Whalers Way Orbital Launch Complex Marine Ecological Assessment

Report to Southern Launch

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Rev 1, 10 June 2021

Cover photo: western blue groper *Achoerodus gouldii* at Redbanks, Whalers Way. Photo: J. Brook, November 2016.

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Executive Summary

The trajectory of rockets launched from the Whalers Way Orbital Launch Complex (WWOLC) is over the Southern Ocean, within an arc between bearings 145° and 265°, with the potential marine impact zone (PMIZ) extending for 1000 km. Two thirds of launches are expected to have Polar or Sun Synchronous trajectories, corresponding to bearings of approximately 185° and 195°, respectively.

The South Australian waters component of the PMIZ overlaps the south-eastern corner of the Thorny Passage Marine Park, which includes a Habitat Protection Zone containing Liguanea Island, about 5–8 km south of the WWOLC. Most of the important values of the park within the PMIZ are concentrated on this island, including:

- A breeding colony of the threatened Australian sea lion (ASL) *Neophoca cinerea*. Liguanea Island is the fifth-largest of 11 breeding colonies within the 'Spencer Gulf' metapopulation, with estimated pup counts of 25–43, corresponding to an estimated total Liguanea Island population size of 100–165. Liguanea Island accounts for about 3% and 1% of the Spencer Gulf and Australian pup production of ASL, respectively. The interval between its breeding seasons is 17–18 months.
- A breeding colony of the long-nosed fur seal (LNFS) *Arctocephalus forsteri*. The pup population of LNFS on Liguanea Island has been estimated at about 1,800, corresponding to a total Liguanea Island population of about 8,700. Liguanea Island accounts for about 9% of the LNFS pup production in South Australia. Breeding occurs between December and March.
- A breeding colony of Short-tailed Shearwater (Mutton Bird) *Ardenna tenuirostris*, listed as Migratory under the EPBC Act 1999. The breeding colony spans about a quarter of the island's area, with more than 10,000 burrows, accounting for about 1% of South Australia's breeding population. Breeding occurs in late November, and fledglings leave the colony in late April (migrating to north of Japan).
- A breeding population of Crested Tern *Thalasseus bergii*, listed as Migratory under the EPBC Act 1999, with 'several thousand' birds (of an estimated South Australian population of 13,000–25,000) recorded.

Collision impacts

No impacts on Liguanea Island are expected by debris from successful launches, because the first stage of orbital rockets would not fall to earth within 500 km, and suborbital rockets (for which the booster would fall to earth within range of 3–8 km) would not be launched with a trajectory over Liguanea Island. Debris from failed launches with Polar and Sun Synchronous trajectories has the potential to impact Liguanea Island, but the risk is remote. Flight safety risk analysis using processes set out by the Federal Aviation Authority and Flight Safety Code shows that:

- An air burst, which results in the launch vehicle breaking up into a number of pieces and landing over a large area, would have an average frequency of LNFS and ASL casualties of one every 3,375 and 194,470 launches, respectively, for small rockets. For mini or micro rockets, expected to collectively account for 95% of launches, the frequency would be 30 or 100 times lower, respectively.
- A ground burst would occur every 3 million launches, with an average frequency of LNFS and ASL casualties of one every 7,700 and 445,000 launches, respectively, for small rockets and almost half as often for mini or micro rockets.

An air burst over Liguanea Island would be a very rare event that could result in mortalities but there would be negligible impact at subpopulation level. Ground bursts on Liguanea Island would be a rarer event than an air burst (provided a flight termination system is used) but could impact more individuals. Although this may result in temporary reductions in ASL pup production, no long-term impact is expected at subpopulation level.

For the entire PMIZ, four sharks, four turtles, 17 marine mammals, 42 marine birds and six shorebirds have been identified as known to occur or possibly occurring. The likelihood of debris colliding with individuals of these species is considered to be remote, and would not occur when animals are submerged. Within the Southern Ocean, including the waters of the Thorny Passage Marine Park surrounding Liguanea Island, there may be occasional debris strike impacts on individual animals on the sea surface but no impact at population level.

Noise impacts

Noise from launches would temporarily alter the quiet setting of the natural environment for one to two minutes during launches. The maximum instantaneous sound pressure level (airborne) would be 90–95 dBA at the northern end of Liguanea Island.

This is close to the threshold at which temporary hearing loss may occur for birds. However, the threshold is very conservative because it is based on continuous exposure of 12–72 hours, rather than two minutes, therefore no impacts on bird hearing are expected.

The temporary hearing loss threshold is 157 dB for seals, therefore no impact is expected on the hearing of ASL or LNFS on Liguanea Island.

Impacts on pinniped behaviour are the primary concern with regard to rocket launches. Marine mammal reactions to rocket launches are highly variable and may be attributable to the species, age, time of year, air temperature and potential habituation to noise. Seals may flush into the water when frightened, with pups being trampled or separated from their mothers in the process.

Significant behavioural responses in pinnipeds are not expected at levels below 90 dB, therefore there may be some behavioural impacts on seals toward the north of Liguanea Island, but unlikely at the south of island where they concentrate.

Southern right whales very close to shore during the launch may be exposed to sound levels approaching the threshold for temporary hearing loss, but could avoid the noise by submerging for less than two minutes.

Approvals have been routinely granted for behavioural impacts on pinnipeds at the Kodiak Launch Complex (KLC) in Alaska and Vandenberg Air Force Base (VAFB) in California, including movement both on land and into the water, but the latter has occurred only rarely with seals hauling out again within minutes to two hours of each launch. Seal populations near the VAFB have increased at an annual rate of 12.6 per cent over a decade despite 5–7 space vehicle launches per year.

Other debris impacts

Other debris impacts, including ingestion by marine fauna, crushing or smothering of biota, emission of toxic contaminants, noise from debris striking the sea surface and provision of habitat would be highly localised, the area impacted would be insignificant in comparison to the extent of the receiving environment and population level effects would be negligible.

Monitoring, management and mitigation

Monitoring of seal behaviour and noise on Liguanea Island before, during and after launches will be undertaken on several occasions, including test launches.

Mitigation measures designed to reduce noise impacts on terrestrial species during rocket take-off, e.g. earth bunds and site structures for acoustic screening, may also benefit seals and seabirds on Liguanea Island. Other mitigation measures specific to marine fauna include:

- avoiding trajectories over Liguanea Island for suborbital launches
- using a flight termination system, which would substantially reduce the risk of a ground burst on Liguanea Island
- consideration, for some launches, of avoiding critical periods (e.g. breeding times) for species.

A review of risks to the marine environment from debris (once fallen) would be undertaken after the first three years of operation.

The conclusions of this assessment are consistent with the findings of a risk assessment undertaken for comparable rocket launches in New Zealand.

1 Introduction

Southern Launch Space Pty Ltd (Southern Launch) are proposing to construct the Whalers Way Orbital Launch Complex (WWOLC) to support the launch of domestic and international launch vehicles to service a growing demand for Polar and sun synchronous orbit (SSO) satellite insertion.

Although the infrastructure, including two launch sites, will be entirely on land, the trajectory of rockets will be over the Southern Ocean. The Polar and SSO trajectories correspond to bearings of approximately 185° and 195°, respectively, and are expected to collectively account for about two thirds of launches. Trajectories for other launches could be within an arc between bearings 145° and 265°. The potential marine impact zone (PMIZ) for orbital rockets extends for 1000 km (Figure 1).

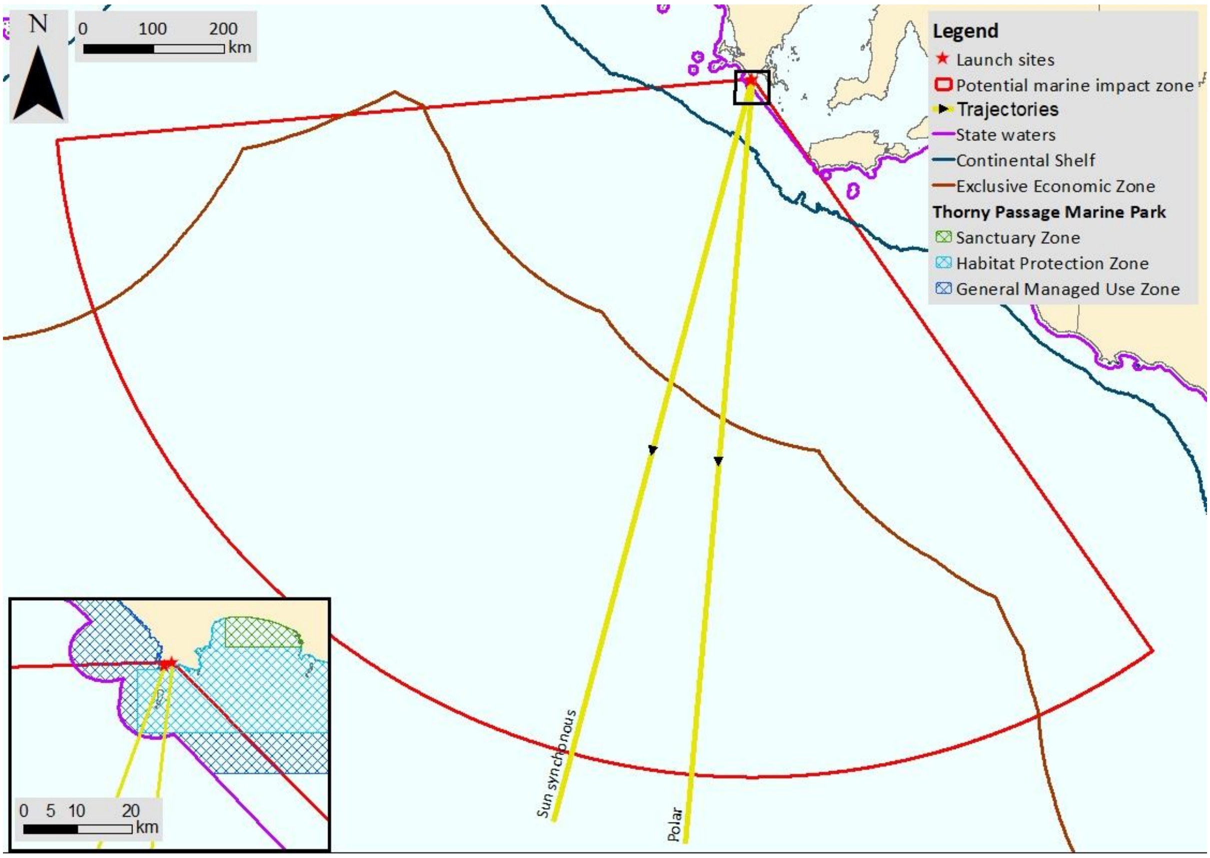

Figure 1. Potential marine impact zone associated with rocket launches from the WWOLC, showing Polar and Sun Synchronous trajectories.

A relatively small proportion of the PMIZ lies within South Australian waters, and all of that area is also within the Thorny Passage Marine Park (TPMP) (Figure 2). The activities of the Project must therefore be consistent with the objects of the *Marine Parks Act 2007*, and the provisions of the TPMP Management Plan (DEWNR 2012). A key feature of the PMIZ/TPMP overlap area is Liguanea Island, which is part of Lincoln National Park.

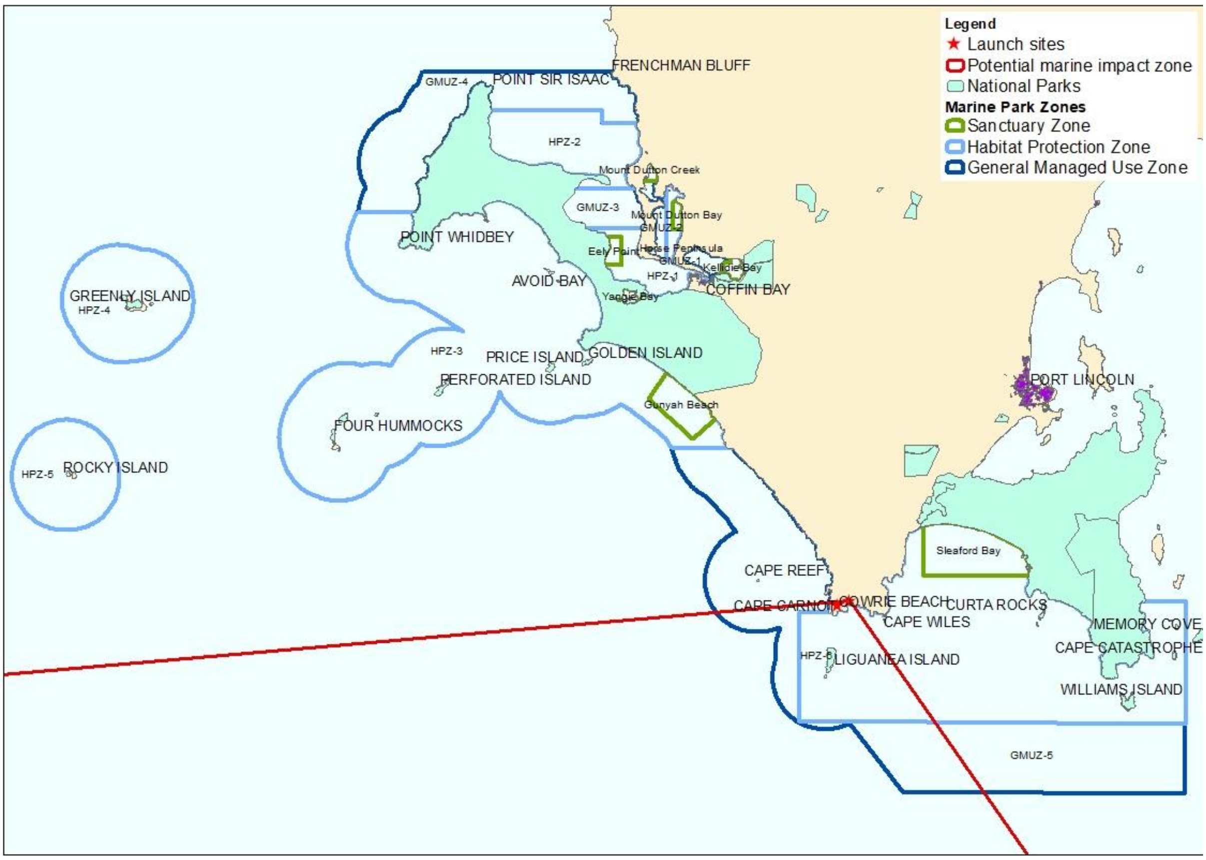

Figure 2. Location of the Potential Marine Impact Zone in relation to the Thorny Passage Marine Park and Coffin Bay and Lincoln National Parks.

This document contributes to responses to a number of the assessment guidelines for the project (Table 1).

Table 1. Contributions of this document to responses to the project assessment guidelines.

