Australian sea lion abundance and movement in the Perth metropolitan area, Western Australia - Final Report

Theme: Apex Predators and Iconic Species

WAMSI Westport Marine Science Program

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WAMSI WESTPORT MARINE SCIENCE PROGRAM

ABOUT THE MARINE SCIENCE PROGRAM

The WAMSI Westport Marine Science Program (WWMSP) is a $13.5 million body of marine research funded by the WA Government. The aims of the WWMSP are to increase knowledge of Cockburn Sound in areas that will inform the environmental impact assessment of the proposed Westport development and help to manage this important and heavily used marine area into the future. Westport is the State Government's program to move container trade from Fremantle to Kwinana, and includes a new container port and associated freight, road and rail, and logistics. The WWMSP comprises more than 30 research projects in the biological, physical and social sciences that are focused on the Cockburn Sound area. They are being delivered by more than 100 scientists from the WAMSI partnership and other organisations.

FUNDING SOURCES
The $13.5 million WAMSI Westport Marine Science Program was funded by the Western Australian Government, Department of Transport. WAMSI partners provided significant in-kind funding to the program to increase the value to >$22 million.

DATA
Finalised datasets will be released as open data, and data and/or metadata will be discoverable through Data WA and the Shared Land Information Platform (SLIP).

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This report is part of the project: Australian sea lions in the Perth metropolitan area (abundance, movement, habitat use and diet).

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FRONT COVER IMAGE
Theme: Apex Predators and Iconic Species
Front cover image: Indo-Pacific dolphins in Cockburn Sound.
Image courtesy of Delphine Chabanne (Murdoch University).

Contents

The WAMSI Westport Marine Science Program is a $13.5 million body of research that is designed to fill knowledge gaps relating to the Cockburn Sound region. It was developed with the objectives of improving the capacity to avoid, mitigate and offset environmental impacts of the proposed Westport container port development and increase the WA Government's ability to manage other pressures acting on Cockburn Sound into the future. Funding for the program has been provided by Westport (through the Department of Transport) and the science projects are being delivered by the Western Australian Marine Science Institution.

Australian Sea Lion Abundance and Movement in the Perth metropolitan area, Western Australia – Final Report

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Executive Summary

The Australian sea lion (ASL) is endemic to Australia and listed as endangered under state and commonwealth legislation based on historic impacts to the population and failure to recover. Perth metropolitan waters (Western Australia) are regularly used by male sea lions that move between haul-out sites in this area and breeding colonies >200 km to the north in the Jurien Bay Marine Park. To determine whether planned developments and human activities in the region may impact sea lions, knowledge regarding their abundance, habitat use, overlap with planned commercial activity and sensitivity to specific impacts is required. While there is some knowledge available regarding these parameters, knowledge of sea lions in WA, is limited. In particular, little is known about the total abundance of sea lions that use Perth metropolitan waters (including Cockburn Sound), and the areas they use including haul-out sites and foraging habitat. This study aimed to (1) trial a non-invasive marking approach, and if successful, estimate the absolute (i.e., total) abundance of Australian sea lions in the Perth metropolitan area using mark-resight techniques and (2) identify foraging habitat, potential migration routes, and ranging information of sea lions in the Perth metropolitan area using telemetry.

Marking trials were successfully conducted in June and August 2022 using black hair dye applied via sponge-covered aluminium numbers attached to an extendable pole. The marks were expected to last up to several months until the sea lions moulted. A total of 49 sea lions were marked between September and mid-November 2022 using this technique for the mark-resight project. Twelve resight surveys were then conducted between December 2022 and February 2023. While some marks were still visible during the last surveys, significant fading of marks was observed over the period, with some marks expected to no longer have been detectable. An abundance estimate ranging from 83 (49-113 HPD credibility intervals) to 122 (67-184 HPD credibility intervals) was estimated using a mixed logit normal mark-resight model during the anticipated seasonal peak of ASL occupancy in the Perth metropolitan area. This represents a proportion of the population of sea lions that presumably breed

in the Jurien Bay Marine Park (WA) and does not include females who remain near the breeding islands. Finally, juveniles were under-represented (only marked) during marking due to their greater responsiveness to marking approaches, thus the abundance is expected to underestimate absolute abundance.

Telemetry tags (Wildlife Computers, MK10 and Splash10-F) were attached to 15 sea lions in September and November 2022 to gain a better understanding of sea lion movement, range patterns and foraging areas. Tags lasted from 1 to 63 days and sea lions were tracked ranging as far north as Jurien Bay Marine Park and as far south as Cape Naturaliste (both >200 km away), however most sea lions spent the majority of their time in the Perth metropolitan area resting on the haul-out islands between relatively short periods at sea. Trips to sea lasted from less than 1 to over 3 days and dive patterns recorded were indicative of consistent benthic foraging dives in relatively shallow coastal waters (i.e., a mean depth of 11 m, and up to a maximum of 48 m). This included Cockburn Sound out to Rottnest Island as well as foraging trips south to coastal waters near Mandurah and Bunbury. At least two sea lions travelled to Jurien Bay Marine Park with one returning within 7 days and one sea lion travelled >200 km south to Cape Naturaliste, in the Ngari Capes Marine Park where he remained at a haul-out site for more than 10 days, interspersed with nearby foraging trips. While tag failure was relatively high due to software bugs and electrical and mechanical malfunctions, and the number of tagged sea lions represented a small proportion of sea lions using the Perth metropolitan area (<10%), telemetry data and visual observations of marked and tagged animals confirmed that the sea lions used a range of haul-out sites across the Perth metropolitan area between foraging trips in the area and beyond.

This study has provided evidence that sea lions utilise Perth coastal waters for foraging and resting. Sea lions move throughout this area and beyond to additional coastal foraging sites. The coastal areas they use are heavily trafficked by commercial and recreational vessels of all sizes. Sea lions are exposed to a range of pressures across their range including noise and other pollution, potential for vessel collisions and depletion of potential prey by fishers or other factors such as climate change (Department of Sustainability Environment Water Population and Communities, 2013). This can result in multiple and cumulative exposure in busy coastal waters. Increasing human use of Cockburn Sound and surrounding areas that increases or adds to these pressures should be evaluated to identify possible impacts on sea lions in relation to critical activities such as foraging, resting and transiting. The current information now available on abundance and movement patterns can be used as benchmark information for future monitoring.

1 Introduction

1.1 Background

The endangered Australian sea lion (*Neophoca cinerea*, heretofore referred to as 'sea lion') is one of six sea lion species in the world and is the only species endemic to Australia (occurring in South Australia and Western Australia). The Australian sea lion experienced a serious decline in their abundance and narrowing of their distribution because of commercial harvesting in the 19th century, from which they have never recovered. A recent assessment has demonstrated that despite a ban on harvesting in the early 20th century, the sea lion population has experienced a >60% population decline across its range over the last 40 years (Goldsworthy et al., 2021). With continued declines in abundance and a vulnerability to localised extinction due to many breeding colonies being small with limited mixing (Campbell, 2003, Campbell et al., 2008b, Goldsworthy and Page, 2007), there is a genuine concern for the conservation of the species. Threats to sea lions include interactions (and mortalities) with fishing gear, disease, pollution and oil spills, injury and mortality caused by marine debris and vessel collision, habitat degradation (including noise exposure), interactions with aquaculture operations, human disturbance/harassment at haul-out and breeding sites, deliberate killings, prey depletion and climate change (Department of Sustainability Environment Water Population and Communities, 2013). While approximately 40% of the known breeding sites for this species are in Western Australia, this likely represents around 18% of the overall population (Goldsworthy et al., 2021).

Due to the severity of past impacts on the population and continued decline, the species is listed on the IUCN 'Red List', the Environmental Protection and Biodiversity Conservation (EPBC) Act (1999) and the WA Biodiversity Conservation Act 2016 as Endangered. Given their conservation status, proposed development activities such as port infrastructure and dredging that could result in a significant impact to the species should be referred to the Commonwealth and the WA Environmental Protection Authority (EPA) for evaluation of severity and risk of impacts to sea lions as part of the Environmental Impact Assessment (EIA) process.

To determine whether planned developments and activities may impact sea lions, knowledge regarding their abundance, habitat use, overlap with planned commercial activity and sensitivity to specific impacts is required. While there is some knowledge available regarding these parameters, this is mostly derived from research in South Australia and is of limited relevance to WA and in particular to the Perth metropolitan area that is exclusively used by males. Foraging behaviour has been demonstrated to vary between the SA breeding islands and those on the south coast of WA (Goldsworthy et al., 2014). Knowledge on sea lions in WA, including those occurring in the Perth metropolitan area, is limited. Little is known about the proportion of the WA population that uses Perth metropolitan waters including Cockburn Sound, and how they use habitats in this area for residency and foraging. The aim of this research was to develop a better understanding of the significance of the Perth metropolitan area to the sea lions and identify areas important for foraging.

1.2 Australian sea lions in the Perth metropolitan area

Sea lions are known to be present year-round in the Perth metropolitan area and are regularly sighted at six haul-out islands. Historically, islands in the Perth metropolitan area may have been occupied by breeding sea lions (Campbell, 2005), however, only males have been documented in contemporary research (Gales et al., 1992). It is believed that breeding likely occurred on Rottnest and Garden islands in the early 1800s, before sealing exterminated females in this area (Campbell, 2005, Gales et al., 1992). These males, which include adults (bulls), subadults, and juveniles, are thought to migrate ~380 km between breeding islands in the Jurien Bay Marine Park to the north and haul-out islands off Perth, with migratory timing associated with their breeding cycle (Gales et al., 1992). Perth metropolitan haul-out islands are used by sea lions for rest and recovery between foraging trips and after return from the breeding islands.

The number of sea lions inhabiting the Perth metropolitan area is currently unknown, however, their occurrence is cyclical with low numbers coinciding with the breeding season at the colonies in the Jurien Bay Marine Park. Recent direct counts indicate that up to ~75 sea lions may be hauled out on these islands at any one time (based on maximum numbers detected at all islands during a survey in the peak period of presence in the Perth metropolitan area, DBCA unpublished data, Salgado Kent and D'Cruz, 2021), with the majority using beaches on Carnac and Seal Islands (Orsini et al., 2006, Osterrieder et al., 2016, Salgado Kent and Crabtree, 2008).

Sea lions spend significant time at sea foraging (e.g., 40-50% based on Costa and Gales, 2003, Campbell et al., 2008a, Fowler et al., 2006), and haul-out behaviour is dependent on time of day, temperature and can vary between islands. For these reasons, an unknown number of sea lions are unaccounted for during haul-out surveys, which have previously been conducted using a single vessel accessing all six haul-out islands separated by up to ~60 kms throughout the course of a day (i.e., counts across all locations are not simultaneous). A true estimate of abundance is an important requirement to understand the potential risk of further developments to sea lions in the Perth region and to the recovery and persistence of the population. It is likely that sea lions in the Perth metropolitan area form a significant proportion of the population that extends to islands in the Jurien Bay Marine Park, as these are the closest breeding islands, and may constitute the majority (or at least a significant number) of the male cohort required for breeding.

In addition to understanding the number of animals that use the Perth metropolitan area, it is equally important to identify the core habitat they depend on for foraging and other activities. To date, knowledge regarding the spatial use of the area is limited (e.g., Campbell, 2008, Goldsworthy et al., 2014). A tagging study of three individuals (Campbell 2009, unpublished data) along with regular anecdotal sightings from local tour groups, the scuba diving community, and the general public, have confirmed that sea lions do forage in Cockburn Sound. Further, DNA analysis of scat samples collected from sea lions in the Perth metropolitan area was used to identify some species sea lions prey on in coastal waters (Berry et al., 2017), many of which can be found in Cockburn Sound as well as coastal waters nearby. Berry et al. (2017) reported that the majority of sea lion samples contained ray-finned fishes (Actinopterygii), cephalopods (Cephalopoda) and sharks and rays. In particular, Chondrichthyes made up the largest proportion of the diet from samples collected in Shoalwater Bay including stingarees (Urolophidae) and wobbegongs (Orectolobidae). Other species included common octopus (*Octopus vulgaris*), giant cuttlefish (*Sepia apama*), western rock lobster (*Panulirus cygnus*), crocodile flathead (*Leviprora inops*) and tasselled leatherjacket (*Chaetodermis penicilligera*). Direct observations by other marine mammal researchers include observations of sea lions feeding on cobbler catfish (*Cnidoglanis macrocephalus*), cuttlefish (*Sepia* sp.) and southern eagle ray (*Myliobatis tenucaudatus*) in Perth metropolitan waters (Delphine Chabanne, personal communication). Spatial foraging patterns of tagged sea lions elsewhere have shown that they range from shallow coastal waters (<10m) to the continental shelf edge when foraging (e.g., Campbell, 2008, Goldsworthy et al., 2014).

This study will increase our currently limited knowledge of sea lions in the Perth area in relation to their abundance, habitat use and foraging patterns. In particular, spatial maps of their home range including key foraging areas and assessment of habitat within and proximal to Cockburn Sound are needed to evaluate their importance to this population along with identification, and quantification of important prey species sea lions target within their habitat. This information is essential for informing EIAs and the ongoing management and recovery of sea lions in this area.

1.3 Objectives

This study aimed to address some of the needs and progress in filling knowledge gaps above through the following objectives:

Objective 1: Test a non-invasive marking approach, and if successful, estimate the absolute (i.e., total) abundance of sea lions using the Perth metropolitan area at the peak of the non-breeding season, using mark-resight techniques.

Objective 2: Identify foraging habitat, potential migration routes, and ranging information of sea lions in the Perth metropolitan area using telemetry, in conjunction with whisker sample collection for future identification of key prey species (not funded in this study, but to be retained for a future project).

Confirming the proportion of the broader WA sea lion population that inhabit the Perth metropolitan area will be useful in EIAs and the management and recovery of this migratory and endangered species in WA. Further, this will provide a baseline estimate of the number of sea lions using the area that can be compared with future studies to determine if sea lion abundance and distribution have changed. Movement data from telemetry will provide distributional and habitat use information for sea lions using Perth metropolitan waters, and future diet analysis will provide context regarding habitat use, including beyond the location information provided through telemetry.

2 Materials and Methods

2.1 Study area

The study area was located in waters off Perth, WA (referred to herein as the Perth metropolitan area) where six non-breeding haul-out sites are regularly used by sea lions (Gales et al., 1992, Shaughnessy et al., 2011) Figure 1). These are Penguin Island (32°18'16" S, 115°41'26" E), Seal Island (32°17'33" S, 115°41'26" E), Carnac Island (32°07'13" S, 115°39'51" E), Dyer Island (32°01'06" S, 115°33'03" E), Little Island (31°48'44" S, 115°42'32" E), and Burns Beach Rocks (31°43'38" S, 115°42'17" E, Figure 1).

As Carnac and Seal Islands are occupied by the greatest numbers of sea lions, are proximal to Cockburn Sound, and have easily accessible sandy beaches, these islands were selected for marking and deploying telemetry tags. Mark-resight surveys (post-marking), however, were undertaken across all islands to provide the best estimates of the number of sea lions using the Perth metropolitan area.

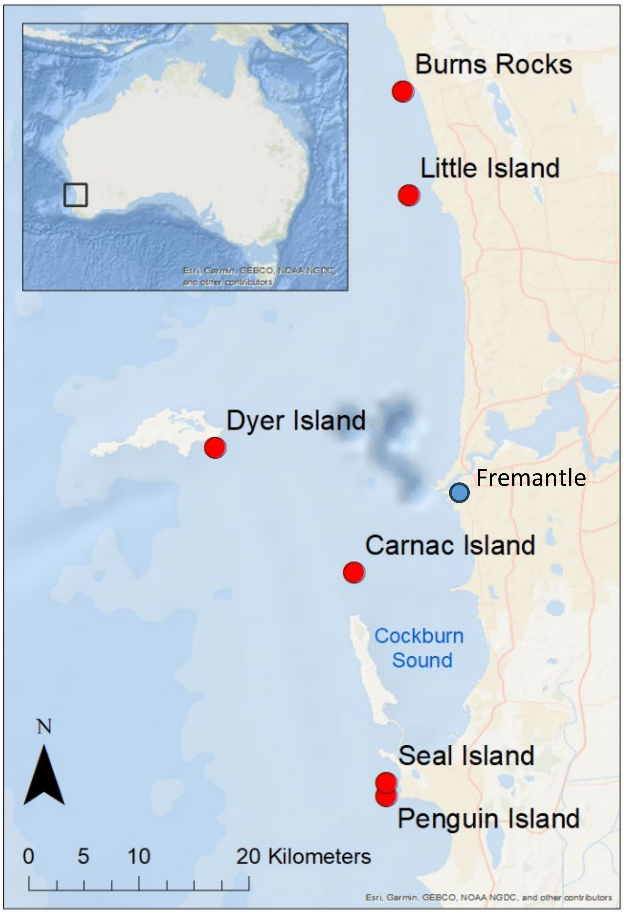

Figure 1. Perth metropolitan area Australian sea lion haul-out sites comprising Penguin Island, Seal Island, Carnac Island, Dyer Island, Little Island and Burns Beach Rocks (Western Australia).

2.2 Study period

While sea lions are sighted year-round in the Perth metropolitan area (DBCA unpublished data, Salgado Kent and D'Cruz, 2021, Osterrieder et al., 2015), their highest occupancy is consistent with non-breeding periodicity, with peak numbers occurring every 17-18 months (i.e., the a-seasonal non-breeding period of ASLs; Salgado Kent and D'Cruz, 2021, Osterrieder et al., 2015, Gales et al., 1992, Kirkwood and Goldsworthy, 2013). Analysis of data, collected during the DBCA Perth metropolitan ASL monitoring program between January 2015 and March 2021 (Salgado Kent and D'Cruz, 2021), predicted the expected peak period in the Perth metropolitan area for this study to be approximately between December 2022 and February 2023. The marking technique was trialled in the winter months of 2022 (June-August), with dedicated marking undertaken in November 2022, just prior to anticipated peak visitation. This was then followed by a series of monthly resight surveys over the subsequent three months (December, January and February), across the expected peak period.

To maximise telemetry data while sea lions were in the Perth metropolitan area, telemetry tags were deployed between September and November 2022, in the anticipated lead up to peak numbers in the region and prior to sea lions leaving the area for breeding. Tagging at this time also allowed for the operation to be carried out during the cooler months of the austral spring to reduce the risk of sea lions overheating while under anaesthesia and to minimise disruption of fairy tern nesting that occurs between December and February at Carnac Island.

2.3 Marking and resight surveys

2.3.1 Marking

To reduce the costs and additional stress associated with applying tags or microchips that require capturing sea lions, a marking technique was trialled using hair dye applied with a pole. While hair dye marks can be readily visible at a greater distance than other longer-term tags (e.g., cattle tags), increasing chances of resighting, hair dye is a temporary mark lasting only until the animal moults (months). Male Australian sea lions moult slowly over an extended period and have been reported starting to moult 9 -months after the breeding season, i.e. they moult on a 17-18 months cycle (Higgins, 1990, Higgins, 1993). Hair dye is an established means of marking pinnipeds that has been used on a variety of species with various application techniques depending on the approachability of the species (South American sea lion, Giardino et al., 2013; northern elephant seals, Le Boeuf and Peterson, 1969). As this method had not been used previously on Australian sea lions, its application was trialled on several individuals in a pilot study, with the intent of identifying the most effective technique prior to marking a total of 50 individuals for the mark-resight study.

Following Giardino et al. (2013) and Giardino's personal recommendations, a marking pole was designed and constructed with a frame and plate at one end on which removable marine grade aluminium numbers (elevated from the plate by spacers) could easily be attached with screws and wing nuts. This system allowed easy swapping of numbers during marking. The numbers had a sponge-like foam in the same shape as the numbers glued to them. Five hair dyes were trialled, including bleach (Schwarzkopf Nordic Blonde), black (ColourU 1 black and Hi Lift creme peroxide 20 Vol – 6%), red (L'Oreal Paris Preference Vivids Permanent Hair Colour 8.624 Montmartre) and temporary blue and pink. Just prior to marking, hair dye and developer were mixed (as per instruction provided with the hair dye product) and applied liberally to cover the foam.

Sea lions were approached slowly, and from downwind when possible, to decrease the probability of detection of a person nearby. The mark was applied via quick contact (i.e., duration of a second or two), and after marking, the researcher immediately moved away from the sea lion (see Appendix 1 for images). Sea lions selected for marking were those resting on the beach or dunes and were monitored closely for signs of disturbance before and during the approach and marking. If the individual showed signs of agitation (e.g., sitting up, forcefully blowing through their nose as to warn, barking, moving away, etc.) the researcher withdrew immediately, and the sea lion was allowed to resettle. Additional personnel with a 'push pole' were positioned nearby in case the sea lion responded aggressively or other sea lions in the area approached.

