Aquatic
Environmental
Sciences

Trans-Tasman Resources Ltd consent application: Ecological assessments

Prepared for Trans-Tasman Resources ltd

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1. Background

Trans-Tasman Resources Ltd (TTR) intends to apply for marine consent from the Environmental Protection Agency (EPA) for the recovery of iron ore deposits from marine sands within the South Taranaki Bight (STB). An earlier application by TTR in 2013 / 2014 was declined by the Decision Making Committee (DMC) appointed by the EPA. In response to this decision TTR have commissioned additional investigations / assessment to support the new marine consent application.

The main issues identified by the DMC in the previous decision were concerns about:

- The scale and uncertainties of the effects and in particular the sediment plume dispersion;
- The lack of information on some components of the affected ecosystem and effects on these components (zooplankton, fish, birds and mammals);
- The extent of effects on primary production and carbon flows; and
- No triggers or compliance levels were provided.

TTR have undertaken an extensive programme to update and refine the physical models that support some of the effects assessments and to address the areas of uncertainty and the concerns raised by the DMC, as well as commissioning further local and international peer reviews of the information available.

There was a considerable body of information and reports provided with the first marine consent application which substantially increased understanding of the existing environment and the potential effects of the iron sand recovery operations (ISR) in the STB. The results of the new work focused on sediment plume source terms, characteristics and dispersion, optical properties, primary production and zooplankton and have been reported in Cahoon et al. (2015), Hadfield & Macdonald (2015), HRW (2015), Pinkerton & Gall (2015), MacDiarmid et al. (2015b).

2. Scope of this report

AES has been commissioned by TTR to provide an overview report assessing the potential effects of ISR operations on the ecological values of the STB. The specific aims of the report are to:

- Summarise what is known about the existing marine environment based on previous published and unpublished reports and publications, studies and reports provided for the previous marine consent application, and new assessments undertaken to provide greater certainty around the potential effects;
- Assess the ecological significance of the proposed activities on the coastal environment; and
- Provide potential triggers and compliance levels.

The assessment is based on relevant specialist reports, workshops and discussions with science and planning experts, published reports and papers, and experience in coastal, offshore marine ecosystems, including off the West Coast of the South Island and in the Taranaki Bight.

The environment in the STB is a very dynamic and complex one thus this assessment is based on the best available information, which is considered sufficiently comprehensive to provide a robust assessment of potential effects.

3. Description of the existing environment

The proposed activities will take place in the STB which can be defined as the large bay to the south and east of the South Taranaki coastline and extending down to Farewell Spit and the western entrance to Cook Strait. In the region potentially impacted by ISR operations the water shallows gently across the Patea Shoals from a depth of 20-50 m offshore of Patea Township. The area is very exposed to southerly and westerly storms with large swells and resulting active bed transport and resuspension of sediments. Four large rivers, the Patea, Whanganui, Rangitikei and the Manawatu flow into the STB (**Figure 1**) and can provide significant inputs of sediments at times.

For the purposes of this report the area which will be potentially impacted and has been modelled in terms of sediment plume dispersion is referred to as the STB sediment Model Domain (SMD) with an area of ~13,300 km^2(**Figure 1**).

A very comprehensive description of the existing environment covering all aspects of physical and biological components was provided by MacDiarmid et al. (2013a). For the purposes of this report MacDiarmid et al. (2013a) and other relevant reports and publications are summarised to provide context for later sections.

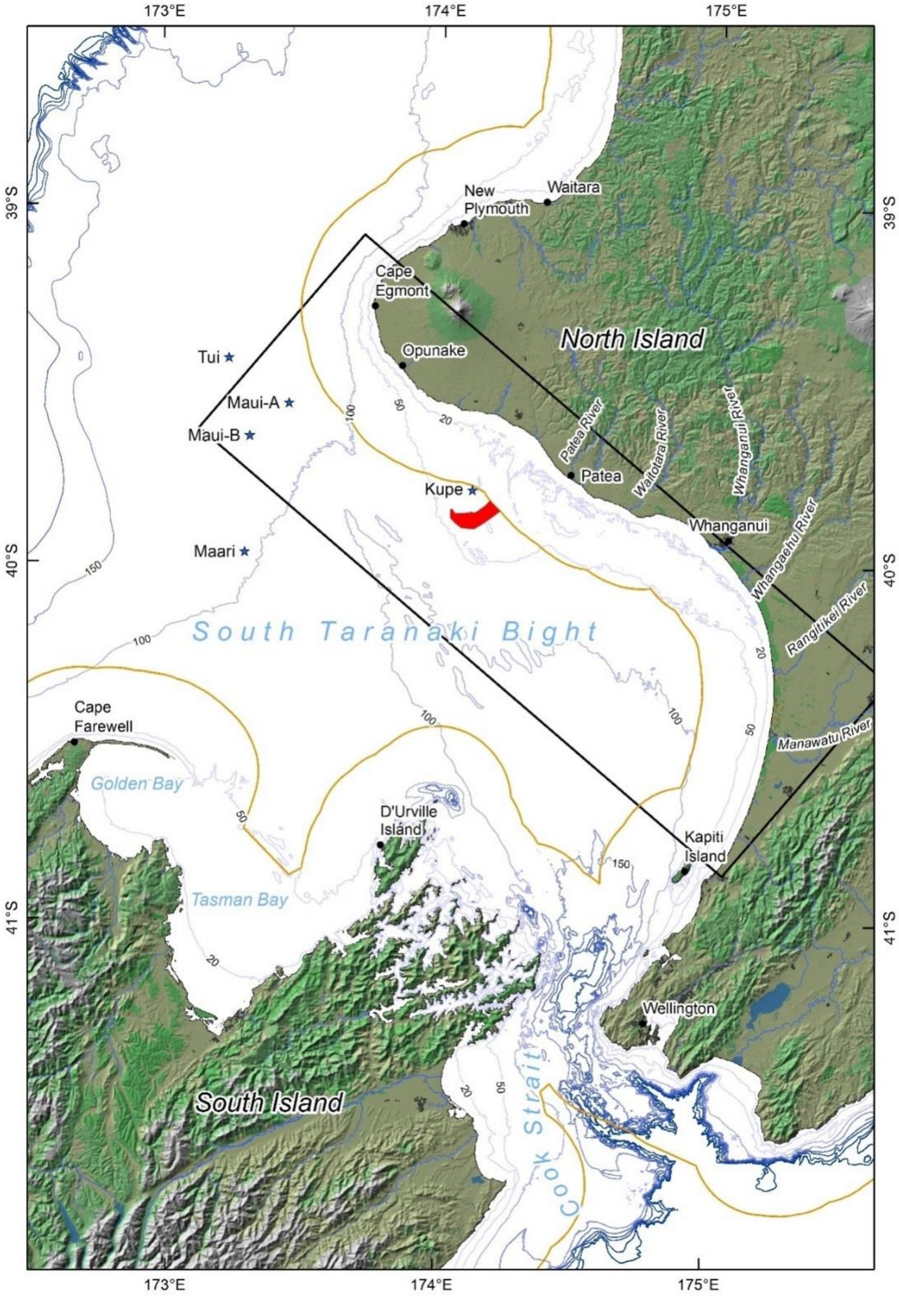

Figure 1: The South Taranaki Bight (STB) region showing the Sediment Model Domain (SMD) (oblique black rectangle). The approximate iron-sand mining location is shown in red and the 12 nm boundary of the Territorial Sea is shown in yellow. (from Cahoon et al. 2015)

3.1 Physical Environment

3.1.2 Currents and tides

The wave and current environment in the STB was described by MacDiarmid et al. (2013a) and the results of an intensive oceanographic field programme to describe the tidal and current environment in more detail and to provide the basis for sediment plume modelling is described in MacDonald et al. (2013). Tidal currents account for a significant proportion of the measured currents in the potentially affected area which covered depths from the 50 m contour to the coast. Forty to 80% of the variability in currents was explained by tidal currents. Peak and ebb current speeds for an average tide ranged from 0.13-0.25 m/s with spring tides higher. The orientation of the tidal flow is in a southeast - northeast direction i.e. parallel to the coast which has important implications for sediment plume dispersion.

Current direction and strength can also be substantially affected by wind conditions with MacDonald et al. (2013) recording surface current speeds of around 1 m/s during high winds. The predominant wind direction recorded was from the west and south-east with strong winds producing currents in a constant direction for more than 24 hours. Under calm conditions there is a prevailing current towards the southeast as a result of the influence of the D'Urville Current which comes up past Farewell Spit, into the STB and then flows towards the southeast. This influence could be enhanced by winds from the west and northwest but reversed under strong winds from the southeast quarter. The variability in strength and direction due to these different drivers has a major bearing on the extent and intensity of the sediment plume (discussed later).

As would be expected the coastal environment out to 50 m water depth is a high-energy environment with significant wave heights in excess of 4.0 m routinely experienced. Significant wave heights of up to 7.1 m were measured during the 7-month instrument deployment as part of the oceanographic studies carried out for TTR (MacDonald et al. 2013). The higher waves recorded generally came from either a south -- south-southeast or southwest -- west-southwest direction with reductions in height as they move towards the coast or down the coast in a south -- southeast direction.

Water column physical properties

As would be expected within the 50 m isobaths, temperature and salinity measurements showed that the water column is mostly well mixed but with lower salinity water evident close to river inputs (MacDonald et al. 2013). There is however some evidence that vertical stratification may occur in summer at depths of 15-25 m (Dr. Helen Macdonald, NIWA, pers. comm., Bradford et al. (1986)).

Suspended sediments

The proposed recovery of iron ore from sands in the STB will result in a sediment plume that will have direct and indirect impacts on the ecosystems. To put the effects into context requires a good understanding of background levels experienced in this coastal environment. Measurements taken as part of the oceanographic studies by NIWA using synoptic surveys and moored instruments around the ISR operations site and across the Patea Shoals (MacDonald al. 2013), recorded typical concentrations of suspended fine-sediments up to 25 mg/l with higher peaks inshore after significant rainfall or following significant wave activity. Offshore near-surface concentrations were typically less than 10 mg/l. Near the seabed fine sediment concentrations were typically <10 mg/l but could be up to 80 mg/l. Highest concentrations were not always associated with events but could also be a result of advection from "upstream" of the area. Concentrations up to 1,900 mg/l were recorded close to the seabed for suspended sand, mostly associated with high wave activity. MacDonald et al. (2013) estimated that sediment transport along this coast could be up to 2.1 m^3/m width of seabed, during large events.

Optical properties

An important consideration when looking at impacts of activities such as mining and dredging is the impact of sediment plumes on optical properties and light availability for primary producers both in the water column and on the seabed. To describe the optical properties of the coastal waters in the area potentially affected requires consideration of spatial and temporal changes in a naturally dynamic and highly variable environment. NIWA used observations from optical sensors from synoptic surveys, grab samples and moorings to describe the optical properties. This provides baseline observations for phytoplankton (chlorophyll-a (chl a) as an indicator of algal biomass), suspended sediment concentrations (SSC) and other optical properties and using algorithms and ground truthing can be used to assess larger spatial and temporal scale characteristics from satellite data. Full details, including more recent observations than provided for the previous marine consent application, are provided in Pinkerton et al. (2013) and Pinkerton & Gall (2015). The new observations and assessments, including additional measurements taken in February 2015 (MacDiarmid et al. 2015b) and updated processing of ocean colour satellite measurements, aimed to provide greater confidence in the background optical properties (including SSC) and subsequent assessments since the previous marine consent application.

Based on the satellite data, annual median concentrations of total suspended matter (TSM - phytoplankton, particulate carbon and inorganic material) between the coast and 10 km offshore was 1.4 mg/l with an interquartile range of 0.5-5.5 mg/l (Pinkerton et al. 2013, Pinkerton & Gall 2015). Median concentrations dropped to 0.2-0.7 mg/l between 10 and 40 km offshore and are typically <0.05 mg/L further offshore. For an average of 27% of the time TSM inshore was > 3 mg/l and was rarely over 3 mg/l offshore. Pinkerton et al. (2013) and Pinkerton & Gall (2015) also found considerable small scale and short term variability with higher levels associated with river plumes, local resuspension and/or erosion. There is some evidence for plumes with sediment concentrations (>4 mg/l) more than 30 km offshore (Pinkerton et al. 2013, Pinkerton & Gall 2015). The mean euphotic depth (the depth where photosynthetic available radiation (PAR) is 1% of its surface value) during sampling was ~25 m.

3.1 Benthic habitat

The production of sediment plumes and turbid water downstream of the ISR operations, as well as the settling out of suspended sediments, is expected to have at least some direct and indirect impacts on benthic habitats and communities, particularly those close to the activity. The scale and severity of this impact and subsequent recovery will depend very much on the habitats and communities present. Until the comprehensive surveys by NIWA on behalf of TTR in the region potentially affected were undertaken there was very little information available on the habitats and communities in this part of the STB (Beaumont et al. 2008). Full details of results from earlier studies for TTR, are provided in Beaumont et al. (2013) and Anderson et al. (2013).

Near shore benthic habitat

Thirty-six seabed sites were surveyed by NIWA (**Figure 2**) using underwater video and still images followed by collection of representative grab samples and benthic dredge collections for sediment and microbenthic surficial samples. The exposed areas to the north and central regions of the STB were characterised by well-sorted fine sands in ripple bedforms and the more protected southern areas were characterised by higher proportions of mud. Shell debris increased moving offshore with coarse shell debris habitats at depths >20 m. Hard rock outcrops were recorded at three sites in the northern section (see **Figure 3** for area of sampling) with mudstone outcrops at a site in 14 m water depth south of Hawera and one offshore of Whanganui (Anderson et al. 2013). Rocky outcrops were found along much of the coastline in the nearshore region (**Figure 3**).

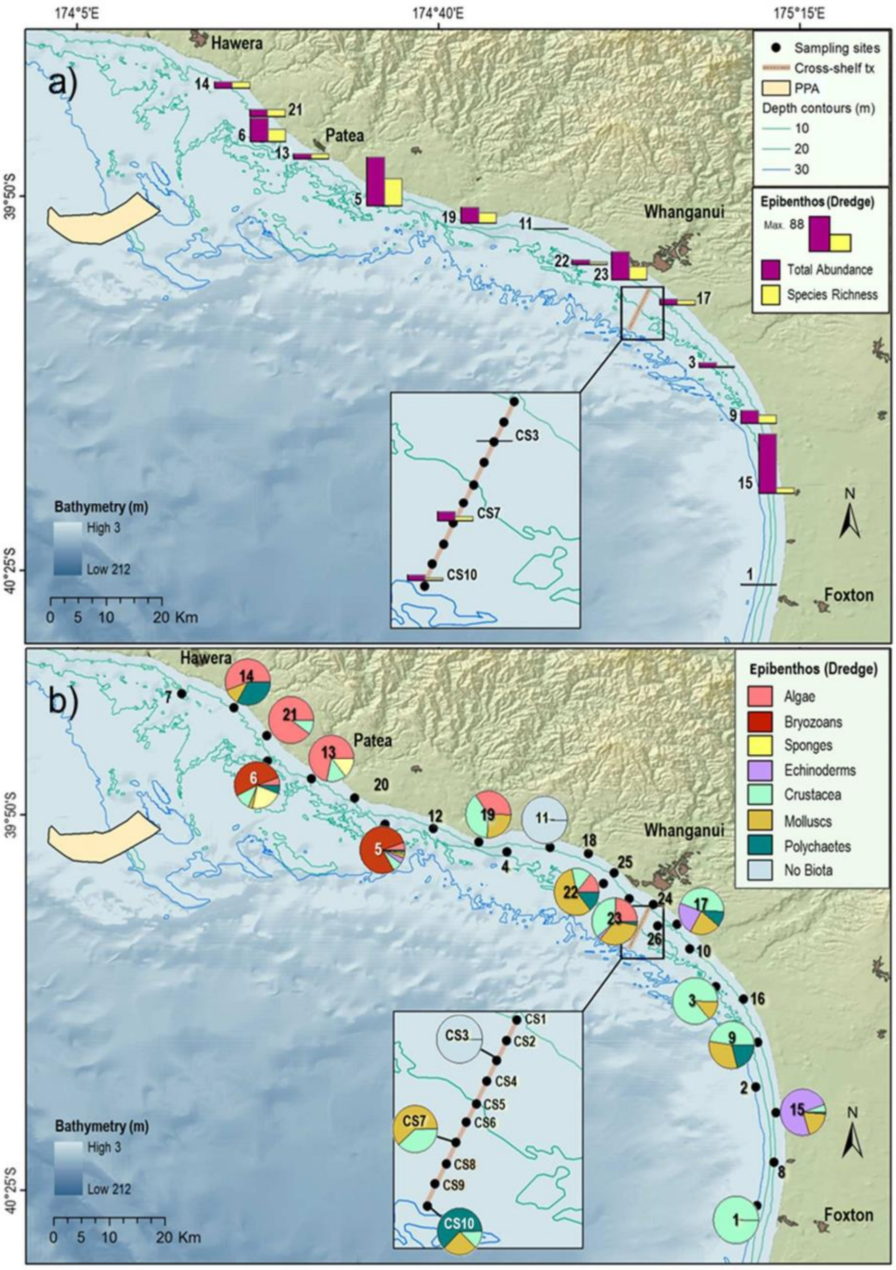

Figure 2. Macrobenthic assemblages collected in dredges at nearshore and cross-shelf sites within the STB. a) Histograms of total abundance and species richness at each dredge site, b) The proportion of major taxonomic groups collected at each dredge site. PPA = Proposed Project Area. Numbers depict sites. (from Anderson et al. 2013)

