NIWA
Taihoro Nukurangi

Marine Ecological Risk Assessment of the cumulative impact of Electron Rocket launches

Prepared for Ministry for the Environment

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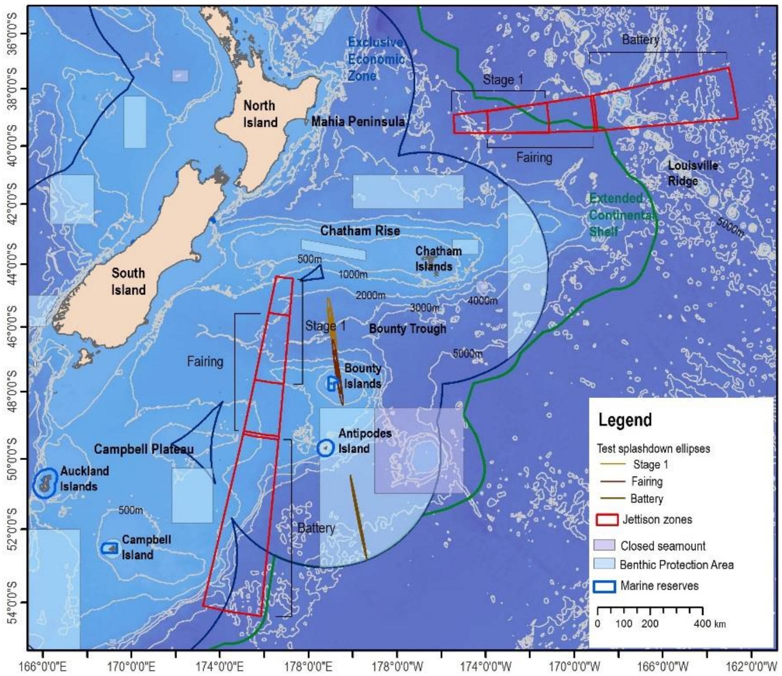

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Cover image: Electron debris impact areas in relation to closed seamounts, Benthic Protection Areas and marine reserves.

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Executive summary

Using a Level 1 likelihood-consequence risk analysis approach, a multidisciplinary panel of experts undertook an Ecological Risk Assessment (ERA) associated with the fall of debris jettisoned during launches of space vehicles. There are three deep-water debris areas corresponding to the trajectories used for test launches, and commercial Sun-synchronous and Eastern launches. The ecological risks associated with a catastrophic failure near the rocket launch facility and potential effects on near-shore locations was not assessed.

The ERA Panel considered the potential ecological impacts of eight threats arising from the fall of debris on five components of the ecosystem in each debris area.

As three test launches of the Electron launch vehicle are planned, the Panel assessed the ecological impact of debris from 1 and 10 launches in case more test launches are required. The debris from the test launches will have a low risk to the marine ecosystems in the Bounty Trough, and across and to the south of the Bounty Plateau. However, some test launch debris could fall into the Bounty Islands Marine Reserve, the Bounty Heritage Benthic Protection Area and the Antipodes Transect Benthic Protection Area.

For the purposes of this assessment, the frequency of commercial launches has been estimated to reach a maximum of one per week. Thus the cumulative impact of 1, 10, 100, 1 000, and 10 000 weekly events was assessed for both the Sun-synchronous (Bounty Trough and eastern flank of the Campbell Plateau) and Eastern (abyssal plain and Louisville Ridge east of the North Island) debris areas. At the rate of one launch per week it would take almost 200 years to reach the upper number of launches.

The ecological risk was assessed to be low for all ecosystem components of the Sun-synchronous and Eastern debris area for up to 100 launches, and low for the pelagic community of phytoplankton, zooplankton, fish and larger invertebrates at all levels of launch activity from 1 to 10 000 launches.

The toxic effects of the components comprising Stage 1, the fairings and the two Stage 2 Lithium-Iron batteries were assessed as low at all levels of launch activity for all debris areas.

Floating debris as attachment for pelagic organisms and the ingestion of debris were both evaluated as having low ecological risk at all levels of launch activity in both the Sun-synchronous and Eastern debris areas.

The probability of debris making a direct hit on a fishing vessel in the debris areas is low. The Panel took a cautious approach and assumed vessels would avoid the debris areas and fish elsewhere. For up to 100 consecutive weekly launches, the effects of fishing displacement on the rebuilding of populations impacted by fishing would be negligible.

For seafloor biota requiring hard substrates the debris would provide further attachment sites. However, even after 10 000 launches this would provide only about 50 ha of additional attachment surface, leading to, at most, moderate consequences in both the Sun-synchronous and Eastern debris areas. Smothering of the feeding or respiratory structures of sea floor organisms by debris was assessed as a low risk for all levels of launches up to 1 000 launches and a moderate risk by 10 000 launches in both the Sun-synchronous and Eastern debris area ecosystems. This is likely to be a factor principally in areas of hard substrate where the debris is unlikely to become buried in sediment so will be important principally on the Campbell Plateau and the Louisville Ridge.

In both the Sun-synchronous and Eastern debris area ecosystems direct strikes causing mortality to ecological components are a low risk up to 1 000 launches over an almost 20 year period. Direct strikes reach moderate levels of risk for the benthic invertebrate community, sensitive benthic environments, and the Magenta petrel population after 10 000 launches over a period of almost 200 years.

Noise and disturbance to marine fauna above and below water is a potential consequence of the fall of debris from rocket launches. The chance of repeated disturbance to the same individuals or groups of marine mammals or seabirds increases with the number of launches. In both the Sun-synchronous and Eastern debris areas this was assessed as a low risk for up to 100 launches over two years, a moderate risk for up to 1 000 launches over almost 20 years, and a high risk for up to 10 000 launches over almost 200 years.

The options for avoiding, remedying or mitigating the effects of debris fall seem limited. Ensuring a greater degree of burnup in the atmosphere or a controlled landing of Stage 1 on mainland New Zealand would minimise the risk.

1 Introduction

1.1 Background

The Ministry for the Environment (MfE) requested NIWA to undertake an Ecological Risk Assessment (ERA) of debris resulting from the launch of space rockets. The only launch vehicle presently being considered is the Electron, a small two-stage liquid-fuelled orbital launch vehicle capable of lifting a 150kg payload to a 500 km orbit (Rocket Lab 2016). In the course of a launch, Stage 1, an aerodynamic nose fairing, and two Stage 2 batteries are released. It is expected that after being jettisoned, Stage 1 will break up into multiple fragments (at least 280) in the atmosphere (some as heavy as 360 kg) before impact with the ocean surface, with the nose fairing and the two Stage 2 batteries impacting further along the trajectory path. Debris from the initial test launches will fall along a path to the south of the Chatham Rise and east and south of the Bounty Islands (shown in Figure 1-1 as ellipses). Debris from commercial launches will fall either to the south over the southern flank of the Chatham Rise, and across the Bounty Trough and the Campbell Plateau (Sun-synchronous launch), or east of the North Island (Eastern launch) (Figure 1-1). MfE has informed NIWA that the frequency of Electron launches will build towards a maximum of one per week.

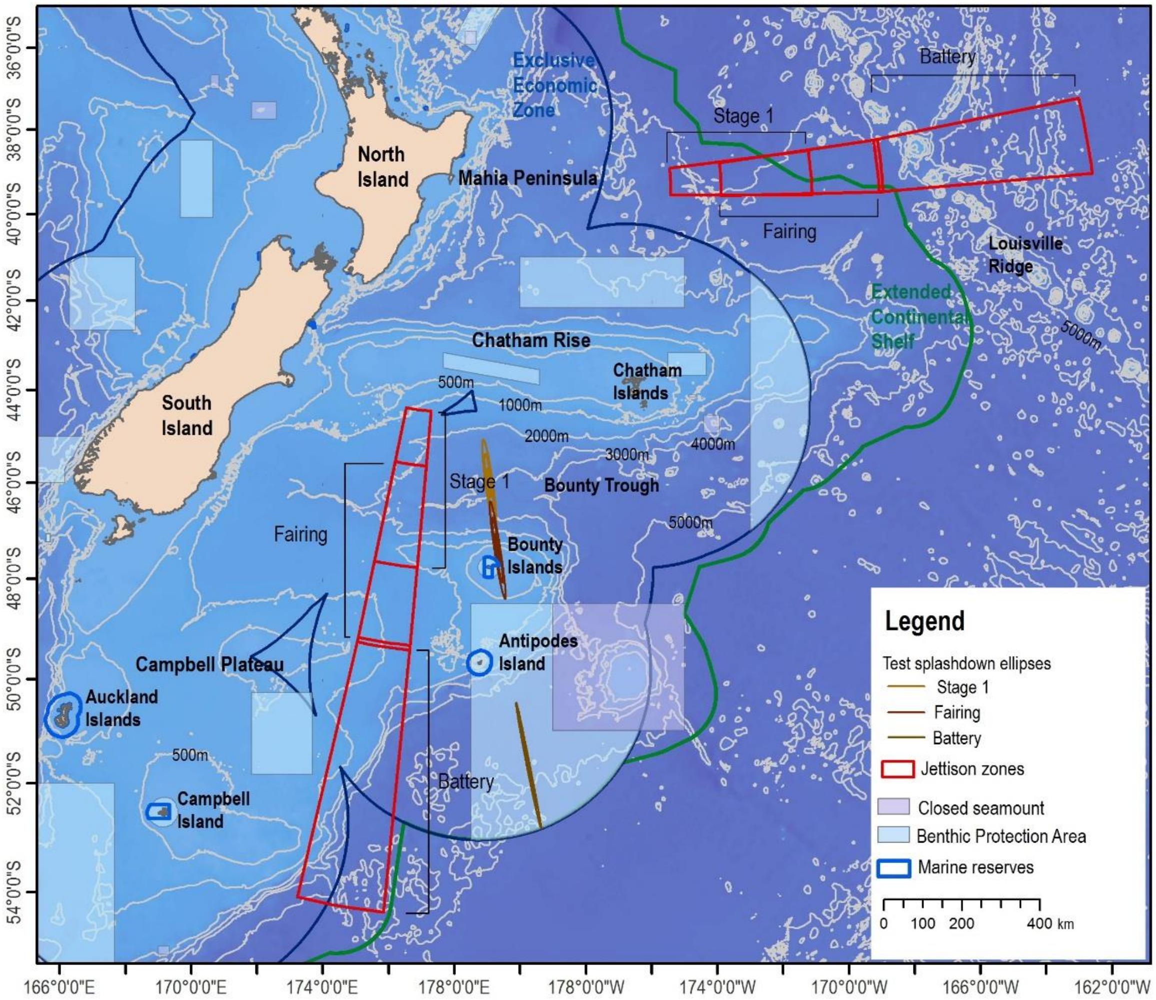

Figure 1-1: Electron debris areas. The splash down areas for debris from Stage 1, nose fairing, and Stage 2 batteries originating from the test launches are shown as ellipses, while shown as red boxes are the debris areas for Sun-synchronous (to the south) and Eastern (to the east) launches. Data supplied by Rocket Lab.

1.2 Approach

There are a number of approaches and methods that have been applied around the world to conduct ERAs. Several of these were reviewed by Rowden et al. (2008) and Baird and Gilbert (2010). Where the activity to be assessed is rare or unpredictable, such as the direct hit of rocket debris causing mortality of marine organisms, then a likelihood-consequence approach is the most suitable. Such an approach summarises risk as the product of the expected likelihood of an event occurring and the ecological consequence of that event. This approach contrasts with the approach taken to assess activities that are deliberate and programmed to take place regularly and repeatedly such as fishing in an area. In these cases an exposure-effects approach (e.g. Smith et al. 2007; Sharp et al. 2009) is the most suitable.

Risk assessment typically consists of three levels, increasing in detail from a qualitative assessment (Level 1) to fully quantitative (Level 3). Level 1 assessments are generally used in data-poor situations where the scale of activity or its impacts on particular species, habitats or the ecosystem are uncertain or only partially described (Hobday et al. 2011). The approach adopted for this assessment was based on a Level 1 likelihood-consequence risk analysis (Hobday et al. 2011), and follows the expert-panel approach used by MacDiarmid et al. (2011) for previous ecological risk assessments conducted for MfE.

The ecological risks associated with a catastrophic failure near the rocket launch facility were not assessed.

2 Methods

2.1 Risk assessment

The risk assessment of the impacts of debris from launches of the Electron Rocket on components of the marine environment was broken into five steps.

1. **Expert panel convened.** An ERA panel of experts (the Panel), made up of relevant NIWA staff based at Wellington and Hamilton was convened. ERA panellists included those with knowledge of likely consequences of the debris for different components of the ecosystem. The panellists were:

    - Dr Alison MacDiarmid – Project Manager, NIWA Wellington
    - Dr Malcolm Clark – impacts on deep-sea benthos, NIWA Wellington
    - Dr Kim Goetz – impacts on marine mammals, NIWA Wellington
    - Dr Chris Hickey – effects of contaminants, NIWA Hamilton
    - Ms Sadie Mills – distribution of marine benthic invertebrates, NIWA Wellington
    - Dr Richard O’Driscoll – impact on fish and fisheries, NIWA Wellington
    - Dr Matt Pinkerton – impact on primary productivity and pelagic ecosystem, NIWA Wellington
    - Dr David Thompson – impacts on seabirds, NIWA Wellington

2. **Scale of debris areas and frequency of launches.** The likely spatial scale of the debris areas and the frequency of launches was first assessed from information originating from Rocket Lab and forwarded to NIWA by MfE. The assessment was undertaken based on the following:

   - It is expected that after being jettisoned, Stage 1 will break up into multiple fragments (at least 280) in the atmosphere before impact with the ocean surface.
   - While most of the debris, including the carbon-fibre components, would fall to the seafloor, some components may float, including approximately 23 kg of cork and 8 kg of foam (Rocket Lab 2016).
   - The potential total fragment area from an individual launch is 50 m^2 (Rocket Lab 2016, p17).
   - The modelled landing area for debris based on flight simulations is as shown in Figure 1-1. The Sun-synchronous debris impact area totals 182 733 km^2. The Eastern debris impact area totals 142 854 km^2.
   - There is no combustion of components during descent;
   - Although only three test launches are planned, we assessed the ecological impact of 1 and 10 launches in case more test launches are required.
   - For commercial launches, the frequency of launches will reach a maximum of one per week. Thus we assessed the cumulative impact of 1, 10, 100, 1 000, and 10 000 weekly events. This range covers the likely number of launches (1-1 000), to an improbable 10 000. At the rate of one launch per week it would take almost 200 years to reach this upper number of launches. This approach will indicate where thresholds may occur, whereby the risk of adverse effects would be moderate or less.

3. **Identification of at risk populations, communities and habitats.** The spatial extent of the debris areas were used to identify the ecosystems that may be impacted. NIWA databases (e.g., *Specify, AllSeaBio*), other data sources, and the published literature were used to assemble the information required for the assessment of impacts.