All sea lions fitted with a telemetry tag were also marked with hair dye (using the same aluminium/sponge numbers) applied to both sides by hand rather than using the pole. Photographs were taken of marked and tagged sea lions at the time of the marking/tagging when possible. All sea lions were marked on their lateral or dorsal side.

While a random sample for marking was desirable to address an underlying assumption of mark-resight models, marking could not be conducted completely without biases. Firstly, marking could not be done safely at all islands, and was therefore only undertaken on the two islands with accessible beaches and the greatest numbers of sea lions present (Carnac and Seal Islands). Also, only one side of each sea lion could be marked as attempts at marking the other side would have caused significant disturbance to sea lions. Attempts were made to mark all sea lion age classes present (bulls, subadult, and juvenile males) in numbers relative to their occurrence.

2.3.2 Resight surveys

Three sets of four-day mark-resight surveys were undertaken in December, January and February over a 10-day period each month. Each survey day involved visiting all six haul-out islands and recording the number of sea lions present, their age classes and whether they had a mark and/or tag visible. Where a mark was sighted, the identifying number was recorded (if it could be discerned). Additional information was also recorded on each individual, including whether both sides, only one side (left or right) or no sides were visible, as this could influence a missed detection of a mark (i.e., sea lions may have been laying on the side marked). During surveys, sea lions sometimes repositioned themselves and some would enter or emerge from the water, which may have introduced some inaccuracies in documenting number of individuals, their age class and whether they were marked or not. Every effort was made to observe both sides of all individuals and to record whether or not a mark was detected; all biases and uncertainties were noted where possible. While every attempt was also made to photograph all sea lions during each survey with a particular focus on obtaining images of all marked or potentially marked individuals, this was not always possible. Photographs were later compared with the photo identification catalogue (described below) to confirm identity.

2.3.3 Data analysis - Photo identification /data processing

A photo identification catalogue of images of each marked sea lion was compiled, including details of age class and the side on which they had been marked based on field notes and the original images taken during marking field days. These were supplemented, where possible, with images from later sightings of individuals to record changes to the marks over time and to improve the capacity of identifying marked animals even with changes to their appearance. After completing the resight surveys, all photographs were compared with photos in the photo identification catalogue and matches confirmed by at least two researchers. In some cases, marks on individuals could not be used to confirm identity and these individuals were recorded as marked but identification unknown.

2.3.4 Data analysis – mark-resight modelling

Encounter histories were compiled from matches recorded during data processing, according to McClintock (2021) to be used as data inputs for fitting models. Encounter histories included a count of the number of individual sea lions that were classified as unmarked as well as those that were marked but not identifiable.

A range of mark-resight models were implemented to estimate abundance, with the model that reduced violations in assumptions most and provided reasonable results selected for reporting. Mark-resight models assume that a sample of individuals have been marked prior to sampling, and sampling occasions are carried out which involve sighting and recording marked and unmarked individuals during surveys (McClintock, 2021), as done in this study. These models are described in depth by McClintock (2021).

Models implemented included the mixed logit normal mark-resight, the Poisson log normal mark-resight with a robust design, and the zero-inflated Poisson log normal mark-resight with a robust design (see McClintock, 2021 for full descriptions). While there was an initial known number of sea lions marked in the population, all models implemented assumed an unknown number of marks in the population to allow for fading of marks over time with the possibility of some individuals no longer being marked at some point during the study. Models implemented with a robust design, aimed at estimating abundance directly within the study area, allowed for an assumption of a geographically open population between primary sampling intervals (e.g., allowing for deaths or emigration to occur), while closure was assumed within primary sampling intervals. To apply the robust design in these models, four secondary sampling occasions (the four survey days within each month) within three primary sampling intervals (the intervals being each of the three months of sampling; December, January and February) were assigned. In contrast to the Poisson and zero inflated log normal with robust design models, the mixed logit normal model applied allowed for abundance of the 'super population' to be estimated, composed of individuals associated with the study area during the survey period (McClintock, 2021) but not necessarily directly in the study area at each sampling occasion. In mixed logit normal models, abundance was estimated for each of the 12 sampling occasions. In all models, all individuals were included without assigning sex or age class (i.e., 'one group'); and individuals whose identity could not be determined, but were known to be marked, were documented.

While details regarding assumptions for the different models fitted are not presented here (see McClintock 2021), relevant assumptions for the model selected for reporting in the results are described further in the results and discussion, to provide context for interpretation of the resulting estimates.

The model selected for reporting here was fitted using Markov chain Monte Carlo (MCMC; a Bayesian parameter estimation procedure used for estimating variance components), with 4000 tuning samples, 1000 burn-in samples, and convergence diagnostics estimated from 10 chains. The 95% highest posterior density interval (HPDI) for N (i.e., the proportion of which the true parameter value falls within the 95% HPDI) in addition to the posterior mean point estimators for N are reported in the results. The Gelman–Rubin diagnostics (r-hat) statistic was used to evaluate model convergence and are also reported. All models were implemented using the Program Mark (White and Burnham, 1999).

2.4 Telemetry tags

2.4.1 Tag specifications and programming

Satellite tags were deployed across both adult and subadult age classes as there is evidence in other regions (southern WA and South Australia) that different age and sex classes vary in the location and spatial extent of habitat use (Goldsworthy et al., 2014). Juveniles were not tagged as the limited number of tags were used to maximise samples for the most abundant cohorts, in addition to juveniles being of a smaller size relative to the size and weight of the tags. They are also more reactive to approaches and commonly hauled out next to other sea lions which would have made them potentially more difficult to target. Satellite tags were Wildlife Computers TDR10-F-297C-01 (TDR = Time-Depth Recorder; https://wildlifecomputers.com/our-tags/tdr/tdr10/) external (non-implantation) tags (referred to hereafter as 'MK10' tags) fitted with a PRD M339A (PRD = Payload Recovery Device). TDRs are data-archiving tags designed for tracking fine-scale movements of marine animals, including pinnipeds. The MK10 allows the collection of depth, temperature, Fastloc GPS, and wet/dry archived data, however, it requires recovery of the tag to download these data. The PRDs have Argos capability which allows their location to be monitored in real time so that recovery of the MK10s can be undertaken when sea lions are known to be hauled out. To retrieve tags when sea lions were known to be hauled-out, personnel travelled to the location, approached on foot to within approximately 100 m of the sea lions, and used a remote controller to send a release signal to the PRD, which then released the MK10, allowing it to fall to the ground for collection and recovery of archival data. The MK10s were 132 g, with dimensions of 86 x 55 x 29 mm; and PRDs were 327 g and 105 mm long and 67 mm wide.

While the MK10s were planned to be the sole devices used in this study, additional tags, including the Splash10-F-391 (https://wildlifecomputers.com/our-tags/splash-archiving-tags/splash-f/splash-f-391-tag/) weighing 160 g with dimensions of 86 x 58 x 28 mm and Splash10-F-351 (https://wildlifecomputers.com/splash10-f-fastloc-gps-tags-product-sheet-splash10-f-351/) with similar dimensions and weight, were also deployed (see Results section). Similar to the MK10s, Splash10-F tags also have depth, temperature, wet/dry, and Fastloc GPS capabilities, however, they do not have a remote release device and are rarely recovered to download archival data, and thus, were programmed to instead transmit depth and location data via satellite.

All tags were pre-programmed to have a battery duration of 2-4 months by limiting the frequency of transmissions. MK10 tags archived depth, temperature and wet/dry sensor data every second and attempted to collect Fastloc GPS data every 5 min, with a maximum of 12 successful Fastloc GPS points per hour. In order to extend battery life, tags were programmed so that Fastloc GPS data were not recorded once a sea lion had hauled out and a good location was obtained. Splash10-F tags were programmed with either of two recording schedules. One schedule recorded a Fastloc GPS location each hour, with a maximum of 24 locations per day spaced apart by an hour (ASL08's tag). The other schedule recorded three Fastloc GPS locations each hour with a maximum of 60 locations per day, spaced apart by 20 min (Sea lions 05, 06, 07 tags). All Splash10-F tags were programmed to transmit data in the hours of 0-3, 8-16, 21–23 UTC. Dives were characterized as beginning and ending at or above 2 m depth, and only transmitted if at least 4 m deep, regardless of dive duration (Fowler et al., 2006, Lowther et al. 2011). To conserve battery life, the PRDs (with MK10 tags attached) were programmed to only transmit Argos positions during the hours of best satellite coverage between 0-2, 12-16 and 22-24 hours UTC.

2.4.2 Tag deployments

Daily operations commenced at first light and were terminated when daytime temperatures reached approximately 25°C to manage the risk of sea lions overheating while under anaesthetic. A team of 12-14 personnel transited either to Carnac or Seal Island from Fremantle (WA) via two vessels – a 6 and a 12 m catamaran. The team consisted of at least two researchers, one wildlife veterinarian, a veterinary assistant, a firearms officer (for delivering the anaesthetic via a dart gun), and operations personnel.

Upon arrival to the haul-out island, all gear was unloaded onto the beach away from the location where sea lions were hauled out. A small scouting team made up of ~3 personnel including a wildlife veterinarian, a firearms officer, and a researcher were deployed to identify a suitable sea lion for tagging. Suitable sea lions were agreed upon by consensus, and were those considered to be in good condition, were not or minimally moulting, not immediately adjacent to the waterline (i.e., were further up the beach), had a body orientation that allowed easy accessibility to the target darting location on the animal (i.e., gluteal muscle), and were considered sufficiently relaxed to pose a low risk of fleeing to the water upon darting or causing others to become alert and/or flee. Each person in the team estimated the weight, and the average or best estimate was used to calculate the required dose of anaesthetic to administer. While the anaesthetic was being prepared by the vet, vet assistant and firearms officer, the tagging and marking equipment (see marking for detailed methods) was prepared by the researchers. At this time, operations personnel anchored the large vessel off the beach area and positioned the smaller vessel crewed by a skipper and swimmers within the vicinity of the beach where darting was anticipated, to be on standby and prepared to collect and assist the vet in the event that a darted sea lion were to enter the water. The smaller vessel and land-based operations personnel not involved in darting or tag preparation also had the function of spotting vessels and public approaching the island and other sea lions approaching the island, and alerting the vet and firearms officer if this occurred before darting commenced.

After the anaesthetic was prepared, and while the remainder of the land-based team remained where the equipment had been unloaded (away from the sea lions), the small darting team composed of the vet, firearms officer, and a researcher quietly and discreetly approached the selected sea lion so as not to disturb at a distance of approximately 10 m. Once the 'all clear' was given by the spotting vessel via radio, anaesthetic was administered intramuscularly (IM) using barbless darts (1 – 1.5-inch gel-collared needles with 1.5 – 5cc Pneu-Darts fired through a 13mm Dan-Inject® rifle). The animal was then observed for signs of induction from a distance (which usually occurred approx. 20 min after darting). Once this was observed, the veterinarian approached the animal and confirmed a safe depth of anaesthesia (eye dilation, position of globe, blink response, flipper and ear stimulation response), and then gave the 'all clear' for the team to approach the sea lion and begin obtaining samples, measurements, attaching the telemetry tag and marking it (these are described below), with a target time to complete these of approx. 30-45 min. Once samples and measurements were obtained, and the tag and marking had been completed, the vet administered the reversal agent, and monitored until recovery.

2.4.3 Anaesthetics

Two anaesthetic regimes were prepared, although only Regime 1 was administered by the wildlife veterinarians (Simone Vitali and Brett Gardner) for use in this project, with the MMB described below as the primary anaesthetic used and Regime 2 a contingency:

Regime 1: Medetomidine/midazolam/butorphanol ("MMB") at dose rates of: Medetomidine 0.03mg/kg body weight Plus Midazolam 0.2mg/kg body weight Plus Butorphanol 0.2 mg/kg body weight. MMB has been used previously for field anaesthesia (Gardner et al., 2021), but not in Australian sea lions. Its main advantage is that animals retain a dive response, and risk of drowning is significantly reduced compared with other anaesthetic regimes. In addition, it is reversible, so recovery from anaesthesia is very rapid. The dose rate given above was used for the first nine sea lions, and titrated down when good sedation for initial doses were achieved (as those were based on doses for other pinniped species). The resulting average dose rate was 0.02/0.14/0.14 mg/kg MMB.

Regime 2: Zoletil® (tiletamine/zolazepam) administered at approximately 1.1 mg/kg body weight. Zoletil has been used extensively for the anaesthesia of otariid pinnipeds and has good safety margins. A drawback of this drug is the lack of a reversal agent, which means recovery is more prolonged than MMB and there is no capacity to reverse the effects if animals take to the water.

Anaesthetised animals were closely monitored by the veterinarians for stage/depth of anaesthesia, respiration rate, heart/pulse rate, mucous membrane colour and capillary refill time every 1-5 minutes. Health parameters were regularly monitored and recorded to allow early determination of complications. The reversal agent for the MMB regime was atipamezole and naltrexone, administered intramuscularly at the completion of satellite tag attachment, marking and sample collection procedure. All recovering animals were monitored from a distance to ensure that respiratory rate was satisfactory and consistent (by the rise and fall of the thoracic cavity) and that conspecifics did not interfere. Shade and cooling using water on the flippers and/or body were applied if required (i.e., when ambient temperatures were relatively high, and recovery was not immediate).

2.4.4 Tag attachment and marking

Following anaesthesia, the satellite transmitter was attached to the guard hairs (cleaned and dried, if necessary, with 100% ethanol) along the mid-dorsal line posterior of the fore flippers, by using a flexible araldite epoxy, Devcon 5 Minute Epoxy, provided by Wildlife Computers with the tags. Following successful attachment, marking occurred using the prepared black hair dye and foam-covered aluminium numbers, pressed to the sea lion's fur by hand. Additional dye was painted on to the fur within the number outline to ensure a suitable amount of dye adhered to the fur.

2.4.5 Biological samples and measurements

Biological samples were collected under the supervision of the wildlife veterinarians. Tissue samples for DNA analysis were collected as per current best practices (van Neer et al., 2021) using a 4-6 mm disposable biopsy punch (Miltex, USA) as per Deyarmin et al. (2020). To reduce the risk of any infection, samples were collected using pre-sterilized, sealed disposable biopsy punches from between the digits of the posterior flippers, and only one disposable biopsy punch was used per individual. A rotating motion in one direction was used to avoid shearing tissue from back-and-forth twisting. Once the required depth was reached, the punch instrument was removed and downward pressure applied on either side of the wound to facilitate extraction of the biopsy sample using a pair of sterilized forceps. A clean gauze was applied post biopsy extraction.

A single whisker (vibrissae) was plucked for the purposes of stable isotope analysis using plyers after a local anaesthetic was applied at the root (5 min before).

Morphometric measurements were also recorded including standard length (nose to end of hind flippers) and girth at the widest point behind the fore flippers. If possible, animals were weighed by lifting them in a stretcher and weighing using a ~200 kg capacity scale suspended from an aluminium tripod. The body condition was noted (robust, thin, emaciated), although no individuals whose health was already compromised (e.g., emaciated) were selected for tagging. Any presence of wounds was documented and photographed, and sex and age class were recorded.

2.4.6 Telemetry tag analysis

All tagging data were pre-processed within Wildlife Computers' Data portal (https://static.wildlifecomputers.com/Portal-and-Tag-Agent-User-Guide-2.pdf) and then downloaded. For the MK10 tags, archived data first had to be downloaded from the tags using Wildlife Computers' MK10 Tag Host program, then uploaded to the portal before processing. The process and workflow for analysis is described in Appendix 2.

2.4.7 Dive trip duration

Dive trip duration was calculated for each dive trip recorded by MK10 and Splash10-F tags. A dive trip here is defined as the period between the time of departure from and return to a haul-out island associated with continuous diving behaviour (i.e. dives interrupted by ascents to the water's surface to breath, consistent with potential foraging behaviour. This would not include short excursions into shallow water in the vicinity of a haul-out site for the purpose of thermoregulating. To distinguish dive trips from one another in archived data from sea lions fitted with MK10s, the time at which a haul-out period ended and a dive trip began was identified as the onset of a wet period (readings of '1' from the wet/dry sensor) after a dry period (readings of '0' from the wet/dry sensor) ended. Wet/dry sensor data were corroborated by evaluating location information from the Fastloc GPS and depth data, when possible, to confirm that an individual had left the island and commenced a dive trip. The start of a haul-out period was conversely determined by the onset of a dry period recorded by the tag's wet/dry sensor, the absence of continuous diving behaviour associated with dive trips, and confirmed by Fastloc GPS locations, if available, indicating arrival at one of the haul-out islands.

To distinguish dive trips from one another in data from sea lions fitted with Splash10-F tags, a similar approach was taken as for MK10s, however, wet/dry sensor recordings were unavailable. For the Splash10-F tags, however, dive summary outputs (rather than the raw data at 1 s temporal resolution) are sent via satellite, as they are relatively small files and can be transmitted (so that tags don't require retrieval to obtain dive information). This, however, requires programming a definition for dives prior to deployment. The tags were programmed so that dives were considered to commence/end at 2 m depth, however, only dives reaching a depth of 4 m were transmitted. The start of the first transmitted dive was used as a proxy for the time a dive trip commenced and the time of the end of the last transmitted dive of the dive trip was considered to be the time the dive trip ended. As the temporal sampling resolution was lower for Splash10-F tags (up to one to three locations per hour, compared to 12 per hour for MK10s), haul-out periods may be overestimated, as the start time of the haul-out period was considered to commence immediately after the time associated with the end of the last transmitted dive for a trip and ended with the commencement of the first dive of the consecutive trip. As for the MK10 data, start and end times of dive trips determined using the GPS location information were corroborated using the depth data, with depths indicative of diving behaviour confirming dive trips. In cases where there were no dive data available for over two hours, but a reliable GPS location (with a time stamp) was available before the sea lion left or returned to a haul-out site, these times were then used as the start or end time of a dive trip (respectively) and as the end or the start of a haul-out period (respectively). Dive trips were only included for analysis if dive data had been transmitted over all or most of the duration of the trip.

If available, the location at the haul-out island prior to departure and upon return from the dive trip, were integrated into analyses to provide a more complete track of each dive trip. Otherwise, GPS locations while hauled-out were excluded from analyses.

2.4.8 Dive data analysis – MK10 tag archived data

MK10 dive data were zero-offset corrected to remove artifacts from changes in accuracy produced by pressure transducers. Correction involved applying an offset to all data by evaluating deviation from a depth of zero, expected during periods in which the animal is known to be at the surface between dives to provide a reference for calibration (Luque and Fried, 2011). The correction, hence, is called a zero-offset correction (ZOC). To determine the required offset, variability in depths recorded was evaluated at times that sea lions were expected to be at constant depth (e.g., hauled-out and resting in one place) to determine the recorded depth range in which accuracy may vary. Variability in accuracy differed among tags, resulting in offsets applied ranging from 1-2.5 m (1 m for ASL01 and ASL13, 1.5 m for ASL101 and 2.5m for ASL10), with a preliminary dive threshold set at a value ranging from 0.5-1 m (1 m for ASL01, and 0.5 m for ASL10, ASL13 and ASL101). The dive threshold defines dives for zero-offset corrected depth. The narrow threshold was applied to ensure that the considerable number of shallow dives were not inadvertently miss-specified as separate dives. A unimodel dive model was used as this is an air-breathing species, and only data registered as 'wet' by the tag's wet/dry sensor was considered to be part of a dive. The *diveMove* package in R (Luque, 2007) was used to apply the ZOC, determine dives according to the given conditions (i.e., dive model, threshold and wet condition) and produce dive summaries.

Dives were then further defined according to the sea lions' diving behaviour. The criteria varied for each sea lion to minimise miss-specification, given the variability in tag accuracy. Dives were defined as having a duration >4s and a minimum recorded depth 1.5 m for ASL01 and 2m for ASL10, ASL13 and ASL101. The surface interval (when sea lions were at the surface of the water between dives), was then re-calculated as the time between the end of a dive and the start of the next dive (indicated by the descent). Dive statistics were calculated for each individuals' dive trips separately and used to calculate descriptive statistics for each individual, including minimum, median, maximum, mean and SD for dive depths, dive duration, bottom times, surface intervals and vertical undulations at the bottom (also referred to as 'wiggles'; see Appendix 3 for summary dive data on each individual).

While this study did not aim to evaluate dive shapes or categorize them, dive shapes for one individual were investigated as a case study with shape categorization according to Wildlife Computer's classification (i.e., Square-shaped: >50%, U-shaped: 20-50%, V-shaped dive: ≤20% bottom time of a dive's total duration; Wildlife Computers, https://static.wildlifecomputers.com/Behavior-Log.pdf).