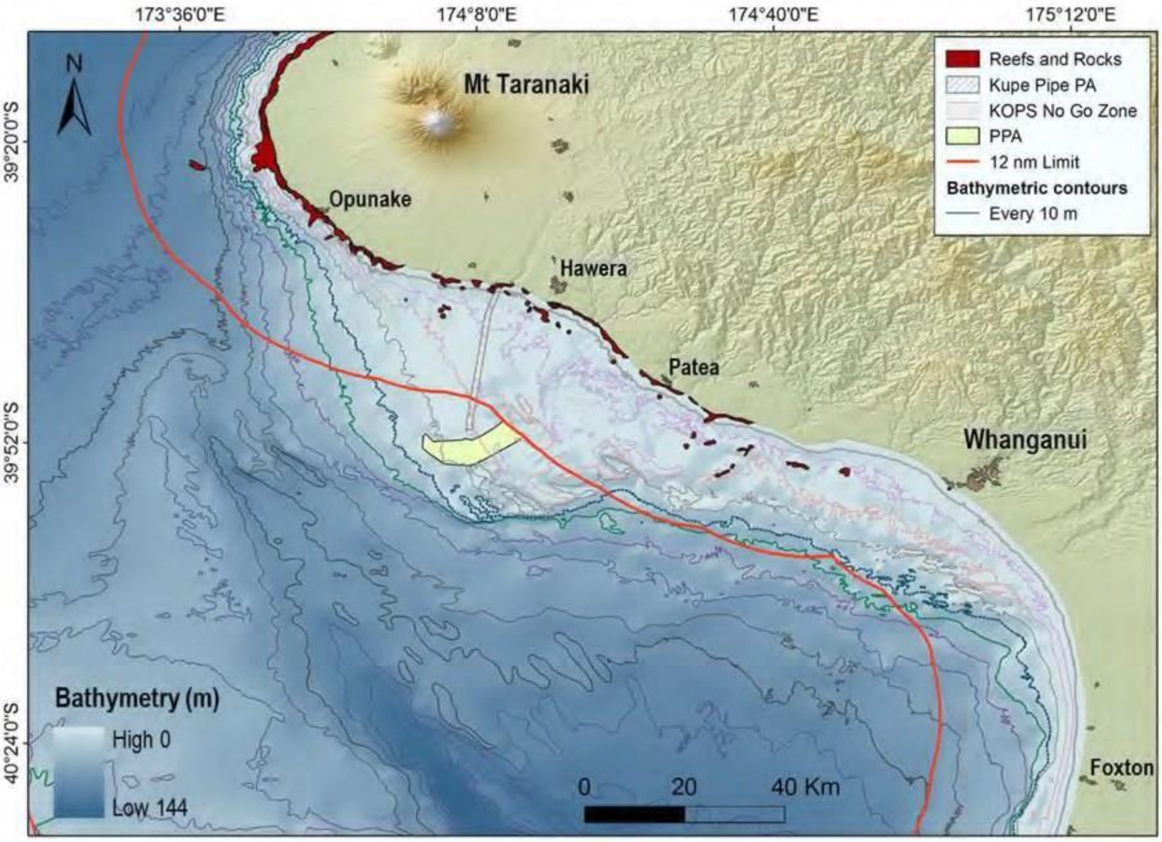

Figure 3. Map of the South Taranaki Bight with the location of TTR's Proposed Project Area (PPA) beyond the 12 nm limit and location of reefs. (from Anderson evidence to EPA).

Generally, soft sediment habitats were characterized by very low numbers of macrobenthos and by deposit, predator/scavenger and suspension feeders. Communities were more abundant and diverse on the rocky outcrops and were dominated by suspension feeders and primary producers (including bryozoans, macroalgae and sponges) along with crabs, amphipods, starfish, brittle stars, gastropods and polychaete worms – **Figure 2**). Mudstone outcrops supported low or negligible macrobenthos. Soft sediment sites off the Whanganui River were characterized by fine rippled sands with low and variable numbers of motile epifauna, such as hermit crabs, gastropods and a few suspension-feeding bivalves. It was also noted that the mudstone outcrop was covered in fine silt with few macrobenthos, a sign of regular disturbance. Most species have been recorded previously from this region and the Patea Shoals, with no new, rare or unique species found during the surveys or species that were restricted to this part of the STB.

Patea Shoals

The Patea Shoals is an area of seabed 25-40 km off the Taranaki Coast (**Figures 3 and 4**) in water depths of 25-45 m. Extensive sampling of this area was undertaken by NIWA in 2011 and 2012 with surveys covering the inner shelf, mid-shelf and deeper offshore areas. The results of video and still photographs from 144 sites, surficial sediment and associated infauna sampling from collections at 103 sites, and from 116 sites for benthic macrofauna and macroflora were reported in Beaumont et al. (2013). The range of habitats is shown in **Figure 4** with 7 habitats identified, the most common one being rippled sand. Large parts of the seabed were characterized by worm communities ("wormfields") which were dominated by *Euchone sp* A, with some very dense patches in the central and mid-shelf zone. Generally inner and mid-shelf habitats supported few visible epifauna apart from small scattered rocky outcrops on the inner shelf which had diverse epibenthic assemblages.

Deeper reefs offshore were characterized by two habitat types; 1) the bivalve rubble habitats dominated by the large robust dog cockle (*Tucetona laticostata*) with live animals at depths of 26-83.5 m and shell debris 44-69 m depth and 2) the bryozoan rubble habitat at depths of >60 m forming a habitat with generic shell debris. These habitats supported diverse assemblages dominated by sessile suspension-feeding taxa (eg bryozoans, sponges, ascidicans, brachiopods and epiphytic bivalves) and a number of motile taxa such as crabs and gastropods.

Sediment and infauna sampling found that the mid and inner shelf habitats were characterised by low abundance and species richness, typical of highly disturbed sediments and the region in general. There was no evidence that the area of the proposed ISR operations was unique with respect to benthic epifauna or infauna.

The deeper offshore benthic habitat, on the other hand, supported a diverse and abundant epifaunal community associated with shell hash and bryozoan rubble and dominated by suspension-feeding taxa. The shallower bivalve rubble habitat supported early successional stages (encrusting corraline algae, small encrusting invertebrates) while the deeper bryozoan rubble habitat supported later successional stages (certain bryozoans, sponges and higher numbers of motile taxa). Bryozoan rubble habitats also supported significantly higher abundances of infauna (Beaumont et al. 2013).

Microphytobenthos (MPB or small algae found on the seabed) are usually found on sandy sediments and where there is sufficient daily light reaching the seabed. Although there are no direct measurements of MPB from the area potentially impacted they are likely to occur there as they are found in similar environments in other parts of the world (e.g., Cahoon, 1999) and seabed images have shown sediment-water interface features, such as colour, consistent with their presence (Cahoon et al. 2015).

3.2 Phytoplankton

As identified in a number of reports (MacDiarmid et al. 2013a, Cahoon et al. 2015) the STB is a dynamic region with plankton communities and primary production influenced by local drivers such as light and nutrient availability and grazing as well as advective processes such as upwelling from the Kahurangi Shoals which bring in nutrients and grazers and the rivers which bring in suspended sediments and nutrients. It is generally considered that nutrients are the main limitation on primary production rather than light availability based on observed nutrient levels, and phytoplankton biomass and primary production (Bradford et al. 1986, Zeldis et al. 2013). In other studies off the West Coast and the Taranaki Bight, James & Wilkinson (1988) and James (1989) also demonstrated that grazing by zooplankton can be a major controlling factor of phytoplankton populations. Cahoon et al (2015) concluded that most phytoplankton production occurs in-situ in the modelled domain but advection shouldn’t be ignored as a source of organic matter.

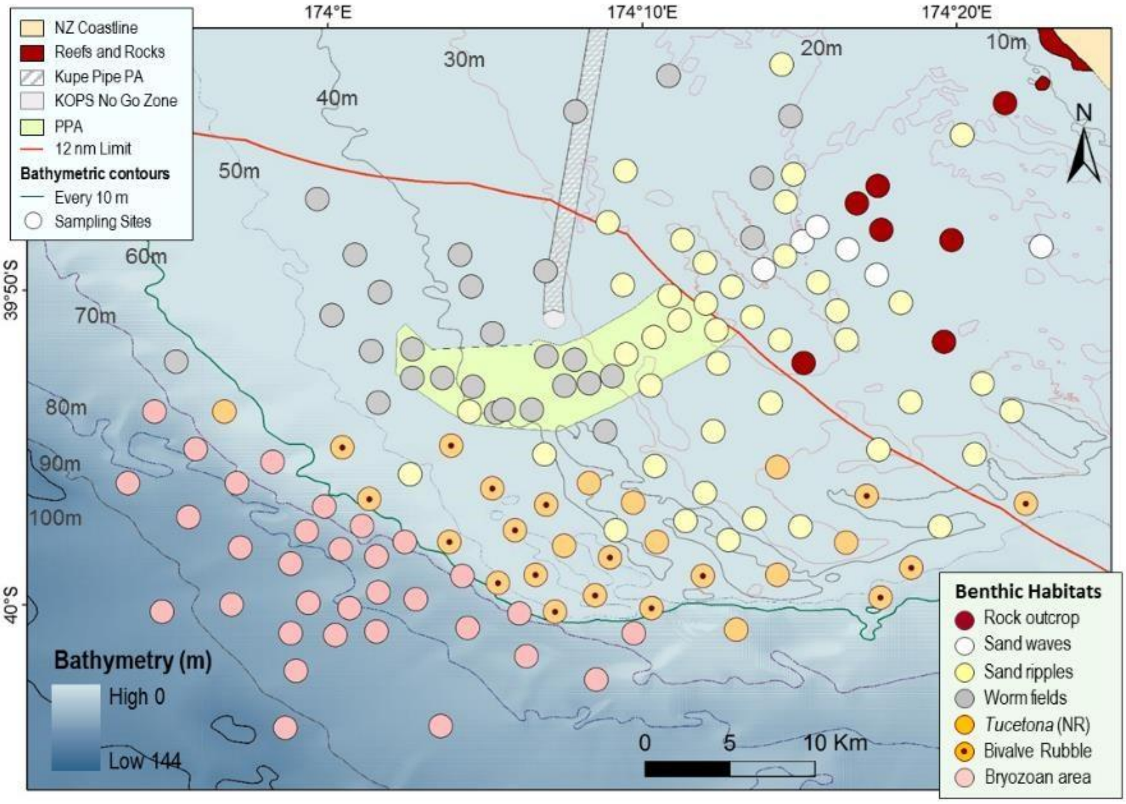

Figure 4. Seabed habitat types observed at each site within the Patea Shoals region, STB. PPA = Proposed Project Area (captions are provided in Figure 2); Coloured circles represent survey sites; *Tucetona* (NR) = sites with live *T. laticostata* but little to no shell debris (i.e. No Rubble). (From Beaumont et al. 2013)

NIWA used locally-tuned algorithms and 10 years of satellite observations (2002-2012) to assess mean conditions and characterise water constituents, such as chl *a* concentrations, which provide a proxy for phytoplankton biomass. Based on the satellite data and some ground-truthing Pinkerton et al. (2013) found that elevated levels of chl *a* could be attributed to two processes, nutrient input from rivers and advected material from further afield. Long-term median chl *a* levels were highest (5 ug/l) close to the coast as a result of river runoff and decreased to an annual median of 0.2 ug/l offshore. Intermittent blooms occur offshore (>10 km offshore) but could be spatially large, covering much of the STB. It is thought that these larger blooms in some cases result from dynamic processes associated with the upwelling off the Kahurangi Shoals and possibly Cook Strait at times. In some cases these blooms could exceed 4 ug/l.

MacDiarmid et al. (2013a) also reported a seasonal component to satellite derived chl *a* concentrations with spring peaks at most sites in the STB although winter peaks could also occur inshore and at the deeper sites to the north. Median chl *a* concentrations are relatively high across the northern and eastern parts of the STB throughout the year with an overall range of 0.02-32 ug/l (median 0.57 ug/l) compared to values <0.1 ug/l for clear blue waters (MacDiarmid et al. 2013a). Recent surveys reported in MacDiarmid et al (2015b) have added to the database on phytoplankton and found chl *a* levels >1 ug/l immediately east of the proposed ISR operations site, indicating a localised algal bloom.

In one of the few studies of primary production in the region Bradford et al. (1986) found the rate of carbon fixation ranged from 2 to 6 mg C/(mg chl a)$^{-1}$hr^{-1}.

3.3 Zooplankton

Zooplankton are microscopic animals which float around in the currents, mostly in surface waters. They range in size from small single celled protozoa to copepods and larval crabs, molluscs and fish as well as the large euphausiids or krill. They play a critical role in marine food webs and are the link between primary producers and fish and mammals. Studies such as those by James (1989), James & Hall (1995) and Hall et al. (1993) off the West Coast of the South Island have shown that the small microzooplankton (protozoans, flagellates <200um) are the major grazers of phytoplankton which then link through to larger zooplankton (subject of most of the studies by TTR in the STB) and to higher trophic levels.

There are limited data available on zooplankton in the STB but the region is considered to be very productive. Biomass estimates are among the highest recorded when considered against other coastal regions around New Zealand (MacDiarmid et al. 2013b). The STB is influenced by the D'Urville Current and upwelling from the likes of the Kahurangi shoals which bring in colder nutrient rich waters. The nutrients drive primary production as the water is advected around the top western side of the South Island and into the STB where, along with other nutrient sources (including Cook Strait), it increases primary production. As the plume from the Kahurangi develops there is an increase in zooplankton biomass (James & Wilkinson 1988). As upwelled water is advected into the STB carbon production was found to exceed utlilisation by larger zooplankton potentially providing a net carbon source, but much of this is likely to be utilized by smaller microzooplankton. These upwelling events are also thought to be important for the squid aggregations which occur in the lower Taranaki Bight.

Although some mesozooplankton sampling in the STB was undertaken in the 1970s and 1980s (Battaerd 1983, Bradford 1977, 1978, Bradford et al. 1993), it was conducted a number of years ago, mostly well offshore and also lacked estimates of zooplankton biomass for the whole water column, which are important components in ecosystem models (MacDiarmid et al. 2013b). To address this and provide greater certainty TTR commissioned a study in early 2015 to sample zooplankton from the surface to the seafloor in the region that may be impacted by a sediment plume from the proposed ISR operations. The results of that study are provided in MacDiarmid et al. (2015b). Acknowledging this is a snap shot in time findings from the latest surveys found:

- There was no obvious pattern in zooplankton biomass inshore-offshore but highest biomass was found over the Patea Shoals and east towards Whanganui;
- Copepods dominated most stations sampled except salps and juvenile euphausiids dominated the stations with highest biomass. Most the copepods were omnivores and dominated by *Oithona* and *Paracalanus*;
- The community was typical of nearshore waters and, as would be expected, was dominated by neritic or coastal species.

3.4 Fish

Reef Fish

The distribution of reef fish in the STB was predicted by NIWA based on models developed from comprehensive dive surveys and habitat information. MacDiarmid et al. (2013b) reported that the region has a moderately diverse reef fish fauna with 38 species likely to be found (cf. 72 species modelled around New Zealand by Smith (2008)). None of the modelled species are nationally threatened. Two species, black angelfish and common roughy, are rare in the region occurring at low abundance on just a few coastal reefs and six other species have restricted distributions occurring at <50% of the reef sites in the region. All other 29 species are predicted to be much more widespread and either occur in low abundance throughout the region (14 species), are moderately common over the entire area (13 species), or are abundant widely distributed species (2 species).

