REPORT NO. 3805

ADVICE ON THE IMPACT OF FORESTRY SLASH ON KAIMOANA IN THE ŪAWA CATCHMENT – TOLAGA BAY

ADVICE ON THE IMPACT OF FORESTRY SLASH ON KAIMOANA IN THE ŪAWA CATCHMENT – TOLAGA BAY

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Prepared for Gisborne District Council
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EXECUTIVE SUMMARY

Gisborne District Council (GDC) and Te Aitanga a Hauiti Iwi / hapu have raised concerns about the impacts on kaimoana from the sediment influx and increased deposition of logs on Tolaga Bay coastlines (Ūawa Catchment /Tairāwhiti region, Figure 1). GDC requested that Cawthron provide advice on the impact of forestry slash (herein referred to as logging residues) on kaimoana in the Ūawa catchment-Tolaga Bay (Envirolink advice grant 2211-GSDC168). As part of this work, we identified potential kaimoana species and habitats of concern in the Tolaga Bay area, undertook a site visit to obtain a preliminary characterisation of several intertidal and subtidal areas in Tolaga Bay, and reviewed what is currently known about the key depositional characteristics of logging residues in coastal ecosystems. The summary of this knowledge identified potential impacts of the logging residues on the kaimoana and associated habitats in the Tolaga Bay coastal area.

Potential effects of logging residues

The potential effects from logging residues identified in this report could either directly, indirectly, or cumulatively have an impact on kaimoana taxa and habitats in the Tolaga Bay coastal area. The most likely adverse effects on the intertidal rocky shore habitats and wider bay (subtidal) from the logging residues are: physical abrasion (from woody debris) and sedimentation (smothering and reduced water clarity from suspended sediments). There is also potential for localised effects (toxicity and deoxygenation) from the leaching of organic compounds in less well flushed, lower salinity locations, such as the Kaitawa estuary. Potentially beneficial effects of logging residues were also identified; residues may provide a source of carbon and other nutrients for sediment and dune-dwelling organisms and may initiate dune formation (buffering erosion). Consequently, increased rates of coastal sediment accretion and dune formation may help to offset inundation and erosional effects associated with increased storminess and sea-level rise.

Persistence and extent of effects

Wood-related physical abrasion is likely to persist for a matter of weeks or months following each mobilisation event, as evidenced by the decomposition rate and the progressive loss of buoyancy of woody debris in the ocean. In the longer term, the abrasion effects are likely to occur intermittently during subsequent storm events (assuming there is no change to harvest management practices). Possible remobilisation may occur from storm surge causing compounding effects as more woody debris is added to the system. This timeframe / frequency for abrasion effects is also supported by site visit observations where: 1) the vast majority of logging residue appeared to be restricted to the high tide and storm surge zones following the preceding flooding event, and 2) there was no evidence of floating logs and little evidence of sunken logs in the subtidal areas after that event (1 month before the site visit).

While large woody debris appears to have intermittent abrasive effects locally, further investigations into: 1) the abrasive potential of the smaller woody debris entrained in crevices and boulders in the intertidal areas, 2) the potential transportation of the single sunken logs observed in the river mouth, and 3) characterisation of the features identified in the sidescan

imagery, would help to clarify how long the potential for abrasion persists and its spatial extent.

The extent and persistence of sedimentation effects from logging residues in the region are likely to be long term and can be expected to combine with existing sedimentation effects from other land use practices. The combined sediment inputs from the Ūawa catchment are likely to contribute to the sediments that cover most of the bed of Tolaga Bay, particularly around the river mouth (most of the sediment in the bay is likely to have come from the coast outside). Sediment from the catchment may also contribute to the material seen deposited on some of the intertidal species assemblages surveyed. The extent that logging activities are contributing to sedimentation-related effects could be clarified through a sediment source tracing investigation.

Potentially impacted kaimoana

There were very few kaimoana taxa identified in the preliminary intertidal survey at Tolaga Bay. These were Kuku (green-lipped mussel), Pōrohe (blue mussels), Ngākihi (limpets), Kaikai tio (oyster borer), Pupu (top snails and cats eyes) and Karengo (sea lettuce / *Ulva* sp.). These kaimoana were generally more prevalent in the low shore areas. Kuku and Pōrohe in particular were only observed on the northern shoreline transects (none were present on the southern shoreline transects). This apparent dearth of kaimoana taxa may reflect logging residue effects, but better characterisation of the kaimoana habitats and associated assemblages in the wider Tolaga Bay would help to clarify whether the kaimoana distribution and community structure is typical for the region.

The site visit surveys did not include a specific investigation into the estuarine species assemblages in Tolaga Bay's Kaitawa estuary (a habitat of significant conservation value). However, we identified kaimoana taxa that may be present in the estuary (based on habitat preference), including (but not limited to) Īnanga (whitebait), Pātiki (flounder), Tuna (eels), and Tuangi (cockles). Characterisation of the Kaitawa estuary and kaimoana taxa would further aid the understanding of the risk of logging residues to this valued habitat.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

Gisborne District Council (GDC) and Te Aitanga a Hauiti Iwi / hapu have raised concerns about the impacts on kaimoana from the sediment influx and increased deposition of logs on Tolaga Bay coastlines (Ūawa catchment / Tairāwhiti region, Figure 1). Influxes of forestry slash / harvest waste (herein referred to as logging residues) onto the beaches of Tairāwhiti have been an issue since at least 2010/11. Since then, logging residue deposits have occurred on an almost annual basis, largely depending on the areas of harvested forest (upstream) and the frequency / severity of high rainfall weather events. With the volume of trees due to be harvested predicted to increase and be maintained into the foreseeable future, it is anticipated that influxes of logging residues onto the beaches will be an ongoing and potentially increasing issue across the region.

GDC have requested that Cawthron provide advice[1] on the impact of logging residues on kaimoana in the Ūawa catchment-Tolaga Bay. The objectives of the advice were to:

1. assist Council's understanding of the impacts of logging residues on kaimoana
2. address the concerns of the local community and Iwi / hapu (Te Aitanga a Hauiti) of the impacts of logging residues on kaimoana
3. inform the forestry industry about the effects of harvest waste on kaimoana, so they can mitigate impacts if they occur.

Council will also use the advice in its future review of the Tairāwhiti Regional Management Plan and come up with planning tools to facilitate consenting frameworks that reduce the risk of such influxes and the impacts on kaimoana in the future.

Section 2 of this report identifies the kaimoana species and habitats of concern in the Tolaga Bay area. Section 3 describes a site visit undertaken to preliminarily characterise representative intertidal and subtidal areas in Tolaga Bay. The key depositional characteristics of logging residues in coastal ecosystems are described in Section 4. Finally, the potential impacts of the logging residues on kai moana and ecosystems in the Tolaga Bay coastal area are discussed in Section 5.

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[1] Envirolink advice grant 2211-GSDC168.