4. **Potential threats arising from the fall of debris.** These were identified as:

   - **Direct strike causing mortality.** Direct strikes could impact seabirds in the air or on the sea-surface, marine mammals when at or near (<10m) the sea surface, pelagic invertebrates and fish near the sea surface, and sedentary or attached seafloor invertebrates. The probability of direct strikes is estimated in Appendix A.
   - **Underwater noise and disturbance.** The impact of the debris on the sea surface is likely to cause noise above and below water, and perhaps a small acoustic shock wave underwater. This noise is likely to disturb nearby birds, marine mammals and fish. Repeated disturbance can cause reduced feeding rates in marine mammals and trigger animals to leave the impacted area (Constantine 1999, Stockin et al. 2008).
   - **Toxic contaminants.** There is potential for components of Stage 1 and the Stage 2 lithium batteries to be toxic to some organisms. The toxicity of these components is evaluated in Appendix B.

- **Ingestion of debris.** The breaking apart of Stage 1, the fairings and the two Stage 2 batteries in the air, and/or on impact with the sea surface may develop splinters or particles small enough to be ingested by a wide range of organisms at the sea surface, in the water column, or on the sea floor. This ingestion could cause injuries or mortalities.
- **Smothering of seafloor organisms, preventing normal feeding and/or respiration.** Smothering could occur if small particles from the debris accumulated on the seafloor, perhaps aided by currents, in sufficient thickness to impact on the normal feeding and/or respiration of attached benthic invertebrates.
- **Provision of biota attachment site.** Larger fragments that do not bury in the seafloor sediments will provide settlement surfaces for benthic invertebrates. Additional attachment sites would be positive for populations of invertebrates living on hard surfaces, but negative for others requiring soft sediments. In the assessment the Panel estimated the net effect of these potentially opposing mechanisms.
- **Displacement of fishing effort.** The probability of a direct hit on a fishing vessel in the debris areas, particularly after successive launches, may be sufficient for vessels to avoid the areas and fish elsewhere. Reduction in fishing activity in an area will, over time, have positive effects on the populations of the target species, and bycatch species including seafloor invertebrates, sensitive benthic environments, seabirds and marine mammals by allowing populations to recover from the effects of fishing mortalities. On the other hand, the displacement of a fishery might either promote fishing in a previously unfished area, thereby generating a new impact on fauna, or concentrate fishing where it already occurs elsewhere which could result in additional impact at that location. In the assessment the Panel attempted to estimate the net effect of these potentially opposing mechanisms. To help inform the Panel if the probability of a vessel strike occurring after successive weekly launches would be sufficient for vessels to avoid the debris areas, the potential for a piece of falling debris to strike a vessel was estimated in Appendix A.
- **Floating debris.** Debris floating at the sea surface may provide shelter for pelagic organisms such as juvenile fish, and attachment and dispersion for organisms such as goose barnacles and marine algae. Effects of ingestion by marine fauna were considered separately.

5. **Assessment of consequences, likelihood, and confidence.** The effects or consequences of the potential threats arising from the rocket debris were then evaluated by the Panel at each cumulative level of launches (1, 10, 100, 1000, 1000) for each component of the ecosystem being considered and scored on a scale of 0 to 5, using a standardised set of prepared consequence descriptions, ranging from negligible to catastrophic (Table 2-1). The ecosystem components evaluated were:

    a. the benthic invertebrate community in the debris area,

    b. the demersal (bottom-associated) fish and mobile invertebrate (squid, octopus, large crabs) community,

    c. the air-breathing fauna, comprising marine mammals and seabirds,

d. sensitive (benthic) environments, as defined in the Exclusive Economic Zone and Continental Shelf (Environmental Effects – Permitted Activities) Regulations 2013 (the Permitted Activities Regulations), and

e. the pelagic community, including phytoplankton, zooplankton, larger invertebrates and fish.

Where data or information did not exist, a precautionary approach was necessarily adopted to reflect the uncertainty in the likely effects of the activity. For example, where the distribution of the ecosystem component was uncertain, there was an assumption that the potential consequence was higher because the ecosystem component under consideration may be exposed to the activity. This is likely to occur, for example, in relation to migratory, rare, highly localised, or data poor species.

Following the scoring of the consequence, the Panel discussed, assessed and then scored the likelihood of the threat from rocket debris occurring for each component of the ecosystem. Likelihood scores can range from 1 to 6, from remote to likely (see Table 2-2). The assessment of the likelihood of a direct strike causing mortality was aided by the calculations in Appendix A.

Following the scoring of the consequences and likelihoods the panellists assessed the level of confidence in the information available to make each assessment based on the categories provided in Table 2-3.

To reach a decision, the Panel engaged in open discussion until a consensus was reached for a draft score of each threat to each ecosystem component. The draft table of scores was then assessed independently by each panellist and suggested changes offered to the whole panel. Final score values were by consensus.

6. **Classification of ecological risk.** Using the tables of defined levels and scores of environmental consequences (Table 2-1) and likelihoods (Table 2-2) ecological risk scores were calculated as the product (multiplication) of consequence and likelihood. Risk scores can range from a minimum of 0 to a maximum of 30.

   Following the classification adopted by MacDiarmid et al. (2011) activities with risk scores of 6 or less are categorised as low. These arise from the lowest two levels of consequence (0 - negligible and 1- minor) (see Table 2-4) at all levels of likelihood (including 6, likely), from moderate levels of consequence (2) at unlikely (3) or lower levels of likelihood, from severe levels of consequence (3) at rare (2) or remote (1) levels of likelihood, or from major and catastrophic levels of consequence at remote levels of likelihood.

   At the upper end, activities with risk scores of 24 or more are categorised as extreme (Table 2-4). These levels of risk arise only from those activities judged to have major (4) consequences at the highest level of likelihood (6) and catastrophic consequences (5) at the two highest levels of likelihood (5 and 6).

   Between these extremes, activities with risk scores from 8 to 12 are categorised as moderate, and those with risk scores from 15 to 20 are categorised as high (Table 2-4).

Table 2-1: Consequence levels for the assessed activity. Summary descriptions of the six sets of consequence levels for the percent overlap of population distribution with debris area, the impact on the population, community or habitat, and the likely recovery period. Adapted from MacDiarmid et al. (2015).

Consequence level	Percent overlap of population distribution with debris area	Population/ community/ habitat impact	Recovery Period
0 - Negligible	Affects <1% of distribution	Interactions may be occurring but unlikely to be ecologically significant (<1% changes in abundance, biomass, or composition) or be detectable at the scale of the population, habitat or community	No recovery time required
1 - Minor	Measurable but localised; affects 1-5% of distribution	Possibly detectable with 1-5% change in population size or community composition and no detectable impact on dynamics of specific populations	Rapid recovery would begin if activity stopped – less than 8 weeks
2 - Moderate	Impacts more common; >5-20% of distribution affected	Measurable with >5-20% changes to the population, habitat, community, or biodiversity components without there being a major change in function. There may some change in species ranges.	Recovery in >2 months to 1-2 years if activity stopped
3 - Major	Impacts very widespread; >20-50% of distribution is affected	Populations, habitats, communities, and biodiversity measures substantially altered (>20-50%), with some function or components missing/ declining/ increasing well outside historical ranges. Some additional species appear in the affected environment while others have shrinking ranges.	Recovery occurs in 2-10 years if activity stopped
4 - Severe	Impact extensive; >50-80% of distribution affected	Likely to cause local extinctions of vulnerable species if impact continues, with a >50-80% change to habitat and community structure and function. Significant change in range of some species. Different population dynamics now occur with biodiversity measures greatly affected.	Recovery period 1-2 decades if activity stopped
5 - Catastrophic	Almost entire distribution is affected; >80%	Local extinctions or booms of a variety of species are imminent/immediate. Total change in habitat, community or ecosystem processes. The abundance, biomass or diversity of most groups is drastically changed (by >80%).	Long term recovery to former levels will be greater than 1-2 decades, perhaps centuries, even if activity stopped

Table 2-2: Threat likelihood categories. Levels and descriptions for each likelihood category (used for all environmental components). Adapted from Fletcher (2005).

Level/score	Descriptor	Likelihood
1	Remote	Highly unlikely but theoretically possible
2	Rare	May occur in exceptional circumstances
3	Unlikely	Uncommon, but has been known to occur elsewhere
4	Possible	Some evidence to suggest this is possible
5	Occasional	May occur
6	Likely	It is expected to occur

Table 2-3: Confidence rating, score and description.

Confidence rating	Score	Rationale for confidence score
Low	1a	No data exist and no consensus among experts
	1b	Data exists, but is considered poor or conflicting
	1c	Agreement among experts, but with low confidence
High	2a	Consensus among experts, but with high confidence, even though data may be lacking
	2b	Consensus among experts supported by unpublished data (not been peer-reviewed but are considered sound)
	2c	Consensus among experts supported by reliable peer-reviewed data or information (published journal articles or reports)

Table 2-4: Risk levels and categories.

Risk Level	Risk score range	Risk score derivation	
		Consequence level	Likelihood levels
Low	0-6	0 – negligible 1 – minor 2 – moderate 3 – severe 4 – major 5 – catastrophic	1-6 (remote to likely) 1-6 (remote to likely) 1-3 (remote, rare or unlikely) 1-2 (remote or rare) 1 (remote) 1 (remote)
Moderate	8-12	2 – moderate 3 – severe 4 – major 5 – catastrophic	4-6 (possible, occasional, likely) 3-4 (unlikely, possible) 2-3 (rare, unlikely) 2 (rare)
High	15-20	3 – severe 4 – major 5 – catastrophic	5-6 (occasional, likely) 4-5 (possible, occasional) 3-4 (unlikely, possible)
Extreme	24-30	4 - major 5 – catastrophic	6 (likely) 5-6 (occasional or likely)

3 Results

3.1 Receiving environment

3.1.1 Test and Sun-synchronous launches

There are several distinct receiving environments. During the test launches and commercial Sun-synchronous launches to the south, the debris from the breakup of Stage 1 will fall into the Bounty Trough, an area of deep water (2 000- 3 000 m) lying between the southern flank of the Chatham Rise and the northern slopes of the Campbell Plateau and the Bounty Platform (Rocket Lab 2016). A wide deeply incised channel draining high-density sediment flows from the edge of the continental shelf off Otago eastwards towards the abyssal plain, meanders down the centre of the Bounty Trough (Figure 1-1). The highly productive waters of the subtropical front lie across the southern flank of the Chatham Rise (Figure 3-1), so some of this production is expected to reach seafloor invertebrates on the northern margin of the Bounty Trough (Nodder et al. 2016). But in sub-Antarctic waters in the Trough itself, surface waters are iron-limited and high in nutrients, but low in chlorophyll with highly variable fluxes of organic material to the sea floor which are lower than the global average for mesotrophic to oligotrophic waters (Nodder et al. 2016). At the seafloor in the middle of the Bounty Trough, water temperatures are approximately 2°C (Ridgway 1969).

Because the Bounty Trough is deep (2000 - 3000 m), it is unfished and has been poorly sampled, thus little is known about the distribution of seafloor habitats and fauna (Figure 3-2 and Figure 3-3). However, where it has been sampled the seafloor substrate is dominated by sandy mud with a high carbonate content, with few areas of hard substrates (Nodder et al. 2003). The macro-fauna is thus likely to comprise polychaete worms, small crustaceans such as isopods and amphipods, and brittlestars (Probert et al. 1996).

The detailed distributions of over 100 species of demersal fish and sharks are known only for the shallower perimeter of the Bounty Trough with little or no data for the central deeper part (e.g., the distributions of a commercially important fish, orange roughy, and a widespread non-commercial species, small-scaled brown slickhead, are shown in Figure 3-4). The diversity of demersal fish on the margins of the trough is low compared with the top and northern flank of the Chatham Rise (Leathwick et al. 2006). The species with the greatest degree of overlap with the Stage 1 debris area from the test launch and Sun-synchronous launches are all deep water specialists including basketwork eels (*Diastobranchus capensis*), black oreo (*Allocyttus niger*), Kaiyomaru rattail (*Caelorinchus kaiyomaru*), four-eyed rattail (*Coryphaenoides subserrulatus*), long-nose velvet dogfish (*Centroselachus crepidater*), Baxter's lantern dogfish (*Etmopterus baxteri*), Johnson's cod (*Halargyreus johnsonii*), ridge-scaled rattail (*Macrourus carinatus*), orange roughy (*Hoplostethus atlanticus*), lighthouse fish (*Photichthys argenteus*), long-nosed deepsea skate (*Bathyraja shuntovi*), widenosed chimaera (*Rhinchimaera pacifica*), big-scaled brown slickhead (*Alepocephalus* sp.), spineback (*Notacanthus sexspinis*), small-scaled brown slickhead (*Alepocephalus australis*), smooth oreo (*Pseudocyttus maculatus*), violet cod (*Antimora rostrata*), white rattail (*Trachyrincus aphyodes*), and warty oreo (*Allocyttus verrucosus*).

Seventeen species of marine mammals are likely to occur within the general region of the Bounty Trough and it is possible another 15 species could also occur (Table 3-1). Because of their rarity or patterns of distribution it is possible, but unlikely, that another 12 species of marine mammal occur within the region (Table 3-1). During the 19th century, southern right whales were commonly sighted or struck by pelagic whalers throughout the Bounty Trough (Torres et al. 2013) (Figure 3-5). Only seven species of whales have been sighted near the Stage 1 debris splashdown areas in the Bounty Trough, in part because the area is under-sampled (Figure 3-5).

Fifty species of seabirds are known from the Bounty Trough region (Table 3-2) but, as detailed distributions are known for only a few satellite tagged species (e.g. Figure 3-6), it is unclear which species are most likely to occur in the vicinity of the Stage 1 debris splashdown areas.

During the test launches, the carbon-fibre nose fairings are predicted to fall across the northern flank and crest of the Bounty Plateau, missing the Bounty Islands by 14 km but falling within the eastern edge of the Bounty Islands Marine Reserve and the Bounty Heritage Benthic Protection Area (Figure 3-7). During commercial Sun-synchronous launches, the nose fairings are calculated to fall across the Bounty Trough and the eastern flank of the Campbell Plateau (Figure 3-7). Like the Bounty Trough these are areas of clear, low productivity waters with bottom waters at about 9^{o}C (Nodder et al. 2016, Ridgway 1969). However, compared with the Bounty Trough, the Bounty Plateau and the Campbell Plateau are relatively well sampled (Figure 3-2 and Figure 3-3) with 118 and over 300 records respectively. Hard substrates are common and provide habitats for an assemblage of sessile filter feeding invertebrates including byozoans, sponges, brachiopods, ascidians or tunicates, corals, and anemones (Tracey et al. 2011, Rowden et al. 2013, 2015, NIWA data). Motile invertebrates such as polychaete worms, sea-stars, brittle-stars, sea-cucumbers, urchins, crustaceans, snails and bivalves occur on both hard and soft substrates (Figure 3-2). The distributions of some species of bryozoans and sponges appear to be very limited (Clark et al. 2014).

