



Environmental Impact Assessment

MCFS (Microalgae Carbon Fixation and Sinking) - Aotearoa New Zealand Exclusive Economic Zone

Prepared for
GIGABLUE AOTEAROA SOUTH PACIFIC LIMITED

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Executive summary

Gigablue is proposing to undertake marine scientific research as a Permitted Activity (PA) within New Zealand's Exclusive Economic Zone (EEZ). The proposed PA (GIGPA04) is a biogeochemical and physical trial which will test the behaviour of an organic particle designed to sequester carbon by allowing the contained growth of oceanic phytoplankton within the particle, followed by an active sinking mechanism. The sequestration method, known as Microalgae Carbon Fixation and Sinking (MCFS), aims to mimic the ocean's natural biological pump — a natural process that transfers carbon from surface waters to the deep sea — in a controlled manner. This trial is part of a wider research plan designed to improve understanding of key oceanographic parameters, including ocean currents, particle dynamics, marine fauna behaviour, and air-sea gas exchange processes. Further details of monitoring to be undertaken are provided in a "Detailed monitoring plan - GIGPA04".

Tonkin & Taylor Ltd has been engaged to prepare an Environmental Impact Assessment (IA)¹ to assist with preparation of Form 1 information to be provided to the Environmental Protection Authority (EPA) in fulfilment of the requirements for a PA. This IA evaluates the potential environmental effects of the trial method and outlines strategies to avoid or mitigate potential impacts.

The GIGPA04 method involves up to five particle release events, with each release containing up to 200 tonnes of particles. This results in a maximum total release of up to 1,000 tonnes. The particles are cellulose-based and contain trace micronutrient oxides (less than 0.1% of the particle mass). The deployed particles will float for approximately 18 days before sinking rapidly (~1.5 cm/s) to the seafloor (i.e. able to descend ~1,300 m within 24 hours). The modelling undertaken by Gigablue to inform this IA takes a conservative approach which assumes that all 1,000 tonnes are deployed in a single event over 24 hours. Particles are modelled to settle at a median concentration of 0.39 g/m², within a broadly oval seabed footprint of 31 x 31 km to 37 x 37 km (976 km² to 1,371 km²) equivalent (25th – 75th percentile). The trial will be conducted over a period of up to 35 days, including 2 – 4 days vessel transit, 12 – 24 days experimental work, and 3 – 7 'reserve' days to account for minor technical or weather issues. The experimental work will include monitoring of ocean currents and particle movement within them, water chemistry, marine biology, and potential ecological interactions. The wider area of interest (AOI) for the trial encompasses a portion of the Bounty Trough containing the required settlement water depth (> 1,000 m), which also avoids specific locations known to have high biodiversity values and sensitive or threatened species such as the Antipodes and Bounty Islands. The AOI is characterised by deep waters, soft sediments, and some areas of diverse marine life.

The distributions of biogenic habitats, seabirds, marine mammals, and other marine fauna was assessed for the AOI based on mapped observations, predictive models, and habitat preference information from various sources. A diverse assemblage of fish, birds, and mammals were found to utilise areas of the AOI, though few species hotspots were identified. Of the reviewed biogenic habitat, corals, xenophyophores, sponges, and sea pens have a low to moderate probability of occurrence across a relatively small proportion of the AOI. A literature review was then undertaken to identify potential adverse environmental effects which could occur from the trial, with further supporting evidence provided by Gigablue from various experiments and modelling undertaken. The identified effects and species distribution data was then used in combination with predictive modelling of particle dispersion and settlement to provide potential release zones and release methods that seek to avoid and minimise adverse environmental effects, particularly for more sensitive species and ecological areas.

¹ As requested by the EPA, this IA has been prepared using section 39(1) of the EEZ and Continental Shelf (Environmental Effects) Act 2012 as a guide. In particular, subsections (a), (b), (d), (e), (f), (i) and (j) have been referred to.

A key operational measure proposed to minimise potential adverse ecological effects is limiting release volumes to the minimum required for the purposes of the research (i.e. up to 5 x 200 tonne releases). Additionally, monitoring for fauna presence will be carried out prior to, and during, the trial, and particles will be deployed across a transect to reduce concentrations at the surface and seabed. The trial design ensures that particle concentrations are highest only at the immediate release site ($\sim 84 \text{ g/m}^2$) and rapidly disperse, reducing any exposure risks.

An assessment of the residual environmental effects on the biological diversity and integrity of marine species, ecosystems, and processes with the proposed management measures in place was then undertaken. All associated research and experiments provided by Gigablue assessed effects of particle concentrations at least as high as the 'worst-case-scenario' particle deployment outlined in this report.

Water and sediment quality and toxicity effects: Acidification and deoxygenation risks from microbial decomposition of sinking and settled particles are expected to be low, or potentially locally beneficial in the case of acidification. Experiments specifically using AOI seawater showed negligible pH change after 24 hours, and the enhanced benthic microbial activity from the predicted increase in benthic organic matter (< 5%) is expected to have negligible effects on sediment oxygen levels. Modelling also predicted a short-term and localised surface water pH increase due to a temporary reduction in dissolved inorganic carbon, which would temporarily improve ocean habitability (i.e. reversing local acidification). Particle toxicity tests of an earlier particle design of a similar material composition (9(2)(b)(i), 9(2)(b)(ii)) showed no adverse effects on algae or mussels. Additionally, ICP-MS analysis of the cellulose substrate showed that concentrations of metal and metalloid contaminants were well below marine water quality guidelines for both 1-hour and 24-hour post deployment scenarios, indicating a low risk of toxicological effects on marine fauna. Incubation experiments utilising eDNA found no promotion of harmful algal species. Turbidity effects are expected to be minimal due to the rapid settlement and large particle size, with experiments showing a negligible increase in turbidity after 24 hours.

In addition to these more general effects on water quality and marine fauna, fauna-specific potential residual effects were assessed for key groups as follows:

- **Phytoplankton and zooplankton:** Phytoplankton are expected to be positively affected through growth within the particles, with modelling showing minimal macronutrient depletion (< 1.8%), and negligible impact on regional productivity. Ingestion by zooplankton is unlikely due to particle size, and bioaccumulation risks are low given their short lifecycles and their primary food-web positions.
- **Benthic invertebrates and biogenic habitat:** Organic matter deposition is predicted to stimulate benthic communities without causing oxygen depletion. The particles' porous structure and biodegradability reduce the risk of smothering or abrasion to sessile organisms. Particles are likely too large to ingest for most species and cellulose is likely digestible by the species most likely to ingest the particles. Known and predicted concentrations of sensitive biogenic habitats will be largely avoided through site selection and operational controls.
- **Fish** may ingest particles, particularly those coated in phytoplankton, but the risk of adverse health effects is considered low as cellulose may be readily digested or excreted and can benefit gut health in fish. Bioaccumulation is unlikely, and if it occurs, it may be beneficial due to potential baseline micro-nutrient deficiencies in fish. Avoidance behaviour and reduced feeding success of visual predators may occur temporarily immediately following particle release.
- **Marine mammals** may encounter particles during feeding, but ingestion is expected to be incidental and non-harmful due to the particles' biodegradability, dispersion, and small relative size. Bioaccumulation of metals is unlikely to occur as the concentration of metals is

not expected to exceed the associated regulatory mechanisms (e.g. metabolism, excretion). Acoustic interference is considered negligible, and the trial area avoids known marine mammal hotspots. However, hydrophone monitoring could be implemented to ensure no animals are present prior to deployment.

- **Seabirds** are the most likely group to interact with floating particles, particularly surface feeders such as petrels and shearwaters. As the particles are unlikely to be broken down via digestion, whilst unlikely, adverse health effects are possible where large quantities of particles are ingested. Seabirds are, however, capable of excreting and/or regurgitating indigestible bone and shell fragments which would likely pose a greater challenge. Seabirds have also exhibited avoidance behaviour in previous trials, and the proposed trial release area avoids hotspots for the most vulnerable species wherever possible. Visibility reduction may temporarily affect foraging efficiency, but effects are expected to be localised and limited to the first few hours or days of floating.

A limitation of this IA is the lack of specific information around the behavioural and physiological responses of marine organisms to the particles, particularly with respect to the likelihood and effects of ingestion. Monitoring of interactions between marine organisms and the particles will therefore be undertaken as part of this trial to increase knowledge and inform future activities.

Robust modelling undertaken by Gigablue draws on over 622,000 model runs of particle releases from 2,869 locations within the recommended release area coupled with 10 years of current data that encompass El Niño/La Niña cycles, seasonal and interannual variability, and long-term trends. With detailed November–January data, the analysis provides high confidence in predicting future deployment scenarios. While all models inherently carry some uncertainty, the scale and depth of this dataset significantly reduce statistical uncertainty, making the available information well-suited for assessing potential impacts on the marine environment.

The release location and methodology have been informed by the environmental setting and the potential environmental effects of the particle in order to avoid and mitigate potential adverse effects. Additionally, the experiments and models which have informed this assessment were generally based on worst-case release scenarios for 1,000 to 10,000 tonne deployments, with settlement densities and concentrations utilising the maximum volume of particles. As such, this IA represents a very conservative assessment of potential effects with respect to what is actually expected for the trial.

The combination of careful site selection, predictive modelling, conservative effects assessment and operational safeguards should therefore ensure that the trial proceeds with minimal ecological disturbance. As such, this IA concludes that the residual adverse environmental effects from the trial are expected to be low to negligible.

1 Introduction

Gigablue is proposing to undertake a marine scientific research trial to monitor the dispersion and sinking of an organic particle within New Zealand's east coast Exclusive Economic Zone (EEZ). Tonkin & Taylor Ltd (T+T) has been engaged by Gigablue to prepare an Impact Assessment (IA) using the environmental requirements of section 39(1) of the EEZ and Continental Shelf (Environmental Effects) Act 2012 as a guide to assess the potential impact of the trial on marine ecosystems. This research is part of Gigablue's wider plans to study the off-shore marine environment, including physical and biogeochemical properties and dynamics, and to develop a safe and controlled method for restoring the ocean's health by removing excess carbon from the surface waters. The specific method has been reviewed by ESNZ and Puro.Earth's scientific advisory board, and was approved as a safe, durable and reliable method for carbon sequestration. This IA has been undertaken in accordance with our proposal of 3 June 2025.

1.1 Background

Oceans are the greatest of earth's carbon sinks, containing 50 times as much carbon as the atmosphere and functioning as a biotic and abiotic thermostat (Levin et al., 2023). They are also estimated to remove approximately one quarter of human carbon dioxide (CO₂) emissions from fossil fuel consumption and deforestation (NASEM, 2022). As such, our oceans play an important role in slowing the atmospheric growth of CO₂ and associated climate change effects. A key process by which long-term oceanic carbon sequestration occurs is through the biological pump which transfers surface carbon towards the seabed via food web processes.

Gigablue is a fully integrated carbon capture and sequestration company which has developed a particle product designed to sequester carbon in the deep ocean. The particle promotes the contained growth of oceanic phytoplankton within its material before sinking to the ocean floor via an active sinking mechanism. The current stage of product development is open ocean trials. A record of previous trials undertaken by Gigablue is provided below.

GIGPA01

A trial of the ability to acoustically detect sinking plumes of wet exfoliated vermiculite were carried out from 18 to 24 May 2024 in an area 37 km to the southeast of Kaikoura Peninsula. Five releases of 3–5 m³ of wet vermiculite were undertaken from a 31 m long catamaran (Seaworker). The resulting plume was observed using an echosounder system operating at 38 and 120 kHz, and an aerial video drone. The plumes were detected to a maximum depth of 200 m with the 38 kHz echosounder, before dispersing to below the detection threshold of ~0.2 particles per cubic metre. This trial led to the conclusion that ship-mounted echosounders will be unlikely to detect vermiculite plumes down to 1000 m depth.

GIGPA02

A second ocean trial was carried out from 17 to 26 October 2024 in a deepwater (approx. 1,500 m) area some 640 km south of Wellington for the purpose of assessing particle tracking methodologies and environmental impacts. The trial involved the deployment of vermiculite particles with trace iron and manganese oxides and was undertaken during a voyage using NIWA's RV Kaharoa II. Testing methods included the operation of an echosounder, current profiling, multibeam systems, deployment of a profiling CTD (conductivity, temperature, depth) with associated sensors and water sampling bottles, tracking of drifting buoys, measurement of surface water properties', and detection of sinking particles with an ROV (Remotely Operated Vehicle). This included the testing of booms/pens for the containment of particles over 6 days.

GIGPA04

GIGPA04², the subject of this IA, is planned to be undertaken using a larger volume of cellulose particles in an EEZ area similar to the GIGPA02 location (Figure 1.1). The aim of the trial is to expand on previous trial deployments to improve understanding of key oceanographic parameters in the mixed layer and deep-sea areas with the characteristics of interest (e.g. water depths, expected current speed, nutrients, temperature) and the particle's interaction with them.

As the trial proposes to release particles in the EEZ, Gigablue is required to comply with the requirements of the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012 (EEZ Act). This IA has been prepared to assess the potential effects of the GIGPA04 method on the environment to assist with the preparation of Form 1 in fulfilment of the requirements for a Permitted Activity (PA).

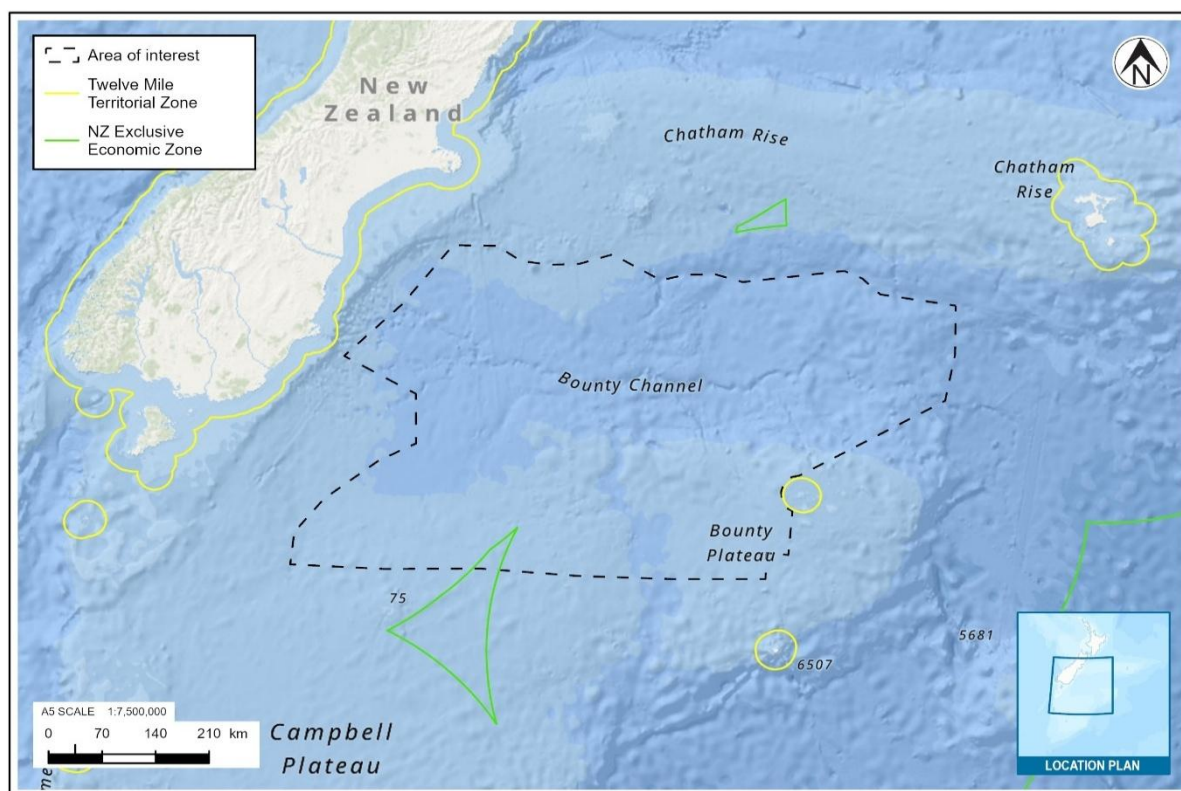


Figure 1.1: Area of interest for GIGPA04 and key oceanographic features.

² GIGPA03 was planned but not undertaken.

1.2 Scope

The EPA has indicated that it would be useful for an IA to be prepared in relation to the proposed GIGPA04 trial and has suggested that the IA should be a 'light' version prepared using section 39(1) of the EEZ Act as a guide, and that the focus should be on addressing matters in section 39(1) of the EEZ Act specifically relating to the assessment of effects on the environment. This IA contains such detail corresponding to the scale and significance of the effects (as required by section 39(3)(a)) in order to enable the EPA to understand the nature of the activity and its effects on the environment (in accordance with section 39(3)(b)). As such, this IA addresses the following matters, as described in section 39(1):

- a) Describe the proposed activity.
- b) Describe the current state of the proposed trial area and the surrounding environment.
- d) Identify the effects of the activity on the environment.
- e) Identify the effects of the activity on the biological diversity and integrity of marine species, ecosystems, and processes.
- f) Identify the effects of the activity on rare and vulnerable ecosystems and habitats of threatened species.
- i) Specify any possible alternative locations for, or methods for undertaking, the activity that may avoid, remedy, or mitigate any adverse effects.
- j) Specify the measures that could be taken to avoid, remedy, or mitigate the adverse effects identified (including measures that the applicant intends to take).