Guideline	Response
1.1 Identify the existing terrestrial and marine environments and species that are known and likely to occur on the subject site and surrounds. Detail the conservation values for the Thorny Passage Marine Park, Jussieu Peninsula to Coffin Bay Peninsula Biodiversity Area and Lincoln National Park (including species listed in the SA *National Parks and Wildlife Act 1972*).	• Potential marine impact zone defined in Section 1 to facilitate identification of relevant surrounds • Shoreline and benthic habitats near mainland and Liguanea Island described in Sections 2.2 and 2.3. Habitats beyond state waters have been broadly classified in Section 3. • Conservation values of the TPMP identified in Section 2 include breeding colonies of Australian sea lion (listed as Vulnerable under the *National Parks and Wildlife Act 1972* (NPW Act 1972) (Section 2.6.1), long-nosed fur seal (Section 2.6.2), Short-tailed Shearwater (Section 2.7.1) and Crested Tern (Section 2.7.2). Other species listed under the NPW Act 1972 are cetaceans including southern right whale, humpback whale and blue whale (Section 2.6.3), and seabirds including Cape Barren Goose, Sooty Oystercatcher and Fairy Tern (Section 2.7.3). Mobile macroinvertebrates and fishes have also been described in Sections 2.4 and 2.5.
1.2 Detail the potential impacts on terrestrial and marine habitat for each potential launching site and associated impact area, including runoff from storm and wastewater into the marine environment due to the increase in impervious surfaces, impacts from noise and vibration during launches and impacts of the exhaust from rockets. Both terrestrial and marine ecosystems must be considered for all operational activities. Provide adequate mitigation and management measures for each area in turn.	• Potential impacts on the marine environment largely restricted to fauna on land or sea surface (Section 4.1) • Primary potential impacts detailed include strikes by debris (Section 4.2) and noise disturbance of seals and seabirds (Section 4.3). • Impacts of debris on marine habitat also considered (Section 4.4) • Management and mitigation measures include avoiding trajectories over Liguanea Island for suborbital launches (Sections 4.2.1 and 4.5), use of a flight termination system and consideration of avoiding (for some launches) critical periods (e.g. breeding times) for species (Section 4.5).
1.3 Identify the potential trajectory of launched vehicles and likely location, extent, composition and amount of debris and spent componentry anticipated to impact on the surrounding area, including the adjoining Marine Park. Propose operational management strategies to limit the impacts on the quantified conservation values.	• Potential trajectories have been described in Section 1. • Location, extent and amount of debris are incorporated within the seal strike risk assessment undertaken by Southern Launch (Appendix 1), summarised in Section 4.2.1. • Composition of debris is identified in Section 4.4.

Guideline	Response
3.1 Describe the location, extent, condition and significance of native terrestrial and marine fauna populations, including individual species and communities in the surrounding area, including on land, cliffs and in adjoining waters, including Liguanea Island.	• See response to Guideline 1.1
3.2 Describe the nature and extent of the impacts likely to affect native terrestrial and marine fauna species and populations during both construction and operation. Describe the ability of communities and individual species to recover, especially threatened or significant species (including those listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and *National Parks and Wildlife Act 1972*). Specifically consider the impact of marine debris.	• See response to Guideline 1.2, including the impact of marine debris (Sections 4.2 and 4.4). • Species listed under the EPBC Act 1999 include Australian sea lion (Section 2.6.1), southern right whale, blue whale, humpback whale (Sections 2.6.3 & 3), Short-tailed Shearwater (Section 2.7.1) and Crested Tern (Section 2.7.2).
3.5 Identify the potential impact of noise and vibrations on terrestrial, coastal and marine native fauna, and the mitigation and monitoring strategies during both construction and maintenance.	• Potential impact of noise on marine native fauna is addressed in Section 4.3. It is limited to birds and pinnipeds, as the noise associated with rocket launches would not effectively transfer across the water surface. • Management and mitigation measures are addressed in Section 4.5 and include mitigation measures in response to Guideline 1.2 above. • Mitigation measures listed by AECOM (2021) to reduce noise impacts on terrestrial species during rocket take-off, e.g. earth bunds and site structures for acoustic screening, may also benefit seals and seabirds on Liguanea Island. • Monitoring of seal behaviour and noise on Liguanea Island before, during and after launches will be undertaken on several occasions, including test launches (Section 4.5).
3.6 Detail appropriate buffer distances that would be required between proposed development (including coastal access points) and threatened terrestrial and marine species, including feeding areas, nesting sites and roosting sites.	• The launch sites were assessed as fixed sites, with noise and debris impact modelling showing acceptable impact or risk to threatened marine species (on Liguanea Island).
3.7 Outline measures to avoid, minimise, mitigate and monitor the effects on native fauna, including any compensatory activities.	• Refer to responses to Guidelines 1.2 and 3.5.

2 Ecological values of the Thorny Passage Marine Park

2.1 Introduction

The Thorny Passage Marine Park covers 2,472 km^2 and is located in the Eyre Bioregion, which extends from Cape Bauer near Streaky Bay into southern Spencer Gulf and along the south coast of Kangaroo Island. The marine park includes the waters off lower Eyre Peninsula, extending from Frenchman Bluff to Memory Cove with discrete offshore sections overlaying Rocky and Greenly Islands (Figure 2).

The potential marine impact zone (PMIZ) for the WWOLC overlaps an area towards the south-east of the Park, including parts of GMUZ-5 and the western end of HPZ-6, which contains Cape Carnot and Liguanea Island. Many of the key features of the Park are situated outside the PMIZ, and are therefore excluded from this assessment, including all other islands, Coffin Bay (with four Sanctuary Zones), the marine waters offshore from Coffin Bay National Park, Sanctuary Zones at Gunyah Beach and Sleaford Bay, and the marine waters surrounding the Memory Cove Wilderness Area and the main body of Lincoln National Park, noting that Liguanea Island itself is a discrete component of that Park (Figure 2).

2.2 Shoreline habitats

The western and eastern coasts and part of the southern coast (Cape Wiles and between Cowrie Beach and Groper Bay) of the Whalers Way site are comprised of ramping (5–30° slope) bedrock platforms of granite at the base of calcarenite cliffs of height 40, 130 and 80 m, respectively, except just south of Redbanks (north-west of the WWOCL) where the granite platforms are backed by sand dunes (DEW 2021a, Figure 3). Cowrie Beach is a sheltered, fine to medium sand beach situated just east of Cape Carnot at the base of 50 m high cliffs, and there are coarse sand beaches near the south-east corner of Whalers Way, backed by cliffs of 100–130 m height which extend across the remaining shoreline of the south coast (Figure 3). Unlike the mainland, the shoreline habitats of Liguanea Island have not been formally described (DEW 2021a), but are comprised of granite platforms and cliffs (Robinson et al. 1996, Google Earth inspections)

2.3 Benthic habitats

The majority (80 per cent) of the subtidal habitats in the TPMP have not been mapped (Bryars et al. 2016). Broad scale (1:100,000) mapping using satellite imagery showed that the western and southern coasts of Whalers Way were surrounded by granite reef for 200–700 m offshore on the western and southern coasts, with sand beyond the reef on the western coast, and unmapped area on the southern coast (DEW 2021b, Edyvane 1999, Figure 3). Dive surveys by Shepherd et al. (2005) at Redbanks encountered both granite and calcareous reef, dominated by large brown canopy-forming macroalgae including common kelp *Ecklonia radiata* and species from the order Fucales including *Acrocarpia paniculata, Cystophora siliquosa, C. subfarcinata* and *C. moniliformis*. This is consistent with descriptions of shallow reef macroalgal canopy communities in the Whidbey biounit, noting that the understorey is dominated by the robust red macroalga *Osmundaria prolifera* and articulated coralline macroalga *Haliptilon roseum* (Edyvane 1999).

Granite reef has also been mapped adjacent to the western and south-eastern shore of Liguanea Island, and around the mainly-submerged rock south of the island (Figure 3).

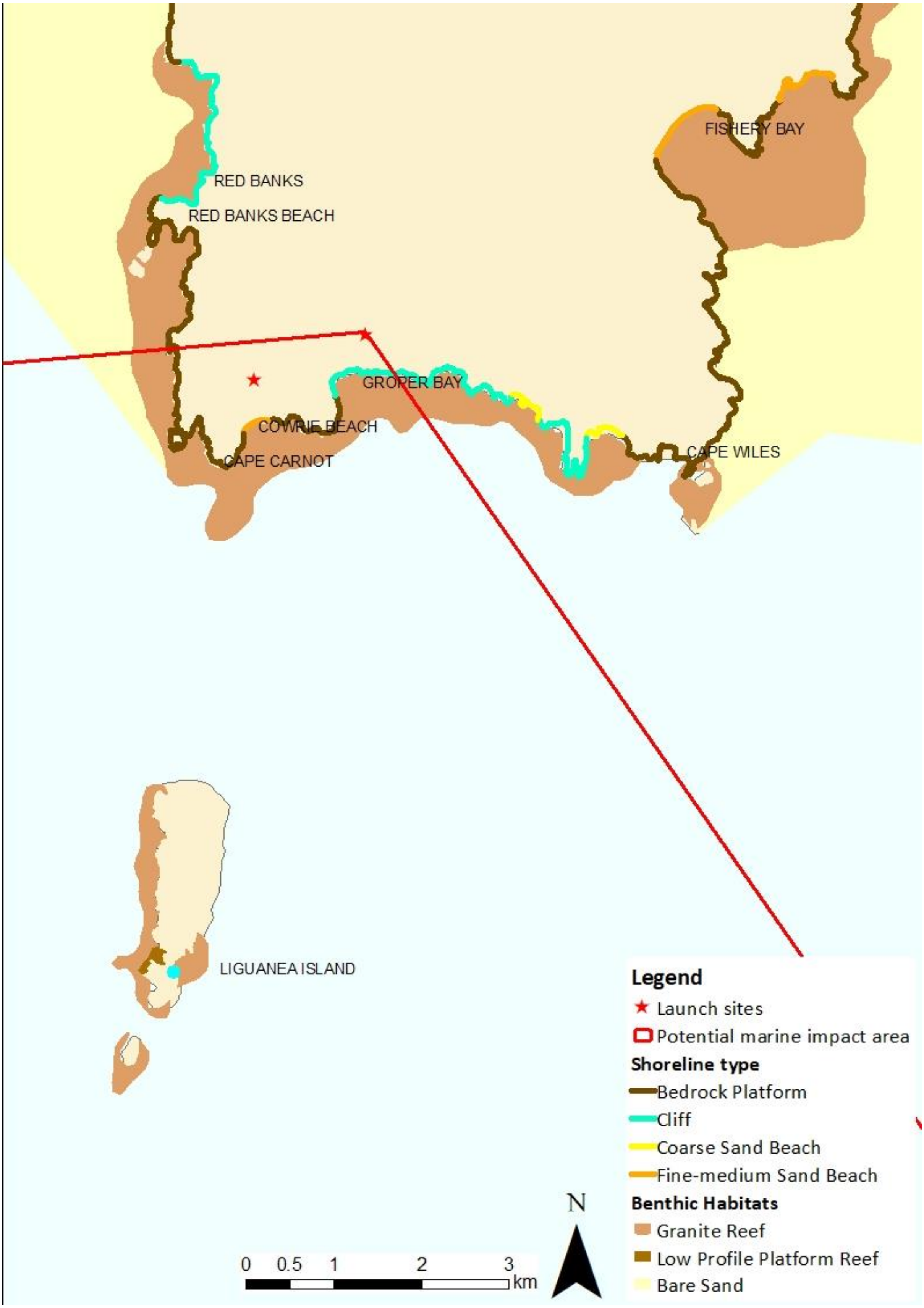

Figure 3. Shoreline and benthic habitats of Whalers Way and Liguanea Island. Source: DEW 2021a, b.

The red macroalga *Erythrotrichia ligulata,* recorded one kilometre south-west of Cape Carnot, has been classified as *Vulnerable* by Cheshire et al. (2000) due to the few records (three) in southern Australia.

The benthic habitat below the intertidal bedrock platforms on the eastern coastline of the Whalers Way site has been mapped as sand (DEW 2021b, Edyvane 1999). No seagrass has been mapped, but it has been observed immediately adjacent to the intertidal habitats around Whalers Way (DEW 2021a).

2.4 Invertebrates

No surveys of invertebrate communities are known from within the PMIZ, but a number of surveys of mobile invertebrates have been undertaken by the University of Tasmania and DEW at coastal and nearshore island sites of southern Eyre Peninsula, both to the east and west of the WWOLC (Reef Life Survey 2021). The dominant organisms recorded were the feather star *Cenolia trichoptera,* purple urchin *Heliocidaris erythrogramma,* long-spined urchin *Centrostephanus tenuispinus,* the sea stars *Meridiastra gunnii, M. calcar, Petricia vernicina* and the gastropods *Turbo undulatus, Dicathais orbita* and greenlip and blacklip abalone *Haliotis laevigata* and *H. rubra.*

Bryars (2003) identified the reef habitat along southern Eyre Peninsula and Liguanea Island as being suitable for various life stages of southern rock lobster *Jasus edwardsii*, southern calamary *Sepioteuthis australis*, giant cuttlefish *Sepia apama*, Maori octopus *Octopus maorum*, greenlip abalone, blacklip abalone and purple urchin.

The eyelet top shell *Cantharidella ocellina*, identified by Baker & Clarkson (2014) as being of potential conservation concern in South Australia, has been recorded at Cape Wiles (its type locality) and a murex species *Monstrotyphis bivaricata* has been recorded south-west of Cape Carnot (and 64 km south of Cape Wiles).

2.5 Fishes and sharks

Surveys of reef fish undertaken near Redbanks in 2004 by Shepherd et al. (2005) recorded 18 species across five transects with varying levels of wave exposure each covering 500 m^2. The most abundant species were sea sweep *Scorpis aequipinnis*, zebra fish *Girella zebra* and bluethroat wrasse *Notolabrus tetricus* (Shepherd, unpublished data). Western blue groper *Achoerodus gouldii,* which is protected in the South Australian gulfs (east of Cape Carnot), was recorded on all transects, generally as sub-adults but with some juveniles and an adult.

Bryars (2003) identified the reef habitat along southern Eyre Peninsula and Liguanea Island as being suitable for various life stages of King George whiting, snapper *Chysophrys auratus*, Western Australian salmon *Arripis truttacea*, Australian herring *Arripis georgiana*, yelloweye mullet *Aldrichetta forsteri*, trevally *Pseudocaranx* sp., yellowtail kingfish *Seriola lalandi,* snook *Sphyraena novaehollandiae*, sea sweep, silver drummer *Kyphosus sydneyanus,* western blue groper, gummy shark *Mustelus antarcticus*, whaler sharks *Carcharhinus* spp., leatherjackets Monacanthidae spp. and wrasse Labridae spp. (including bluethroat wrasse). Species of recreational and commercial fishing interest recorded during the surveys by Shepherd et al. (2005) included bluethroat wrasse, sea sweep, King George whiting *Sillaginodes punctata* and southern sea garfish *Hyporhamphus melanochir* (Shepherd, unpublished data).

Southern Eyre Peninsula is a biologically important area (for foraging) for the white shark *Carcharadon carcharias* (DSEWPC 2013).

2.6 Marine mammals

Liguanea Island supports breeding populations of Australian sea lion and long-nosed fur seal, and a number of cetaceans have been recorded in the waters of the TPMP.

2.6.1 Australian sea lion

The Australian sea lion (ASL) *Neophoca cinerea* is currently listed as Vulnerable under the South Australian *National Parks and Wildlife Act 1972* (NPW Act 1972) and Endangered under the EPBC Act 1999. It is endemic to Australia, with 58 regular breeding colonies and 151 haul-out sites identified in South Australia and Western Australia. The breeding sites are generally on offshore islands, and have an average pup production of 40 pups, with only five sites producing more than 100 pups per breeding season and most sites producing fewer than 30 pups (DEE 2018). Thirteen distinct ASL metapopulations or regions have been identified based on geographic distance analysis among colonies as a proxy for genetic differences (Pitcher 2018).

The ASL is late-maturing (about 6 years) and makes a high investment of maternal care into relatively few pups. Pupping occurs over 4–5 months (Goldsworthy 2020) with an interval between pupping seasons of 17–18 months (the only pinniped to have a non-annual breeding cycle), with breeding occurring at any time of year and occurring at different times in different breeding colonies. Females breed only at the sites at which they were born. Females nurse their pups until 1–3 months before giving birth again (or up to three years if they don't pup or new pup dies). Males fight for and defend their access to females (DEE 2018).

ASL forage the seafloor of the continental shelf for a variety of prey including fish, sharks, cephalopods, lobster and penguins. Juveniles, adult females and adult males have been recorded foraging 118 km, 190 km and 340 km from their colony, respectively, but behaviour varies both within and between-colonies. Adult females alternate between foraging trips to sea and nursing onshore. Pups explore adult foraging habitat at least eight months prior to weaning. ASL forage at all times of day and dive continuously while at sea, although individual dives rarely exceed eight minutes in duration (DEE 2018).