Demersal fish are relatively well described from the Bounty Plateau and the eastern flank of the Campbell Plateau with a low to moderate diversity of species compared with the most species-rich areas along the northern flank of the Chatham Rise (Leathwick et al. 2006). Common species that overlap with the Fairings splash down areas of the test and Sun-Synchronous launches include basketwork eel, black oreo, banded rattail (*Caelorinchus fasciatus*), Kaiyomaru rattail, serrulate rattail (*Coryphaenoides serrulatus*), four-eyed rattail, longnose velvet dogfish, Baxter’s lantern dogfish, pale ghost shark (*Hydrolagus bemisi*), Johnson’s cod, hoki (*Macruronus novaezelandiae*), javelin fish (*Lepidorhynchus denticulatus*), long-nosed chimaera (*Harriotta raleighana*), ridge scaled rattail, orange roughy, lighthouse fish, longnosed deepsea skate, ribaldo (*Mora moro*), bigscaled brown slickhead, spineback, southern blue whiting (*Micromesistius australis*), smallscaled brown slickhead, smooth oreo, violet cod, and warty oreo.

A winter fishery for southern blue whiting occurs around the Bounty Plateau and there is some trawling for southern blue whiting and hoki along the eastern flank of the Campbell Plateau (Figure 3-8).

Seven species of whales have been sighted within 50 km of the test and Sun-synchronous fairings debris fall areas (Figure 3-5) but another ten species are likely to occur over the Bounty and Campbell Plateaus and it is possible that a further 15 species also occur in the area (Table 3-1).

Fifty species of seabirds are known from the region shown in Figure 3-7 (Table 4 5) but, as detailed distributions are known for only a few satellite tagged species (e.g. Figure 3-6), it is unclear which species are most likely to occur in the vicinity of the Fairing splashdown areas over the Bounty and Campbell Plateaus.

Assuming that the two lithium-iron batteries from Stage 2 do not burn up in the atmosphere, during the test launch they are likely to fall into very deep (4000 – 5000 m), cold (about 1^{o}C, Ridgway 1969) water southeast of the Bounty Platform and across part of the Antipodes Transect Benthic Protected

Area (Figure 3-7). During commercial Sun-synchronous launches the batteries will fall across the eastern flank of the Campbell Plateau or into the deep waters beyond. Part of the both battery debris fields lie across a belt of seafloor polymetallic nodules up to 500 km wide spanning from west of the Macquarie Ridge to Bollons Seamount – the Campbell polymetallic nodule field (not shown) (Carter and McCave 1997, Wright et al. 2005, Graham et al. 2004). Lighter debris are likely to be carried along the seafloor by the strong Deep Western Boundary Current that sweeps up the east flank of the Campbell and Bounty Plateaus (Figure 3-1). There are few biological records from these deeper area (see Figure 3-2) and little is known of the seabed invertebrate fauna, demersal fish (Figure 3-4), marine mammals (Figure 3-5), or sea birds (e.g. Figure 3-6) from this area. Underwater images of the nodule field indicate epibenthic fauna at very low densities, including ophiuroids, holothurians and sponges (Figure 3-9). Traces of life (e.g., faecal coils, tracks, burrow disturbance) are also visible.

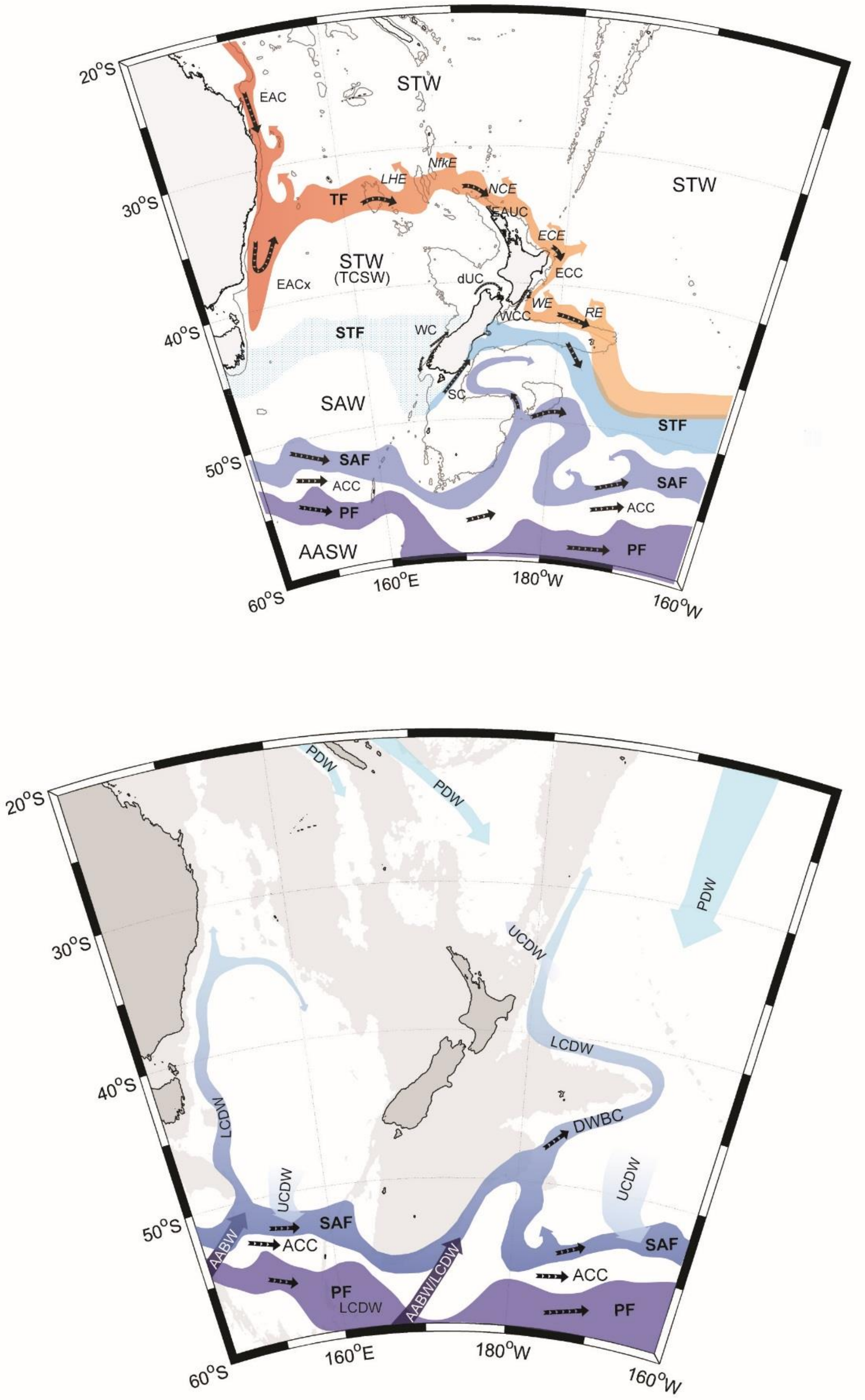

Figure 3-1: Major surface (top panel) and bottom (lower panel) currents around New Zealand. From Chiswell et al. 2015.

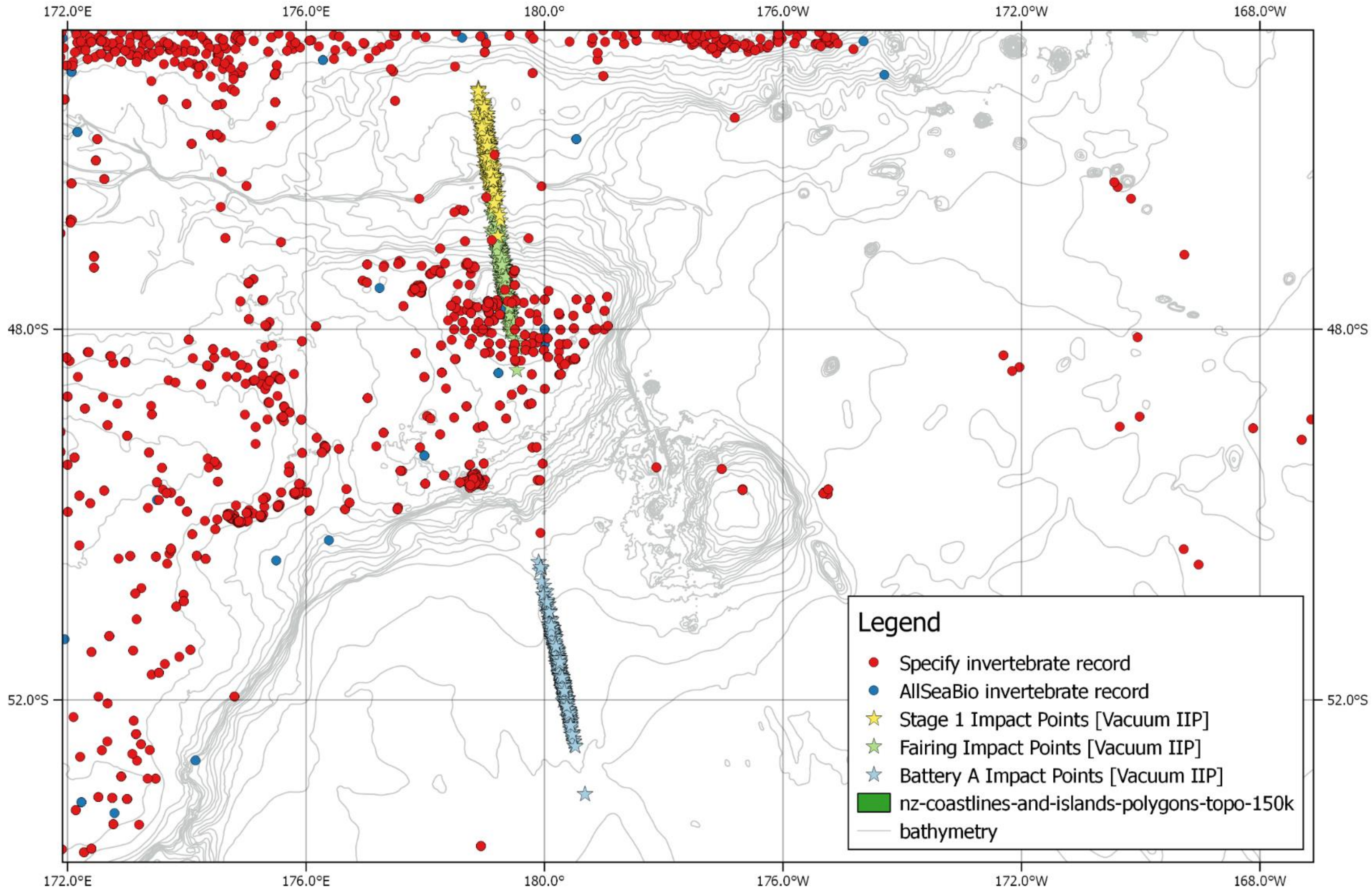

Figure 3-2: Map showing the sampling points for invertebrates held in NIWA databases in relation to the three potential debris areas associated with the test launches. Debris data provided by Rocket Lab.

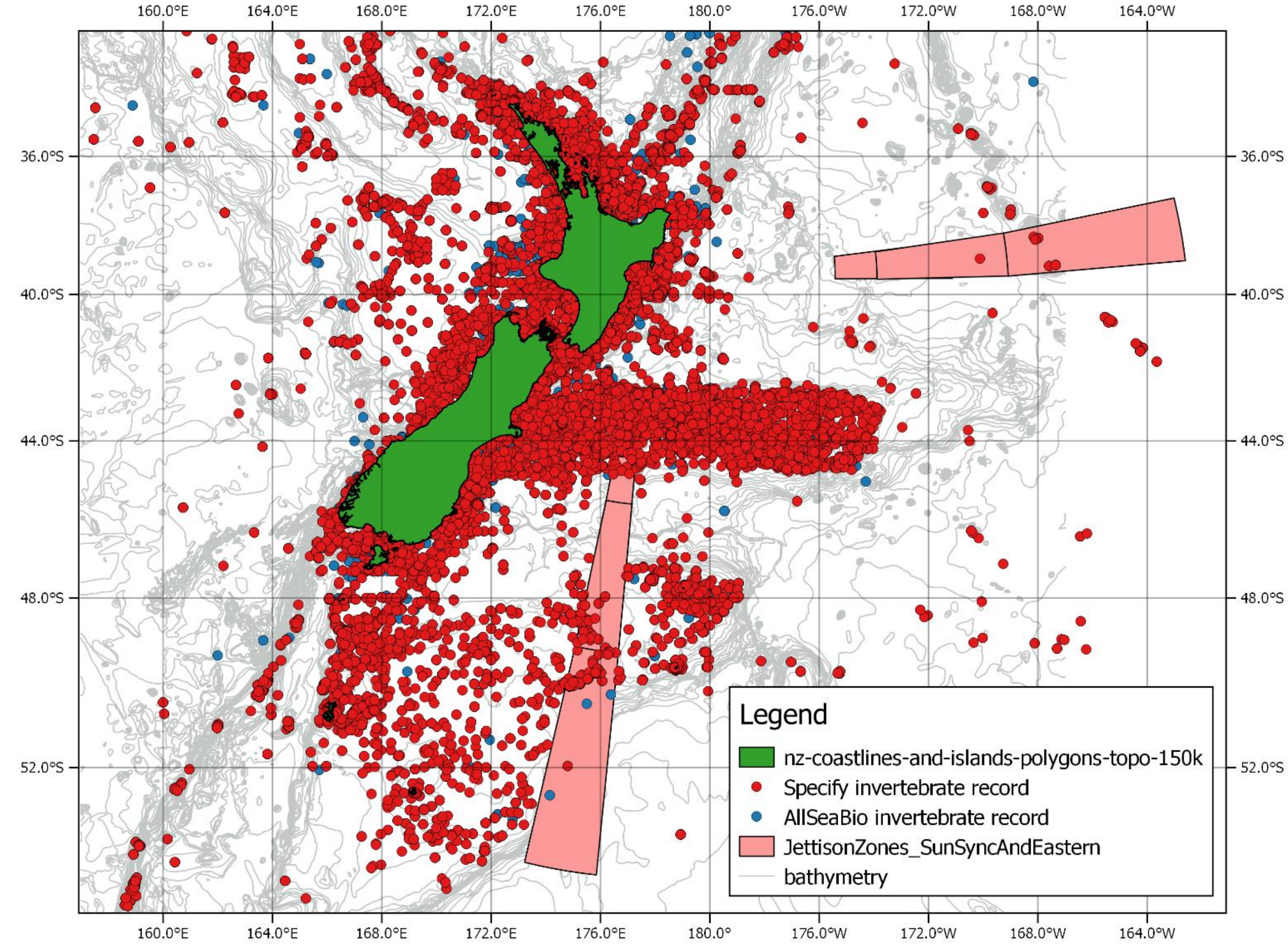

Figure 3-3: Map showing the sampling points for invertebrates held in NIWA databases in relation to the Sun-synchronous (southern) and Eastern debris areas. Predicted debris area locations supplied by Rocket Lab.