To address the matters detailed above, a literature review has been undertaken based on information provided by Gigablue, and from independent scientific literature. The aim of this review was to:

- Identify the current state of the wider potential trial area and the surrounding environment which may be affected by the trial, including any known sensitive environments.
- Describe any likely effects of the activity on the environment, including both direct and indirect effects.
- Identify trial areas where potential adverse ecological effects are likely to be minimised.

2 Reviewed information

2.1 Review process

A semi-systematic literature review was undertaken to describe the existing environment within the broader area of interest (AOI) for GIGPA04, and to identify the potential effects of the trial on the environment. The review was geographically focused on this AOI which extends between the Bounty Trough and the northern edge of the Campbell Plateau (Figure 1.1). The AOI is bounded by the Pukaki Rise and Bounty Islands to the south, the Antipodes Islands to the east, and the Chatham Rise to the north. The results from experimental studies and modelling undertaken and commissioned by Gigablue were also reviewed for this IA.

The review process focused on identifying and assessing the following information in the specified order to appropriately narrow the scope of the review:

- 1 Particle composition and behaviour during the activity.
- 2 Physical and biological environmental information for the AOI.
- 3 Potential effects on marine fauna, including benthic ecology, seabirds, marine mammals, fish and plankton.
- 4 Gigablue particle trajectory modelling.

Relevant independent literature and databases were identified primarily through web searches using Google, Google Scholar, and ScienceDirect. These search engines were selected to provide exposure to both traditional academic literature (e.g. journal articles) and alternative published literature and databases (e.g. government or research institute reports). The search methodology followed the order of the four focus areas listed above and involved trialling various combinations of associated keywords. Some examples of these search combinations include:

Toxicity of [cellulose with trace amounts of iron oxides bound within the particle], New Zealand marine fauna [fish, biogenic habitats, seabirds, marine mammals, coral], New Zealand currents, New Zealand biogenic habitats, Bounty Trough, Campbell Plateau, Great South Basin, marine carbon dioxide removal (mCDR), ocean acidification, bioaccumulation.

Literature and databases were reviewed and filed in a spreadsheet with a summary of key information, a topic label, and an author reference. Approximately 40 hours was spent reviewing and filing information obtained from the literature review.

2.2 Limitations

Due to the large spatial extent of the AOI within the marine environment, aspects of the environmental setting assessment have been generalised across the AOI to a scale appropriate for this IA. The marine species identified in this assessment are also not an exhaustive list of species which may be present within the AOI, but are based on a mixture of the best available modelled and observed distributions.

Robust modelling undertaken by Gigablue draws on over 622,000 model runs of particle releases from 2,869 locations within the recommended release area coupled with 10 years of current data that encompass El Niño/La Niña cycles, seasonal and interannual variability, and long-term trends. With detailed November–January data (8 dates per month), the analysis provides high confidence in predicting future deployment scenarios. While all models inherently carry some uncertainty, the scale and depth of this dataset significantly reduce statistical uncertainty, making the available information well-suited for assessing potential impacts on the marine environment.

Given the novel composition and dimensions of the particles in the context of the marine environment, limited comparable research has been undertaken regarding the potential behavioural and physiological responses of marine fauna.

Despite these limitations, the available information is still considered to provide an adequate level of detail for characterising the marine environment and quantifying the potential adverse effects from the trial. This is because the assessment has been undertaken based on multiple layers of conservatism regarding the expected environmental conditions, the distribution of particles during the trial, and the potential adverse environmental effects which could occur. The recommended release area has been refined to avoid sensitive areas (known and predicted) and areas where information is more limited. Further refinement was also undertaken based on particle trajectory modelling utilising detailed historical environmental data. This refinement process is detailed further in Section 5.2.

3 Activity description

GIGPA04 involves up to five releases of up to 200 tonnes each of particles (8 mm in diameter) to a maximum total of 1,000 tonnes. Particles will be released from a boat departing from Dunedin over the course of a single voyage between November 2025 and January 2026. Released particles are expected to float on the sea surface for a period of 18 days (up to 21 days) before sinking to the seabed. During the floating and sinking phases the particles will be tracked and a variety of scientific observations made relating to the ocean currents, water chemistry and other parameters as described in more detail in Section 4.1. The total period of the experiment is expected to be up to 35 days, including allowing for vessel transit and reserve days to account for technical or weather constraints. Sections 3.1 to 3.4 detail the known and modelled experimental parameters and methodologies to be employed during the GIGPA04 trial.

3.1 Particle composition

The GIGPA04 particle is composed of cellulose-and contains trace amounts of iron oxides ($\text{Fe}_2\text{O}_3 \cdot 0.5\text{H}_2\text{O}$, FeHO_2 , Fe_2O_3 , Fe_3O_4) bound within. Key physical and chemical properties of the particle are presented in Table 3.1 and Table 3.2.

Table 3.1: Physical properties of the particle

Physical property	Description (25 th – 75 th percentiles)
Colour	Brownish-yellowish white
Width (x) / Length (y)	8 mm (5 – 12 mm), 12 mm $\pm$ 5% when wet
Thickness (z)	4 mm (2 – 6 mm), 5 mm $\pm$ 20% when wet
Weight (per unit)	15 mg (5 – 30 mg), 30 – 180 mg with organic matter*

* Organic matter weight range is based on a theoretical maximum increase of six times the particle weight which has not been reached in real-world trials.

Table 3.2: Chemical properties of the particle

Component	Amount (w/w%)	Amount (mg/kg) ($\pm$ 2.5%)
Dry component		
Cellulose	99.9	879,000 - 959,720
Iron oxides (as Fe)	< 0.1	280 to 1000
Wet component		
Water	4 – 12	40,000 to 120,000

3.2 Particle quantity

The particle volumes used in the previous trials were found not to be sufficient to allow for effective physical tracking into the deep ocean, or a detectable change of biogeochemical properties. Modelling and analysis undertaken by ESNZ (NIWA) showed that for detection of particles at depth using acoustic methods, a particle concentration of at least 10 particles per m^3 would be required. Achieving this detectable concentration threshold requires a larger quantity of particles by a factor of 4 – 50 compared to the 45 m^3 of particles released for GIGPA02. Accordingly, GIGPA04 is proposing to deploy up to 1,000 metric tonnes of particles in total, made up of a maximum of five deployments of up to 200 tonnes per deployment.

It is proposed that the trial and associated monitoring will be undertaken during a single voyage (which may comprise more than one vessel to support both deployment and monitoring on different vessels). Allowance is made for a second voyage to complete the trials if factors such as weather conditions or equipment failure interrupt the work. In the event that a second voyage is required, the maximum combined mass of particles deployed across both voyages will not exceed the limit of 1,000 tonnes.

3.3 Particle movement

Research undertaken by Gigablue indicates that following their release, particles will float at the surface for a period of approximately 18 days (up to 21 days) before sinking. Modelling predicts the particles may travel approximately 130 km, and up to a maximum of 360 km horizontally between the release location and the sinking location depending on sea conditions and currents. During this floating stage, microalgae growth is expected to occur within the gaps of the particle.

Following the initial floating phase, saturated particles are expected to sink at approximately 1.5 cm/s, meaning a depth of ~1,300 m could be reached within ~24 hours. The additional algae growth and the added water within the interstitial spaces of the particles is expected to increase the dry weight of each particle (15 mg) by up to six times.

3.4 Particle settlement

Modelling has been undertaken by Gigablue to estimate the particle footprint density under various release scenarios. Key variables influencing the characteristics of the footprint include the distance over which the particles are released, the time over which the particles are released, and the environmental conditions at the time of release. Increasing the area and time over which the particles are released increases the size of the footprint but reduces the overall settlement density.

Gigablue ran more than 622,000 simulated particle releases to assess the potential extent of surface dispersion and deposition of particles on the seabed. Modelling was undertaken based on two scenarios:

- 1 A single, conservative, 200 tonnes deployment over 24 hours in a single transect.
- 2 An extreme, non-realistic scenario of a total volume of 1,000 tonnes deployed in a single deployment over 24 hours in a single transect.

The modelling produced the following key findings:

200 tonnes scenario

- Particles are expected to be deposited on the seabed across an overall area of approximately 976 to 1,371 km².
- The median density of particles at the surface after 24 hours is expected to be 0.822 g/m² (0.514 – 1.29 g/m²) (min – max), which equates to approximately 55 particles per m².
- The median density of particles at the surface immediately prior to settlement (i.e. ~18 days) is expected to be 0.08 g/m² (0.048 – 0.128 g/m²) (25th – 75th quartiles), which equates to approximately 5 particles per m².
- The median density of settled particles is expected to be 0.078 g/m² (0.048 g/m² – 0.118 g/m²) (25th – 75th quartiles), which equates to approximately 5 individual particles per m². With the addition of organic matter, this increases the median density to 0.468 g/m² (0.288 g/m² – 0.708 g/m²).

1,000 tonnes scenario

- Particles are expected to be deposited on the seabed across an overall area of approximately 976 to 1,371 km².
- The median density of particles at the surface after 24 hours is expected to be 4.11 g/m² (2.57 – 6.45 g/m²) (min – max), which equates to approximately 274 particles per m².
- The median density of particles at the surface immediately prior to settlement (i.e. ~18 days) is expected to be 0.40 g/m² (0.24 – 0.64 g/m²) (25th – 75th quartiles), which equates to approximately 27 particles per m².
- The median density of settled particles is expected to be 0.39 g/m² (0.24 g/m² – 0.59 g/m²) (25th – 75th quartiles), which equates to approximately 26 individual particles per m². With the addition of organic matter, this increases the median density to 2.34 g/m² (1.44 g/m² – 3.54 g/m²).

4 Environmental setting

The area of interest (AOI) for GIGPA04 covers a large geographical area to account for the wide potential extent of particle settlement under various release scenarios. The broader AOI was selected to include waters deeper than 1,000 m whilst avoiding areas known or suspected to contain more sensitive or threatened ecology including the Bounty Islands, the Chatham Rise, the Antipodes Islands, and inland areas of the Otago continental shelf. This section details the expected physical and biological environmental setting within the AOI.

4.1 Physical environment

4.1.1 Geology and bathymetry

The area of interest (AOI) for this IA primarily covers the Bounty Trough beyond the continental shelf approximately 50 km off the coast of the Otago Peninsula. The Bounty Trough is bounded to the north by the Chatham Rise and to the south by the Campbell Plateau (Appendix A). The southern section of the AOI covers the northern extent of the Campbell Plateau, including part of the Great South Basin (GSB) which is the largest deepwater basin in the Campbell Plateau (Osli et al., 2019).

The northwestern corner of the AOI includes part of the Otago Fan Complex which consists of a series of eastward-draining canyons and channels carved into the continental shelf along a 200 km long area off the Otago Peninsula. The complex extends to depths of up to 750 m and acts as a conduit to the deep sea for clastic material eroded from the Southern Alps and discharged onto the Otago continental shelf (Carter and Carter, 1996). The many canyons and channels merge into the Bounty Channel which flows through the centre of the AOI onto the abyssal depth Bounty Fan to the east of the AOI (Neil et al., 2015).

The seabed within the AOI encompasses relatively flat areas with shallow gradient slopes, as well as large, steep channels. Bathymetric raster imagery (NIWA, 2016) indicates water depths are relatively consistent across much of the AOI, with a median value of 1,450 m, and with 95% of data points lying between 700 m and 3,380 m. The shallowest region is along the eastern edge of the AOI adjacent to the Bounty Islands (~60 m), whilst the deepest region is across the northeastern corner of the AOI within the Bounty Channel (~4,490 m).

Surficial sediments within the AOI have been characterised by the nzSEABED predictive model generated by Bostock et al. (2018) for the entire New Zealand EEZ-ECS. The model indicates that substrates across the majority of the AOI within the Bounty Trough have a high proportion of finer mud sediments. This assessment is supported by Beaumont et al. (2019) who reported muddy sediments (foraminiferal-nannoplankton pelagic ooze) as the dominant substrate type observed during a voyage across the Bounty Trough area. A higher proportion of sand is, however, predicted along the path of the Southland Current from the Pukaki Saddle across the northern slopes of the Campbell Plateau to the Great South Basin. The modelling shows high carbonate content across the majority of the AOI (> 70%), with patches of lower carbonate in smaller central and northern areas of the Bounty Trough.

A small number of seamount features are also present within the AOI near the Pukaki Saddle and central area of the AOI. Beaumont et al. (2019) found these features to be dominated by hard substrates with dense layers of barnacle plates in places. Smooth bedrock and boulders were also present around these features.

4.1.2 Meteorology and currents

There are three key features that determine New Zealand's climate: prevailing winds, oceans, and mountain ranges. Due to the offshore nature of the AOI, winds and oceans are the two main features controlling the climate within this area.

Strong winds known as the roaring forties and furious fifties blow from the west across the country and dominate atmospheric circulation. Low-pressure systems develop within these westerly winds as they head towards New Zealand, bringing rain and stormy weather conditions as they pass across, or south of the country.

The main currents around New Zealand are illustrated below in Figure 4.1. The main currents influencing the AOI are the Southland Current (SC) and the Subantarctic Front (SAF) in Figure 4.1.

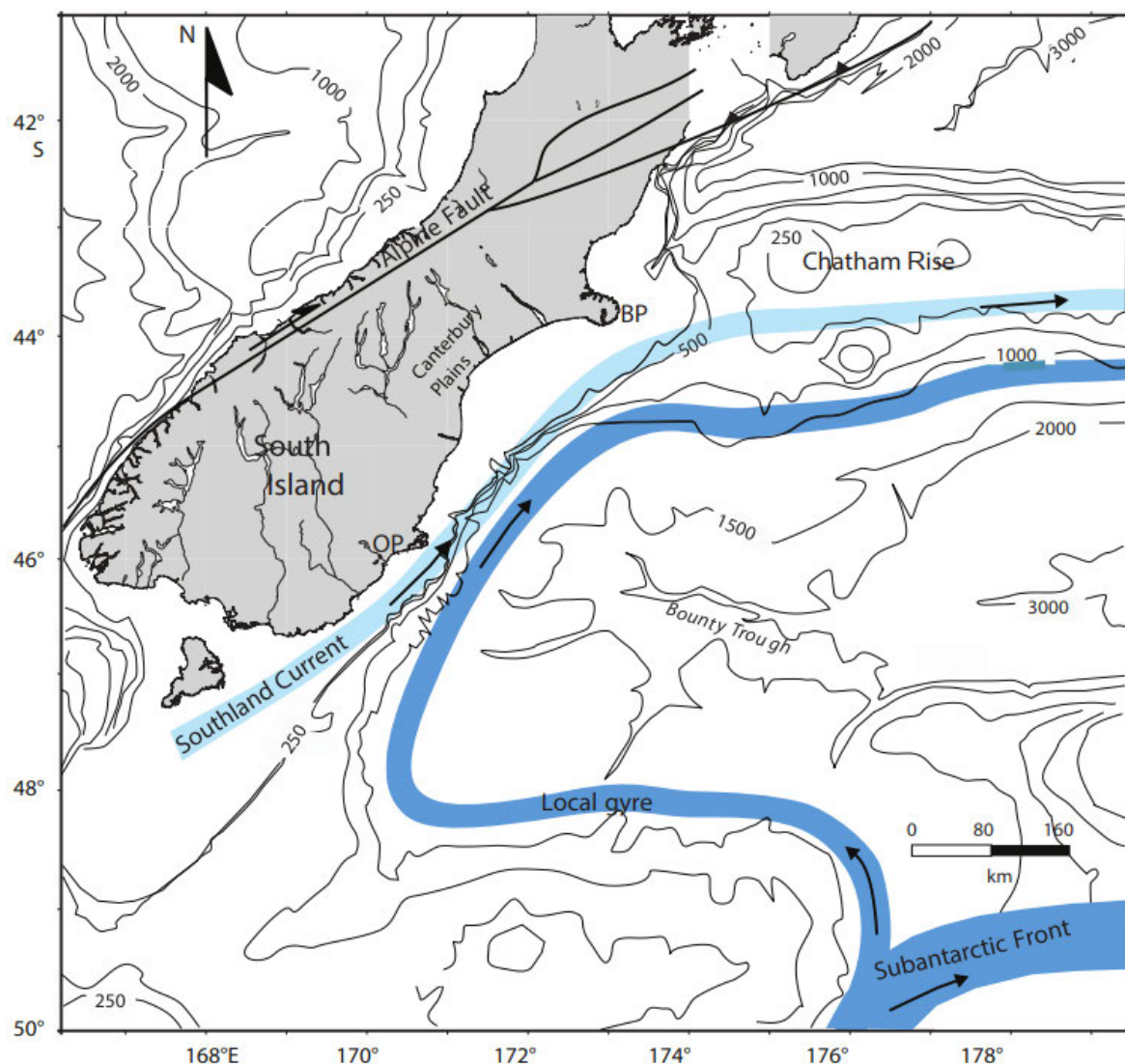


Figure 4.1: Location map showing the major geological features and currents off the east coast of Otago, New Zealand. The Otago Peninsula is labelled OP, and Banks Peninsula as BP. Major currents are marked in blue, with the darker blue of the Subantarctic Front and northern gyre indicating colder water than the lighter coloured Southern Front. Adapted from Clark (2014).