Smith (2008) and MacDiarmid et al. (2013b) point out that there are a number of limitations with the modeling approach to predicting reef fish abundances, including that in this case none of the reef sites surveyed for the modelling were from along the coastline of the STB. Thus, these predictions need to be interpreted cautiously. However, MacDiarmid et al. (2013b, 2015a) consider that the information provides an appropriate basis for assessment for effects on rocky reef habitats.

Demersal and Pelagic Fish

Demersal (bottom dwelling) and pelagic (open water and in the water column) fish occur throughout the STB, supporting commercial, recreational and customary fisheries. MacDiarmid et al. (2013b) provides a description of the distribution of these species based on models developed from trawl surveys throughout New Zealand and statistical relationships with habitat, as well as a thorough literature review for all species, including egg and larval stages. Depth, temperature, and salinity have been found to be the main predictors of demersal species abundance (Leathwick et al. 2006).

Fifty-one species of demersal fish occur in the STB (MacDiarmid et al. 2013b). The richness of this assemblage was similar to that recorded off the west coasts of both the North and South Island but was slightly lower than in depths <50 m off Patea and slightly higher compared with inshore to the southeast of the STB, i.e from north of Kapiti to Whanganui. Overall the richness is moderate on a New Zealand wide basis. A few species are very widespread and abundant but most species are common only within a restricted depth range. MacDiarmid et al. (2013b) also reported earlier work by Hurst et al. (2000) who found evidence of spawning activity by 13 demersal and pelagic fish in the STB along with juveniles of 24 species. However, the surveys were based in deeper areas (>20 m depth).

Species with their main distribution along the South Taranaki coastline, that coincide with areas relevant to the proposed area for ISR operations and which could potentially be impacted, include anchovy, blue cod, eagle rays, red gurnard, golden mackerel, leather jacket, lemon sole, snapper, rig and trevally (MacDiarmid et al. 2013b).

Commercial Fisheries

The commercial fisheries in the STB potentially impacted by ISR operations was assessed by Fathom Consulting Ltd (Fathom 2013). The region is considered to support a diverse and productive commercial fishery. The main forms of commercial fishing carried out in the region are bottom trawling (variety of species including trevally, leatherjacket, gurnard and snapper), and set netting (mainly for school shark, rig and blue warehou). Coastal trapping for rock lobster and midwater trawling mainly for jack mackerel are also important nearby. Although fishing does occur year-round most of the trawling is carried out during the summer months with the “rolling grounds’ being a particularly productive area (Fathom 2013).

Most of the fishing effort is between New Plymouth and Cape Egmont, relatively close inshore, and between Hawera and Whanganui near the 50 m contour (MacDiarmid et al. 2013b). Most of the trawl fishery is concentrated beyond the 50 m contour and seaward of the proposed ISR operations area.

Red Rock Lobster

One of the most important species for recreational and customary fishing on the reefs close to the coast is the red rock lobster. Large males may migrate offshore across sandflats to feed on shellfish at certain times of the year and egg-brooding females may form offshore aggregations in spring. MacDiarmid et al (2013b) concluded that these migrations would be unlikely to be as far as the ISR operations area. The potential extent of sediment plumes and effects will be discussed later.

Customary fisheries

In their review of customary fisheries in the region, MacDiarmid et al. (2013b) found little information was available but recorded at least 40 species of invertebrates (shellfish, crustaceans and fish) that could be fished with shallow intertidal and subtidal reefs likely to be the most important area. However, some fishing for various finfish species would also occur offshore for likes of rig and leatherjacket.

The earlier work reported in MacDiarmid et al. (2013b) was also updated recently by NIWA to provide greater detail on the scale and temporal variability of the distribution of fish, bird and mammal species as the basis for a more robust assessment of the effects of the ISR operations (MacDiarmid et al. 2015a). This study summarised all known information on commercial and recreational and customary fisheries using catch data from the Quota Management Area information, modelled fish distribution and relevant data and information that was available. Tables for all the species including distribution, habitat, diet and relevant fishery information are provided in MacDiarmid et al. (2015a).

3.5 Mammals

There have been relatively few sightings of cetaceans within the northern and southern Taranaki Bights. Aerial surveys were conducted along transects parallel to the shoreline from inshore and up to 28.5 nm offshore in July and October 2011 and January 2012. The results were reported in Cawthorn (2013) noting the paucity of mammals with only 10 fur seals and a pod of 6 common dolphins seen. This was not unexpected given the habitat and exposed conditions of the area. However, three endangered or critically endangered species, the Hector's dolphin (*Cephalorhynchus hectori*) and sub-species of Maui dolphin *(Cephalorhynchus hectori maui*), killer whale (*Orcinus orca*), and southern right whale (*Eubalaena australis*) have been recorded in the area. A dedicated field programme to gain additional information confirmed the presence of blue whales at the western entrance to the STB in summer 2014 (Torres et al. 2014). Hector's dolphins have only been rarely encountered in the STB and are considered to be on the margins of their current range.

Distribution models for these species were developed by NIWA using sightings throughout New Zealand (presence/absence) and environmental predictors. The ISR operations area was predicted to have low suitability for the southern right whale and Hector's dolphins but areas close to the coast could be of moderately suitability. The region was also predicted to have low suitability for killer whales other than an area of moderate suitability which began ~8 km seaward of the proposed ISR operations area.

Information for all the mammal species that have been recorded in the region, including distribution, habitat, diet and relevant fishery information are provided in MacDiarmid et al. (2015a).

3.6 Bird life

Thompson (2012) summarised what is known about bird life in the region noting that the STB supports a relatively modest seabird assemblage, but that detailed, systematic and quantitative information on the at-sea distribution of virtually all species is currently lacking. Many of the species occurring in the area are likely to be relatively coastal in their distributions. Such species include blue penguin, shags, gulls and terns, although these latter taxa can extend to more offshore areas. By contrast, and although some species have been observed from and relatively close to the coast, albatross and petrel species tend to be more pelagic and wide-ranging in their distributions and will likely occur at times throughout the area.

The area does not support large breeding colonies for any species but a number of estuarine sites are of significant value to coastal, shore, wading, and migratory bird species. These sites include the Waikirikiri Lagoon, and the Whanganui, Whangaehu, Turakina, Manawatu and Rangitikei river estuaries.

More detailed information for key species that may be found in the STB including distribution, migration, habitat, and diet are provided in MacDiarmid et al. (2015a) in response to concerns expressed in the DMC's decision on the previous marine consent application and provide the basis for a more robust assessment of potential effects. Maps of foraging areas for Gibson's albatross (Threatened – nationally critical), Westland petrel, Sooty shearwater, Red-billed gull (Threatened – nationally vulnerable) and little blue penguin are also provided in MacDiarmid et al. (2015a).

4. Nature of activity

TTR is seeking marine consent for the recovery of iron sand from a total area of 65 km^2 located outside the 12 nm limit between Patea and Hawera (see **Figures 1-3**). TTR intends to apply for a marine consent to operate for 20 years excavating a total of 50 million (M) tonnes of seabed containing iron sands per year. The area excavated each year will be up to 5 km^2, extracting from lanes 12 m wide and up to 11m deep below the seabed, depending on the depth of the resource. It is expected that a 900 m x 600 m block would be worked over a 30 day period. After extraction of the iron ore (approximately 10% of the seabed sediments) the remaining 45 M tonnes will be returned annually to the seabed as de-ored sediment.

The recovery of iron sands will be undertaken in a planned way to ensure operational efficiency and minimize environment impact. A submerged remote controlled crawler will extract sand to a predetermined depth and will be operated from an extraction and processing vessel (See **Figure 5**). The suction head of the crawler will pump seawater via nozzles to the extraction face to fluidise the sediment. The processing vessel will receive the pumped sand by a slurry delivery pipe.

The iron ore (titano-magnitite) will be separated from the sediment using physical separation techniques (screening and magnetic separation) with no chemicals involved. The initial screening will remove material greater than 2 mm. De-ored sediment will be released back to the seabed via a pipe at a depth of 4 m above the seabed in order to minimize potential for sediment plumes. The material will be re-deposited in a thick slurry onto previously worked over areas.

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Figure 5. Extraction and processing vessel.

5. Effects on the physical environment

It is inevitable that the recovery of iron sands will have some impact on the physical properties of the seabed and the water column. In this regard, the immediate environment will be significantly impacted, however, it is the spatial and temporal extent of the effects beyond the immediate environment that is more difficult to assess. There are three main sources of effects on the physical environment:

1. Physical disruption of the seabed during the recovery and re-deposition phases
2. The production of a sediment plume during the recovery operation and deposition of sediments back to the seabed and potential resuspension; and
3. Effects on optical properties of the water column through suspended sediment.

Physical disruption

As described above the area directly impacted by the recovery of iron sands will be ~ 5 km^2 per year in blocks of 900 m x 600 m over 30 days. The benthic habitat in the area, including both surface and down to 11 m below the seabed, will be physically removed and a small area along the margins will be disturbed. The impact of this removal on the benthic habitat, along with recovery times, is discussed below.

Sediment plumes

The production and dispersion of a sediment plume during the recovery of iron sands is one of the key features of the proposal. Considerable work has gone into understanding the potential plume in terms of source material, concentration, dispersal and spatial and temporal variability. NIWA undertook extensive modelling to describe the plume dispersion for the previous marine consent application (Hadfield 2013, Hadfield 2014).

Following the decline of the previous marine consent application in 2014 TTR commissioned a peer review of the reports and assessments that have been prepared, and the comments expressed in the decision by the DMC. TTR has subsequently carried out more work to provide greater certainty and confidence in the source terms used and model assumptions and thus interpretation of effects. An important area that required greater certainty was the way discharged de-ored sediment would behave in the marine environment, and in particular potential flocculation and settling rates for finer particles. To address this HR Wallingford conducted laboratory tests using sediment samples from the STB to build on the earlier assessments. This included refining settling velocity of the finest fraction, the erosive forces required to resuspend this fraction once it had settled and the “trapping” of the finest fraction within the pit during the ISR operations. The full results are provided in HRW (2015). The modelling of near-field processes and plume around the discharge (Hadfield & Macdonald 2015) is now based on effectively all the fine sediment fractions settling at 10 mm/s depositing on to the seabed within the pit. The finer fractions with slower settling rates are expected to remain well mixed in the water column. An important aspect of the new work is that the slowest settling fraction have a chance to combine to form faster settling flocs. Initial settling velocities were conservative and the new information has allowed a more realistic assessment of the plume development and modelling.

Following this new work on source rates and sediment parameters and processes, as well as improvements to the way background suspended sediment (SS) are treated, the sediment plume dispersion model has been rerun. In the latest modelling exercise two source locations are considered, one at the inner end (Location A) and one at the outer edge (Location B) of the ISR operations area. The new analyses were based on the sediment being introduced over 1000 days and reporting focused on the median and 99^{th} percentile of effects. The area that has been considered can be broken into three regions; the Greater Cook Strait region, the SMD, and the Patea Shoals. Most of the discussion on the effects assessment in this report is based on effects that occur in the modelled sediment domain (referred to here and in Hadfield & Macdonald 2015 as the Sediment Modelling Domain or SMD, see **Figure 1**). This domain covers approximately half of what is often termed the STB and likely covers the area where any significant impact would occur.

The results of the new model runs and assumptions around source terms and rates are reported in Hadfield & Macdonald (2015). The plume is predicted to predominantly travel to the east-southeast with the plume from Location A reaching the coast between Patea and Whanganui. An important consideration is the background levels of SSC (Suspended Sediment Concentrations) that would be experienced. Background levels are shown in **Figure 6 and 7.**

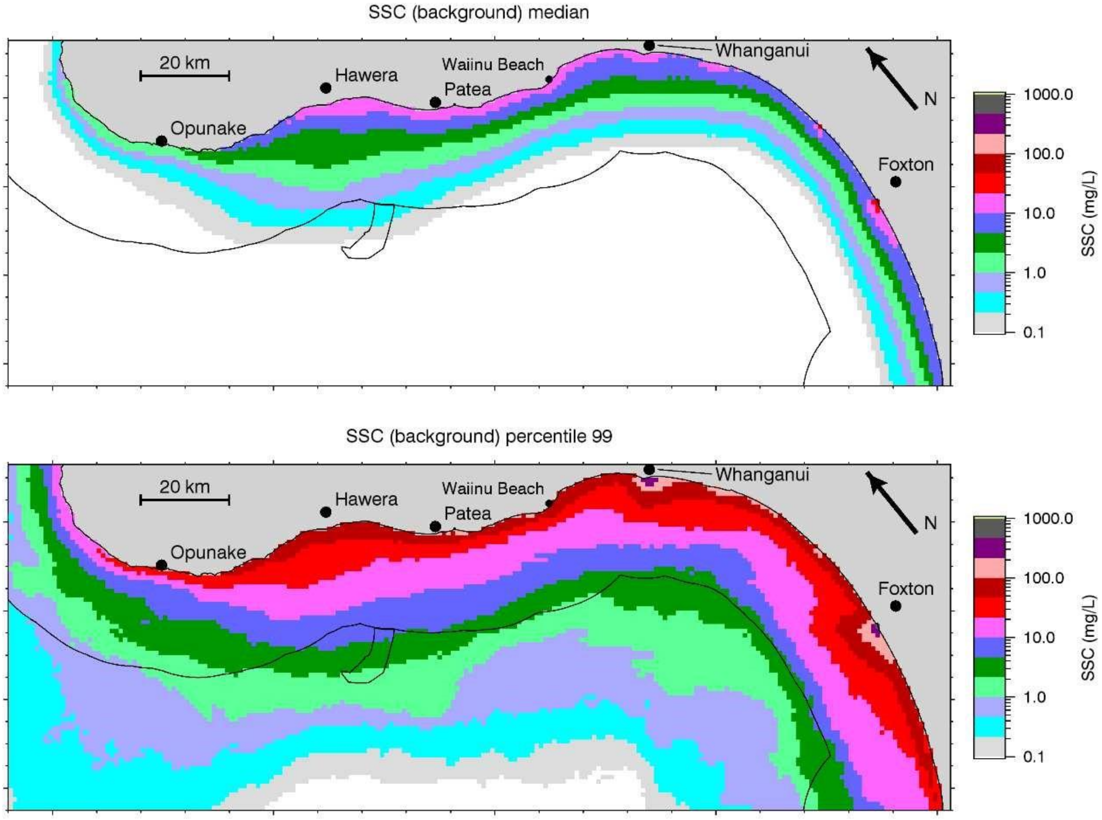


Figure 6. Background near-surface concentration of suspended sediment**.** a) Median SSC; b) 99th percentile SSC. (from Hadfield & Macdonald 2015)

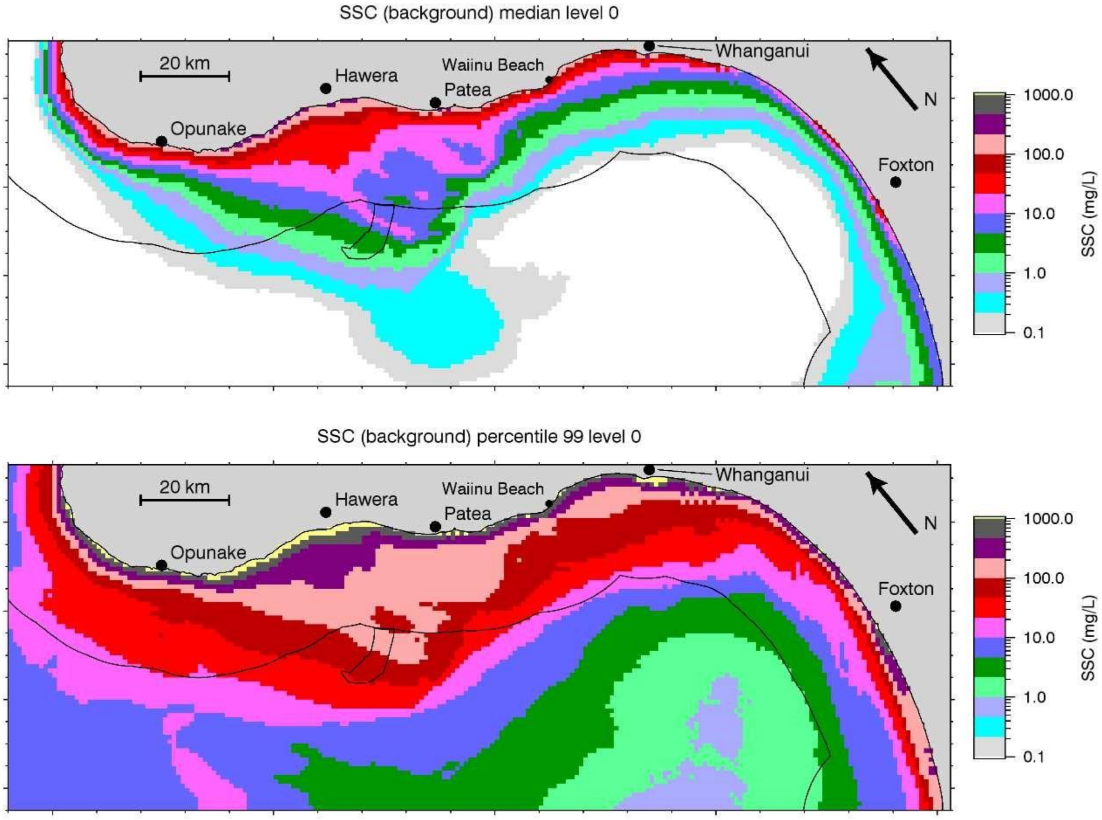


Figure 7. Background near-bottom concentration of suspended sediment. a) Median SSC; b) 99th percentile SSC. (from Hadfield & Macdonald 2015)

As would be expected, the SSC levels are higher inshore and decline offshore and away from the rivers. The median background near-surface levels reach over 20 mg/L (typically 10-20 mg/L) and the 99^{th} percentile typically up to 100 mg/L close to the coast (maximum over 200 mg/L close to major rivers) (**Figure 6**), while the levels at the seabed reach median levels over 100 mg/L and 99^{th} percentile levels over 1000 mg/L (**Figure 7**). Median surface levels close to the ISR operations site are typically 0.4 mg/L at the inshore end and ~0.05 mg/L at the offshore end. Median levels of SSC in the surface waters of the offshore region are typically at or less than 0.1 mg/L. Near-bottom SSC levels are typically less than 1 mg/L (<0.1 mg/L 60 km offshore) with a 99^{th} percentile of less than 10 mg/L. Winter levels tend to reach higher levels than in summer.