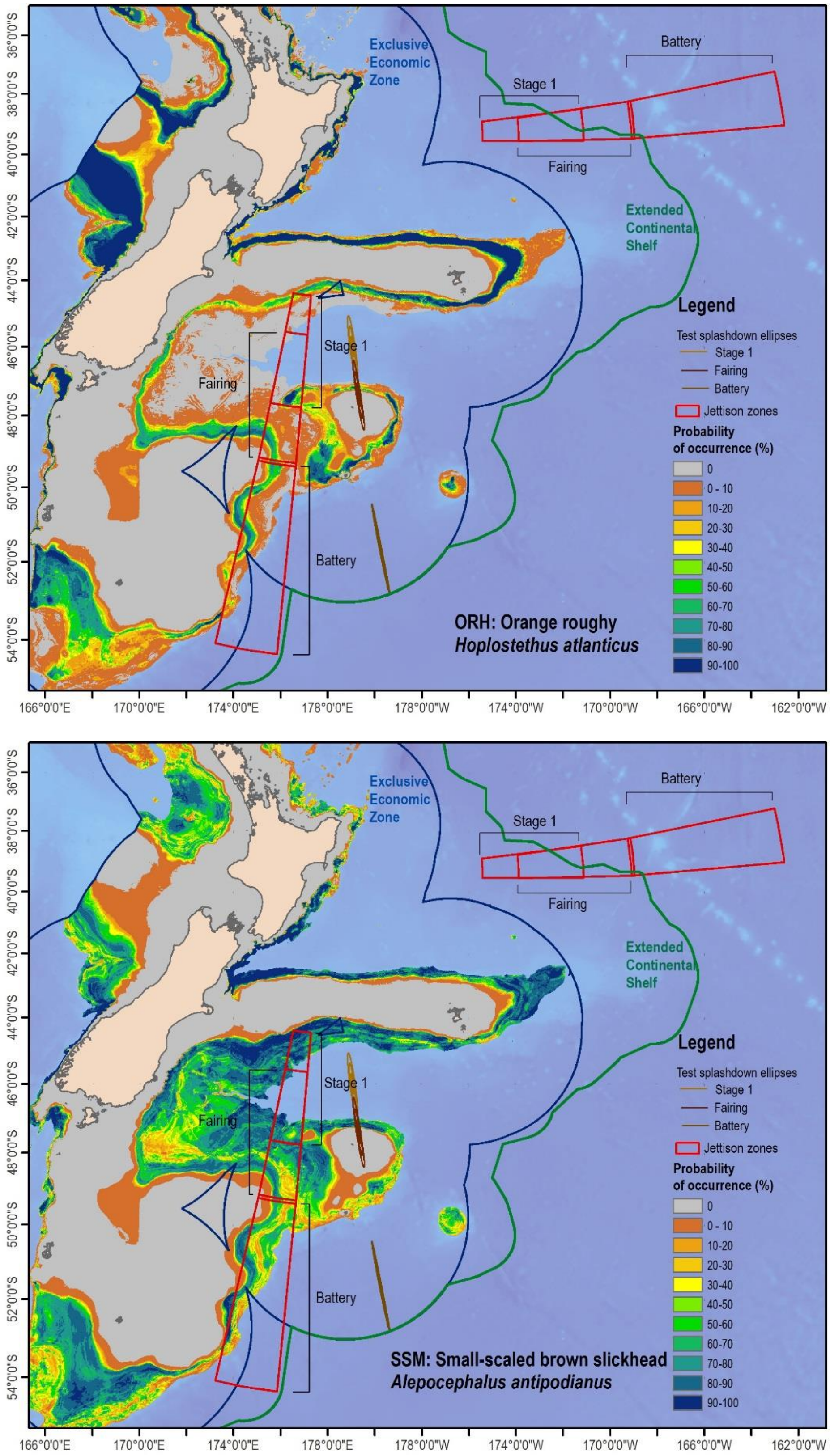

Figure 3-4: Predicted distributions of two fish species (to depths of about 1 600 m) in relation to the predicted debris areas. Orange roughy – a commercially fished species (upper panel), small-scaled brown slickhead – not a commercial species (lower panel). NIWA unpublished data. Shown as red boxes are the debris areas for Sun-synchronous (to the south) and Eastern (to the east) launches.

Table 3-1: Marine mammal species likely to occur, may possibly occur, and possible but unlikely to occur in the rocket debris areas. This list applies to test and commercial debris areas. Also shown for each species is the DOC Conservation status and IUCN status from Baker et al. (2010).

Scientific name	**Common name**	**DOC Conservation Status**	**IUCN status**	**In debris Area**
Mesoplodon bowdoini	Andrews' beaked whale	Data deficient	Data deficient	Likely
Mesoplodon layardii	Strap-toothed beaked whale	Data deficient	Data deficient	Likely
Mesoplodon grayi	Gray's beaked whale	Not threatened	Data deficient	Likely
Balaenoptera physalus	Fin whale	Non-resident native-migrant	Endangered	Likely
Balaenoptera musculus brevicauda	Pygmy blue whale	Non-resident native-migrant	Data deficient	Likely
Balaenoptera borealis	Sei whale	Non-resident native-migrant	Endangered	Likely
Balaenoptera bonaerensis	Antarctic minke whale	Not threatened	Data deficient	Likely
Balaenoptera acutorostrata	Dwarf minke whale	Not threatened	Least Concern	Likely
Megaptera novaeangliae	Humpback whale	Non-resident native-migrant	Least Concern	Likely
Globicephala macrohynchus	Short-finned pilot whale	Non-resident native-migrant	Data deficient	Likely
Globicephala melas	Long-finned pilot whale	Not threatened	Data deficient	Likely
Lagenorhynchus obscurus	Dusky dolphin	Not threatened	Data deficient	Likely
Lissodelphis peronii	Southern right whale dolphin	Not threatened	Data deficient	Likely
Tursiops truncatus	Bottlenose dolphin	Threatened-nationally endangered	Least Concern	Likely
Orcinus orca	Killer whale	Threatened-nationally critical	Data deficient	Likely
Physeter macrocephalus	Sperm whale	Not threatened	Vulnerable	Likely
Arctocephalus forsteri	New Zealand fur seal	Not threatened	Least Concern	Likely
Ziphius cavirostris	Cuvier's beaked whale	Data deficient	Least Concern	Possible
Mesoplodon densirostris	Dense-beaked whale	Data deficient	Data deficient	Possible
Caperea marginata	Pygmy right whale	Data deficient	Data deficient	Possible
Tasmacetus shepherd	Shepherd's beaked whale	Data deficient	Least Concern	Possible
Hyperoodon planifrons	Southern bottlenose whale	Data deficient	Least Concern	Possible
Mesoplodon traversii	Spade-toothed beaked whale	Data deficient	Data deficient	Possible
Phocoena dioptrica	Spectacled porpoise	Data deficient	Data deficient	Possible
Balaenoptera musculus intermedia	Antarctic blue whale	Non-resident native-migrant	Critically endangered	Possible

Scientific name	**Common name**	**DOC Conservation Status**	**IUCN status**	**In debris Area**
Berardius arnouxi	Arnoux’s beaked whale	Non-resident native-migrant	Data deficient	Possible
Mesoplodon ginkgodens	Ginkgo-toothed beaked whale	Non-resident native-vagrant	Data deficient	Possible
Mesoplodon peruvianus	Lesser/pygmy beaked whale	Non-resident native-vagrant	Data deficient	Possible
Stenella coeruleoalba	Striped dolphin	Non-resident native-vagrant	Least Concern	possible
Delphinus delphis	Common dolphin	Not threatened	Least Concern	Possible
Pseudorca crassidens	False killer whale	Not threatened	Data deficient	Possible
Kogia breviceps	Pygmy sperm whale	Not threatened	Data deficient	Possible
Mirounga leonina	Southern elephant seal	Threatened-nationally critical	Least Concern	Possible
Lagenorhynchus cruciger	Hourglass dolphin	Data deficient	Data deficient	Possible but unlikely
Grampus griseus	Risso’s dolphin	Non-resident native-vagrant	Least Concern	Possible but unlikely
Mesoplodon mirus True	True's beaked whale	Data deficient	Data deficient	Possible but unlikely
Kogia sima	Dwarf sperm whale	Non-resident native-vagrant	Data deficient	Possible but unlikely
Balaenoptera edeni/brydei sp.	Bryde’s whale	Threatened-nationally critical	Data deficient	Possible but unlikely
Eubalaena australis	Southern right whale	Threatened-nationally vulnerable	Least concern	Possible but unlikely
Arctocephalus gazella	Antarcitc fur seal	Non-resident native-vagrant	Least concern	Possible but unlikely
Lobodon carcinophagus	Crabeater seal	Non-resident native-vagrant	Least concern	Possible but unlikely
Hydrurga leptonyx	Leapard seal	Non-resident native-vagrant	Least Concern	Possible but unlikely
Arctocephalus tropicalis	Subantatctic fur seal	Non-resident native-vagrant	Least concern	Possible but unlikely
Eubalaena australis	Southern right whale	Threatened-nationally vulnerable	Least concern	Possible but unlikely

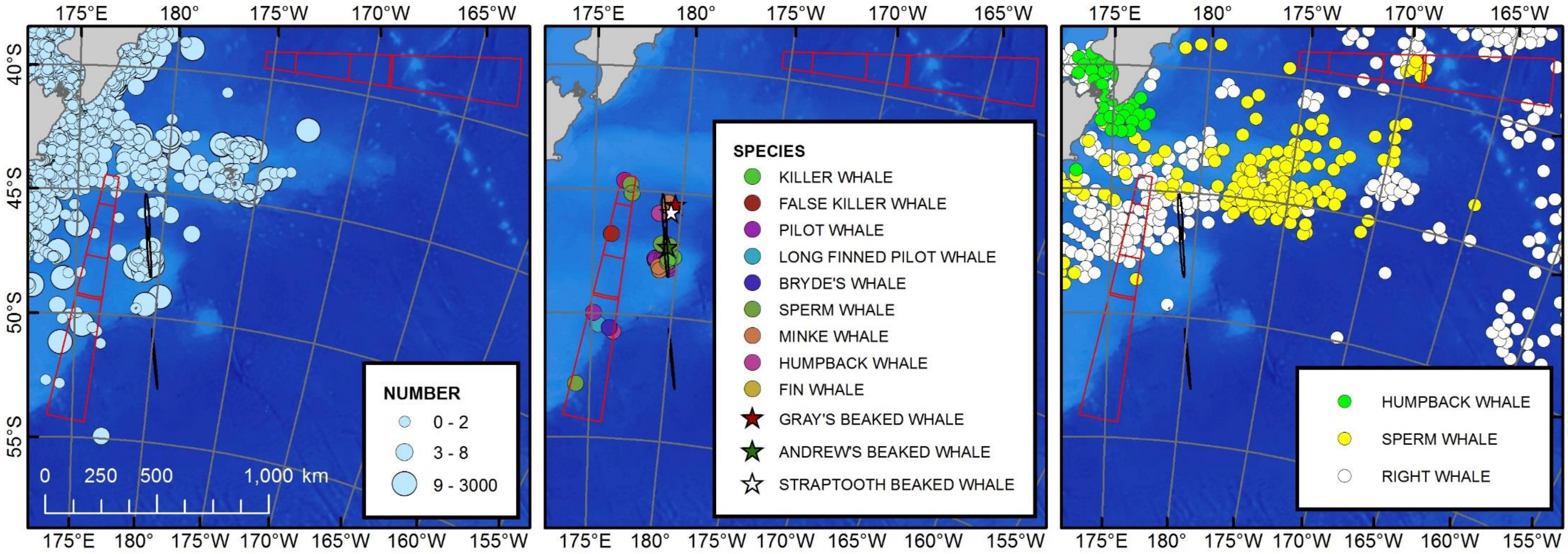

Figure 3-5: Locations of whale and dolphin sightings east of New Zealand, including the debris areas. Shown as red boxes are the debris areas for Sun-synchronous (to the south) and Eastern (to the east) launches. The test launch debris areas are shown as black ellipses. The panels from left to right are numbers of animals per sighting up until 2013 (collated from DoC, MPI (Cawthorn, COD), and NIWA sources), the species sighted within the debris areas for Sun-synchronous and Eastern launches and within a 50 km of the test launch area, and the historical distribution of sightings or strikes of three species from http://canada.wcs.org/wild-places/global-conservation/townsend-whaling-charts.aspx.

Table 3-2: Summary information on the conservation status, relative abundance and occurrence of seabirds that may be encountered within the debris areas. Taxa marked * are unlikely to occur in the Eastern launch area, while those marked # are likely to only occur in the Eastern launch area. Taxonomy and New Zealand conservation status classification follows Robertson et al. (2013). Relative abundance scores reflect the New Zealand population size for each species and follow Townsend et al. (2008), whereby a score of 1 = < 250 mature individuals (defined as an individual capable of reproduction and here calculated as double the best estimate of number of annual breeding pairs for each species); 2 = 250-1 000; 3 = 1 000-5 000; 4 = 5 000-20 000; 5 = 20 000-100 000 and 6 = > 100 000 mature individuals.

Common Name	Latin Name	IUCN Threat Ranking (as of July 2016)	New Zealand Conservation Status	Relative Abundance	Approximate Percentage Of Year In Zone
Erect-crested penguin*	*Eudyptes sclateri*	Endangered	At Risk - Declining	6	50
Eastern rockhopper penguin*	*Eudyptes filholi*	Vulnerable	Threatened – Nationally Critical	5	50
Antipodean albatross	*Diomedea antipodensis antipodensis*	Vulnerable	Threatened – Nationally Critical	4	100
Gibson's albatross	*Diomedea antipodensis gibsoni*	Vulnerable	Threatened – Nationally Critical	4	100
Southern royal albatross	*Diomedea epomophora*	Vulnerable	At Risk – Naturally Uncommon	4	100
Northern royal albatross	*Diomedea sanfordi*	Endangered	At Risk – Naturally Uncommon	4	100
Northern Buller's albatross	*Thalassarche bulleri platei*	Near Threatened	At Risk – Naturally Uncommon	5	75
Southern Buller's albatross	*Thalassarche bulleri bulleri*	Near Threatened	At Risk – Naturally Uncommon	4	75
Chatham albatross	*Thalassarche eremita*	Vulnerable	At Risk – Naturally Uncommon	4	75
Salvin's albatross	*Thalassarche salvini*	Vulnerable	Threatened – Nationally Critical	5	66
Campbell albatross	*Thalassarche impavida*	Vulnerable	At Risk – Naturally Uncommon	5	66
Black-browed albatross	*Thalassarche melanophrys*	Near Threatened	Coloniser	2	66
White-capped albatross	*Thalassarche steadi*	Near Threatened	At Risk - Declining	6	100
Grey-headed albatross	*Thalassarche chrysostoma*	Endangered	Threatened – Nationally Vulnerable	4	66
Light-mantled albatross	*Phoebetria palpebrata*	Near Threatened	At Risk - Declining	4	100
Snares Cape petrel	*Daption capense australe*	Least Concern	At Risk – Naturally Uncommon	4	100
Northern giant petrel	*Macronectes halli*	Least Concern	At Risk – Naturally Uncommon	3	100
Fulmar prion	*Pachyptila crassirostris*	Least Concern	At Risk – Naturally Uncommon	5	100
Antarctic prion	*Pachyptila desolata*	Least Concern	At Risk – Naturally Uncommon	6	100
Fairy prion	*Pachyptila turtur*	Least Concern	At Risk - Relict	6	100
Broad-billed prion	*Pachyptila vittata*	Least Concern	At Risk - Relict	6	100
White-chinned petrel	*Procellaria aequinoctialis*	Vulnerable	At Risk – Declining	6	66
Grey petrel	*Procellaria cinerea*	Near Threatened	At Risk – Naturally Uncommon	6	66