The Southland Current runs up the lower east coast of the South Island from its subantarctic origins. Its seaward distribution is restricted along the continental shelf and slope by low salinity

subantarctic surface waters drawn northwards by the SAF (Jillett, 1969). A large component of the Southland Current separates from the coast near Banks Peninsula where it transports water into the subtropical convergence region near the Chatham Rise (Heath 1972). The Southland Current influences local oceanographic conditions off the southeast coast of the South Island, where it helps to maintain a cooler climate than on the North Island (Heath, 1972; Hopkins et al., 2010).

The Northern Branch of the SAF originates to the south of the Campbell Plateau, diverting northwards then westward around the plateau's eastern and northern edges due to its shallow bathymetry (Clark, 2014). After skirting the Campbell Plateau, the northern branch flows north-eastward across the Bounty Trough. The northern SAF branch is then steered eastward along the southern flank of the Chatham Rise, constrained by the ridge's shallow bathymetry.

Flows are expected to be weaker and more variable across the central and eastern reaches of the AOI outside of the major frontal systems.

4.1.3 Water quality

Water quality within the AOI is not expected to be impacted by anthropogenic activities or from riverine inputs due to its offshore distance. Water samples collected in March 2019 by Beaumont et al. (2019) from within the AOI contained concentrations of metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc) below analytical detection limits. Furthermore, all results for total petroleum hydrocarbons and BTEX (Benzene, Toluene, Ethylbenzene and Xylenes) compounds were below analytical detection limits. Results for total suspended solids were also very low, with concentrations ranging between < 0.5 and 5.2 g/m^3 (Beaumont et al., 2019).

Salinity ranged from 34.22 – 34.29 ppt in surface waters before a halocline at 70 – 100 m into a slightly higher salinity mass 250 – 400 m thick, below which salinity returned similar levels to those recorded in surface waters. Salinity increased again towards the seabed, indicating the presence of a more saline, very cold bottom water layer close to the seabed (Beaumont et al., 2019).

Surface-water dissolved-oxygen levels ranged from 7.7 – 8.3 mg/L down to water depths close to 400 – 500 m where they began to decrease with depth to approximately 5.1 mg/L near the seabed (Beaumont et al., 2019). This reduction of dissolved oxygen with depth is due to the lack of photosynthetic processes below the photic zone, and a reduced circulation with surface water and the atmosphere. The results of Beaumont et al (2019) are indicative of cold, clean, and well mixed offshore waters and are aligned with levels of surface-water dissolved oxygen elsewhere around New Zealand (NIWA, 2017).

Water temperature modelling within the GSB region in the south-east of the AOI from a 36-year (1980 – 2015) hindcast data set indicates water temperatures vary seasonally near the surface, with a monthly range of approximately 8 – 14°C, 10 m below the surface (MetOcean Solutions Ltd, 2017). Water temperature decreases with increasing depth and seasonal variability is reduced. The mean monthly temperature range decreases to 7 – 9°C at 500 m, and to 5 – 6°C at 1000 m. The stability of the thermocline profile does, however, vary with surrounding environmental conditions such as local weather, tides, and currents (SLR, 2019). The pH of water within the AOI is expected to be similar to levels recorded across the Munida Transect off the coast of Otago which indicate an average pH of approximately 8.05 with an average annual decline of 0.0016 units per year since 1998 (Stats NZ, 2022).

Studies have found that dissolved iron is present in relatively low concentrations in seawater due to its low solubility in oxygenated surface waters and the high cellular requirements of phytoplankton (Lohan & Tagliabue, 2018). A study of the western South Pacific Ocean near the AOI found dissolved iron to be nearly depleted in surface waters across the study area, indicating strong scavenging of dissolved iron in the water column (Zheng et al., 2024).

Subantarctic waters are generally rich in nitrates, low in silicates, and low in chlorophyll, whilst Subtropical waters are relatively nutrient poor (Boyd et al., 1999). The Subtropical Front where these waters mix is known to be highly productive (Wood and Probert, 2013).

4.2 Biological environment

The predicted distributions of biogenic habitats, seabirds, marine mammals, and other marine fauna in New Zealand's marine environment have been mapped across various studies based on observations and predictive models (NIWA, 2019; Anderson et al., 2014; Forest & Bird, 2014; Stephenson et al., 2020, MPI, 2024). These models and the information provided below have been used to identify areas within the AOI which present the minimum likelihood of potential disturbance to known sensitive environments or species hotspots.

4.2.1 New Zealand Marine Environmental Classification

The New Zealand Marine Environment Classification (MEC) divides geographic domains in the CMA and EEZ into classes with similar environmental and biological characteristics. Such characteristics include depth, solar radiation, sea-surface temperature, waves, tidal current, sediment type, seabed slope and curvature (Snelder et al., 2005). This classification is useful in providing a general understanding of what marine species could be present in an area when data is limited. The AOI is mainly classified by Class 47, and 178 which are described as follows (Snelder et al., 2005):

Class 47 – Occurs extensively in deep (mean = 2,998 m) waters over a latitudinal range from approximately 37 – 47°S. Average chlorophyll- α concentrations within this class are moderately low. Characteristic fish species include smooth oreo (*Pseudocyttus maculatus*), Baxter's lantern dogfish (*Etmopterus baxteri*), rattail (*Macrourus carinatus*), Johnson's cod (*Halargyreus johnsonii*), and orange roughy (*Hoplostethus atlanticus*).

Class 178 – Occurs extensively the south of New Zealand. It covers moderately deep water (mean = 750 m) as far south as 55°S. This class experiences low annual solar radiation and cool wintertime sea surface temperatures. Average chlorophyll- α reaches low to moderate concentrations. Characteristic fish species include ling (*Genypterus blacodes*), javelin fish (*Coelorinchus australis*), hoki (*Macruronus novaezelandiae*), and pale ghost shark (*Hydrolagus bemisi*).

4.2.2 New Zealand Benthic Optimised Marine Environment Classification

The New Zealand Benthic Optimised Marine Environment Classification (BOMEC) was developed to assess the impacts of bottom trawling on benthic organisms. This classification used environmental variables as well as distributional data for eight taxonomic groups (i.e. asteroids, bryozoans, benthic foraminiferans, octocorals, polychaetes, matrix-forming scleractinian corals, sponges, and benthic fish) to assess the potential impacts from other human activities at the sea floor on demersal fish communities. The AOI lies primarily within BOMEC Groups M, N, and O. Additionally, a small area around the Bounty Islands is classified as Group F. These groups have been described by Leathwick et al (2012) as follows:

Group M – Occupies lower slope depths in the southern region of the AOI. Temperatures and salinity are generally low, as is productivity. This group occurs in deeper waters of the generally gently sloping banks of the Campbell and Bounty Plateaux.

Groups N and O – Occupies the deepest waters in the northern region of the AOI, with Group N averaging 1,400 m in the upper parts of the troughs, and Group O averaging water depths of approximately 2,400 m in lower parts further from the coast. Waters within both groups have a low sea surface temperature gradient, tidal currents, and fine sediments.

Group F – Includes offshore waters of the continental shelf and upper continental slope including the Bounty Islands. This group is characterised by low water temperatures and salinities, strong tidal currents, and coarse sediments.

4.2.3 Marine invertebrates

A wide range of marine invertebrates are expected to inhabit the benthic and pelagic zones of the AOI. Beaumont et al. (2019) report on one of the few detailed benthic surveys undertaken within the Great South Basin (TAN1902). The report describes the benthic environment within a region of the AOI at the southern end of the Bounty Fan. More recently, a voyage (TAN2402) was undertaken to investigate the infaunal diversity in continental shelf and slope habitats of the Bounty Trough which is reported on by Mills et al. (2024).

These surveys visually identified or collected samples from a diverse range of taxa. Commonly observed groups with higher diversities included sponges (Porifera), corals and jellyfish (Cnidaria), shellfish such as squids and clams (Mollusca), segmented worms (Annelida), starfish, sea urchins, and sea cucumbers (Echinodermata), and crabs, shrimp, and sea spiders (Arthropoda). Benthic fauna modelled by Stephenson et al. (2021) as likely to be present within the AOI includes sea snails (buccinids and ranellids), urchins (echinoids and cidaroids), sea cucumbers (holothuroids), and sea stars (asteroids).

A number of marine invertebrates also create biogenic habitat which provides important shelter, protection and resources for other marine flora and fauna, as detailed in the following section.

4.2.4 Sensitive environments and biogenic habitat

Schedule 6 of the EEZ and Continental Shelf (Environmental Effects – Permitted Activities) Regulations (2013) defines a number of sensitive environments within the New Zealand marine benthic environment. This IA focuses on identifying these sensitive environments and species protected under the Wildlife Act (1953) based on information presented by Beaumont et al. (2019) and Mills et al. (2024), as well as the biogenic habitat distribution models prepared by Anderson et al. (2019) and Anderson et al. (2014) on New Zealand's biogenic habitats, and the benthic taxa models prepared by Stephenson et al. (2021). The models prepared by Anderson et al. (2014) are of particular interest in this assessment as they focus specifically on mapping the habitat suitability for key habitat forming Vulnerable Marine Ecosystems (VMEs) including corals and sea pens.

The Anderson et al. (2014) models are, however, limited to depths up to 3,000 m, and the models of Stephenson et al. (2021) are limited to depths up to 2000 m. As such, the habitat of the deepest regions of the Bounty Trough in the northwestern corner of the AOI is assessed based on probabilities for adjacent areas, the expected benthic substrate, and on the typical depths utilised by different taxa.

4.2.4.1 Coral thickets or reefs

Stony coral thickets or reefs are sensitive environments, and a number of coral species are also protected under Schedule 7A of the Wildlife Act (1953), including:

- Black corals (all species in the order Antipatharia).
- Gorgonian corals (all species in the order Gorgonacea).
- Stony corals (all species in the order Scleractinia).
- Hydrocorals (all species in the family Stylasteridae).

During the TAN1902 voyage, gorgonian corals were abundant on seamount features and occasionally within channels, and stony corals and hydrocorals were occasionally observed on the

flanks of several seamount features (Beaumont et al., 2019). This included several genera that have been classified as 'At Risk' within the New Zealand Threat Conservation System (NZTCS), such as the branching stony corals *Enallopsammia* sp., *Madrepora* sp., *Gorgonocephalidae* (basket star), and *Paragoriidae* (bubblegum corals) (Funnel et al., 2023). No black corals were observed.

During the TAN2402 voyage, stony coral and black coral were observed at several seamount sites, whilst small hydrocoral colonies and gorgonian corals were observed on seamount features and slopes within the Bounty Trough (Mills et al., 2024).

A review of existing data on New Zealand's biogenic habitats indicates relatively high probabilities of abundance of coral in central and southern regions of the AOI across the southern side of the Bounty Trough and upper parts of the GSB and Pukaki Saddle, north of the Campbell Plateau (Anderson et al., 2014).

Predicted distribution mapping indicates varying probabilities of stony corals species occurring within the AOI. There is a relatively high probability of *Solenosmilia variabilis* occurring across central and southern areas of the AOI, whilst probabilities of *Enallopsammia rostrata* and *Madrepora oculata* are generally lower and restricted to isolated patches near the Otago Fan Complex and Bounty and edges of the Bounty Plateau and Pukaki Saddle. Small patch reefs or thickets of stony coral have also been directly observed on many seamounts around New Zealand, several of which have been identified within the AOI.

The predicted distribution of black corals (*Antipatharia*) indicates a relatively high probability within the flow path of the Subantarctic Front (SAF) at the southern end of the AOI (Anderson et al., 2014). *Stylasteridae* hydrocorals are also modelled as patchily concentrated across the AOI, with higher abundances following crossed lines through the centre of the AOI running north-south and east-west. Both the models of Anderson et al. (2014) and Stephenson et al. (2021) indicate a very low probability of bushy hard coral (*Goniocorella dumosa*) being present within the AOI.

Additionally, the low predicted probability of modelled coral species at depths of 2,500 – 3,000 m within the Bounty Trough suggests that deeper eastern areas beyond the extent of the model are also unlikely to have high abundances of coral, despite the ability of several coral taxa (i.e. black corals) to inhabit deeper ocean regions (Anderson et al., 2019).

4.2.4.2 Sea pen fields

Sea pens typically occur on soft sediments (fine gravels, soft sand, mud or abyssal ooze) and in areas where turbulence is unlikely to dislodge them (Anderson et al., 2019). Seafloor sampling and deep-sea habitat modelling (> 200 m) suggests that sea pens commonly occur in the Great South Basin between the Chatham Rise and the Campbell Plateau (Anderson et al., 2019).

During the TAN1902 voyage, sea pens were observed in many soft-sediment transects, and rock pens (*Anthoptilidae*) were observed on a number of seamount features (Beaumont et al., 2019). Similarly, sea pens were observed in both channel and non-channel sites within the Bounty Trough during the TAN2402 voyage (Mills et al., 2024). Neither survey observed sea pens at the density required to be considered a sea pen field (2 per m²) which is considered a sensitive environment.

The predictive mapping of Anderson et al. (2019) and Stephenson et al. (2021) indicates sea pens are most likely to be distributed in central and northern regions of the AOI in deeper waters on the southern edge of the Bounty Trough. Sea pens have generally been observed as isolated individuals and in small patches, although this may reflect the limited exploration of New Zealand's EEZ (Anderson et al., 2019). Additionally, the low predicted probability of sea pens at depths of 2,500 – 3,000 m within the Bounty Trough suggests that deeper eastern areas beyond the extent of the model are also unlikely to have high abundances of sea pens, despite their proclivity for soft sediments of the abyssal plain (Anderson et al., 2019).

4.2.4.3 Sponge gardens

Sponges are the one of most common marine invertebrates inhabiting the waters around New Zealand. They are found across a wide range of benthic habitats including intertidal zones, continental shelves, deep ocean trenches, and abyssal plains.

Sponges (Porifera) are habitat-forming, filter-feeding, sessile organisms found in all marine environments. During both voyages, sponges were observed in abundance at most sites across a range of environments including the Bounty Trough channels, slopes, seamounts, pock marks, shelf, and canyons (Beaumont et al., 2019; Mills et al., 2024). Mills et al. (2024) notes that close to 60% of sponge specimens were recovered from seamounts, and close to 30% from channels, highlighting their relative importance as sponge habitat.

The maximum density of sponges observed during the TAN1902 voyage was, however, well below the density threshold for a sponge garden sensitive environment (Beaumont et al., 2019). Anderson et al. (2019) maps the known locations of sea sponge gardens which are largely restricted to shallower waters outside of the AOI, with very few locations bordering the AOI at its south-western extent. No predictive mapping is provided due to the relatively limited historical mapping of sponge gardens within New Zealand.

The predictive modelling undertaken by Stephenson et al. (2021) indicates a high probability of Demospongiae occurrence at low abundance levels across the AOI. As many glass sponge species (i.e. *Amphidiscella abyssalis*) are known to inhabit deeper regions of the ocean (~4,000 m), they are likely present at low abundance levels in unmodelled regions of the eastern Bounty Trough (Kelly, 2022).

4.2.4.4 Xenophyophore beds

Xenophyophores are large, single celled protozoans common in deep sea areas around New Zealand (> 500 m) (Anderson et al., 2019). These organisms extract minerals from their surroundings such as sediment grains, sponge fragments, and organic debris to form an exoskeleton known as a test. Xenophyophores feed on fine particles such as bacteria and are particularly abundant below areas of high surface productivity (Anderson et al., 2019).

During the TAN1902 voyage, xenophyophores were observed in 55 of 73 video transects analysed, though the report notes that only the most obvious xenophyophores could be recorded from video analysis which may result in an under-estimate of abundances and associated density estimates (Beaumont et al., 2019). Xenophyophores were also observed at bed-level densities (i.e. sensitive environment) at numerous sites in muddy sediments within channels and on basin slopes above channels. These organisms were also commonly observed during the TAN2402 voyage in Bounty Trough channel and non-channel sites, slopes, seamounts, and pock marks (Mills et al., 2024).

Anderson et al. (2019) notes that very little is known about New Zealand's xenophyophore distribution. Deep sea surveys rarely collect Xenophyophore specimens due to difficulties in retrieving whole specimens and due to the lack of targeted image surveys. Consequently, they are likely to be significantly under-sampled.

The predictive modelling undertaken by Stephenson et al. (2021) indicates a high probability of Xenophyophore occurrence and high predicted abundance across the majority of the AOI, particularly across the southern extent. As xenophyophores are confined to depths greater than 500 m and commonly inhabit deep sea trenches many thousands of metres deep, they are also likely to be relatively abundant across the unmodelled areas of the Bounty Trough below 3000 m (Ashford et al., 2014).