An important consideration in such a dynamic and exposed environment is that the dispersion of suspended sediment and its effects on the physical and biological environments depend not only on the main tidal currents but also major larger scale current flows such as the D'urville Current, upwelling off the top of the West Coast, freshwater inputs from the major rivers, and wind direction, strength, and weather events. The influence of wind direction is shown in Figures 3-5 to 3-17 in Hadfield & Macdonald (2015). Examples of the modelled plume under different wind scenarios is shown in **Figures 8 and 9** below following southwest and southeast winds respectively.

There is also a temporal consideration with a time series now modelled for SSC at locations 2, 8 and 20 km from the ISR site. The results are provided in Hadfield & Macdonald (2015) (see Fig 5-2 to 5-4) which show how the plume's presence and severity will change over time and the "spikiness" of the natural SSC. The net differences between background and mining plus background for the site 2 km away is an increase in median SSC from 0.4 to 1.5 mg/L and 99th%ile from 5.5 to 6.8 mg/L, for 8 km away is an increase from 0.5 to 1.3 mg/L and 6.9 to 7.1 mg/L and at 20 km is an increase of 0.9-1.4 mg/L and 10.5 to 10.8 mg/L. These plots demonstrate the episodic nature of events, that there are only small increases when levels are higher and likely to be ecologically most important, and that at 20 km away, mining would only occasionally add over 2-3 mg/L (max 4.4 mg/L).

The full set of model runs for plume development from Locations A and B over the 1,000 days is provided in Hadfield & Macdonald (2015) with examples shown in **Figures 10 and 11** of this report for median levels in surface waters and on the seabed when recovering iron sands from Location A. **Figure 10** shows that SSC in the plume is very low with SSC of 1.45 mg/L around the source and very low concentrations away from the source. The comparison of background with background plus ISR (a cf c) shows a slight movement offshore of the 1 mg/L threshold of about 6 km outwards over the Patea Shoals. The ecological implications of such differences are discussed below.

Figure 11 shows that median background SSC in the near-bottom waters can be in excess of 200 mg/L close to shore and 1000 m g/L near the mouth of major rivers. Adding the plume as a result of ISR operations the only perceptible difference is within 2-3 km of the source. There is an extensive area of 0.1-0.2 mg/L reaching the coast from Patea to Foxton and southwards but there is very little difference between background and background plus ISR operations. The highest surface SSC for Location A were 1.45 mg/L (median) and 8.2 mg/L (99th percentile) right at the source and at 20 km downstream of the source surface concentrations were predicted to be 0.35 mg/L (median) and 2.8 mg/L (99th percentile). SSC for Location B were considerably lower.

Deposition

The deposition of sediments as a result of release of the de-ored substrate can have significant impacts on biota through smothering. The levels of deposition were modelled and the results reported by Hadfield & Macdonald (2015) for the maximum 5 and 365 day deposition rates. The results show that the deposition rate can only be distinguished from background within a few kilometers of the source. The deposition could occur over a reasonably extensive area but at extremely low rates of 0.01-0.05 mm over 5 days. Except right at the source background is indistinguishable from background plus mining. Maximum deposition would be at the source and 0.6 and 1.1. mm for 5 and 365 day accumulations respectively. Erosion, dispersion and resettlement of sediments from the pit are likely to be at very low rates with rates of >0.01 mm over 2 years up to 10 km away from the pit area. SSC in these plumes will be very small relative to background.

Optical properties

The revised sediment plume model results have been used to refine and model the impacts on optical properties of the water column and to give greater confidence in the assessment of effects than assessments for the previous marine consent application. Full details of the model approach, assumptions, results and effects are reported by Pinkerton & Gall (2015). The changes of concern in terms of water column and seabed ecology are underwater visibility for divers and visual feeders and light attenuation for primary producers (water column and seabed micro-algae and seabed and reef macroalgae). As for the sediment plume there is considerable background variability in optical properties and the effects of ISR operation are likely to be highly variable in time and space, depending on prevailing conditions.

a)

b)

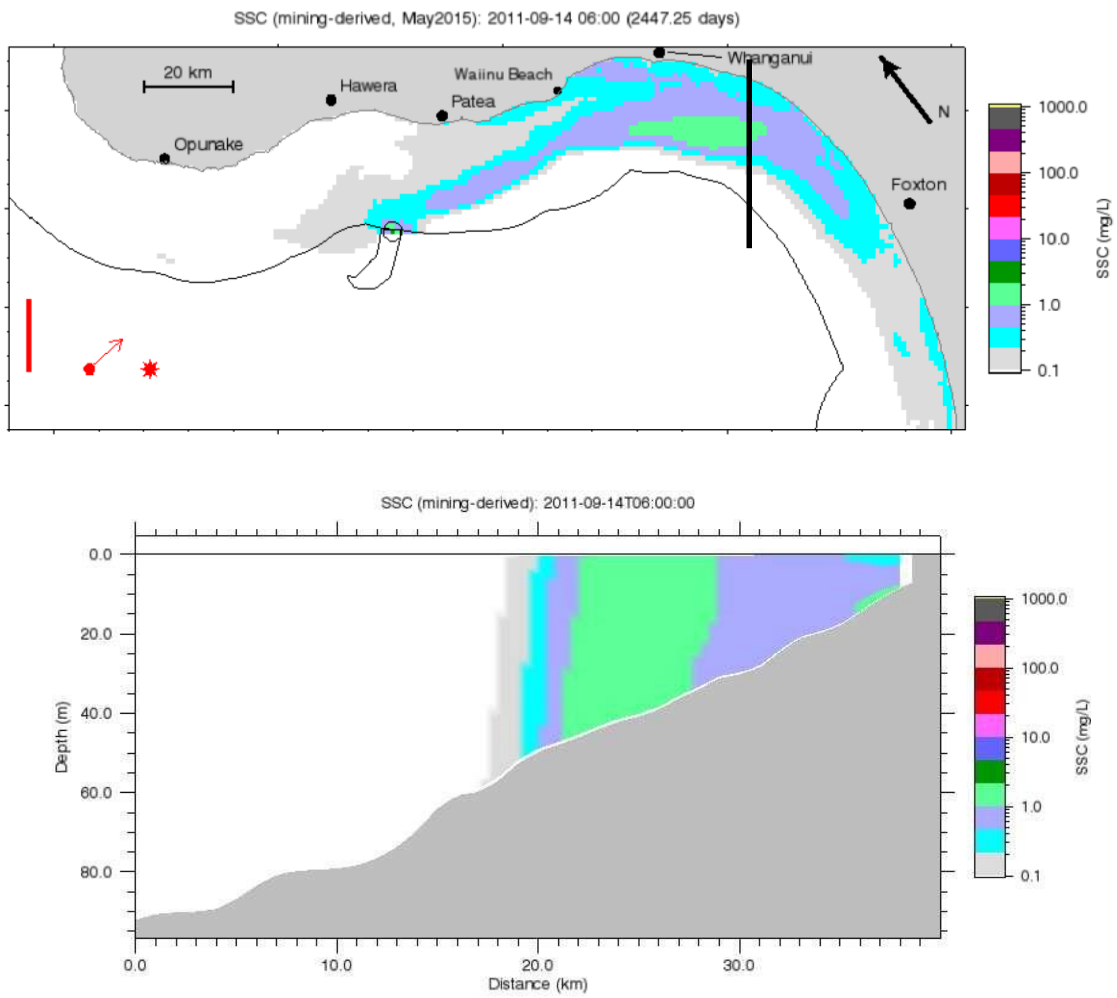
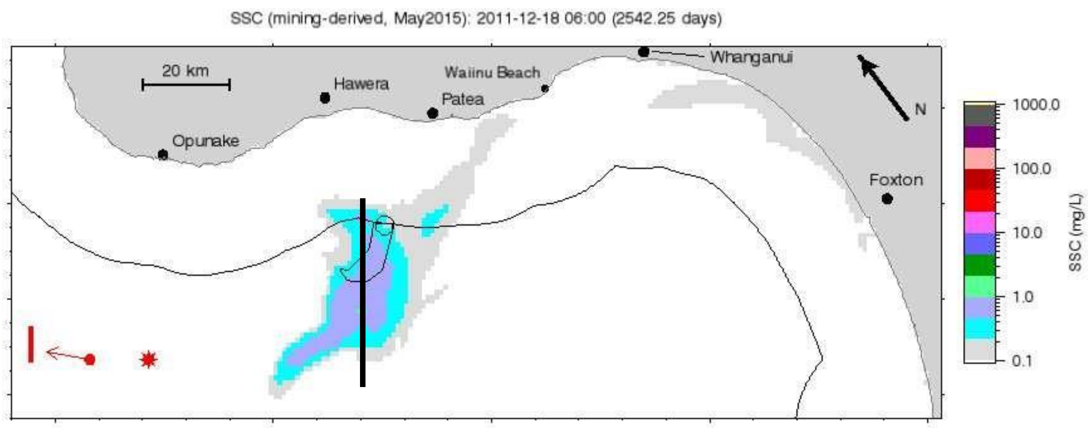


Figure 8. Plume case study 2 for ISR at source location A. The near-surface mining derived SSC (panel a) and a vertical transect through the plume (panel b). The location of the vertical transect is indicated in panel a as a thick black line. The day shown is the 14 September 2011 following 2 days of westerly winds. In the top panel the vertical bar in the lower left corner shows significant wave height. The arrow shows the surface wind stress. The sun icon indicates that ISR is assumed to be operating at this time. **(from Hadfield & Macdonald 2015)**

a)



b)

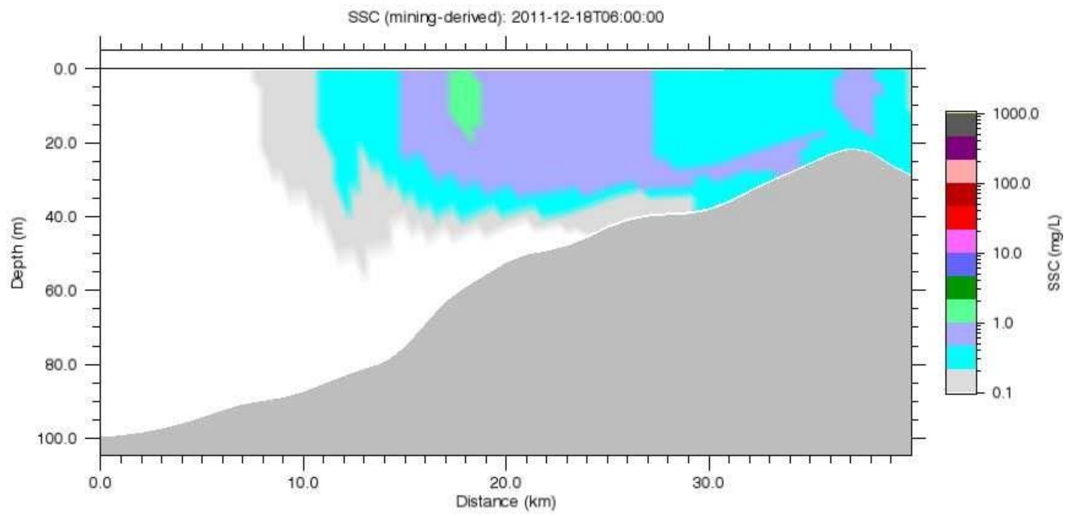


Figure 9. Plume case study 5 for ISR operations at source location A. The near-surface mining derived SSC (panel a) and a vertical transect through the plume (panel b). The location of the vertical transect is indicated in panel a as a thick black line. The day shown is the 18 December 2011 and follows south easterly winds. In the top panel the vertical bar in the lower left corner shows significant wave height. The arrow shows the surface wind stress. The sun icon indicates that ISR is assumed to be operating at this time. **(from Hadfield & Macdonald 2015)**

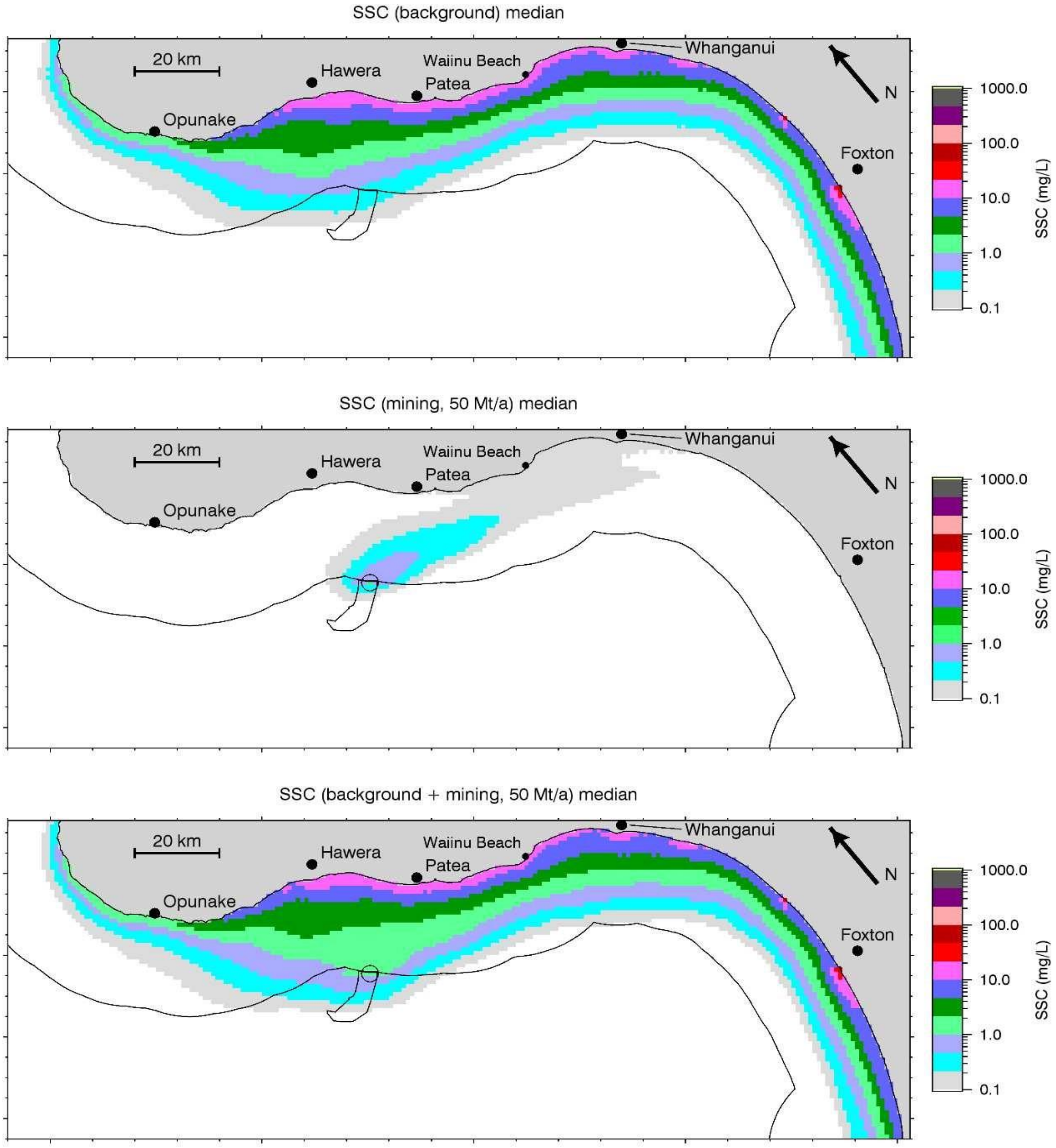


Figure 10. Median near-surface concentration of suspended sediment from ISR (50 Mt/a) at source location A. a) Background SSC; b) mining-derived SSC; c) background plus mining-derived SSC. An open circle of 2 km radius in panels b and c indicates the source location. **(from Hadfield & Macdonald 2015)**