Estimated pup counts were 30 in 1990[1] (Gales et al. 1994), 43 in 2004 (Shaughnessy et al. 2005), 25 in 2015 (Goldsworthy et al. 2015) and 27 in 2019 (Goldsworthy 2020). Liguanea Island is the fifth-largest of 11 breeding colonies within the 'Spencer Gulf' metapopulation, representing about 3.3% of that metapopulation and about 0.9% of total pup production (Goldsworthy 2020). ASL breed mainly on the southern peninsula of the island, although pups have been seen on the east coast, and haul-out around the entire coastline, as well as on top of the island (Professor S. Goldsworthy, SARDI, 31 August 2020). A total population for the island can be estimated from pup numbers using a multiplier of approximately four (Goldsworthy et al. 2015), i.e. 165 and 100 ASLs in 2004 and 2015, respectively.

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[1] Note that Robinson et al. (1996) cite Gales et al. 1994, reporting 23 pups and 30 adults, whereas these numbers correspond to number of pups recorded and the estimated number of pups. Robinson et al. (1996) also refer to counts of 16 pups and 96 adults in 1990, but the primary source of this information is not specified.

The decline in pup numbers between 2004 and 2015 reflects a statewide decline which has been partly attributed to bycatch in a gillnet fishery. Measures were put in place eight years ago to enhance recovery (DEE 2018), and should now be starting to have a positive impact on pup production now that the pups of sea lions protected by these measures will have now reached sexual maturity.

2.6.2 Long nosed fur seal

The Long nosed fur seal (LNFS) *Arctocephalus forsteri* is not listed as threatened under the South Australian NPW Act 1972 or the EPBC Act 1999, but is listed as 'Marine' under the latter act. Fur seal populations in southern Australia were heavily exploited by colonial sealers in the early 1800s, resulting in major reductions in range and abundance, but are now recovering exponentially, assisted by protection of breeding habitat (Shaughnessy et al. 2014).

LNFS breeds in New Zealand and its subantarctic islands, and southern Australia from New South Wales to Western Australia, mostly (83%) from 29 breeding sites in South Australia, of which 97% are from colonies between Kangaroo Island and the southern tip of Eyre Peninsula (Shaughnessy et al. 2014).

LNFS breeds annually from late November to mid-January, generally over a month (Goldsworthy & Shaughnessy 1994). Most females breed for the first time at age five years (range 4–8 years), and males hold territories for the first time at nine years (McKenzie et al. 2007).

Adult females forage over the continental shelf during the early breeding season (December-March), after which they increasingly forage in oceanic waters. Adult males mainly forage over the shelf and slope waters, although they sometimes forage in oceanic waters. Sub-adult males favour the shelf in winter (Goldsworthy et al. 2019).

The population of LNFS on Liguanea Island in February 2014 was estimated at 1832, across four sub-colonies separated by three distinctive features: two chasms and a group of white rocks (Shaughnessy et al. 2014, Figure 4). The total for Liguanea Island represented 9% of the LNFS pup production in South Australia. A total population for the island can be estimated from pup numbers using a multiplier of 4.76 (Shaughnessy et al. 2015), i.e. 8720.

Although not formally documented (DEW 2021c, Goldsworthy & Page 2009, Shaughnessy et al. 2014), Cape Wiles is known as a haul-out site for LNFS (McFarlane 2016).

Although the overall population of LNFS has increased in South Australia, the populations of some colonies, including Liguanea Island, appear to have stabilized (Shaughnessy et al. 2014).

Figure 4. Landmarks on Liguanea Island separating four sub-colonies

2.6.3 Cetaceans

There are a number of ALA records of whale species in the TPMP:

- blue whale *Balaenoptera musculus*, a pair 9 km south-east of the WWOLC in February 2007
- humpback whale *Megaptera novaeangliae*, from autumn 2001 (individual) and 2003 (pair), in both cases 20 km south-east of the WWOLC
- killer whale *Orcinus orca*, undated record 8 km south-west of the WWOLC
- southern bottle-nosed whale *Hyperoodon planifrons,* from February 1994, 1.5 km south of the WWOLC
- southern right whale *Eubalaena australis*, records of up to 8 individuals from winter on four occasions during 1991–2002, within 1.5 km of the WWOLC, noting that Sleaford Bay, just east of the WWOLC, has been identified as a site where small, but increasing, numbers of mostly non-calving southern right whales regularly aggregate briefly (DSEWPaC 2012).

There is a single ALA record of 200 dolphins from 10 km south of the WWOLC in December 2003. However, an aerial survey was used to estimate dolphin populations in central South Australia, including the shelf waters offshore from Eyre Peninsula (Figure 5). The estimated population size (95% confidence interval) of short-beaked common dolphin *Delphinus delphis* from this area was 2,800–10,600 in summer and 13,000–20,000 in winter (Moller et al. 2012). Densities have not been calculated for this study, but a similar study in the eastern Great Australian Bight (just north-west of the Moller study) had estimates of 20,000 – 22,000 individuals at a density of 0.67 – 0.73 dolphins/km^2 (Goldsworthy et al. 2017).

The estimated population size of bottlenose dolphin *Tursiops* sp. was 3–104 in summer and zero in winter (Moller et al. 2012).

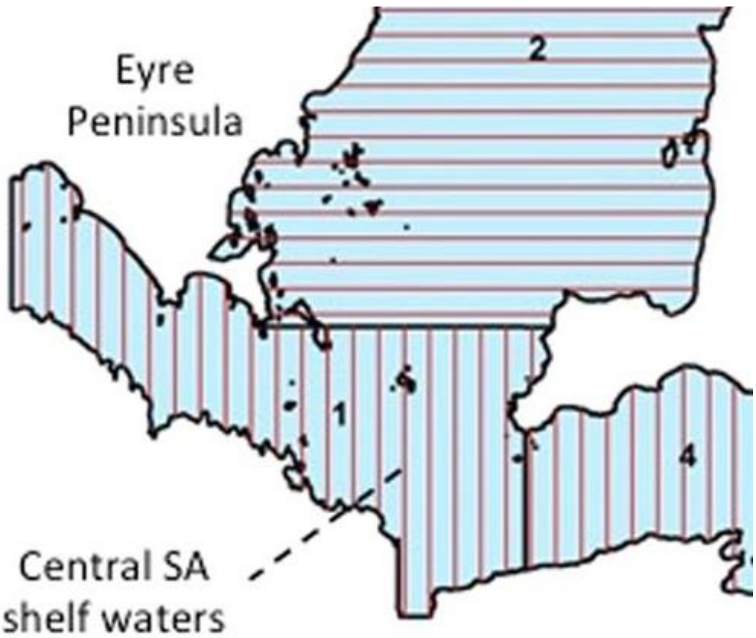


Figure 5. Dolphin aerial survey areas. Source: Bilgmann et al. 2019.

2.7 Seabirds

Liguanea Island supports breeding populations of short-tailed shearwater and crested tern, both migratory species. A number of other seabirds have been recorded on Liguanea Island elsewhere in the TPMP.

2.7.1 Short-tailed shearwater

The short-tailed shearwater (STS) or mutton bird *Ardenna tenuirostris* is currently listed as Migratory under the EPBC Act 1999. The STS breeds in summer on Tasmania and off the coast of southern Australia, migrating to north of Japan for winter in May before returning in October, travelling in dense flocks (Copley 1996, Einoder 2009, Robinson et al. 1996). There are more than 10 million breeding pairs in southern Australia (Skira 1991), including one million in South Australia (Copley 1996) across at least 33 colonies (Robinson et al. 1996), including 14 in the TPMP (Bryars et al. 2016). STS live up to 20 years and begin breeding at about 7 years of age. The male and female have a high interannual fidelity to each other and their previous burrows (which are dug to up 2 m in length), and both participate in incubation of their single egg during a breeding period that is highly synchronised through the range of the species, occurring in late November (McLeay 2014). Fledglings leave the colony in late April, with an estimated mortality rate of at least 50% (Copley 1996).

STS adopt a range of foraging strategies, with short trips on the continental shelf up to 100 km from their colony, often to specific areas, and longer trips of about 1000–7000 km (for up to 32 days), including to subantarctic and Antarctic waters (Einoder 2009).

The breeding colony on Liguanea Island spans 45 ha, which is about a quarter of the island's area (Figure 6). The total number of burrows has been estimated at 10,665 (corresponding to a population of 20,330), based on an average burrow density of a number of other South Australian colonies that have been surveyed (Robinson et al. 1996).

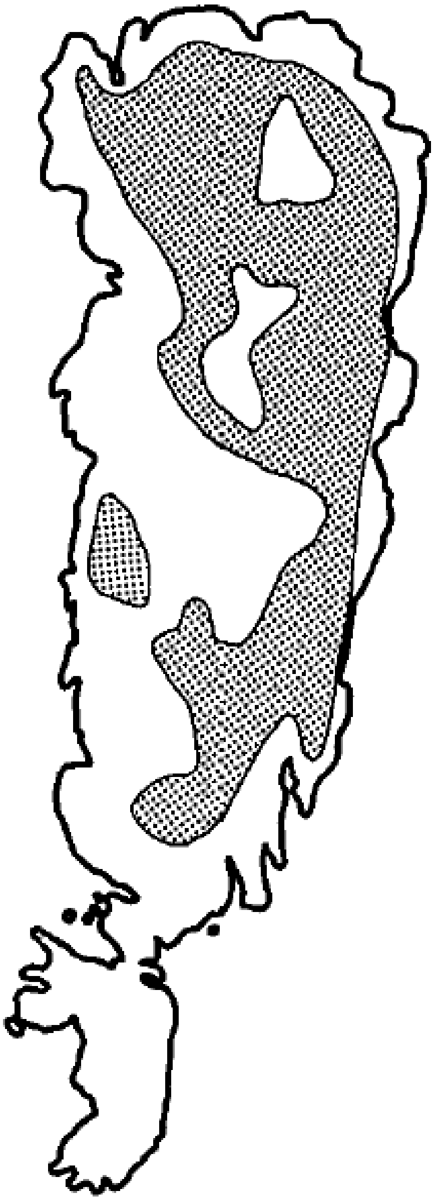


Figure 6. Distribution of breeding colonies of short-tailed Shearwater *Ardenna tenuirostris* on Liguanea Island. Source: Robinson et al. 1996.

2.7.2 Crested Tern

The Crested Tern *Thalasseus bergii* is listed as Migratory under the EPBC Act 1999. There is a breeding population of 'several thousand' birds (Goldsworthy & Page 2010), of an estimated South Australian population of 13,000–25,000 (Copley 1996). Breeding in South Australia typically occurs in October (McLeay et al. 2017).

2.7.3 Other seabirds

For most seabird species in the Great Australian Bight, there are few data on species distributions, and little or no quantitative data on their abundances (Goldsworthy et al. 2017). Available information includes:

- Cape Barren Goose *Cereopsis novaehollandiae* (Rare under the NPW Act 1972) breeds on Liguanea Island during winter (Robinson et al. 1996).
- Silver Gull *Chroicocephalus novaehollandiae* and Pacific Gull *Larus pacificus* are common along the coast of Liguanea Island, and Sooty Oystercatcher *Haematopus fuliginosus* (Rare under the NPW Act 1972) and White-faced Heron *Egretta novaehollandiae* also use the intertidal rocks, particularly on the east coast (Robinson et al. 1996).
- Other seabirds with ALA records from Liguanea Island include Fairy Tern *Sternula nereis* (Endangered under the NPW Act 1972 and Vulnerable under the EPBC Act 1999), Little Penguin *Eudyptula minor* and Pied Cormorant *Phalacrocorax varius*.
- Assessment of the Southern Osprey *Pandion haliaetus* and White-bellied Sea Eagle *Haliaeetus leucogaster*, both of which are listed as Endangered under the NPW Act 1972, and the former listed as Migratory under the EPBC Act 1999, has been undertaken by AECOM (2021)

3 Ecological values of the Southern Ocean

Seabed assemblages of southern Australia have been mapped by examining changes in demersal species composition along environmental gradients. Two assemblages have been identified within the PMIZ, which correspond geographically to the continental shelf and continental slope (Figure 7). The remainder of the PMIZ is over the abyssal plain.

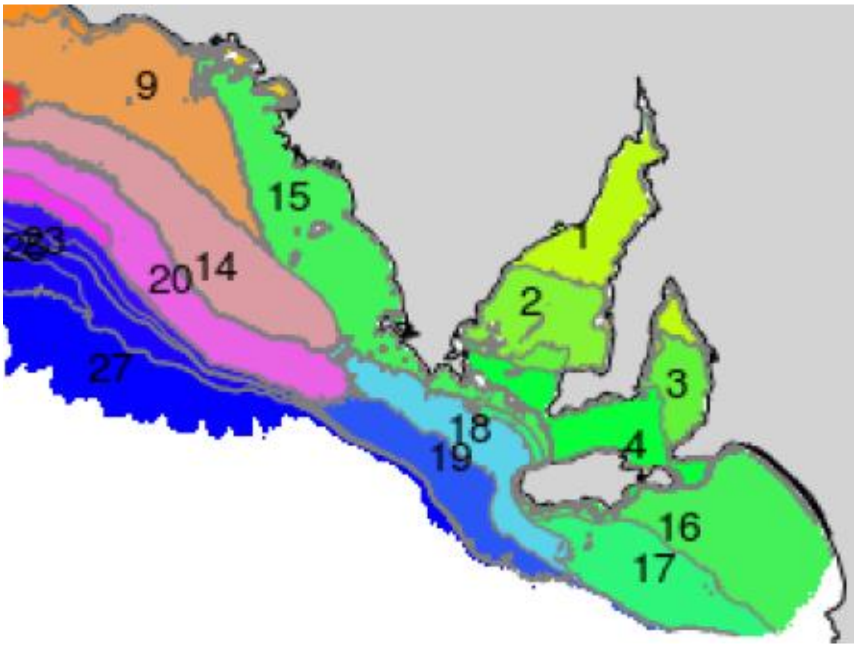


Figure 7. Map of offshore assemblage patterns in southern Australia. Source: Pitcher et al. 2018.