4.2.4.5 Bryozoan thickets

Bryozoans are colonial filter feeders which build networks of branching tubes attached to the seabed. These animals are commonly present in seamount habitat and on hard substrata, though their diversity typically decreases with depth, suggesting they are less likely to be present within the deeper waters of the AOI (Smith & Gordon, 2011 and Rowden et al., 2004).

During the TAN1902 voyage, occasional large frame-building bryozoans were observed in low densities over small areas on hard substrates (Beaumont et al., 2019). These animals were also observed during the TAN2402 voyage at seamount and pockmark transect sites within the Bounty Trough (Mills et al., 2024).

The predictive modelling undertaken by Stephenson et al. (2021) indicates a low probability of bryozoan occurrence and abundance across the majority of the AOI, with the exception of the shallower waters of the Bounty Plateau where the probability of occurrence is relatively high.

4.2.4.6 Brachiopods

Brachiopods are marine invertebrates characterized by two hard valves/shells on their dorsal and ventral sides. A brachiopod bed was observed during the TAN1902 voyage on the barnacle plates of one seamount, and individual samples were collected during the TAN2402 voyage (Beaumont et al., 2019; Mills et al., 2024).

The predictive modelling undertaken by Stephenson et al. (2021) indicates a low probability of brachiopod occurrence and abundance across the majority of the AOI, with the exception of the shallower waters of the Bounty Plateau where the probability of occurrence is relatively high.

4.2.4.7 Chaetopterid worm fields

Chaetopterid worms are parchment-tube polychaetes that build flexible, U-shaped tubes in soft sediments from coastal shelves to abyssal plains. They are relatively uncommon in the waters around New Zealand but are more widespread in basin muds continental-slope areas.

In the Bounty Trough, the TAN2402 expedition confirmed that the environment's fine silts and muds support only very low densities of chaetopterids, with no dense aggregations recorded (Mills et al., 2024). This finding is comparable to surveys on the adjacent Campbell Plateau (TAN2004), which also found chaetopterids as only single individuals or sparse patches in muddy seabeds to ~2,000 m (Anderson et al., 2020).

In summary, chaetopterids in the Bounty Trough are expected to be present at low density within soft muds from approximately 900 – 4,200 m depth. Structured fields or biogenic mats are unlikely to be present.

4.2.4.8 Calcareous tube worm thickets

Calcareous tube worms build rigid calcium-carbonate tubes on hard substrates. Their distribution is limited by substrate availability and water depths above the carbonate compensation depth.

The TAN2402 survey of the Bounty Trough found no calcareous tube-worm aggregations. This absence is attributed to the predominantly soft, muddy seabed and depths (> 4,000 m) that are near or below the regional carbonate compensation depth (Mills et al., 2024). Data from the adjacent Campbell Plateau (TAN2004) support this, showing serpulids are restricted to upper-slope terraces (< 1,500 m) and absent from deeper basins (Anderson et al., 2020).

In summary, calcareous tube worms are expected only as isolated tubes on occasional hard substrate fragments along the upper slopes of the trough, with aggregations or reef-like structures unlikely to be present.

4.2.4.9 Potential Methane or Cold Seep Communities

Although pockmark fields on the Otago continental margin were investigated as potential cold-seep habitats during the TAN2402 survey, no characteristic chemosynthetic fauna (e.g., vestimentiferan tube worms or clam beds) were found (Mills et al., 2024). This aligns with the findings of Hillman et al. (2023) which found a distinct lack of correlation between active seafloor seeps and pockmarks around New Zealand.

The absence of confirmed methane flux or sulphide-oxidising communities suggests any seepage activity is likely weak, localised, or transient. However, isolated burrows and tubes observed in imagery indicate they may be present at low densities in isolated locations (Mills et al., 2024).

4.2.4.10 Sensitive environments not expected to be present

Marine flora including rhodolith beds, kelp forests, and algal beds provide biogenic habitat but are not expected to be present within the AOI due to the light limitations associated with the deeper waters. Additionally, no records of deep-sea hydrothermal vents were found for the AOI.

4.2.5 Phytoplankton and Zooplankton

Phytoplankton (plants) and zooplankton animals are primary producers of the ocean which form the basis of the marine food web, and aid in nutrient cycling and carbon sequestration (Botterell et al., 2023). The productivity of phytoplankton drives zooplankton growth, especially during bloom periods (Nogueira et al., 2012).

The AOI is categorised as a ‘deep offshore ocean’ environment which is typically characterised as an area beyond the shelf break that has less inorganic and organic particulate matter compared to the nearshore coastal zone (Gibbs et al., 2006). The offshore ocean also typically has less phytoplankton, zooplankton and detritus compared to the coastal zone (Gibbs et al., 2006). Phytoplankton inhabit the euphotic zone due to their dependence on light. This zone typically limited to the upper 200 m of ocean (Church & Bottjer, 2013).

The lower South Island, near the Subtropical Convergence, experiences strong nutrient gradients that influence phytoplankton dynamics (Vincent et al., 1991). Chlorophyll- α serves as a proxy for phytoplankton abundance which shows seasonal cycles with peaks in summer/autumn and lows in winter (Murphy et al., 2001; Pinkerton et al., 2006; Boyd et al., 2004). In the sub-Antarctic ‘SAC’ region near the AOI, concentrations rarely exceeded 0.4 mg/m³, reflecting macro-nutrient richness but micro-nutrient scarcity (Murphy et al., 2001). The long-term average chlorophyll-a concentration for New Zealand (1997–2014) shows low average concentrations within the AOI of approximately 0.20 – 0.25 mg/m³ (MfE, 2016). Boyd et al. (2003) notes that the low micronutrient status of the Southern Plateau area creates a food web characterised by low chlorophyll concentrations and small phytoplankton cells.

Specific information on zooplankton communities in the AOI were not readily available. However, as zooplankton biomass is largely determined by phytoplankton productivity, zooplankton biomass is expected to be relatively low with similar seasonal shifts. Jillett (1976) carried out zooplankton surveys through the deeper waters of the Bounty Fan off the shelf edge which found species that reach their northern limits (i.e. *Eukrohnia hamata*, *Sagitta gazellae*, and *Clausocalanus laticeps*), cosmopolitan species (i.e. *Primno macropa* and *Pseudoconchoecia serrulate*), and species at their southern limit (i.e. *Mecynocera clausi*, *Centropages bradyi*, and *Clausocalanus ingens*). The chaetognath *Sagitta tasmanica*, copepod *Neocalanus tonsus*, and amphipod *Parathemisto gaudichaudi* occur widely in subantarctic waters and are particularly abundant (Jillett, 1976). More recent surveys of a similar area by Meyers (2020) identified 13 general zooplankton taxa from samples collected along the Munida Transect, including copepods, amphipods, euphausiids,

ostracods, crustacean nauplius, crustacean zoea, salps, appendicularians, chaetognaths, thecosome pteropods, bivalves, scyphomedusa, and ctenophores.

4.2.6 Fish

Fish species potentially present within the AOI include various demersal and pelagic species, most of which are widely distributed throughout New Zealand's deep offshore waters. Depth has been found to be the strongest predictor of fish species richness, with richness peaking at mid depths (800 – 1,000 m), and reducing in abyssal waters. There is also a strong association at any given depth between species richness and primary productivity, with maximum species richness concentrated in the zone of high productivity associated with the mixing of waters of subtropical and subantarctic origins along the Subtropical Front (Leathwick et al., 2006).

The fish species potentially present within the AOI are listed in Table 4.1. This information was collated from the MPI fish guides (McMillan et al. 2019), more than 35 years of summer trawl surveys of the Sub-Antarctic Ocean near the AOI (Stevens et al., 2024), and an interrogation of the NABIS database (MPI, 2025). Table 4.1 is not intended to be an exhaustive list of all species present, but lists the main species based on published literature.

Records of fish from video imagery and trapping by Beaumont et al. (2019) and Mills et al. (2024) near the AOI included several species of rattail, shark, ghost shark, deep-sea skate, oreo, eel, orange roughy, morid cod, and lanternfish to name a few.

The NABIS database also identifies black oreo (*Allocyttus niger*), blue shark (*Prionace glauca*), giant stargazer (*Kathetostoma giganteum*), hapuku (*Polyprion oxygeneios*), ling (*Genypterus blacodes*), orange roughy (*Hoplostethus atlanticus*), and porbeagle shark (*Lamna nasus*) as potentially spawning within the AOI (MPI, 2025).

Table 4.1: Fish species potentially present within the AOI

Species – Common Name		
Albacore tuna	Hake	Redbait
Alfonsino	Hammerhead shark	Ribaldo
Arrow squid	Hapuku	Ridge scaled rattail
Banded bellowsfish	Hatchetfish	Robust cardinalfish
Banded rattail	Hoki	Rough skate
Barracouta	Humpback rattail	Rubyfish
Basketwork eel	Javelinfish	Rudderfish
Basking shark	Johnson's cod	Sandfish
Bass	Kaiyomaru rattail	Scaly dragonfish (<i>Stomias</i> spp.)
Baxter's dogfish	Lanternfish (<i>Myctophidae</i> spp.)	School shark
Bearded cusk-eels	Lanternfishes	Sea perch
Bigeye cardinalfish	Leafscale gulper shark	Seal shark
Black cardinalfish	Lighthouse fish	Sealshark
Black dragonfish (<i>Idiacanthus</i> spp.)	Ling	Serrulate rattail
Black javelinfish	Long barbel rattail	Shovelnose dogfish
Black oreo	Longnose deepsea skate	Silver warehou
Blackspot rattail	Longnose spookfish	Silverside

Species – Common Name		
Blobfish	Longnose velvet dogfish	Sleeper ray (<i>Typhlonarke</i> spp.)
Blue mackerel	Lookdown dory	Small banded rattail
Blue shark (adult and juvenile)	Lucifer dogfish	Small-headed cod
Blue warehou	Lyconus spp.	Smallscaled brown slickhead
Bluenose	Mahia rattail	Smooth deepsea skate
Bollons's rattail	Mako shark	Smooth oreo
Brown chimaera	Moonfish	Smooth skate
Catshark (<i>Apristurus</i> spp.)	Morid cod	Snailfish
Codheaded rattail	Murray's rattail	Snipefish
Common roughy	Notable rattail	Softnose skate
Cookie-cutter shark	Oblique banded rattail	Southern blue whiting
Dark ghost shark	Oliver's rattail	Southern bluefin tuna
Dark toadfish	Orange roughy	Southern boarfish
Dawson's catshark	Owston's dogfish	Spiky oreo
Dealfish	Pacific bluefin tuna	Spiny dogfish
Deepsea flathead	Pacific spookfish	Spinyback eel
Deepsea smelt	Pale ghost shark	Swollenhead conger
Discfish	Pale toadfish	Thresher shark
Eelpout	Pelagic cod	Trumpeter
Electric ray	Plunket's shark	Tubeshoulder
Finless flounder	Pointynose blue ghost shark	Violet cod
Four-rayed rattail	Porbeagle shark.	Violet squid
Frostfish (adult)	Prickly deepsea skate	Viperfish
Gemfish	Prickly dogfish	Warty squid
Giant stargazer	Ragfish	White pointer shark (great white)
Golden mackerel	Rattail	White rattail
Hairy conger	Ray's bream	White warehou
Hake	Red cod	

Data obtained from: Trawl surveys (Stevens et al., 2024), MPI fish guides (McMillan et al., 2019), NABIS Database (MPI, 2025), and other surveys within the AOI (Beaumont et al., 2019; Mills et al., 2019).

4.2.6.1 Protected species

Schedule 7A of the Wildlife Act 1953 lists eight species of fish as protected. Of these eight, two have the potential to be present within the waters of the AOI: white shark (*Carcharodon carcharias*) and basking shark (*Cetorhinus maximus*). In addition to the protection offered under the Wildlife Act 1953, white sharks and basking sharks are also protected under the Fisheries Act 1996.

Although marine fish have not generally been assessed under the NZTCS, the conservation status of 113 New Zealand chondrichthyan taxa was classified by Duffy et al. (2018). Of the species which may be present within the AOI, white sharks are classified as 'Nationally Endangered', and basking sharks have been classified as 'Nationally Vulnerable' (Duffy et al., 2018). Other identified species are 'Not Threatened' or are classified as 'Data Deficient'.

In terms of their expected distribution, tagging has shown that outside of their migration period (March – September), white sharks generally remain over the continental shelf and rarely swim deeper than 100 m (Bonfil et al., 2010). During migration, sharks may make deeper dives to depths of 200 – 800 m (Duffy et al., 2012). Habitat suitability modelling for basking sharks has identified shallow depths (< 100 m) to have the highest suitability for this species, with depths between 200 and 500 m also showing high suitability (Finucci et al., 2021). Basking sharks have, however, been recorded to dive as deep as 1,254 m and have been regularly recorded at depths of 600 – 1,100 m (Francis and Duffy, 2002).

4.2.7 Marine reptiles

The distribution of marine reptiles is generally restricted to the warmer, temperate waters that flow along New Zealand's northern and north-eastern coastlines, typically in the summer months (Dunn et al., 2022). As such, given the much cooler water temperatures in the AOI and the geographical distance from where most of the marine reptiles are observed, it would be unlikely that any marine reptile will be present within the AOI.

4.2.8 Marine mammals

Due to the typically extensive home-ranges of marine mammals, a variety of species may be present within the AOI. Marine mammal distribution has been assessed based on the DOC Marine Mammals Sightings Database from 1968 to 2025 (Richard & Berkenbusch, 2024), and from distribution modelling (Stephenson et al., 2020; MPI, 2025).

The reviewed data indicates that while approximately 30 marine mammal species are known from the AOI and wider Great South Basin, only the following species are 'likely' to be present on a year-round or seasonal basis:

- New Zealand fur seals (*Arctocephalus forsteri*)
- Southern elephant seals (*Mirounga leonina*)
- Dusky dolphins (*Lagenorhynchus obscurus*)
- Long-finned pilot whales (*Globicephala melas*)
- Southern right whale dolphins (*Lissodelphis peronii*)
- Southern right whales (*Eubalaena australis*)
- Sperm whales (*Physeter macrocephalus*)
- Blue whales (*Balaenoptera musculus*)
- Humpback whales (*Megaptera novaeangliae*)
- Dwarf minke whales (*Balaenoptera acutorostrata*)
- Sei whales (*Balaenoptera borealis*)
- Beaked whales – Shepherd's (*Tasmacetus shepherdii*), Cuvier's (*Ziphius cavirostris*), Gray's (*Mesoplodon cavirostris*), Gray's (*Mesoplodon grayi*), and Strap-toothed (*Mesoplodon layardii*)

Of the annual species distributions modelled by NABIS (2025), only southern right whale, southern elephant seal, and New Zealand fur seal cover most or all of the AOI. There is also hotspot for New Zealand fur seal around the Bounty Islands bordering the eastern edge of the AOI. Other modelled species, particularly dolphin, are generally restricted to more coastal areas bordering the western edge of the AOI.

Other species that are expected to be present less frequently include leopard seals (*Hydrurga leptonyx*), New Zealand sea lions (*Phocarctos hookeri*), killer whales (*Orcinus orca*), false killer whales (*Pseudorca crassidens*), common dolphins (*Delphinus delphis*), bottlenose dolphins (*Tursiops*

truncatus), Hector's dolphins (*Cephalorhynchus hectori*), spectacled porpoises (*Phocoena dioptrica*), pygmy sperm whales (*Kogia breviceps*), southern right whales (*Eubalaena australis*), fin whales (*Balaenoptera physalus*), Antarctic minke whales (*Balaenoptera bonaerensis*), Bryde's whales (*Balaenoptera edeni*), and several additional beaked whale species.

Although none of the species 'likely' to be present within the AOI are classified as 'Threatened' or 'At Risk' under the New Zealand Threat Classification System (NZTCS), most of the less frequently present species mentioned are classified as 'Threatened' or 'At Risk'.

The AOI borders but does not intersect with the Coast and Shelf Waters of the Eastern Te Waipounamu Important Marine Mammal Areas (IMMA) defined by the IUCN. While the AOI likely supports some foraging, breeding, resting, and migrating behaviours, there is little evidence to suggest that the AOI represents important marine mammal habitat relative to other deep water pelagic habitat off the east coast of the South Island.

4.2.9 Seabirds

A range of seabirds may be present within the AOI during the trial period. The term 'seabirds' includes species that spend some part of their life cycle feeding over open marine water (Taylor, 2000). Approximately 60% of New Zealand's seabirds commonly forage more than 50 km from shoreline, whilst the remaining 40% feed over inshore waters and are infrequently observed away from land (Taylor, 2000). Knowledge of the at-sea distribution of New Zealand's seabird species is limited and generally restricted to targeted studies and observations from commercial fishing vessels (Richard et al., 2020).