Common Name	Latin Name	IUCN Threat Ranking (as of July 2016)	New Zealand Conservation Status	Relative Abundance	Approximate Percentage Of Year In Zone
Westland petrel	*Procellaria westlandica*	Vulnerable	At Risk – Naturally Uncommon	3	66
Chatham petrel	*Pterodroma axillaris*	Endangered	Threatened – Nationally Vulnerable	2	66
Cook’s petrel	*Pterodroma cookii*	Vulnerable	At Risk - Relict	6	66
Mottled petrel	*Pterodroma inexpectata*	Near Threatened	At Risk - Relict	6	66
White-headed petrel	*Pterodroma lessonii*	Least Concern	Not Threatened	6	66
Grey-faced petrel	*Pterodroma macroptera gouldi*	Least Concern	Not Threatened	6	66
Magenta petrel	*Pterodroma Magentae*	Critically Endangered	Threatened – Nationally Critical	1	66
Soft-plumaged petrel	*Pterodroma mollis*	Least Concern	Coloniser	3	66
Black-winged petrel	*Pterodroma nigripennis*	Least Concern	Not Threatened	6	66
White-naped petrel#	*Pterodroma cervicalis*	Vulnerable	At Risk - Relict	5	66
Kermadec petrel#	*Pterodroma negelcta*	Least Concern	At Risk - Relict	6	66
Kermadec little shearwater#	*Puffinus assimilis kermadecensis*	Least Concern	At Risk - Relict	5	66
Subantarctic little shearwater	*Puffinus elegans*	Least Concern	At Risk – Naturally Uncommon	6	66
Buller’s shearwater	*Puffinus bulleri*	Vulnerable	At Risk – Naturally Uncommon	6	66
Flesh-footed shearwater	*Puffinus carneipes*	Least Concern	Threatened – Nationally Vulnerable	4	66
Fluttering shearwater	*Puffinus gavia*	Least Concern	At Risk - Relict	5	66
Sooty shearwater	*Puffinus griseus*	Near Threatened	At Risk – Declining	6	66
Hutton’s shearwater	*Puffinus huttoni*	Endangered	At Risk – Declining	6	66
Wedge-tailed shearwater#	*Puffinus pacificus pacificus*	Least Concern	At Risk - Relict	6	66
Common diving petrel	*Pelecanoides urinatrix*	Least Concern	At Risk - Relict	6	66
Black-bellied storm petrel	*Fregetta tropica*	Least Concern	Not Threatened	5	66
Grey-backed storm petrel	*Garrodia nereis*	Least Concern	At Risk - Relict	5	66
White-faced storm petrel	*Pelagodroma marina*	Least Concern	At Risk - Relict	6	66
White-bellied storm petrel#	*Fregetta grallaria grallaria*	Least Concern	Threatened – Nationally Endangered	3	66
Bounty Island shag*	*Leucocarbo ranfurlyi*	Vulnerable	Threatened – Nationally Endangered	2	100
Australasian gannet	*Morus serrator*	Least Concern	Not Threatened	5	100

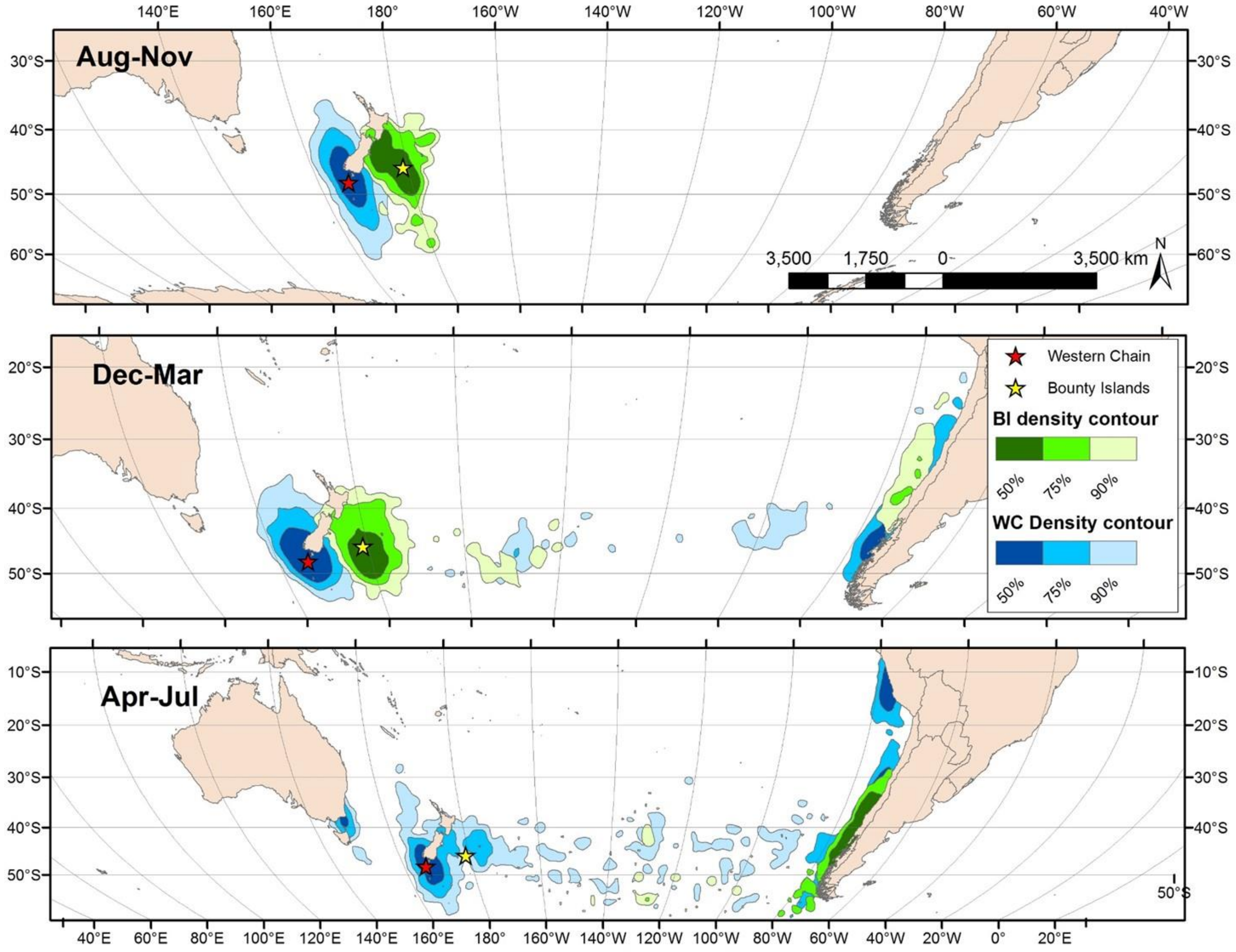

Figure 3-6: Kernel distributions for Salvin's albatross breeding at the Western Chain (red star) and Bounty Islands (yellow star). This species has high conservation status ('nationally critical' in New Zealand). The distributions are based on unpublished NIWA geolocation data.

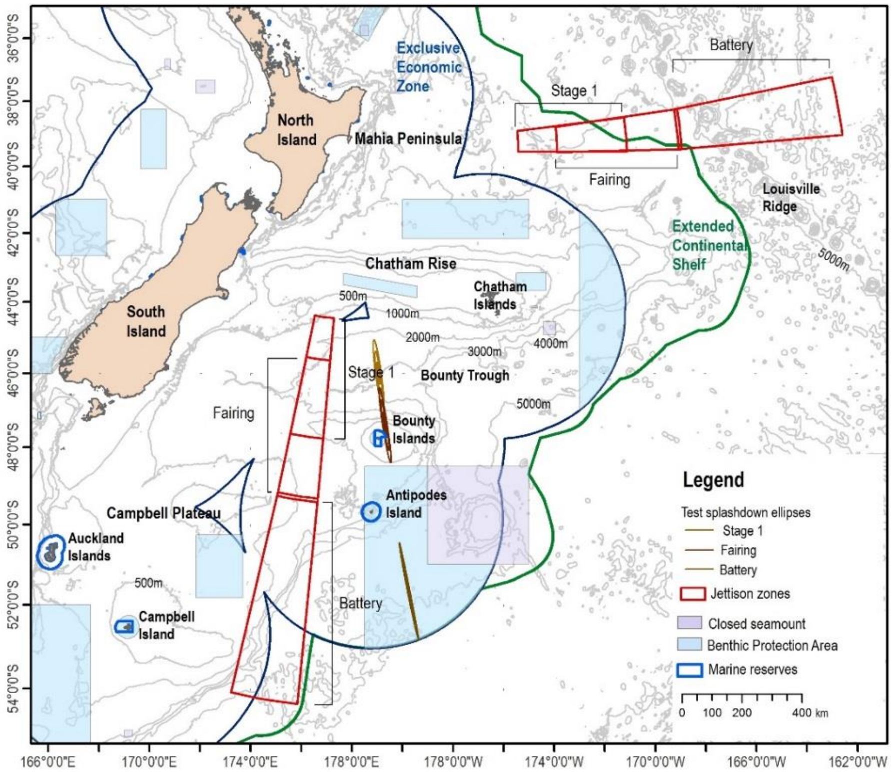

Figure 3-7: Map showing marine reserves, benthic protected areas and closed seamounts in the vicinity of the debris fall areas. Shown as red boxes are the debris areas for Sun-synchronous (to the south) and Eastern (to the east) launches.

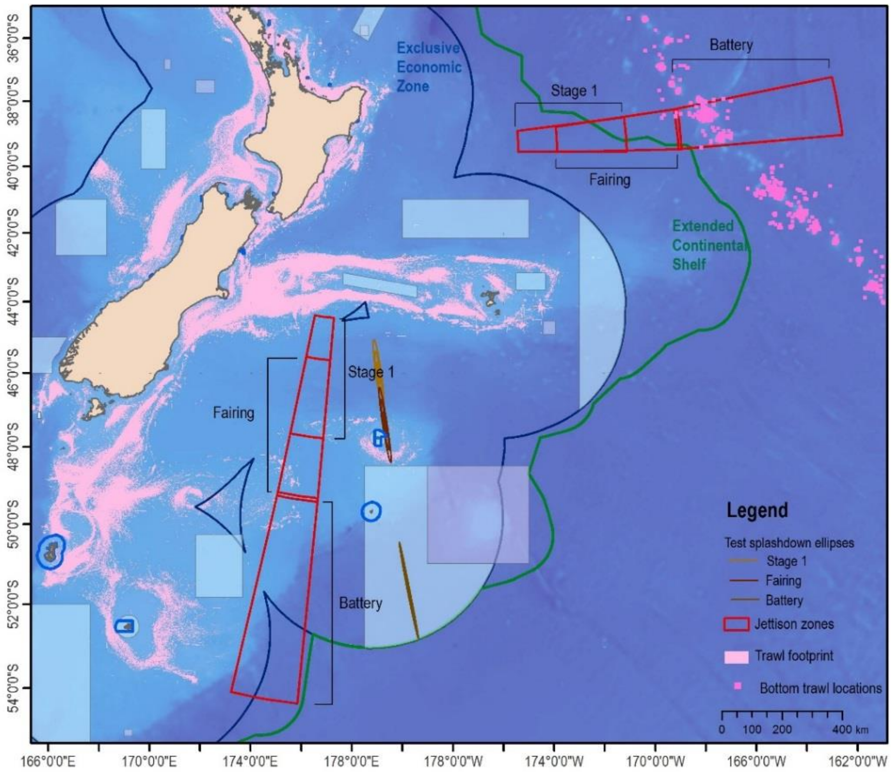

Figure 3-8: Bottom trawl locations in the relation to the Electron launch vehicle debris areas. Shown as red boxes are the debris areas for Sun-synchronous (to the south) and Eastern (to the east) launches. Fishing data courtesy of MPI.

Figure 3-9: Seafloor photographs showing benthic fauna associated with polymetallic nodules. Images from (top panel) site (U1380; 4 811 - 4 846 m) with relatively high nodule cover (79 ± 12 % of image) and (bottom panel) at a site (U1397; 4 487 - 4 490 m) with relatively low nodule cover (37 ± 19 % of image) in the Campbell nodule field (data from Wright et al. 2005).

3.1.2 Eastern launches

The debris area for the Eastern commercial launches lies outside the EEZ but debris from Stage 1 and the nose fairings of these launches is calculated to fall largely in very deep water (mainly 3 000-5 000 m) within the Extended Continental Shelf (ECS) (Figure 1-1). The Stage 2 batteries are expected to fall almost entirely outside the ECS in international waters and straddling the volcanic Louisville Ridge which rises to within a few hundred meters of the surface (Figure 1-1). In this part of the southwest Pacific region, subtropical surface water is relatively warm (14°C in winter and 20°C in summer) and saline (around 35.4‰) and becomes macronutrient depleted in late spring and summer (Nodder et al. 2016). Cold water from the Deep Western Boundary Current flow northwards into this area around the eastern foot of the Chatham Rise (Figure 3-1) with water temperatures near the seafloor around 2°C (Nodder et al. 2016).

Because of its great depth and remoteness this debris area has been little explored with very few seafloor samples in NIWA records (Figure 3-3). Like other Pacific abyssal plains the soft sediments in the zone are likely to have a high level of biodiversity, with up to 2000 species of bacteria, 250 species of protozoans, and 500 species of polychaete worms, crustaceans and molluscs, typically found at single sampling site (Smith et al. 2006). The larger fauna, including macrourid fish and holothurians, are likely to have low to moderate local diversity and very broad distributions, with the flux of food from surface waters likely to strongly influence species abundance and diversity (Smith et al. 2006). In contrast to the soft sediment of the abyssal plain, a more diverse and abundant epifauna is likely on the exposed rock surfaces on the Louisville Ridge. Here the seamounts provide habitat for a range of encrusting, sedentary and mobile invertebrate groups including corals, sponges, brachiopods, crustaceans, echinoderms and molluscs (Clark et al. 2015; Rowden et al. 2013, 2015). The occurrence of sensitive benthic habitats is confirmed from some of the seamounts in the debris zone (Clark et al. 2015), consisting largely of the stony coral *Solenosmilia variabilis*. The seamounts in this region (termed “JCM” and “39 South”) are also included in an “Ecologically or Biologically Significant Area” (EBSA) which was defined on the basis of topographic diversity of seamount and guyot characteristics, having sensitive benthic environment-forming taxa (stony corals), being spawning areas for orange roughy, and the fishery including a bycatch of deepwater sharks. The seamounts have been commercially fished for orange roughy (*Hoplostethus atlanticus*) since the mid-1990s, although catch levels have declined since 2005. The fishery in the area is managed by the South Pacific Regional Fishery Management Organization.