Commonwealth Marine Parks overlapping the PMIZ include (Figure 8):

- South-west Marine Parks Network (Director of National Parks 2018):
  - Great Australian Bight Marine Park
  - Western Eyre Marine Park
  - Western Kangaroo Island Marine Park
  - Southern Kangaroo Island Marine Park
- South-east Marine Parks Network (Director of National Parks 2013):
  - Murray Marine Reserve
  - Nelson Marine Reserve
  - Zeehan Marine Reserve

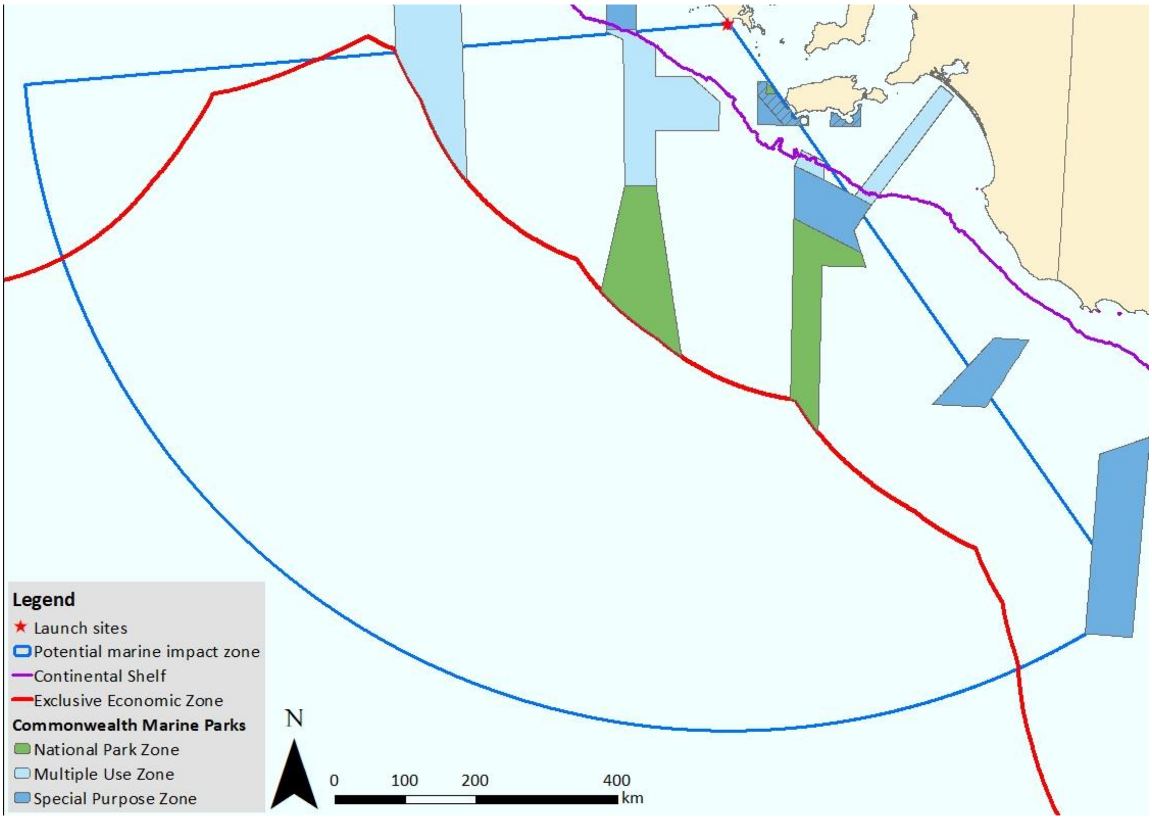


Figure 8. Commonwealth Marine Parks. Source: DAWE (2018).

A number of megafauna and bird species recorded in or considered possible to occur within the PMIZ, including those listed in Section 2, are provided in Table 2. A number of sources have been used to identify these species, including:

- Atlas of Living Australia (ALA) records, which include records from the South Australian Museum, other museums, BirdData and credible citizen science databases including iNaturalist, from particular studies (e.g. IFAW & MCRL 2013), and a seabird atlas (Reid et al. 2002).
- EPBC Act 1999 Protected Matters Search Tool (PMST) (DAWE 2021a)
- The Great Australian Bight Research Program (Baghurst undated)
- *South-west Marine Region: Ecosystems and Key Species* report (McClatchie et al. 2006).

Table 2. Summary of megafauna and bird species that may be present within the PMIZ

Notes: EPBC = *Environment Protection and Biodiversity Conservation Act 1999*; MNES = Matters of National Environmental Significance; SA Status = status under the South Australian *National Parks and Wildlife Act 1972*; PMST = Protected Matters Search Tool. Information about distribution sourced from Atlas of Living Australia (ALA) database or Australian Government's Species Profile and Threats (SPRAT) database (DAWE 2021b) unless otherwise indicated.

Scientific name	**Common name**	**MNES Category**	**SA Status**	**PMST results**	**Knowledge of distribution with respect to the search area**
Sharks					
Carcharodon carcharias	White shark	Vulnerable, Migratory		Foraging, feeding, or related behaviour known to occur within area	Wide ranging species, with most frequent observations around seal breeding colonies. One ALA record from 500 km south of the WWOLC.
Lamna nasus	Porbeagle, Mackerel shark	Migratory		Species or species habitat likely to occur within area	Oceanic range with occasional temporary visits to coastal waters. No ALA records within search area.
Rhincodon typus	Whale shark	Vulnerable, Migratory		Species or species habitat may occur within area	Occurs in 124 countries. In Australia, it is most commonly seen in waters off northern Western Australia, Northern Territory and Queensland, and only occasionally in South Australia. No ALA records within search area.
Isurus oxyrinchus	Shortfin mako	Migratory		Species or species habitat likely to occur within area	Worldwide in tropical and warm-temperate oceanic waters in depths to at least 500 m, mostly in water temperatures above 16°C. Recorded in Australia from all states except the Northern Territory - usually in offshore waters (Bray 2021a). Individual sharks are wide ranging across southern Australia (Rogers et al. 2016). There are 13 ALA records (from fisheries data) from along the edge of the continental shelf during 2000–2002 and an additional record from the edge of the shelf in 2015.

Scientific name	Common name	MNES Category	SA Status	PMST results	Knowledge of distribution with respect to the search area
Marine turtles					
Caretta caretta	Loggerhead turtle	Endangered, Migratory	Endangered	Species or species habitat likely to occur within area	Key breeding and foraging habitats are in tropical Australia. No ALA records within search area.
Chelonia mydas	Green turtle	Vulnerable, Migratory	Vulnerable	Species or species habitat known to occur within area	Key breeding and foraging habitat is in tropical Australia. No ALA records within search area.
Dermochelys coriacea	Leatherback turtle	Endangered, Migratory	Vulnerable	Species or species habitat known to occur within area	Pelagic feeder with no known breeding habitat in Australia. No ALA records within search area.
Lepidochelys olivacea	Olive Ridley turtle	Endangered, Migratory		Not reported	Normally inhabits northern Australia. One ALA record from 650 km south-east of the WWOLC.
Marine mammals					
Arctocephalus gazella	Antarctic fur seal	N/A (Listed Marine)		Not reported	Widely distributed in Antarctic waters, breeding and hauling out on numerous islands (FAO 2021). One ALA record (Australian Antarctic Data Centre) from 950 km south of the WWOLC in January 1982.
Balaenoptera bonaerensis	Antarctic minke whale	Migratory	Rare (as *Balaenoptera acutorostrata*)	Species or species habitat likely to occur within area	Found near Antarctica throughout summer. Recorded from all Australian states but not Northern Territory. No ALA records of this species but there are two ALA records of the northern Minke whale *B. acutorostrata* from about 90 km south-west of the WWOLC from aerial surveys in December 2003 and March 1979, which are likely to be *B. bonaerensis.*
Balaenoptera borealis	Sei whale	Vulnerable, Migratory	Vulnerable	Foraging, feeding or related behaviour likely to occur within area	Migrate from Antarctic feedings areas to breeding areas in tropical waters, and are infrequently recorded in Australian waters. No ALA records within study area.
Balaenoptera edeni	Bryde's Whale	Migratory		Species or species habitat may occur within area	Wide ranging across temperate and tropical Australia, with no specific breeding or feeding habitats known in Australia. No ALA records within study area.

Scientific name	Common name	MNES Category	SA Status	PMST results	Knowledge of distribution with respect to the search area
Balaenoptera musculus	Blue Whale	Endangered, Migratory	Endangered	Foraging, feeding or related behaviour known to occur within area	Migrate between polar and tropical waters and have a number of aggregations worldwide, but are globally rare. Nearest blue whale aggregation area is Robe in south-eastern South Australia. Outside aggregation areas coast is used only for migration and opportunistic feeding. There are 244 records (including about 100 of the subspecies *B. musculus brevicaudata*) in the search area from aerial surveys in December 2003, associated with seismic surveys, extending in a north-westerly/south-easterly direction, 70–100 km offshore from the WWOLC (Morrice et al. 2004). There are a further 11 sightings from an aerial survey in December 2005.
Balaenoptera physalus	Fin whale	Vulnerable, Migratory	Vulnerable	Foraging, feeding or related behaviour likely to occur within area	Migrate between polar and tropical waters. Most Australian records are from strandings in temperate waters. There are records for South Australia but no ALA records within the search area.
Caperea marginata	Pygmy Right Whale	Migratory	Rare	Species or species habitat likely to occur within area	Wide ranging across temperate Australia, with some concentration at the entrance to the South Australian gulfs. No ALA records within the search area.
Delphinus delphis	Short beaked common dolphin	N/A (Cetacean)		Species or species habitat may occur within area	Recorded in offshore waters off all Australian states and territories (although rarely in northern Australian waters). Seventeen ALA records from a survey 70 km south of the WWOLC in April 2011. See Section 2.6.3 for details of the population on continental shelf south of the WWOLC.
Eubalaena australis	Southern Right Whale	Endangered, Migratory	Vulnerable	Breeding known to occur within area	Contrary to the PMST results, breeding is not understood to occur in the area (see further detail in Appendix 1). Three SA Museum records from May 1993, May 2005 and August 2005 at distances of 45, 90 and 107 km south of the WWOLC, respectively, and two SA Museum records from June 1995 and October 1996 from 360 and 480 km south-south-west of the WWOLC, respectively.
Globicephala melas	Long-finned pilot whale	N/A (Cetacean)		Not reported	Found throughout southern hemisphere. Widely recorded in waters off southern Australia. Two SA Museum records from March 1995 and 1998 at 150 km south-west and 930 km south-east of the WWOLC. Note that there are an additional 14 records of undistinguished pilot whales (same genus) from December to May, during 1979–2009, within an area 180 km south to 550 km west of the WWOLC.

Scientific name	Common name	MNES Category	SA Status	PMST results	Knowledge of distribution with respect to the search area
Hyperoodon planifrons	Southern bottlenose whale	N/A (Cetacean)		Not reported	Found in mid- to high latitudes around southern hemisphere, including offshore areas of southern Australia. Five ALA records (SA Museum or Australian Antarctic Data Centre) from February 1996 and 1980, from 160–190 km south or 100–120 km south-west of the WWOLC.
Lagenorhynchus obscurus	Dusky Dolphin	Migratory		Species or species habitat likely to occur within area	Occur throughout southern hemisphere, but considered uncommon in Australia with only 13 reports since 1828, including two in the early 1980s, all in temperate waters. No ALA records within the search area.
Lissodelphis peronii	Southern right whale dolphin	N/A (Cetacean)		Not reported	Found in mid- to high latitudes around southern hemisphere, including southern continental Australia. One SA Museum record from August 1998 from 350 km south-east of the WWOLC.
Megaptera novaeangliae	Humpback Whale	Vulnerable, Migratory	Vulnerable	Species or species habitat likely to occur within area	Global distribution is fragmented. In Australia, migration occurs between Antarctic feeding grounds and calving areas in northern Western Australia and Queensland. Five ALA records from 1990–2006 during January to June, 20–230 km south-west to south-south-east from the WWOLC, including two records within the TPMP.
Neophoca cinerea	Australian Sea Lion	Endangered	Vulnerable	Species or species habitat known to occur within area	Temperate water species ranging from western Victoria to Western Australia. Nearest breeding area is Liguanea Island (see Section 2.6.1). There are more than 800 ALA records from sea lions tracked foraging on the continental shelf.
Orcinus orca	Killer whale	Migratory		Species or species habitat likely to occur within area	Occur in all oceans, including all Australian states (possibly in fragmented populations), with concentrations in Tasmania and frequent sightings in South Australia and Victoria. There are 46 ALA records along the edge of the continental shelf, mainly from a 2010–2016 study of interactions of the species with a longline fishery (Tixier et al. 2018), and an additional five SA Museum records from 1985–1992 from further offshore or inshore, including one 3 km west of Liguanea Island.

Scientific name	**Common name**	**MNES Category**	**SA Status**	**PMST results**	**Knowledge of distribution with respect to the search area**
Physeter macrocephalus	Sperm whale	Migratory	Rare	Foraging, feeding or related behaviour known to occur within area	Occurs in deep waters in all oceans including all Australian states (possibly in fragmented populations), with concentrations near the continental shelf edge, including south-west of Kangaroo Island. There are 37 ALA records within the search area (SA Museum or Australian Antarctic Data Centre, many associated with aerial surveys for tuna spotting or near seismic activity) from 1979–2013, between December and July, beyond but within 50 km of the continental shelf.
<u>Marine birds</u>					
Ardenna carneipes	Flesh-footed shearwater	Migratory	Rare	Foraging, feeding or related behaviour likely to occur within area	A trans-equatorial migrant, and a locally common visitor to waters of the continental shelf and continental slope off southern Australia. There are 35 records from 100–1000 km, south-west to south-east of the WWOLC.
Ardenna grisea	Sooty shearwater	Migratory		Species or species habitat may occur within area	Breeds in southern hemisphere in summer, including islands off New South Wales and Tasmania and is a moderately common migrant and visitor to South Australia. During winter most birds move to the North Pacific Ocean. Seven ALA records from 400–1000 km south-west to south of the WWOLC.
Ardenna tenuirostris	Short-tailed shearwater	Migratory		Not reported	Breeds in summer on Tasmania and off the coast of southern Australia, migrating to north of Japan for winter. There are 62 ALA records from 100–1000 km south-west to south-east of the WWOLC, and two near Liguanea Island. The estimated breeding population on Liguanea Island is greater than 10,000 (see Section 2.7.1).
Cereopsis novaehollandiae	Cape Barren Goose	N/A (Listed Marine)	Rare	Not reported	Resident in south-eastern Australia (to Eyre Peninsula) and south-western Australia. Nearest important areas are Kangaroo Island and the Sir Joseph Banks Group in Spencer Gulf (BirdLife Australia 2021a). One ALA record from Liguanea Island and one other from 100 km south-east of the WWOLC.
Chroicocephalus novaehollandiae	Silver Gull	N/A (Listed Marine)		Not reported	Common throughout Australia and is also found in New Zealand and New Caledonia. Found at virtually any watered habitat but seldom venture far out to sea (Birdlife Australia 2021b). One ALA record from 30 km south-west of the WWOLC

Scientific name	**Common name**	**MNES Category**	**SA Status**	**PMST results**	**Knowledge of distribution with respect to the search area**
Diomedea antipodensis	Antipodean albatross	Vulnerable, Migratory		Foraging, feeding or related behaviour likely to occur within area	Endemic to, and breeds in, New Zealand but forages widely in the Southern Ocean. No ALA records within search area.
Diomedea dabbenena	Tristan albatross	Endangered, Migratory		Species or species habitat likely to occur within area	Occurs in a single population which breeds on Atlantic Ocean islands and disperses to Africa, South America and south-western Australia during non-breeding periods. No ALA records within search area.
Diomedea epomophora	Southern royal albatross	Vulnerable, Migratory	Vulnerable	Foraging, feeding or related behaviour likely to occur within area	Moderately common in offshore areas of southern Australia (Iron Road 2014). Eleven ALA records from more than 500 km offshore in a south-westerly to south-easterly direction.
Diomedea exulans	Wandering Albatross	Vulnerable, Migratory	Vulnerable	Foraging, feeding or related behaviour likely to occur within area	Breeds on Macquarie Island and feeds in Southern Ocean. There are 87 ALA records south to west from Kangaroo Island.
Diomedea sanfordi	Northern Royal Albatross	Endangered, Migratory	Endangered	Foraging, feeding or related behaviour likely to occur within area	Breeds in New Zealand. Ranges widely over the Southern Ocean, feeding regularly in Tasmanian and South Australian waters. Five ALA records from 100 or 700 km south of Kangaroo Island.
Egretta novaehollandiae	White-faced Heron	N/A		Not reported	Found wherever there is water throughout the mainland and Tasmania, and most coastal islands (Australian Museum 2021a). One ALA record from 700 km south-east of the WWOLC.
Eudyptula minor	Little penguin	N/A (Listed Marine)		Not reported	Distributed in coastal waters around the southern mainland and Tasmania (Australian Museum 2021b). One ALA record from Liguanea Island.
Haematopus fuliginosus	Sooty oystercatcher		Rare	Not reported	Resident around the Australian coastline, with nearest important area at Coffin Bay (BirdLife Australia 2021c). Two ALA records from Cape Carnot and one from Liguanea Island.
Haliaeetus leucogaster	White-bellied sea eagle	N/A (Listed Marine)	Endangered	Not reported	Refer AECOM (2021).