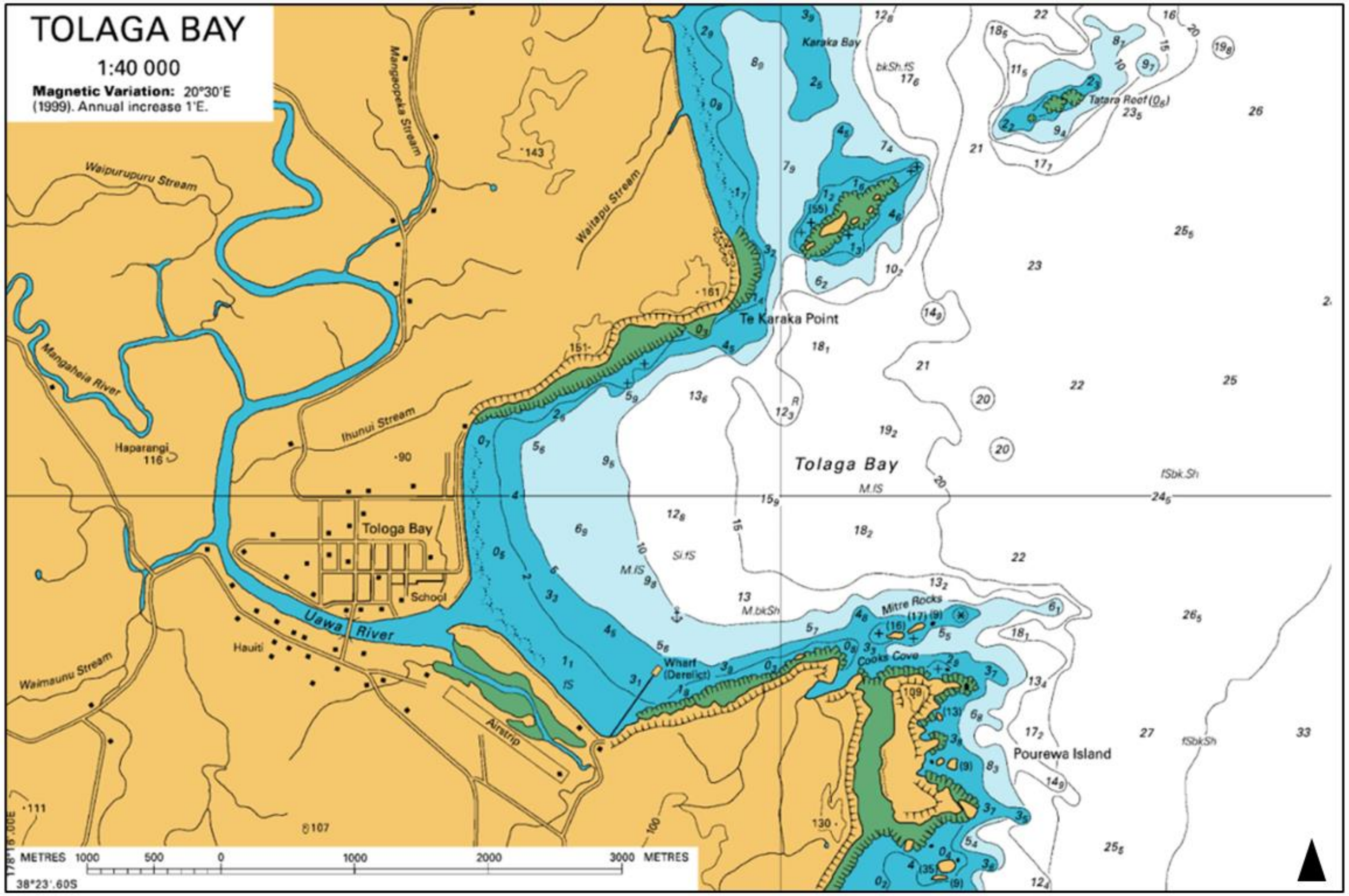

Figure 1. Tolaga Bay study area, Ūawa catchment, Tairāwhiti (LINZ chart NZ551). Crown copyright, licensed under the Creative Commons Attribution 4.0 International.

2. KAIMOANA SPECIES OF CONCERN

To understand the impact from logging residues on kaimoana in the Tolaga Bay / Ūawa catchment (Tairāwhiti region), we first identified the kaimoana species that inhabit this location. A recent review by Ross (2021) found there were few data available to describe the nearshore coastal habitat and biological communities in the Tairāwhiti region. The review recommended (amongst other things) that: 1) coastal habitat mapping of the region should be undertaken, 2) an understanding of the spatial distribution of biodiversity should be developed, and 3) a clear understanding of the impacts of anthropogenic stressors should be obtained. Without this knowledge it is very difficult to successfully manage the impacts from anthropogenic stressors on habitats and biodiversity in the coastal marine area (CMA). In the absence of any clearly defined kaimoana species distributions for the Tolaga Bay region, we compiled a species list (Table 1) from a number of information sources (Palmer 2010; Ross 2021; TeAra 2021; FNZ 2022). This information was supplemented by local knowledge on kaimoana species in the region (species of interest) obtained through an initial project hui (video meeting[2], 28 October 2021). We then summarised the key potential intertidal and shallow subtidal kaimoana habitats (where the majority of the potential kaimoana species listed occur) in Tolaga Bay from available information sources (Table 2). These lists should be considered preliminary, and further work on the spatial distribution of kaimoana (and marine mahinga kai) communities and habitats in the area should be undertaken to improve accuracy.

It is noted that the current species distributions are unlikely to reflect the true historic background. For example, investigation of archaeological sites at the foot of Titirangi Maunga (Kaiti Beach, 50 km south of Tolaga Bay) showed 39 marine shellfish species were used for food by pre and post-European Māori (Palmer 2010), suggesting there was a diverse array of kaimoana species consumed in the area in the past. However, this diversity / availability of kaimoana has been altered by anthropogenic influences (deforestation, urbanisation, agriculture, industrialisation and fisheries) and changing coastal management processes, e.g. how coastal resources are used and protected / regulated (Palmer 2010).

Shellfish from Tolaga Bay have occasionally been deemed not suitable for human consumption. In most parts of the Gisborne region these occasions followed periods of significant rainfall; however, the ‘Tolaga Bay Beach end of Wharf Road’ monitoring site results were not always explained by high rainfall (Palmer 2010). Despite this impact to the mauri and life-supporting capacity of the Moana, Palmer (2010) reported that in the Tairāwhiti region “there remains a significant utilisation of coastal resources by local individuals, whanau, and commercial operators, at a range of scales”.

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[2] Attendees included Victor Walker (Te Aitanga-a-Hauiti Centre of Excellence Trust and Ministry of Education), Murry Cave (Gisborne District Council), Olivia Johnston and Don Morrisey (Cawthron Institute),

Table 1. The potential and known kaimoana species in the Tolaga Bay region with associated habitats. Orange highlighting represents those taxa identified during the initial project hui as the key 'species of interest'. Other taxa listed are 'potentially present' and are recognised as being of special importance to Tangata Whenua and are edible (FNZ 2022). Taxa with asterisks were also identified by Te Ara Encyclopaedia of New Zealand (TeAra 2021) as 'still gathered and eaten by Māori today' (as opposed to traditionally eaten). Note, 'potentially present' taxa are not confirmed (through existing literature and species lists) as being present in the Tolaga Bay region.

Maori name	Common name	Species / taxa name	Type	Habitat
Kuku*	Green-lipped mussels	*Perna canaliculus*	Bivalvia	Rocky intertidal
Pōrohe / Kuku / Kutae, Toretore*	Blue mussels	*Mytilus edulis aoteanus (?) / Mytilus galloprovincialis*	Bivalvia	Rocky intertidal
Pipi*	Pipi	*Paphies australis*	Bivalvia	Sand intertidal
Kōura	Crayfish / spiny lobster	*Jasus edwardsii, Jasus / Sagmariasus verreauxi*	Decapoda	Rocky intertidal
Kina	Sea urchin	*Evechinus chloroticus*	Echinodermata	Rocky intertidal
Hihiwa / Karariwha	Yellowfoot pāua / Queen pāua	*Haliotis australis*	Gastropoda	Rocky intertidal
Marapeka / Koio	Virgin pāua	*Haliotis virginea*	Gastropoda	Rocky intertidal
Pāua*	Blackfoot pāua	*Haliotis iris*	Gastropoda	Rocky intertidal
Īnanga / Inaka	Whitebait (spp.)	Inanga, kōaro, banded kōkopu, giant kōkopu, shortjaw kōkopu, smelt, bullies and juvenile eels	Osteichthyes, Chordata	Estuary / brackish / freshwater
Pātiki tōtara	Yellowbelly flounder	*Rhombosolea leporina*	Osteichthyes, Chordata	Estuary / brackish
Pātiki mohoao	Black flounder	*Rhombosolea retiaria*	Osteichthyes, Chordata	Estuary / brackish / freshwater
Pātiki	NZ turbot	*Colistium nudipinnis*	Osteichthyes, Chordata	Sand and mud intertidal / subtidal
Pātiki rore	NZ sole	*Peltorhamphus novaezeelandiae*	Osteichthyes, Chordata	Sand and mud intertidal / subtidal
Pātiki tore	Lemon sole	*Pelotretis flavilatus*	Osteichthyes, Chordata	Sand intertidal / subtidal
Pātiki	Sand flounder	*Rhombosolea plebeia*	Osteichthyes, Chordata	Subtidal
Karengo	Sea lettuce	*Ulva* spp.	Algae	Mud and rocky intertidal, shallow subtidal
Parengo	Southern laver	*Porphyra*/*Pyropia* complex / *Porphyra columbina*	Algae	Rocky intertidal