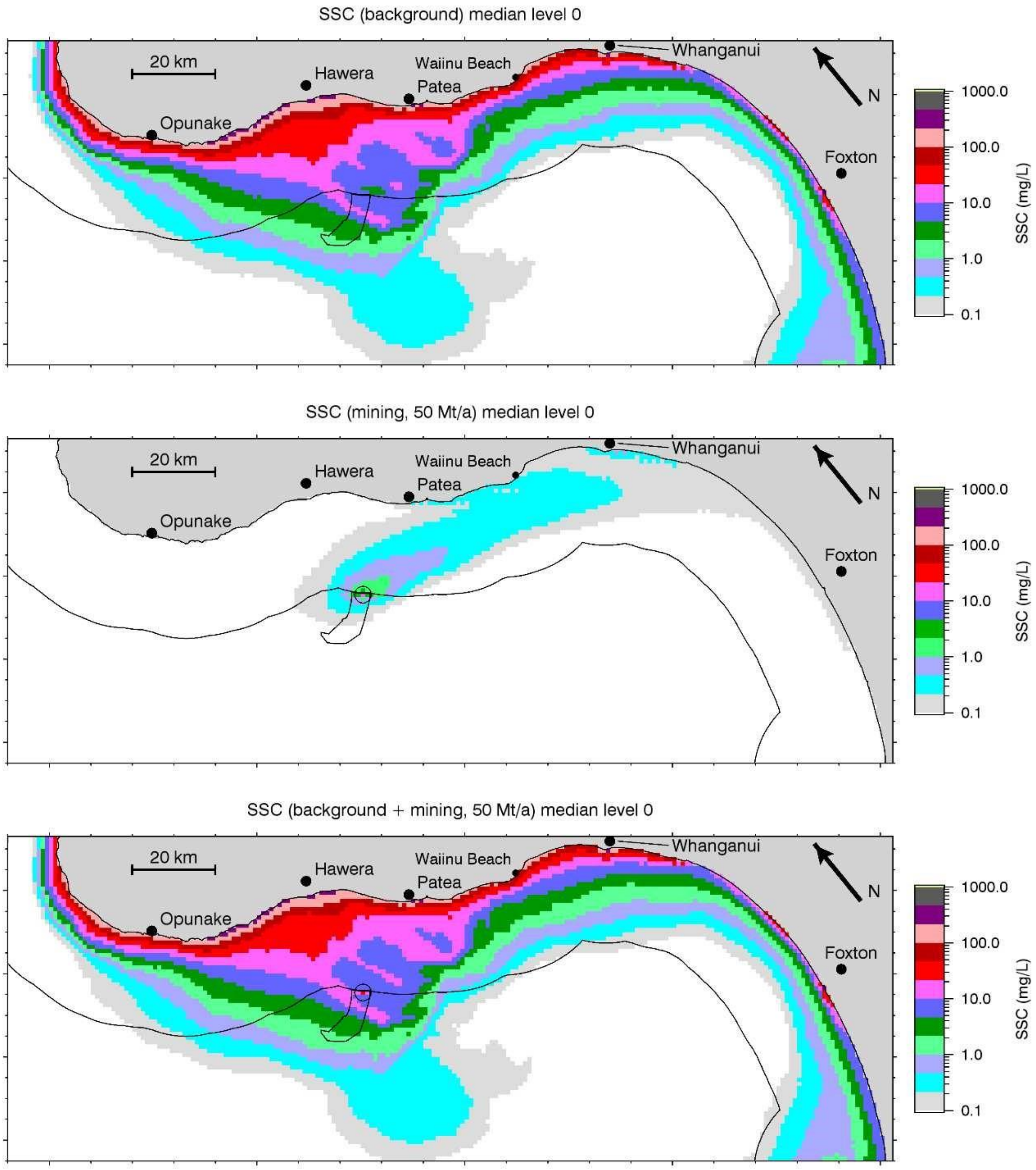


Figure 11. Median near-bottom concentration of suspended sediment from ISR (50 Mt/a) at source location A a) Background SSC; b) mining-derived SSC; c) background plus mining-derived SSC. **(from Hadfield & Macdonald 2015)**

The findings of Pinkerton & Gall (2015) can be summarized as:

- The recovery of iron sand and the resulting plume is predicted to have minor or less than minor effects on optical properties within 5 km of the coast;

- Reductions in light availability in the water column are likely to be predominantly to the east of the sites but over the modelled sediment domain will average only 1.9% (when recovering from Location A) and 1.6% (Location B) with up to 25% reduction within 20 km downstream of the activity;
- Microphytobenthos (micro-algae living on the seafloor) are predicted to occur over an area of ~3,800 km^2 in the modelled domain and ISR operations are predicted to decrease this area by 7% and only 2% of the total modelled domain area;
- The reduction in total light at the seabed is likely to be mostly to the east of the ISR operations site and is predicted to be 23% and 16% of the SMD for Locations A and B respectively (note this is total light not light that is used for primary production). Optical properties would return to previous levels within a few days of ISR operations ceasing;
- The Traps and Graham's Bank areas have high recreational and ecological values with areas of hard substrate and macroalgae. At the Traps the euphotic depth will potentially be reduced by 11% and 3% for operations at Locations A and B respectively and the days that more than 1% light reaches the seabed will be reduced by 32 and 11 days respectively (out of 138 days/yr); and
- At Graham's Bank the euphotic zone depth will be reduced by 24% and 12% for ISR operations at source Locations A and B respectively and the days that 1% of surface light reaches the seabed will reduce by 94 and 45 days for ISR at source Locations A and B respectively (out of 216 days/yr).

Summary – Effects on the physical environment

The area impacted directly by the recovery of iron sands will be ~ 5 km^2 per year in blocks of 900 x 600 m over 30 days.

Median and 99th percentile background levels of suspended sediments in surface waters close to the coast can be in excess of 20 and 100 mg/L respectively (especially closer to river mouths) and typically 100-200 mg/L (median) and 1000 mg/L (99th percentile) close to the seabed. Offshore of the iron sand recovery operations site median suspended sediment concentrations are typically less than 0.05 mg/L in surface waters and less than 1 mg/L in near bottom waters. At the inshore end of the iron sand recovery operations site median background level for surface waters is 0.4 mg/L and at the offshore end 0.05 mg/L and near bottom suspended sediment concentrations is 6 mg/L and 1.5 mg/L respectively.

The recovery of iron sands will produce a plume of suspended sediment during the excavations and on release of de-ored material. Modeling of this sediment plume indicates that median and 99th percentile suspended sediment concentrations in the plume for surface waters will be low with a median of 1.45 mg/L and 99th percentile of 8.2 mg/L at the source and very low concentrations 20 km downstream from the source (< 0.35 mg/L and 2.8 mg/L respectively). Median and 99th percentile suspended sediment concentrations in waters near the seabed will be higher with median 14 mg/L and 99th percentile 45 mg/L at the source and 0.5-1 mg/L up to 20 km downstream of the source.

Modelling predicts deposition of sediment on the seabed could occur over an extensive area but at extremely low rates of 0.01 - 0.05 mm for 5 day increments, and a maximum of 0.6 and 1.1 mm respectively for 5 and 365 days at the source itself.

Modelling of the effects of light attenuation by the sediment plume predict that the plume will have minor or less than minor effects within 5 km of the coast. Reductions in light reaching the seabed over the modelled domain will average 1.9% and 1.6% for iron sand recovery at source Locations A and B respectively and up to 25% within 20 km downstream. The area occupied by microphytobenthos is predicted to reduce by 7%. The euphotic depth at the Traps will potentially reduce by 11 and 3% for Locations A and B respectively and 24 and 12% respectively for Graham's Bank. The degree of impact is likely to be variable depending on prevailing conditions for generation of the plume.

6. Assessment of ecological effects

An assessment of the effects of the ISR operations proposed by TTR needs to be based on a good understanding of the biological and physical resources present, the type of activity, the ecological consequences of those activities and the sensitivities of the receiving environment, its habitats and biological communities to those activities.

The major impacts have been identified as:

- Loss or physical disturbance of seabed habitat and the communities associated with these habitats;
- Impacts on physiological processes including clogging of respiratory surfaces and feeding structures and processes for animal biota;
- Smothering of benthic habitats and communities;
- Avoidance of areas of disturbance and sediment plumes by fish, birds and mammals;
- Reductions in primary production in the water column (phytoplankton) and on the seabed or reefs (microphytobenthos and macroalage) through reduced light availability;
- Reduced prey and prey detection for fish, birds and mammals;
- Release of contaminants (nutrients and toxic compounds); and
- Noise effects on some fish and mammals

Any evaluation of the effects of the ISR operations must take into account severity, and the spatial and temporal extent, including recovery, of these effects. The spatial effects will depend on the scale of the impact, such as development of a sediment plume, compared with the distribution of different communities and their mobility, with sedentary taxa and communities expected to be most impacted. It should also be acknowledged that the dynamic and complex nature of the environment of the STB, the range of habitats and the lack of defined boundaries for most physical and biological processes makes the assessment of effects on ecosystems particularly challenging.

There are various ways to assess the risk associated with these effects. A number of studies and approaches have been used to assess the predicted extent, duration and severity of an activity against the sensitivities of various components of the ecosystem. Ones which are relevant and could be applied to the assessment of the effects of the ISR operations include:

- Assessments undertaken for Port Otago Ltd's dredging and disposal operation (James et al. 2009), which were based on the approaches by IADC/CEDA (1998) for the management of dredge spoil and Emmett's (2002) study of the environmental effects of shellfish farming. These approaches rate the severity of the impact as low, medium or high with classifications depending on a number of ecological indicators and processes, the duration which can be long (> 5years), medium (1-5 years) or short-term (<1 year) and spatial extent (site specific, local, regional).
- In his evidence to the previous marine consent application, Dr McClary (McClary 2014) used a risk analyses based around a protocol adapted from "AS/NZS ISO 31000:2009 Risk Management" (AS/NZS 2009) as well as an "Expert Risk Assessment of Activities in the NZ EEZ and Extended Continental Shelf". The risk scores were expressed as low, moderate, high and extreme.
- To provide more certainty around the potential effects of TTR's proposed activities a more detailed assessment of effects on zooplankton, fish, kai moana, sea birds and marine mammals was recently made by MacDiarmid et al. (2015a) based on a risk assessment approach for prospecting and exploration for seabed minerals, developed for the Ministry of the Environment (MFE). The approach developed for MFE (MacDiarmid et al. 2014) was based on an expert panel of NIWA scientists and a table of consequences for the intensity of the activity and different magnitudes of sediment discharge (for 1

tonne up to 1 M tonnes). The case studies included ISR operations off the west coast of the North Island (TTRs proposal), the recovery of phosphorite nodules on the Chatham Rise and sulphide deposits along the Kermadec volcanic arc.

The approaches by McClary (2014) and MacDiarmid et al. (2014, 2015a) along with experience with other consents involving dredging and reclamations in the coastal environment (such as Port Otago dredging), as well as published and unpublished reports and papers, have been used in the following assessment of ecological effects.

The assessment for effects on primary producers is based on a new assessment undertaken for TTR (Cahoon et al. 2015) which includes consideration of the spatial and temporal extent of a sediment plume, more information on optical property relationships with suspended sediments and closer examination of light-primary producer relationships. These revised considerations were aimed at providing greater confidence in the results and the best information available for decision makers.

The assessment presented in the following sections uses and in some cases builds upon the assessments for the previous marine consent application on benthic fauna (Beaumont et al. 2013 and McClary 2014) and scale of effects on zooplankton, fish, bird life and mammals in MacDiarmid et al. (2015a) - as well as discussions with a range of experts. The assessment by MacDiarmid et al. (2015a), and in this report uses the same approach for the scale of effect as that developed for MFE in MacDiarmid et al. (2014) with expected severity of effects rated from negligible to severe (see Appendix 1 for classifications). The present report also includes more information on threshold levels, sensitivity of organisms to the potential effects and recovery times from the proposed ISR operations. This is an area identified by the DMC as requiring more information than was provided with the previous application.

In his evidence for the previous marine consent application, McClary (2014) identified 40 effects he considered to be “low” environmental risk and the following key ones as “moderate” to “high” risk:

- Effects on benthos within the direct extraction and deposition area, particularly direct effects on the tubeworm *Euchone sp* A (rated “High environmental risk”);
- Effects on benthos in the close vicinity of the extraction and deposition area (rated “Moderate risk”);

- Potential impacts on biogenic offshore habitats due to potential “choking” effect (“Moderate risk”); and
- Potential effects of unplanned events including biosecurity incursions and oil spills (“Moderate risk”).

Applying the same approach as was used for Port Otago dredging would produce a similar environmental risk outcome but with the additional of “moderate” to “high” risk for effects on microbenthos primary production and carbon flux to the seabed.

4.1 Physical disturbance

The main direct physical impact on aquatic communities will be the physical removal of sessile and sedentary, as well as relatively immobile taxa, within the ISR area. It is likely that all larger, hard-bodied organisms will be screened out but larger soft-bodied organisms will be destroyed as they go through the extraction pump and will be removed from the area of the extraction pit. Smaller organisms such as bacteria and protozoa and maybe some polychaete worms will possibly survive the ISR process and be redeposited on the seafloor.

The area where ISR operations will take place is characterized by rippled fine-medium sands and a “worm-field” benthic community with locally high but patchy tubeworms (suspension feeding sabellid tubeworm *Euchone* sp A) (Beaumont et al. 2013). Few other epifuana were found in this area apart from low numbers of hermit crabs, small gastropods and an orange bryozoan. Total abundance and diversity were relatively low in the area (highest epibenthic abundance and diversity were found at depths beyond 60 m (Beaumont et al. 2013)). For the infauna, polychaete worm diversity in the region directly impacted was similar to surrounding areas with abundance relatively high in the area of ISR operations mainly due to the presence of high numbers of *Euchone*. Amphipods and small crustacea (cumacaeans, isopods, copepods) were also relatively abundant and diverse in the region where iron sands would be recovered. Echinoderms and molluscs were low-moderately abundant in the ISR operations region but with some taxa more abundant inshore or offshore of the area proposed for ISR operations.

The area directly impacted over the 20 years proposed by TTR will be 65.76 km^2. However, it is likely that in any one year only 5km^2 or a block 900 x 600 m (0.54 km^2) per month would have iron sand extracted. McClary (2014) estimated that the area in the STB that falls between 20 and 40 m depth occupies approximately 1,860 km^2. Thus to put the extraction area, where most taxa would be lost, into perspective, approximately 0.03% of this part of the STB per month would be impacted or 0.3% per year. In terms of the SMD this represents 0.04% per year. Ongoing recovery of iron sand will mean areas within adjacent 5 km^2 blocks of the ISR operation will be at different stages of recovery.

There is the potential for impacts on fish populations through disturbance during the mechanical dredging, and entrainment during the removal of sediment. Most fish will be able to avoid becoming entrained or will move away from the physical disturbance. However, it is possible that because of the intake water velocity occasional entrainment of smaller fish near the suction point may occur, but this is unlikely to be significant (McClary 2014). There will be some physical disturbance during recovery of iron sand due to the operation of the crawler but most fish will be able to avoid this and move away from the area. As with dredging programmes elsewhere, the disturbance of the sediment could actually enhance the availability of food for fish, at least initially, as invertebrates are disturbed and potentially made available.

