebrate reef and 4) flat relief invertebrate reef.

3.2 Modelling benthic habitats on the continental shelf

Random Forest training models predicted benthic habitats on test datasets with a 99.5% accuracy rate for habitats around Olive Island (out-of-bag error rate= 0.5%), and a 98.6% accuracy rate for habitats around Seal Bay (out-of-bag error rate= 1.4%).

Predicted benthic habitats from Random Forest modelling varied between the two sites (Figure 6). Macroalgae reefs to the northeast of Olive Island constituted most of the predicted habitat at depths shallower than ~25-30m (Figure 6). Bare sand and sponge/sand habitats were predicted to be the dominant habitat types at depths greater than ~25-30m, with small areas of invertebrate reefs predicted mostly to the northwest of Olive Island (Figure 5a). Macroalgae reefs and macroalgae meadows were predicted to be the dominant benthic habitat types off Seal Bay at depths shallower than ~50-60m (Figure 6). At depths greater than ~50-60m, sponge/sand and invertebrate reef habitats were the dominant habitat types predicted, along with smaller areas of bare sand and invertebrate boulder habitats (Figure 6).

Sea lion-borne video enabled mapping of benthic habitats within and outside of State and Commonwealth marine reserves on the continental shelf off southern Australia (Figure 6 and 7). Data obtained from the four female sea lions at each site, enabled the mapping of 1,023 km^2 adjacent to Olive Island and 4,004 km^2 south of Seal Bay, over 5,000km^2 of seabed in total (Figure 6 and 7).

Olive Island

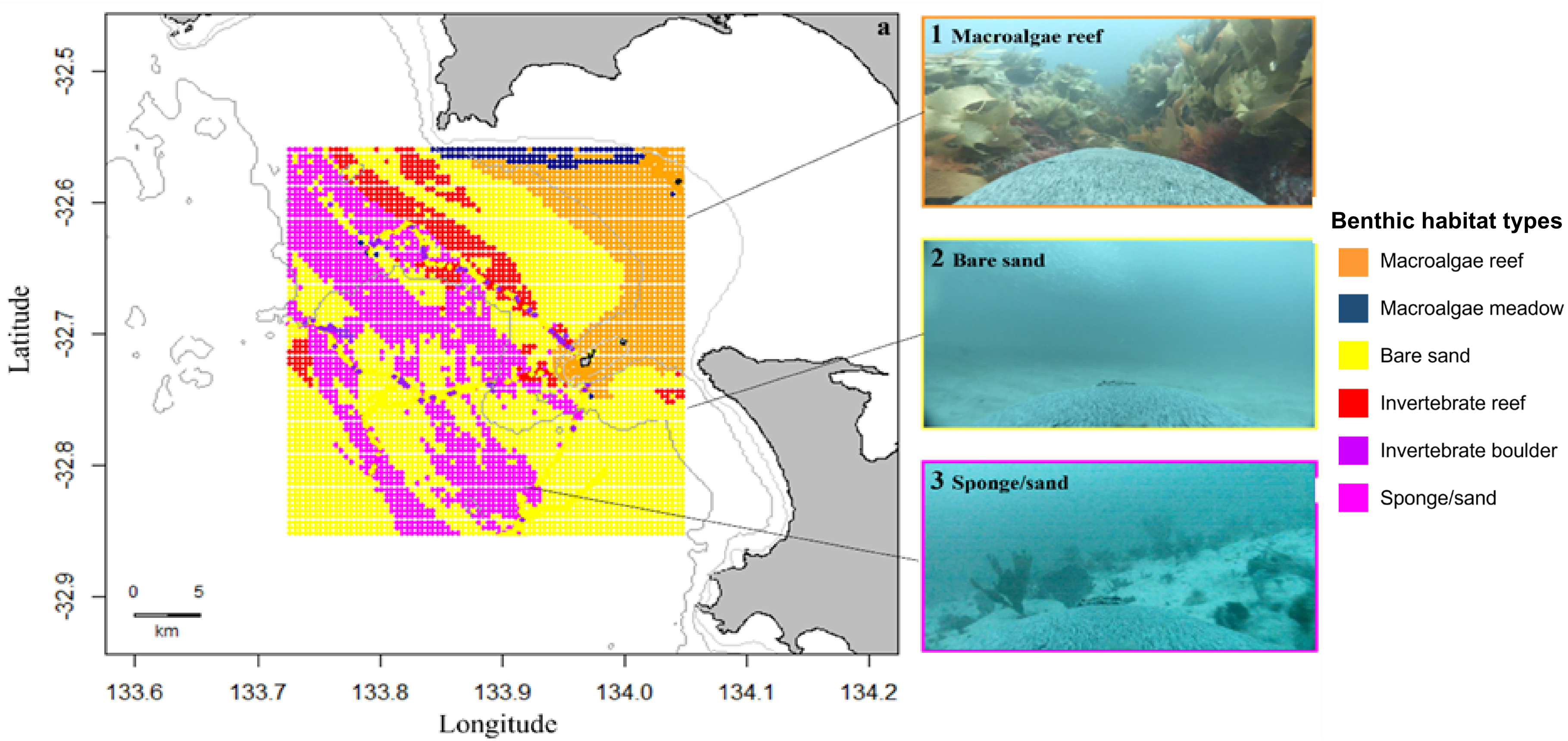

Figure 6 Modelled distributions of benthic habitats for Olive Island, western Eyre Peninsula (a, above), and Seal Bay, Kangaroo Island (b, below) in South Australia. Maps show predicted distributions of benthic habitats by random forest modelling of animal-borne video data from eight adult female Australian sea lions. Maps show distributions of macroalgae reef (orange), macroalgae meadow (navy), bare sand (yellow), invertebrate reef (red), invertebrate boulder (purple) and sponge/sand (pink) habitats. Isobaths represent depth contours at 10, 25 and 50m for Olive Island and 50, 75, 100, 150 and 200m for Seal Bay. Annotated images show examples of 1) macroalgae reef, 2) bare sand, 3 and 6) sponge/sand, 4) invertebrate boulder and 5) invertebrate reef habitats.