Scientific name	Common name	MNES Category	SA Status	PMST results	Knowledge of distribution with respect to the search area
Halobaena caerulea	Blue Petrel	Vulnerable		Species or species habitat may occur within area	Breeds in sub-Antarctic territory, with some records from south-eastern Australia. Eleven ALA records from at least 300km south to south-west from Kangaroo Island.
Hydroprogne caspia	Caspian Tern	Migratory		Foraging, feeding or related behaviour known to occur within area	Global distribution. Migratory species but has widespread resident populations in Australia. One ALA record from 30 km west of Kangaroo Island.
Larus pacificus	Pacific gull	N/A (Listed Marine)		Foraging, feeding or related behaviour known to occur within area	Endemic to southern Australia. Prefers areas that are protected from ocean swells (BirdLife Australia 2020d). One ALA record from 30 km west of Kangaroo Island.
Macronectes giganteus	Southern Giant Petrel, Southern-Giant Petrel	Endangered, Migratory	Vulnerable	Species or species habitat likely to occur within area	Widespread throughout the Southern Ocean and breed on six subantarctic and Antarctic islands in Australian territory. Ten ALA records from at least 300 km south of Kangaroo Island.
Macronectes halli	Northern Giant Petrel	Vulnerable, Migratory		Species or species habitat may occur within area	Breeds on sub-Antarctic islands. Visits south-eastern Australia, with nearest record being from western Eyre Peninsula in 2003. There are 14 ALA records 150–750 km from Kangaroo Island in a westerly to south-easterly direction.
Pachyptila belcheri	Slender-billed Prion	N/A (Listed Marine)		Not reported	Southern hemisphere distribution, breeding on the southern Indian Ocean islands (BirdLife International 2021a). Eight ALA records at least 300 km south of Kangaroo Island.
Pachyptila turtur subantarctica	Fairy Prion (southern)	Vulnerable		Species or species habitat may occur within area	Breeds on subantarctic islands but wide-ranging along southern Australian coastline. There are 29 ALA records 150–1000 km from Kangaroo Island in a westerly to south-easterly direction.
Pandion cristatus (listed as *P. haliaetus*)	Southern Osprey	Migratory	Endangered	Species or species habitat may occur within area	Refer AECOM (2021).
Phalacrocorax fuscescens	Black-faced Cormorant	N/A (Listed Marine)		Species or species habitat likely to occur within area	Found along southern Australian coasts, common in Bass Strait and in Spencer Gulf, South Australia (BirdLife Australia 2021e). One ALA record from about 30 km south-west of the WWOLC.

Scientific name	**Common name**	**MNES Category**	**SA Status**	**PMST results**	**Knowledge of distribution with respect to the search area**
Phalacrocorax varius	Pied Cormorant	N/A		Not reported	Found throughout mainland Australia but most common to the south and along the south-western coastline (BirdLife Australia 2021f). No ALA records within study area.
Phoebetria fusca	Sooty Albatross	Vulnerable, Migratory	Endangered	Species or species habitat likely to occur within area	Breeds on islands in the southern Indian and Atlantic Oceans, sometimes observed foraging on southern Australian coasts. There are 33 ALA records from 300–1000 km south-west to south-east of the WWOLC.
Phoebetria palpebrata	Light-mantled Sooty Albatross	Migratory	Vulnerable	Not reported	Widespread circumpolar distribution. Breeds on Antarctic and subantarctic islands and occurs over southern Australian waters. There are 25 ALA records (Birdata and Museum New Zealand), mostly from 450–950 m south of the WWOLC.
Pterodroma leucoptera leucoptera	Gould's Petrel	Endangered		Species or species habitat may occur within area	Breeds on islands in New South Wales, uses south-eastern Australian waters and there have been records from further west. Four ALA records from 250–650 km south of the WWOLC.
Pterodroma macroptera	Great-winged Petrel	N/A (Listed Marine)		Foraging, feeding or related behaviour known to occur within area	There are 86 ALA (including 62 Bird Life records) from 100–1000 km south-west to south-east of the WWOLC.
Pterodroma mollis	Soft-plumaged Petrel	Vulnerable		Foraging, feeding or related behaviour likely to occur within area	Breeds on southern Tasmanian islands. Inhabits sub-Antarctic oceanic areas and visits southern Australian seas, mainly to the west. Three ALA records within 550–600 km south-west to south-east of the WWOLC.
Stercorarius skua	*Great skua*	N/A (Listed Marine)		Species or species habitat may occur within area	No ALA records in search area.
Sternula nereis nereis	Australian Fairy Tern	Vulnerable	Endangered	Foraging, feeding or related behaviour likely to occur within area	Widespread through temperate Australian coasts. One ALA record from Liguanea Island.
Thalassarche bulleri	Buller's Albatross	Vulnerable, Migratory	Vulnerable	Foraging, feeding or related behaviour likely to occur within area	A New Zealand resident but are regular visitors to Australian waters between New South Wales and South Australia. One ALA record from 300 km south of the WWOLC.

Scientific name	**Common name**	**MNES Category**	**SA Status**	**PMST results**	**Knowledge of distribution with respect to the search area**
Thalassarche bulleri platei	Northern Buller's albatross	Vulnerable	Vulnerable (as *Diomedia bulleri*)	Foraging, feeding or related behaviour likely to occur within area	Breeds in New Zealand. Most birds seem to disperse outside Australasian seas during the non-breeding season. Some birds forage near the eastern Australian mainland. No ALA records in search area.
Thalassarche carteri	Indian yellow-nosed albatross	Vulnerable, Migratory	Endangered	Foraging, feeding or related behaviour may occur within area	Breeds in South Africa and on French Antarctic islands. Forages mostly in the southern Indian Ocean including Western Australia Thirteen ALA records from 100–600 km south-west to south-east of the WWOLC.
Thalassarche cauta	Shy Albatross	Endangered, Migratory	Vulnerable (as *Thalassarche cauta cauta*)	Foraging, feeding or related behaviour likely to occur within area	Breeds in Tasmania, but uses southern Australian coastline. Thirty ALA records from 80–1000 km south-west to south-east of the WWOLC.
Thalassarche chlororhynchos	Atlantic yellow-nosed albatross	Migratory	Endangered	Not reported	Resident of the South Atlantic Ocean (BirdLife International 2021b). There are 35 ALA records (mainly BirdLife Australia) from 100–300 km south-west of the WWOLC.
Thalassarche chrysostoma	Grey-headed albatross	Endangered, Migratory	Vulnerable	Species of species habitat may occur within area	Circum-global southern hemisphere distribution, breeding on subantarctic islands including Macquarie Island. Most Australian records from Tasmania. There are 83 ALA records from 200–1000 km south-west to south-east from the WWOLC.
Thalassarche impavida	Campbell Albatross	Vulnerable, Migratory	Vulnerable	Foraging, feeding or related behaviour likely to occur within area	Does not breed in Australia but forages in south-eastern Australian waters, and may visit southern Australian shelf waters. Five ALA records from 150–650 km south to south-east of the WWOLC.
Thalassarche melanophris	Black-browed Albatross	Vulnerable, Migratory		Foraging, feeding or related behaviour likely to occur within area	Breeds on subantarctic islands but is distributed throughout Southern Ocean. There are 122 ALA records from 70–1000 km south-west to south-east from the WWOLC.
Thalassarche salvini	Salvin's Albatross	Vulnerable, Migratory	Vulnerable	Foraging, feeding or related behaviour likely to occur within area	Breeds in New Zealand and the southern Indian Ocean. Forages over most of the southern Pacific Ocean, including Australia. One ALA record from 300 km south of the WWOLC.

Scientific name	Common name	MNES Category	SA Status	PMST results	Knowledge of distribution with respect to the search area
Thalassarche steadi	White-capped Albatross	Vulnerable, Migratory		Foraging, feeding or related behaviour likely to occur within area	Breeds in New Zealand but considered common across southern Australia. There are 75 ALA records mainly from 200–350 km south-west of the WWOLC.
Thalasseus bergii	Crested Tern	Migratory		Not reported	Breed on islands and coastlines of Africa, Asia, Australia and western Pacific Ocean in spring and summer, dispersing to sea at other times. One ALA record from near Redbanks within the WWOLC, one from Liguanea Island and 18 records from 80–330 km south-west to south-east of the WWOLC.
Shorebirds					
Actitis hypoleucos	Common Sandpiper	Migratory		Species or species habitat may occur within area	Breeds in Europe and Asia. Areas of national importance for the species are primarily in the north of Australia. Known to use coastal habitats, including sandy beaches and rocks. No ALA records within search area.
Calidris acuminata	Sharp-tailed Sandpiper	Migratory		Species or species habitat may occur within area	Range includes large areas of the Australian coastline and inland areas. No ALA records within search area.
Calidris canutus	Red knot	Endangered, Migratory	Endangered (as *Calidris canutus rogersi*)	Species or species habitat may occur within area	Range includes large areas of the Australian coastline. No ALA records within search area.
Calidris ferruginea	Curlew sandpiper	Critically Endangered, Migratory	Endangered	Species or species habitat may occur within area	Range includes large areas of the Australian coastline and inland areas. No ALA records within search area.
Calidris melanotos	Pectoral sandpiper	Migratory	Rare	Species or species habitat may occur within area	Broad distribution across Australia but in South Australia is generally found to the east of Spencer Gulf. No ALA records within search area.
Numenius madagascariensis	Eastern curlew	Critically Endangered, Migratory	Endangered	Species or species habitat may occur within area	Range includes large areas of the Australian coastline and inland areas. No ALA records within search area.

4 Impact Assessment

4.1 Introduction

The following impacts on the marine environment within the TPMP and the broader PMIZ are assessed:

- Operational impacts:
    - Debris collision with fauna on land or the sea surface (Section 4.2)
    - Other debris impacts, including ingestion by marine fauna, crushing or smothering of biota, emission of toxic contaminants and provision of habitat (Section 4.3).
    - Noise, including acoustic trauma and behavioural impacts (Section 4.4)
- Construction noise

Details of the various rocket stages and their expected return to earth are provided in Table 3 for sub–orbital vehicles and Table 4 for orbital vehicles. The rockets can be classified according to their payload capacity, namely micro (< 150 kg), mini (150–500 kg) and small (500–2000[2] kg). It is expected that only two of 36 rockets launched annually would be of the small class, with more than half being near the lower end, i.e. an order of magnitude smaller, and the rest being about a third of the payload size range.

The operational impacts listed above include all those considered during a generic ecological risk assessment of debris jettisoned during successful launches in New Zealand of *Electron* space vehicles of similar scale to the 'mini' class proposed for the WWOLC (NIWA 2017). All of the issues assessed by NIWA (2017) were classified as low risk, having varying degrees of likelihood but negligible or minor consequences. Minor consequence was defined as measurable but localised change with 1–5% impact on populations and recovery within weeks. NIWA (2017) considered that the risk profile of the issues assessed may change after multiple launches if there were significant spatial overlap of their debris fields. The impacts associated with rocket launches were not considered to make a significant difference to the overall cumulative impact of other stressors including commercial fishing and climate change (NIWA 2017).

Table 3. Size of suborbital vehicles proposed for launch from the WWOLC. Note that dry mass = without fuel, wet mass = with fuel (whether solid or liquid), n/a = not applicable. Source: compiled from information provided by Southern Launch.

Attribute	Entire vehicle	Stage 1	Stage 2
Length (m)	2.8–8	2–6	0.08–2
Diameter (m)		0.3–0.8	0.05–0.7
Dry mass (kg)	5–480	3–400	2–80
Wet mass (kg)	22–2800	20–2600	2–200
Payload mass (kg)	<1–50		
Return to earth range (km)	n/a	3–8	40–150

[2] Note that the largest payload proposed for WWOLC is 1500 kg (Table 4).

Table 4. Size of orbital vehicles proposed for launch from the WWOLC. Note that dry mass = without fuel, wet mass = with fuel (whether solid or liquid), n/a = not applicable. Source: compiled from information provided by Southern Launch.

Attribute	Entire vehicle	Stage 1	Stage 2	Stage 3	Stage 4	Fairing
Length (m)	12.5–34	8–20	3–6	1.5–6	0–2	5–10
Diameter (m)		0.8–3.5	0.6–3	0.5–2.8	0–2.5	
Dry mass (kg)	1400–13,200	800–8000	400–3000	200–1200	0–1000	50
Wet mass (kg)	9700–120,000	8000–60,000	1200–35,000	500–25,000	0–12,000	n/a
Payload mass (kg)	<50–1500					
Return to earth range (km)		500–900	>900	>900	>900	600–1000

4.2 Collision of debris with fauna

Several scenarios could result in fauna being struck by high speed projectiles associated with a rocket launch (Appendix 1):

- Nominal success: orbit achieved with slight variations in trajectory – some stages fall to earth at distances of 3–8 and 40–150 km for suborbital rockets (Table 3) and >500 km for orbital rockets (Table 4), respectively.
- Failure – air burst: a launch vehicle explodes while in the air. This results in the launch vehicle breaking up into a number of pieces and landing over a large area. This can be the result of a manual detonation of a rocket (using a flight termination system) that is not behaving as expected.
- Failure – ground burst: launch vehicles motors fail shortly after lift-off. The flight termination system fails and the vehicle remains whole as it falls to the ground/water and explodes on impact.

Debris, functioning as a high speed projectile, would not have any significant impact on marine life below the surface because of rapid attenuation of its kinetic energy on entering seawater. Other impacts associated with debris are discussed in Section 4.3.

4.2.1 Liguanea Island

Rockets launched from either launch station with Polar and Sun Synchronous trajectories are the most likely to pass close enough to Liguanea Island to present a risk of debris falling onto the island (Figure 9). Although any point on the island could be considered a sensitive receiver with the possible presence of seabirds or pinnipeds, there are a number of focal areas (all abundances and areas are estimates):

- 165 ASL occupying 15 ha on the southern peninsula of the island
- 9,500 LNFS occupying 20 ha along the east coast of the island
- 10,665 STS burrows occupying 45 ha inland on the island

Flight safety risk analysis using processes set out by the Federal Aviation Authority and Flight Safety Code has been undertaken using established frameworks for estimating the probability of human casualties, applied to seals (Appendix 1). The probabilities are expressed as the average number of launches expected between seal casualties for scenarios for each of the micro, mini and small size classes.

The modelling is conservative in many respects, including:

- the assumption that the modelled number of seals are all on land, when many would be foraging at sea, particularly outside of the breeding season.
- the use of near worst-case (99.5th percentile) of debris interactions with Liguanea Island, rather than mean, to calculate expected casualties
- the assumption that all debris striking with energy greater than 15 joules would be fatal.