There are no modern sightings of whales or dolphins from Eastern debris area, probably because of a lack of sampling effort, but historically sperm and southern right whales were hunted in these waters (Figure 3-5). Recent satellite tracking data suggests that humpback whales follow the Louisville Ridge south to Antarctic summer feeding grounds (Tremlett 2016). It is likely that several species of beaked whale occur in these deep waters.

Similarly, up to fifty species of seabirds may occur in the Eastern debris area (Table 3-2) but, as detailed distributions are known for only a few satellite tagged species (e.g. Figure 3-6), it is unclear which species are most likely to occur in the Eastern launch debris area.

3.2 Risk assessment

Below are detailed the Panel’s separate assessments of the consequences of the potential threats arising from the rocket debris (using Table 2-1) for the test, Sun-synchronous, and Eastern launches for each component of the ecosystem being considered, the likelihood of the threat occurring (using Table 2-2), and the level of confidence in the supporting information used in reaching the individual decisions (using Table 2-3). Risk was then determined as the product of the individual consequence and likelihood scores (see Table 2-4).

The Panel assessed the risks associated with the Magenta petrel separate from the other air-breathing fauna because it is so rare that the consequences of even one death from a direct strike would be significant for the population.

For each level of launch activity in each debris area, the Panel assessed if the probability of a vessel strike occurring after successive weekly launches (see Appendix A) would be sufficient for vessels to avoid the debris areas and fish elsewhere. Reduction in fishing activity in an area will, over time, allow the populations of target and by catch species to rebuild.

3.2.1 Test launches

Although only three test launches of the Electron rocket vehicle are planned we assessed the ecological risk from debris of 1 and 10 launches in case more test launches are required.

1 launch

The debris from just a single test launch was assessed as having a low ecological risk (Table 3-3). In most cases the consequences would be negligible and the likelihoods remote. In a few cases, likelihoods would be elevated, such as for debris providing attachment sites for seafloor biota, but the consequences would be negligible and thus risk low. Although the consequences of even one death from a direct strike would be significant for the population of Magenta petrel, the probability of this occurring is remote, so the risk is low. The toxic effects of the components comprising Stage 1, the nose fairings and the two Stage 2 Lithium-Iron batteries were assessed as low risk for 1 test launch.

10 launches

It was assessed that after ten successive test launches the consequences for a few ecosystem components would be slightly modified. Although after a single test launch the probability of a direct strike of rocket debris on a vessel is low, the Panel assessed that if the ten successive weekly test launches occur during the winter fishing season for southern blue whiting, they are likely to displace the fishing fleet from the debris area for the entire fishing season thereby allowing some minor rebuilding of exploited stocks to occur (Anderson 2013, Richard and Abraham 2013, Thompson et al. 2013). However, these populations may also be impacted in the areas to which fishing is displaced so the risk remains low. Seafloor invertebrate communities and sensitive benthic environments are unlikely to be affected by displaced fishing activity as the southern blue whiting fishery has a low invertebrate bycatch (Ministry for Primary Industries 2016). After ten successive weekly launches there may be minor consequences of noise and disturbance to air-breathing fauna in particular, though the likelihood is rare and thus the risk low. Although the consequences of one or more deaths from a direct strike would be significant for the population of Magenta petrel, the probability of this occurring after ten launches was assessed as being remote, so the risk to this threatened population remains low. The toxic effects of the components comprising Stage 1, the nose fairings and the two Stage 2 Lithium-Iron batteries were assessed as low risk for up to 10 test launches.

Table 3-3: Expert panel assessment for test launches. Levels of consequence, likelihood, risk and confidence for the potential threats arising from the rocket debris at each cumulative level of launches (1, 10) for each component of the ecosystem (see Figure 1-1 for location of test launch debris areas). Positive consequences (i.e. increases in populations) are marked +. The maximum possible level of risk is 30. All activities were identified as low risk. No moderate, high or extreme environmental risks were identified (see Table 2-4 for definitions).

Risk Assessment: Test launches		**Benthic Invertebrate Community**				**Demersal fish and mobile invertebrates**				**Air breathing fauna** **(assessment for Magenta petrel)**				**Sensitive benthic environments**				**Pelagic Community**			
Number of launches (years at 1 launch per week)	**Potential effect**	**Consequence**	**Likelihood**	**Risk**	**Confidence**	**Consequence**	**Likelihood**	**Risk**	**Confidence**	**Consequence**	**Likelihood**	**Risk**	**Confidence**	**Consequence**	**Likelihood**	**Risk**	**Confidence**	**Consequence**	**Likelihood**	**Risk**	**Confidence**
1 (0.02)	Direct strike causing mortality	0	1	0	2a	0	1	0	2a	(2), 0	(1), 1	(2), 0	(2b), 2b	0	1	0	2a	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	1	0	1c	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	4	0	2a	0	2	0	1c	(0), 0	(1), 1	(0), 0	(2a), 2a	0	4	0	2a	0	1	0	2a
	Smothering of seafloor organisms	0	1	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	1	0	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Displacement of fishing effort	0	1	0	1c	0	1	0	1c	(0), 0	(1), 1	(0), 0	(1c), 1c	0	1	0	1c	0	1	0	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
10 (0.2)	Direct strike causing mortality	0	1	0	2a	0	1	0	2a	(3), 0	(1), 1	(3), 0	(2b), 2a	0	1	0	2a	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	1	0	1c	(1), 1	(1), 2	(1), 2	(1c), 1c	0	1	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	5	0	2a	0	3	0	1c	(0), 0	(1), 2	(0), 0	(1c), 1c	0	5	0	2a	0	1	0	2a
	Smothering of seafloor organisms	0	2	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	1	0	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Displacement of fishing effort	0	3	3	1c	+1	3	3	1c	(0), 0	(3), 3	(0), 0	(1c), 1c	0	3	3	1c	0	1	0	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a

3.2.2 Sun-synchronous launches

1 launch

The debris from just a single commercial Sun-synchronous launch was assessed as having a low ecological risk (Table 3-4). In most cases the consequences would be negligible and the likelihoods remote. Although the consequences of even one death from a direct strike would be significant for the population of Magenta petrel, the probability of this occurring is remote, so the risk is low. The toxic effects of the components comprising Stage 1, the nose fairings and the two Stage 2 Lithium-Iron batteries were assessed as low risk for 1 launch and at all higher levels of launch activity.

10 launches

It was assessed that after ten successive launches the consequences of a few activities would be slightly modified. Although the consequences of one or more deaths from a direct strike would be significant for the population of Magenta petrel, the probability of this occurring after ten launches was assessed as being remote, so the risk to this threatened population remains low. After ten successive weekly launches there may be minor consequences of noise and disturbance to air-breathing fauna in particular, though the likelihood is rare and thus the risk low. Displacement of fishing effort is likely to temporarily displace the fishing fleet from the debris area, particularly over the eastern flank of the Campbell Plateau, but over a period of ten weeks there is unlikely to be much rebuilding of exploited stocks and bycatch species of seafloor invertebrates. These populations may also be impacted in the areas to which fishing is displaced (Anderson 2013, Richard and Abraham 2013, Thompson et al. 2013).

100 launches

The debris from 100 launches was assessed as having a cumulative low risk to all components of the marine ecosystem (including the Magenta petrel). After 2 years of weekly launches the Panel assessed that it is likely that fisheries would move elsewhere, with minor impacts on the rebuilding of affected populations of seafloor invertebrates, but with only negligible rebuilding of fish, and marine mammals and seabirds as these populations may also be impacted in the areas to which fishing is displaced (Anderson 2013, Richard and Abraham 2013, Thompson et al. 2013).

1 000 launches

With two exceptions, the debris from 1 000 launches was assessed as having a cumulative low risk to all components of the marine ecosystem, including the Magenta petrel. The consequences of noise and disturbance to air-breathing fauna in particular was assessed as moderate with a possible likelihood, placing this fauna at moderate risk. The Panel assessed that it was likely that almost 20 years of weekly launches would displace fishing effort from affected areas with moderate rebuilding of affected populations of seafloor invertebrates, but with only minor rebuilding of fish, and marine mammals and seabirds as these populations may also be impacted in the areas to which fishing is displaced (Anderson 2013, Richard and Abraham 2013, Thompson et al. 2013).

10 000 launches

The splashdown of debris from 10 000 launches was assessed as having a low cumulative risk to the pelagic community, but for other components of the marine ecosystem the risk would vary among threats. There would be a moderate risk to the Magenta petrel population as the likelihood of a direct hit increased from remote to rare. There would be a moderate risk to the benthic invertebrate community and sensitive benthic environments as the likelihood of direct hits increased from unlikely to possible. The Panel assessed that there would be a moderate risk to sedentary seafloor invertebrates and sensitive benthic environments from the effects of smothering of respiratory or feeding surfaces. The consequences of debris providing attachment sites for seafloor biota would increase from minor to moderate, with likely 5-20% increases in the populations of groups that use hard surfaces for attachment. For seafloor invertebrates requiring soft sediments, the loss of about 50 ha of habitat (<<0.1% of available sediments) would be negligible. In this case the net risk is moderate.

There would be a high risk to air breathing fauna as the consequences and likelihood of noise and disturbance generated by 10 000 weekly launches increased to major and occasional respectively. The Panel assessed that it was likely that almost 200 years of weekly launches would displace fishing effort from the eastern flank of the Campbell Plateau in particular, with moderate rebuilding of affected populations of seafloor invertebrates, but with only minor rebuilding of fish, and marine mammals and seabirds as these populations may also be impacted in the areas to which fishing is displaced (Anderson 2013, Richard and Abraham 2013, Thompson et al. 2013).

Table 3-4: Expert panel assessment of Sun-synchronous launches. Levels of consequence, likelihood, risk and confidence for the potential threats arising from the rocket debris at each cumulative level of launches (1, 10, 100, 1000, 1000) for each component of the ecosystem (see Figure 1-1 for location of debris areas). Positive consequences (i.e. increases in populations) are marked +. The maximum possible level of risk is 30. High environmental risks are highlighted in yellow, and moderate in green. Low risk activities are not highlighted. No extreme environmental risks were identified (see Table 2-4 for definitions).

Risk Assessment: Sun-synchronous launches		**Benthic Invertebrate Community**				**Demersal fish and mobile invertebrates**				**Air breathing fauna (assessment for Magenta petrel)**				**Sensitive benthic environments**				**Pelagic Community**			
Number of launches (years at 1 launch per week)	**Potential effect**	**Consequence**	**Likelihood**	**Risk**	**Confidence**	**Consequence**	**Likelihood**	**Risk**	**Confidence**	**Consequence**	**Likelihood**	**Risk**	**Confidence**	**Consequence**	**Likelihood**	**Risk**	**Confidence**	**Consequence**	**Likelihood**	**Risk**	**Confidence**
1 (0.02)	Direct strike causing mortality	0	1	0	2a	0	1	0	2a	(2), 0	(1), 1	(2), 0	(2b), 2b	0	1	0	2a	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	1	0	1c	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	4	0	2a	0	2	0	1c	(0), 0	(1), 1	(0), 0	(2a), 2a	0	4	0	2a	0	1	0	2a
	Smothering of seafloor organisms	0	1	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	1	0	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Displacement of fishing effort	0	1	0	1c	0	1	0	1c	(0), 0	(1), 1	(0), 0	(1c), 1c	0	1	0	1c	0	1	0	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
10 (0.2)	Direct strike causing mortality	0	1	0	2a	0	1	0	2a	(3), 0	(1), 1	(3), 0	(2b), 2a	0	1	0	2a	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	1	0	1c	(1), 1	(1), 2	(1), 2	(1c), 1c	0	1	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	5	0	2a	0	3	0	1c	(0), 0	(1), 2	(0), 0	(1c), 1c	0	5	0	2a	0	1	0	2a
	Smothering of seafloor organisms	0	2	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	1	0	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Displacement of fishing effort	0	3	0	1c	0	3	0	1c	(0), 0	(3), 3	(0), 0	(1c), 1c	0	3	0	1c	0	1	0	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a

100 (1.9)	Direct strike causing mortality	1	1	1	2a	0	1	0	2a	(5), 1	(1), 1	(5), 1	(2b), 1c	1	2	2	2a	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	2	0	1c	(1), 1	(1), 3	(1), 3	(1c), 1c	0	1	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	6	0	2a	0	4	0	1c	(1), 1	(1), 3	(1), 3	(1c), 1c	0	6	0	2a	0	2	0	2a
	Smothering of seafloor organisms	0	3	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	3	0	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Displacement of fishing effort	+1	6	6	1c	+1	6	6	1c	(0), +1	(6), 6	(0), 6	(1c), 1c	+1	6	6	1c	+1	3	3	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
1 000 (19.2)	Direct strike causing mortality	2	3	6	1c	0	1	0	2a	(5), 2	(1), 2	(5), 4	(2b), 1c	2	3	6	1c	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	3	0	1c	(2), 2	(1), 4	(2), 8	(1c), 1c	0	1	0	2a	0	6	0	2a
	Toxic contaminants	1	1	1	1c	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	1	1	1	1c	0	1	0	2a
	Ingestion of debris	0	6	0	2a	1	5	5	1c	(1), 1	(1), 4	(1), 4	(1c), 1c	0	6	0	2a	0	2	0	2a
	Smothering of seafloor organisms	1	4	4	1c	NA	NA	NA	NA	NA	NA	NA	NA	1	4	4	1c	NA	NA	NA	NA
	Provision of biota attachment site	+1	6	6	1c	NA	NA	NA	NA	NA	NA	NA	NA	+1	6	6	1c	NA	NA	NA	NA
	Displacement of fishing effort	+2	6	12	1c	+1	6	6	1c	(+1), +1	(6), 6	(6), 6	(2b), 2b	+2	6	12	1c	+1	4	4	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
10 000 (192.3)	Direct strike causing mortality	3	4	12	1b	0	1	0	2a	(5), 3	(2), 2	(10), 6	(2b) 1c	3	4	12	1b	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	4	0	1c	(3), 3	(1), 5	(3), 15	(1c), 1c	0	1	0	2a	0	6	0	2a
	Toxic contaminants	2	1	2	1c	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	2	1	2	1c	0	1	0	2a
	Ingestion of debris	0	6	0	2a	1	6	6	1c	(1), 1	(2), 5	(2), 5	(1c), 1c	0	6	0	2a	0	3	0	2a
	Smothering of seafloor organisms	2	5	10	1c	NA	NA	NA	NA	NA	NA	NA	NA	2	4	8	1c	NA	NA	NA	NA
	Provision of biota attachment site	+2	6	12	1c	NA	NA	NA	NA	NA	NA	NA	NA	+2	6	12	1c	NA	NA	NA	NA
	Displacement of fishing effort	+2	6	12	1c	+1	6	12	1c	(+1), +1	(6), 6	(6), 6	(2b), 2b	+2	6	12	1c	+1	5	5	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a

3.2.3 Eastern launches

1 launch

The debris from just a single commercial Eastern launch was assessed as having a low risk to components of the marine ecosystem (Table 3-4). In most cases the consequences would be negligible and the likelihoods remote. In a few cases, likelihoods would be elevated, such as for debris providing attachment sites for seafloor biota, but the consequences would be negligible and risk low. Although the consequences of even one death from a direct strike would be significant for the population of Magenta petrel, the probability of this occurring is remote, so the risk is low. The toxic effects of the components comprising Stage 1, the nose fairings and the two Stage 2 Lithium-Iron batteries were assessed as low risk for 1 launch and at all higher levels of launch activity.