Maori name	Common name	Species / taxa name	Type	Habitat
Rimurapa	Bull kelp	*Durvillaea antarctica*	Algae	Rocky Intertidal / shallow subtidal
Waharoa	Horse mussel	*Atrina zelandica*	Bivalvia	Muddy-sand low intertidal, subtidal to 50 m
Kukupara	Black mussel	*Xenostrobus pulex*	Bivalvia	Rocky intertidal
Karauria, tio*	Rock oyster	*Saccostrea glomerata*	Bivalvia	Rocky intertidal (mid) and mudflats
Tuatua*	Tuatua	*Paphies subtriangulata*	Bivalvia	Sand intertidal
Kuakua, tupe, pure, tipa, tipai, kopa*	Scallop	*Pecten novaezelandiae*	Bivalvia	Soft bottom subtidal
Kaikaikaroro	Triangle shell	*Spisula aequilatera*	Bivalvia	Sandy intertidal
Poua	Long trough shell	*Oxyperas (Longimactra) elongatum*	Bivalvia	Sandy intertidal
Whāngai karoro / Pūrimu	Surf clam / large trough shell	*Spisula (Mactra) discors*	Bivalvia	Sandy intertidal
Whāngai karoro / Pūrimu	Surf clam / large trough shell	*Spisula (Mactra) murchisoni*	Bivalvia	Sandy intertidal
Harihari	Ringed dosinia	*Dosinia anus*	Bivalvia	Soft bottom subtidal
Toheroa, Tupehokura	Toheroa	*Paphies ventricosa*	Bivalvia	Soft bottom subtidal
Tuangi*	NZ cockle	*Chione stutchburyi*	Bivalvia	Soft sediment, estuary
Wheke	Octopus	*Macroctopus maorum*	Cephalopoda	Soft bottom and rocky subtidal
Whai	Stingray	*Dasyatis rhinobatis (?), Dasyatis brevicaudatus (short tailed), Dasyatis* spp.	Chondrichthyes, Chordata	Estuarine, rocky reef, inshore, coastal water habitats.
Pioke	School shark	*Galeorhinus galeus*	Chondrichthyes, Chordata	Coastal waters and the open ocean
Mangō / Pioke	Sharks	e.g. bronze whalers, blue sharks, whale shark, short finned mako, school shark, rig, spiny dogfish. hammerhead.	Chondrichthyes, Chordata	Intertidal / subtidal
Pāpaka	Paddle crab	*Ovalipes catharus*	Decapoda	Soft bottom subtidal
Karekawa	Cook’s turban	*Cookia sulcata*	Gastropoda	Low intertidal to 5 m on northern shores
Hopetea	White whelk	*Dicathais orbita*	Gastropoda	Rocky intertidal
Kaikai tio	Oyster borer	*Haustrum scobina*	Gastropoda	Rocky intertidal

Maori name	**Common name**	**Species / taxa name**	**Type**	**Habitat**
Kaio / Ngaeo	Dark rock whelk	*Haustrum haustorium*	Gastropoda	Rocky intertidal
Ngākihi	Limpet	Families Patellidae, Acmaeidae and Lepetidae	Gastropoda	Rocky intertidal
Pupu / Korama*	Cats eye / mud snail	*Lunella smaragdus*	Gastropoda	Rocky intertidal
Mākerekere / Matangaarahu	Nerita / sea snail	*Nerita atramentosa, Nerita melanotragus*	Gastropoda	Rocky intertidal
Rori	Shield shell	*Scutus breviculus / S. antipodes*	Gastropoda	Rocky subtidal / intertidal
Kawari	Whelks	*Cominella* species (e.g. *C. glandiformis)*	Gastropoda	Sandy / mud intertidal
Whetiko*	Mud snail	*Amphibola crenata*	Gastropoda	Soft bottom intertidal
Takai	Ostrich foot snail	*Struthiolaria papulosa*	Gastropoda	Soft bottom subtidal
Papatai	Turret shell	*Maoricolpus roseus*	Gastropoda	Soft bottom subtidal / intertidal
Rori, Rore	Sea cucumber	*Australostichopus mollis, Class Holothuroidea*	Holothuroidea	Soft bottom subtidal
Parore	Parore	*Girella tricuspidata*	Osteichthyes, Chordata	Estuarine, rocky reef, inshore, coastal water habitats (esp. seagrass).
Aua	Yellow-eyed mullet	*Aldrichetta forsteri*	Osteichthyes, Chordata	Estuary / brackish
Tuna heke, putu, hao	Shortfin glass eel	*Anguilla australis*	Osteichthyes, Chordata	Estuary / brackish
Tuna heke, putu, hao	Longfin glass eel	*Anguilla dieffenbachii*	Osteichthyes, Chordata	Estuary / brackish
Kōkopu, Hawai	Giant bully	*Gobiomorphus gobioides*	Osteichthyes, Chordata	Estuary / brackish / freshwater
Taiwharu	Giant kōkopu	*Galaxias argenteus*	Osteichthyes, Chordata	Estuary / brackish / freshwater
Piharau, hirau, kanakana wairaki, Ute	Lamprey	*Geotria australis*	Osteichthyes, Chordata	Estuary / brackish / freshwater
Piripiripohatu, papane, pānonoko, pārīkoi	Torrent fish	*Cheimarrichthys fosteri*	Osteichthyes, Chordata	Estuary / brackish / freshwater
Kanae	Grey mullet	*Mugil cephalus*	Osteichthyes, Chordata	Estuary/brackish / intertidal
Kahawai	Kahawai / sea trout	*Arripis trutta*	Osteichthyes, Chordata	Intertidal / subtidal

Maori name	**Common name**	**Species / taxa name**	**Type**	**Habitat**
Tāmure	Snapper	*Pagrus auratus*	Osteichthyes, Chordata	Intertidal / subtidal
Moki	Moki	*Latridopsis ciliaris*	Osteichthyes, Chordata	Rocky subtidal
Araara	Trevally	*Pseudocaranx dentex*	Osteichthyes, Chordata	Open water offshore and coastal. Juveniles inhabit estuaries, bays and shallow shelf
Mohimohi	Pilchard	*Sardinops neopilchardus*	Osteichthyes, Chordata	Pelagic
Kōiro, ngōiro, totoke, ngōio, ngoingoi, putu	Conger eel	*Conger verreauxi*	Osteichthyes, Chordata	Rocky intertidal/shallow subtidal
Ngākoikoi / Hiwihiwi	Kelpfish	*Chironemus marmoratus*	Osteichthyes, Chordata	Rocky intertidal (esp. macroalgae reefs)
Marari	Butterfish	*Odax pullus*	Osteichthyes, Chordata	Rocky intertidal/shallow subtidal
Paraki, Ngaiore	Common smelt	*Retropinna retropinna*	Osteichthyes, Chordata	Estuary/brackish/freshwater
Kumukumu	Gurnard	*Chelidonichthys kumu*	Osteichthyes, Chordata	Sandy intertidal and subtidal (to 200 m)
Tarakihi	Tarakihi	*Nemadactylus macropterus*	Osteichthyes, Chordata	Soft mud intertidal/subtidal
Haku	Kingfish	*Seriola lalandi / grandis*	Osteichthyes, Chordata	Subtidal
Pātukituki	Rock cod	*Lotella rhacinus / Parapercis colias*	Osteichthyes, Chordata	Subtidal (up to 150 m) bedrock outcrops on gravel or sandy seabed (esp. macroalgae or sponges habitats).
Hāpuka	Groper	*Polyprion oxygeneios*	Osteichthyes, Chordata	Subtidal, at depths between 30 and 800 m.