2.4.9 Dive data analysis – Splash10-F tags

Splash10-F tag dive data, including the start and end times for each transmitted dive and surface interval were obtained from the 'Behavioural' file from Wildlife Computer's portal. Dive and surface interval durations were provided as minimum and maximum durations that usually varied only by 2 s, thus, the average was used in analyses here. Dive depth and shape were also included in the portal's data output, and the percentage for each dive shape, per individual and per trip, was calculated and included in the overall dive statistics (see Appendix 3 for summary dive data on each individual).

2.4.10 Location data

For MK10 tags, that were successfully retrieved, sufficient Fastloc GPS locations were available to undertake spatial analysis, while for those that could not be retrieved, only Argos data from the PRD's were available. For Splash10-F tags, both the transmitted Fastloc GPS and Argos data were combined for analysis to increase the sample size of available data.

2.4.11 State space models

Fastloc GPS and Argos data have become a vital tool for gaining insight on the movements of highly mobile species. These data do not come without measurement error, however. State-space models (SSM) have been developed to separate signal from noise and are used for quality control of location data susceptible to error and for inferring changes in movements of animals (Jonsen et al. 2023, Arnould and Hindell, 2001, Le Boeuf et al., 1992, Goldsworthy et al., 2009). SSMs are composed of two components: the movement process (i.e., associated with the behaviour of the animals) and the measurement error (i.e., associated with the instrumentation used). Three different movement process models, including the simple random walk (rw), correlated random walk (crw) and a move persistence (mp) SSMs, were fitted to each dive trip with the *R* package *aniMotum* (Jonsen et al., 2023). Random walk models assume that movements are random in direction and magnitude, correlated random walk models assume that movements are random and correlated in direction and magnitude (Jonsen et al., 2023). Move persistence models assume movements are random with correlation in direction and magnitude that varies over time (Jonsen et al., 2023). The measurement error component of the model is automatically detected in the *aniMotum* package based on the format and content of the input data. For Argos data, *aniMotum* uses Argos location quality class and error multiplication factors (see Section 2.4.12 below), while for Fastloc GPS data, locations are assumed to have an error variance ten times smaller than class 3 Argos locations (Jonsen et al. 2023).

To run the models, data were pre-processed within the *aniMotum* package, which involved applying a speed filter so that the SSM ignores what may be considered extreme locations. The filter applied consisted of a swim speed threshold of 4 m s^{-1} with those greater excluded, based on maximum swim speeds of pinnipeds reported in previous studies (Arnould and Hindell, 2001, Le Boeuf et al., 1992, Goldsworthy et al., 2009). The time intervals in which to predict (i.e., the *time step* in *aniMotum*) locations from the SSMs were given as the average time interval between measured locations.

All models were checked for model fit and validated by plotting predicted versus observed locations and predicted versus observed residuals to ensure they were within reasonable agreeance, and plotting autocorrelation of residuals using correlograms to identify the presence of autocorrelation. To determine the best fitting model for each validated dive trip, the Akaike information criterion (AIC) values (an estimator of prediction error often used to evaluate relative quality of statistical models) of converging models and their fitted and predicted locations including confidence intervals were extracted and compared. The predicted values of the best fitting model were used for home range analysis (see Section 2.4.12 below).

2.4.12 Brownian bridge movement model

Space use patterns for each sea lion's dive trips were estimated using the predicted locations from the best fitting SSM. Space use patterns, commonly quantified and reported in research as a probability distribution for the use of space (i.e., the utilisation distribution), or more simply put, "the probabilities of where an animal might have been found at any randomly chosen time" (Powell and Mitchell, 2012). Often, these utilisation distributions are used to describe an animal's *home range*. While definitions for home range have varied over time, they are related to a part of an animal's cognitive map (e.g., using smell, hearing, sight) regarding the location and status of resources (food, potential mates, safe locations, etc.) and where it is "willing to go to meet its requirements" (as per definition proposed by Powell and Mitchell, 2012). Utilisation distributions can, thus, provide a level of quantification of some home range attributes.

Utilisation distributions were estimated using Brownian bridge movement models (BBMM), which are ideal for satellite tracking technology that yield highly correlated tracking data (an animal's location at frequent intervals, Walter et al., 2011). Briefly, BBMMs not only take into account location data (as in classical kernel methods), but also; the time lags and distances between successive location measurements, and the estimated location measurement error. As a result, BBMMs predict trajectories of movement between successive locations, with *core areas* of use commonly defined as 50% BBMM utilization distributions (i.e., the area where an animal might be expected to be found 50% of the time during the dive trip). Importantly, 50% BBMMs are reported here, representing core areas for each dive trip a sea lion undertook within its home range. They do not represent standard home ranges (i.e., 95% BBMM; Fischer et al., 2013) for each individual sea lion.

The 50% BBMM were fitted using the Brownian bridge kernel method in the *adehabitatHR* package in *R* (Calenge, 2006, Calenge, 2023*)*. Two smoothing parameters are required as inputs in *adehabitatHR*. The first parameter ('sig1' in *adehabitatHR*) refers to the variance of the position of the animal between two relocations, which is used to control the width of the bridge connecting successive relocations, and was estimated using the maximum likelihood approach developed by Horne et al. (2007) and implemented in *adehabitatHR*. The second smoothing parameter ('sig2' in *adehabitatHR*) "controls the width of the bumps added over the relocations" (Calenge, 2023) and the input is the mean standard deviation. For Fastloc GPS locations, as an approximation, an error estimate of 43 m (based on analysis of data from ASL01 with a mean number of satellite fixes per location of 7.02, as a proxy)**.** This error rate was consistent with findings from Dujon et al. (2014) and reported that for data derived from 7 satellites, 95% had locations within 43 m. For Argos locations, based on the location error classification descriptions by Argos (https://www.argos-system.org/wp-content/uploads/2023/01/CLS-Argos-System-User-Manual.pdf, p.14) and Wildlife Computers (https://static.wildlifecomputers.com/2019/05/10152339/Spreadsheet-File-Descriptions.pdf, p.5), location classes 3, 2 and 1 were associated with error radius under 250 m, 375 m and 1000 m respectively. No error radius estimation is given for Argos A and B classed locations, and therefore these were combined with class 0 Argos data, for which an error radius of 1500 m was used.

The utilization distributions were then estimated, 50% BBMM areas extracted, and the isopleths (Cheng et al., 2023) plotted alongside the SSM predicted locations using the R package leaflet (Cheng et al., 2023). Sea lions with limited location measures yielding limited or unrealistic 50% BBMM isopleths (e.g., including a large area of the mainland) are not included in reporting here. Note that while accounting for the presence of physical boundaries in the study area may be desirable, we have not yet explored their implementation within the BBMM. While land may potentially be considered a physical boundary while strictly foraging, sea lions are physically capable of occupying terrestrial locations and do so when resting or mating. Thus, accounting for a meaningful physical boundary for this species would require further consideration and perhaps be context specific, which at this point has not been included in the current analyses.

3 Results

3.1 Marking and resight surveys

3.1.1 Marking

Marking trials were undertaken over two days (28 June 2022 at Seal Island and 4 August 2022 at Carnac Island), using the marking pole and a range of hair dye products as per the methods described in section 1.3.3 above, to determine which combination would prove to be the most visible and long lasting. The marking pole, developed for marking sea lions with individual numbers, proved suitable for the application. We were able to approach sea lions sufficiently close to apply the mark with minimal disturbance. Nine sea lions were marked during the trial using bleach, black, blue, red and pink hair dyes. Opportunistic sightings were recorded by DBCA Marine Rangers over the following weeks, to determine visibility and longevity of the marks. Both, bleach and black hair dye, had the best duration of those trialled, and both were further trialled on sea lions that were anesthetised and tagged in September to determine the best option between the two. An additional four sea lions were marked between 7 and 9 September 2022 using a combination of bleach and black hair dye, and on both sides of their bodies during the tagging process (Table 1).

Based on resights of these individuals, the black hair dye left the most visible marks as the bleach markings could blend into the blonde colour of some individuals' fur. Hence, black hair dye was used exclusively for all further marking associated with the mark-resight study. Between 2 and 15 November 2022, 11 sea lions were marked on both sides of their bodies during the tagging process. Between 9 and 22 November 2022, 35 sea lions were marked on one side of their bodies using the marking pole. All marking took place on Carnac and Seal islands. In total, 58 sea lions were marked between June and November 2022. Photos were taken, when possible, of all marked sea lions to be used for photo-identification and subsequent resighting and information recorded on individuals at time of marking included the unique number used, its appearance (full/partial/smudged), age class and response to the marking process (Table 1).

Table 1. Summary of all marked sea lions, including the ID number they were marked with, the colour used, age class, date of marking and location where marking took place. Rows highlighted in green indicate the trial animals whose marks did not last through to the resight surveys (SAM=subadult male, UNK=unknown).

ID Number	Colour	Age class	Mark placement	Date Marked	Location Marked
100	Bleach	Bull	Right side	28-Jun-22	Seal Island
3 Blobs	Bleach	Bull	Right side	28-Jun-22	Seal Island
102	Bleach	Bull	Left side	28-Jun-22	Seal Island
101	Bleach	Bull	Left side	28-Jun-22	Seal Island
103	Bleach	Bull	Left side	28-Jun-22	Seal Island
122	Bleach, red, black	Bull	Left side	4-Aug-22	Carnac Island
177	Bleach, black, red	Bull	Left side	4-Aug-22	Carnac Island
440	Blue, pink, bleach	Bull	Left side	4-Aug-22	Carnac Island
Chain*	Bleach	Bull	Left side	4-Aug-22	Carnac Island
O1	Black, bleach	Bull (young)	both sides	7-Sep-22	Carnac Island
O2	Black, bleach	Bull (young)	both sides	8-Sep-22	Carnac Island
O3	Black, bleach	SAM	both sides	8-Sep-22	Carnac Island
O4	Bleach, black	Bull	both sides	9-Sep-22	Carnac Island
O5	Black	Bull	both sides	2-Nov-22	Carnac Island
O6	Black	SAM	both sides	2-Nov-22	Carnac Island
O7	Black	SAM	both sides	3-Nov-22	Carnac Island
O8	Black	Bull	both sides	4-Nov-22	Carnac Island
O9	Black	Bull	both sides	9-Nov-22	Seal Island
O10	Black	SAM	both sides	10-Nov-22	Seal Island
O11	Black	Bull	both sides	10-Nov-22	Seal Island
O12	Black	SAM	both sides	15-Nov-22	Seal Island
O13	Black	Bull	both sides	15-Nov-22	Seal Island
O17**	Black	Bull (young)	both sides	21-Nov-22	Seal Island
101	Black	Bull	both sides	15-Nov-22	Seal Island
O16	Black	SAM	Right side	9-Nov-22	Carnac Island
O18	Black	SAM	Right side	9-Nov-22	Carnac Island
O19	Black	SAM	Right side	9-Nov-22	Carnac Island
O21	Black	Bull	Left side	14-Nov-22	Carnac Island
O23	Black	Bull	Right side	14-Nov-22	Carnac Island
O24	Black	Bull (young)	Right side	14-Nov-22	Carnac Island
O25/141***	Black	Bull	Right side	14Nov-22	Carnac Island

O26	Black	Bull	Right side	14-Nov-22	Carnac Island
O27	Black	Bull	Right side	14-Nov-22	Carnac Island
O28	Black	Bull	Left side	14-Nov-22	Carnac Island
O29	Black	SAM	Left side	14-Nov-22	Carnac Island
O38	Black	Bull	Right side	14-Nov-22	Carnac Island
O39	Black	Bull	Left side	14-Nov-22	Carnac Island
O51	Black	Bull	Left side	21-Nov-22	Carnac Island
O52	Black	UNK	Left side	21-Nov-22	Carnac Island
O53	Black	Bull	Right side	21-Nov-22	Carnac Island
102	Black	SAM	Right side	15-Nov-22	Seal Island
103	Black	Bull (young)	Left side	15-Nov-22	Seal Island
104	Black	Bull (young)	Left side	15-Nov-22	Seal Island
105	Black	SAM	Left side	21-Nov	Seal Island
106	Black	SAM	Left side	21-Nov-22	Seal Island
108	Black	juvenile	Right side	21-Nov-22	Seal Island
142	Black	juvenile	Left side	21-Nov-22	Seal Island
143	Black	SAM	Left side	21-Nov-22	Seal Island
144	Black	SAM	Right side	21-Nov-22	Seal Island
145	Black	Bull	Left side	21-Nov-22	Seal Island
150	Black	SAM	Right side	22-Nov-22	Seal Island
151	Black	SAM	Left side	22-Nov-22	Seal Island
152	Black	Bull	Right side	22-Nov-22	Seal Island
153	Black	SAM	Left side	22-Nov-22	Seal Island
154	Black	SAM	Right side	22-Nov-22	Seal Island
155	Black	SAM	Left side	22-Nov-22	Seal Island
156	Black	SAM	Left side	22-Nov-22	Seal Island
158	Black	SAM	Left side	22-Nov-22	Seal Island

*The mark on this sea lion did not go on cleanly and resemble a number, rather it had the appearance of several chain links.

**This sea lion was marked originally on the right side (017) 9 November at Carnac Island, then tagged and marked on the left side on 21 November on Seal Island.

***This sea lion was originally marked on the right side (025) on 14 November at Carnac Island, but was then marked on the left side (141) on 21 November at Seal Island.

While all attempts were made to obtain as random a sample as possible, some sea lions could not be approached for marking without causing them to move away, some reacted to marking, thus causing a partial or smudged number, and some were wet and not selected as good candidates. In addition, only two juveniles were marked as this cohort was much more responsive and difficult to approach without disturbance, including displaying vigilant posture and moving away.

3.1.2 Resight surveys

A total of 12 resight surveys were undertaken, four in December 2022, four in January and four in February 2023. Surveys within each month were undertaken over a 10-day period to allow testing of a 'robust' mark-resight modelling approach (see section 2.3.4). Table 2 contains a summary of counts for each survey day, including the number of marked and tagged animals observed (the number tagged are also included in the number marked).

Table 2. Summary data of sea lion resight surveys between December 2022 through February 2023.

Date	Number of Juveniles	Number of SAMs	Number of Bulls	Total	Number marked	Number tagged
7-Dec-22	8	21	21	**50**	13	7
9-Dec-22	13	17	32	**62**	18	7
14-Dec-22	8	19	16	**43**	18	9
16-Dec-22	8	10	28	**46**	15	7
4-Jan-23	13	22	17	**52**	12	6
6-Jan-23	10	23	18	**49**	12	3
11-Jan-23	10	28	19	**57**	10	4
13-Jan-23	10	17	19	**46**	5	2
8-Feb-23	16	23	16	**55**	3	1
10-Feb-23	17	22	15	**54**	5	3
15-Feb-23	16	12	28	**56**	10	2
17-Feb-23	9	12	22	**43**	4	0

Note: The numbers reported are across all haul-out sites and are not broken down here by location. The dark lines demarcate monthly survey sessions. The numbers marked and tagged do not take into account individuals that could not be identified (i.e., had a discernible mark or tag baseplate, but could not be confidently identified). SAM = subadult males.

As an indication of resight rate, 22 of the 58 marked sea lions were not seen again after being marked. During the 12 resight surveys, individual sea lions were resighted 1 to 8 times across a range of 1 to 3 haul-out islands. While those individuals sighted more often were more likely to be observed on multiple haul-out islands, there were several sea lions sighted 4 or 5 times at the same island. Photographically confirmed opportunistic sightings of marked sea lions outside of the island surveys recorded animals that travelled southwards from the Perth area to coastal waters of Cape Naturaliste, Ngari Capes Marine Park and Comet Bay off Mandurah metropolitan waters and northwards to Jurien Bay Marine Park.

3.1.3 Abundance estimate

Of the mark-resight models implemented, the mixed logit normal was selected for reporting abundance estimates. The logit-normal estimator with incomplete marked individual identification was used similar to McClintock et al. (2014) for abundance estimation of western Steller sea lions (*Eumetopias jubatus*) in Alaska. As in that study, incomplete marked individual identification was known to be possible as a result of animal body position only showing the unmarked side, for example, or another animal's body obstructing the observer's view. In addition, the model allowed for an unknown number of marked individuals, which was relevant given that marks were observed to fade over time. Because the population is assumed to be 'closed' with this modelling approach, the abundance estimates represent a 'super population' (N*) of individuals associated with the study area during the period (McClintock, 2021), but not necessarily directly in the study area at each sampling occasion. The logit-normal model which assumes a closed population was selected over the Poisson and zero-inflated log normal models with robust design, as the tag data indicated regular movement in and outside of the study area.

The logit normal mark-resight model yielded abundance estimates for each of the 12 sampling occasions presented in Table 3. The model resulted in an estimated abundance ranging from 80 (49-113 HPD credibility intervals) to 122 (67-184 HPD credibility intervals) individuals based on estimates with good convergence diagnostics (r-hat < 1.01; Table 3).

Table 3. Absolute abundance (N*) in the study area during the study period, lower and upper 95% HPD Credibility Intervals, and r-hat a measure of model convergence, for surveys from December 2022 through February 2023. Rows highlighted in blue indicate the estimates associated with a good convergence diagnostic.

Date	N*-hat	95% HPD Credibility Intervals		r-hat
		Lower	Upper	
7-Dec-22	82.9	46.3	128.9	1.00
9-Dec-22	118.4	77.2	166.0	1.00
14-Dec-22	80.0	48.7	113.4	1.00
16-Dec-22	107.3	65.3	161.5	1.07
4-Jan-23	157.2	86.1	240.6	1.14
6-Jan-23	121.9	67.0	183.9	1.00
11-Jan-23	167.4	95.2	250.0	1.03
13-Jan-23	224.6	106.8	372.8	1.77
8-Feb-23	340.5	153.9	629.2	1.70
10-Feb-23	218.9	109.4	355.0	1.27
15-Feb-23	185.1	94.7	288.6	1.48
17-Feb-23	231.5	92.7	411.5	1.67

Parameter estimates associated with a relatively poor convergence diagnostic (r-hat > 1.00), increasingly occurred over the study period (Table 3).

3.2 Telemetry tagging

3.2.1 Deployment

A total of 15 telemetry tags were deployed (Figure 2) in September and November 2022 following the methods described above in Section 2.3.2. An initial 4 tags were deployed in September to trial and refine the deployment process and test the tags before deploying the remainder of the tags in November. This proved a useful and important strategy as the PRD was unable to communicate with the tag as programmed, due to a software bug, and required the supplier to develop and provide a software update to work. This led to an initial high tag loss, and the tag supplier subsequently provided four Splash10-F tags used in the second deployment. Thus, the 15 deployed tags included: 11 MK10 tags with ARGOS PRDs and 4 Splash10-F tags.

In addition, we were able to refine the process for darting, anaesthetising and processing sea lions. This included testing and refining the new anaesthetic regime (to be published by the wildlife veterinarians who developed the method), adapting the sea lion approach methodology to reduce initial disturbance and possible fleeing into the water and developing a technique and equipment to weigh the sea lions.

Tag deployment longevity and retrieval success varied across tags (Figure 2). Of the 11 MK10 tags, four were successfully retrieved, while seven were lost. Of the seven lost, four were prematurely released due to mechanical or electrical failure of the PRD and two could not be released despite many attempts, due to the PRD software bug. The Splash10-F tags did not require retrieval, however, two Splash10-F tags stopped transmitting data prematurely, after 9 and 10 days, possibly due to battery failure, although they remained attached and with no problems obvious or visible externally for a much longer period of time.

Deployment length ranged from 1 to 63.5 days (mean = 21, SD = 18.6); with MK10 tag deployment durations ranging from 1 to 58.8 days and Splash10-F tags ranging from 9 to 63.5 days. The resulting data from these tags, includes relatively low-resolution locations (Argos) from all tags (n=15), fine scale location (Fastloc GPS), time, depth and temperature data for all MK10 tags that were retrieved (n=4), and high-resolution location (i.e., Fastloc GPS) and moderate resolution time data, and depth summaries for all Splash10-F tags (n=4). In summary, the data from all 15 tags provide the information required for describing movement of the sea lions during their deployment periods, while eight tags provide information on dive characteristics that may be considered consistent with foraging behaviour.