The area of disturbance can be assessed using the new information provided in MacDiarmid et al (2015a). In that study the distribution of different fish, seabirds, and marine mammals were compared to the area that would be influenced by a turbid plume. The extent of the turbid plume that may cause avoidance or changes in food resources (20-75 km^2) is considerably greater than the area of physical disturbance, which will be approximately 5-6 km^2/y. MacDiarmid et al. (2015a) concluded that the effects of the turbid plume would be negligible in spatial extent compared with their foraging area thus direct physical disturbance of fish, seabirds, and marine mammals is expected to be negligible. The only exception was the eagle ray where the plume could result in a moderate effect but again the extent of actual physical disruption would be negligible compared to their foraging range and rays are often found in turbid environments.

Summary

In the iron sand recovery area total abundance and diversity of benthic animals is relatively low and dominated by tube worms. However, most sessile and sedentary organisms will be removed during the excavation with some small bodied taxa, bacteria and protozoa possibly surviving. The area directly impacted is ~5 km^2 per year or 0.3% of the South Taranaki Bight or 0.04% of the sediment model domain per year but adjacent blocks will be in various stages of recovery. Occasional small fish may be entrained but most fish will be able to avoid entrainment. The area excavated is negligible compared with the distribution and foraging range of fish, seabirds and marine mammals.

4.2 *Suspended sediments*

The effects of increases in suspended sediments and sedimentation are shown schematically in **Figure 12**. The most likely potential effects are through directly impacting on physiological processes, smothering and indirect effects through reduced light impacting on primary production and biota that rely on phytoplankton, MPB and macroalgae.

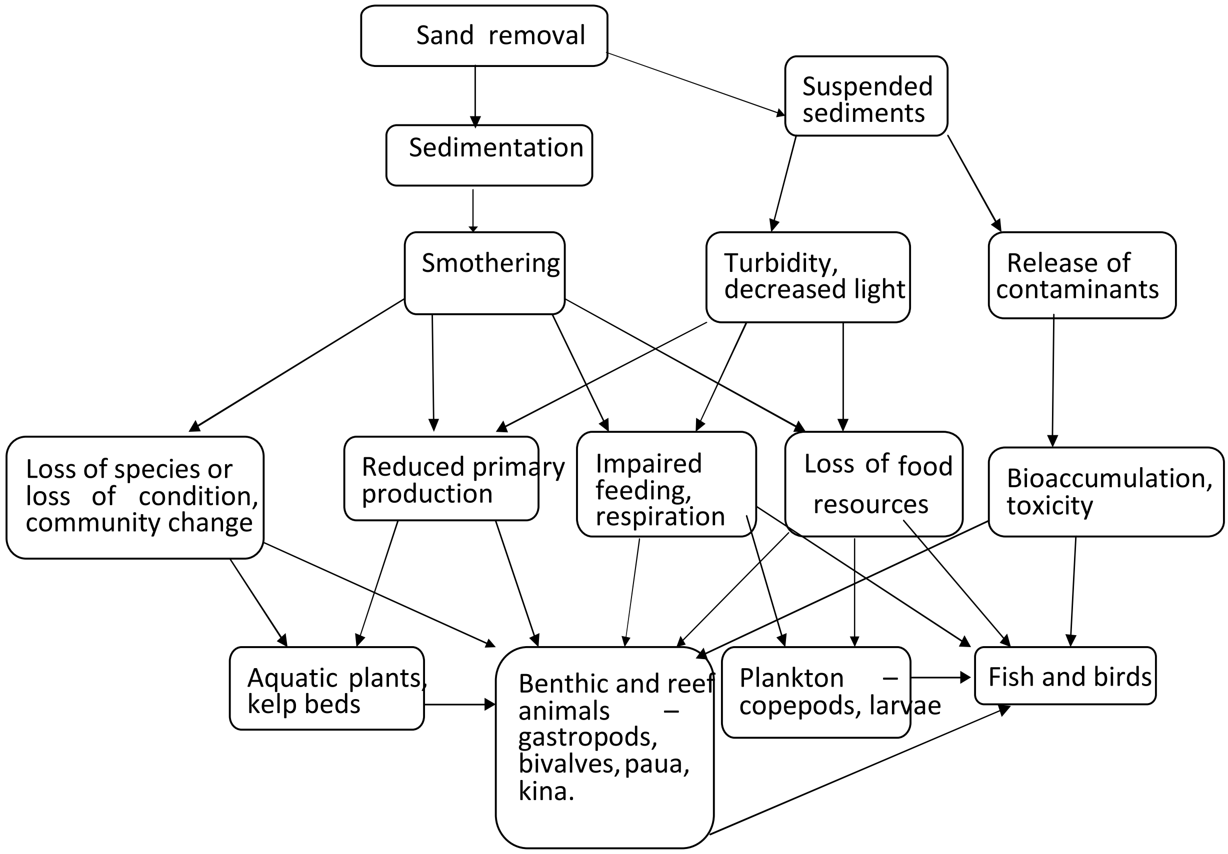


Figure 12. Schematic diagram of effects of suspended and settled sediment

4.2.1 *Phytoplankton and primary production*

The factors which drive primary production have already been discussed above and include physical processes such as major currents, winds, upwelling, nutrient supply, light availability, and grazing impacts by benthic and planktonic animals. As discussed earlier nutrient availability is considered to be a more important driver of water column phytoplankton production than light availability in these coastal systems. However, there will be spatial and temporal patterns in these drivers. Assessing the impacts on primary producers is particularly challenging because of the dynamic and complex processes involved and that there are no fixed boundaries. For example, while many primary producers, particularly phytoplankton, may have turnover rates of a few days and thus most of the production will be considered in-situ, others such as MPB and macroalgae will integrate conditions over much longer periods. The supply of nutrients advected into the STB from the likes of the Kahurangi upwelling area as well as organic matter that is produced in this plume, are likely to be very important to the STB and overall carbon flow in the region.

The original assessment of changes to optical properties on primary production was described in Pinkerton et al. (2013). The potential effects of the sediment plume on primary production has been further assessed based on revised sediment plume and optical property models, literature searches of relevant information and additional local and international expert input. The new assessment is based on more robust assessments of the effects taking into account the degree of photo-saturation and – adaptation, actual light that is likely to be utilized, new assessment of the importance of microphytobenthos (MPB) production compared with phytoplankton and the importance of advected fluxes of organic carbon versus in-situ production for the benthos. The background to the approach taken, the assessment of effects on primary production and results of that assessment have been revised from the earlier work carried out prior to the previous marine consent application to give greater certainty and address issues raised by the DMC. The following summary is based largely on the findings and report by Cahoon et al. (2015).

Propogation and dispersal of a sediment plume will result in absorption and backscattering of light which will in turn reduce light availability for phytoplankton and benthic plants. Water column primary production averaged over the SMD would reduce by 1% and 0.8% when ISR operations are being undertaken at Locations A and B respectively, with the main reduction focused close to the operational site (Cahoon et al. 2015). Because of natural variability these effects would be essentially indistinguishable at the SMD scale. The high natural interannual and seasonal variability in optical properties and primary production in the region mean that a chronic reduction of up to 1% due to the operations is very unlikely to lead to fundamental changes in the structure and processes associated with primary production of phytoplankton (Cahoon et al. 2015).

Macroalgae will be found wherever there is a hard substrate and sufficient light (0.1-1% of surface light) reaches the seabed which includes rocky reefs, particularly inshore, the Traps area, areas with high levels of shell debris and some cobbled areas on the deeper margins of banks. Macroalgae and in particular kelp beds are a very important habitat for a range of invertebrates (including the likes of kina and paua) and fish. Recruitment processes are important in determining the distribution and abundance of kelp populations. In a study off the Otago Peninsula Fyfe (2000) found the kelp *Macrosystis pyrifera* has a “recruitment window” when light and temperature requirements are met and allow the establishment of sporophytes. Recruitment was observed along the Otago coastline through spring and summer months following thinning of the canopy during winter storms. Similar processes in macroalgae recruitment would be expected to operate in the STB.

Using the best available information Cahoon et al. (2015) predicted there could be some reductions in macroalgal growth but impacts are likely to be no more than minor in areas inshore where there are naturally high SSCs at times, including the Traps some 20 km away where there are macroalgae beds. Effects would often be indistinguishable from background levels.

There is little information on the distribution of MPBs (algae which live on or in the softer sediments) in the modeled domain (~13,300 km^2) although photos of the seabed indicate features consistent with the presence of MPBs. As described in Cahoon et al. (2015) the area where production by MPBs can be expected is the area bounded by the 30-35 m contour and compromises much of the Patea Banks, particularly the eastern Patea Banks, including Graham Bank. The high variability in the amount of light reaching the seabed (annual average has a standard deviation of 25% and can vary by +36% and -32% compared to long term means) suggests that the communities in the region and particularly inshore are predisposed to tolerate variability similar to that predicted for the effects of the plume and would be unlikely to lead to unnaturally low benthic production in the SMD, outside the natural envelope.

Reductions in light at the seabed are expected to be highest close to the sites where the iron sand is recovered and de-ored material redeposited. The reduction in light levels at these sites could be up to 95% at times but over a very small area (less than 10 km from the recovery site) and can be considered a localized effect. This reduction in light and subsequent effects on primary producers on the seabed are likely to be highly variable and episodic, ranging from negligible to moderately significant effects depending on the location prevailing wind and current conditions as well as naturally high levels of suspended sediments entering the SMD from the rivers inshore. Taking into account the latest refinements and revised understanding on the predicted plume, background and predicted changes to optical properties, light availability at the seabed, light-photosynthesis relationships, including photoadaptation and photosaturation, and potential distribution of MPBs, Cahoon et al. (2015) estimated that benthic primary production (PP) averaged over the SMD will reduce by 19% (ISR at source Location A) and 13% (ISR at source Location B). Area specific reductions in benthic PP (and thus carbon flux to seabed) could be reduced by up to 40% in the area to the east of the recovery operations where the plume of SS moves over the relatively shallow (20-40 m deep) sandy area, which is part of the Patea Banks, and includes the Graham Bank, although Cahoon et al. (2015) note that while growth may be impacted complete loss of benthic biomass is unlikely.

The effects of optical properties on PP of phytoplankton, microphytobenthos and macroalgae would be expected to rapidly return to pre-mining levels following a few months for SS to be flushed out.

The benthic and planktonic biological communities cover a range of feeding modes including filter feeders, visual predators, suspension feeders, and deposit feeders. Animals living on the seabed will rely on in-situ production as well production that falls out of the water column. There are few estimates of water column versus seabed PP but this could vary from 2:1 to 10:1 and the fraction of PP transferred to the seabed is likely to be ~15% (Cahoon et al. 2015). Cahoon et al. (2015) estimated that total PP would be reduced over the SMD by 1.9% (range 1.6-2.2% depending on detrital flux rates and degree of PP by MPB) for recovery activities at Location A and 1.4% (range 1.2-1.7%) for Location B. Energy flow to the seabed averaged over the SMD would reduce by 5.8% (range 3.1-11.9%) for location A and 4.1% (range 2.3-8.3%) for location B.

Additional effects such as those associated with release of nutrients in pore water were considered by Cahoon et al. (2015) to be negligible.

The overall conclusion from Cahoon et al. (2015) was that there would be decreases in MPB production and organic carbon flux to the seabed and its communities locally in close proximity to the ISR operations that would exceed natural variability. However, because of inherent variability at the regional scale effects would be minor and indistinguishable from variability experienced now for short lived biota. Some effects at the local scale could be propagated more widely through more mobile animal taxa but this is unlikely to lead to changes in the communities or more than minor effects at the wider scale. Cahoon et al. (2015) were confident that their conclusions represent sound scientific assessments that use the best available information and will lie within the bounds of reasonable probability. It must also be emphasised that effects will be transient and thus no area will be impacted long term.

Summary – Effects of suspended sediments on primary production

Primary production is controlled by a number of physical, chemical and biological drivers including nutrient and light availability and grazing by zooplankton with nutrient supply likely to be more important than light. An improved, more robust assessment of the effects on primary prodcution has been undertaken following the previous marine consent application based on better informed relationships between light availability and phytoplankton photosynthesis. Water column primary production is predicted to reduce on average by 0.8 to 1% across the sediment model domain depending on the location of iron sand recovery operations but would be indistinguishable from natural variability and is very unlikely to lead to fundamental changes in phytoplankton and production. There would be some reduction in growth of macroalgae but because most of these are found inshore where background suspended sediment concentrations are high, any effects are likely to be no more than minor and indistinguishable from background.

There is little information on microphytobenthos but they are likely to occur on the seafloor at least down to depths of 30-35 m on the Patea Banks. There is relatively high and variable background levels of SSC inshore and across the Patea Shoals and the plume is unlikely to lead to changes in benthic primary production outside the envelope of natural variation. However, reductions in benthic primary production could be up to 95% at the iron sand recovery site itself, 40% immediately to the east of the iron sand recovery operations site, and 13-19% over the sediment model domain. Total primary production (pelagic + benthic) averaged over the SMD could be reduced by 1.4-1.9% depending on the location and could range from 1.2-2.2% depending on flux rates and contribution of phytoplankton primary production to benthic primary production. Energy flow to the seabed averaged over the sediment model domain would reduce by 4.1-5.8% depending on location with a range of 2.3-11.9%.

Overall because of inherent high natural spatial and temporal variability, effects of the iron sand recovery operations on primary production at the regional scale would be minor and indistinguishable. At the local scale close to the site, reductions in benthic primary production would exceed natural variability and there could be localized flow on effects but productivity would return to previous levels once activities ceased.

Effects of nutrients released from pore water during excavation is considered to be negligible.

4.2.2 Benthic communities

The assessment of the effects of a sediment plume require a good understanding of the communities present and the values (eg. biodiversity, food for higher trophic levels) of those communities, the spatial and temporal scale of the severity and dispersion of the plume, the tolerances of the communities to increased SSC and potential for recovery from the effects. Uncertainties around tolerances or thresholds, temporal variation and recovery of benthos were raised as concerns by the DMC in the previous marine consent application. More information and a more robust assessment is provided in the following sections to address these uncertainties.

Open water ecosystems are dynamic and often in a state of perpetual change with periodic disturbances due to storm and other events. This perpetual change is not necessarily detrimental to benthic systems as it maintains diversity by resetting communities. Benthic communities, such as those in the STB, are often in a state of transition because of seabed disturbance by wave activity and can be represented by both opportunistic early successional taxa, which are often dominated by small polychaetes and taxa which reproduce rapidly and disperse easily and later by more stable larger successional taxa (large gastropods and bivalves). Adults tend to be more tolerant of higher SSC than larval forms and deposit feeders and burrowers more tolerant than suspension feeders.

Areas of high ecological value in the region of the proposed ISR operations and the wider region, that would be potentially impacted include:

- The North and South Traps – “urchin burrows”, rocky outcrops with sea urchin;(*Evechinus chloroticus*), red and brown algae and a diverse invertebrate and fish community (Beaumont et al. 2013, McClary 2014);
- The Graham Bank – coarse-sandy shelly habitat with scallops and hermit crabs;

- Inshore and mid-shelf reefs off Patea and Hawea – support very abundant and diverse algae, invertebrate and fish communities, mostly close inshore;
- Biogenic habitat off shore:
    - Bivalve rubble characterised by large populations of the robust dog cockle, *Tucetona laticostata* at depths of 26-83.5 m for live specimens and 44-69 m for shell hash.
    - Bryozoan rubble at depths > 60 m that support diverse benthic assemblages (bryozoan, sponges , ascidians etc)
- Coralline red algae on shell rubble inshore and at the 40-50 m contour (Beaumont et al. 2013).

As described earlier under physical disturbance, the region where iron sands would be recovered is dominated by a "Wormfield" benthic community. Although the direction of the sediment plume will be variable, depending on prevailing weather conditions, the prevailing direction is likely to be to the north-east. The benthic habitat and communities to the north-east of the ISR operations area and across the Patea Shoals is very similar to those described above for the site itself in terms of epifauna in general, although some bivalves such as *Glycymeris modesta* were more abundant as well as a slightly more diverse echinoderm community being common to the northeast. The substrate also tended to get coarser to the east and northeast of the ISR operations site with more medium-coarse sand and fine gravels.

The levels of SSC in the sediment plume due to the ISR operations, as modelled by Hadfield & Macdonald (2015), can be summarized as:

- Median background SSC close to the coast can reach over 10 mg/L and 99th percentile over 100 mg/L in surface waters and 100 mg/L and 1000 mg/L respectively on the seabed;
- The differences in SSC with and without iron sand extraction are imperceptible except within a few kilometers of the source. The highest surface SSC from ISR for Location A was 1.45 mg/L for the median and 8.2 mg/L for the 99th percentile at the source and 0.35 mg/L and 2.8 mg/L respectively 20 km downstream; and
- The SSC of the sediment plume is extremely low inshore from Patea to Foxton (0.1-0.2 mg/L).