Table 2. Intertidal and subtidal areas / habitats in the Tolaga Bay / Ūawa region identified as being outstanding natural landscapes (coastal land and marine), areas of significant conservation value, or significant value and general coastal management areas (SVMA and G, respectively) and natural resources in the Tairāwhiti Plan[3]. Other potentially sensitive / valued / protected marine habitats listed here were identified by Ross (2021) and Jones et al. (2016). Specific unit code / map references are in reference to the location maps in each respective appendix at the end of this report.

Area name	Planning classification / reference	Unit code/map ref.	Appendix
Karaka Bay	Outstanding natural landscapes (land)	Unit 9	App. 1
	Outstanding natural landscapes (marine)	Unit 9	App. 3
Tatarahake Cliffs	Terrestrial areas of significant conservation value	WR12	App. 4
	Outstanding natural landscapes (land)	Unit 10	App. 1
	Outstanding natural landscapes (marine)	Unit 10	App. 3
	SVMA coastal management area	SVMA	App. 2
Tolaga Bay Estuary / Kaitawa Estuary	Terrestrial areas of significant conservation value	WR36/50	App. 4
	Marine area of significant conservation value	05-022	App. 3
	Outstanding natural landscapes (land)	Unit 10	App. 1
	Outstanding natural landscapes (land and marine)	Unit 10	App. 3
	SVMA coastal management area	SVMA	App. 2
Waimoko River mouth	Terrestrial areas of significant conservation value	WR56	App. 4
Ūawa River / Mouth	Discussed in Ross (2021)	Unit 10	App. 1
Tolaga Bay North	Outstanding natural landscapes (land)	Unit 10	App. 1
	G coastal management area	GMA	App. 2
Tolaga Bay Wharf	Marine area of significant conservation value	05-023	App. 3
	SVMA coastal management area	SVMA	App. 2
Te Pourewa / Island	Terrestrial areas of significant conservation value	WR37	App. 4
	Marine area of significant conservation value	05-024	App. 3
	Outstanding natural landscapes (land)	Unit 11	App. 1
	Outstanding natural landscapes (land and marine)	Unit 11	App. 3
	SVMA coastal management area	SVMA	App. 2
	Incl. Cooks Cove / Opoutama	Unit 11	App. 3
	Incl. Hole in the wall, Tolaga Bay. Natural resources / Geological sites	GL3	App. 2
	Incl. Pourewa Island blow hole. Natural resources / geological site	GL20	App. 2
Subtidal[4] reef habitats	Discussed in Ross (2021), sourced from Jones et al. (2016)	Biogenic habitat No. 6 (closest at 50 m), 7, 4 & 5, 8 & 9, 'Ariel Bank' area to the south and No. 16 (further offshore).	App. 5
Te Tapuwae o Rongokako Marine Reserve.	Closest marine reserve. Discussed in Ross (2021).	20+ km south of Tolaga Bay	NA

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[3] Tairāwhiti Plan is a free mapping application that enables viewing of planning data from the Tairāwhiti Resource Management Plan (https://maps.gdc.govt.nz/H5V2_12/).

[4] Subtidal = the area where the seabed is below the lowest tide.

3. SITE VISIT

To better understand the extent and magnitude of the potential effects on kaimoana from logging residues we made a site visit to Tolaga Bay / Ūawa on 27-28 April 2022. The primary objectives of this visit were to: 1) undertake a preliminary characterisation of the receiving environment and kaimoana habitat and taxa, and to 2) document any evidence of logging residue-related effects. The following sections present the methods and findings to address these objectives, using a combination of quantitative rocky shore intertidal surveys and side-scan seafloor imagery.

3.1. Rocky shore intertidal survey

3.1.1. Methods

An intertidal survey was undertaken on the northern and southern Tolaga Bay rocky shore substrate at low tide (Figure 2). The survey consisted of three 20-m long, shore-parallel transects in the high-, mid- and low-shore at the southern rocky shore location (27 April 2022), and two 20-m longshore parallel transects at the low-tide zone at the northern rocky reef location (28 April 2022, Figure 2).

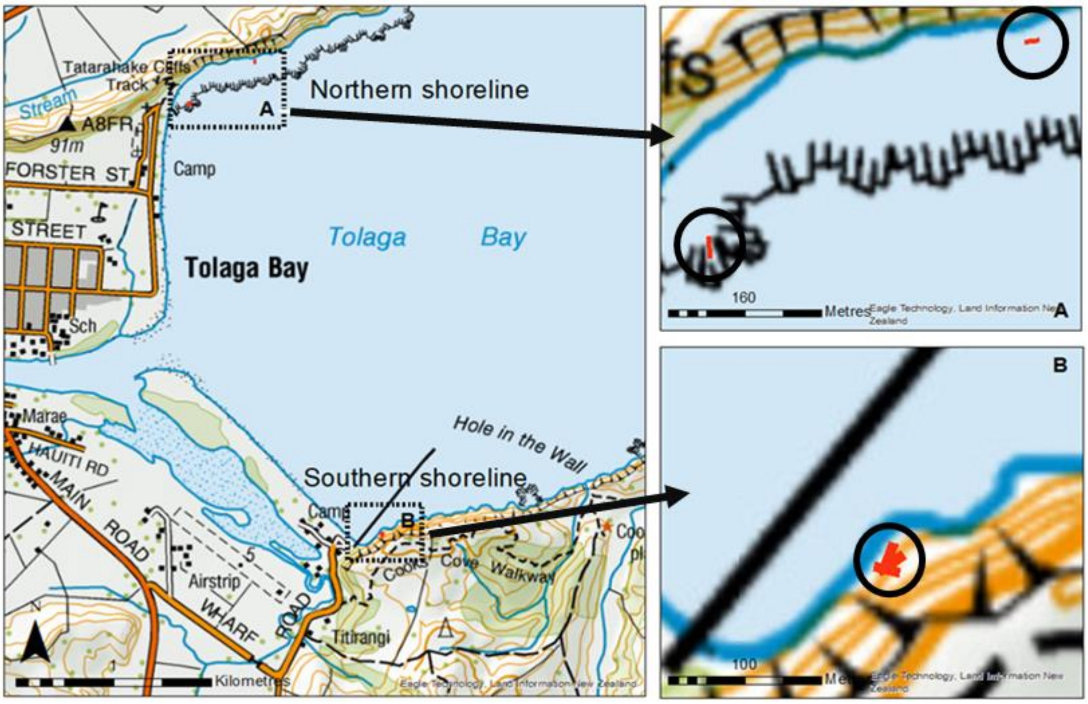

Figure 2. Intertidal transect locations, A) northern shoreline, B) southern shoreline, Tolaga Bay. Transects are in red.

Each transect contained ten 0.25 m^2 quadrats, which were set along the transect haphazardly. Quadrats contained an internal grid with 49 points (including the quadrat sides). From the grid intersection points, we recorded the percent cover for the type of substrate (bedrock, boulder, cobble, gravel, sand, shell gravel, shelly sand, and shell), woody debris, macroalgae and sessile invertebrates. For example, two intersection points with bedrock directly below = 4% bedrock. Because macroalgae, sessile invertebrates and woody debris occupy space both on the substrate and above it, total cover may exceed 100%. Numbers of mobile invertebrates were also recorded (results presented in Table 3, Table 4 and Table 5).

3.1.2. Results

Types of rocky shore habitat

The centre of Tolaga Bay contains a largely sandy beach, intersected by the mouth of the Ūawa River. The bay also has an estuary (Kaitawa estuary) to the south-east and is bordered to the north and south by rocky shorelines. The northern rocky shore has steep, eroded (unconsolidated sedimentary rock) cliffs with prominent bedrock platforms that are exposed at low tide only, and high tide cobble / boulder beaches that are exposed at the high tide mark (Figure 3). The southern shoreline is also lined by steep, eroding soft rock cliffs (Figure 3), with bedrock, boulder and cobble substrate dropping sharply to sandy seafloor (cf. the northern rocky shore).