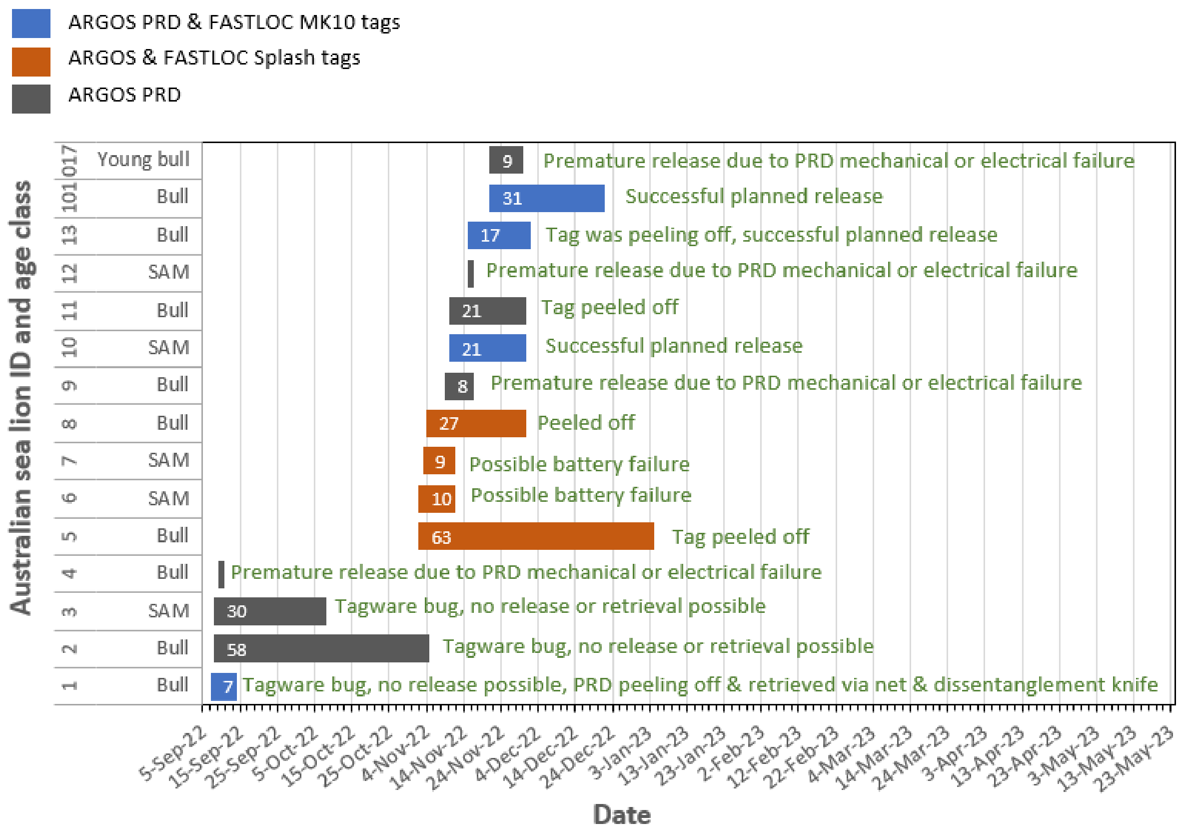

Figure 2. Telemetry tag deployment summary. SAM = subadult male.

3.2.2 Sea lion dive trips

Dive trip duration to sea for tagged sea lions during this study ranged from 0.20 to 2.87 days, with an overall mean of 1.21 (SD = 0.65) days (Table 4). Dive trip durations, from the PRD data (for MK10 tags that could not be recovered) and from the Splash tags were considered to be underestimations due to the rules applied during data processing, which maximised consistency and comparability, and the lower temporal resolution for locations. Haul-out periods were also relatively short, ranging from 0.36 days to 3.86 days with a mean of 1.40 (SD = 0.85) days for all sea lions.

The mean percent of time each sea lion spent hauled out while tagged ranged from 36% to 80%, with an overall mean of 54% (SD = 12%) across all sea lions. The mean time hauled out was slightly greater from Splash tags (59%, SD = 14%) data than from MK10s (51%, SD = 3%) and PRDs (51%, SD = 13%), with the greatest precision resulting from MK10s.

Based on observations only of all marked sea lions, most sea lions (65%, n=38) were observed at only one haul-out location in the Perth metropolitan area, 27% (n=16) were observed on at least two islands and 7% (n=4) from three islands, indicating movement and use of the broader Perth metropolitan area. By comparison, when using both the tagging data and observations during mark-resight surveys, for the tagged individuals 40% (n=6) were recorded at one haul-out site, 20% (n=3) at two haul-out sites and 40% (n=6) at three haul-out sites. At least three tagged and one marked individual were also observed at haul-out sites outside the Perth metropolitan area.

Table 44. Mean dive trip and haul-out period duration for all sea lions.

ID	# of trips	Mean dive trip duration (days)	SD dive trip duration (days)	# of haul-out periods	Mean haul-out duration (days)	SD haul-out duration (days)	Mean percent of time hauled out	Haul-out location(s)*
ASL01	3	0.93	0.48	2	0.92	0.55	50	Carnac
ASL10	10	1.18	0.79	9	1.10	0.49	48	Seal
ASL13	5	1.35	0.29	4	1.61	0.49	54	Seal
ASL101	11	0.60	0.63	10	0.58	0.09	49	Seal, Cape Naturaliste
All MK10 tags	**29**	**1.0**	**0.68**	**25**	**1.05**		51	
ASL05	26	1.11	0.55	26	1.11	0.45	50	Carnac, Seal, Dyer
ASL06	5	0.49	0.54	5	1.08	0.48	69	Carnac, Seal, Dyer*
ASL07	5	0.28	0.12	5	0.92	0.36	77	Carnac
ASL08	11	0.84	0.67	11	1.58	1.09	80	Carnac, Dyer, Seal*
All Splash tags	**47**	**0.89**	**0.61**	**47**	**1.17**		59	
ASL02	22	1.14	0.74	22	1.40	0.82	55	Carnac, Seal, Dyer, North Fisherman**
ASL03	9	1.62	1.15	9	1.20	0.60	43	Carnac, Seal
ASL04	1	1.42	NA	NA	0.59	NA	NA	Carnac, Seal
ASL09	2	2.38	NA	1	1.51	NA	39	Seal
ASL11	3	1.96	0.91	3	4.04	2.55	67	Seal
ASL12	1	NA	NA	NA	NA	NA	NA	
ASL017	3	2.07	1.13	2	1.14	1.45	36	Seal, Carnac, Burns Beach Rocks
All PRDs	**41**	**1.77**		**37**	**1.86**		51	
Total/Average	**117**	**1.21**		**109**	**1.40**		54	

PRD = Payload Release Device

*Some sightings at additional haul-out sites were recorded after the tags were no longer active, during the mark-resight surveys.

** North Fisherman Island is one of the breeding islands in Jurien Bay Marine Park and ASL02 visited this island.

3.2.3 Sea lion movement

Sea lions fitted with satellite tags were recorded as far north as Jurien Bay Marine Park and as far south as Cape Naturaliste, Ngari Capes Marine Park (WA). While most individuals spent the majority of time within the Perth metropolitan and surrounding area, moving between haul-out islands, coastal areas and open water, forays were made to coastal waters of Mandurah (Comet Bay and the inlet Collins Pool), Preston Beach, and Bunbury (Koombana Bay) by seven of the 15 sea lions during the period their tags transmitted locations (see Figures 3-15 for maps of ASL01, 02, 03, 04, 05, 06, 07, 08, 10, 13, 101 and 017). These included bulls and subadult males.

Tagged individuals (ASL02, ASL03 and ASL101) that undertook longer range movements (in the order >200 km) travelled north and south respectively and included return trips to the Perth area. These movements were consistent with longer diving trip times (2.48 to 3.10 days). ASL02 travelled over 200 km north to Fisherman Islands (30°08' S, 114°56' E), with North Fisherman Island a known breeding island in Jurien Bay Marine Park, before returning to the Perth metropolitan area 7 days later (Figure 5). ASL03 travelled north to just south of Jurien Bay Marine Park before the tag failed and no further locations were transmitted (Figure 4). A marked sea lion that was not tagged was also photographed in Jurien Bay Marine Park before being resighted again in the Perth area. ASL101 travelled south along the coast to Cape Naturaliste, Ngari Capes Marine Park, and spent multiple days between haul-out periods at "East Island" (33°31'55" S, 115°01'23" E), Cape Naturaliste and short diving, presumably foraging, trips in Bunker Bay and Geographe Bay, as indicated by the dive trips recorded for this individual and visual observations (Figure 15). For each of his ten dive trips off Cape Naturaliste, ASL101 left "East Island" between approximately 7 – 8:30 am local time to return 6 – 12 h later.

BBMMs identified a range of core areas used by individuals during diving trips captured by deployed tags and are highlighted in Figures 3-15 as coloured polygons.

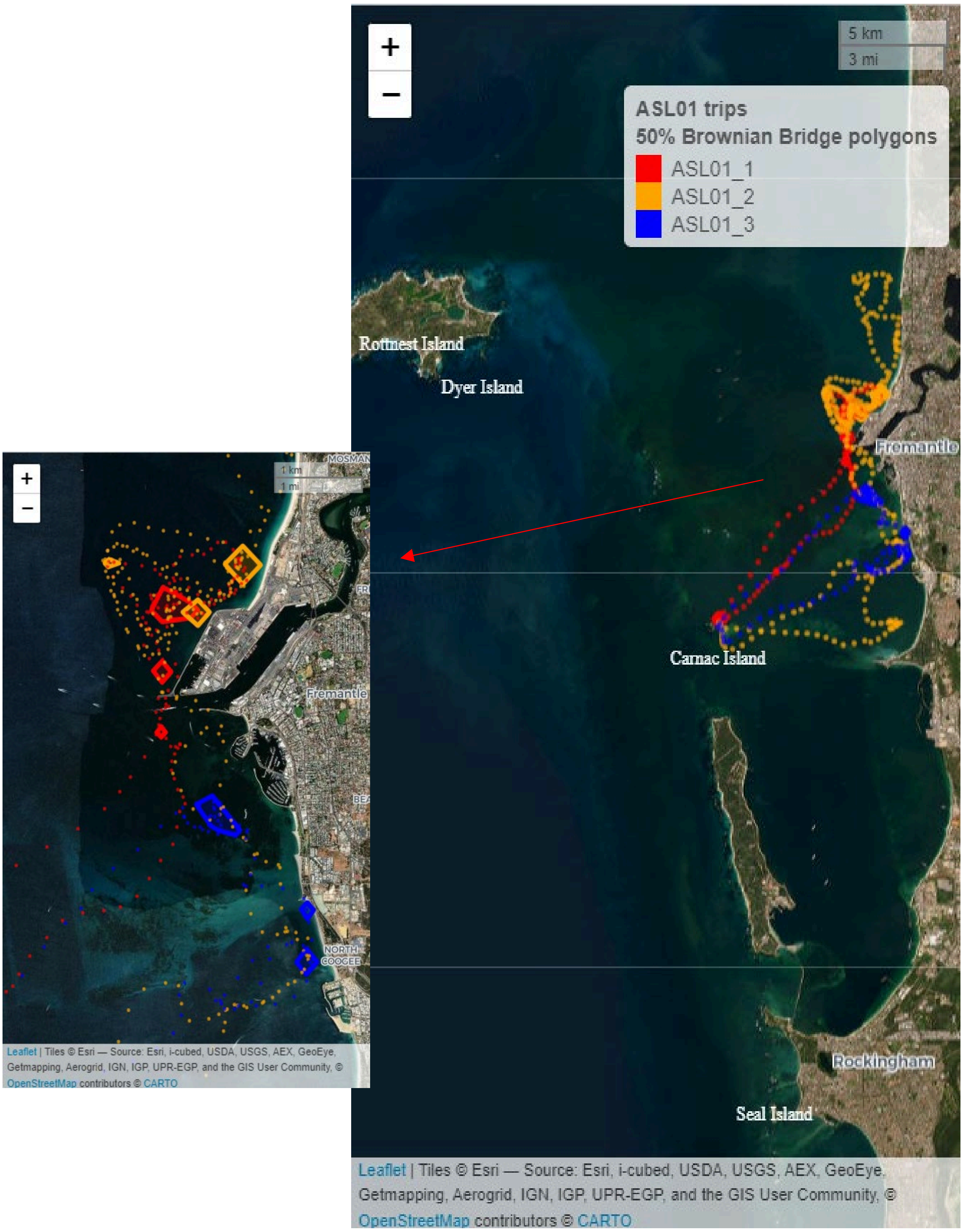

Figure 3. Map of estimated locations from state space models for each trip based on all received locations (Fastloc GPS and Argos) for ASL01 (a bull) over 7 days from the tagging date on 7 September 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

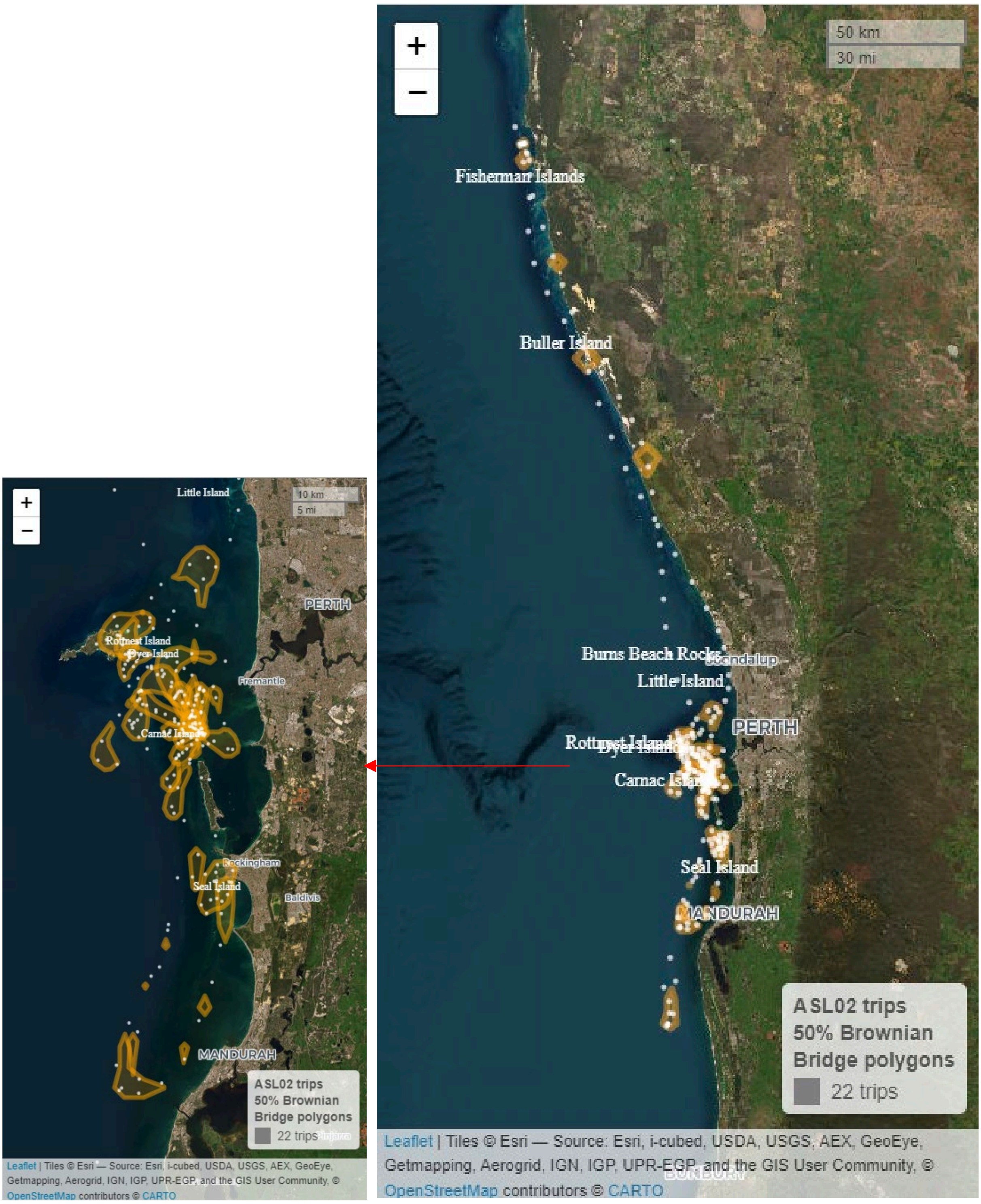

Figure 4. Map of estimated locations from state space models for each trip based on all received locations (Argos only) for ASL02 (a bull) over 58 days from the tagging date on 8 September 22. High use areas for each dive trip are depicted with polygons representing the 50% Brownian Bridge movement model area for each trip.

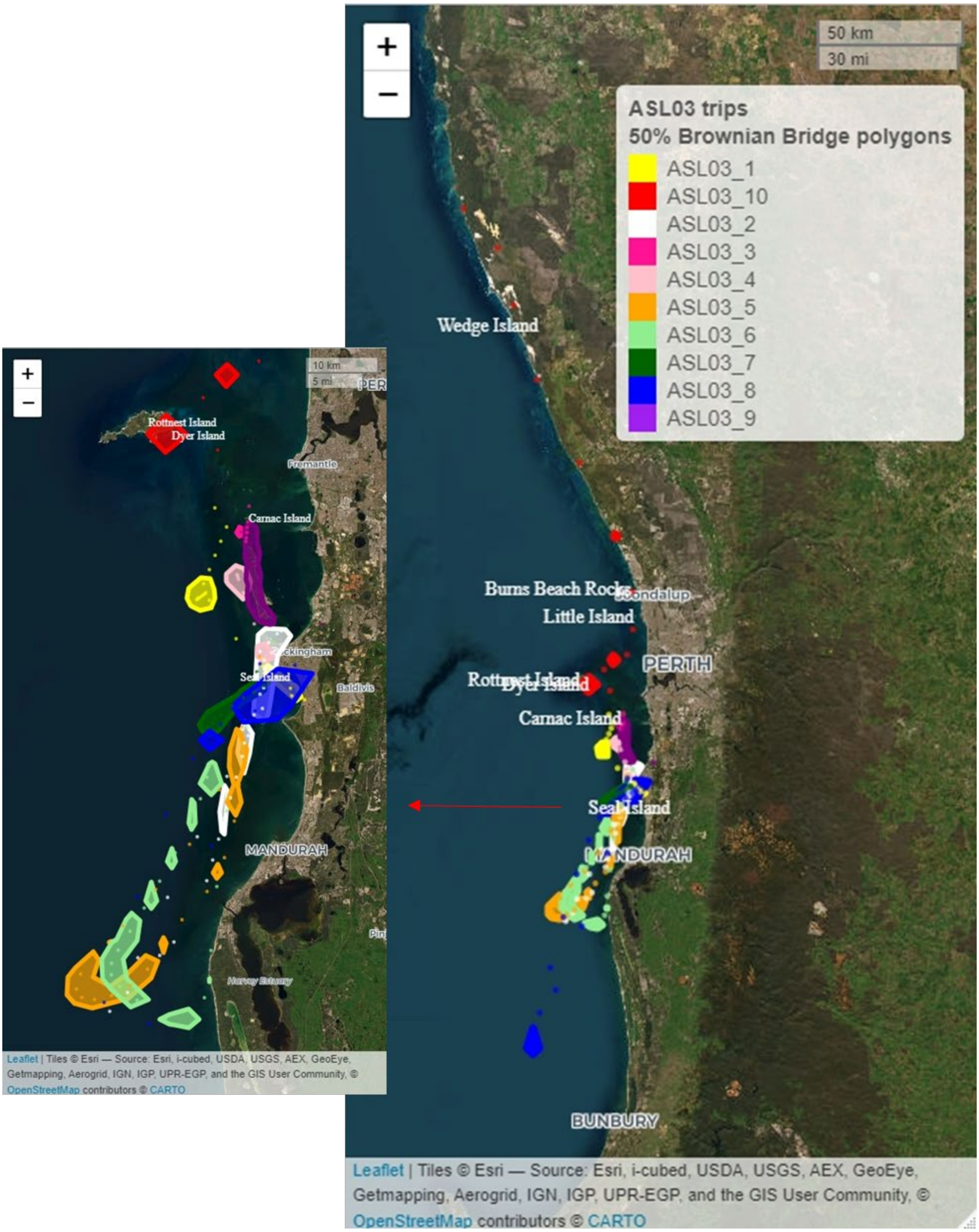

Figure 4. Map of estimated locations from state space models for each trip based on all received locations (Argos only) for ASL03 (a subadult) over 30 days from the tagging date on 8 September 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

Figure 55. Map of estimated locations from state space models for each trip based on all received locations (Argos only) for ASL04 (a bull) over 2 days from the tagging date on 9 September 22. High use areas for each dive trip are depicted with polygons representing the 50% Brownian Bridge movement model area for each trip.