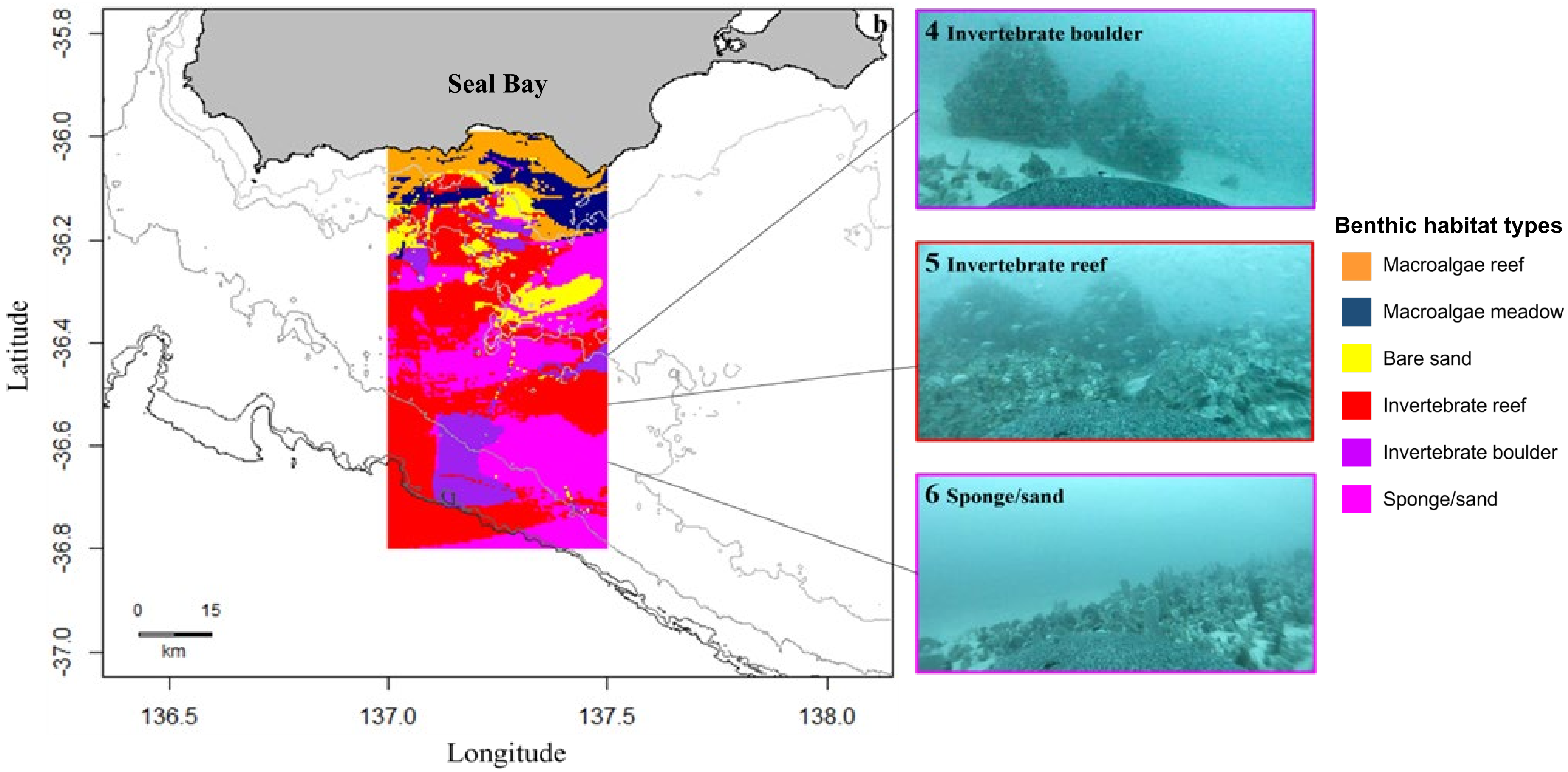

Figure 6. Continued.