At the scale of the transects and quadrats (1–10s of metres), bedrock was the predominant substrate (13–91% [mean] cover, see Table 3). This was particularly evident at the northern shoreline on transect 5, which was characterised by large areas of bedrock reef. Boulders, cobbles and pebbles were present at both north and south shore areas, with sand absent only from the high tide transect (transect 3). Sand, shell or finer sediment was sometimes present as a thin veneer in the low shore, and was often deposited on and in biological assemblages (e.g. *Xenostrobus neozelanicus* mussel beds). Woody debris was present[5] in the southern shoreline quadrats (P, Table 3), but not within quadrats. On the northern shoreline mean cover of woody debris was 2–5% (Table 3). Note that transect sampling targeted areas of rocky shore, and large areas of cobbles, shingle and sand were not sampled.

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[5] Present in quadrat, but not under a grid-point.

Figure 3. Representative images of the Tolaga Bay southern shoreline (A, B) and northern shoreline (C, D) intertidal survey areas.

Table 3. Mean substrate percentage cover per transect (ten quadrats) at the southern and northern shoreline intertidal survey sites in Tolaga Bay. Note, means values of percentage cover will not add to 100 percent per transect. P = present in quadrat, but not under a grid-point.

Name	Transect (tidal zone)				
	1 (Low)	2 (Mid)	3 (High)	4 (Low)	5 (Low)
Survey area	Southern shoreline			Northern shoreline	
Bedrock	13	31	72	83	91
Boulder	58	59	24	6	-
Cobble	11	6	3	3	-
Pebbles	3	3	1	6	-
Sand	7	0	-	3	9
Shell gravel	2	-	-	-	-
Shelly sand	6	0	-	-	-
Shell	-	0	-	-	-
Stick/wood debris	-	P	P	1	2

Taxa

High-shore transects contained no seaweeds, but exposure-tolerant taxa such as the encrusting coralline algae were present occasionally at the mid-shore (Table 4). The abundances of both mobile and sessile taxa were also correspondingly low at the high-shore transect, with a mean value of fewer than 1 individual on per quadrat, comprising solely of limpets and periwinkles (4 taxonomic groups represented, Table 4 and Table 5).

Diversity and abundance of seaweeds were highest at the low-shore transect, notably at the northern shoreline area. For example, the northern (low) shoreline transects (4 and 5) had a mean of 4–6 seaweed taxa represented, with mean cover of 6–22% (Table 4). The predominant taxa were encrusting and turfing coralline algae, including *Pterocladia* sp. (red filamentous), brown crustose, brown and red turfing algae, and green filamentous algae, with *Ulva* sp. and brown bladed algae also present in the quadrat (but not quantified as not under a grid-point, Table 4). The abundances of both mobile and sessile taxa were correspondingly high at the low-shore transects, with 6–12[6] taxonomic groups represented per transect and mean abundances ranging from < 1 to 4 individuals per quadrat (Table 4 and Table 5).

Kaimoana taxa present[7] were Kuku (green-lipped mussels, 2 individuals) and Pōrohe (blue mussels, ‘present’), Ngākihi (limpets, 26 individuals) Kaikai tio (oyster borer, 6 individuals), Pupu (top snails and cats eyes, 6 individuals) and Karengo (sea lettuce / Ulva sp., ‘present[8]’). These kaimoana were observed on all transects but were generally more prevalent in the low shore transects. Kuku and Pōrohe in particular were observed only on the northern shoreline transects; none were present on the southern shoreline transects.

N.B. mean abundance is used here as a relative measure to show how abundant each taxon is over the area surveyed.

All raw data are available on request.

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[6] The *Pagurus* sp. identified in transect 4 is included in this total but was marked as ‘P’ present in the quadrat (not able to be enumerated as not under a grid point in the quadrat).

[7] Number of individuals in total across 5 transects, each with 10 quadrats.

[8] Present in quadrat, but not under a grid point.

Table 4. Sessile invertebrate and algal taxa identified from the intertidal survey of the Tolaga Bay north and south rocky shoreline on 27–28 April 2022. Results are presented as mean counts (for mussels) and mean percentage cover (for sessile taxa) of the ten 0.25 m^2 quadrats per transect. P = present in quadrat, but not under a grid-point. Seaweed taxa are shaded green.

				Transect (tidal zone)				
Name	**Common name**	**Kaimoana**	**Unit of measure (per 0.25m^2)**	**1 (Low)**	**2 (Mid)**	**3 (High)**	**4 (Low)**	**5 (Low)**
Sessile								
Encrusting coralline algae (ECA)	Coralline algae		Mean percentage cover	6.4	1.2		14.6	2.2
Turfing coralline algae (TCA)	Coralline algae		Mean percentage cover				16.1	2.0
Pterocladia sp.	Seaweed - Red filamentous		Mean percentage cover					0.6
Brown crust algae	Seaweed - Brown crust		Mean percentage cover				25.0	8.0
Brown turfing algae	Seaweed - Brown turfing		Mean percentage cover				2.2	
Green filamentous algae	Seaweed - Green filamentous		Mean percentage cover					8.3
Red turfing algae	Seaweed - Red turfing		Mean percentage cover	1.6				
Brown algae small blades	Seaweed - Brown bladed		Mean percentage cover					P
Ulva sp.	Seaweed - Green sea lettuce	Karengo	Mean percentage cover		P			
Chamaesipho columna	Barnacle		Mean percentage cover	10.4	4.0			0.2
Spirobranchus cariniferus	Tube worm		Mean percentage cover	P	P		P	
*Xenostrobus neozelanicus**	Little black mussel		Mean percentage cover					22.8
Biofilm	Diatom / bacteria and microalgae slime		Mean percentage cover				4.6	
*Perna canaliculus**	Green-lipped mussel	Kuku	Mean count					0.3
*Mytilus galloprovincialis**	Blue mussel	Pōrohe	Mean count					P

* Mussels are semi-sessile. *X. neozelanicus* have been quantified using percentage cover as the individuals were too small to count.

Table 5. Mobile invertebrate taxa identified from the intertidal survey of the Tolaga Bay north and south rocky shoreline, undertaken 27–28 April 2022. Results are presented as mean counts of the ten 0.25 m^2 quadrats per transect. P= present in quadrat, but not under a grid-point.

				Transect (tidal zone)				
Name	**Common name**	**Kaimoana**	**Unit of measure (per 0.25m^2)**	**1 (Low)**	**2 (Mid)**	**3 (High)**	**4 (Low)**	**5 (Low)**
Mobile								
Sypharochiton pelliserpentis	Snakeskin chiton		Mean count	1.1	1.0		4.0	0.6
Cellana radians	Limpet	Ngākihi	Mean count	1.3	2.1	0.6	1.0	0.3
Cellana ornata	Limpet	Ngākihi	Mean count			0.3		
Cellana flava	Golden limpet	Ngākihi	Mean count			0.1		
Juvenile limpet	Limpet	Ngākihi	Mean count					2.9
Haustrum scobina	Oyster borer	Kaikai tio	Mean count	0.6	1.1		0.1	
Diloma aethiops	Top snail	Pupu	Mean count	0.7			0.9	
Diloma sp.	Snail	Pupu	Mean count	0.1				
Lunella smaragdus	Cats eye	Pupu	Mean count	0.1			0.1	0.1
Siphonaria australis	False limpet (air-breathing)		Mean count		0.4		0.3	0.3
Pholadidae	Piddocks / boring bivalves / angel wings		Mean count		P			
Terebellidae	Polychaete worm		Mean count		0.1			
Anthopleura hermaphroditica	Anemone		Mean count				0.1	
Austrolittorina antipodum	Periwinkle		Mean count			0.3		
Hemigrapsus sexdentatus	Crab		Mean count				0.1	
Micrelenchus sp.	Small top shell		Mean count				0.5	
Micro snail	Micro snail / top shell		Mean count					0.2
Halicarcinus sp.	Pill box crab		Mean count				0.1	
Zeacumantus sp.	Turret shell mud snail		Mean count				0.1	
Pagurus sp.	Hermit crab		Mean count				P	

Observations

We also inspected the northern and southern shorelines for physical evidence of logging residues and their potential physical effects on the kaimoana habitats as part of the intertidal surveys. Observations made during the intertidal survey are listed below.