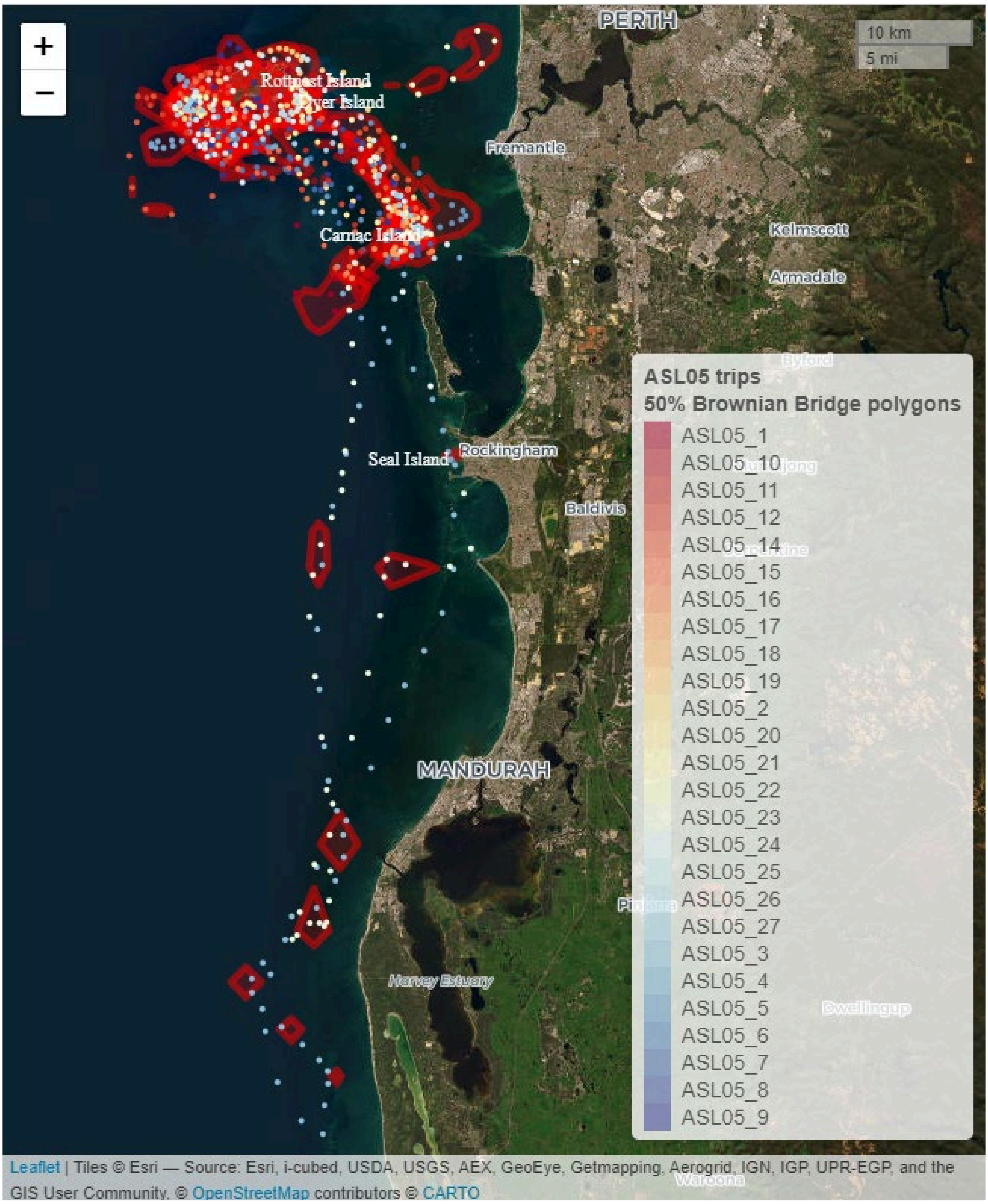

Figure 6. Map of estimated locations from state space models for each trip based on all received locations (Fastloc GPS only) for ASL05 (a bull) over 63 days from the tagging date on 2 November 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

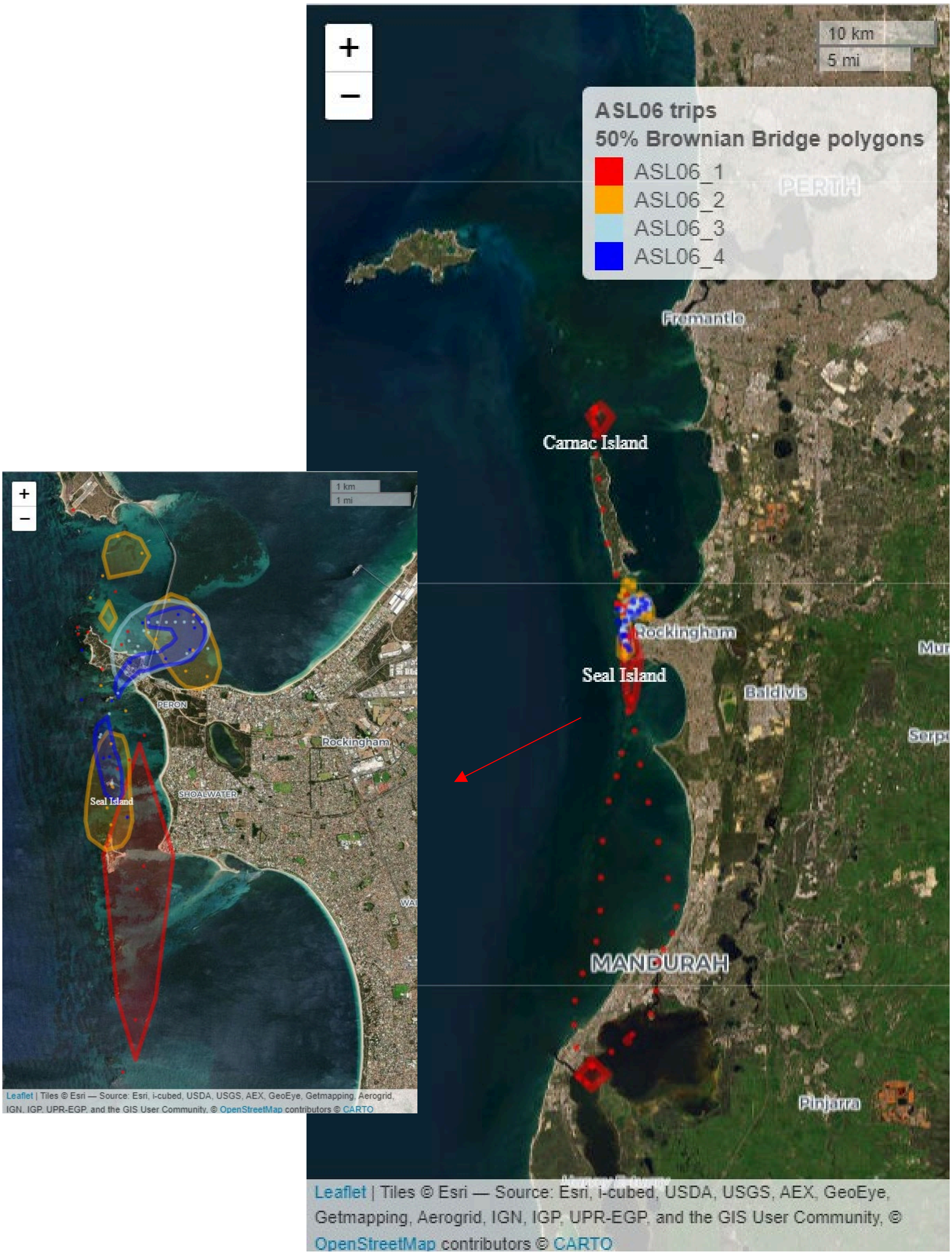

Figure 7. Map of estimated locations from state space models for each trip based on all received locations (Fastloc GPS only) for ASL06 (a subadult) over 10 days from the tagging date on 2 November 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

Figure 8. Map of estimated locations from state space models for each trip based on all received locations (Fastloc GPS only) for ASL07 (a subadult) over 9 days from the tagging date on 3 November 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

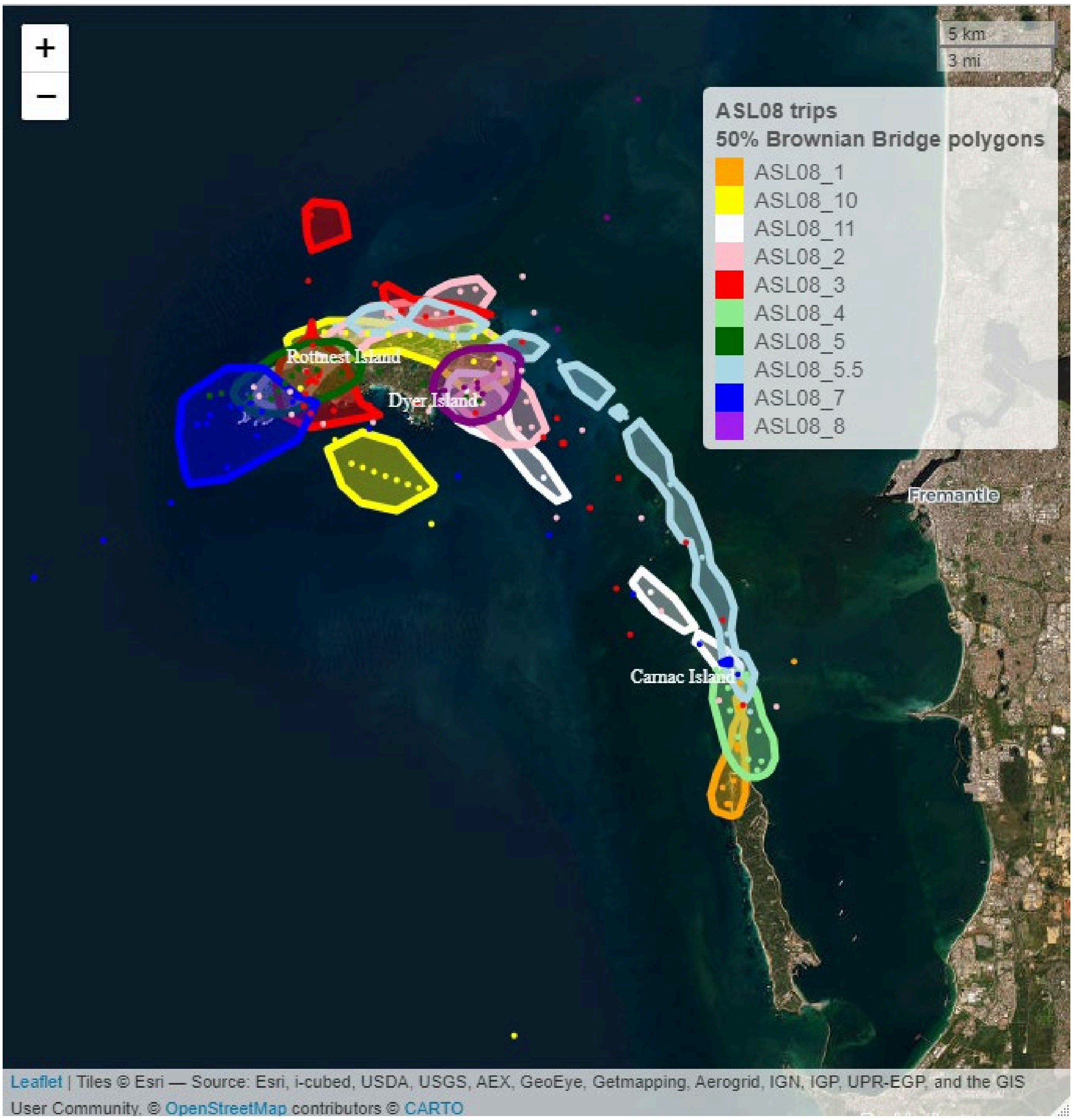

Figure 9. Map of estimated locations from state space models for each trip based on all received locations (Fastloc GPS only) for ASL08 (a bull) over 27 from the tagging date on 4 November 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

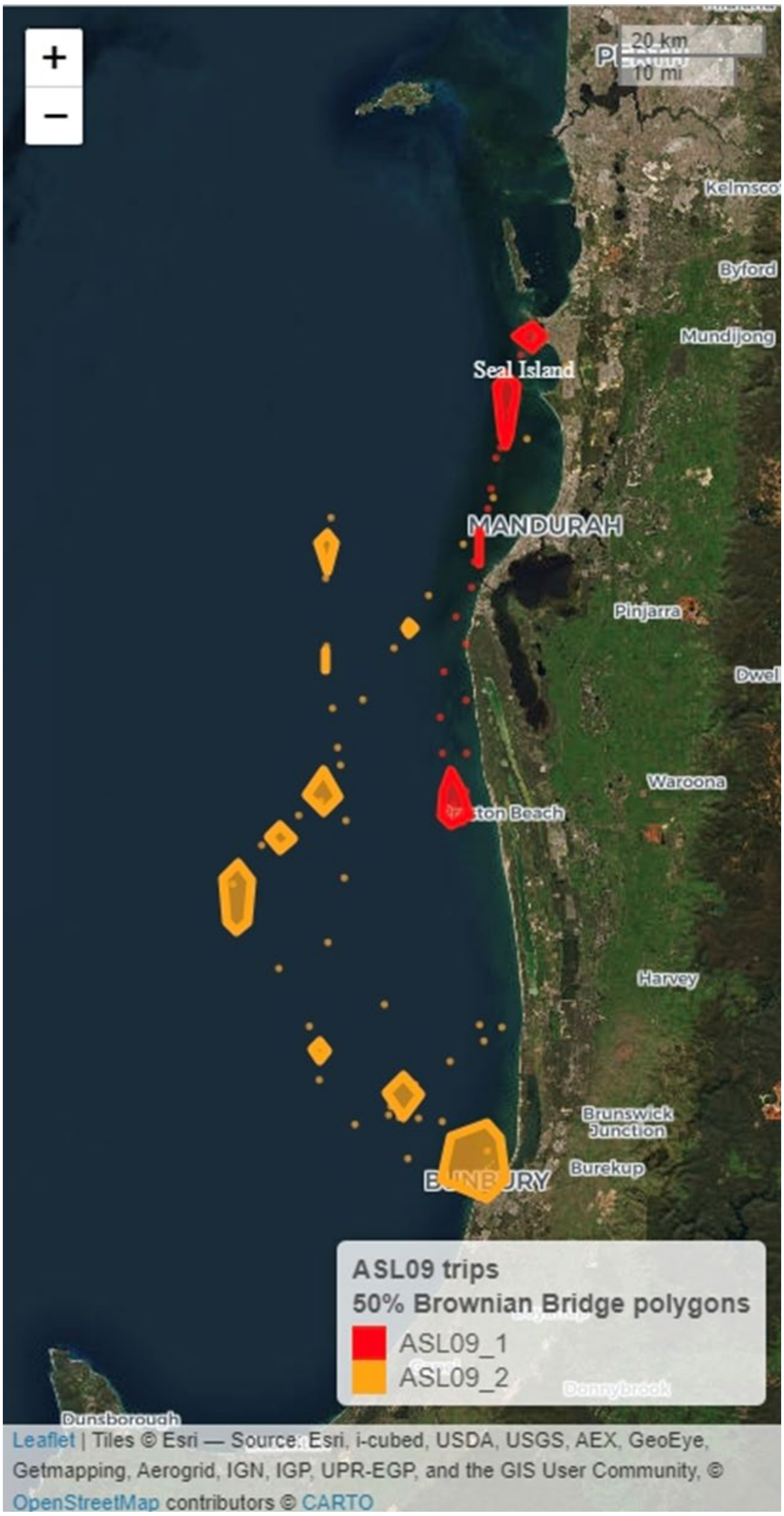

Figure 10. Map of estimated locations from state space models for each trip based on all received locations (Argos only) for of ASL09 (a bull) over 8 days from the tagging date on 9 November 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

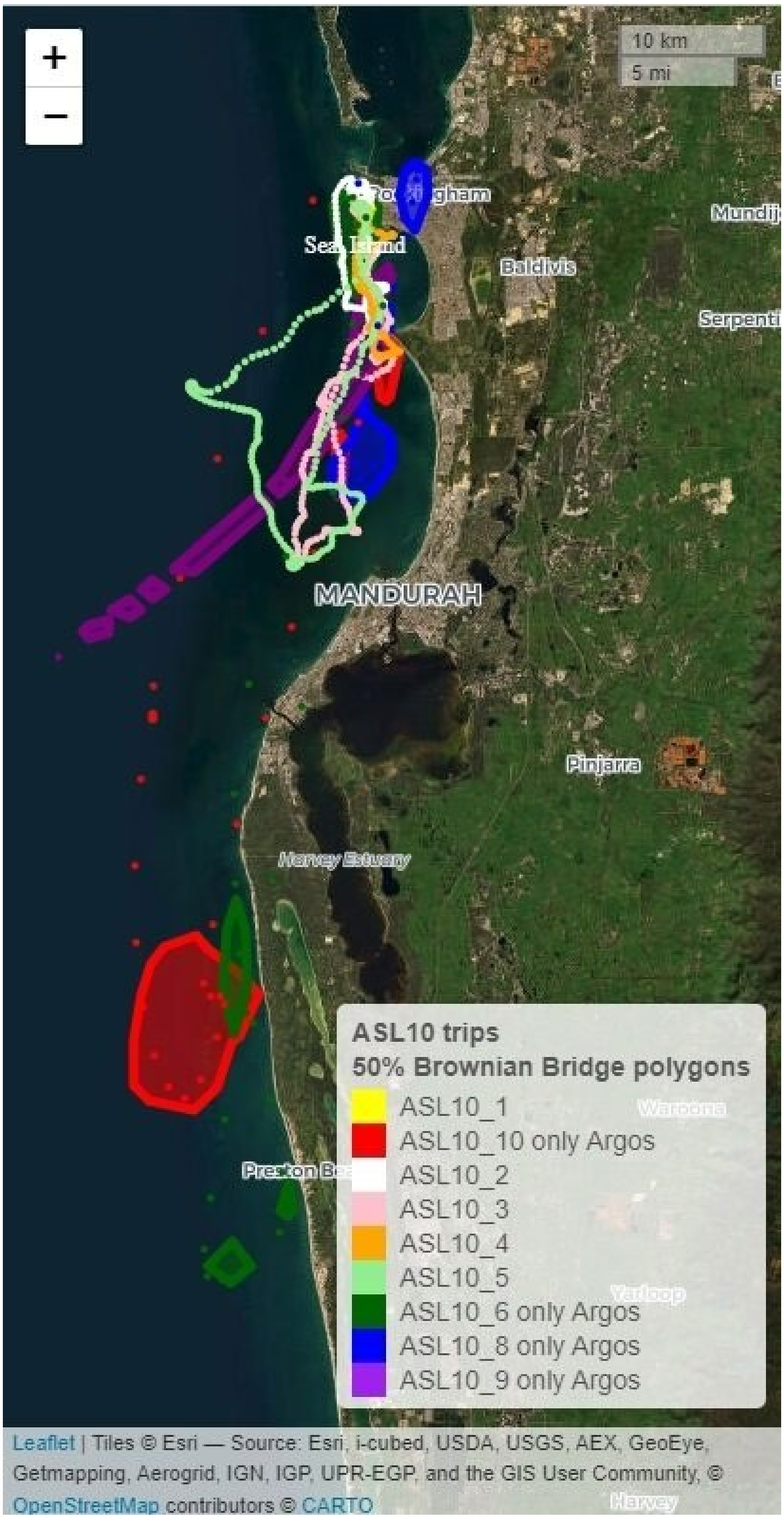

Figure 11. Map of all estimated locations from state space models for each trip based on all received locations (Fastloc GPS and Argos) for ASL10 (a subadult) over 21 days from the tagging date on 10 November 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