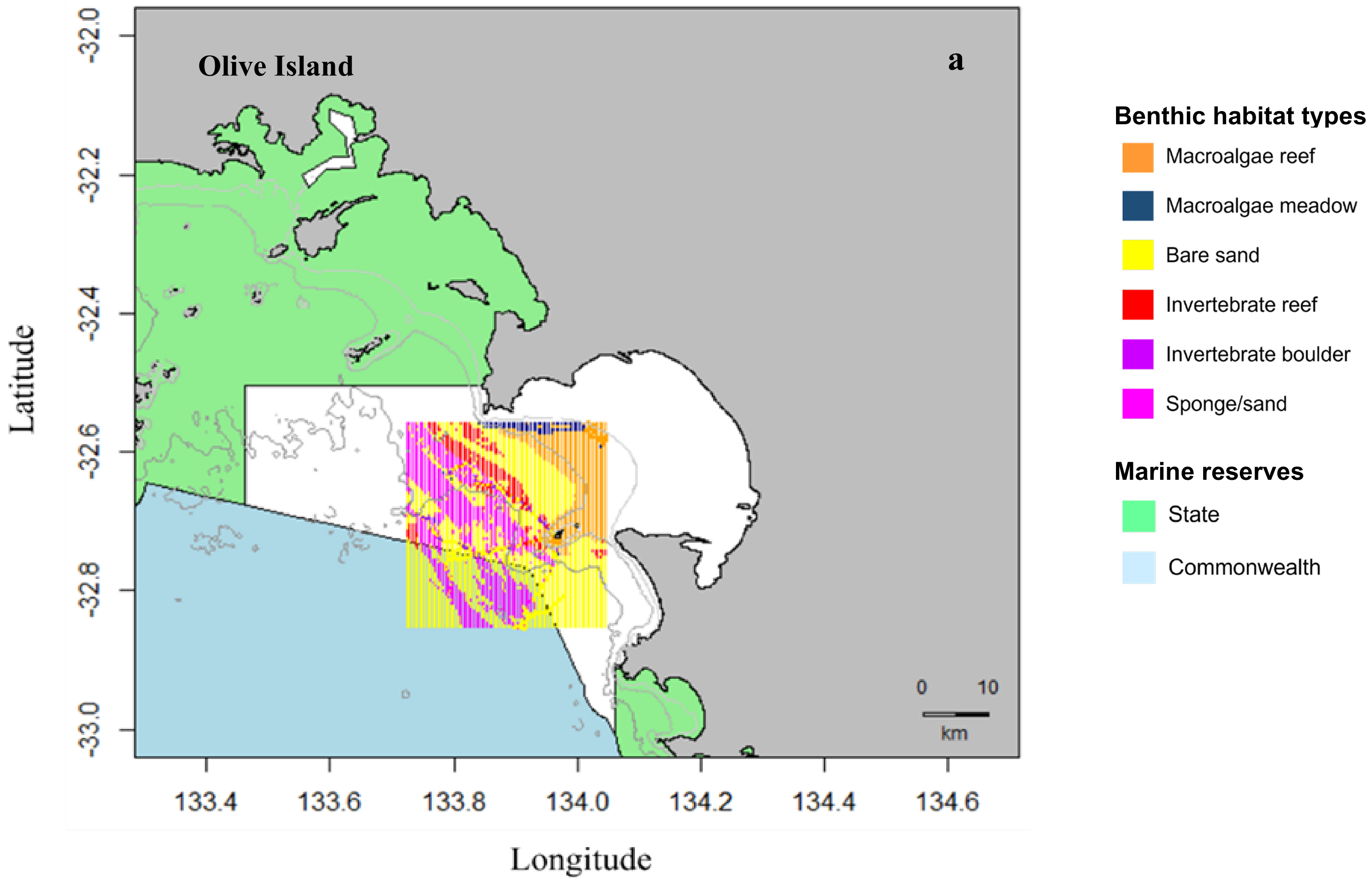

Figure 7 Modelled distributions of benthic habitats in relation to State (South Australian; green) and Commonwealth (Australian; light blue) marine reserves for Olive Island, western Eyre Peninsula (a, above), and Seal Bay, Kangaroo Island (b, below) in South Australia. Maps highlight predicted distributions (via random forest modelling), for macroalgae reef (orange), macroalgae meadow (navy), bare sand (yellow), invertebrate reef (red), invertebrate boulder (purple) and sponge/sand (pink) habitats. Isobaths represent depth contours at 10, 25 and 50m for Olive Island and 50, 75, 100, 150 and 200m for Seal Bay.