- Large numbers of logs and a range of woody debris (branches, bark, sticks) were present on the northern shoreline and adjacent sandy beach, largely at the high tide / storm surge mark. There was also evidence of smaller pieces of woody debris (sticks and bark) mobile on the shoreline (including sandy shore locations) between the high- and low-tide marks.
- Possible scouring / scrape marks on the northern shoreline rocky reef.
- Large sections of clear bedrock (patchy communities) on the northern shoreline.
- Most taxa were present in cracks and protected reef; exposed reef was either bare or only had biofilm present.
- Empty limpet attachment points and weathered pock marks, possibly indicating that limpets had been dislodged.
- Wood entrained among boulders, on sand and in cracks / holes in bedrock (notably on the northern shoreline).
- Shelly-sand and silt layers present on sessile organisms (notably on the northern shoreline).
- Presence of kaimoana species largely restricted to the northern shoreline / reef (though access to the rugged southern rocky shore was difficult and consequently few observations could be made of this area).
- Grazing tracks on biofilm at the northern shoreline.

3.2. Sidescan survey

3.2.1. Methods

A subtidal sidescan survey of inner Tolaga Bay (from 7 to 15 m depths) was undertaken using a towable sidescan from the Harbour Master's vessel *Kaitiaki*, on 28 April 2022 (Figure 4a, Figure 5). Additionally, a small autonomous plastic boat (c. 1 m long and 0.5 m wide) equipped with sidescan sonar was used to scan the shallower Ūawa River / estuary mouth on 27 April 2022 (Figure 4B, Figure 5).

A sidescan sonar uses high-frequency sound pulses that bounce off the seafloor to create an image of the seafloor morphology and show differences in seabed texture and substrate types. The two systems used for the survey are described below.

The Blueprint Subsea StarFish 425F PRO[9] towable sidescan was used to map the subtidal seabed in Tolaga Bay (Figure 4a). The system featured a 450kHz CHIRP operation with up to a 200-m swath width (100 m port and 100 m starboard)—apart from Transect 1 (Figure 5), which was set to a 60 m swath width. The unit had a GPS antenna to allow geotagging of items observed. The length of the cable / tether was adjusted to change the height of the sidescan above the seabed to improve and maintain imaging quality. Approximately 4 m of tether was out for most of the survey, and it was submerged to approximately 1.5 m (although was readjusted during some turns). The topside GPS unit was a GlobalSat BU-353-S4, which is typically accurate to 2.5 m (in worst case conditions it is accurate to < 15 m). There was no option in the software to offset where the GPS unit was relative to the location of the sidescan. However, given the accuracy of the GPS unit and the relatively short length of tether used, it is unlikely to have much of an impact on positioning accuracy.

The autonomous sidescan system comprised a Lowrance TotalScan Med/High/455/800kHz transducer that was hull-mounted just below the boat's thrusters (Figure 4B). The system was designed to operate in shallow, relatively calm water. The boat was 1 m long and 0.5 m wide. The system has a GPS antenna and was programmed to follow GPS tracks, operating on battery power for 8-12 hours at a time. The system did not compensate for the depth of the transducer below the boat but, given the accuracy of the GPS unit, it is unlikely to have much of an impact.

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[9] Blueprint Subsea | StarFish 452 PRO

Figure 4. A) The towable sidescan system 'Blueprint Subsea StarFish' and B) the autonomous sidescan system.

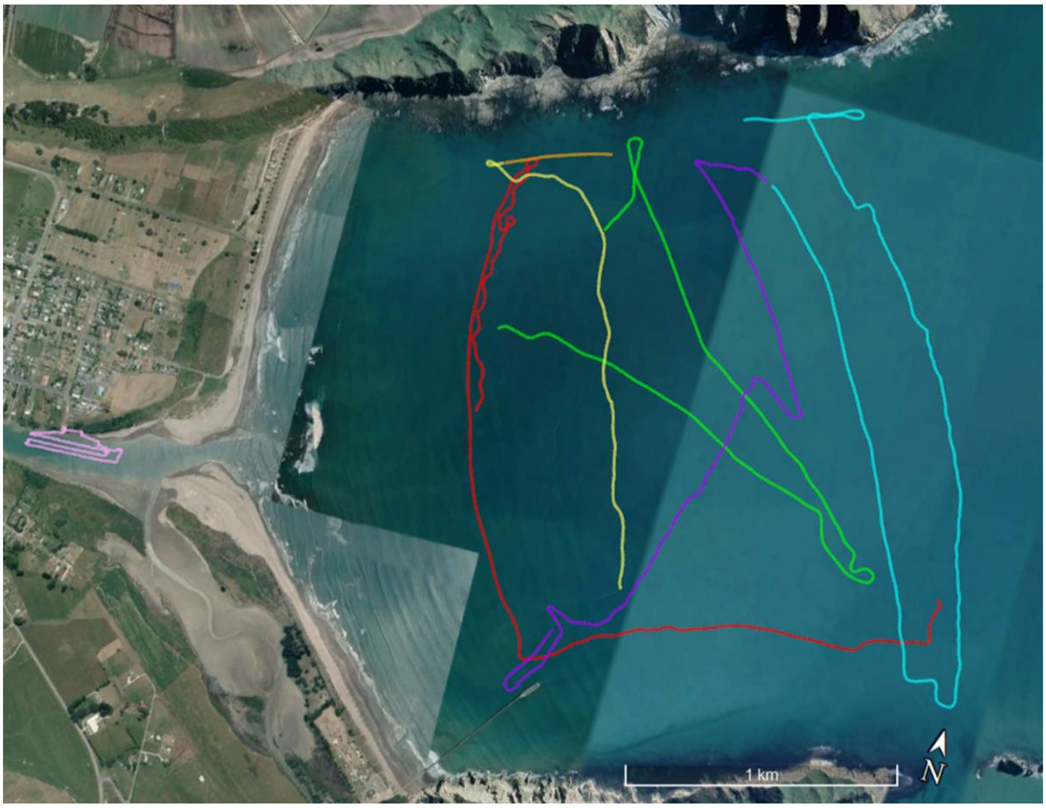

Figure 5. Towable sidescan survey area, Tolaga Bay. Transect 1: yellow, Transect 2: orange, Transect 3: blue, Transect 4: purple, Transect 5: red and Transect 6: green. The area surveyed by the autonomous sidescan was: Transect 7: pink.

The search pattern for both sidescan systems used a random stratified approach, with the intention of covering as much area as possible and marking potential sites during the course of the survey for more intensive inspection (e.g. ROV deployment). ROV inspection could not be performed however, as preliminary trials with the equipment showed the visibility was too poor. Both sonar systems were travelling approximately 2.5–3 knots during the scans.

Seabed maps were generated by using the StarFish software 'Scanline' to produce a straight, 2-dimensional picture with hidden GPS metadata. This was then overlaid onto a map using 'SonarTRX' software, whereby each pixel then had a latitude / longitude associated with it (georeferenced). The resulting maps / images were reviewed, and all substrate and object features were described and logged.