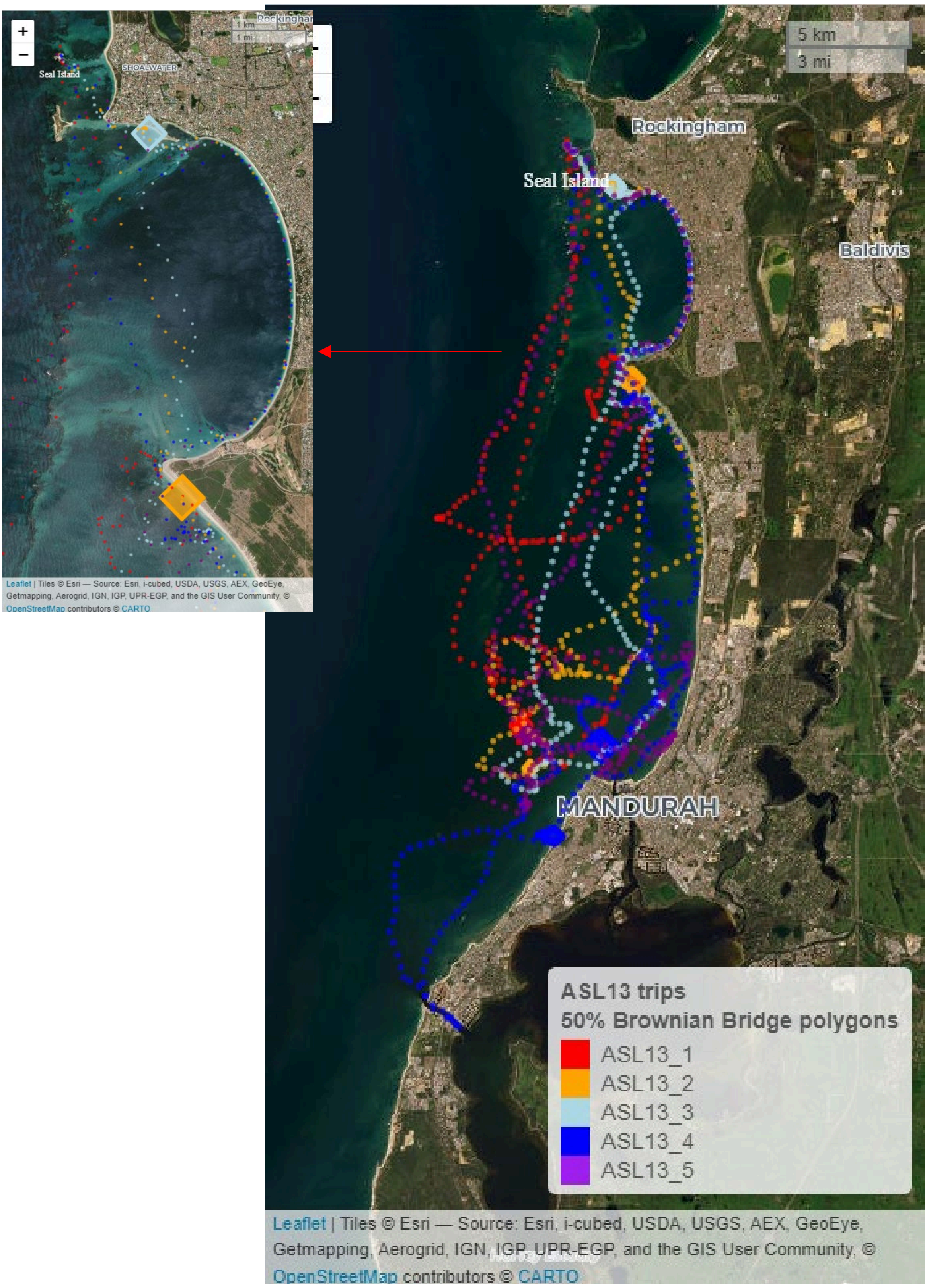

Figure 12. Map of estimated locations from state space models for each trip based on all received locations (Fastloc GPS and Argos) for ASL13 (a bull) over 17 days from the tagging date on 15 November 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

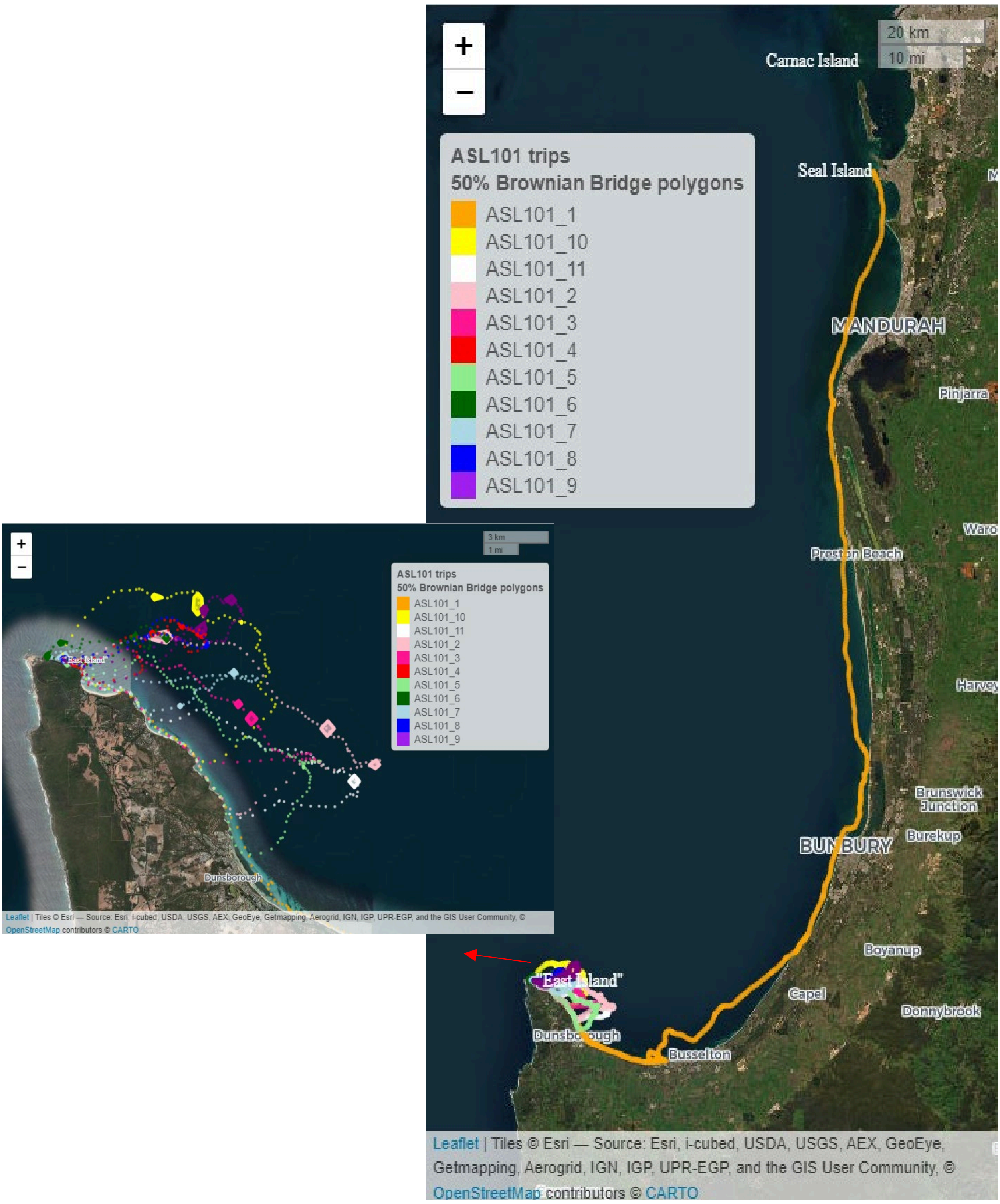

Figure 13. Map of estimated locations from state space models for each trip based on all received locations (Fastloc GPS and Argos) for ASL101 (a bull) over 31 days from the tagging date on 20 November 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

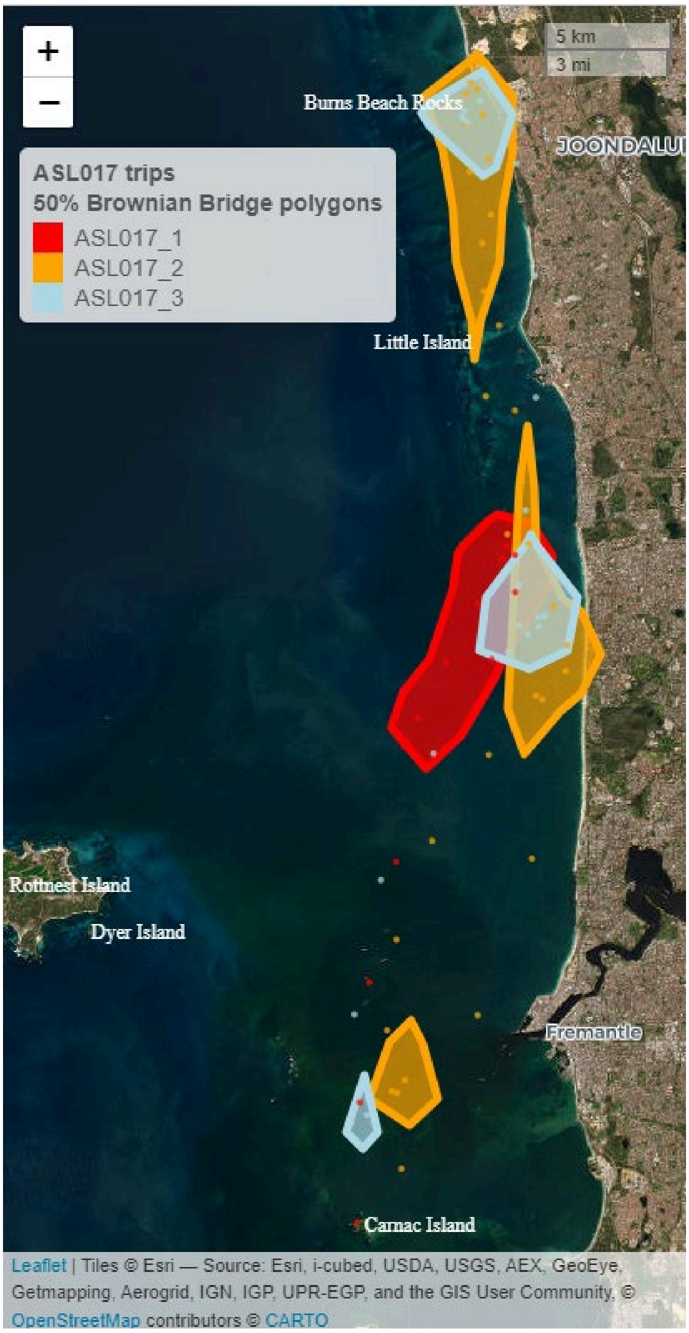

Figure 14. Map of estimated locations from state space models for each trip based on all received locations (Argos only) for ASL017 (a young bull) over 9 days from the tagging date on 21 November 22. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

3.2.4 Dive patterns

During trips within the Perth metropolitan area, most sea lions using the coastal waters occupied the region between the mainland coast and haul-out islands, and were presumably foraging. Some individuals were recorded having dive trips over very short durations where they likely temporarily left a haul-out and entered the water for thermoregulatory purposes rather than foraging. Dive depth during presumed foraging trips reached a maximum of 48 metres with a mean of 6.7 metres (SD=6.4).

Other studies of sea lions classified dives as those >6 m (e.g., Costa and Gales (2003), however, in this study this would have excluded many of the dives where sea lions were likely foraging in shallow water, close to shore. We, therefore, applied an approach more consistent with Lowther et al. (2011) and Waluda et al. (2010) in an effort to capture the majority of foraging behaviour, whilst avoiding misidentification of dives.

Using Wildlife Computers' categorization of dive shapes, 81% of ASL01's dives were classed as Square-shaped dives, and 12% and 7% of dives as U- and V-shaped dives, respectively. Preliminary analysis of these dive shapes over the period of dive trips showed that dives of all shapes were distributed in proportion to the time spent in the area. This is likely to indicate that sea lions were following the benthos throughout their dive trips on consecutive dives, presumably foraging.

Despite there being variation between tagged individuals in locations where dives occurred, some fidelity to particular foraging areas was apparent with multiple individuals revisiting locations they, or other sea lions, had previously visited. For example, ASL01 travelled towards the shoreline of Fremantle in a relatively straight line, spent time close to the coast in shallow inshore waters, before heading directly back to Carnac Island. He then visited nearshore waters of North Fremantle for an extended period during multiple trips and spent most of the time, while not hauled-out, off South Fremantle in shallow water (~3-5 m water depth) (Figure 4). Similarly, several individuals (ASL02, ASL05, ASL08) revisited Rottnest Island on multiple occasions (Figures 5, 8 & 11).

3.3 Stable isotope - whiskers

Whisker samples were obtained from all 15 sea lions that were tagged. All were successfully plucked, with one whisker incurring a slight level of damage from the pliers, and another breaking at the root.

As the analysis of stable isotopes from whiskers is within the scope of WAMSI-Westport Project 4.2.3 (Trophic pathways and food web structure), reporting of analyses is not included in this Project.

4 Discussion

4.1 Sea lion abundance in Perth metropolitan waters

This study produced sea lion abundance estimates ranging from 83 (49-113 HPD credibility intervals) to 122 (67-184 HPD credibility intervals) during the anticipated seasonal peak of sea lion occupancy in the Perth metropolitan area. This represents a proportion of the population of sea lions that presumably breed at the colonies in Jurien Bay Marine Park (WA) as this does not include females who remain near the breeding islands. Similarly, a proportion of males and juveniles may remain at the breeding/haul-out islands during the non-breeding season or travel to other haul-out only locations (e.g., Geraldton). The overall population size for sea lions in WA is thought to be in the low thousands (Goldsworthy et al., 2021). To better understand the proportion of the Jurien Bay Marine Park breeding population that uses the Perth metropolitan area requires a better understanding of movement between breeding and haul-out areas along the west coast and throughout the breeding/non-breeding cycle. For example, at least three sea lions travelled from the Perth metropolitan area to Jurien Bay Marine Park, with two known to return to Perth during the study. Previously, it had been assumed that once sea lions left Jurien at the end of the breeding season, they did not return until the following breeding season. This has implications for the model selected and associated assumptions.

While the model selected provided an estimate of the 'super-population' (i.e., the absolute abundance of individuals associated with the study area, rather than those within the study area), resights were conducted over only three months of the ~9-month non-breeding period, and abundance estimates only had reliable convergence for earlier occasions during the mark-resight study. In addition, juveniles were under-sampled during this study as only two juveniles were marked. As a result, the estimates presented here do not include the juvenile cohort of the population using the Perth metropolitan area.

More regular movement between the metropolitan haul-out and breeding areas could mean that this region is used by a larger number of sea lions than represented in the model, as the modelled abundance may represent the number present at any given time during the peak of the non-breeding season but not the total that use the area over the entire non-breeding season. In addition, this estimate is biased towards adults and subadults and does not account entirely for the juvenile cohort The reliability of the resulting abundance estimates decreased over the study period, and this can be partially explained by a loss of the dyed numbers, that were the temporary marks used for individual identification, over time.

Importantly, the abundance estimates from the mark-resight modelling approach were roughly around the proportion that might be expected to have been hauled out based on haul-out times from tag data in this study and counts of sea lions hauled-out during previous haul-out island counts conducted monthly by DBCA staff. Peak estimates from those monthly sea lion counts conducted between 2015 and 2020 range from 55-74 (DBCA unpublished data, Salgado Kent and D'Cruz, 2021). In this study, based on what is considered the most accurate and precise data from tags deployed (i.e., the MK10s), sea lions spent on average 51% of time hauled out. If this could be inferred to the population (which in this study has not been done), then a total abundance during the monthly counts might have ranged from 108-145. While the total abundance estimates from mark-resight modelling in this study are below (83-122) those that might have been expected from past monthly counts, the HPD credible intervals are within the range (49-113 and 67-184 HPD Cis, respectively). Knowing that mark-resight estimates can be expected to be slight underestimates, this provides some confidence in the mark-resight approach taken here. In addition, it provides confidence in the ongoing use of monthly counts as an approximate indicator of sea lion abundance within the Perth metropolitan area. This may be suitable for management purposes to monitor relative patterns of abundance and distribution for this species, however, for scenarios requiring more accurate and precise measures of abundance and/or behaviour (haul-out duration), such as evaluating pressure-response relationships from industry, coastal development, and human activities more robust abundance estimates to detect change within the natural variability of monthly counts would be required.

While this study provides the first abundance estimates of sea lions in the Perth metropolitan area, it would be improved by effort to account for the younger, juvenile sea lion cohort, that remained under-sampled during this study. In addition, there may be opportunities to further improve the accuracy of estimates through implementation of models that integrate parameters derived from movement of satellite tracked sea lions as well as opportunistic sightings. As mark-resight requires an initial disturbance to sea lions to apply marks, and requires greater effort and resources, ongoing monthly counts are recommended to provide an approximate indicator of large changes in trends for sea lion abundance within the Perth metropolitan area. Mark-resight studies can provide detection of smaller changes in trends, as they can involve more intense sampling and may account for biases in the detection process and variability in behaviour of individual sea lions and cohorts. Any future mark-resight efforts should plan the resight surveys sooner after the initial mark application based on the learnings from this study on how quickly the number marks faded.

4.2 Sea lion movement patterns and foraging behaviour

4.2.1 Sea lion movement

Tagged sea lions in this study were recorded traveling as far north as Jurien Bay Marine Park and as far south as Cape Naturaliste, Ngari Capes Marine Park. While most individuals spent most of their time within the Perth metropolitan and surrounding area at haul-out sites, moving between coastal areas and open water and haul-out sites, and between haul-out sites, forays were made to coastal waters off Mandurah and Bunbury by some sea lions. The long-range trips by multiple individuals up to, or towards, the breeding islands in Jurien Bay Marine Park during the non-breeding season, confirmed by the telemetry data (ASL02, ASL03) or direct observation of the temporary marks (ASL026, DBCA unpublished data, 2022), were most unexpected.

The pattern of trips to sea, with a duration ranging from several hours to over three days, interspersed with haul-out periods ranging from just under half a day to over four days, indicates relatively short foraging trips followed by periods of rest and recuperation, and typically occurring within the study area of Perth metropolitan waters and surrounding regions. In this study, subadults and bulls also travelled beyond Perth metropolitan waters during what were likely forging trips to and from the haul-out islands in the Perth metropolitan region (in addition to undertaking trips to reach haul-out destinations outside of Perth metropolitan region). All of the trips with a departure and return to haul-out sites in the Perth metropolitan area were within approximately 40 km (out to waters off Mandurah), except for one bull that travelled over 100 km (to waters off Bunbury). The results here vary with those from other studies. Dive trip distances for bulls in other studies have documented foraging at ranges up to 340 km away from haul-out sites, while younger sea lions have been documented to travel shorter distances (Goldsworthy et al. 2009b, Lowther and Goldsworthy 2011, Lowther et al. 2011). Foraging in comparison to previous studies is further discussed below (section 4.2.2). While sea lions in this study may have travelled comparably short distances compared to some sea lions in other studies, the overall proportion of time recovering was comparable to sea lions in previous studies (e.g., 40-50% based on Costa and Gales, 2003, Campbell et al., 2008a, Fowler et al., 2006), with approximately half their time spent hauled-out.

In this study, generally, the longer the tag deployments and the higher the temporal resolution of the location data, the more numerous and larger the core areas identified were for individual sea lions. This suggests that the deployment periods and/or resolution of the data were insufficient to map the full extent of individual core areas, or in fact, the range of areas used by sea lions. The average number of days tags transmitted location data was 21 days, and ranged from 1 to 64 days – a period well shy of the total time sea lions spend in the Perth metropolitan area. While the data have shown definite areas of activity, there are limitations to their interpretation due to the small sample size, short temporal coverage and technical issues with the tag such that habitat use and importance cannot be considered definitive. For example, few tag locations occurred within Cockburn Sound during the deployment period for the relatively small sample of sea lions tagged in this study, with the exception of the southern area within Mangles Bay where core areas for two subadults were identified, and the north area of Cockburn Sound (Pig Trough Bay and the area between Carnac Island and Jervoise Bay) where core areas were identified for two bulls. Cockburn Sound, however, is known to be used by sea lions based on visual observations and past telemetry data (2009; Campbell, unpublished data), including for foraging. During this study, there were seven sightings of sea lions at sea within Cockburn Sound, with four observed feeding on cobbler catfish, eagle ray, cuttlefish and an unidentified prey (Delphine Chabanne, personal communication/unpublished data, see project report 8.3.3 Appendix 8.2). In addition, tag data from 2009 (Campbell, unpublished data) confirmed that sea lions use Cockburn Sound waters, including for foraging (see Appendix 4). While use of Cockburn Sound is known, there is still insufficient data to determine the relative importance of this area compared to offshore reef habitat.

It should be noted, that estimates of home range and core areas within home ranges are, at best, limited models of reality. Powell and Mitchell (2012), who discuss several conceptual challenges of spatial use quantification and identification of important areas, indicate: “It is a statistical approximation of an animal's behaviour that has the limitations of any statistic”. The spatial use quantified in this study was limited by the relatively small deployment/data collection times on a small proportion of individuals that make up the sea lion population that uses the Perth metropolitan area (less than 10%). In addition, as resources are dynamic and change over time, “often on timescales that differ from the timescale needed to collect enough data to estimate a home range” (Powell and Mitchell, 2012), so can the core areas and home ranges used by sea lions.