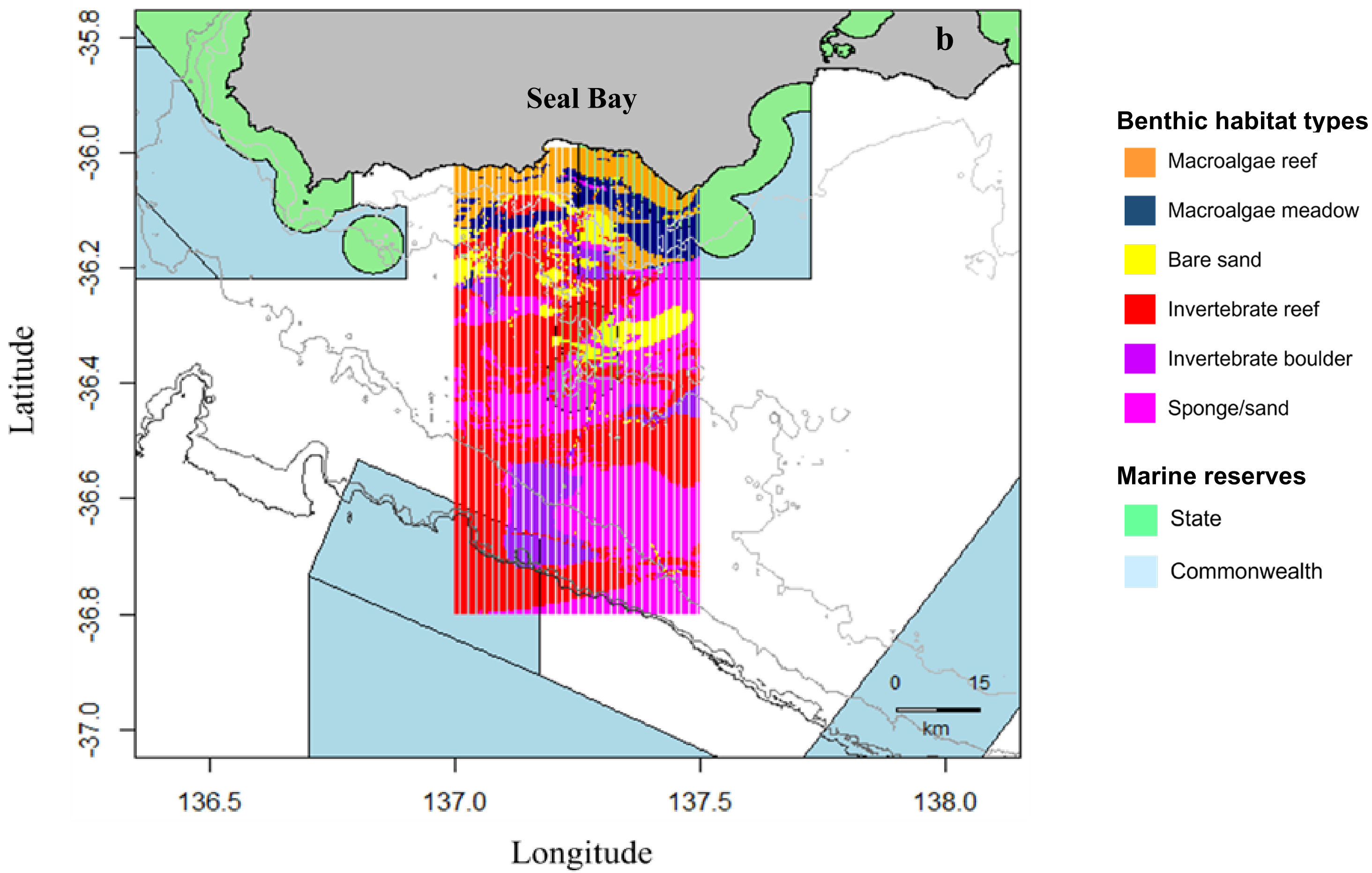

Figure 7. Continued.

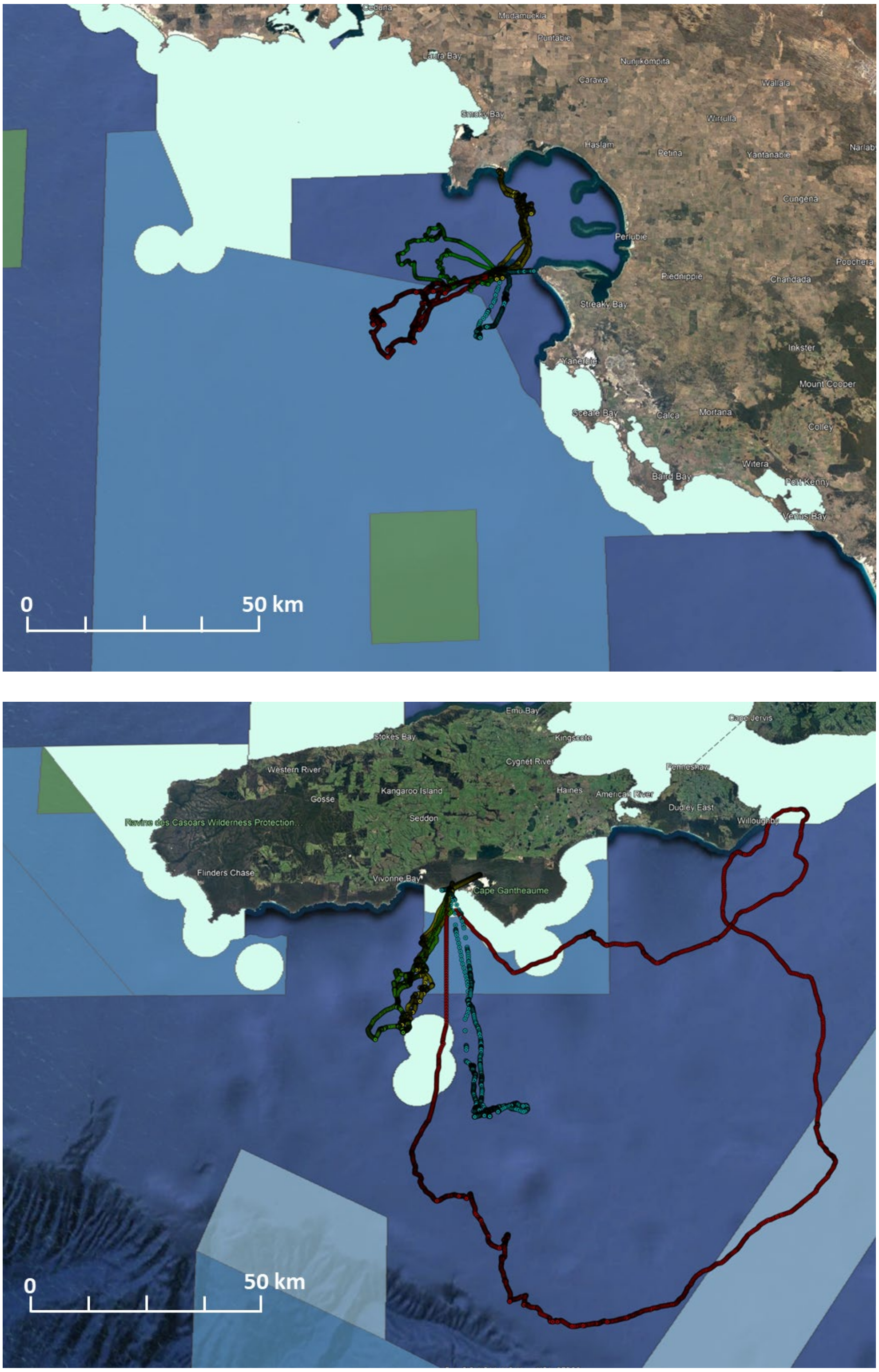

Figure 8 GPS tracks from eight adult female Australian sea lions from Olive Island (above) and Seal Bay (below) (four at each site) in relation to the location of State (pale blue, mostly adjacent to the coast) and Commonwealth (darker blue and green) marine reserves. For Commonwealth marine reserves, green areas represent National Park Zones (IUNC II), light blue Multiple Use Zones (IUCN VI) and dark blue Special Purpose Zones (IUCN VI).