Outside the ISR operations area, the direct and indirect effects on benthic communities as a result of the sediment plume may be manifest through:

- Smothering resulting in the loss of organisms;
- Clogging of gills and feeding apparatus and other physiological processes such as respiration;
- Loss or changes to food resources;
- Indirect effects of light attenuation and PP of algae, macroalage and MPB; and
- Impacts on larval supply and retention.

Based on a detailed risk assessment McClary (2014) suggested that clogging and choking of biota on offshore biogenic habitats was a “moderate risk” with other effects such as clogging and light reduction of inner, mid-shelf and other offshore habitats a “low risk”. More in-depth analyses of effects on PP and benthic carbon fluxes, since the previous marine consent application, by Cahoon et al. (2015) however, would suggest that attenuation of light and its effects on PP and carbon fluxes could be manifest to higher trophic levels but would only really be a higher risk close to the site of ISR operations and deposition area.

Although some effects on the benthic habitat close to the ISR operation are unavoidable, comparison of SSCs that would be experienced by benthic biota with tolerance levels, allows us to assess the potential significance of increased SSC from plume development. Although information is limited for some taxonomic groups there is a good body of information from New Zealand studies on the effects of suspended sediments on a range of benthic biota including molluscs, polychaete worms, and sea urchins, and kelps and other macroalgae.

Studies by Hawkins et al. (1999), Clarke & Wilbur (2000) and Hewitt & Norkko (2007), found suspension feeding animals, such as cockles and mussels, can actually benefit from suspended sediments as it aids processing of foods or they can adapt their feeding processes to changes in suspended sediment levels. Condition of cockles (*Austrovenus stuchburyi*) did not decline until SSC reached 400 mg/L and development of oyster eggs was impacted at levels over 188 mg/L and larvae at SSC of 750 mg/L. The greenshell mussel *Perna canaliculus* can adjust its filtering processes very effectively and will continue filtering even at levels of 1000 mg/L (Hawkins et al. 1999). Some species are more sensitive with condition of the horse mussel (*Atrina)* impacted by levels over 80 mg/L (Ellis et al. 2002). Some deposit feeding polychaete worms, heart urchins and pipis show some effects if concentrations are over 80 mg/L (Hewitt et al. 2001, Nicholls et al. 2003). Other taxa, such as the small mudsnail *Zeacumatus* showed no response at levels up to 750 mg/L over 9 days. Polychaete tube worms dominated the community at the ISR operations site itself and heart urchins are an important taxa on reefs and in habitats at depths over 60 m. James et al. (2009) suggested that 100 mg/L over short periods (days/weeks) was a reasonable level that would prevent risk of impacts on the more tolerant taxa in Otago Harbour and Blueskin Bay. Taking into account that the communities in the STB, in the region potentially impacted, may include some more sensitive species then periodic levels of 80 mg/L could be tolerated by most species. These limits are summarized in **Table 1.** It should also be noted that duration of increased suspended sediment should be taken into account as most taxa could tolerate short events. It is likely that the effects of the sediment plume on the benthos more than a few kilometers away from the source is likely to be transient, because of variable currents and wind conditions.

Modelling by Hadfield & Macdonald (2015) shows that in the SMD the inshore region naturally experiences SSCs with a median of 10 mg/L and over 100 mg/L at times in surface waters and a median of 100 mg/l and peaks of 1000 mg/L near the seabed. The SSC resulting from ISR operations would add less than 2 mg/L to SSC in surface waters near the coast and most of the time would add <0.2 mg/L to this area. Thus the effects on the inshore biota would be expected to be no more than minor and indistinguishable from the effects of background SSC. The highest levels of SSC in surface waters at the ISR operations site itself would be 1.45 mg/L as a median and 8.2 mg/L as the 99th percentile and less than 2.8 mg/L 20 km downstream, thus effects, if they were to occur would be no more than minor beyond the immediate area. Near the seabed, SSC would be up to a median of 1 mg/L and 99th percentile of 5 mg/L up to 20 km away from the source and up to 14 mg/L at the source itself.

Author	**Species**	**Sediment concentration***
Hewett et al. 2001	Cockle (*Autrovenus stutchburyi*)	300-400 mg/l
Hewett et al. 2001	Pipi (*Paphies australis*)	75 mg/l
Nicholls et al. 2003	Gastropod (*Zeacumantus lutulentus*)	>750 mg/l
Bricelj & Malouf 1984	Juvenile hard clam (*Mercenaria mercenaria*)	44 mg/l
Hawkins et al. 1999	Green lipped mussel (*Perna canaliculus*)	1000 mg/l
Ren et al. 2000	Oyster (*Crassostrea gigas*)	>600 mg/l
Schwarz et al. 2006	Kelp (*Ecklonia radiata*)	20 mg/l
Schwarz et al. 2006	Paua and kina larval mortality	35 mg/l
Phillips and Shima 2006	Paua and kina	18-74 mg/l

* Levels that had an impact on condition/growth

Table 1. SSC that have been found to affect benthic invertebrates.

Small grazing and suspension-feeding invertebrates found on rocky reefs are an important trophic link between primary producers and fish, with kelp often being the main habitat. In addition to being indirectly impacted by decreased light levels for plant growth these communities can be impacted directly by clogging of feeding apparatus or smothering of food resources such as epiphytes. Epifaunal abundance, biomass and productivity were found to be 50% lower at turbid sites (up to 16 mg/l) than "cleaner" sites (undetectable to 7 mg/l) off the Whitianga Harbour (Schwarz et al. 2006). Using a range of natural concentrations Schwarz et al. (2006) found a drop-off in mussel and oyster condition at suspended sediment concentrations over 26 mg/l and sponges at over 15 mg/l. Concentrations in the plume reaching the inshore region off Patea, if it did reach the coast, would be <2 mg/L. The documented inshore communities along this coast are presently able to tolerate considerably higher levels of SSC which can occur during natural storm events and often persist for a period after.

Benthic algae and kelp beds support diverse and abundant invertebrate and fish communities inshore and on mid-shelf reefs. Increased SSC can reduce light availability, as discussed earlier, which in turn can impact on the growth and condition of reef macro and micro-algae and the animals that rely on them. The larger kelps, such as *Macrocystis pyrifera*, are often subject to die-off during winter storms and have “recruitment windows” when light and temperature requirements allow establishment of sporophytes. Time averaged SSC at sites off New Plymouth inshore in depths of <0.5 m where the common kelp *Ecklonia radiata* occurs, were found to range from 3.4-150 mg/L (Schwarz et al. 2006) naturally.

As discussed earlier the small increases in suspended sediments, if they were to occur inshore, would be no more than minor and indistinguishable from background levels.

The sediment plume would only occasionally go offshore from the recovery site and modelling results presented in Hadfield & Macdonald (2015) indicate that the bryozoan beds offshore at depths >60 m would rarely experience any sediment plume and if they did so SSC would be < 1 mg/L. The seafloor in deeper areas is also likely to naturally be sediment depositional zones because they are rarely disturbed by wave activity.

MacDiarmid et al. (2015a) reviewed the spatial and foraging ecology of key invertebrate fauna in the STB, to provide some scale to the potential effects of the ISR operations. Most of the invertebrate species gathered recreationally or for cultural reasons are found inshore in the intertidal or subtidal zone and include various mussel species, crabs, mud-snails, pipis, surf clams (purimu), rock oyster (karaura), paua, sea tulip (kaeo) and cats eyes (pupu). As discussed above these species presently occur in coastal environments and experience episodic periods of high SSC due to river inputs and resuspension during storm events.

Summary – Effects of suspended sediments on benthos

The benthic invertebrate community in the region of the ISR operations and surrounding area is characterized by a “Wormfield” community and a mix of opportunistic, early successional taxa and larger later-stage taxa. The dynamics and production of these communities are largely driven by the persistent and dynamic changes in the physical processes and carbon fluxes to the seabed. There are areas of increased abundance and diversity of bivalves and echinoderms.

Direct effects of suspended sediments on these communities include smothering, effects on feeding and other physiological processes, and indirect effects of changes to food availability, and larval supply. Most of the effects have been assessed as low risk or no more than minor apart from potential interference with physiological processes and reduced carbon flux in areas close to the activity. Evidence from a number of studies indicates that most taxa are relatively tolerant of significantly higher levels of suspended sediments than will be experienced even close to the site itself. Suspended sediment concnetrations in the plume that could potentially reach the inshore reefs, kelp beds and associated fauna is low compared with background levels and thus will have no more than a minor effect. Similarly, more diverse offshore bryozoan beds would only be impacted occasionally and not at levels that would cause more than minor effects.

4.2.3 Zooplankton and larval fish

Neritic or coastal zooplankton contain a range of taxa including copepods, salps, and larval crustacea, bivalves and fish. The distribution of many benthic invertebrates depends on dispersal by currents for recruitment and colonization. Most species are able to tolerate relatively high levels of SSC, at least for a short period, and in the case of copepods will have several generations a year. Thus populations are able to rapidly recover following disturbance.

Suspension and filter-feeding zooplankton can be affected by high levels of suspended sediments. Arendt et al. (2011) found concentrations of fine sediment above 20 mg/l can clog zooplankton respiratory surfaces and/or feeding apparatus as well as impair prey detection. Considerably higher levels would be required to have a significant impact with Wilber & Clarke (2001) finding fish eggs and larvae were only impacted if SSC was over 500 mg/L. Any impact if it were to occur would be short-term as these populations will move through the region with the currents and zooplankton have generation times of days to months. SSC in near surface waters are predicted to increase by up to 3 mg/L away from the source and in a well-defined plume.

As discussed above, effects on primary producers can also impact on higher trophic levels that depend on phytoplankton as their major food resource. However these indirect effects if they were to occur would be no more than minor and not alter the zooplankton community or impact on production.

Summary – Effects of suspended sediments zooplankton and larval fish

The neritic zooplankton community and its distribution depends on the prevailing currents and advective processes as well as in-situ primary production. Away from the source suspended sediment concentrations are predicted to be well below levels that would impact on these communities. Zooplankton communities can be highly transient, depending on the currents, and if impacted effects would be no more than minor and they would recover rapidly.

4.2.4 Fish populations

The direct and indirect effects of suspended sediment on fish populations, as a result of ISR operations, must take into account the level of suspended sediment compared with background levels, the tolerances or thresholds for different species, and the duration and spatial area that the effect is above those tolerance levels. The potential effects of the sediment plume and associated changes in turbidity and suspended sediments include:

- Impacts on physiological processes such as respiration and feeding;
- Impaired visibility for prey detection;
- Loss or changes in feeding area and food resources; and
- Loss or changes in spawning areas.

Lowe (2013) and Page (2014) identified 2 mg/l and 3 mg/l as the lowest SSC that would be avoided by pelagic and demersal fish respectively. Acute and chronic impacts would be expected to be at much higher levels. In a recent study on juvenile snapper in estuaries Lowe (2013) reported 35-40 mg/L as the level that started affecting foraging strategies, and declining condition. Page (2014) provides a very comprehensive list of published threshold concentrations with most species only impacted beyond avoidance or a reduction in feeding, at levels well over 500 mg/L. Such levels would not be encountered even right at the source and near the seabed.

Based on their modeling Hadfield & Macdonald (2015) predicted that the only perceptible difference in SSC would be within 2-3 km of the source with a median and 99^{th} percentile of 1.45 and 8.2 mg/L in surface waters at the source (Location A) and 0.35 and 2.8 mg/L respectively 20 km downstream. Near the seabed SSC would be up to a median of 1 mg/L and 99^{th} percentile of 5 mg/L up to 20 km away and up to 14 mg/L at the source itself. Areas close inshore already experience high levels of SSC and the levels resulting from ISR operations would be within the range of natural variability in SSC that fish would experience.

MacDiarmid et al. (2015a) used spatial information on the occurrence and foraging of different species, a SSC limit of 3 mg/L and the potential dispersion of the sediment plume to assess the scale of impact from the ISR operations. They demonstrated that <1% of the area occupied by the different fish species found in the STB would potentially be impacted and effects would be negligible or no more than minor. The only species identified as potentially impacted as more than minor in the study by MacDiarmid et al (2015a) was the eagle ray as 8% of its “core” distribution in the STB coincides with the area potentially impacted by the sediment plume. However, as MacDiarmid et al. (2015a) note, this species concentrates inshore at certain times of the year where SSC can be naturally very high and thus the use of 3 mg/l as a threshold for effects is likely to be very conservative. Rays are also commonly encountered in harbours and estuaries where SSC can be very high at times (pers. obs.) thus the effect would be expected to be no more than minor.

The area potentially impacted by ISR operations is not known as an important spawning area for fish and thus any impacts of SSC if they were to occur would be no more than minor in the context of this part of the STB. For fish that spawn inshore the effects are likely to be within the range of background levels of SSC that the fish populations would encounter naturally.

Summary – Effects of suspended sediments on fish

Fish are relatively mobile and will tend to avoid areas of high turbidity. Suspended sediment concentrations of 2-3 mg/L may be avoided but acute and chronic impacts would only occur at significantly higher concentrations and at levels that would only be found in bottom waters close to the source. Based on spatial information on fish distribution and a conservative level of 2-3 mg/L, less than 1% of the area occupied by each fish species in the South Taranaki Bight would be impacted. The only exception is the eagle ray where 8% of its core area could be impacted but this species is likely to be tolerant of higher levels of suspended sediment concentrations and is often found in more turbid inshore environments. No critical areas for spawning near the activity have been identified and levels would be lower than inshore species would experience naturally.

4.2.5 Seabirds

Because of their mobility and wide foraging range, effects on seabirds recorded in the region potentially impacted by higher SSC due to ISR operations, will be negligible. MacDiarmid et al. (2015a) selected five representative species for more in-depth assessment - the Gibson's albatross, Westland petrel, Sooty shearwater, red-billed gull and little blue penguin.

As reported in MacDiarmid et al. (2015a), Walker & Elliott (2006) found that the STB was not a particularly important area for Gibson's albatross and using the criteria in MacDiarmid et al. (2015) the ISR operations would have negligible effects on this albatross.

The Westland petrel is of high conservation concern (though not on the threatened list) due to its very restricted mainland breeding distribution and modest population size (MacDiarmid et al. (2015a). The at-sea distribution of this species during the winter breeding season spans central New Zealand, including the STB. It is likely that this species could occur in the area impacted by ISR operations but the area affected is relatively small compared to the overall distribution of Westland petrels (<0.1%) and MacDiarmid et al. (2015a) concluded that the effects would be negligible.

Sooty shearwaters are found throughout New Zealand when breeding and based on a relatively conservative estimate of the spatial extent of sooty shearwater distribution, the area of surface SSC elevated above 2 mg/l due to ISR operations would represent less than 0.01% of its foraging area. Off the Otago Peninsula this species is found to forage widely diving to depths of over 40 m feeding on small fish, squid, krill and other crustaceans (James et al. 2009). Its wide ranging foraging and depth range, compared with the area potentially affected by the proposed ISR operations, means effects are considered negligible (MacDiarmid et al. 2015).

Red-billed gulls are found around the entire coastline of the North and South Islands, including the STB and possibly including the area affected by the ISR operations (MacDiarmid et al. 2015a). The STB does not have a major breeding colony and the area potentially affected by the sediment plume represents <0.1% of the coastal distribution of this species. Thus MacDiarmid et al. (2015) considered the effects would be negligible even if just the inshore area was considered.

Little blue penguins are found in coastal areas around New Zealand. The closest breeding sites to the area impacted by the ISR operations are more than 50 km away from the area of the sediment plume and the area potentially impacted is less than 0.1% of the area available, thus the effects would be negligible (MacDiarmid et al. 2015).

For the Port of Melbourne dredging programme the threshold for protecting terns and gannets was 25 mg/L (Port of Melbourne 2008). The SSC in the plume in surface waters will be less than 3 mg/L 20 km downstream and even at the ISR source itself will only be up to 8 mg/L. Thus the levels will be well below those used to protect these species.

Summary – Effects of suspended sediments on birds

Because of their mobility and wide foraging range effects on seabirds as a result of iron sand recovery operations are predicted to be negligible. More detailed assessments of five key species – Westland petrel, sooty shearwater, red-billed gull, Gibsons' albatross and little blue penguins have found that the sediment plume would affect <0.1% of their foraging area and thus effects would negligible.

4.2.6 Mammals

Potential effects of SSC on mammals would be through avoidance behavior, reduced visibility for feeding and impacts on food resources. The distribution of mammals based on observations are documented in Torres et al. (2014) and summarized by MacDiarmid et al. (2015a). The distribution of mammals is also summarized in previous sections of this report.