3.2.2. Results

Review of the sidescan outputs suggested that the inner-central subtidal area of Tolaga Bay predominantly comprises large, clear areas of sand (or other types of soft sediment) (Figure 6 and Figure 7). The sandy areas were identified by large ripples in the swath, perpendicular to the shore and parallel with the river mouth (Transects 1, 5 and 6 in Figure 5 and Figure 6). The northern and southern shorelines showed evidence of extensive subtidal rocky reef platforms, with some rocky reef outcrops visible at the centre of the bay at approximately 15–18 m depth (Transect 3, Figure 5 and Figure 6). Along the southern shoreline, rocky platforms were patchier and interspersed with soft sediment / sand seabed (Figure 6). The swaths from the river mouth consist largely of soft sediments and show two features that appear to be logs, and a potential drag mark evident on the seafloor was associated with a 3D feature (possibly wood or rock) of unknown origin (Figure 7). Overall, there was no evidence of accumulations of logs or woody debris on the seafloor in most of the subtidal area surveyed. A possible exception to this was in the north-west corner of the bay (between 10–15 m depth) where there appeared to be some hummocky seabed, potentially a debris accumulation with objects that may be logs evident as faint lines on the seabed (Transect 5, Figure 5 and Figure 6).

Ground truthing the sidescan outputs with an ROV when the water clarity has improved would help to characterise these features. Ground truthing in this way is typically considered good practice (Kaeser & Litts 2008) and would potentially help to identify accumulations of smaller woody material (like bark and sticks) on the seabed that are likely to be harder to detect using sidescan compared to an object with a larger 3D profile.

All raw data results are available on request.

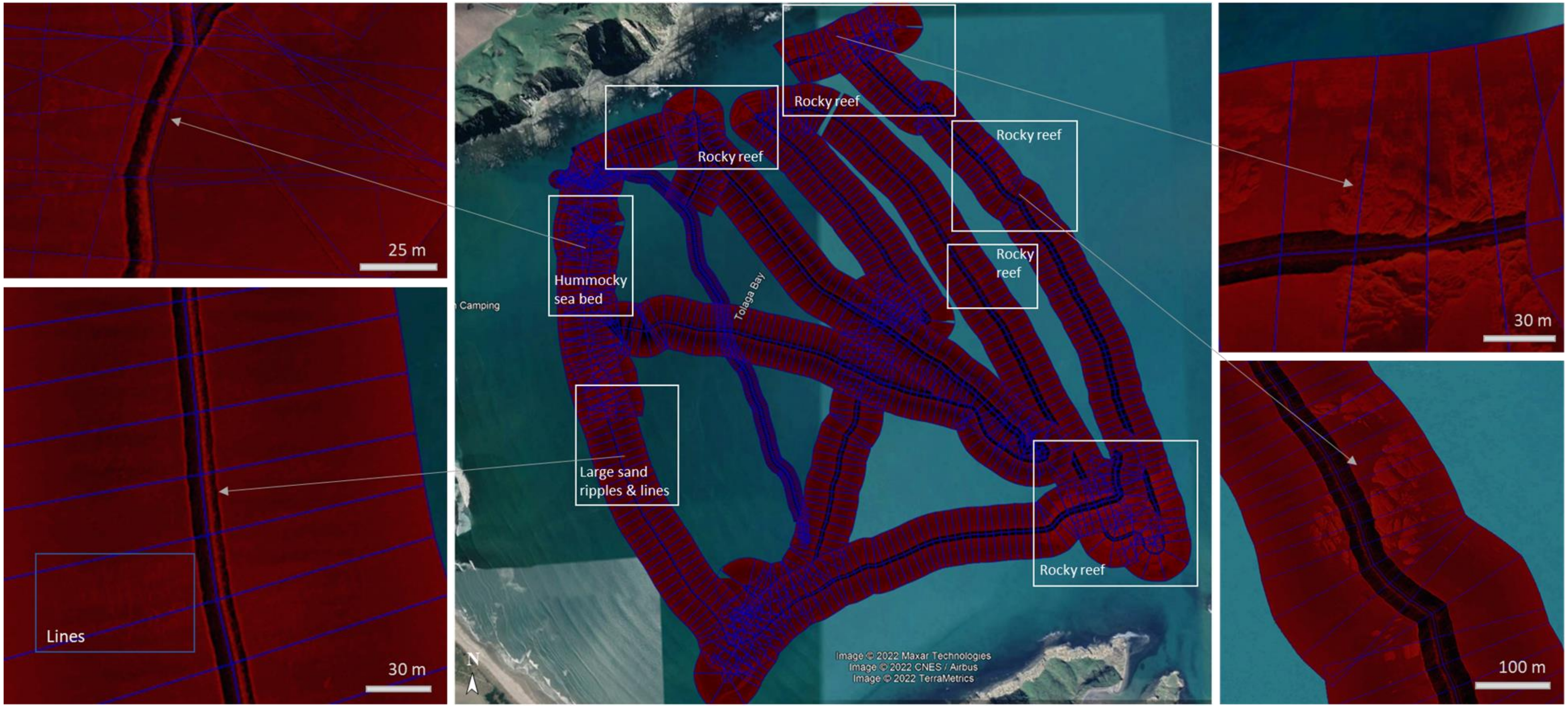

Figure 6. Observations of seabed characteristics made during the preliminary side scan survey of inner Tolaga Bay, 28 April 2022.

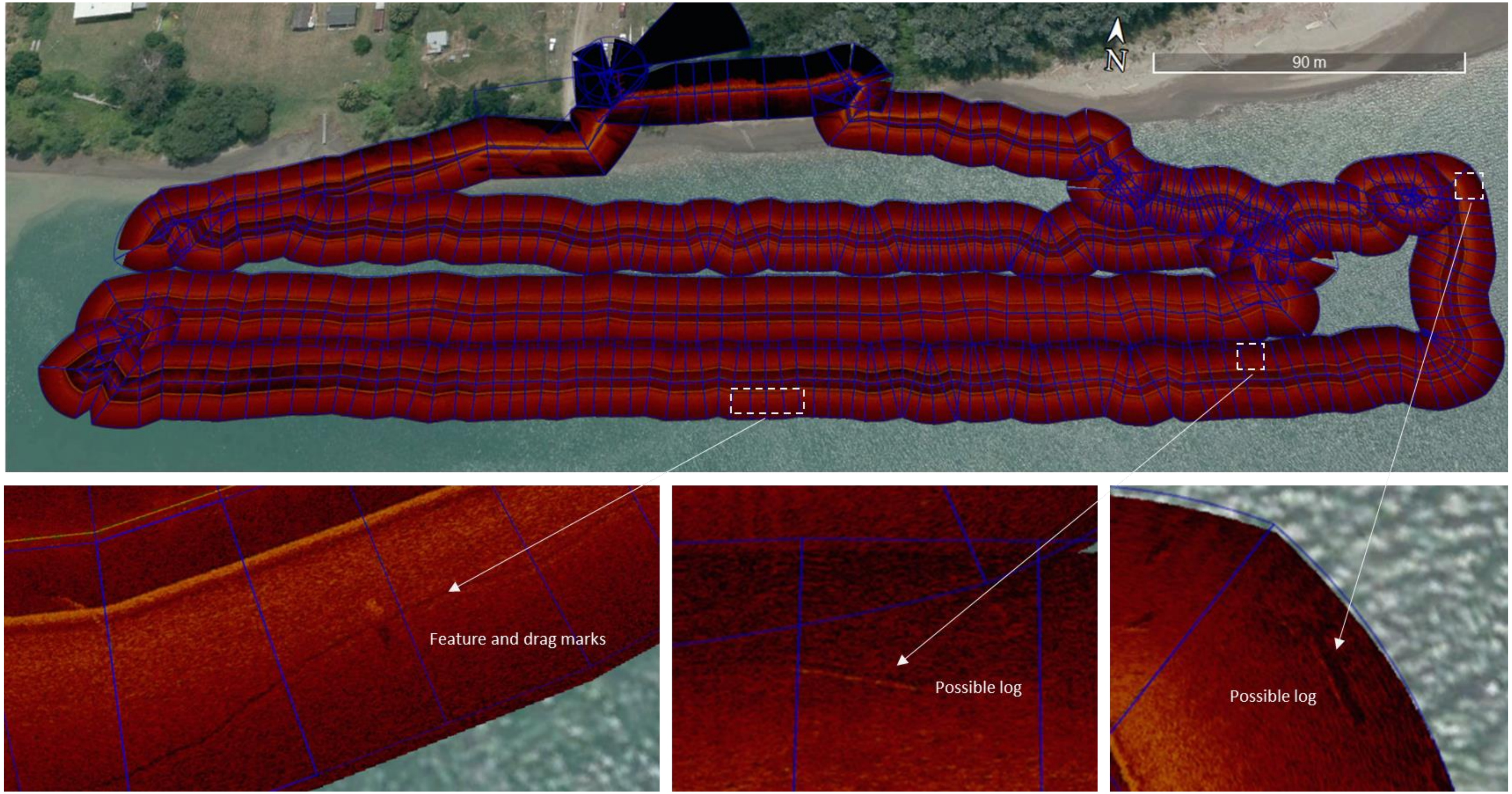

Figure 7. Observations of river mouth/estuary characteristics made during the preliminary side scan survey of inner Tolaga Bay, 27 April 2022.