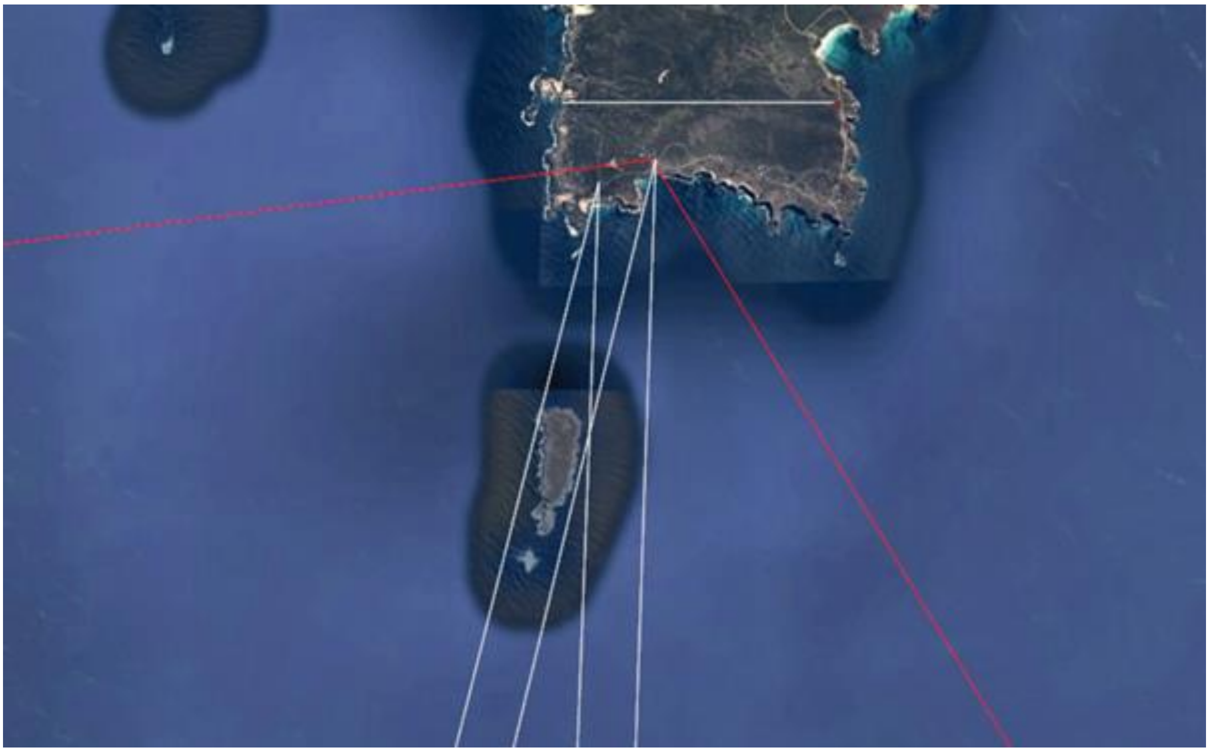


Figure 9. Range of possible bearings for sun synchronous and polar trajectories from each launch site. Source: Southern Launch (see Appendix 1).

Successful launches

No impacts on Liguanea Island are expected from debris arising from successful launches, because the first stage of orbital rockets would not fall to earth within 500 km (Table 4).

A booster from a suborbital rocket is typically 2–3 m long, with a diameter of 400 mm. It is expected to fall to earth within 3–8 km from the launch pad (Table 3). For a polar or sun synchronous orbit over the Liguanea Island, the entire island would be within that range; the northern tip of the island is about 4.6 and 5.4 km from launch sites A and B, respectively, and the length of the island is 2.7 km. However, no impacts are expected from suborbital rockets as they would not be launched with a polar, sun synchronous or any other trajectory that could result in debris falling on Liguanea Island.

Air burst

An air burst would result in a scatter of debris over an area that would increase with distance from the launch. For a debris fragment to collide with fauna on Liguanea Island, it would require not only failure of the rocket, but at such a precise time as would result in fallout over the island, and one or more of the few fragments falling on the island to coincide with the sparsely distributed fauna.

The risk analysis modelling predicted that an air burst would have an average frequency of LNFS and ASL casualties of one every 3375 and 194,470 launches, respectively, for small rockets. For mini or micro rockets, expected to collectively account for 95% of launches (Appendix 1), the frequency would be 30 or 100 times lower, respectively (Table 5). The low number of casualties per air burst for both species suggests that there would be no impact at subpopulation level for either species.

Table 5. Probabilities of seal casualties from air burst events. Source: Southern Launch (Appendix 1)

		LNFS		ASL	
Vehicle	**1 Accident per [X] Launches**	**Casualties per air burst**	**1 Casualty Per [X] Launches**	**Casualties per air burst**	**1 Casualties Per [X] Launches**
Small	11,764	3.48	3375	0.0604	194,470
Mini	7407	0.07	105,814	0.0012	6,170,000
Micro	7407	0.02	370,350	0.0004	18,510,000

Ground burst

Rockets can be installed with a flight termination system (FTS) that allows the rocket to be detonated in mid-air in the event of unexpected and undesirable behaviour. Explosion of a rocket on Liguanea Island would require failure of the FTS, in addition to other factors such as launch failure at the precise time that resulted in a collision with Liguanea Island.

The risk analysis modelling predicted that a ground burst would occur about every 4.7 million launches for a small rocket and every 3 million launches for mini or micro rockets, with an average frequency of LNFS and ASL casualties of one every 7700 and 445,000 launches, respectively, for small rockets and almost twice as many launches for mini or micro rockets (Table 6).

Despite the very low frequency of ground bursts on Liguanea Island, the higher number of casualties relative to air bursts warrants further assessment of the potential impact at subpopulation level of a single accident. For LNFS, population viability analysis undertaken by Goldsworthy et al. (2007), in the context of fisheries bycatch, found that more than 1,000 additional mortalities of immature females would be required annually to drive the Liguanea Island subpopulation to extinction over 32 years, compared with 613 mortalities (all age and sex, so less for immature females) for the worst-case predicted mortalities per ground burst (Table 6). Therefore there would be no subpopulation level impact on LNFS. For ASL, population viability analysis found that 2 additional mortalities of immature females would be required annually to drive the Liguanea Island subpopulation, already assumed to be in decline, to extinction over 46 years, or for a subpopulation of the current size of Liguanea Island, 1.3 additional annual mortalities over 32 years (Goldsworthy et al. 2007). This suggests that the worst case ground burst mortalities of about 11 (all age and sex, so less for immature females) (Table 6) may have a minor impact on pup production over six years but there would be no long-term subpopulation level impact. More certainty could be gained from additional population viability analysis specifically targeting mortality rates predicted for ground bursts.

Table 6. Probabilities of seal casualties from ground burst events. Source: Southern Launch (Appendix 1)

		LNFS		ASL	
Vehicle	1 Accident per [X] Launches	Casualties per ground burst	1 Casualty per [X] Launches	Casualties per ground burst	1 Casualty per [X] Launches
Small	4,716,981	613	7,694	10.6	444,998
Mini	2,914,176	226	12,894	3.9	747,224
Micro	2,914,176	199	14,644	3.4	857,110

Conclusion

Debris from successful launches would not impact on Liguanea Island fauna. An air burst over Liguanea Island would be a very rare event that could result in mortalities but there would be negligible impact at subpopulation level. Ground bursts on Liguanea Island would be a rarer event than an air burst but could impact more individuals. Although this may result in temporary reductions in ASL pup production, no long-term impact is expected at subpopulation level.

4.2.2 Southern Ocean

High speed strikes by debris on marine biota below the sea surface are not expected because of rapid attenuation of the kinetic energy of the debris on entering seawater. Impacts of debris settling onto the benthic environment are discussed in Section 4.3.

The probability of an animal (including birds) being struck by debris decreases with downstream distance and lateral distance from the trajectory. Figure 10 shows debris impact probability isopleths for a particular launch scenario (Perigee rocket, sun synchronous trajectory). Inside each isopleth the probability of debris striking a particular location is greater than the value of the isopleth. For the scenario shown, a given location beyond the continental shelf would have less than one in a million chance of debris falling on it.

For the TPMP, there would be no impact from successful orbital launches because the stages would all return to earth more than 500 km offshore (Table 4), but for successful suborbital rockets the spent first stage (3–400 kg mass) may fall into the TPMP (away from Liguanea Island), at least 3 km offshore (Table 3).

An ecological risk assessment of direct strikes of rocket debris on air breathing fauna in New Zealand found that the likelihood of individuals being killed by a direct strike was remote and consequences at the population and community scale were negligible, resulting in a low risk classification (NIWA 2017).

Marine fauna likely to occur at least some time on or above the surface with records from within the PMIZ provided in Section 3. These records do not represent a systematic survey of marine fauna across the PMIZ but are opportunistic sightings, related to particular studies, e.g. fishery bycatch or seismic surveys. These records provide little information about the density of each species or whether debris from polar, sun synchronous or any other orbit would be more or less likely to encounter marine fauna.

More spatially structured data are available for cetaceans in the outer shelf and upper slope region (50–100 km south of the WWOLC) from an aerial survey associated with the Great Australian Bight Research Program (Gill 2016). Dolphins and pilot whales were the most commonly sighted (including a pod of 500 bottlenose dolphins), but there were insufficient sightings of any species in that study to calculate densities. However, the density of common dolphin *Delphinus delphis* was calculated to be 0.67–0.73 dolphins/km^2 in a region immediately to the north-west (Bilgmann et al. 2014), and this can be adopted as a conservative upper bound for all cetaceans.

Noting that the surveys by Gill (2016) were in summer and autumn, further consideration is given to southern right whales during their migration to and from the calving areas at Head of Bight and Fowlers Bay that they inhabit between May and October. Southern right whales within the PMIZ are likely to be from the south-western Australian population, which extends eastwards from WA at least as far as Encounter Bay (Carroll et al. 2011)[3]. The south western population of southern right whales is increasing at a rate of about 6 per cent, close to its biologically plausible maximum (Bannister 2018, Charlton 2017, Carroll et al. 2011).

The exact path of whales between summer offshore and winter coastal habitat is not well understood, but they travel west along the southern coastline during winter (Burnell 2001). Sleaford Bay, just east of the WWOLC, has been identified as a brief aggregation area for whales on their way to calving areas at Head of Bight and Fowlers Bay (DSEWPaC 2012).

Maximum counts of SRW were 172 from shore and aerial surveys at Head of Bight (Charlton 2017, Charlton et al. 2014a), and 55 from aerial surveys at Fowlers Bay (Charlton et al. 2014b), i.e. 227 in total, and 206 from a simultaneous aerial survey at both sites (Mackay & Goldsworthy 2015). Not all of these would pass through the PMIZ.

Theoretical and simulation models developed by BMT WBM (2018) found that 260 SRWs migrating through the Great Australian Bight, generally as individuals (DSEWPaC 2012), would collide about once every 300 years with vessels passing at 15 knots every two weeks during the whale migration season. The probability of colliding with falling debris at particular instants would be much less likely.

It is concluded that there may be occasional debris strike impacts on individual animals on the sea surface but no impact at population level.

[3] DSEWPaC (2012), which cites Carroll (2011), refers to Ceduna, South Australia as the boundary between the south-western and south-eastern Australian populations but this is considered to be an error.

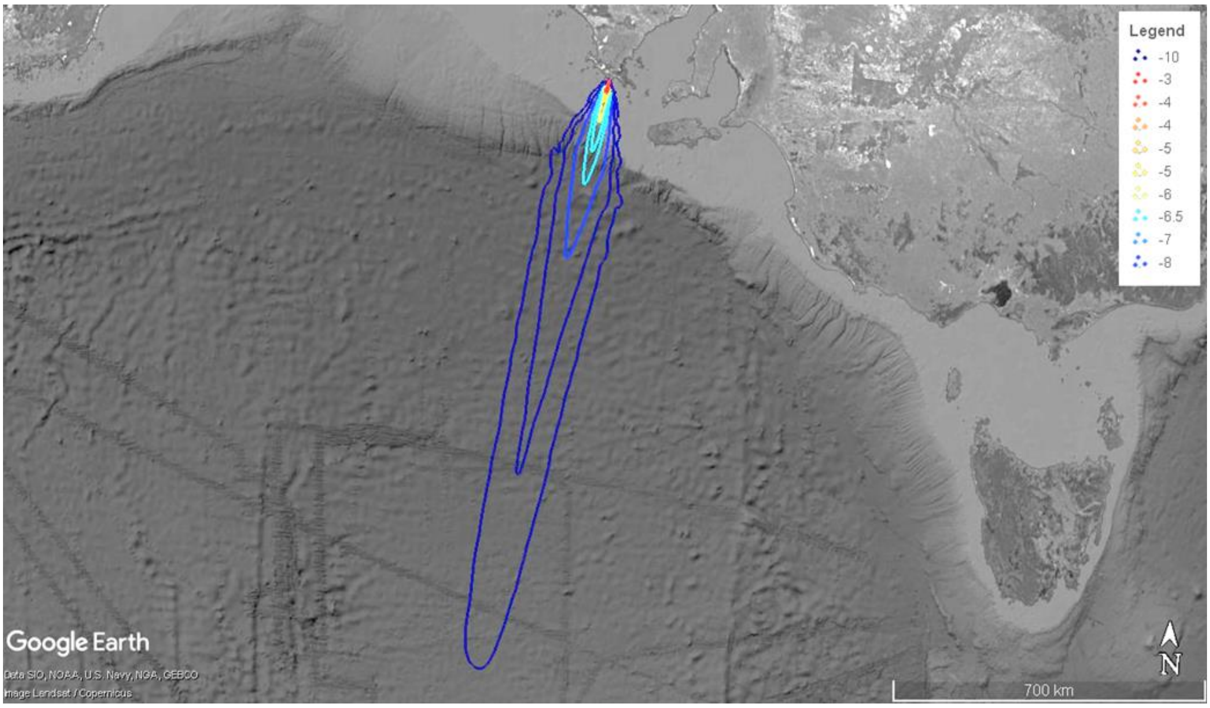


Figure 10. Isopleths showing probability of impact from falling debris associated with a particular rocket launch scenario (Perigree rocket, sun synchronous trajectory). Source: Southern Launch.

4.3 Other debris impacts

The impacts of debris following contact with the sea surface depend on the nature of the rocket components of which the debris is comprised. Southern Launch has provided details of these components (refer Section 22 of the Draft EIS). Key points include:

- all component materials are inert and harmless to the marine environment except lithium (within batteries) and copper (within electrical wiring)
- Fuels would be expended before contact with the sea floor, or would burn, remain inert (rubber-based solid fuel) or vaporise (liquid fuels)
- Most materials would sink, except rubber-based solid fuels (and liquid fuels prior to vaporisation) and some small pressure vessels which have not been punctured
- Casings that have not already broken up during re-entry would generally shatter into thousands of pieces on impact with sea surface, with the possible exception of some thick carbon fibre components.

4.3.1 Toxic contaminants

Copper fragments would sink to the seafloor where their slow dissolution may have long-term local effects on sediment infauna, or be dispersed from areas of hard substrate, adding a very low total mass of copper relative to natural oceanic copper quantities (NIWA 2017).

Lithium ion batteries (about the size of two car batteries in volume) would likely rupture on impact with the sea surface or at depth. Lithium is already elevated in seawater and is not toxic, but would react with seawater and in sufficient quantity could cause alkaline conditions with localised, short-term toxic effects (NIWA 2017).

4.3.2 Crushing or smothering of benthic organisms

Sessile organisms may be impacted by larger items of debris or accumulations of fragments settling on the seafloor, but the descent of such debris is expected to be slow enough for mobile fauna to avoid (NIWA 2017). Fragile biota may be damaged or destroyed, and feeding or respiration may be inhibited. However, the area impacted would be insignificant in comparison to the extent of the receiving environment and population level impact would be negligible.

4.3.3 Ingestion of debris

The breakup of rocket debris during re-entry or on impact with the sea surface would create particles small enough to be ingested by most biota, but will likely sink fast enough to avoid air-breathing fauna. Although ingestion may impact some individuals, population level impact would be negligible.

4.3.4 Habitat changes

The settlement of larger fragments of debris on soft sediment would result in a shift to benthic communities requiring hard surfaces. Floating debris may provide shelter for pelagic organisms and substrate for attachment and dispersion of sessile organisms. In the context of the size of the receiving environment, these changes are considered to have negligible impact at population level.

4.4 Operational noise

Acoustic energy from in-air noise does not effectively transfer across the sea surface meaning that most of the noise is reflected off the water surface. In the case of noise arising from debris striking the sea surface, it is noted that an ecological risk assessment of underwater noise impacts from rocket launches in New Zealand found that the consequences were negligible for most fauna but for air-breathing fauna (and some other fauna in shallow environments) were assessed as minor with measurable, localised, short-term effects at a population or community scale (NIWA 2017).