Gigablue commissioned NIWA to undertake a desktop assessment of the potential effects of their particle on seabirds likely to occur within the AOI (NIWA, 2025). The assessment identified 71 seabird taxa known to, or very likely to, occur in the area of interest, with 20 taxa (28%) classified as 'Threatened' and 36 taxa (51%) classified as 'At Risk' under the New Zealand Threat Classification System (NZTCS) (Robertson et al., 2021). Threatened species are those at high risk of extinction in the near future due to declining populations or vulnerability to unpredictable events, whilst At Risk species are not currently threatened but are declining slowly, naturally scarce, or recovering from a previously threatened status (Rolfe et al., 2022). Of particular risk are the Whenua Hou diving petrel (*Pelecanoides whenuahouensis*) and Chatham Island tāiko (*Pterodroma magenta*) which are classified as 'Threatened – Nationally Critical' due to their very small populations (< 250 mature individuals).

It should be noted that seabirds have a large home range so their presence within the AOI is not guaranteed and is likely to be transient. Additionally, the offshore distance of the AOI means that no breeding colonies are expected to be present as most seabirds have strong natal site fidelity and typically return to, or in the general vicinity of, the same breeding colony where they were reared (Taylor, 2000).

A report by Forest & Bird identified important biodiversity areas (IBA) for New Zealand seabirds which are used by known colonies for feeding, maintenance behaviours, and social interactions (Forest & Bird, 2014). Criteria applied in the marine environment for identification of IBAs are: Regular presence of threatened species and more than 1% of global population regularly occurring (Forest & Bird, 2014). The Southern East Coast South Island (offshore) IBA bordering the AOI includes colonies of:

- Yellow-eyed penguin (*Megadyptes antipodes*)
- Stewart Island shag (*Leucocarbo chalconotus*)
- Fiordland penguin (*Eudyptes pachyrhynchus*)
- Northern royal albatross (*Diomedea sanfordi*)

- White-capped albatross (*Thalassarche steadi*)
- Salvin's albatross
- Buller's albatross (*Thalassarche bulleri*)
- Hutton's shearwater (*Puffinus huttoni*)
- Sooty shearwater (*Ardenna grisea*).

These species are listed as utilising this IBA for passage and/or foraging.

5 Managing environmental effects

This section details the potential adverse effects of the trial on the environment and the measures implemented to avoid, remedy, or mitigate the adverse effects. This is followed by a summary of the potential adverse effects on the environmental aspects identified in Section 4 considering the implemented management measures.

5.1 Potential environmental effects

The deployment of particles to the marine environment may result in adverse effects on marine fauna based on a wide range of variables relating to the particle properties and the location of the activity. Note this section summarises the *potential* effect types without quantifying the likelihood of any actual effects or considering proposed mitigation measures. Predicted residual effects after mitigation are presented in Section 6. Potential adverse effects include:

- **Deep sea acidification:** Increased CO₂ sequestration can lower pH in deep waters, leading to dissolution of carbonate-based structures and habitat loss for corals, molluscs, and crustacea.
- **Macronutrient depletion:** Increased uptake of inorganic carbon and macronutrients may deplete the local nutrient supply, potentially hindering phytoplankton growth.
- **Ecotoxicity from iron oxides:** Excess bioavailable iron may cause toxicity in marine organisms, affecting growth, reproduction, or survival.
- **Harmful algal blooms:** A small subset of experiments involving direct iron application (i.e. iron not attached within a particle as per the current proposed activity) have resulted in algal blooms which have included some toxin-producing algae.
- **Bioaccumulation and biomagnification:** Iron may accumulate in tissues and magnify through the food web, potentially impacting higher trophic levels.
- **Ingestion by marine fauna:** Particles may be ingested by fish, crustaceans, seabirds, and marine mammals, potentially affecting digestion, nutrient absorption, or gut health.
- **Organic matter accumulation and smothering of sessile benthic organisms:** Particle deposition that exceeds natural sedimentation rates can bury benthic organisms, reducing oxygen exchange and survivability.
- **Alteration of sediment composition:** Changes to seafloor sediment structure may reduce habitat suitability for species adapted to existing conditions.
- **Abrasion of sessile fauna:** Physical contact from particles may cause tissue damage or stress to non-mobile, seafloor-dwelling organisms.
- **Turbidity and visibility reduction:** Suspended particles can decrease water clarity, reducing the foraging efficiency of visual predators and interfering with photosynthesis.
- **Behavioural disruption:** Mobile species may avoid particle plumes or change feeding and movement behaviours due to reduced visibility or altered habitat cues.
- **Acoustic interference:** Particles suspended in the water may alter sound transmission, potentially interfering with echolocation and communication in marine mammals.

Some positive effects may, however, result from the deployment of particles to the marine environment. These could include:

- **Improved substrate colonisation and food source:** An increase in larger particles deposited to the seafloor may enable new species to colonize the areas of deposition, and the additional deposited phytoplankton may provide additional nutrient resources for some species.
- **Temporary increase in surface pH:** The increased removal of dissolved inorganic carbon by sinking particles is expected to result in a temporary decrease in surface ocean DIC

concentrations. This is expected to temporarily result in a minor and localised increase in surface water pH, potentially aiding calcifying organisms.

5.2 Trial area refinement

5.2.1 Initial recommended release and settlement areas

Based on the information presented in Section 4, certain areas within the AOI have been identified as preferable locations for the purposes of avoiding and minimising effects on ecological values and sensitive environments. As the type of effects and the taxa most at risk of effects varies at different stages of the trial (i.e. initial release and floating phase vs sinking and settlement), consideration has been given to both the initial release area and the final settlement area.

The available benthic ecology information was used to delineate the most suitable areas for particle settlement which avoids areas most likely to contain particularly sensitive and vulnerable organisms. Predicted distributions of deep-sea corals and sea pens classified as 'Vulnerable Marine Ecosystems' (VMEs) were mapped using a threshold of > 5 % probability of occurrence (Anderson et al., 2014). Observation points of in-situ biogenic habitat and known seamount locations were overlaid on the same map along with a bathymetric depth layer (Anderson et al., 2014). An initial recommended targeted settlement area was then selected to minimize potential interaction with these observed and predicted habitat areas at depths of at least ~1,000 m. The recommended settlement area map and guiding datasets are presented in Appendix A Figure 1.

The release and early floating phase areas have been determined based on marine mammal, fish, and seabird distributions. However, available marine mammal databases do not have refined distribution layers for most species, and potential distributions of many marine mammal and seabird species cover large parts of the proposed trial area. Consequently, refinement of the recommended release area focused on avoiding NABIS (2025) marine fauna hotspots (i.e. high concentrations of biodiversity or ecological significance).

A review of the NABIS database showed a number of seabird hotspots overlapping the AOI. As the particles are expected to pose the greatest threat to seabirds at a high surface density, the proposed release location was selected to preferentially avoid hotspots of birds with a 'Threatened' status where possible (Appendix A Figure 2). This included avoidance of hotspots for Southern royal albatross (*Diomedea epomophora*), Salvin's albatross (*Thalassarche salvini*), and Gibson's albatross (*Diomedea antipodensis gibsoni*), as well as several other 'At Risk' species. A large hotspot area for the Antipodean Albatross (*Diomedea antipodensis*) could not be completely excluded from consideration due to its broad coverage of the AOI. Additionally, the floating plume may still pass through sections of some hotspots across the Otago Fan Complex and western Bounty Trough, but natural dispersion will help mitigate potential risk to seabirds. The initial recommended release area also ensures there is a low probability of particles entering the shallower Bounty Plateau and Bounty Islands which include areas of known biogenic habitat and hotspots for Salvin's albatross and New Zealand Fur Seal. The initial recommended release area map and guiding datasets are presented in Appendix A Figure 2.

The following criteria were included in the initial recommended trial refinement mapping area exercise:

Settlement area:

- A minimum depth criterion of ~1,000 m (indicated by bathymetry data).
- Avoidance of marine seamounts (biodiversity hotspots likely to include biogenic habitat).
- Avoidance of biogenic habitats at known locations, and of locations with high modelled habitat suitability for VMEs (Anderson et al., 2014; Stephenson et al., 2021).

Release area:

- Avoidance of predicted fisheries, mammal, and seabird hotspots for the most vulnerable species (NABIS database).

5.2.2 Model-refined release and settlement areas

Due to the relatively long particle floating phase required for GIGPA04, particle trajectories are influenced by a combination of environmental factors including large-scale currents, mesoscale eddies, and surface winds. As it is too difficult to forecast the precise movements of particles at this scale, predictive modelling can be used to estimate future trajectories based on historical meteorological and oceanographic information.

Gigablue have modelled 622,573 runs of particle releases (of both 200 tonnes and 1,000 tonnes) from 2,869 locations within the recommended release area at 10 km intervals. The model conditions for a 1,000 tonne release represent a conservative and unrealistic scenario where all particles are released during a single event instead of five separate 200-tonne events. Models were run using conditions from 240 historical November-January dates over a 10-year period, with 18-day trajectories. Of these modelled releases, approximately 31.6% ended within the recommended settlement area. These models were filtered to identify locations with a suitably high probability (> 75%) of settling within the recommended settlement area. A total of 178 locations had their trajectories ending within the settlement area. These 178 locations are predominately concentrated at the central-western extent of the recommended release area (Figure 5.1a)³. Based on the trajectories from these release locations, a heatmap was created to visualise the concentration of particle settlement within the recommended settlement area (Figure 5.1b).

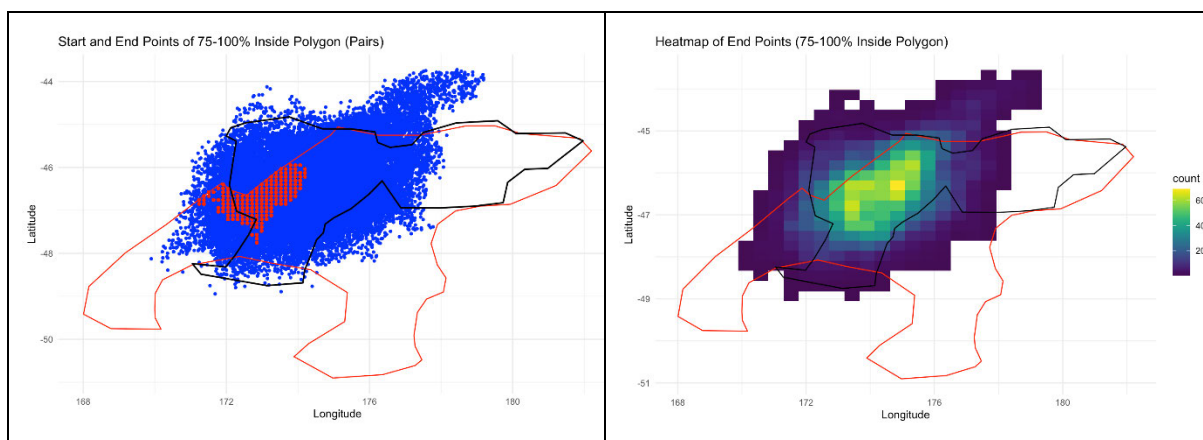


Figure 5.1: Gigablue modelling of particle trajectories for 178 different starting locations. Figure a) shows the release locations (red) and settlement locations (blue) for locations with more than 75% of modelled trajectories ending inside the recommended initial settlement area polygon (black). Figure b) is a heatmap showing the distribution and count of settlement locations for trajectories that ended within the initial recommended settlement area polygon (black).

³ Note that Figure 5.1 displays the release and settlement footprints of 178 starting locations so portrays a much larger footprint than that for an individual deployment. An individual deployment footprint example is presented in Section 5.3

Figure 5.1b shows the highest concentration of settlement areas centred approximately 100 – 200 km northeast of the bulk of the modelled release locations. The rough extents of these model-refined release and settlement areas within the initial recommended areas are presented in Appendix A Figure 3.

The model-refined release area is considered a particularly suitable location within the initial recommended release area as it also avoids all known seabird hotspots. Additionally, the likely settlement area is set back from the more sensitive seamount locations and benthic environments of the Bounty Plateau and Pukaki Rise.

5.3 Indicative particle release example

The heatmaps above provide a picture of the wider potential release and settlement areas based on numerous modelled release and subsequent settlement scenarios. As such an individual release will only influence a very small proportion of this wider area. To demonstrate this the surface dispersion path and settlement area for an individual modelled release scenario is presented in Figure 5.2 below. The figures indicate the initial deployment transect (blue pins), the final surface location (orange pin), and the final settlement centroid (green pin) and associated area polygon.

Figure 5.3 provides a more detailed view of the particle plume trajectory (a) and settlement distribution (b) for the modelled particle release. Particle concentrations immediately prior to sinking (c) and the final settlement location (d) show the highest concentration areas centred approximately 100 – 200 km northeast of the modelled release locations.

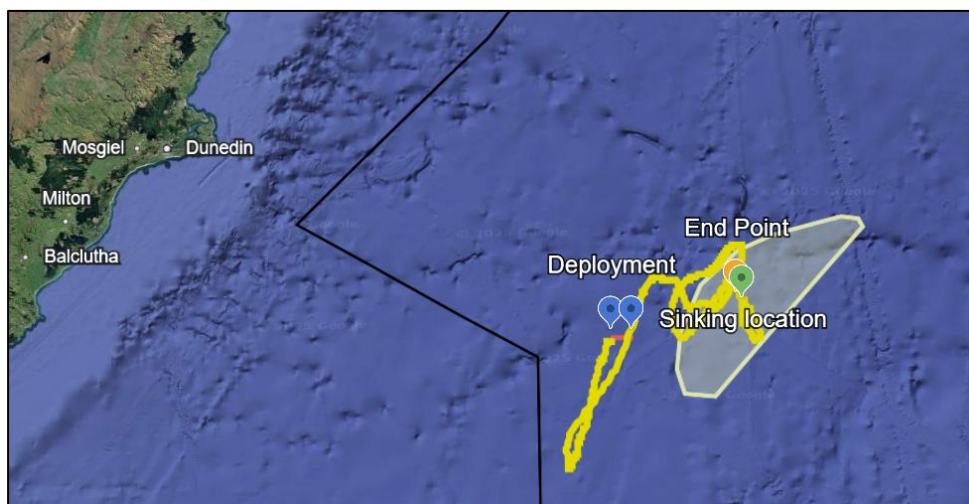


Figure 5.2: Gigablue modelling of particle trajectory from a representative transect within the model-refined release area (46.4S,173.45E to 46.4S,173.35E) based on conditions on 1 December 2018.

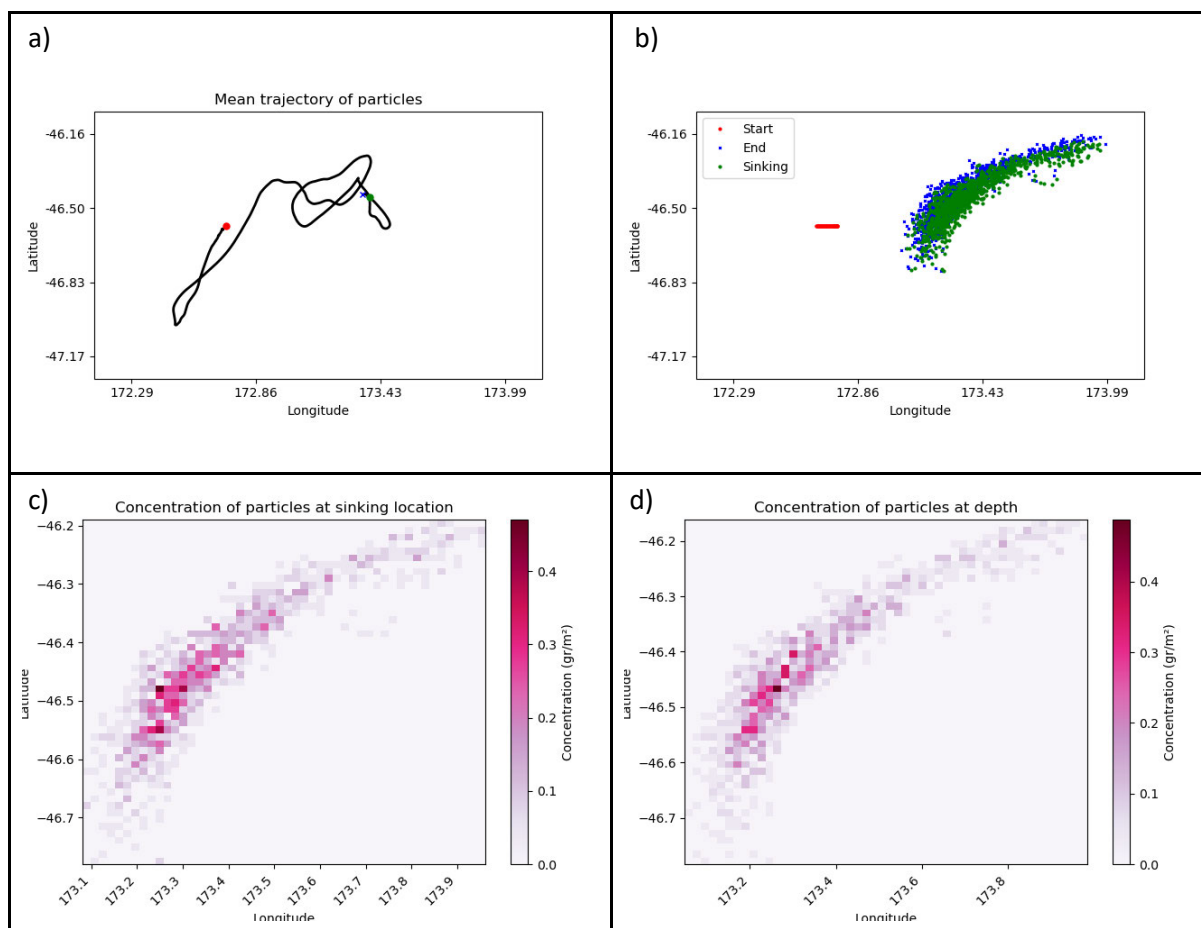


Figure 5.3: Gigablue modelling of the particle trajectory from a deployment transect between 46.4 S, 173.45 E and 46.4S, 173.35 E, from 2018-12-01. a) The mean trajectory (red point) is the centre of the deployment transect, the green point is the sinking location, and the blue x is the final position on the seabed. b) Particle plume with individual particle locations prior to sinking (green) and once settled (blue) from the release transect (red). Concentration of the plume at the sinking location (c) and at the final position on the seabed (d).