3.3 Use of marine reserves

Based on the small number of deployments in this pilot study, most of the habitat used by Australian sea lions from Olive Island and Seal Bay, were outside of marine reserves (Figure 8). Three of the four Olive Island sea lions spent some time within the Western Eyre Marine Park (Special Purpose Zone – IUCN VI). This marine reserve was extensively use by one female (Figure 8). All the Seal Bay sea lions transited through or spent some time foraging within the Southern Kangaroo Island Marine Park (Special Purpose Zone – IUCN VI), with one female also spending some time in the Murray Marine Park (Multiple Use Zone – IUCN VI) (Figure 8). Most of the Seal Bay females spent most of their time in mid-shelf waters between the Southern Kangaroo Island and Murray Marine Parks (Figure 8).

3.4 Indigenous engagement and participation

This project was developed in consultation with the Far West Coast Aboriginal Corporation (FWCAC), to examine ways in which the activities and outcomes could provide opportunities to engage with traditional owners and provide opportunities for Aboriginal Rangers to be involved in field work.

Key engagement activities included:

- presentation to traditional owners at the Saltwater Country Workshop – Ceduna (7 June 2022);
- marquee and video display of the project at the NAIDOC Family Day, Koonibba Oval, Ceduna, 2 July 2023 (Figure 8);
- presentation to Yalata Anangu School students and educators, Yalta Aboriginal Community, 4 July 2023 (Figure 8);
- presentations to years 8-10 and years 11-12 students at Ceduna Area School, 5 July 2023 (Figure 9); and
- presentation to the Yumbarra Conservation Park Co-Management Board and FWCAC on the outcomes of the Project 2.6 and future opportunities with Project 4.14, 29 February 2024.

Six FWCAC rangers assisted in field work on Olive Island over a 10-day period in December 2022. The rangers assisted project staff in the deployment and recovery of instruments from Australian sea lion females (Figure 9). The field work also provided an opportunity for a Wirangu elder (Neville Miller) to visit Olive Island.

Figure 9 Photos of the display and presentations to the school children during the NAIDOC Family Day, Koonibba Oval (Ceduna), and Ceduna Area School on Australian sea lions by the project team (July 2023).

Figure 10 Far West Coast Aboriginal Corporation rangers Charlie Colman and Jordie Miller with an Australian sea lion adult female at Olive Island. The sea lion is fitted with GPS and camera tags and is sleeping-off an anaesthetic procedure (Image: Simon Goldsworthy; reproduced with the permission of Charles Coleman, Jordy Miller and FWCAC).

4. Conclusions and recommendations

This pilot study sought to evaluate the reliability and feasibility of new state-of-the-art animal-borne cameras, combined with high resolution GPS and tri-axial accelerometer/ magnetometer devices, to identify and map critical benthic habitats used by Australian sea lions on the continental shelf off southern Australia. From eight deployments on adult females at two sites, we recorded almost 80 hours of video across ~560km of benthos, between 5 and 110m depth. The video provided footage detailing the relationship of sea lions with their marine environment, such as new information on their habitat use, foraging behaviours and prey species. The method has great potential in 1) recording sea lion habitat and foraging strategies in detail; 2) mapping the distribution of different habitats across large areas of the continental shelf; and 3) evaluating the importance of different habitats to Australian sea lions.

4.1 Identifying key benthic habitats for Australian sea lions

This project combined sea lion-borne video and high-resolution movement data to identify important benthic habitats utilised by Australian sea lions on the continental shelf off southern Australia. Australian sea lions foraged across a range of benthic habitats, including macroalgae reef, macroalgae meadow, bare sand, sponge/sand, invertebrate reef and invertebrate boulder habitats. These findings suggest that a variety of benthic habitats are ecologically important to Australian sea lions and that different benthic habitats may be important for different individuals, as well as for sea lions from different colonies (Figure 4 and 5). In shallower habitats, macroalgae reefs and macroalgae meadows were the dominate habitats (<25m for Olive Island and <50m for Seal Bay).

Each deployment provided new and unique information that refined our understanding of the relationship between sea lions and the benthic ecosystems on which they depend. Furthermore, our deployments have demonstrated that sea lion-borne cameras provide an efficient tool to directly gather data on habitats important to sea lions. While at sea, sea lions dive continuously from the surface to the seabed, and therefore, the sea lion-borne cameras record information on both the habitats they transit over, but don't feed in, as well as the locations and habitats where prey are caught. As such, the feeding rates along an animal's foraging path (transect) provide a means to assess the importance and value of different habitats to the species, providing an important conservation and management context to the movement and habitat-use data. The importance and value of benthic habitats are difficult to interpret from traditional survey approaches and anthropocentric metrics, using proxies for habitat value such as species richness and habitat heterogeneity. With further deployments and data analyses, including incorporating accelerometery data that can be used to infer prey capture events (e.g. Vacquié-Garcia et al. 2015), at locations and times where there is no corresponding video, there is an opportunity to improve our understanding of the value of different habitats to different sea lion populations.

In this project, we only deployed instruments on adult females. Future deployments on adult males and juveniles could provide important comparisons in habitat-use and foraging behaviour of different age/sex classes that have varying dive and movement capabilities (Fowler et al. 2006, Lowther and Goldsworthy 2012, 2016). Furthermore, since Australian sea lions forage throughout the day (Costa and Gales 2003), capturing footage of crepuscular (twilight) or night foraging could improve our understanding of key foraging behaviours and habitat-use for the species. Pinnipeds are poor at detecting the longer wavelengths of light in the visible spectrum, i.e., yellow-red colours (Fasick and Robinson 2000, Griebel and Peichl 2003). Therefore, infrared, or red light-emitting diodes (LEDs) may be integrated into animal-borne cameras without disturbing foraging behaviour (Heaslip and Hooker 2008, Hooker et al. 2008).