Hereafter this assessment of marine species is limited to exposure of birds and pinnipeds to airborne noise from rocket launches. Noise from launches would temporarily alter the quiet setting of the natural environment for one to two minutes during launches. The maximum instantaneous sound pressure level during a launch would be 125 dBA[4] at the closest shoreline to either launch site, less than 95 and 100 dBA at Cape Wiles for launches from Site A and Site B, respectively, and about 95 dBA at the northern end of Liguanea Island (slightly higher for Site A launches) (Figure 11, AECOM 2020). Sound exposure levels (SELs), representing the sound level of a constant sound that would generate the same acoustical energy in one second as the actual time-varying noise event, were typically 15 dBA higher (Figure 11, AECOM 2020). These modelled noise predictions are compared with thresholds relevant to birds and seals in the following Sections.

Noise impacts associated with testing have not been considered as the noise would be for a shorter duration (15 seconds) and further from the marine environment and at maximum levels of 10–20 dB lower than the launch scenarios (AECOM 2020).

[4] dBA refers to the “A-weighted” sound pressure levels in decibels, adjusted to correspond to the human hearing frequency range.

Noise impacts from sonic booms would be limited to behavioural impacts but are considered unlikely to occur on the coast or Liguanea Island. Sonic booms would be generated several kilometres offshore during ascent, but are typically directed in front of the rocket and would not be close enough or strong enough, due to the relatively small size of the rockets, to reach the earth's surface (AECOM 2020).

4.4.1 Birds

AECOM (2021) cited noise thresholds reported by Dooling & Popper (2016) for assessing impacts on birds, namely 140 dBA for permanent hearing loss, and 93 dBA for temporary hearing loss and behaviour change. However, the latter threshold is very conservative because it is based on continuous exposure of 12–72 hours duration, rather than two minutes.

Based on these thresholds, hearing loss resulting from rocket noise is not expected for STS or other birds inhabiting Liguanea Island, where noise levels are predicted to be below 100 dBA. Although some areas to the north of the island may be exposed to noise just above the behaviour change threshold of 93 dBA, the exceedance is considered to be insignificant due to the short duration of exposure compared with the exposure time associated with the threshold.

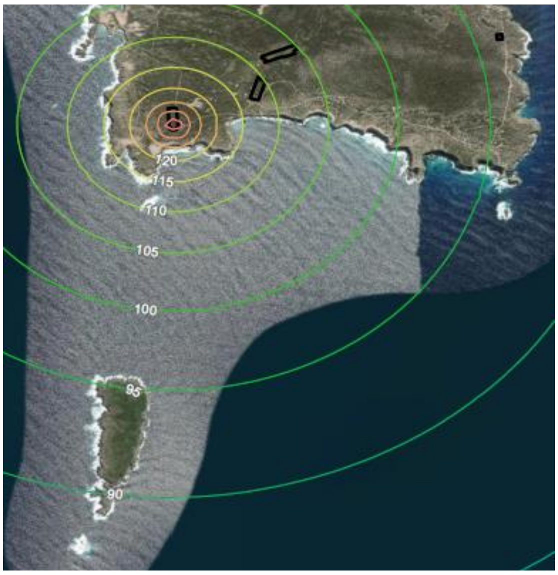
There may be temporary hearing loss or behavioural impacts on birds using sections of the mainland coastline near the launch sites. An assessment of impacts on Fairy Tern *Sternula nereis*, Eastern Osprey *Pandion haliaetus* and White-bellied Sea Eagle *Haliaeetus leucogaster* has been undertaken by AECOM (2021).

Masking of acoustic signals is not expected to have any significant impact on bird communication due to the short duration of the rocket noise.

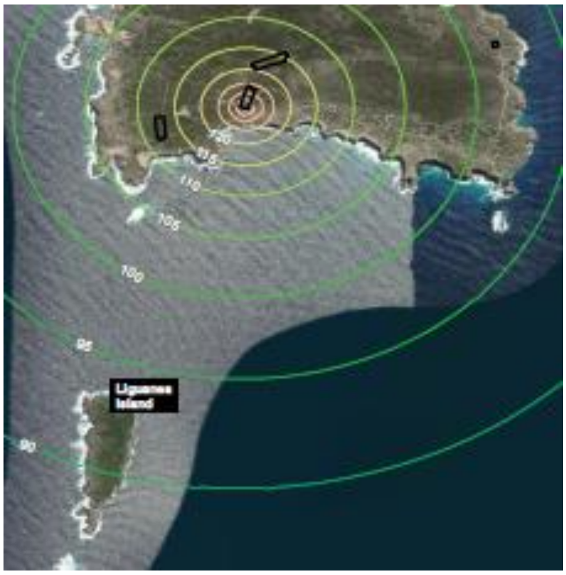
4.4.2 Pinnipeds

Criteria presented by Southall et al. (2019) for noise impacts on eared seals above water suggest that there would be no temporary hearing loss for ASL or LNFS below M-weighted sound exposure levels (SELs) of 157 dB. M-weighted sound pressures are based on the hearing frequency range of marine mammal groups. In the case of eared seals (out of the water), their hearing range extends up to 200 kHz, compared with human hearing of 20 kHz. However, in the case of rocket launch noise, sound pressure in the range 20–200 kHz is relatively low (Bowles 2000), suggesting that the A-weighted values modelled for this study are representative of the noise to which seals will be exposed.

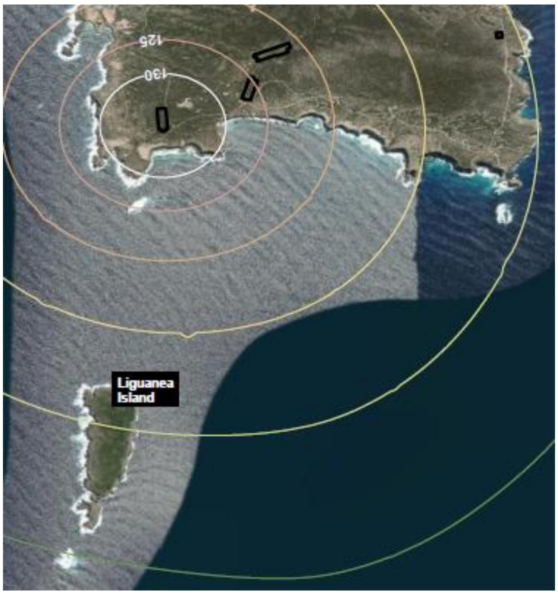
Therefore no impact is expected on the hearing of ASL or LNFS on Liguanea Island, or LNFS hauled-out at Cape Wiles, where L_{Amax} and SEL values are less than 100 and 115 dBA, respectively (Figure 11).



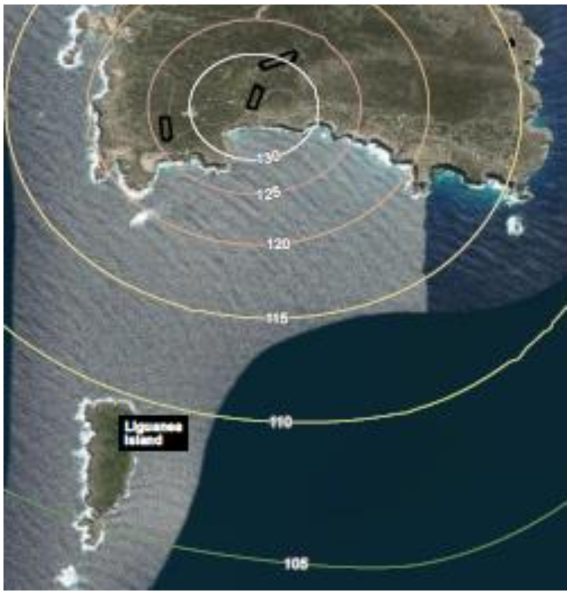
(a) Site A, maximum instantaneous sound level (L_{Amax}).



(b) Site B, L_{Amax}



(c) Site A, Sound exposure level (SEL)



(d) Site B, SEL

Figure 11. Predicted noise level contours from modelling of launches at Sites A and B. Source: AECOM 2020.

Impacts on pinniped behaviour are the primary concern with regard to rocket launches (FAA 2016). Wildlife typically exhibit a startle response to sudden loud, uncommon, short-term noise, and pinnipeds may enter the water when frightened and a stampede could cause pups to be trampled or separated from their mothers in the process (Sandegren 1969, Johnson 1979, Pitcher and Calkins 1979, Back et al 2018). Marine mammal reactions to rocket launches are highly variable and may be attributable to the species, age, time of year, air temperature and potential habituation to noise (FAA 2016, Bowles 2000). Animals can be sensitive to sound pressures of a given level one day and not the next (AAC 2017). However, it is generally accepted that significant behavioural responses in pinnipeds are not expected at sound pressure levels below 100 dB[5], but 90 dB for harbor seal *Phoca vitulina* (USAF 1997, Oliver 2006, Southall et al. 2007, Marzin 2018, Rauch 2019). Therefore some behavioural impacts on pinnipeds toward the north of Liguanea Island are possible, but unlikely at the south of island where they concentrate, particularly for launches from Site B (Figure 11). If seals were to be sufficiently startled to stampede towards the water, pups are unlikely to be injured by trampling because the narrow habitat does not allow for a sufficiently dense concentration of seals, and after their first month, the pups are quite robust (pers. comm. Professor S. Goldsworthy, SARDI Aquatic Sciences). Approvals have been routinely granted for behavioural impacts on pinnipeds at the Kodiak Launch Complex (KLC) in Alaska and Vandenberg Air Force Base (VAFB) in California (Oliver 2006, Marzin 2018, Rauch 2017, 2019), including movement both on land and into the water, but the latter has occurred only rarely with seals hauling out again within minutes to two hours of each launch (USAF 2018), and harbor seal populations near the VAFB increase at an annual rate of 12.6 per cent over a decade despite 5–7 space vehicle launches per year (Oliver 2006).

Seals are also known to respond to helicopter noise (Bowles 2000, Oliver 2006), which was found to exceed launch noise at Ugak Island in Alaska, near the Kodiak Launch Complex[6] (Oliver 2006). It is noted that helicopters have been used to conduct aerial surveys and/or facilitate ground surveys of ASL on Liguanea Island (Goldsworthy et al. 2015), with no suggestion of adverse impacts.

It is concluded that behavioural impacts on seals on Liguanea Island are possible but likely to be short-term.

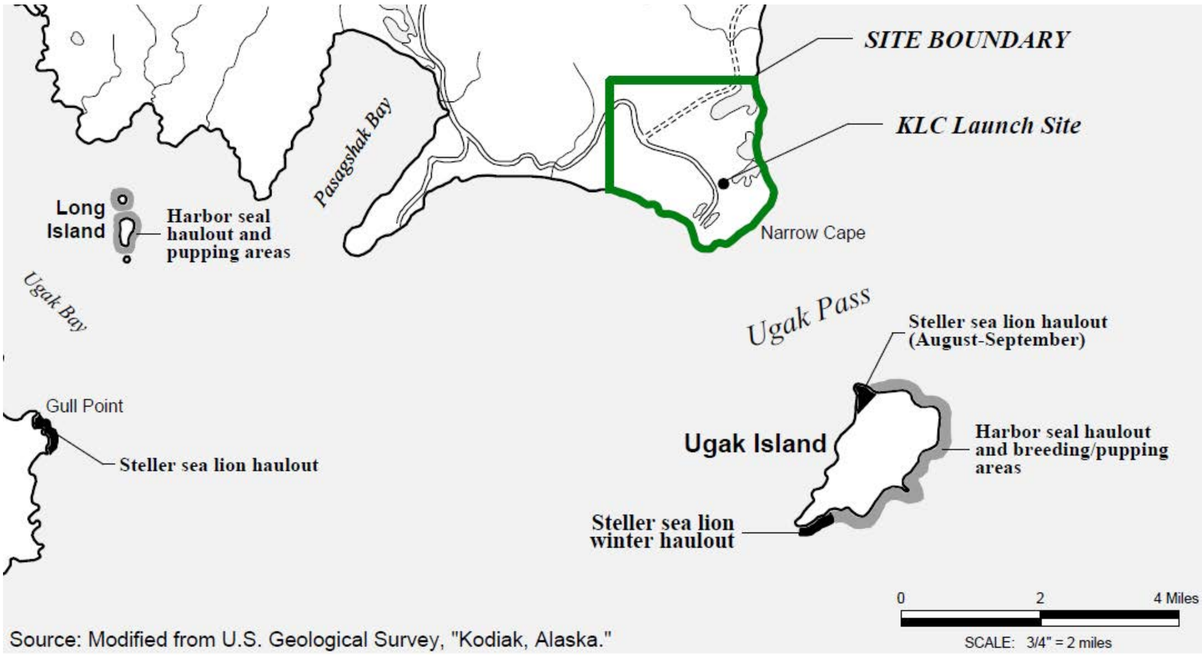


Figure 12. Pinniped colonies near the Kodiak Launch Complex, Alaska. Source: Brown & Root Environmental 1996.

[5] Root mean square

[6] Now known as the Pacific Spaceport Complex Alaska

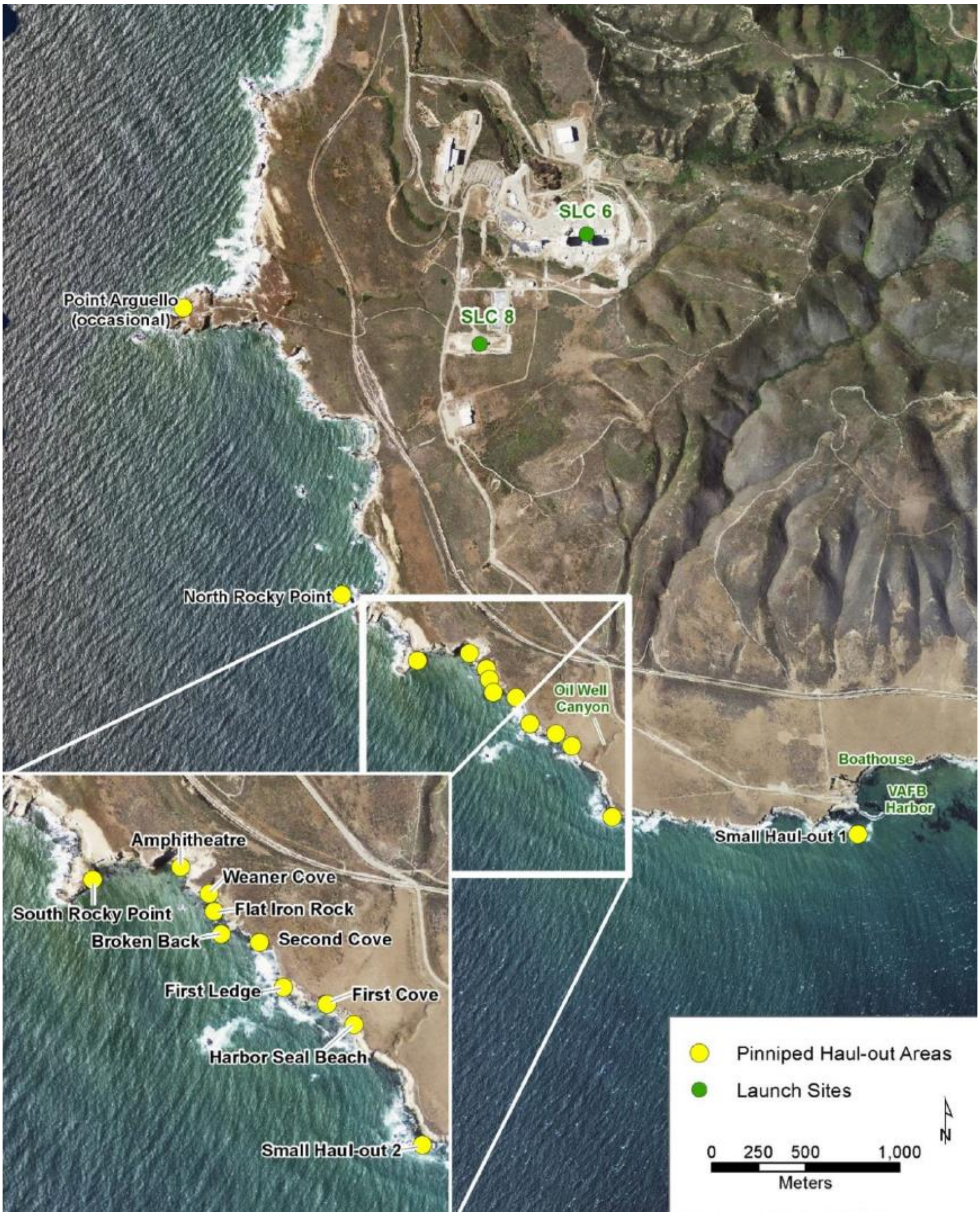


Figure 13. Pinniped haul-out sites near launch sites at the Vandenberg Air Force Base. Source: USAF 2018.