Associated summary parameters (i.e. distance travelled, area of plume, concentrations) for the trajectory of an indicative particle release from the model-refined release area on 1 December 2018 are presented in Table 5.1.

Table 5.1: Particle distribution statistics (median) for the release of particles from a representative point within the model-refined release area (46.58S, 172.72E) based on conditions on 1 December 2018.

Parameter	Value
Azimuth to settlement location	75°
Aerial distance to sinking location	79.8 km
Area of plume at 24 hours	256 km ²
Area of settlement	1,122 km ²
Median concentration at 24 hours (Min – Max)	3.77 (3.77 – 18.87) grams per m ²
Median settlement concentration (Min – Max)	0.46 (0.23 – 3.21) grams per m ²

* Median and minimum values are equal as modelling indicated more than half of the concentrations equalled the minimum concentration.

5.4 Operational measures

Operational measures proposed to minimise potential effects of the trial in the refined areas in Appendix A include:

- Limiting the volume and frequency of particle deployments to the minimum amount required for effective monitoring. NIWA has determined that the minimum amount required for echosounder monitoring through the water column is approximately 10 particles per m³ while sinking.
- Deploying particles across a defined transect length to manage the size and density of the plume to minimise both the overall area of effect (i.e. avoiding sensitive environments) and the magnitude of effect on any impacted environments (i.e. minimising particle densities).
- Limiting the area over which the bulk of particles will settle on the seabed to approximately 976 – 1,371 km², as indicated by representative modelling.
- Utilising particles designed to sink quickly following their floating stage, thereby minimising the duration and magnitude of visibility interference within the water column.
- Selecting materials that are inert (where possible), and which carry minimal toxicological risk to marine organisms.
- Avoiding deploying particles in areas where there is obvious marine fauna activity occurring, and exploring the use of a hydrophone to monitor for marine mammals prior to release.

6 Residual effects assessment

This section assesses the potential residual environmental effects of the activity on the biological diversity and integrity of marine species, ecosystems, and processes following the management measures detailed in Section 5. Broader effects on the physical marine environment are first discussed, followed by effects assessments for each of the key marine fauna groups identified in Section 4.

6.1 Water quality effects

6.1.1 Acidification and deoxygenation

One potential adverse side effect of this activity is an increase in deep-sea acidity. As the GIGPA04 particles sink, microbes will continue to decompose the attached organic matter via aerobic respiration, releasing CO_2 into the water. The reaction of CO_2 with water produces carbonic acid (H_2CO_3), which quickly dissociates into bicarbonate (HCO_3^-) and hydrogen (H^+) ions, resulting in a reduction in pH (i.e. acidification). The decomposition of organic matter also raises a potential issue on the other side of the decomposition equation with the consumption of oxygen by microbes through the aerobic respiration of fixed carbon in organic matter.

Ocean acidification has been observed to negatively affect many marine species, with studies observing adverse effects below pH 7.8 (Pörtner et al., 2014). In particular, the acidification of the deep ocean can shift the carbonate saturation horizon, reducing habitat suitability for deep-sea calcifiers like corals, molluscs, and crustaceans (Williamson & Wallace, 2012).

Some studies have raised concerns that large-scale marine carbon dioxide removal (mCDR) may notably enhance the rate of acidification of deep waters (Cao and Caldeira, 2010). The size of these “large-scale” studies have, however, assumed gigatonnes of additional carbon capture over multiple decades, which is many orders of magnitude greater than what is expected from GIGPA04. To further investigate potential acidification effects, Gigablue commissioned an experiment to directly assess the potential for their particle to alter pH levels in marine water taken from within the AOI at the Munida transect eastern station (approx. 65 km offshore) (report in preparation). No significant differences were found between the pH values of the control and particle treatment after 24 hours for a much higher particle concentration (0.42 g/L equivalent to 420 g/m^3) than is expected to occur during the trial (up to $\sim 6.45 \text{ g/m}^3$)⁴ (report in preparation).

Gigablue also modelled the most extreme case of deploying particles instantaneously with no lateral dispersion. Under this scenario, a 1 – 2% decrease in the DIC concentration of the upper photic zone (60 m) was estimated, resulting in an increase of approximately ~ 0.15 units in surface waters. Any detectable increase is expected to be relatively short-lived (i.e. days to weeks) as the ocean re-equilibrates with atmospheric CO_2 and particles disperse. Considering the ongoing acidification of New Zealand’s subantarctic surface waters (Stats NZ, 2022), this temporary reversal essentially acts as a beneficial temporary offset for marine life, particularly for calcifying organisms.

Simulations of large-scale mCDR have also found that this could lead to a loss in seawater dissolved oxygen that is 4–40 times larger than the oxygen gain from mCDR-induced reduction in global warming only (Oschlies et al., 2025). Again, however, such simulations are many orders of magnitude greater than the volumes and timeframes proposed for this trial. Multi-box modelling was undertaken by Gigablue based on a more extreme 10,000 tonne release scenario over 24 hrs to evaluate potential effects of particle settlement on sediment-water interface dissolved oxygen consumption. Modelling indicated a maximum reduction in dissolved oxygen concentrations of $\sim 0.565\%$ under eddy diffusion of $10^{-4} \text{ m}^2/\text{s}$ and bottom current velocity of 0.04 m/s. This suggests

⁴ Based on a conservative mixing depth of 1 m and a 1,000 tonne release scenario after 24 hours.

that oxygen levels would remain consistent with expected deep-ocean concentrations (i.e. oxygen minimum ~5.76 mg/L), even with low diffusivity.

Given the low mass and concentration of particles and organic matter expected to be sequestered on the ocean floor, and the experimental and modelling results, any changes in the pH of deep ocean waters are anticipated to be negligible.

6.1.2 Toxification

No direct effects on water quality are expected to result from the cellulose material components of which the particle is primarily composed. Cellulose is also biodegradable in marine environments and not expected to release any toxic bioproducts (Tachioka et al., 2024). The more minor iron oxide components incorporated in the particles play an important role in allowing the efficient growth of phytoplankton within the particle. These metal nutrients are particularly important where existing concentrations may be growth-limiting, which include areas of the South Pacific Ocean near the AOI (Zheng et al., 2022; Zheng et al., 2024).

Iron oxides present a potential ecotoxicological risk to marine organisms when present in high concentrations or highly reactive forms, particularly as fine particles or under low-oxygen conditions (Adams & Chapman, 2007; ANZG, 2018). Cawthron Institute undertook experiments to assess the acute aquatic toxicity of material components utilised by Gigablue for their particle trials which included cellulose infused with iron and manganese oxides (Champeau, 2024). Of interest for this assessment is the cellulose component (with iron oxide) which comprises the GIGPA04 particle. To enable testing, aqueous leachates of the material containing no particles were prepared using a mixing ratio for material to water of 1:4 in accordance with conservative elutriate methods in the NZ Guidelines for Sea Disposal of Waste (1999). The compounds were screened for toxic effects against the green microalga *Dunaliella tertiolecta* and blue mussel *Mytilus galloprovincialis*. The cellulose material was classified as non-toxic at all tested concentrations (i.e. > 1,000 mg/l), with elutriated metal concentrations of < 2 mg/L (iron).

Further testing of the cellulose material was undertaken to assess for potential cross-contamination. Two sets of analyses were performed on two substrates to assess the signatures associated with two cellulose form/source combinations. The testing methodology utilised inductively coupled plasma mass spectrometry (ICP-MS) analysis to determine the elemental concentrations of a range of metals, metalloids, and non-metals in the cellulose material. The analytical results were then compared against the most conservative ANZG 99% marine Species Protection Levels (SPL) Default Guideline Values DGVs. As a highly conservative exercise, it was assumed that all contaminants would completely dissolve in water and would be entirely bioavailable to marine fauna. Dilution factors were determined based on the maximum modelled density of particles from a 1,000-tonne deployment over 24 hrs after dispersing for 1 hour (210 mg/L) and 24 hours (6.45 mg/L). As the particles will remain near the surface during this timeframe, a relatively shallow mixing depth of 1 m was assumed, which is considered appropriately conservative given the 20 m mixing depth assumed in the New Zealand Guidelines for Sea Disposal of Waste (Marine Safety Authority of New Zealand, 1999). A comparison of the modelled concentrations against the ANZG 99% SPLs is provided in Appendix C Table 1. The results show that all concentrations are below detection limit and/or well below applicable marine guidelines for the 1-hour dispersion scenario, and for the 24-hour dispersion scenario, indicating that adverse toxicological effects on marine fauna from these analytes at the maximum modelled particle densities are unlikely to occur.

These findings suggest that even in large quantities, the particles are unlikely to have a notable ecotoxicological effect on even the most sensitive of marine species due to the low quantities of metals expected to be made bioavailable relative to the toxicity thresholds of marine organisms.

6.1.3 Turbidity

As GIGPA04 involves the release of a larger number of particles, turbidity is the primary concern in terms of the physical properties of marine water. However, particles are unlikely to notably alter turbidity levels for any length of time due to their large size and short suspension period (i.e. ~24 hours). Turbidity in aquatic environments is primarily influenced by clay and silt-sized particles which have a greater surface area-to-volume ratio and a longer time in suspension than the GIGPA04 particles, resulting in increased light scattering over a longer timeframe (Merten et al., 2014). Additionally, Gigablue commissioned a 24-hour elutriation test in artificial seawater using a higher concentration of particles (200 mg/L) than is expected to occur during the trial over the same period (6.45 mg/L). Experimental results showed a very minor increase in turbidity following 24 hours of stirring (1.3 NTU to 1.9 NTU).

A reduction in light penetration through the water column might, however, be expected where particles form a dense surface layer (i.e. immediately following particle release). Given the quantity of particles being released, any light reduction effects are expected to be largely localised to the deployment site, with the intensity of visual disruption dissipating rapidly based on the modelled median 24-hour density (4.11 g/m²) compared to the median density after 18 days of floating (0.40 g/m²).

6.1.4 Toxic algal blooms

Based on eDNA analyses of water and Gigablue particle samples in incubation experiments in May and October 2024 (Saenz-Agudelo & Thomson-Laing, 2024; Saenz-Agudelo & Thomson-Laing, 2025), the presence of harmful algal bloom (HAB) species was minimal across all samples. Indeed, the proportion of HAB organisms was lower in treated samples than in the control during the May 2024 experiments, indicating that none of the treatments favoured the proliferation of pathogens or HABs that were already present in the seawater samples used in the experiment.

6.1.5 Benthic organic matter increase

Organic matter delivered to the seafloor is expected to become mixed into the upper 10 - 20 mm of the sediment by bioturbation and sediment reworking (Teal et al., 2010), resulting in a minor increase in the concentration of organic matter in the sediment. Gigablue have calculated that a single deployment is expected to temporarily increase the organic matter concentration in the upper 10 cm of sediment by <5% based on the average organic carbon storage expected within the marine sediment (Nodder et al., 2023). As fresh organic matter is highly reactive and undergoes decay by aerobic microorganisms on short timescales (i.e. years) (DeMaster et al., 2021), the long-term increase in sedimentary organic matter concentrations is expected to remain small, even in the case of sustained deployment over decades. The additional organic matter is expected to stimulate benthic communities while causing only a negligible increase in oxygen consumption within the sediments. Additionally, D'Hondt et al. (2015) found that sediments beneath the South Pacific Gyre adjacent to the AOI frequently remain oxygenated to depths of tens of meters due to the low baseline organic matter supply, low microbial respiration rates, and favourable physical conditions for oxygen diffusion (D'Hondt et al., 2015).

6.2 Phytoplankton and zooplankton

Macronutrient Depletion: Phytoplankton may be positively affected through growth within the particle but enhanced uptake of inorganic carbon and macronutrients (primarily nitrate and phosphate) to produce biomass could potentially perturb the regional budgets of these elements. Gigablue's worst-case-scenario modelling using a very shallow mixed layer (10 m) showed that the reduction in macronutrient percentages from ambient values was less than 1.8% for each macronutrient based on a particle density of 3.9 g/m² for a deployment mass of 10,000 tonnes and a

float time of 21 days. Reduced nutrient levels in the Area of Interest (AOI) resulted in a maximum phytoplankton growth rate reduction of 0.1% from ambient levels.

Ingestion: Ingestion is unlikely as the particles are too large to ingest for most zooplankton.

Ecotoxicity: As detailed in Section 6.1.2, no ecotoxicity effects on marine fauna are expected.

Bioaccumulation: Due to the short lifecycles of plankton and their position as the primary consumers of the particle nutrients, bioaccumulation is not considered to pose a significant adverse effect.

6.3 Marine Invertebrates and Biogenic Habitat

Deep Sea Acidification and oxygen depletion: As detailed in Section 6.1.1, experimental and modelling results indicate that potential reductions in pH and dissolved oxygen will be negligible even under worst-case-scenario conditions.

Ingestion: Cellulose is naturally produced by certain macroalgae (e.g. *Ulva Lactuca*) and plays a key role in fuelling benthic food webs, particularly for grazing invertebrates (Andrade et al. 2025; Yaich et al. 2015). Although the particles are unlikely to be completely swallowed by most macroinvertebrates due to their large relative size, material which may be released from the particles during decomposition or mechanical fragmentation (i.e. chewing, abrasion) will likely be taken up by benthic invertebrates via scavenging, grazing, and filter-feeding (Remy et al., 2015; Berlino et al., 2021; Andrade et al., 2025). Given the dietary role of cellulose in benthic food webs and their high rate of biodegradation, any adverse effects are expected to be limited to potential digestive issues resulting from the rare uptake of large quantities of whole particles.

Ecotoxicity: As detailed in Section 6.1.2, no ecotoxicity effects on marine fauna are expected.

Bioaccumulation: Iron is an essential trace metal for many marine invertebrate species (Jeong et al., 2023; Oweson & Hernoth, 2009). As such, many species have evolved mechanisms to regulate the uptake of this metal (Chiarelli & Roccheri, 2014). However, bioaccumulation can occur where concentrations exceed an organism's regulation capacity. Given the very low concentration of metals in the GIGPA04 particles and the high proportion of affected phytoplankton organic matter expected to sink to the ocean floor within the particles, bioaccumulation of particle materials is expected to be negligible.

Smothering: In some circumstances oral mortality has been observed due to successive microbial processes triggered by the presence of organic matter in naturally and artificially deposited marine sediments (Weber et al., 2012). Colonies of deep-sea coral (*Lophelia pertusa*) have also presented high mortality rates under complete burial conditions, but could effectively shed shallower surface coverages of sediment within 15 minutes through ciliary action and mucus production (Brooke et al., 2009).

Even at the highest expected settlement density (26 per m²), particles are expected to settle gently (i.e. 1.5 cm/s) across a single diffuse layer. Additionally, the large grain size and permeable structure of the particles will allow interstitial water flow between and through particles, reducing the risk of localised deoxygenation around sessile fauna. Natural and regenerated cellulose can also undergo complete biodegradation within 35 days at the seafloor of shallow coastal waters (Royer et al., 2023), though this rate would likely be slower in a deep-sea environment (i.e. reduced temperature and oxygen). As noted in Section 6.1.5, the additional organic matter is also expected to stimulate benthic communities and to negligibly increase O₂ consumption within the sediments.

Considering the low density of particle deposition, the biodegradation of particles, and the potential stimulation of benthic communities, no significant adverse effects are expected to occur, even within more sensitive biogenic habitat areas. Furthermore, if high probability biogenic habitat areas

are avoided through careful release site selection, only low to negligible effects are expected to occur.

Abrasion: No direct abrasion effects are expected for mobile fauna which will likely be able to avoid the large and dispersed particles within the water column. For sessile fauna, abrasive effects from falling particles are unlikely to be detectable due to the slow rate of descent and the soft texture of the particle (i.e. no hard or sharp components).

Turbidity: As detailed in Section 6.1.3, the particles themselves will be too large and diffuse within the water column to affect turbidity except immediately after release, and experimental results indicate that even under the worst-case-scenario, any increase in turbidity would be minimal and short lived.