Video data from sea lion-borne cameras has also provided a wealth of data on foraging strategies and prey species use, providing direct information on the feeding rates, resource requirements and the ecological role of sea lions in different habitats (Appendix A, Figure 11). Future deployments will continue to build on the important data gathered in this project. Video data has also provided records of novel encounters with other species, providing insights into the diversity of marine megafauna that Australian sea lions interact with in their marine environment (Appendix B, Figure 12).

4.2 Informing species risk assessments

Data obtained from this project provides new information on the movement and habitat-use of Australian sea lions, which is important for informing future risk assessments for the species. Australian sea lions are endangered, and they are the only marine mammal species identified as a priority species in the Australian Government's Threatened Species Action Plan (2022-2032). An improved understanding of the benthic habitat requirements and variation in habitat types across the range of Australian sea lions, provides important context for the evaluation of threats to individual sea lion populations, especially those with declining population trajectories. Information on habitat-use, habitat value and quality (feeding rates), derived from sea lion-borne cameras at adjacent sites with different population trajectories, could provide important insights into the role of habitat availability and quality in accounting for different population trajectories and its potential in mediating threats to the species. Furthermore, sea lion camera data provides quantitative data on how sea lion diet and consumption vary in different habitats, facilitating the development of ecosystem models to evaluate potential ecological change and resource depletion impacts on seals, from anthropogenic factors including commercial fisheries and climate change.

4.3 Mapping benthic habitats on the continental shelf in southern Australia

Video data obtained from sea lion-borne cameras was used to develop a novel method for broad-scale mapping of benthic habitats on the continental shelf off southern Australia (Figure 6). Random Forest models suggested that different benthic habitats (e.g., bare sand plains, sponge gardens, macroalgae reefs, invertebrate reefs) cover large areas of the continental shelf (Figure 6). These data also highlighted substantial high-relief reef systems south of Kangaroo Island that were previously unknown (Figure 5). For most of southern Australia, benthic habitat maps are not available and information on the structure and distribution of benthic communities is limited (Ward et al. 2006, Currie et al. 2007, O'Connell et al. 2016). Results from this pilot study using sea lion borne cameras, indicate that sea lions have the capacity to sample their 3D benthic habitats, at rates, depths and scales that would be difficult to achieve using standard ship-based methods, and at a fraction of the cost. Future analyses of sea lion camera deployments will include and integrate other available data sets (e.g., through NESP 2.1 and other projects), from camera drops, towed camera surveys and swathe mapping. Data from this project will be made available to other mapping projects to improve the seafloor habitat maps of our southern shelf.

4.4 Evaluating habitat protection by marine reserves

Animal-borne video from Australian sea lions enabled the mapping and use of benthic habitats, both within and outside of State and Commonwealth marine reserves on the continental shelf off southern Australia (Figure 8). Based on the small number of deployments in this pilot study, most of the habitat used by Australian sea lions from Olive Island and Seal Bay, were outside of marine reserves, although marine reserves were used extensively by some animals (Figure 8). Further camera deployments (planned to be undertaken a part of Project 4.14) will build on our existing satellite telemetry data collected over the last 25 years. Satellite telemetry data on its own can be used to evaluate the portion of time-at-sea spent in marine reserves. The camera data, with satellite telemetry, provide the additional habitat and feeding rate data that can be used to evaluate the importance of the habitats within reserves, and the extent of critical habitat occurring outside the current reserve network. Such information will be important for both species protection and marine reserve planning. With more dual camera and satellited telemetry data, we can evaluate the value and limitations of just using telemetry data alone to determine the use of, and degree of habitat protection provided by marine reserves. Such analyses would help determine the level of sampling required for individual breeding sites to obtain representative data.

4.5 Final comments

This project has shown that Australian sea lions utilise the entire cross-section of the continental and a broad range of habitats. Each deployment provided new and unique information, refining our understanding of sea lion habitat-use and behaviour. The instrumentation used enabled hundreds of kilometres of previously unmapped seabed to be documented, which included previously unknown rocky reefs and kelp forests. The approach provides a cost-effective way to explore large areas of unmapped shelf and locate valuable sea lion habitat both within and outside of marine reserves, complementing existing survey methods. In the future, these data will be extremely valuable for directing management initiatives for Australian sea lions and other marine species, marine park planning, and benthic surveying more broadly.

The sea lion camera data also provides robust observational data to inform Biologically Important Areas (BIAs) for the species and delineate zones that would be valuable for the protection of Australian sea lions, including protection of habitat types critical to their survival. Additional analyses of feeding rate data will facilitate estimation the ecological value of different habitats to the species, and to evaluate the value and efficiency of current marine park zoning for protecting critical sea lion foraging habitats.

Sea lion camera data could be used to validate existing benthic habitat models and improve foraging models for the Australian sea lion. Camera data also provide valuable georeferenced observational records of habitat, providing capacity for future repeat surveys to evaluate ecological and habitat quality changes over time, especially those critical to the survival of the Australian sea lion.

The present pilot study was restricted to adult female sea lions at two sites. In future, we plan to increase the sample size of female deployments at Seal Bay (Kangaroo Island) so we can better understand population level use of habitats, diet and consumption rates, then potentially target juveniles, subadult and adult males. This will allow us to examine how habitat use and prey selection vary with age and sex. This information will be augmented by deployments at other breeding sites. Improved data on habitat use, diet and consumption rates will facilitate the development of ecosystem models that will enable the evaluation of prey depletion and ecological change due to commercial fisheries, climate change or other anthropogenic factors. Evaluating such risks has been challenging in the past because the trophic and habitat data for Australian sea lions have been very limited. Better ecological models and improved understanding of sea lion prey requirements are needed to facilitate an ecosystem-based approach to fisheries and marine management, and better understand and manage potential indirect fishery impacts. Such capacity will also facilitate a greater understanding of how emerging industries, such as offshore renewables, may impact marine ecosystems and priority species.