In summary, with the movement patterns captured by the telemetry tags in this study, we have an improved understanding of sea lion ranging patterns and areas of use within the Perth metropolitan area. Sea lions in this study were highly mobile, using multiple haul-out sites within the Perth metropolitan area as well as further afield. All haul-out sites can be considered important for the portion of the population that uses the region, as are the coastal waters of Perth metropolitan area and surrounds. While sea lions are engaging in foraging trips north and south along the coast, there is still a substantial use of Perth waters by this population.

4.2.2 Foraging patterns

There have been limited tagging studies of this species in WA, with a few individuals tagged in the Perth metropolitan area (n=3), Jurien Bay Marine Park and the Abrolhos Islands (Campbell unpublished data, 2009; Campbell et al., 2008a) and more data available on sea lions on the south coast (Campbell, 2008, Goldsworthy et al., 2014). However, most sea lions that have been tagged and for which there is movement data available are females and juveniles, with little data available on subadult and adult males. In previous studies where adult males have been tagged, they were found to range further than other age classes on the south coast, into deeper water and for longer periods of time (Goldsworthy et al., 2014), a pattern that is perhaps more similar to what has been observed of sea lions in South Australia (Costa and Gales, 2003, Lowther et al., 2013). However, a difference in ranging pattern is apparent between the west and south coast of WA (Campbell, 2008), supported by the results in this study, that likely reflects the difference in bathymetry, habitat and associated prey in these areas.

In this study, most dive trips were relatively short, in shallow water, often close to shore. Studies show that sea lions tagged at west coast colonies, including the Abrolhos Islands, Jurien Bay Marine Park and Perth metropolitan area typically don’t range as far from the islands where they were tagged and favour shallower water (Campbell unpublished data 2009, Campbell, 2008, Campbell et al., 2008a). The dive data in conjunction with the water depth at their location confirmed that sea lions were foraging benthically in Perth metropolitan and nearby waters which is consistent with the known foraging behaviour for this species (Costa and Gales, 2003). This was further confirmed by the vast majority of dives that were square shaped, which has been interpreted as showing foraging behaviour in other pinniped studies (Thums et al., 2008, Hindell et al., 1991). This corroborates findings from Campbell’s unpublished data (2009) who found three sea lions that were tagged on Carnac Island, frequented shallow water habitat (<20 m) including in Cockburn Sound for foraging between haul-out periods at Carnac and Dyer Islands and occasionally Seal Island. Importantly, Campbell’s unpublished data (2009) noted that sea lions spent roughly half their time at sea on the benthos feeding, a similar finding reported here, across a larger sample size. Furthermore, the high-resolution tag data confirms that they are foraging relatively closely to the haul-outs and only travelling short distances between periods of resting. Both Campbell unpublished data (2009; see maps in Appendix 4) and this study reported individuals returning to the same site repeatedly and engaging in foraging dives. This might be explained by the availability of prey and an effort to minimize energetic cost by not travelling far or deep. The mark-resight modelled estimates confirm that it’s a relatively small population of sea lions using the area, suggesting that con-specific competition may be low. The sympatric long nosed fur seal population (*Arctocephalus forsteri*) that reside at Rottnest Island are thought to feed in deeper water off the continental shelf on mid water column fish species, and this difference in foraging behaviour may lead to habitat preferences linked to prey availability and resource segregation (Kirkwood and Goldsworthy, 2013).

Studies of sea lions in South Australia have shown that although there is much inter-individual variation, some have apparent foraging specializations and return to use the same habitat, showing fidelity to foraging areas (Lowther et al., 2011, Lowther et al., 2013). Our dataset, although limited, also supports this inter-individual variation in foraging, albeit in males, with foraging site fidelity apparent for some individuals. ASL02, ASL05, ASL08, revisited Rottnest Island several times foraging and using the adjacent haul-out, Dyer Island. Similarly, ASL01 and ASL03 visited locations in coastal waters of Fremantle more than once.

This extensive use of shallow coastal habitat could mean that the sea lion population that uses the metropolitan area is more exposed to anthropogenic pressures in coastal waters which can potentially lead to displacement or disturbance. A spatial risk assessment using the tagging data and occupancy of haul outs is a logical next step to better understanding the overlap with such pressures.

4.3 Technical issues with telemetry

Several complications were encountered with the telemetry equipment that have resulted in limitations to the study, both in the quantity and quality of data that could be collected and analysed on the movement patterns of the sea lions. Some of these were resolved during the study and some have led to learnings that could be applied in future satellite tagging studies of sea lions where fine-scale information on movement patterns and area use is important.

We experienced several technical failures with the tags used, including failure of the PRD to release the tags remotely on command, premature release by the PRDs due to mechanical or electrical failures, failure of Fastloc GPS data recording, inconsistent transmission of location and dive data, and Splash tag transmission failure after a very short period. All of these have limited the amount of data that was collected, including data collection over a much shorter period than expected (days rather than months) and in some cases limited and/or lower quality positional data.

Additionally, a major issue was identified in the MK10 archived tag data, with a time discrepancy between the times of the dive data and the Fastloc GPS locations. While Wildlife Computers (WC) confirmed the tag software was causing the time of the MK10 data to lag behind the real-time Fastloc GPS time stamp, the time drift in the dive data was random and therefore difficult to rectify. WC is still working to correct and re-process these data, however, this has yet to be completed and re-processed data was not available for this report for the four retrieved MK10 tags.

Finally, while Splash tags were programmed to limit transmission time each day to conserve the battery and prolong the time over which data were to be obtained, this limited location measurements received per dive trip as each dive trip was relatively brief. Future research on sea lions using telemetry in the region can benefit from being informed by our experience, with careful consideration given to the research question, animal behaviour and sample size required when planning a programming regime. For example, given the resulting data set collected during this study, a larger sample size (i.e., more frequent transmissions) of locations would have more fully captured the tracks of the relatively short dive trips of sea lions in the Perth metropolitan area. As tag failure was high and led to numerous relatively short deployments in this study, our aim of limiting transmissions per day to allow a longer deployment and temporal scale was mostly not achieved in any case. Further, if the depth information when the sensor is dry is not being used, only recording depth when the wet/dry sensor is wet would simplify dive data processing and potentially improve the consistency of the zero-offset correction.

5 Conclusions/recommendations

The Australian sea lion is an endangered species that has not recovered from significant historical population depletion and, in fact, has shown recent evidence of ongoing declines. Thus the species is particularly vulnerable to pressures and threats across its range. The number of sea lions that uses Perth metropolitan waters is likely an important proportion of the male population within the region, and their persistence in this region may be tenuous. While this study has provided a significant increase in knowledge for the region, sample sizes were small and data collection was further limited by unanticipated technological failures and therefore limited. Further, pressures on sea lions across their range in WA are not well understood, and far more needs to be known before we can manage the recovery of this species with confidence, especially given the anticipated growth of the Perth coastal region.

This study has provided a quantitative estimate of sea lion abundance at the peak non-breeding season for the Perth metropolitan waters that can be used as a baseline estimate for future monitoring and pressure-response studies to inform the ongoing conservation and sustainable management of this species relative to local pressures. A greater proportion of marked sea lions and larger number of resight occasions within a period in which significant numbers of marks are not expected to fade may result in greater accuracy and precision. Additionally, a further analysis of the dataset from this study, which includes tag data and opportunistic sightings of marked sea lions is suggested, as it is expected to further improve the accuracy and precision of abundance estimates. Based on abundance estimates here, the monthly direct counts at haul-out islands performed by DBCA likely yield results that might be expected given the approximate 50% of time spent away from haul-out sites, confirmed by the satellite tagging data. However, the mark-resight surveys provide an estimate of absolute abundance (of the adult and subadult male cohorts) in addition to an evaluation of uncertainty (credible intervals in this study) as they account for individuals foraging at sea, and which are not present during the island haul-out counts. The juveniles were underrepresented and future mark-resight modelling efforts would need to include a concerted marking effort of this age cohort to be able to estimate their abundance. The temporary marking corroborated telemetry data, in confirming suspected movement between haul-out sites, indicated a broad use of the Perth metropolitan waters by individual sea lions.

The satellite tagging of 15 individuals, for varying lengths of time, revealed that sea lions haul out for less than 1 to over 4 days between dive trips. During these dive trips they use coastal waters, generally <10 metres water depth, presumably for short foraging trips of similarly short lengths, less than 1 to over 3 days. Foraging activity is assumed, given most time (based on ASL01) appears to have been spent close to the benthos, and is consistent with their known benthic foraging behaviour. The coastal areas they are using are highly trafficked by commercial vessels using Fremantle Port and by recreational boaters using coastal waters. Sea lions in the Perth metropolitan area are exposed to a range of anthropogenic pressures that may have cumulative or synergistic impacts on this endangered species. Not only is there a need to better understand the current level and impact of pressures across the species range, but any development, current or planned, within their range, including Perth metropolitan coastal waters, will also need to consider the significance of potential impacts on sea lions using the area for critical activities such as foraging, resting and migration.

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WILDLIFE COMPUTERS Behavior Log. Redmond, WA, USA.

Appendices

Appendix 1: Examples of the process and result of sea lion marking using hair dye applied via a pole and aluminium number stamps.

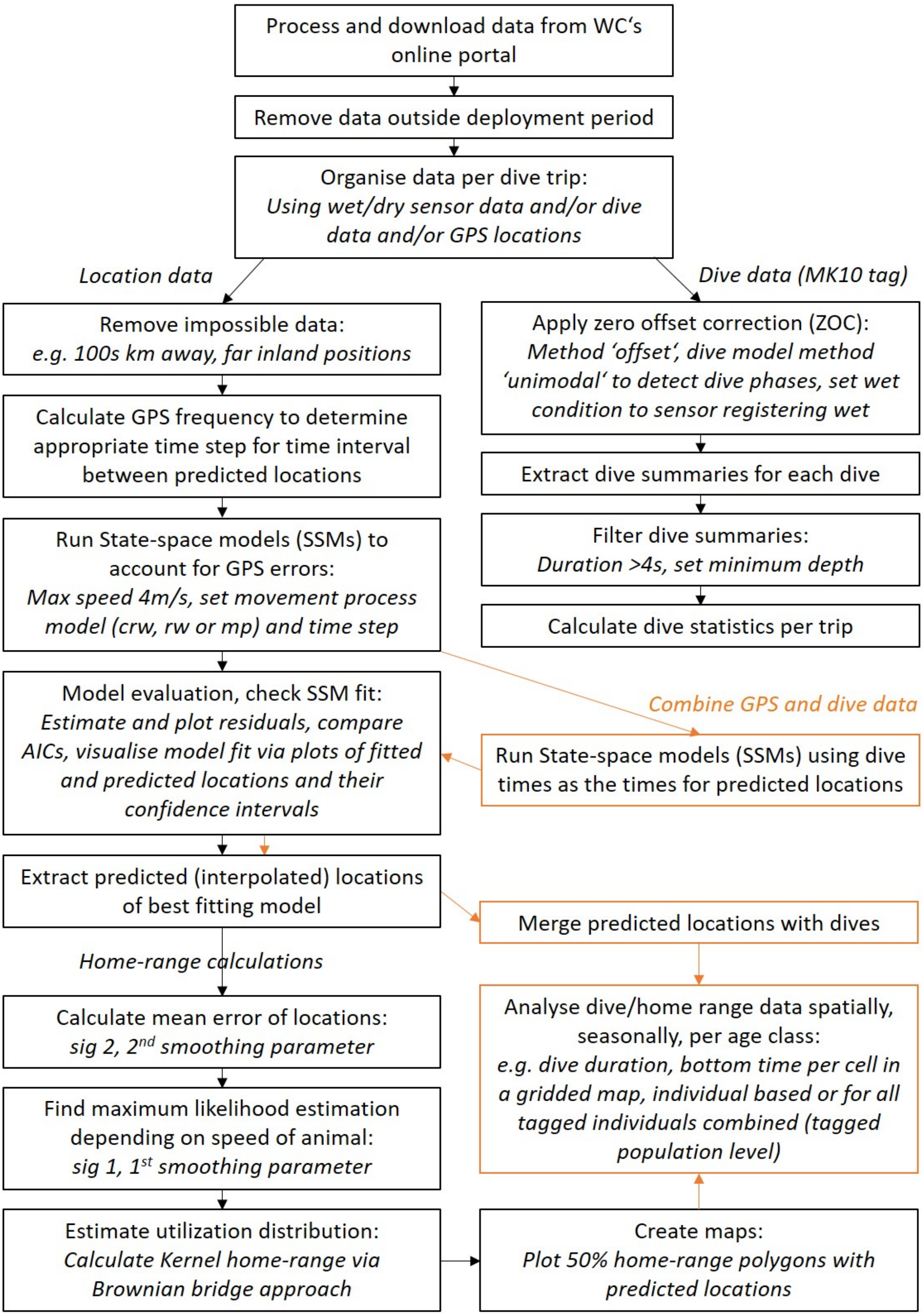
Appendix 1-1. Approaching and marking an adult bull.

Appendix 1-2. Approaching and marking a subadult male with several juveniles nearby.

Appendix 1-3. Mark clearly legible after marking with hair dye product dried on fur, before the sea lion has entered the water.

Appendix 1-4. Mark clearly legible after the sea lion has entered the water and excess hair dye presumably washed away.

Appendix 2: Flowchart showing the analysis process for the tagging data, noting the difference between analysis for location and for dives.



Note: The orange boxes (and arrows) indicate work components that could not be completed during this project due to tag malfunctions, limited sample size and time/budget constraints. WC = Wildlife Computers.

Appendix 3: Summary of dive tag data per sea lion and dive trip, including trip duration, number of dives, dive depth, surface intervals, bottom time and wiggle for all sea lions with MK10 tags and Splash10F tags.

MK10 Tagged ASL																	
ID	**trip**	**trip duration (days)**	**n dives**	**max depth (m)**	**mean depth (m)**	**SD depth (m)**	**median depth (m)**	**max dur (min)**	**mean dur (min)**	**SD dur (min)**	**mean surf interval (min)**	**SD surf interval (min)**	**median surf interval (min)**	**mean bottom time (min)**	**SD bottom time (min)**	**mean wiggle distance (m)**	**SD wiggle distance (m)**
ASL01	1	0.81	292	17.5	9.0	3.7	8.5	4.7	2.6	1.2	1.3	0.9	1.2	1.9	1.1	31.0	17.2
ASL01	2	1.46	922	16.5	6.5	3.8	5.5	4.4	1.6	1.1	0.6	0.7	0.6	1.2	0.9	19.4	14.9
ASL01	3	0.51	367	17.0	5.4	2.9	4.5	4.0	1.4	0.9	0.6	0.8	0.5	1.0	0.7	16.9	12.6
ASL01 total	**3**	**0.93**	**1581**	**17.5**	**6.7**	**3.7**	**6.0**	**4.7**	**1.7**	**1.1**	**0.7**	**0.8**	**0.7**	**1.3**	**0.9**	**21.0**	**15.7**
ASL10	1	0.10	16	2.0	2.0	0.0	2.0	0.3	0.2	0.0	5.6	5.9	3.6	0.0	0.0	0.4	0.3
ASL10	2	1.30	1012	17.0	4.7	2.8	4.0	4.7	1.3	0.9	0.6	2.0	0.3	0.9	0.8	14.9	13.4
ASL10	3	1.38	865	16.5	5.9	3.9	4.5	4.5	1.6	1.0	0.7	1.9	0.5	1.2	0.9	19.4	14.9
ASL10	4	0.69	438	17.0	3.8	1.9	3.5	4.8	1.4	1.0	0.8	2.9	0.5	1.0	0.8	16.8	14.0
ASL10	5	1.12	512	34.5	10.8	8.4	9.0	5.4	2.1	1.4	1.0	1.8	0.7	1.6	1.1	27.5	20.1
ASL10	6	2.67	1201	19.0	8.8	3.6	9.5	5.8	2.3	1.0	0.9	1.7	0.6	1.8	0.9	28.8	15.0
ASL10	7	0.20	89	5.5	3.3	1.1	3.0	3.7	1.5	1.0	1.1	2.9	0.5	1.1	0.9	17.7	14.6
ASL10	8	1.34	659	17.5	7.2	4.3	5.5	5.2	2.0	1.1	0.9	2.0	0.6	1.5	0.9	25.0	16.2
ASL10	9	0.92	451	18.0	7.6	4.8	6.0	4.6	1.8	1.1	1.1	3.1	0.7	1.3	0.9	20.8	15.4
ASL10	10	2.10	866	26.0	10.6	5.4	10.0	5.0	2.6	1.1	0.9	1.0	0.7	2.0	0.9	32.8	16.2
ASL10 total	**10**	**1.18**	**6109**	**34.5**	**7.4**	**5.1**	**5.5**	**5.8**	**1.9**	**1.2**	**0.8**	**2.0**	**0.6**	**1.4**	**1.0**	**23.5**	**16.7**
ASL13	1	1.27	576	21.0	9.3	5.1	10.0	4.6	2.2	1.1	1.0	1.3	0.7	1.6	1.0	27.4	17.0
ASL13	2	1.11	544	19.0	8.4	5.2	9.0	3.8	1.8	1.1	1.1	4.2	0.6	1.3	0.9	20.9	14.8
ASL13	3	1.07	522	19.5	7.3	4.9	5.0	4.5	1.8	1.1	1.1	4.7	0.6	1.3	0.9	20.2	15.0
ASL13	4	1.59	895	17.5	6.8	4.0	5.5	4.9	1.9	1.1	0.7	1.1	0.5	1.4	1.0	21.7	15.5
ASL13	5	1.70	769	20.0	8.3	4.9	7.0	4.8	2.0	1.1	0.9	3.5	0.6	1.5	1.0	23.9	15.8
ASL13 total	**5**	**1.35**	**3306**	**21.0**	**7.9**	**4.8**	**6.5**	**4.9**	**1.9**	**1.1**	**0.9**	**3.1**	**0.6**	**1.5**	**1.0**	**22.8**	**15.8**

ASL101	1	2.48	1158	20.0	6.9	4.2	6.0	5.0	2.0	1.3	1.1	2.2	0.8	1.4	1.1	22.8	17.3
ASL101	2	0.49	182	36.5	17.5	12.7	21.8	6.6	2.4	1.8	1.4	1.3	1.1	1.6	1.4	25.5	22.8
ASL101	3	0.44	185	35.5	14.3	12.5	6.0	5.8	2.0	1.6	1.4	1.6	1.1	1.2	1.1	19.2	19.4
ASL101	4	0.41	149	37.0	20.0	15.4	29.0	6.0	2.4	1.6	1.5	1.7	1.1	1.5	1.2	25.5	20.7
ASL101	5	0.58	187	33.5	16.5	11.8	20.0	5.7	2.4	1.5	1.9	3.3	1.1	1.6	1.2	25.2	19.0
ASL101	6	0.31	120	36.5	16.2	13.5	10.3	5.1	2.0	1.5	1.5	2.0	1.1	1.3	1.1	21.4	19.0
ASL101	7	0.43	168	32.5	14.2	12.4	8.5	5.3	2.2	1.3	1.3	2.0	0.9	1.4	1.0	22.7	17.1
ASL101	8	0.25	81	36.5	25.5	12.9	33.5	6.2	2.9	1.3	1.4	1.3	1.2	1.8	1.1	30.6	18.5
ASL101	9	0.33	112	36.5	25.0	13.2	33.5	4.9	2.8	1.2	1.2	0.9	1.2	1.8	1.0	30.0	17.3
ASL101	10	0.44	143	40.0	21.8	14.7	29.5	6.1	2.5	1.6	1.7	2.5	1.1	1.7	1.2	27.8	21.2
ASL101	11	0.47	194	29.5	13.5	10.1	12.0	4.9	1.8	1.3	1.5	4.3	0.9	1.2	1.0	19.3	16.2
ASL101 total	**11**	**0.60**	**2679**	**40.0**	**13.0**	**11.7**	**8.5**	**6.6**	**2.2**	**1.4**	**1.3**	**2.4**	**0.9**	**1.5**	**1.1**	**23.5**	**18.6**
All MK10 tags	**29**	**1.0**	**13675**	**40.0**	**10.9**	**7.0**	**11.1**	**6.6**	**2.0**	**1.2**	**1.3**	**2.3**	**0.9**	**1.4**	**1.0**	**22.6**	**16.3**