6.4 Fish

Ingestion: Many studies have reported on the ingestion of anthropogenic marine debris, typically plastic, by fish (Gall & Thompson, 2015). Fish may try to eat entire particles or pieces of particles, particularly when coated in phytoplankton, presenting some potential health risks. Herman et al. (2021) found that the transfer of iron from zooplankton to fish through direct ingestion resulted in lower uptake compared to the uptake directly from water to fish, suggesting this pathway presents a lower toxicological risk for fish than directly from the water.

The size of the particles may also present a digestive issue for fish of a certain size where many particles are ingested whole. Although limited studies have been undertaken on this topic, some have noted impairment and inflammation of the digestive system of fish following the ingestion of large soft-plastic fragments (Alhmoudi et al., 2024; Rummel et al., 2016). However, the favourable physical properties of the particles (i.e. soft, compressible, and hydrophilic) suggest that they are relatively unlikely to result in significant adverse health effects unless consumed in very high quantities. Additionally, the fish species most likely to ingest particles are also the algal-feeding fish most likely to be able to digest cellulose material (Augustine & Joseph, 2018). There is also some evidence that the inclusion of cellulose in fish diets can have health benefits (e.g. improved intestinal health) (Zhang et al., 2022).

The reviewed information suggests that while there is a moderate risk of ingestion, adverse effects are anticipated to be low to negligible.

Ecotoxicity: As detailed in Section 6.1.2, no ecotoxicity effects on marine fauna are expected.

Bioaccumulation: As for marine invertebrates, iron is an essential trace metal for marine fish (Chandrapalan & Kwong, 2021). As such, fish have evolved specific physiological mechanisms (i.e. involving intestine and gills) to regulate metal absorption, and there is even evidence that fish can modulate trace metal uptake at the gill (Chandrapalan & Kwong, 2021). However, bioaccumulation can occur where concentrations exceed an organism's regulation capacity.

The main ecological issue for fish is more a lack of bioaccumulation owing to low environmental iron concentrations, resulting in deficiencies for marine phytoplankton and fish (ANZG, 2025). Similarly, iron deficiencies in lower trophic levels have been reported to limit the growth of marine fish, suggesting that increasing bioaccumulation is generally desirable (Galbraith et al., 2019).

Ingested cotton and viscose material is hydrophilic (water-attracting), making it less likely to cross lipid membranes when ingested (i.e. gut and blood vessel). This reduces its potential to accumulate in fatty tissues, unlike hydrophobic microplastics which are consequently more resistant to environmental degradation (Egan & Salmon, 2022).

Given the above evidence, the very low concentration of metals in the GIGPA04 particles, and the high proportion of affected phytoplankton organic matter expected to sink to the ocean floor with

the particles, bioaccumulation of iron is not expected to occur. If it were to occur, it would likely have a positive effect on fish communities.

Abrasion: No direct abrasion effects are expected for mobile fauna which will likely be able to avoid the large and dispersed particles within the water column.

Turbidity: As detailed in Section 6.1.3, the particles themselves will be too large and diffuse within the water column to affect turbidity except immediately after release, and experimental results indicate that even under the worst-case-scenario, any increase in turbidity would be minimal and short lived.

The blocking of surface light during the initial floating phase may, however, result in indirect effects including avoidance behaviour and reduced feeding success of visual predators, and possibly a subsequent reduction in growth condition and reproductive output (Colin & Hart, 2015; Wenger et al., 2017). Given the quantity of particles being released, any light reduction effects are expected to be largely localised to the deployment site and limited to the first few days due to the rapid rate of surface dispersion (See Section 6.1.3). As such, no adverse effects are expected to occur.

6.5 Marine Mammals

Ingestion: Many studies have reported on the ingestion of anthropogenic marine debris, typically plastic, by marine organisms (Gall & Thompson, 2015). The likelihood of ingestion is expected to be related to feeding methods. Filter feeders (e.g. Blue, Bryde's, Humpback, Southern Right whales) may incidentally consume particles mistaken for plankton, and dolphins may visually investigate particles resembling prey. Based on the relatively small size of the particles combined with their biodegradability and relatively rapid dispersion to low concentrations, if incidentally ingested, particles are likely to pass through the digestive systems of marine mammals without adverse effects. Additionally, the offshore location of the selected trial area avoids the distribution of many of the smaller dolphin species which might be more at risk.

Ecotoxicity: As detailed in Section 6.1.2, no ecotoxicity effects on marine fauna are expected.

Bioaccumulation: As for marine fish and invertebrates, iron is an essential trace metal for marine mammals which can be regulated through various mechanisms including hepatic metabolism, biotransformation, and excretion (Page et al., 2024). However, bioaccumulation can occur where concentrations exceed an organism's regulation capacity, particularly for marine mammals which are generally at the top of the food web. Food web accumulation is, however, expected to be limited given the baseline deficiency of iron in the trial area and the relatively small scale and duration of the trial. No evidence exists for accumulation of cellulose in marine mammals, and its hydrophilic nature means it is less likely to penetrate lipid membranes or accumulate in fatty tissue (Zantis et al., 2020; Egan & Salmon, 2022).

Abrasion: No direct abrasion effects are expected for mobile fauna which will likely be able to avoid the large and dispersed particles within the water column.

Turbidity: As detailed in Section 6.1.3, the particles themselves will be too large and diffuse within the water column to affect turbidity except immediately after release, and experimental results indicate that even under the worst-case-scenario, any increase in turbidity would be minimal and short lived. Additionally, reduced visibility is not expected to affect echolocating species which have been found to rely on sonar rather than vision in turbid environments (Todd et al., 2014).

The blocking of surface light during the initial floating phase may, however, result in indirect effects including avoidance behaviour and reduced feeding success of visual predators, and possibly a subsequent reduction in growth condition, and reproductive output (Colin & Hart, 2015; Wenger et al., 2017).

Given the quantity of particles being released, any light reduction effects are expected to be largely localised to the deployment site and limited to the first few days due to the rapid rate of surface dispersion (See Section 6.1.3). As such, no adverse effects are expected to occur.

Acoustic interference: Particles may alter the acoustic properties of the water, potentially reducing the effective communication range or detection capabilities of marine mammals, especially in species that rely heavily on acoustic cues such as Southern right whale (Erbe et al., 2016). These effects are expected to be greatest for particles within the water column which would likely act similarly to suspended sediment (Erbe et al., 2022). However, given the very low density of the suspended particles within the water column and the short suspension time, any interference is expected to be negligible.

6.6 Seabirds

Ingestion: Ingestion of pumice or gastroliths is common across many seabird species (e.g. penguins, albatrosses, petrels, storm-petrels, skuas, auks) to aid in the mechanical digestion of food (Lavers & Bond 2023). Thompson (2025) notes that given the propensity of seabirds to ingest non-food items, and given the spatial overlap between the AOI and the wide range of taxa utilising the area, it is likely that seabirds will ingest particles. Indeed, seabirds are one of the vertebrate groups most affected by the ingestion of plastic through direct uptake (i.e. mistaken for food) and indirect uptake via bioaccumulation (Kibria, 2024).

Petrels, shearwaters, and fairy prion are likely to be at the greatest risk of ingesting particles due to their surface feeding behaviour and/or their diets targeted to crustaceans and plankton (Roman et al., 2019). Birds which typically feed on larger fish and squid prey such as albatross are less likely to target the relatively small particles (Van der Reis et al., 2024). As such, the proximity of 'Threatened' albatross hotspots to the likely trajectory of surface particles is unlikely to notably increase their risk of ingestion. Birds which forage using diving methods are also less likely to incidentally ingest particles compared to those which filter at the surface, as they would likely exhibit avoidance behaviour due to visibility limitations (Darby et al., 2022).

Thompson (2025) does note considerable uncertainty surrounding the interaction between the seabirds and the released particles, however, Gigablue have video evidence from their smaller scale trial in October 2024 showing seabirds avoiding the particles and only resting in waters well clear from the plume.

Where ingestion could occur, the stomach acid of some seabirds (i.e. wandering albatross) may be concentrated enough to aid in particle digestion (Grémillet et al., 2012), but, whilst considered unlikely, the consumption of large volumes of particles could cause intestinal blockages and nutrient absorption impairment (Thompson, 2025). In smaller volumes, cellulose is unlikely to result in abrasion damage in the digestive tract and would likely pass through the digestive tract or be regurgitated, particularly considering the ability of seabirds to excrete harder materials such as bones, otoliths, and shells (Barrett et al., 2007).

Though the likelihood of seabirds ingesting particles at volumes sufficient to cause adverse health effects is expected to be low, the consequence of the loss of an individual from a vulnerable taxon within the AOI would be significant. Consequently, the proposed release site in the western extent of the AOI has been selected to avoid known bird hotspots for the most vulnerable species, thereby reducing the overall risk of birds encountering and ingesting large numbers of particles in these areas. The western release site also reduces the likelihood of Chatham Island tāiko encountering the plume when it is at its densest, with species observations limited to eastern areas of the AOI (eBird, 2025).

As such, the overall magnitude of effect (i.e. likelihood + effect) from direct particle ingestion is expected to be low.

Turbidity and visibility: Most of New Zealand's seabirds rely solely on vision for prey detection. As detailed in Section 6.1.3, the particles themselves will be too large and diffuse within the water column to affect turbidity except immediately after release, and experimental results indicate that even under the worst-case-scenario, any increase in turbidity would be very low.

The particles are, however, likely to restrict visibility at the surface during the initial floating phase. Potential adverse effects on seabirds may include avoidance behaviour and reduced feeding success of visual predators, and possibly a subsequent reduction in growth condition and reproductive output (Colin & Hart, 2015; Wenger et al., 2017; Lukies et al., 2021). The rapid dispersion of the particles from an initial 7.2 km transect to an area of 976 – 1,371 km² at the time of sinking indicates that visual obstruction will likely be undetectable shortly after their release (i.e. within the first few hours to days).

Abrasion: No direct abrasion effects are expected given the soft material composition of the particle and the relatively limited expected interaction.

Bioaccumulation: As for other marine fauna, iron is an essential trace metal for seabirds which are typically regulated through feather moult and excretion (Roman et al., 2023). However, bioaccumulation can occur where concentrations exceed an organism's regulation capacity, particularly for seabirds which are generally at the top of the food web. Food web accumulation is, however, expected to be relatively limited given the baseline deficiency of iron in the trial area and the relatively small scale and duration of the trial. No evidence exists for accumulation of cellulose based material in seabirds, and cellulose material is hydrophilic, less likely to penetrate lipid membranes or accumulate in fatty tissue (Zantis et al., 2020; Egan & Salmon, 2022).

7 Residual effects summary and conclusions

The recommended model-refined settlement and release areas and particle release methodology for GIGPA04 have been selected to avoid sensitive habitats and vulnerable species wherever possible. Northern regions of the Bounty Trough bordering the Chatham Rise offer the most suitable trial locations in terms of avoiding sensitive environments and marine fauna whilst maintaining minimum desired settlement depths (i.e. exceeding ~1000 m). A release area has been recommended which has a high modelled probability of settling particles in a central area of the AOI within the Bounty Trough, which avoids the majority of sensitive environments and marine fauna (Appendix A Figure 1). The model-refined release area and surface trajectory of the plume was also selected to avoid most fauna hotspots identified from NABIS (2025), particularly for more vulnerable seabird species (i.e. 'Threatened' and 'At Risk') (Appendix A, Figure 2).

Residual environmental effects from GIGPA04, even under worst-case-scenario conditions, are expected to be minimal. Modelling and experimental results indicate negligible acidification and oxygen depletion, with any minor increases in surface pH temporarily improving ocean habitability. No toxic effects are expected from the cellulose-based particles or the iron components, which are present at concentrations well below ecotoxicological effects thresholds. Turbidity and/or light reduction effects are predicted to be minor, localised, and short-lived due to the particles' large size and rapid dispersion and settling.

Effects on individual marine species groups are expected to be low to negligible, and phytoplankton may be positively affected through growth within the particle, with only minor impacts on nutrient availability. Zooplankton and marine invertebrates are unlikely to ingest particles due to their size, and both bioaccumulation and ecotoxicity risks are low. Benthic communities may experience slight enrichment from organic matter, but without smothering or oxygen stress occurring. Though there is some risk of fish, marine mammals, and seabirds consuming particles, no ecotoxicity effects are expected to occur, and potential adverse effects on the digestive system are anticipated to be low to negligible, primarily due to the favourable physical properties of the particle. There is also some evidence that seabirds may actively avoid the particle plume, and the diets of the more vulnerable albatross species suggest they would be unlikely to actively target particles.

The release location and methodology have been informed by the environmental setting and the potential environmental effects in order to avoid and mitigate adverse effects. Additionally, the experiments and models which have informed this assessment were generally based on worst-case deployment scenarios for a 1,000 to 10,000 tonne deployment with deposition densities and concentrations utilising the maximum volume of particles. The actual total release volume for this trial will be no more than 1,000 tonnes total and could be as small as 50 tonnes per release with a maximum of five releases. As such, this IA represents a very conservative assessment of potential effects with respect to what is actually expected for the trial.

The combination of careful site selection, predictive modelling, conservative effects assessment, and operational safeguards should therefore ensure that the trial proceeds with minimal ecological disturbance. As such, this IA concludes that the residual adverse environmental effects from the trial are expected to be low to negligible.

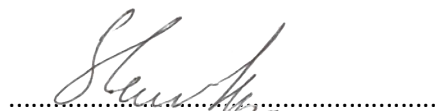
8 Applicability

This report has been prepared on behalf of our client GIGABLUE AOTEAROA SOUTH PACIFIC LIMITED, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement. We understand and agree that this report will be used by the Environmental Protection Authority in undertaking its regulatory functions.