4.4.3 Southern right whale

Southern right whales could potentially be exposed to sound exposure levels up to 135 dBA close to the shore near Cowrie Beach or Groper Bay, decreasing to about 125 dBA within one kilometre offshore (Figure 11). There are no known criteria specific to airborne sound for whales, but the threshold for phocid seals, which have comparable sensitivity to underwater noise with southern right whales, is 134 dB. Whales would be able to respond to hearing discomfort by submerging for the duration of the launch noise, which would be less than two minutes and considered not to be a significant disruption to their behaviour.

4.5 Construction noise

As close as 25 m from source, sound pressure levels associated with various sources of construction noise are all predicted to be below the thresholds associated with acoustic trauma or behavioural change for birds and marine mammals (AECOM 2020), and underwater species would not be impacted by construction noise (see Section 4.4). Therefore no impacts on marine species are expected from noise associated with construction activities.

4.6 Monitoring, management and mitigation

Monitoring of seal behaviour and noise on Liguanea Island before, during and after launches will be undertaken on several occasions, including test launches.

Mitigation measures listed by AECOM (2021) to reduce noise impacts on terrestrial species during rocket take-off, e.g. earth bunds and site structures for acoustic screening, may also benefit seals and seabirds on Liguanea Island.

Other mitigation measures specific to marine fauna include:

- avoiding trajectories over Liguanea Island for suborbital launches (Section 4.2.1)
- using a flight termination system, which would substantially reduce the risk of a ground burst on Liguanea Island
- consideration, for some launches, of avoiding critical periods (e.g. breeding times) for species. Relevant critical periods are provided in Table 7. Note that management of Southern Osprey and White-bellied Sea Eagle have been addressed by AECOM (2021).

A review of risks to the marine environment from debris (once fallen) would be undertaken after the first three years of operation.

Table 7. Critical periods for species potentially impacted by launches.

Month	Australian sea lion[1]	Long-nosed fur seal[2]	Southern right whale[3]	Short-tailed shearwater[4]	Crested tern[5]	Cape Barren Goose[6]
July	Breeding (every third year from 2022)		Migration to calving areas			Breeding
August						
September						
October				Inbound flock	Breeding	
November				Breeding		
December		Breeding (one month)				
January						
February	Breeding (every third year from 2024)					
March						
April						
May			(as above)	Outbound flock		
June						

Sources:

1. Derived from Goldsworthy (2020). Note that times will shift incrementally due to the inter-breeding interval of 17–18 months, which is also subject to variation (DEE 2018).
2. Goldsworthy & Shaughnessy 1994
3. DSEWPaC 2012
4. Copley 1996, Einoder 2009, Robinson et al. 1996, McLeay 2014
5. McLeay et al. 2017
6. Australian Museum 2021c

5 Summary of conclusions

Debris from successful launches would not impact on Liguanea Island fauna (provided that suborbital launches avoid trajectories over the Island). An air burst over Liguanea Island would be a very rare event that could result in mortalities but there would be negligible impact at subpopulation level. Ground bursts on Liguanea Island would be a rarer event than an air burst (provided a flight termination system is used) but could impact more individuals. Although this may result in temporary reductions in ASL pup production, no long-term impact is expected at subpopulation level.

Within the Southern Ocean, including the waters of the Thorny Passage Marine Park surrounding Liguanea Island, there may be occasional debris strike impacts on individual animals on the sea surface but no impact at population level.

Other debris impacts, including ingestion by marine fauna, crushing or smothering of biota, emission of toxic contaminants, noise from debris striking the sea surface and provision of habitat, would be highly localised, the area impacted would be insignificant in comparison to the extent of the receiving environment and population level effects would be negligible.

Launch noise would not result in hearing loss or behavioural change for Short-tailed Shearwaters or other birds inhabiting Liguanea Island. Launch noise would not impact the hearing of seals on Liguanea Island, or LNFS hauled-out at Cape Wiles. Behavioural impacts on seals on Liguanea Island are possible but likely to be short-term. Noise mitigation measures at the launch site may reduce behavioural impacts on species on Liguanea Island, and avoidance of particular periods in the breeding cycles would further mitigate any potential impacts.

No impacts on marine species are expected from noise associated with construction activities.

The above conclusions are consistent with the findings of a risk assessment undertaken for comparable rocket launches in New Zealand.

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Appendix 1. Southern Launch - *Liguanea Island Seal Risk Assessment*

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Liguanea Island Risk Analysis

Calculation of Seal Expected Casualties

Background

The methodologies described by this document follow standard practice for performing flight safety risk analysis using processes set out by the Federal Aviation Authority (FAA) and Flight Safety Code (FSC). In addition to this is the use of Southern Launch's in-house Risk Hazard Analysis software that is consistent with the FAA and FSC requirements. The FAA and FSC methodologies are designed to quantify the potential risk of rocket launches to humans, though the methodology is directly applicable to other fauna.

1.0 Rocket Model

A rocket model is one that includes all the physical properties of the rocket including the aerodynamics, mass properties, launch settings and the environment (including the Earth shape, gravity and atmosphere). This also includes the underlying mathematics and physical phenomena that govern the solving of the ordinary differential equations of motion that describes how a rocket moves through three-dimensional space.

The model as constructed by Southern Launch for the purposes of assessing the risk to seals using information describing different types of rockets that have the potential to be launched from the Whalers Way Orbital Launch Complex. These rockets were chosen to represent three class types, based on their payload capability, being micro, mini and small sized launch vehicles (Table 1).

Table 1 Different Rocket Mass Classes

Vehicle Type	Payload (kilograms)	Expected Launches Per Year
Small	500 to 2000	2
Mini	150 to 500	15
Micro	Less than 150	19
TOTAL		36

2.0 Monte Carlo Analysis

A Monte Carlo Analysis is performed where specific parameters of a rocket model and the associated environment are varied to simulate all possible outcomes for a given launch attempt. The parameters are varied according to the expected mathematical variation. These simulations are flown until the rocket reaches orbit, or the rocket, spent stages, or portions of the rocket following a mid-air breakup intersect with the ground. Intersections with the ground are called Ground Impact Points (GIPs) and are the key points of interest for performing a risk analysis.

It should be noted that some trajectories will result in multiple ground impact points, either as a result of multiple stages returning to the ground or as a result of an object breaking into multiple pieces before they intersect with the ground.

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3.0 Worst Case Failure Response Mode (FRM) for Liguanea Island

Simulations were performed that cover both nominal flights of the rockets as well as failures. Under nominal flights, the resultant dispersions in trajectories are due to stochastically varied wind profiles, simulations of the on-board electronics or atmospheric variations. Flights that resulted in an on-board failure and ultimate loss of the rocket were simulated by catastrophically reducing the thrust of the rocket, exceeding structural limits, or explosions mid-flight.

For the purposes of this analysis, the trajectories were limited to those where portions of the rocket had the potential to land on Liguanea Island, namely Polar and Sun Synchronous orbits (Figure 1).

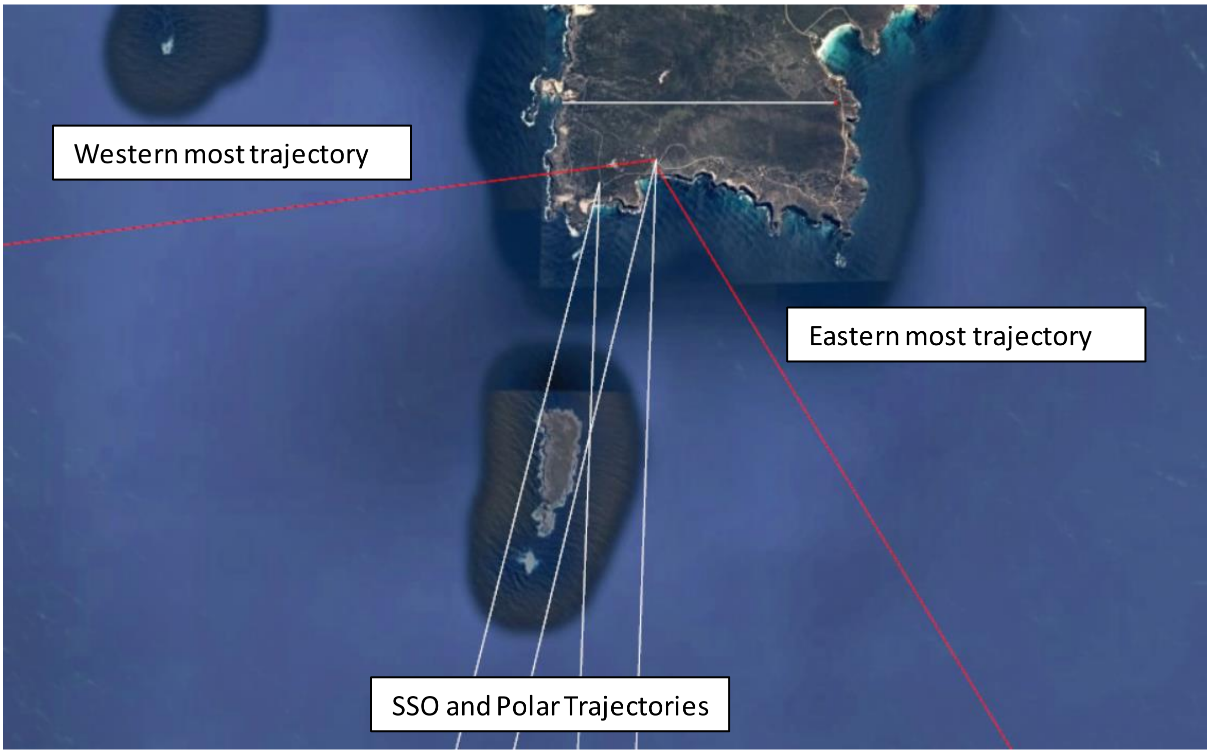

Figure 1 Full range of trajectories from WWOLC with Liguanea Island

The analysis to assess the expected casualties of fauna on the island included the possibility that a failure might lead to an explosion sufficiently early in the flight and pieces of rocket falling on the island.

Vehicles are fitted with Flight Termination Systems (FTS) which seek to reduce the risk to life and property on the ground in the event of a failure. An FTS is a safety critical system and is subject to the same level of design scrutiny and certification as ABS brakes. FTS work in multiple ways which can include, but are not limited to:

1) guiding the vehicle to a lower risk location prior to it intersecting the ground; or
2) turning off the rocket engines so the rocket falls back to Earth; or
3) a controlled destruction of the vehicle mid-flight

The simulations undertaken include the normal operation and potential failure of the FTS.

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In essence there are three modelled possible outcomes from a launch:

- Nominal success: orbit achieved with slight variations in trajectory – some stages intersect with the ocean but this occurs within the projected boundaries with negligible risk;
- Failure – air burst: a launch vehicle explodes while in the air. This results in the launch vehicle breaking up into a number of pieces and landing over a large area; and
- Failure – ground burst: launch vehicles motors fail shortly after lift-off. The flight termination system fails and the vehicle remains whole as it falls to the ground/water and explodes on impact.

Monte Carlo simulations were applied to each of the vehicle class types described in the first section.

4.0 Casualty Area

Under the standard FAA and FSC the casualty area represents the area of impact within which a human could become a casualty. A scaling was applied to increase the size as seals are larger than humans. All other aspects of the flight safety analysis was kept constant, including energy thresholds used by the FAA and FSC.

A casualty under FAA and FSC is defined an impact with a kinetic energy threshold of greater than 15 joules. Even though such an impact would often cause injury rather than death, all casualties can conservatively be assumed to be fatalities.

A combination of the FAA Casualty Area formulation for explosive debris and the FSC Casualty Area formulation for non-explosive debris was used for this analysis.

5.0 Probability Distribution Function (PDF)

The GIPs generated from the Monte Carlo analysis are used to perform the risk analysis to seals on a per launch basis. Due to the probabilistic nature of these simulations it is possible to use this information to predict the likelihood of locational impact. This forms the basis for the Probability Distribution Function (PDF) which determines the likelihood of being hit by a piece of debris in any given square metre.

6.0 Expected Casualties

The Expected Casualties (EC) is a standard output from FAA Guidelines (and the FSC) to assess how many people (or seals in this case) can be expected to result in a casualty (see the definition of casualty in Section 4).

This is determined by integrating the PDF over the area of the island (thereby obtaining the total probability of debris that could impact the island) and then multiplying that number by the casualty area (the area of debris that could cause a casualty). A penultimate multiplication of the total probability of that failure happening is applied, before finally multiplying this value by the population density of seals on the island to get an expectation of casualty on a per launch basis.

For the purposes of this analysis, the casualty area that was used to calculate the Expected Casualties was determined from a list of values comprising one from each simulated launch failure of debris that could hit the island. The top 0.5% of these values was used in order to calculate a conservatively high estimate of the number of seal casualties.

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7.0 Seal Population

The risk to seals has been calculated separately for the Australian Sea Lion and Long-nosed Fur Seal

The analysis considers the following animal numbers:

- Sea Lion – 165, distributed mainly on the southern peninsula of the island
- Fur Seal – 9500, distributed mainly along the east coast of the island

This is conservative because it assumes that all seals are on the island at any time, which is unlikely even during the peak of breeding season.

Simulation results

Results for air and ground burst are presented as a frequency of debris interaction with Liguanea Island, the (conservatively high) estimate of casualty numbers per interaction and an Annual Recurrence Interval (ARI), i.e. the number of years between casualties.

Risk Analysis – Air Burst

Vehicle	1 Island Interaction per [X] Launches
Small	11,764
Mini	7407
Micro	7407

Vehicle	Fur Seal Casualties per Island Interaction	Sea Lion Casualties per Island Interaction
Small	3.48	0.0604
Mini	0.07	0.0012
Micro	0.02	0.0004

Vehicle	1 Fur Seal Casualty per [X] Launches	1 Sea Lion Casualty per [X] Launches
Small	3,375	194,470
Mini	105,814	6,170,000
Micro	370,350	18,510,000

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Vehicle	Fur Seal Casualty ARI By Vehicle Type (Years)	Sea Lion Casualty ARI By Vehicle Type (Years)
Small	2,410	138,907
Mini	10,077	587,619
Micro	27,845	1,391,729

Risk Analysis – Ground Burst

Vehicle	1 Island Interaction per [X] Launches
Small	4,716,981
Mini	2,914,176
Micro	2,914,176

Vehicle	Fur Seal Casualties per Island Interaction	Sea Lion Casualties per Island Interaction
Small	613	10.6
Mini	226	3.9
Micro	199	3.4

Vehicle	1 Fur Seal Casualty per [X] Launches	1 Sea Lion Casualty per [X] Launches
Small	7,694	444,998
Mini	12,894	747,224
Micro	14,644	857,110

Vehicle	Fur Seal Casualty ARI By Vehicle Type (Years)	Sea Lion Casualty ARI By Vehicle Type (Years)
Small	5,495	317,855
Mini	1,228	71,164
Micro	1,101	64,444