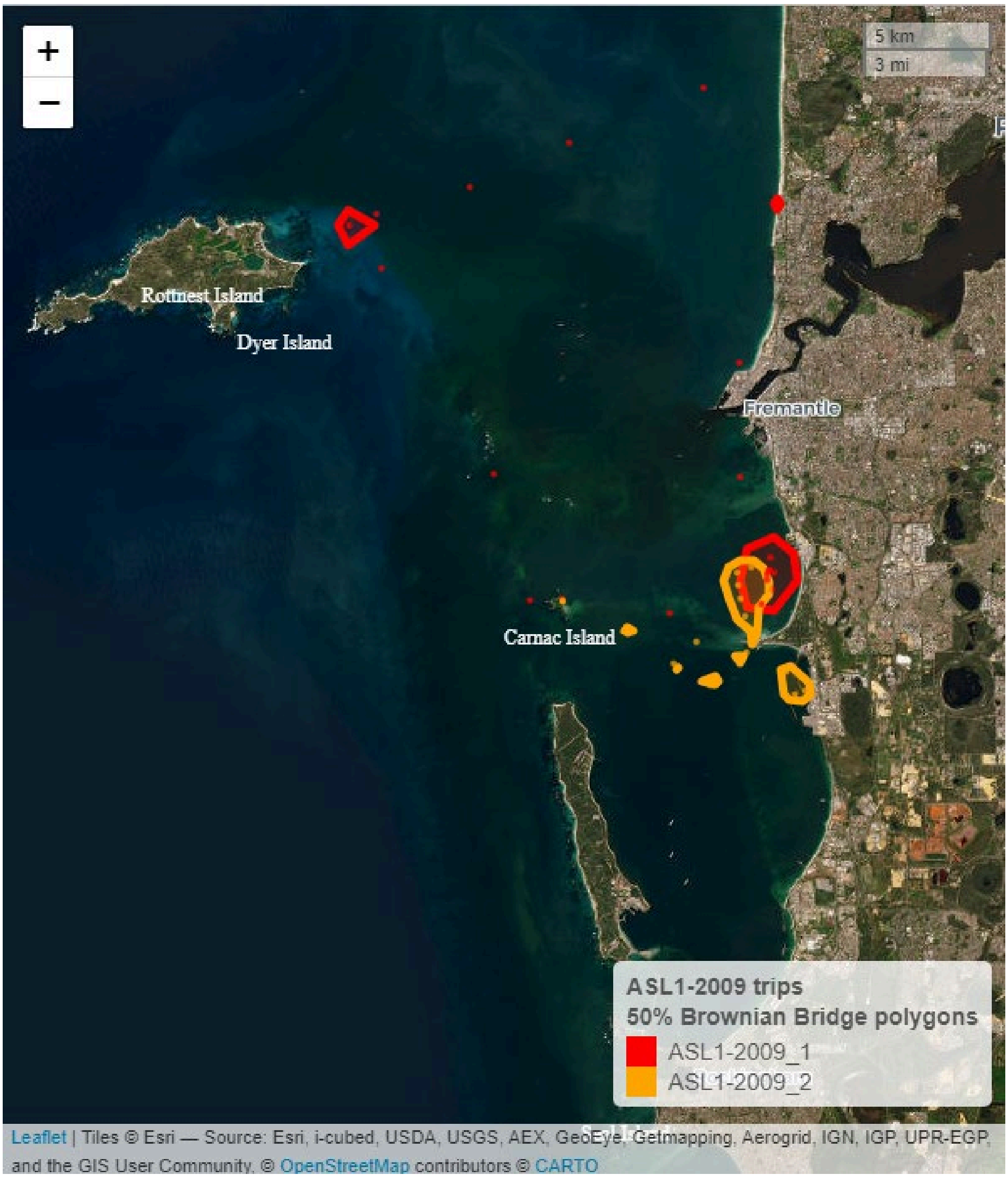
SPLASH10-F tags																
ID	**trip**	**trip duration (days)**	**n dives**	**max depth (m)**	**mean depth (m)**	**SD depth (m)**	**median depth (m)**	**max dur (min)**	**mean dur (min)**	**SD dur (min)**	**mean surf interval (min)**	**SD surf interval (min)**	**median surf interval (min)**	**% Square**	**% U**	**% V**
ASL05	1	1.23	360	36.0	12.3	8.7	10.0	6.0	2.3	1.5	1.2	2.1	0.9	93.1	5.6	1.1
ASL05	2	1.68	554	47.0	14.1	10.2	11.0	5.5	2.2	1.4	0.9	1.6	0.7	90.3	9.4	0.0
ASL05	3	2.26	410	38.0	17.5	9.2	16.0	5.3	3.0	1.4	1.3	1.2	1.1	93.9	5.9	0.2
ASL05	4	1.76	470	47.0	14.6	11.0	12.0	5.2	2.2	1.4	1.6	8.3	0.8	92.8	6.8	0.2
ASL05	5	1.15	283	46.0	18.8	13.4	13.5	5.9	2.5	1.4	1.1	1.3	0.9	97.9	2.1	0.0
ASL05	6	0.84	147	47.0	20.6	15.1	15.0	5.5	2.3	1.4	1.5	2.0	1.1	87.8	12.2	0.0

ASL05	7	1.24	230	34.0	11.5	6.6	10.8	6.8	2.4	1.6	1.2	1.5	0.8	95.2	4.8	0.0
ASL05	8	1.34	331	46.0	13.9	10.1	11.5	5.6	2.4	1.5	1.0	1.8	0.7	92.4	7.6	0.0
ASL05	9	1.32	304	46.0	17.5	13.6	12.3	5.5	2.6	1.4	1.2	3.4	0.9	95.1	3.9	1.0
ASL05	10	0.40	82	21.5	11.3	4.6	12.3	5.8	2.6	1.5	2.0	5.9	1.0	95.1	4.9	0.0
ASL05	11	1.36	383	47.0	11.9	9.0	9.5	6.1	2.1	1.4	1.3	3.5	0.8	91.1	8.4	0.5
ASL05	12	1.73	485	47.0	13.7	11.2	10.0	6.0	2.3	1.5	1.0	1.0	0.8	90.1	8.5	1.4
ASL05	13	0.06	27	9.5	6.0	1.9	5.5	3.0	1.1	0.8	2.2	5.2	0.5	96.3	3.7	0.0
ASL05	14	1.32	478	48.0	11.7	10.2	9.0	6.8	2.1	1.5	0.8	0.8	0.7	95.4	4.2	0.4
ASL05	15	1.36	398	37.0	9.3	5.6	7.5	6.4	1.9	1.5	1.1	1.9	0.7	90.7	8.0	1.0
ASL05	16	0.43	51	21.5	10.0	5.6	8.5	4.0	1.9	1.4	1.0	0.7	1.0	94.1	5.9	0.0
ASL05	17	0.41	96	17.5	11.1	4.2	12.0	5.5	2.6	1.3	0.9	0.7	0.8	100.0	0.0	0.0
ASL05	18	0.39	65	21.5	11.9	4.6	11.0	4.4	2.5	1.2	0.8	0.4	0.8	98.5	1.5	0.0
ASL05	19	1.05	189	18.5	8.6	3.5	8.5	4.4	1.6	1.0	0.9	1.1	0.7	97.9	2.1	0.0
ASL05	20	0.54	100	20.0	11.0	4.6	12.3	5.4	2.1	1.3	1.0	1.8	0.8	90.0	10.0	0.0
ASL05	21	1.17	330	34.0	11.0	6.4	9.5	6.4	2.3	1.5	0.9	1.1	0.8	93.6	6.4	0.0
ASL05	22	0.76	195	20.5	12.7	3.6	13.5	4.4	2.6	1.0	1.2	0.8	1.0	96.4	3.6	0.0
ASL05	23	1.76	338	38.0	19.3	8.9	16.5	6.6	3.8	1.3	1.4	1.1	1.2	96.2	3.6	0.3
ASL05	24	1.71	364	47.0	10.9	9.2	8.5	6.3	1.9	1.5	1.1	4.3	0.6	90.4	8.8	0.8
ASL05	25	1.16	163	17.5	8.4	3.4	8.0	7.0	2.0	1.3	1.1	2.7	0.8	94.5	4.9	0.6
ASL05	26	0.39	81	17.0	11.5	4.0	13.0	4.1	2.5	1.1	1.0	0.6	1.0	96.3	3.7	0.0
ASL05 total	**26**	**1.11**	**6914**	**48.0**	**13.4**	**9.8**	**10.5**	**7.0**	**2.3**	**1.5**	**1.1**	**3.0**	**0.8**	**93.3**	**6.2**	**0.4**
ASL06	1	1.46	301	22.5	8.7	4.5	7.5	6.7	2.6	1.5	2.9	18.4	0.8	96.3	3.7	0.0

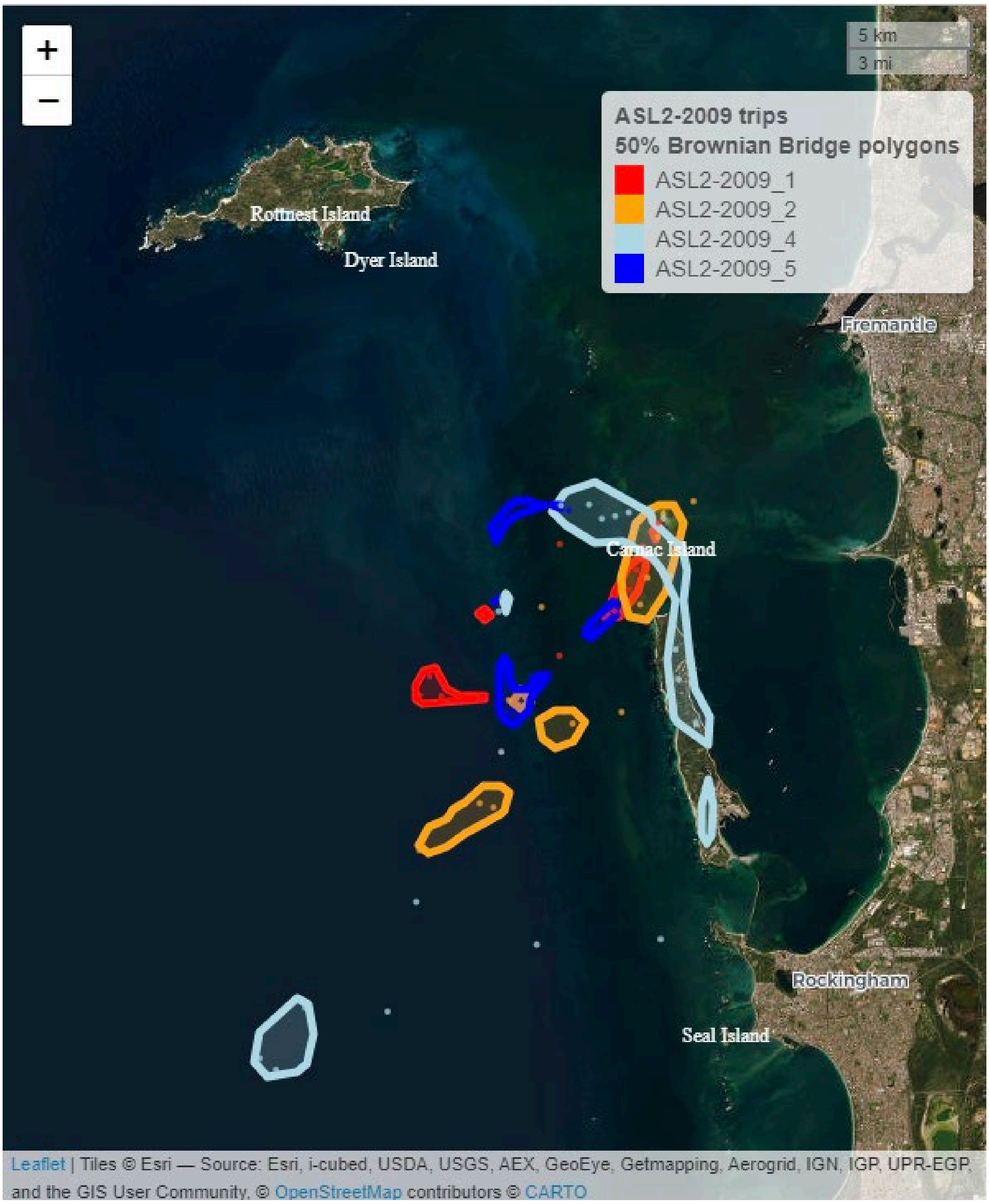
ASL06	2	0.30	29	12.5	5.8	2.2	5.0	3.0	1.2	0.6	13.7	34.3	0.7	89.7	10.3	0.0
ASL06	3	0.25	85	10.0	5.2	1.3	5.0	3.4	1.2	0.7	0.9	3.0	0.2	98.8	0.0	1.2
ASL06	4	0.20	35	10.0	5.5	1.6	5.0	3.7	1.6	0.9	6.1	16.7	1.3	91.4	8.6	0.0
ASL06	5	0.25	33	22.5	12.0	6.7	10.0	4.4	2.5	1.2	0.8	0.5	0.1	93.9	6.1	0.0
ASL06 total	**5**	**0.49**	**483**	**22.5**	**7.9**	**4.5**	**6.0**	**6.7**	**2.2**	**1.4**	**3.3**	**17.6**	**0.8**	**95.9**	**3.9**	**0.2**
ASL07	1	0.25	117	17.0	8.6	3.4	8.0	3.3	1.6	0.9	0.7	1.0	0.6	97.4	2.6	0.0
ASL07	2	0.42	128	23.5	12.6	5.1	12.3	4.2	2.0	0.9	0.9	1.1	0.7	95.3	4.7	0.0
ASL07	3	0.11	40	13.0	7.8	2.5	7.5	3.3	1.6	0.9	0.5	0.3	0.5	97.5	2.5	0.0
ASL07	4	0.35	90	23.0	14.3	5.1	14.0	4.3	2.2	0.9	0.7	0.5	0.6	94.4	5.6	0.0
ASL07	5	0.25	52	18.0	12.5	3.4	12.8	3.0	1.7	0.8	0.8	0.9	0.7	98.1	1.9	0.0
ASL07 total	**5**	**0.28**	**427**	**23.5**	**11.4**	**4.9**	**11.5**	**4.3**	**1.9**	**0.9**	**0.7**	**0.9**	**0.6**	**96.3**	**3.7**	**0.0**
ASL08	1	0.51	90	13.0	6.6	2.7	5.8	4.7	1.5	1.1	3.9	12.7	0.9	90.0	6.7	0.0
ASL08	2	2.06	160	25.0	7.2	5.0	5.0	4.2	1.3	0.9	4.6	25.2	0.6	86.9	10.6	1.9
ASL08	3	1.68	187	28.0	14.9	7.6	11.0	4.9	2.5	1.0	0.9	0.5	0.9	96.3	3.7	0.0
ASL08	4	0.29	63	13.0	7.2	2.1	7.0	3.0	1.2	0.8	0.7	0.7	0.5	87.3	12.7	0.0
ASL08	5	0.49	75	19.0	8.3	4.2	6.5	3.4	1.3	1.0	3.5	14.0	0.6	86.7	12.0	0.0
ASL08	6	0.32	75	28.0	11.0	8.0	6.5	3.6	1.6	1.1	2.2	4.2	0.8	96.0	2.7	1.3
ASL08	7	0.50	25	13.0	8.3	2.6	8.0	2.7	1.5	0.7	0.7	0.6	0.6	100.0	0.0	0.0
ASL08	8	1.39	170	23.0	9.8	5.5	9.0	4.8	1.7	1.0	1.2	2.9	0.6	94.1	5.9	0.0
ASL08	9	0.08	30	25.0	19.2	5.9	22.3	5.3	3.1	1.3	0.8	0.6	0.6	96.7	3.3	0.0
ASL08	11	1.11	75	25.0	10.0	6.5	7.5	4.2	1.8	1.1	0.8	1.5	0.5	94.7	5.3	0.0
ASL08 total	**11**	**0.40**	**950**	**28.0**	**10.1**	**6.6**	**7.5**	**5.3**	**1.7**	**1.1**	**2.2**	**11.9**	**0.7**	**92.3**	**6.7**	**0.4**

All Splash tags	**47**	**0.80**	**8774**	**48.0**	**11.5**	**6.2**	**10.1**	**7.0**	**2.1**	**1.2**	**1.7**	**4.3**	**0.8**	**94.1**	**5.5**	**0.3**

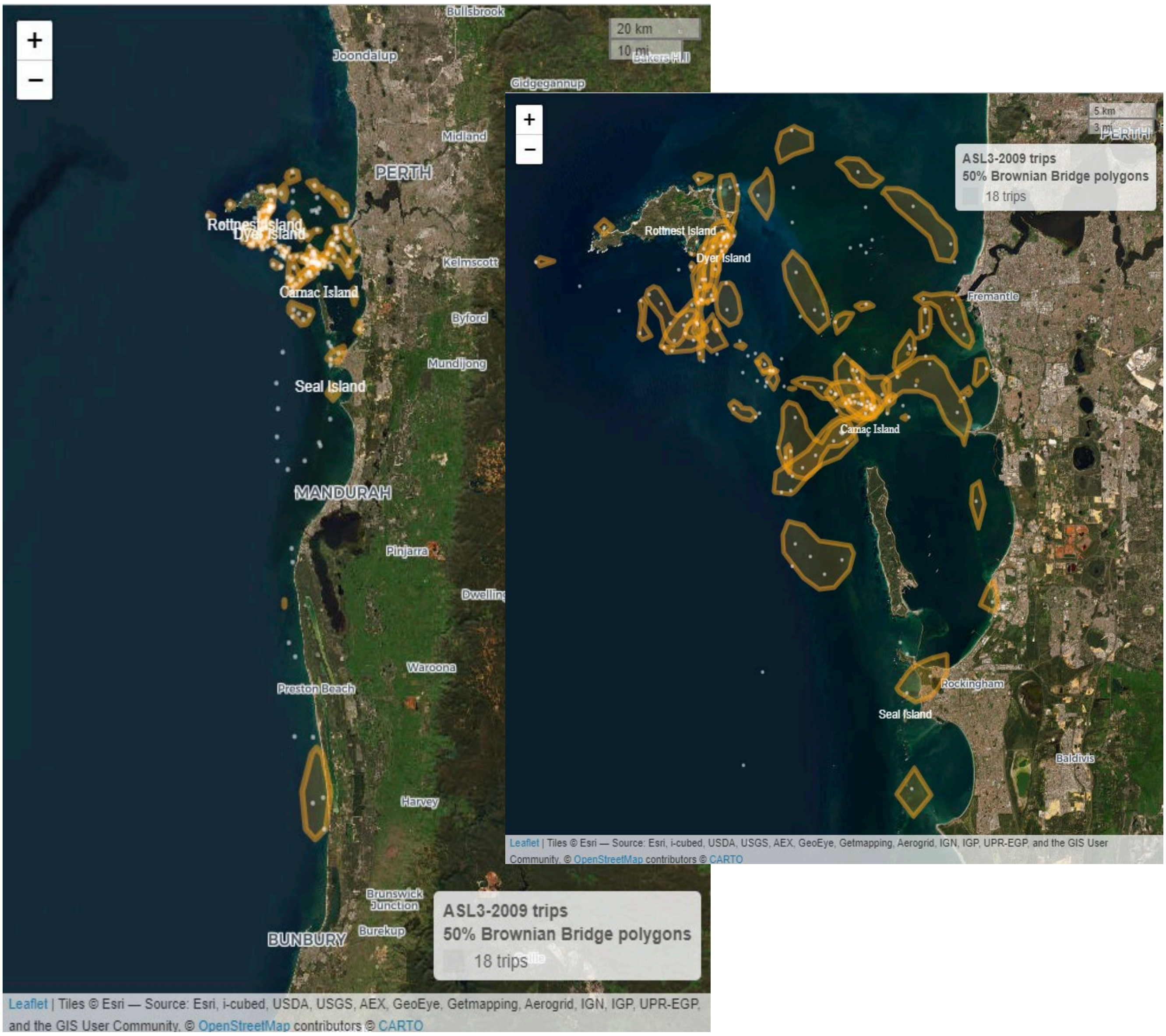
Appendix 4: Map of all estimated locations from state space models for each trip based on all available FastGPS locations and movement model areas for three tagged sea lions by Campbell *et al.* (unpublished) from the tagging undertaken in 2009.



Appendix 4-1. Map of estimated locations from state space models for each trip based on all received FastGPS locations for ASL001 in Campbell *et al.* (unpublished) from the tagging in 2009. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.



Appendix 4-2. Map of estimated locations from state space models for each trip based on all received FastGPS locations for ASL002 in Campbell *et al.* (unpublished) from the tagging in 2009. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.



Appendix 4-3. Map of all estimated locations from state space models for each trip based on all archived FastGPS locations retrieved from the tag for ASL003 in Campbell *et al.* (unpublished) from the tagging in 2009. High use areas for each dive trip are depicted in different colours with the polygons representing the 50% Brownian Bridge movement model area for each trip.

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