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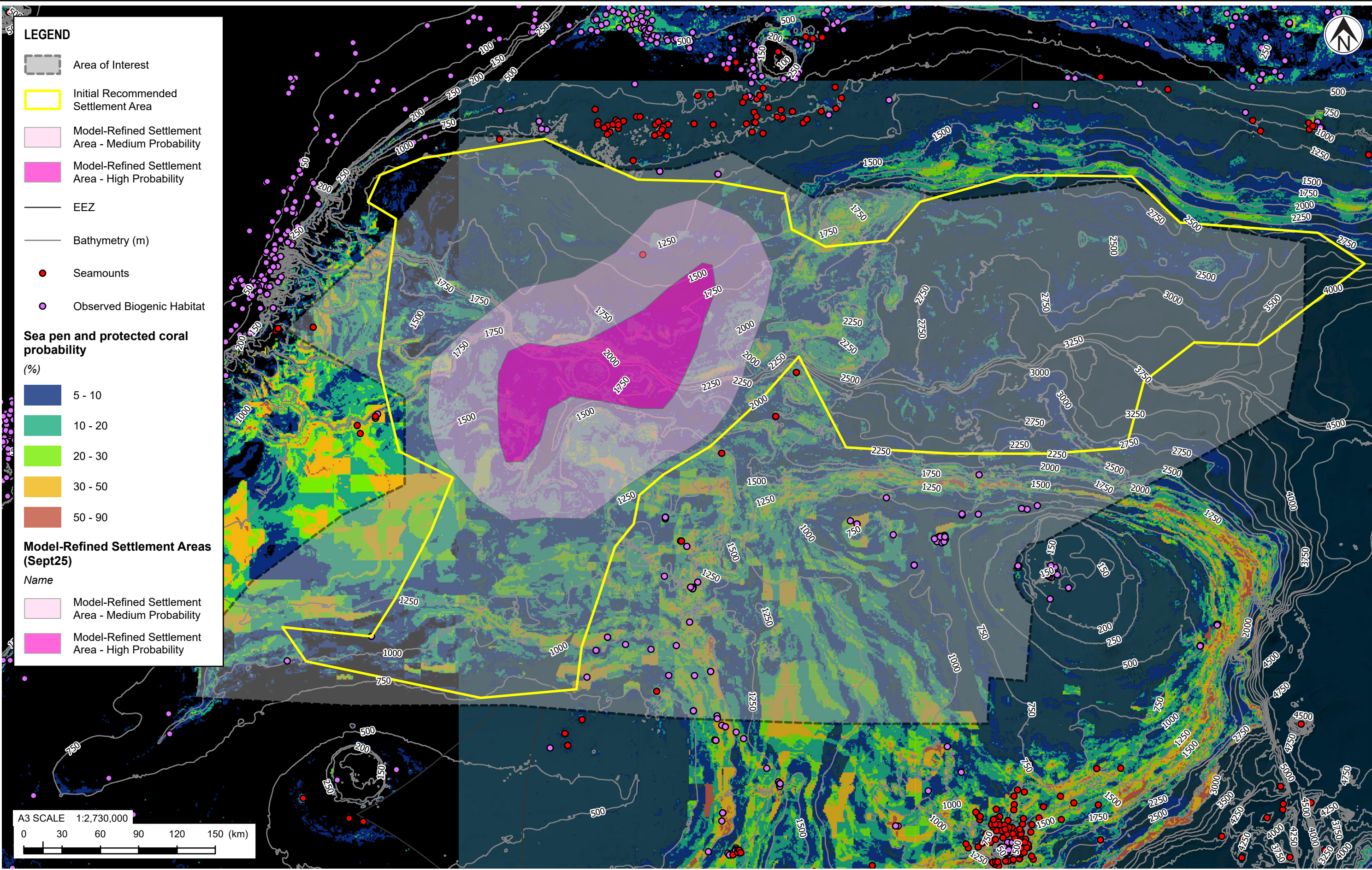
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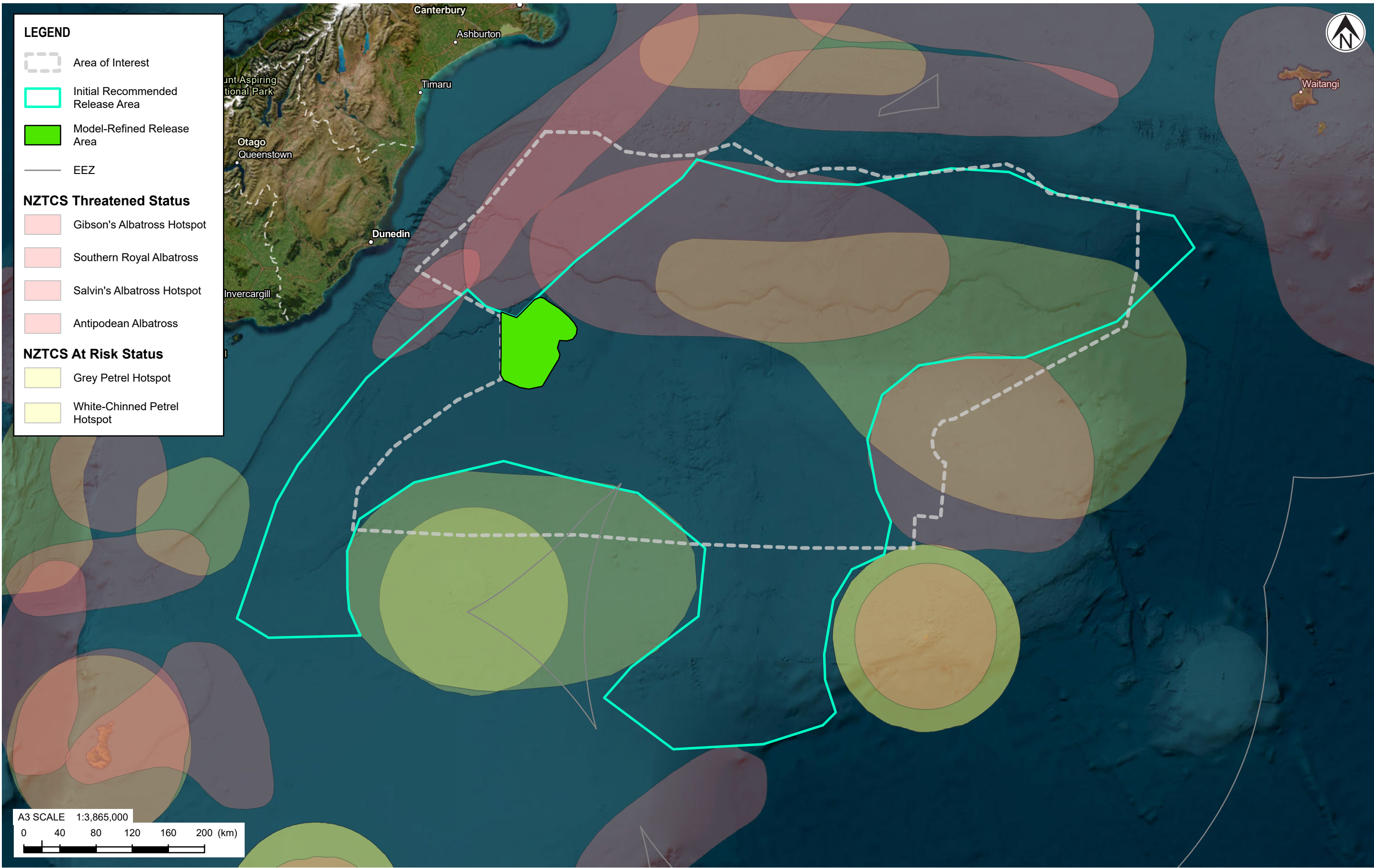
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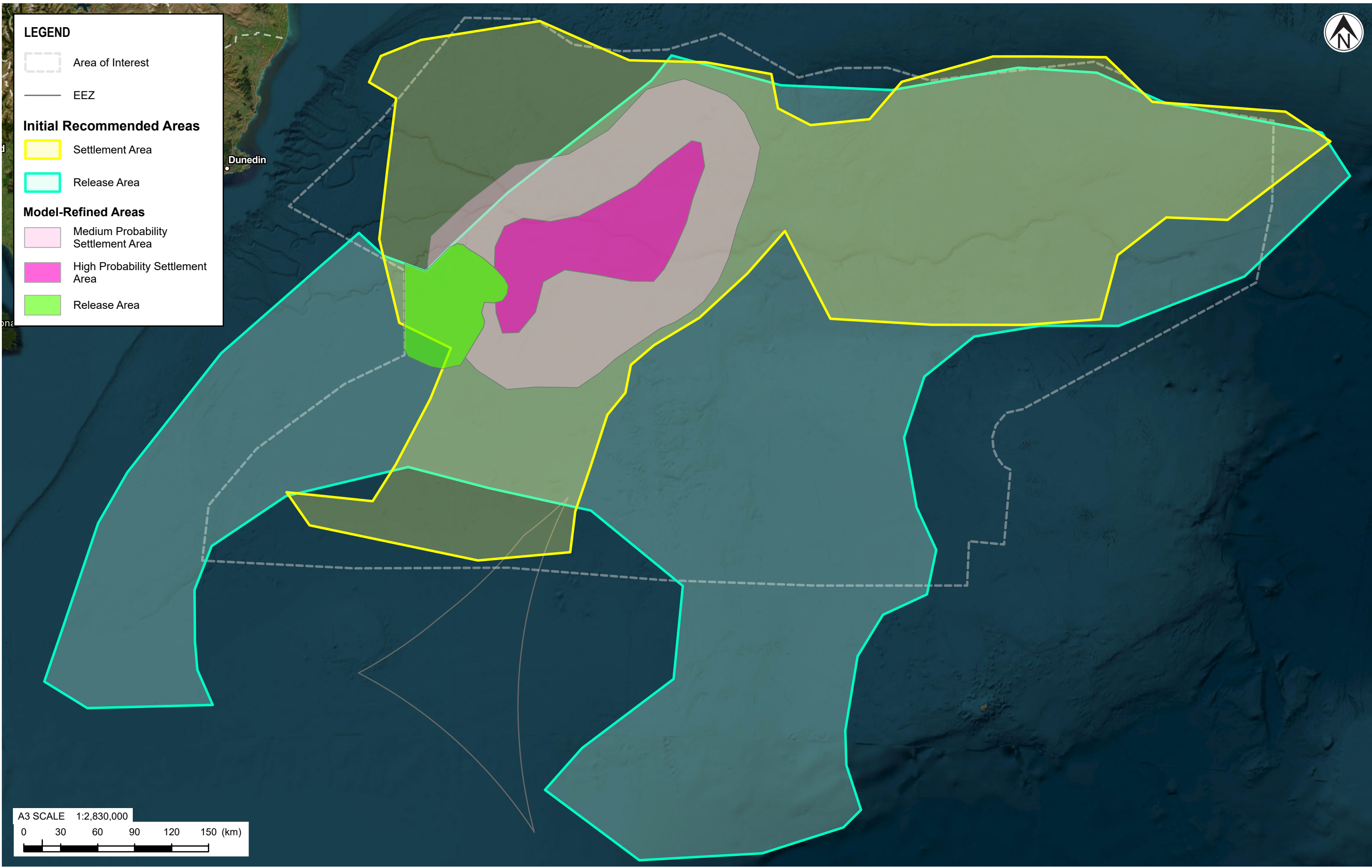
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Appendix A Site location maps

- **Appendix A Figure 1: Recommended release areas to minimise overlap with vulnerable seabird hotspots**
- **Appendix A Figure 2: Recommended settlement areas to minimise overlap with sensitive benthic habitat**
- **Appendix A Figure 3: Model-refined release areas and predicted settlement area centroid**







Appendix B Seabird summary table

Appendix B Table 1: Summary information on the conservation status and relative abundance of seabirds likely to occur in the area of interest. Taxonomy and conservation status, based on the New Zealand Threat Classification System (NZTCS), follows Robertson et al. (2021). International Union for Conservation of Nature (IUCN) Red List classifications follow data at <http://www.iucnredlist.org/> (accessed May 2025). Relative abundance scores follow Townsend et al. (2008) based on information available at the New Zealand Birds Online and/or NZTCS websites*.

Common Name	Scientific Name	Conservation Status - NZTCS	IUCN Red List Classification	Relative Abundance
Antipodean albatross	<i>Diomedea antipodensis antipodensis</i>	Threatened - Nationally Critical	Endangered	4
Gibson's albatross	<i>Diomedea antipodensis gibsoni</i>	Threatened - Nationally Critical	Endangered	4
Whenua Hou diving petrel	<i>Pelecanoides whenuahouensis</i>	Threatened - Nationally Critical	Critically Endangered	1
Chatham Island tāiko	<i>Pterodroma magentae</i>	Threatened - Nationally Critical	Critically Endangered	1
Salvin's albatross	<i>Thalassarche salvini</i>	Threatened - Nationally Critical	Vulnerable	5
Black-fronted tern	<i>Chidonias albostratus</i>	Threatened - Nationally Endangered	Endangered	4
Yellow-eyed penguin	<i>Megadyptes antipodes</i>	Threatened - Nationally Endangered	Endangered	3
Subantarctic skua	<i>Catharacta antarctica lonnbergi</i>	Threatened - Nationally Vulnerable	Least Concern	3
Southern royal albatross	<i>Diomedea epomophora</i>	Threatened - Nationally Vulnerable	Vulnerable	4
Northern royal albatross	<i>Diomedea sanfordi</i>	Threatened - Nationally Vulnerable	Endangered	4
Caspian tern	<i>Hydroprogne caspia</i>	Threatened - Nationally Vulnerable	Least Concern	3
Foveaux shag	<i>Leucocarbo stewarti</i>	Threatened - Nationally Vulnerable	*	3
Lesser fulmar prion	<i>Pachyptila crassirostris flemingi</i>	Threatened - Nationally Vulnerable	Least Concern	3
Light-mantled sooty albatross	<i>Phoebastria palpebrata</i>	Threatened - Nationally Vulnerable	Near Threatened	4
Chatham petrel	<i>Pterodroma axillaris</i>	Threatened - Nationally Vulnerable	Vulnerable	3
Hutton's shearwater	<i>Puffinus huttoni</i>	Threatened - Nationally Vulnerable	Endangered	6
Spotted shag	<i>Stictocarbo punctatus punctatus</i>	Threatened - Nationally Vulnerable	Least Concern	5
Grey-headed albatross	<i>Thalassarche chrysostoma</i>	Threatened - Nationally Vulnerable	Endangered	4
Otago shag	<i>Leucocarbo chalconotus</i>	Threatened - Nationally Increasing	*	3
Antarctic tern	<i>Sterna vittata bethunei</i>	Threatened - Nationally Increasing	Least Concern	3
Fiordland penguin	<i>Eudyptes pachyrhynchus</i>	At Risk - Declining	Near Threatened	4

Common Name	Scientific Name	Conservation Status - NZTCS	IUCN Red List Classification	Relative Abundance
Erect-crested penguin	<i>Eudyptes sclateri</i>	At Risk - Declining	Endangered	6
Southern blue penguin	<i>Eudyptula minor minor</i>	At Risk - Declining	Least Concern	4
Black-billed gull	<i>Larus bulleri</i>	At Risk - Declining	Near Threatened	5
Red-billed gull	<i>Larus novaehollandiae scopulinus</i>	At Risk - Declining	Least Concern	5
Buller's shearwater	<i>Puffinus bulleri</i>	At Risk - Declining	Vulnerable	6
Sooty shearwater	<i>Puffinus griseus</i>	At Risk - Declining	Near Threatened	6
White-fronted tern	<i>Sterna striata striata</i>	At Risk - Declining	Near Threatened	5
Southern Buller's albatross	<i>Thalassarche bulleri bulleri</i>	At Risk - Declining	Near Threatened	4
White-capped albatross	<i>Thalassarche cauta steadi</i>	At Risk - Declining	Near Threatened	6
Australian little penguin	<i>Eudyptula novaehollandiae</i>	At Risk - Recovering	**	4
Northern giant petrel	<i>Macronectes halli</i>	At Risk - Recovering	Least Concern	3
Pied shag	<i>Phalacrocorax varius varius</i>	At Risk - Recovering	Least Concern	3
Grey-backed storm petrel	<i>Garrodia nereis</i>	At Risk - Relict	Least Concern	5
Antarctic prion	<i>Pachyptila desolata</i>	At Risk - Relict	Least Concern	6
Fairy prion	<i>Pachyptila turtur</i>	At Risk - Relict	Least Concern	6
Broad-billed prion	<i>Pachyptila vittata</i>	At Risk - Relict	Least Concern	6
White-faced storm petrel	<i>Pelagodroma marina maoriana</i>	At Risk - Relict	Least Concern	6
Southern diving petrel	<i>Pelecanoides urinatrix chathamensis</i>	At Risk - Relict	Least Concern	6
Black shag	<i>Phalacrocorax carbo novaehollandiae</i>	At Risk - Relict	Least Concern	3
Little shag	<i>Phalacrocorax melanoleucos brevirostris</i>	At Risk - Relict	Least Concern	4
Grey petrel	<i>Procellaria cinerea</i>	At Risk - Relict	Near Threatened	5
Cook's petrel	<i>Pterodroma cookii</i>	At Risk - Relict	Vulnerable	6
Mottled petrel	<i>Pterodroma inexpectata</i>	At Risk - Relict	Near Threatened	6
Fluttering shearwater	<i>Puffinus gavia</i>	At Risk - Relict	Least Concern	5
Snares Cape petrel	<i>Daption capense australe</i>	At Risk - Naturally Uncommon	Least Concern	4

Common Name	Scientific Name	Conservation Status - NZTCS	IUCN Red List Classification	Relative Abundance
Snares crested penguin	<i>Eudyptes robustus</i>	At Risk - Naturally Uncommon	Vulnerable	5
Bounty Island shag	<i>Leucocarbo ranfurlyi</i>	At Risk - Naturally Uncommon	Vulnerable	2
Fulmar prion	<i>Pachyptila crassirostris crassirostris</i>	At Risk - Naturally Uncommon	Least Concern	5
Chatham fulmar prion	<i>Pachyptila crassirostris pyramidalis</i>	At Risk - Naturally Uncommon	Least Concern	4
Westland petrel	<i>Procellaria westlandica</i>	At Risk - Naturally Uncommon	Endangered	3
Soft-plumaged petrel	<i>Pterodroma mollis</i>	At Risk - Naturally Uncommon	Least Concern	4
Subantarctic little shearwater	<i>Puffinus elegans</i>	At Risk - Naturally Uncommon	Least Concern	5
Northern Buller's albatross	<i>Thalassarche bulleri platei</i>	At Risk - Naturally Uncommon	Near Threatened	5
Chatham Island albatross	<i>Thalassarche eremita</i>	At Risk - Naturally Uncommon	Vulnerable	4
Campbell albatross	<i>Thalassarche impavida</i>	At Risk - Naturally Uncommon	Vulnerable	5
Black-bellied storm petrel	<i>Fregetta tropica</i>	Not Threatened	Least Concern	5
Southern black-backed gull	<i>Larus dominicanus dominicanus</i>	Not Threatened	Least Concern	6
Australasian gannet	<i>Morus serrator</i>	Not Threatened	Least Concern	5
White-chinned petrel	<i>Procellaria aequinoctialis</i>	Not Threatened	Vulnerable	6
White-headed petrel	<i>Pterodroma lessonii</i>	Not Threatened	Least Concern	6
Grey-faced petrel	<i>Pterodroma macroptera gouldi</i>	Not Threatened	Least Concern	6
Pomarine skua	<i>Coprotheres pomarinus</i>	Migrant	Least Concern	
Cape petrel	<i>Daption capense capense</i>	Migrant	Least Concern	
Wandering albatross	<i>Diomedea exulans</i>	Migrant	Vulnerable	
Antarctic fulmar	<i>Fulmarus glacialisoides</i>	Migrant	Least Concern	
Southern giant petrel	<i>Macronectes giganteus</i>	Migrant	Least Concern	
Wilson's storm petrel	<i>Oceanites oceanicus exasperatus</i>	Migrant	Least Concern	
Short-tailed shearwater	<i>Puffinus tenuirostris</i>	Migrant	Least Concern	
Arctic skua	<i>Stercorarius parasiticus</i>	Migrant	Least Concern	
Black-browed albatross	<i>Thalassarche melanophris</i>	Coloniser	Least Concern	1

Note: *<http://nzbirdsonline.org.nz/> and <https://nztc.org.nz/>

Appendix C Solid particle testing results

Appendix C Table 1:

9(2)(b)(i), 9(2)(b)(ii)

9(2)(b)(i), 9(2)(b)(ii)

9(2)(b)(i), 9(2)(b)(ii)



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