10 launches

It was assessed that after ten successive launches the consequences of a few activities would be slightly elevated. After ten successive weekly launches there may be minor consequences of noise and disturbance to air-breathing fauna in particular, though the likelihood is rare and thus the risk low. Although the consequences of one or more deaths from a direct strike would be significant for the population of Magenta petrel, the probability of this occurring after ten launches was assessed as being remote, so the risk to this threatened population remains low.

100 launches

The debris from 100 launches was assessed as having a cumulative low risk to all components of the marine ecosystem (including the Magenta petrel). There is an unlikely possibility that bottom trawling around specific Louisville seamounts would be displaced elsewhere for two years, resulting in minor rebuilding of affected populations of seafloor invertebrates, but with negligible rebuilding of fish, and marine mammals and seabirds as these populations may also be impacted in the areas to which fishing is displaced (Anderson 2013, Richard and Abraham 2013, Thompson et al. 2013).

1 000 launches

With one exception, the debris from 1 000 launches was assessed as having a cumulative low risk to all components of the marine ecosystem, including the Magenta petrel. The consequences of noise and disturbance to air-breathing fauna in particular was assessed as moderate with a possible likelihood, placing this fauna at moderate risk. The Panel assessed that after almost 20 years of weekly launches it was possible that fishing effort would be displaced from specific Louisville seamounts leading to minor rebuilding of affected populations of seafloor invertebrates, but with negligible rebuilding of fish, and marine mammals and seabirds as these populations may also be impacted in the areas to which fishing is displaced (Anderson 2013, Richard and Abraham 2013, Thompson et al. 2013). Similarly, after 1 000 launches the panel considered that sufficient debris will have accumulated on the seafloor to make measurable but minor net positive impacts on the seafloor invertebrate community through the provision of hard attachment sites for some fauna. For seafloor invertebrates requiring soft sediments, the loss of about 50 ha of habitat (<<0.1% of available sediments) would be negligible.

10 000 launches

The splashdown of debris from 10 000 launches was assessed as having a low cumulative risk to the pelagic community, but for other components of the ecosystem the risk would vary among threats.

There would be a moderate risk to the Magenta petrel population as the likelihood of a direct hit increased from remote to rare. There would be a moderate risk to the benthic invertebrate community and sensitive benthic environments as the likelihood of direct hits increased from unlikely to possible and the consequences increased from negligible to minor. The Panel assessed that there would be a moderate risk to sedentary marine seafloor invertebrates and sensitive biogenic habitats from the effects of smothering of respiratory or feeding surfaces. The consequences of debris providing attachment sites for seafloor biota would increase from minor to moderate, with likely 5-20% increases in the populations of groups requiring hard surfaces for attachment. For seafloor invertebrates requiring soft sediments, the loss of about 50 ha of habitat (<<0.1% of available sediments) would be negligible. In this case the net risk is moderate.

There would be a high risk to air breathing fauna as the consequences and likelihood of noise and disturbance generated by 10 000 weekly launches increased to major and occasional respectively. The ERA panel assessed that after almost 200 years of weekly launches there would be an increased likelihood of displacement of fishing effort from the debris area with minor rebuilding of affected populations of seafloor invertebrates, but with negligible rebuilding of fish, and marine mammals and seabirds as these populations may also be impacted in the areas to which fishing is displaced (Anderson 2013, Richard and Abraham 2013, Thompson et al. 2013).

Table 3-5: Expert panel assessment of Eastern launches. Levels of consequence, likelihood, risk and confidence for the potential threats arising from the rocket debris at each cumulative level of launches (1, 10, 100, 1000, 1000) for each component of the ecosystem (see Figure 1-1 for location of debris fields). Positive consequences (i.e. increases in populations) are marked +. The maximum possible level of risk is 30. High environmental risks are highlighted in yellow, and moderate in green. Low risk activities are not highlighted. No extreme environmental risks were identified (see Table 2-4 for definitions).

Risk Assessment: Eastern launches		Benthic Invertebrate Community				Demersal fish and mobile invertebrates				Air breathing fauna (assessment for Magenta petrel)				Sensitive benthic environments				Pelagic Community			
Number of launches (years at 1 launch per week)	**Potential effect**	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence
1 (0.02)	Direct strike causing mortality	0	1	0	2a	0	1	0	2a	(2), 0	(1), 1	(2), 0	(2b), 2b	0	1	0	2a	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	1	0	1c	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	4	0	2a	0	2	0	1c	(0), 0	(1), 1	(0), 0	(2a), 2a	0	4	0	2a	0	1	0	2a
	Smothering of seafloor organisms	0	1	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	1	0	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Displacement of fishing effort	0	1	0	1c	0	1	0	1c	(0), 0	(1), 1	(0), 0	(1c), 1c	0	1	0	1c	0	1	0	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
10 (0.2)	Direct strike causing mortality	0	1	0	2a	0	1	0	2a	(3), 0	(1), 1	(3), 0	(2b), 2a	0	1	0	2a	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	1	0	1c	(1), 1	(1), 2	(1), 2	(1c), 1c	0	1	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	5	0	2a	0	3	0	1c	(0), 0	(1), 2	(0), 0	(1c), 1c	0	5	0	2a	0	1	0	2a
	Smothering of seafloor organisms	0	2	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	1	0	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Displacement of fishing effort	0	1	0	1c	0	1	0	1c	(0), 0	(1), 1	(0), 0	(1c), 1c	0	1	0	1c	0	1	0	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a

100 (1.9)	Direct strike causing mortality	0	1	0	2a	0	1	0	2a	(5), 1	(1), 1	(5), 1	(2b), 1c	0	1	0	2a	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	2	0	1c	(1), 1	(1), 3	(1), 3	(1c), 1c	0	1	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	6	0	2a	0	4	0	1c	(1), 1	(1), 3	(1), 3	(1c), 1c	0	6	0	2a	0	2	0	2a
	Smothering of seafloor organisms	0	3	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	3	0	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Displacement of fishing effort	0	3	0	1c	0	3	0	1c	(0), 0	(3), 3	(0), 0	(1c), 1c	0	3	0	1c	0	3	0	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
1 000 (19.2)	Direct strike causing mortality	1	3	3	1c	0	1	0	2a	(5), 2	(1), 2	(5), 4	(2b), 1c	1	3	3	1c	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	3	0	1c	(2), 2	(1), 4	(2), 8	(1c), 1c	0	1	0	2a	0	6	0	2a
	Toxic contaminants	1	1	1	1c	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	1	1	1	1c	0	1	0	2a
	Ingestion of debris	0	6	0	2a	1	5	5	1c	(1), 1	(1), 4	(1), 4	(1c), 1c	0	6	0	2a	0	2	0	2a
	Smothering of seafloor organisms	1	4	4	1c	NA	NA	NA	NA	NA	NA	NA	NA	1	4	4	1c	NA	NA	NA	NA
	Provision of biota attachment site	+1	6	6	1c	NA	NA	NA	NA	NA	NA	NA	NA	+1	6	6	1c	NA	NA	NA	NA
	Displacement of fishing effort	+1	4	4	1c	0	4	0	1c	(0), 0	(4), 4	(0), 0	(2b), 2b	+1	4	4	1c	0	4	0	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
10 000 (192.3)	Direct strike causing mortality	2	4	8	1b	0	1	0	2a	(5), 3	(2), 2	(10), 6	(2b) 1c	2	4	8	1b	0	6	0	2a
	Underwater noise and disturbance	0	1	0	2a	0	4	0	1c	(3), 3	(1), 5	(3), 15	(1c), 1c	0	1	0	2a	0	6	0	2a
	Toxic contaminants	2	1	2	1c	0	1	0	2a	(0), 0	(1), 1	(0), 0	(2a), 2a	2	1	2	1c	0	1	0	2a
	Ingestion of debris	0	6	0	2a	1	6	6	1c	(1), 1	(2), 5	(2), 5	(1c), 1c	0	6	0	2a	0	3	0	2a
	Smothering of seafloor organisms	2	5	10	1c	NA	NA	NA	NA	NA	NA	NA	NA	2	4	8	1c	NA	NA	NA	NA
	Provision of biota attachment site	+2	6	12	1c	NA	NA	NA	NA	NA	NA	NA	NA	+2	6	12	1c	NA	NA	NA	NA
	Displacement of fishing effort	+1	5	5	1c	0	5	0	1c	(0), 0	(5), 5	(0), 0	(2b), 2b	+1	5	5	1c	0	5	0	1c
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a

4 Summary and conclusions

Using a Level 1 likelihood-consequence risk analysis approach the expert panel assessed the ecological risks associated with the fall of jettisoned rocket debris into debris areas corresponding to the trajectories used for test launches, and commercial Sun-synchronous and Eastern launches. The panel assumed that during descent through the atmosphere the debris would breakup into at least 280 fragments (some as heavy as 360 kg) but that no combustion of debris would occur. While most of the debris, including the carbon-fibre components, would fall to the seafloor, some components may float, including approximately 23 kg of cork and 8 kg of foam (Rocket Lab 2016).

The Panel considered the potential ecological impacts of eight threats arising from the fall of debris on five components of the ecosystem in the debris areas: the benthic invertebrate community, the demersal (bottom-associated) fish and mobile invertebrate community, marine mammals and seabirds, sensitive (benthic) environments, and the pelagic community.

Although only three test launches of the Electron launch vehicle are planned, the Panel assessed the ecological impact of debris from 1 and 10 launches in case more test launches are required. The debris from the test launches will have a low risk to the marine ecosystems. But some test launch debris will fall into the Bounty Islands Marine Reserve, the Bounty Heritage Benthic Protection Area and the Antipodes Transect Benthic Protection Area.

The frequency of commercial launches will reach a maximum of one per week. Thus the cumulative impact of 1, 10, 100, 1 000, and 10 000 weekly events was assessed for both the Sun-synchronous and Eastern debris areas. This range covers the likely number of launches (1-1 000), to an improbable 10 000. At the rate of one launch per week it would take almost 200 years to reach this upper number of launches. This approach indicated where thresholds may occur, whereby the risk of adverse effects to the environment would be moderate or less.

The ecological risk was assessed to be low for all ecosystem components of the Sun-synchronous and Eastern debris areas for up to 100 launches, and low for the pelagic community of phytoplankton, zooplankton, fish and larger invertebrates at all levels of launch activity from 1 to 10 000 launches.

The toxic effects of the components comprising Stage 1, the nose fairings and the two Stage 2 Lithium-Iron batteries were assessed as low at all levels of launch activity.

Floating debris as attachment for pelagic organisms and the ingestion of debris were both evaluated as having low ecological risk at all levels of launch activity in both the Sun-synchronous and Eastern debris areas.

Although for a single launch the probability of debris making a direct hit on a fishing vessel in the debris areas is low (see Appendix A), the Panel assessed if the probability of a vessel strike occurring after successive weekly launches would be sufficient for vessels to avoid the debris areas and fish elsewhere. A reduction in fishing activity in an area will, over time, allow the populations of target and by catch species to rebuild. For up to 100 consecutive weekly launches, the Panel assessed that the effects of fishing displacement on the rebuilding of populations impacted by fishing would be negligible. For the benthic invertebrate community, and sensitive benthic environments (as defined in the Exclusive Economic Zone and Continental Shelf (Environmental Effects – Permitted Activities) Regulations 2013) in the Sun-synchronous debris area, the Panel assessed that because of displaced fishing activities there may be a moderate rebuilding of seafloor invertebrate communities after 1 000 and 10 000 consecutive weekly launches. For the demersal fish and mobile invertebrate community and marine mammals and seabirds, the Panel assessed that only minor rebuilding of populations may occur due to the displacement of fishing from the debris areas because these populations could also be impacted in the areas to which fishing is displaced.

In the Eastern launch debris area there is much less fishing activity and rebuilding of seafloor invertebrate communities, sensitive benthic environments, demersal fish and mobile invertebrates, marine mammals and seabirds as a consequence of fishing being displaced elsewhere was assessed as negligible, with, at most, minor rebuilding of the seafloor invertebrate community and sensitive benthic environments on the Louisville Ridge after 1 000 or more launches.

For seafloor biota requiring hard substrates the debris would provide further attachment sites. However, even after 10 000 launches this would provide only about 50 ha of additional attachment surface, leading to, at most, moderate consequences for this fauna in both the Sun-synchronous and Eastern debris area. For seafloor invertebrates inhabiting soft sediments, the loss of about 50 ha of habitat (<<0.1% of available sediments) would be negligible. Smothering of the feeding or respiratory structures of sea floor organisms by debris was assessed as a low risk for all levels of launches up to 1 000 launches and a moderate risk by 10 000 launches in both the Sun-synchronous and Eastern debris area ecosystems. This is likely to be a factor principally in areas of hard substrate where the debris is unlikely to become buried in sediment so will be important principally on the Campbell Plateau and the Louisville Ridge.

In both the Sun-synchronous and Eastern debris areas, direct strikes causing mortality are a low risk for all components of the ecosystem up to 1 000 launches over an almost 20 year period. Direct strikes reach moderate levels of risk for the benthic invertebrate community, sensitive benthic environments, and the Magenta petrel population after 10 000 launches over a period of almost 200 years.

Noise and disturbance to marine fauna above and below water is a potential consequence of the fall of debris from rocket launches. Repeated disturbance can cause reduced feeding rates in marine mammals and trigger animals to leave the impacted area. The chance of repeated disturbance to the same individuals or groups of marine mammals or seabirds increases with the number of launches. In both the Sun-synchronous and Eastern debris areas this was assessed as a low risk for up to 100 launches over two years, a moderate risk for up to 1 000 launches over almost 20 years, and a high risk for up to 10 000 launches over almost 200 years. It should be noted that after 10 000 launches the risks to marine mammals and seabirds associated with this factor were higher than the risks associated with rebuilding of populations due to the displacement of fishing effort.

There are often ways of avoiding, remedying or mitigating the effects of activities that would otherwise put marine species or ecosystems at risk. The options for these strategies seem limited in this instance. A slightly more eastward launch trajectory would ensure the debris did not fall into the Bounty Islands Marine Reserve during the test launches. Ensuring a complete burnup of debris in the atmosphere or a controlled landing of Stage 1 on mainland New Zealand would minimise the risk.

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Appendix A Calculation of the likelihood of a direct hit causing mortality

Purpose

An important consequence identified during the ERA was for a piece of falling debris to hit and kill an endangered seabird, such as the Magenta petrel / Chatham Island taiko, (*Pterodroma magentae*). This species has an estimated population size of 80 -100 mature adults, and forages in the region where debris is predicted to fall. Here the chance that debris from the launch of Electron will hit a seabird after different numbers of launches is estimated. The potential for a piece of falling debris to strike a vessel is also estimated because this might help to estimate the likelihood that the launches will reduce fishing effort in the area where debris falls.