Future work to be carried out under NESP Project 4.14 aims to continue camera deployments at Seal Bay, a major breeding site that is relatively easy to access, and at other sites off the western Eyre Peninsula. Further deployments at Seal Bay will provide a greater understanding of the level of within-colony, and inter-individual variability in habitat-use and foraging strategies and allow us to validate and build on the habitat models developed for this location, as part of Project 2.6. Deployments planned at other sites off the western Eyre Peninsula will progress knowledge on the variability of habitat-use and foraging strategies among colonies, as well as provide new data and maps of the distribution of benthic habitats elsewhere in the sea lion's range. Further indigenous engagement and participation opportunities will also be developed as part of Project 4.14.

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Appendix A

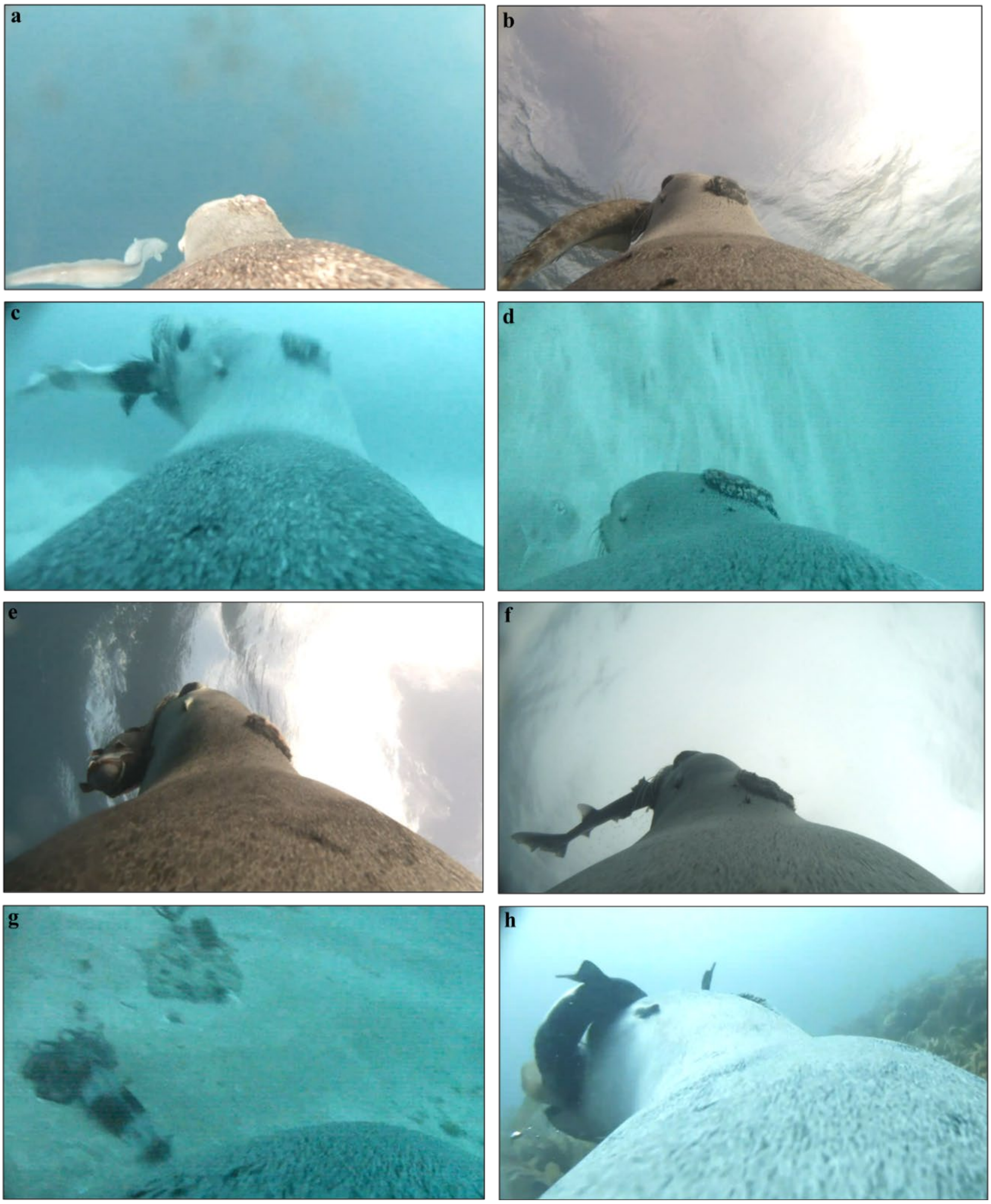

Figure 11 Prey events identified by animal-borne video from adult female Australian sea lions, showing captures of a) conger eel (*Conger* sp.), b) southern sand flathead (*Platycephalus bassensis*), c), magpie perch (*Pseudogoniistius nigripes*), d) western shovelnose stingaree (*Trygonoptera mucosa*), e) cod (Pseudophycis sp.), f) gummy shark (Mustelus antarcticus), g) southern calamari (*Sepioteuthis australis*), and h) a varied carpetshark (*Parascyllium variolatum*).