Blue whales have been observed in the western and central part of the STB predominantly at depths of 50-150 m. However, they are unlikely to occur at the ISR operations site which is thought to be at the edge of their feeding grounds. The area of SSC above 2 mg/L represents only 0.2% of their foraging area (excl shallower areas of the STB) and thus MacDiarmid et al. (2015) concluded that any displacement or impacts on feeding would be negligible.

Based on habitat modelling the southern right whale prefers sheltered shallow coastal waters and the only sightings in the STB have been to the north. Thus MacDiarmid et al. (2015a) concluded that the ISR operations would not impact on this species. Similarly killer whales are found throughout New Zealand and the STB is only moderately favourable as a habitat. Its prey (eg school shark and rays) are found over a wider area of the STB thus like the other species would be unlikely to be impacted (MacDiarmid et al. 2015a).

Pilot whales commonly feed on squid and have a wide distribution and forage over wide areas around the New Zealand coastline. The area potentially impacted compared with the area of foraging will be negligible for the pilot whale populations.

The majority of the STB is unsuitable habitat for Hectors dolphins which are endemic to New Zealand and at a very high risk of extinction. Hectors dolphins prefer areas of low water clarity and are opportunistic feeders. In addition, the near absence of sightings and the small potential foraging area impacted compared with their range led MacDiarmid et al. (2015a) to conclude that there would be negligible impact. The common dolphin is found throughout New Zealand. A common prey is jack mackerel which is widely distributed in the area and along with the large area occupied by the common dolphin and its ability to range over large areas, led MacDiarmid et al. (2015) to conclude that any effects on the common dolphin population in the STB and on Hectors dolphin would be negligible.

The New Zealand fur seal is found throughout New Zealand and numbers have been increasing in numbers in recent years. They typically forage offshore at night but can be found foraging inshore as well. Tracking has shown that mean foraging trips are 100 km thus the ISR operations area could be accessed from nearest colonies

(Stephens Island, Sugar Loaf Island). At sea sightings have observed animals in the area potentially impacted by the ISR operations and the plume (Torres et al. 2014, Cawthron 2013, MacDiarmid et al. 2015a). Based on the foraging area, potential displacement and extent of potential effects MacDiarmid et al. (2015a) concluded impacts would be negligible.

Summary – Effects of suspended sediments on marine mammals

A number of mammal species including blue whale, southern right whale, pilot whale and dolphins have been observed in the area. However, the area potentially impacted by a turbid plume is negligible compared with their foraging range. There have been very few sightings of the threatened Hector's dolphin in the region but they have also have a wide foraging range, are opportunistic feeders and actually prefer low water clarity areas, thus effects of the proposed iron sand recovery operations would be negligible, if there were any effects at all. Similarly fur seals forage over wide areas and thus effects would be negligible.

4.3 Deposition.

Sedimentation will be most significant at the ISR operations site as the sand is redeposited in the excavated trench after recovery of the iron ore. Close to the ISR operations source, and for some distance downstream, suspended sediment will also settle out of the water column at times and could potentially result in the smothering of the benthic community. Many taxa found inshore will be exposed to naturally high levels of sediment deposition at times, while well offshore in deeper water is a general deposition zone for fine sediments originating from land.

There is now a reasonable body of evidence on the effects of sedimentation on benthic communities, including a number of New Zealand studies in harbor environments (**Table 2**). Experiments in a range of studies, mostly on the Manukau Harbour, have shown that generally most soft-bottom species can only escape a maximum burial depth of 2-10 cm depending on the species and type of material deposited (Norkko et al. 1999, 2001). Some benthic taxa, such as the bivalves *Nucula* and *Macomona* and some polychaete worms, can survive and escape burial under at least 20-30 cm of sand while 50% of *Zethalia zelandica*, a small trochid wheel shell, similar to some species found off the Taranaki Coast, did not survive burial in 17 cm of sand or 3.8 cm of mud (Paavo and Probert 2005). This clearly demonstrates the difference in effects between sandy versus muddy depositions. The deposition of clay material will have the greatest effect with experiments in the Auckland Region demonstrating that layers as thin as 3-7 mm had some impact on macrofauna and rapid accumulations of 20 mm can smother entire benthic communities (Norrko et al. 1999). The material being redeposited at the ISR operations site will contain very little clay.

Cockles (tuaki), pipis and tuatua are important for recreational and cultural harvesting in coastal environments. Experiments have shown that cockles can survive burial under several cm of sand but only up to 30 mm of fine silt. Pipi are active burrowers and can be found buried in up to 100 mm of sand and larger ones can even tolerate up to 400 mm. While limpets and whelks are highly sensitive to the silt /clay content of the substrates some surface grazing animals like the gastropod snail *Zeacumantus lutulentus* are relatively robust to high levels of settled sediments and some crabs show a preference for fine silts and muds. Shrimps and some crabs can survive up to 9 cm of deposition but cockles and other molluscs generally start responding at levels of 20-30 mm, depending on the grain size.

Most MPBs are adapted to dynamic environments and episodic events and disturbances due to sediment resuspension and deposition. Many species are also motile and will migrate through thin layers of deposited sediments.

Sedimentation can impact on macroalgae and rocky shore communities through effects on settlement, recruitment, growth, and survival. Indirect effects include loss of photosynthetic capacity with a film of a few mm of sediment potentially reducing photosynthesis of plants. While most established alga can survive burial for short periods, attachment of germlings can be impacted by a light dusting of sediment (Schiel et al. 2006) and relatively heavy settlement (2 mm) can prevent attachment altogether.

Some intertidal algae can remain intact after 3 months of burial but growth is inhibited, while others do not survive burial under thick sediments for a month. Deposits of up to 3-7 mm can have a negative effect on microphytes (microscopic benthic algae) and repeated additions over several months have been found to have a cumulative negative effect. Coralline crusts have been found to be unaffected by burial in sand for a few months.

Average sedimentation rates over the SMD are estimated to be 0.5 - 1 mm/yr in the plume which is virtually indistinguishable from background levels and will have negligible, if any, effects on benthic communities outside the pit and immediate area.

In the pit area where the sediment is redeposited initially there will be no living benthic community but as described below the community would rapidly recover through settlement of larvae and transport of adults into the area. Very few animals would be able to migrate through the several meters of deposited sediment in the pit area and thus the degree of recovery will depend on the level of recruitment from outside sources, the way the material is deposited, and the length of time since the seabed was excavated.

The sampling of infauna commissioned by TTR focused on organism in the surface 5 cm. Holes from deep burrowing mantis shrimps are commonly found in inshore sandy habitats but NIWA saw very few surface holes/burrows and caught no shrimps in dredge tows across the Patea Shoals. If they are present then mantis shrimps and some crab species have been shown to survive up to 9 cm of sediment deposition (Norkko et al. 1999), thus would only be impacted at the excavation site.

Author	**Species**	**Sediment deposition**
Norrko et al. 2001	Various benthic species	3-7 mm clay
Doorn-Groen 1998	Sessile animals including corals	1.7 mm/14 days
Lohrer et al. 2004	Various benthic species	>2 cm in one event
Norrko et al. 1999	Shrimps and crabs	9 cm
Vermaat et al. 1997	Seagrasses	5 cm for 2 months
Devinny & Volse 1978	*Macrocystis* mortality of germlings (90%)	10 mg cm^{-2} (~0.45 mm Hepburn evidence)
Schiel et al. 2006	Macro-algae germlings attachment	2 mm

Table 2. Tolerance levels for a range of invertebrates and microalgae to sediment deposition.

Summary – Effects of deposition

There are two sources of material that would deposit on the seabed, material that has had the iron sand removed and is re-deposited on the seabed near the excavation activity, and secondly finer material that settles after being dispersed by the sediment plume. The predicted levels of sedimentation has been modelled over 5 and 365 accumulation periods and indicate that average sedimentation rates over the sediment model domain will be 0.5- 1 mm/yr which will be virtually indistinguishable from natural levels and is negligible compared with known tolerance levels for benthic invertebrates and macroalgae.

4.4 Recovery from suspended and deposited sediment effects

Recovery will depend on the type of sediment present, extracted and deposited, severity of the effect, potential for migration into the area, and the availability of larval and adult recruits. There is now a good body of information available in New Zealand on recovery rates following sediment plume and sedimentation events as a result of dredging and other activities. This information is based on experimental trials as well as following recovery following dredging operations.

Experiments carried out as part of studies around maintenance dredging by Port Otago Ltd provide some indication of recovery following disposal of dredge spoil (Paavo and Probert 2005). In those experiments muddy spoil from Dunedin Harbour was deposited off Aramoana and recovery followed. Surveys showed that 119 days after depositing muddy spoil, the benthic community was still depauperate (low population size and number of species) compared with pre-disposal and it took up to 180 days for the disposal site to recolonise and have a similar community to a site protected from disposal. It should be noted that recolonisation was much quicker for sand disposal with the community being similar to predeposition within 12 days. For the present application where predominantly sandy material will be deposited on top of the existing communities downstream of the actual excavation, recovery would be expected to be quicker because only a thin layer would settle out from the plume. The redeposited material will be similar to that extracted in terms of particle size which James et al. (2009) suggested will aid recovery. Recovery in the pit area as the sand is redeposited would be expected to be longer as it would rely on recruitment and advection from outside the area, although this recovery would start as soon as the material is deposited.

Surveys following dredging at the Port of Auckland and disposal of 262,000 m^3 in the Hauraki Gulf found there was an initial increase in abundance and diversity of benthic communities then a decline (Gowing et al. 1997). Early successional communities, which included the likes of tube-dwelling polychaetes, were evident immediately after disposal followed by an increase in longer lived successional stages 8 and 11 months after disposal (found at 45% of sites at the disposal site cf. 68% at control sites after 11 months). A number of overseas studies (Newell et al. 1998) have shown that while communities associated with muds may recover within months, communities in sand deposits are likely to be in a transitional stage and take up to 2-3 years to recover. Some longer lived species in these communities, such as heart urchins and large bivalves which are found in the STB, could take several years to fully recover in the actual area where sands are extracted but there would be some movement into the area immediately after the recovery activities move to the next block. Monitoring at dredge disposal sites in 1992 off the Port of Tauranga found that large scale irreversible changes in benthic fauna had not occurred and there are no documented cases of large-scale irreversible changes with other dredging operations in New Zealand.

Material from the STB was used by NIWA to experimentally assess recolonization that would be expected to occur in the STB. The experiments had to be conducted in Wellington Harbour because of the exposed nature of the STB, and although the focus was on assessing the effects of removing iron from the sediments the results do provide some indication of recovery. The experiment was run for 7 months after which time several “opportunistic species” (e.g. copepods and small polychaetes such as *Capitella capitata*) were found to have recolonized the sediments (Beaumont et al. 2013).

The existing community in the STB where the iron sand recovery is proposed is a very exposed, highly dynamic sandy environment where much of the benthic community will be exposed to episodic disturbances from wave events and river inputs during high rain-fall events. The existing community is dominated by short-lived, opportunistic and early successional stages. The abundant polychaete *Euchone*, *Aricidea* as well as syllid and photid polychaete worms and isopod *Pseudaega* spp. which are found in the area of potential impact (Beaumont et al. 2013) are known as early colonisers and along with the low abundance of longer lived organisms is indicative of an environment that is regularly disturbed.

As described earlier, the community further offshore (60 m water depth) is dominated by later successional stages (certain bryozoans, sponges, larger gastropods and higher numbers of motile taxa) while the bivalve rubble habitat in shallower waters supports early successional stages (encrusting corraline algae, small encrusting invertebrates). The dominance by early successional stages in the area potentially impacted suggests that recovery should be relatively rapid and likely to be at the scale of months to a few years. Recovery of some taxa such as small polychaete worms would be expected to start within a few weeks of the ISR operations moving elsewhere within the consent area. There is likely to be a gradation of recovery as the activity moves across the area where sands are extracted and redeposited.

The effects of activities such as dredging and ISR operations can be both positive and negative with disposal of dredge spoil in some cases enhancing the availability of small invertebrates and particulate organic matter for suspension and deposit feeders as well as fish, at least initially. In a study by Gilkenson et al. (2005) and reported by McClary (2014) populations of the tubeworm *Euchone papillosa* had increased by over 100% 2 years after disposal of dredge material.

Summary – Recovery from suspended sediments and sedimentation

The recovery of the benthic environment as the iron sand recovery operations moves across the site will depend on the type of sediment, the severity of effects from excavation and the sediment plume and availability of recolonisers and recruitment. The existing community is dominated by short-lived, opportunistic and early successional stages but with populations of some larger longer-lived taxa also occurring. The dynamic nature of the environment means abundance and diversity for most groups is relatively low. The offshore community is more diverse and contains more larger and late successional stage taxa.

The dominance by opportunistic taxa in the region directly impacted by excavation and the sediment plume means recovery is likely to be rapid once the excavation and redeposition moves away with recovery of the likes of polychaete worms likely to start immediately. Larger, long-lived taxa may take several months to a few years to recover. There is likely to be a gradation in recovery as the activities move to new blocks each year.

4.5 Contaminants

Contaminants, such as heavy metals and PCBs, can potentially affect offshore biota through direct toxic effects and bioaccumulation into the food web. Contaminants in the sediments of the STB, such as heavy metals, were investigated by Vopel et al. (2013). As would be expected for such a dynamic exposed environment, organic content and concentrations of contaminants such as heavy metals were at low levels with some metals below detection limits. No contaminants exceeded ANZECC guidelines (ANZECC 2000) although levels of nickel and copper in elutriate were slightly higher and would require some dilution to get to the 99% protection level (Vopel et al. 2013). Any contaminants that were released into the water column during extraction of iron sands would be rapidly diluted and dispersed.

There is always the potential for oil spills from vessels and recovery machines and it will be important that best practices are followed throughout and contingency plans be in place.

Similarly, the release of nutrients from pore water in the sediments during extraction is highly unlikely to result in increased PP and potentially phytoplankton blooms. Cahoon et al. (2015) used literature values and sediment characteristics to assess the potential for increased nutrients from the ISR operations and concluded that increases in the likes of ammonium-N would be undetectable and insignificant. There could potentially be a very slight increase in nutrient levels in the downstream plume but they would disperse and dilute very quickly and would not cause a noticeable increase in local production locally.

Summary – Contaminants

As would be expected, contaminants in the sediments of this dynamic exposed environment contained low levels of heavy metals with some below detection limits. The only contaminants that breached the 99% protection ANZECC guidelines were nickel and copper in the elutriate. These contaminants would be rapidly diluted once they were released into the water column.

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Appendix 1. Consequence levels for the intensity of the activity. Summary descriptions of the six sets of consequence levels for the proportion of the habitat affected, the impact on the population, community or habitat, and the likely recovery period. From MacDiarmid et al. (2014), MacDiarmid et al. (2015).

Consequence level	Proportion of habitat affected	Population/ community/ habitat impact	Recovery Period
1 - Negligible	Affecting <1% of area of original habitat area	Interactions may be occurring but unlikely to be ecologically significant (<1% changes in abundance, biomass, or composition) or be detectable at the scale of the population, habitat or community	No recovery time required
2 - Minor	Measurable but localized; affects 1-5% of total habitat area	Possibly detectable with 1-5% change in population size or community composition and no detectable impact on dynamics of specific populations	Rapid recovery would occur if activity stopped – less than 8 weeks
3 - Moderate	Impacts more common; >5-20% of habitat area is affected	Measurable with >5-20% changes to the population, habitat or community components without there being a major change in function	Recovery in >2 months to 1-2 years if activity stopped
4 - Major	Impacts very widespread; >20-60% of habitat is affected/ removed	Populations, habitats or communities substantially altered (>20-50%) and some function or components are missing/ declining/ increasing well outside historical ranges. Some new species appear in the affected environment	Recovery occurs in 2-[1] years if activity stopped
5 - Severe	Impact extensive; >60-90% affected	Likely to cause local extinctions of vulnerable species if impact continues, with a >50-90% change to habitat and community structure and function. Different population dynamics now occur with different species or groups now affected	Recovery period 1-2 decades if activity stopped

[1] Assessment of the scale of marine ecological effects of seabed mining in the South Taranaki Bight:

6 - Catastrophic	Entire habitat in region is in danger of being affected; >90% affected/ removed	Local extinctions of a variety of species are imminent/immediate. Total collapse of habitat, community or ecosystem processes. The abundance, biomass or diversity of most groups is drastically reduced (by 90% or greater) and most original ecological functional groups (primary producers, grazers etc.) have disappeared	Long term recovery to former levels will be greater than 1-2 decades or never, even if activity stopped