Method

Debris from the rocket has mass M kg per launch which falls into an ellipse-shaped area D km^2. With the aim to calculate the *maximum chance* that a target is hit by a piece of falling debris, the maximum chance occurs if:

The target spends the maximum amount of time in the debris impact area (ellipse). Assuming that the seabird foraging distribution is approximately circular and centred on the Bounty Islands, the maximum overlap occurs if the outer limit of this area just touches the far side of the debris ellipse (Figure A-1). This assumption leads to an overlap of about 19% (Table A-1; i.e. a seabird would spend about 19% of its time in the zone that debris is likely to impact).

The debris is assumed to break up during descent into the largest number of pieces each of which is just big enough to kill a seabird when falling at terminal velocity, and none burns up while falling. The more separate pieces of lethal-sized debris there are, the higher the chance that one will strike a target. If the pieces are smaller than the minimum size for lethal effect, a strike will be less important. If the pieces are larger than this minimum lethal size, there will be fewer of them and so less chance of a strike occurring. Given that some debris will burn up before it hits the water, and some will be larger or smaller than this minimum lethal size, this analysis will likely overestimate the risk of a lethal impact with a seabird.

In the “target overall region” assume there are n targets each of cross-sectional area size B km^2 (birds or vessels for example). The expected fraction of targets in the overlap area with the potential landing zone of the space debris at the time when the debris arrives is α. If the targets are evenly distributed through F then:

$$\alpha = \frac{A}{F}$$

If the targets are not evenly distributed in time/space, then α is the time-weighted spatial overlap fraction of the target distribution and the debris potential envelope.

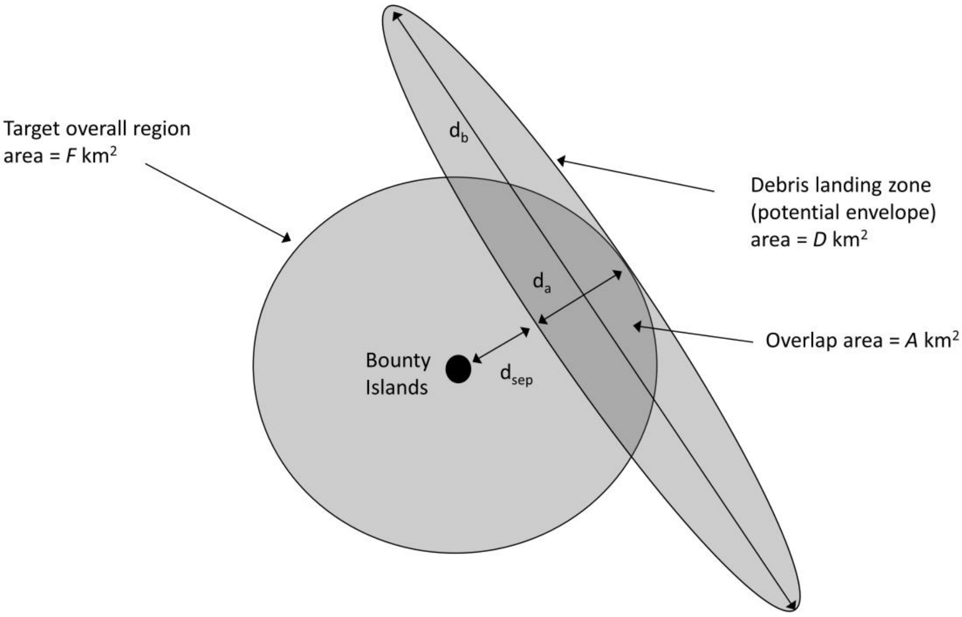

Figure A-1: Conceptual sketch of overlap between debris area and seabird foraging or commercial fishing area.

The probability that any one piece of debris (mass m kg) from one launch will hit any of the n targets is given by:

$$P(1\, piece\ debris\ hits\ a\ target) = n\alpha \frac{B}{D}$$

Imagine the debris consisting of N pieces each of size m kg, where N=M/m. Let m kg be the smallest piece of debris of interest because this is the smallest mass of material that will cause a significant event: kill a seabird or cause damage to a vessel, for example. Further assume that this falling piece of debris is spherical in shape. This assumption of spherical shape leads to an estimate of the highest chance that a piece of debris will hit a target. If the debris is in other shapes such as flat sheets, it will fall more slowly so a higher mass will be needed for significant effect and this reduces the chance of a significant target strike. Hence, the assumption that the pieces of debris are spherical is a conservative (i.e., it overestimates the risk).

There are N chances that debris will significantly hit a target. Each of these chances is very small, so the overall probability of at least one significant hit is approximately:

$$P(at\ least\ one\ target\ hit) = n\alpha \frac{B}{D} N = \frac{n\alpha BM}{Dm}$$

Intuitively, this means there is more chance of a target being hit if: there are more targets, each target is bigger, the targets spend more time in the debris landing area, there is more total mass of debris, the debris falls in a smaller area (without a change in α), or if the lethal mass of a piece of debris is small.

For debris of two different types, the total probability of a target being hit is simply the sum of the probabilities of being hit by material of each separate type because each individual probability is small. In this analysis, two types of debris are assumed: steel-like (all metal debris) and fibreglass-like (all non-metal debris).

Results are calculated based on one target (n=1), for just material from the fairing (which falls closest to the Bounty Islands) and for all debris (Stage 1, fairing and battery A) which equates to "worst-case".

The probability of at least one strike after X launches is given by:

$$P(at\ least\ one\ strike\ after\ X) = 1 - (1 - P)^X$$

Where "P" = Probability of at least one strike after 1 launch.
Parameters given in Table A-1.

Table A-1: Parameters used in estimation of likelihood of a direct hit causing mortality. In this case near the Bounty Islands during a test launch.

Parameter	Method	Value
D	Debris fallout zone approximated by ellipse: d_a=8.8 km (2sd ellipse for fairing) d_b=151 km (2sd ellipse for fairing)	D=1040 km^2
α	Maximum overlap occurs if the targets occupy an area (assumed circular centred on Bounty Islands) that just touches the far side of the debris ellipse (Figure A-1). d_{sep}=14 km leads to estimate of overlap area ~ 317 km^2	α=0.19
m	Some web resources[1] suggest that bullets must fall at more than about 100 m/s to be lethal to people, which, for steel, equates to about a mass of about 15 g. Spherical objects may fall slower for the same mass (greater drag coefficient). We assume a terminal velocity of 75 m/s is needed to be lethal to birds. For this, a spherical mass of ~33 g of steel is needed (steel density of 7850 kg/m^3) which equates to ~10 mm radius. For a spherical ball of fibreglass (typical density 1500 kg/m^3), an object of radius 50 mm (weight 800 g) is needed to achieve 75 m/s terminal fall velocity. These estimates assume a drag coefficient for a spherical body of ~0.3 and air density of 1.23 kg/m^3.	m = 33 g (steel) m = 800 g (fibreglass)
B	Target area of 0.25 m^2 assumed for bird, and 500 – 1000 m^2 for vessel of length 50-70 m, and beam 10-14 m (like a medium-sized fishing vessel to Tangaroa size (70 m).	B = 0.25 m^2 (bird) B = 500 -1000 m^2 (vessel)
M	Total mass of debris released on each launch from Stage 1, the nose fairings and the two Stage 2 batteries (from Rocket Lab information) is: **Fairing only** — **All debris** **Metal** 8.7 kg — 380 kg **Non-metal** 86 kg — 657 kg All metal assumed similar to steel. All non-metal assumed similar to "fibre-glass" composite.	M between 8.7 kg and 1037 kg

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[1] http://www.slate.com/articles/news_and_politics/explainer/2011/03/watch_out_for_falling_bullets.html

Results

These estimates suggest that the debris (Stage 1, fairing, battery A), when broken into lethal-sized, spherical pieces, will cover an area of 9.9 m^2. The "metal" will cover 3.6 m^2 and the "non-metal" 6.3 m^2. These areas are about a fifth of the area estimated by Rocket Lab (2016) (~50 m^2) which suggests their estimate includes some flat sheets or smaller pieces, both of which are likely to reduce the chances of significant effects on seabirds or vessels.

Results given below are for the Fairing debris (Table A-2) because only this debris is predicted to fall near the Bounty Islands.

For comparison, the odds of winning Lotto jackpot is estimated to be 1 in 3,800,000.

Table A-2: Odds (1/probability) of at least one target being hit by fairing only material.

	1/P(at least one strike)		
Number of launches	**Bird**	**Small vessel**	**Large vessel**
1	7,267,725	28,895	14,743
10	726,773	2890	1475
100	72,678	289	148
1000	7268	29	15
10,000	727	3	2

Conclusions

The chance that falling debris hits a single target (seabird or vessel) depends on the following main factors:

- The proportion of time the target spends in the area where the debris hits the sea surface. (Spending more time in the debris impact area leads to a greater chance of being hit.)
- How big the target is. (Larger targets like vessels are more likely to be hit than smaller ones like seabirds.)
- The extent parts of the debris burn up while falling. No burn-up is assumed in this analysis.
- The sizes and shapes of the debris. The analysis assumes that all debris is spherical and just large enough to kill a seabird. This is the worst-case assumption.

Taking the worst-case assumptions for all of these, we estimate that there is a remote chance of a single bird being killed by falling debris. Even after 10,000 launches, the chance of killing a seabird is less than 1 in 700.

The chance of a small (50 m) vessel which spends 19% of its time in the debris (fairing) ellipse being hit by a piece of debris of the same size that would kill a seabird is about 1 in 300 after 100 launches. Note that debris of this size would probably not damage a vessel but may injure an exposed crew member. However, this risk may be sufficient to mean that fishing vessels will avoid the area that is potentially subject to falls of debris after a launch, at least for a period following a launch.

The analysis developed above assumes that the debris falls in an ellipse close to the Bounty Islands and that the seabird foraging is centred on the Bounty Islands. This gives a maximum overlap between the seabird distribution and debris distribution of about 19%. In reality, the foraging range of seabirds will be larger than this and possibly not centred on the Bounty Islands. Also, the areas into which the debris falls are likely to be much larger than estimated here, and may not be close to the Bounty Islands at all. This means that the risk of an endangered seabird being hit by debris is likely to be much less than predicted here *unless* the debris falls into areas where endangered seabirds congregate (such as nesting areas). Avoiding debris falling into any known areas where seabirds are congregated is recommended to reduce the risk of seabird mortality. If distributions of endangered seabirds can be estimated, the approach developed above can be used to estimate the chance of seabird mortality due to debris as required.

Similar comments apply to the chance of debris striking a vessel. Minimizing the spatial overlap between areas where vessels are commonly found (e.g. fishing areas, shipping routes) and areas into which debris is likely to fall is recommended to minimise the chance that debris will strike a vessel. If the spatial overlap is known, the analysis approach developed above can be used to estimate the chance of vessels being hit by debris.

Appendix B Electron toxics assessment

Rocket Lab provided information on the makeup of the launch vehicle (Rocket Lab 2016). This information was used to assess the potential toxicity of each of the components comprising Stage 1, the nose fairings and the two Stage 2 batteries (Table B-1). It was assumed that break-up during descent through the atmosphere did not result in combustion of the components during descent. The conclusions from this assessment were:

1. The risk from potential kerosene toxicity is very low. This is because the Stage 1 fuel will be effectively exhausted by the time it is jettisoned. Any small amounts reaching the ocean will be lost by evaporation from the surface.
2. Metal fragments will likely be partially buried in the soft bottom seabed areas but remain on the surface of the seabed in hard-bottom areas (probably a small proportion of the Stage 1 debris impact area).
3. The metal mass components of the engines are constructed of Inconel, which is highly resistant to corrosion and release of any toxic components.
4. The metallic copper is the only metallic component representing a potential toxic issue. The level of potential impact will be related to number and dispersion of small metallic copper fragments. The slowly dissolving copper will add to the natural low background concentrations and disperse from local area. Such effects would be only of potential concern in hard rock bed areas with sensitive faunal assemblages where there is little chance of the copper fragments being buried in sediment. Because of the persistence of metallic copper in these areas there will be a cumulative and increasing impact with multiple launches.
5. The major metallic mass in the batteries is lithium. Should they reach the ocean surface then the batteries are likely to implode with depth and release the reactive lithium. The lithium present will react with seawater with release of hydrogen. Battery lithium will not be toxic and will add insignificantly to natural background seawater. There is insufficient information available on the battery casings to provide a high surety of their fate in deep ocean.

Table B-1: **Assessment of potentially toxic debris components.** Details on the parameter, form and quantity were taken from Rocket Lab (2016).

Parameter	Form	Quantity (kg)			Fate in seawater	Comment
		Fairing	Stage 1	Stage 2		
Kerosene	Liquid		2785 kg		Float on surface; Volatile so lost by evaporation. Relatively low toxicity of soluble fraction.	Potential greater issue if rocket aborts near launch site. Assumed that fuel will be effectively all exhausted and lost before ocean landing. *No issue anticipated.*
Aluminium	Solid	3.5	117.6		Sink to seabed. Nature of alloy will affect corrosion/dissolution rate. Aluminium toxicity not considered a high risk.	*No issue.*
Brass	Solid		1.2		Sink to sediments.	Very small quantity. *No issue.*
Copper	Solid		10.3		Sink to sediments. Slow dissolution of copper will occur with long-term affects to sediment-dwelling species in vicinity of the fragments.	Level of potential impact will be related to number and dispersion of small metallic copper fragments. Such effects would be only of potential concern in hard rock bed areas with sensitive faunal assemblages. *Potential issue.* Dissolved copper will add to the natural low background concentrations and disperse from local area. Very low total mass of copper being added relative to natural oceanic copper concentrations.
Inconel	Solid		172.9		Sink to sediments. Material is highly resistant to corrosion. No expectation of release of toxic metals which are bioavailable.	*No issue.*
Steel	Solid	5.2	68.5		Sink to sediments. Rapid corrosion likely to occur. Released iron will not be toxic to sediment-dwelling species.	*No issue.*
Batteries (Lithium)	Solid		227.2	17.5	Sink to sediments. If batteries reach the ocean they are likely to rupture at depth. The lithium present will react with seawater with release of hydrogen. Battery lithium will not be toxic and will add insignificantly to natural background levels in seawater.	Lithium is naturally elevated in seawater. *No issue.*

Parameter	Form	Quantity (kg)			Fate in seawater	Comment
		Fairing	Stage 1	Stage 2		
Adhesives	Solid	30.3	2.8		Slow sinking to seabed of carbon fibre composite. Expected to be very long-lived and resistant to degradation process. Burial will ultimately occur in soft-bottomed areas.	Carbon fibres are not expected to be released from fairing debris pieces. Therefore no potential for ecosystem effects other than physical debris impact and habitat alteration. *No issue.*
Carbon fibre	Solid		37.1		Slow sinking to seabed of carbon fibre composite. Expected to be very long-lived and resistant to degradation process. Burial will ultimately occur in soft-bottomed areas.	Carbon fibres are not expected to be released from fairing debris pieces. Therefore no potential for ecosystem effects other than physical debris impact and habitat alteration. *No issue.*