Appendix B

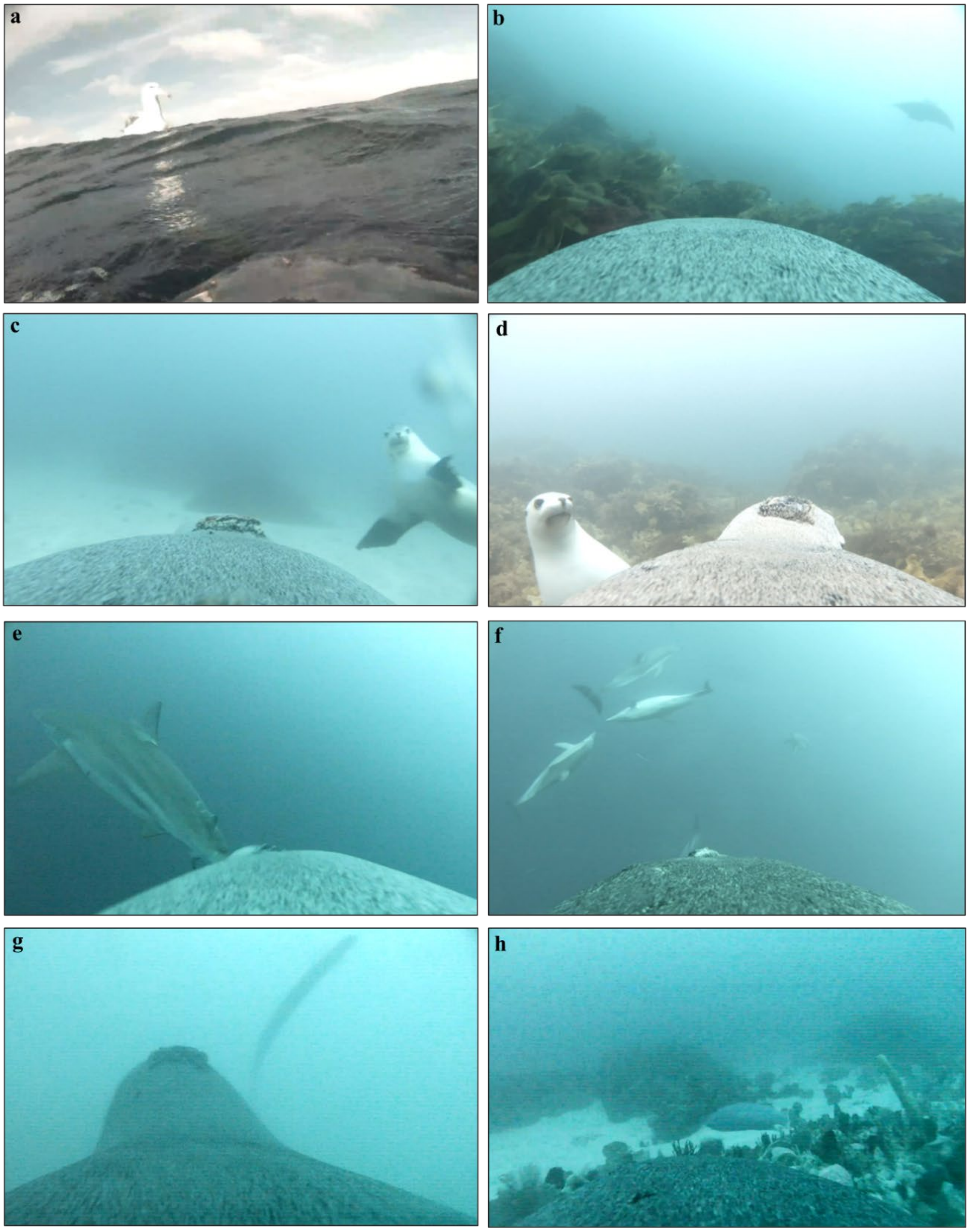

Figure 12 Novel encounters with marine species captured by animal-borne video from adult female Australian sea lions, showing interactions with a) an albatross (Diomedeidae sp.), b) a southern eagle ray (*Myliobatis australis*), c) and d) other Australian sea lions, e) a bronze whaler (*Carcharhinus brachyurus*), f) short-beaked common dolphins (*Delphinus delphis*), g) a thresher shark (*Alopias* sp.) and h) a western blue groper (*Achoerodus gouldii*).

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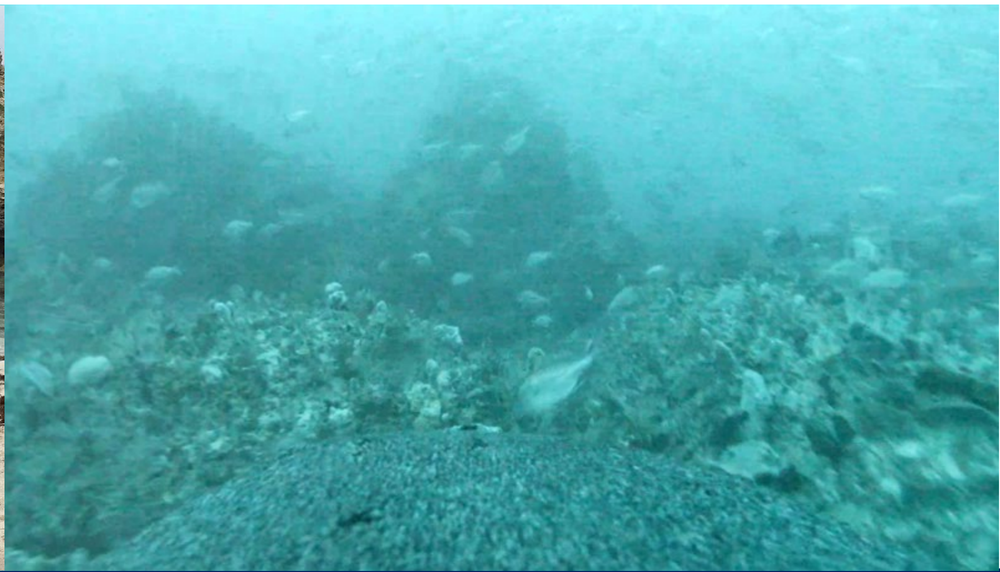

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