4. KEY DEPOSITIONAL CHARACTERISTICS

An understanding of the potential effects on kaimoana from logging residues requires consideration of the characteristics of the material being deposited in Tolaga Bay / Ūawa. These depositional characteristics are discussed in terms of volume, frequency, physical characteristics (buoyancy) and spatial extent.

4.1. Volume and frequency of mobilisation events

There are no known numerical volume estimates of logging residue deposition along Tolaga Bay coastlines, so it is difficult to determine the relative deposition over time. The exception to this was during 2018, where 47,000 m^3 of woody debris was estimated to have been deposited on the beach at Tolaga Bay (see note 5 in Dwyer 2020).

The estimated volume of sediment produced by thousands of landslides, and extensive river bank collapse to the Ūawa River system during the June 2018 storm alone (Table 6) was 2,100,000 m^3 due to landslides and 200,000 m^3 due to bank collapse (Rosser et al. 2019). Extrapolated over the last 5 events, this equates to 11.5 million m^3 of sediment from these flooding events alone. Landslides were associated predominantly with recently logged plantation forests (within the last three years), and often in proximity to logging roads and haul sites / landings (Rosser et al. 2019). Sediment mobilisation is common during heavy rainfall irrespective of the presence of woody debris, and to a certain degree is part of the natural coastal processes. However, the advent of land clearing has dramatically increased the frequency and volume of sediments mobilised to coastal habitats, compared to pre-human times (Johnston et al. 1981; Fahey & Coker 1992; Thrush et al. 2004).

Deposition events appear to have become annual and region-wide occurrences since approximately 2010 (Table 6). It is likely that the frequency of these deposition events will increase with climate change, due to more frequent high intensity rainfall events and increased forestry harvesting (SOE 2020).

In the future, the potential for mobilised woody harvest residues could be estimated using the forecasted or existing harvesting surface areas (i.e. hectares of cutover) and the regional harvest residue estimate, which was estimated[10] to be 120 m^3/ha based on the high production stands in the Gisborne region (Visser et al. 2018). However, at the time of this investigation these data were not available.

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[10] It is noted that the volume of residues mobilised during a storm event will be dependent on cutover site management and harvesting systems, i.e. volumes could be lower if the debris is well spread out over the site and cut-to-length , and higher if left in a waterway or on a steep slope and whole-tree harvested (Visser et al. 2018).

Table 6. Weather events recorded as causing harvest residue mobilisation in Tairāwhiti, modified from SOE (2020) using information from more recent literature and news reports (citations within table). ND: No further details available.

Year	Key event details	Location	Key impacts
2022	Severe storms 22 March 13 April 'Cyclone Fili'	Region-wide	A state of emergency declared for the Gisborne region on 22 March. Severe flooding hit Tolaga Bay and Tokomaru Bay in Tairāwhiti. Up to 150 mm in the Gisborne forecasted (1News 2022b). On 13 April ex-Cyclone Fili swept through the East Coast. Heavy rain in Tairāwhiti-Gisborne and Wairoa amid a red warning issued by MetService. Overnight, 59 mm of rain fell in some parts of Gisborne. Road closures around Tolaga Bay (1News 2022a).
2021	Flash flooding 20 June	Region-wide	Parts of Gisborne and East Cape were inundated with areas of flash flooding. Part of State Highway 35 between Tolaga Bay and Gisborne and a number of roads were flooded. Some areas recorded over 30 mm of rain in one hour (Fyfe et al. 2021).
2020	Severe storm 25-26 June 2020.	Region-wide	This storm followed several weeks of storms which caused flooding and some slips but only a little mobilisation of woody waste within the catchment. The 25–26 June storm was not in itself significantly larger than the previous storms but did result in the mobilisation of woody material onto the Tolaga Bay beaches (Cave 2020).
2019	Moderate storm 15–16 October 2019	Region-wide	A moderate storm caused region-wide flooding. In the Ūawa catchment this resulted in the remobilisation of logs that had been displaced from logging sites within the forests during the 2018 Queen's Birthday storm. The major log jam in the Mangatokerau River was no longer present, with the logs flushed downstream. Forestry debris was noted on Tolaga Bay beaches (Cave 2019).
2018	Severe storms 3–4 June 2018 11–12 June 2018 The 'Queen's Birthday Storms'	Mangapoike, Waimata, Tolaga, Waiau, Waiapu	Extensive landslides and slips with significant mobilisation of forest harvest residues, particularly in the inland Tolaga Bay (Ūawa) area. Estimated 47,000 m³ of woody debris deposited on the beach at Tolaga Bay. On 3–4 June the headwaters of the Ūawa catchment received 234 mm of rain in 24 hours, with most falling over an eight-hour period (Rosser et al. 2019). On 11–12 June a further 270 mm of rain fell in 48 hours north of Gisborne (Ūawa and Mata catchments) resulting in land sliding and remobilisation of existing landslides/debris (GDC 2018; Rosser et al. 2019).
2017	Severe storms 12 April 2017 The 'Cyclone Debbie Storm'	Waimata, Tolaga, Mata	Extensive landslides and slips with significant mobilisation of forest harvest residues, particularly in the inland Tolaga Bay (Ūawa) area. Cyclone Debbie occurred a week before Cyclone Cook (Cave et al. 2017).
2015	ND	Wharerata Forest	Major slash mobilisation, debris on beaches, sedimentation of waterways and coastal environment, destruction of farm infrastructure.
2014	ND	Inland Tolaga, Wharerata Ranges	Slash mobilisation, debris on beaches.
2013	ND	Tokomaru Bay	Slash mobilisation, debris on beaches.
2012	ND	Wharerata Forest	Major slash mobilisation, debris on beaches, sedimentation, loss of railway line, loss of culvert on SH2 (closing the road).
2002	ND	Muriwai-Manutuke	Widespread flooding caused by forestry slash blocking culverts on public and private land.
1994	ND	Wharerata Forest	First major post-forestry harvest event – substantial erosion and landslides, sedimentation and slash mobilisation.

4.2. Physicochemical characteristics of logging debris

The most recent investigations of logging residue mobilisation events in the Ūawa area were reported by Cave et al. (2017), GDC (2018), Cave (2019) and Cave (2020). These events were all triggered by extreme rainfall. In most instances, the woody debris was pine (~66–89%) and consisted largely of long-resident pine logs (weathered or abraded logs without root balls at one end) and cut pine logs (consistent weathering of cut and trunk, Figure 8). The remainder of the woody debris typically comprised willow and poplar, likely dislodged from riparian zones of the Ūawa River (Cave et al. 2017). Interestingly, the mix of woody debris occurring in the most recently investigated event (Cave 2020) appears to be more diverse than occurred during previous events (e.g. Cyclone Cook 2017, Queen's Birthday 2018 and October 2019 storms), with much of the material appearing to have been remobilised from riverbanks downstream of the forested catchments. Details on more recent wood debris / flooding event characteristics have yet to be released.

The sediments associated with the logging debris are derived predominantly from landslides and riverbank collapse in the Ūawa River catchment. The Ūawa River catchment covers 559 km^2 and is underlain by poorly consolidated, Tertiary Age sedimentary rocks (mudstone and sandstone) that are susceptible to erosion (Rosser et al. 2019).

Past studies of recently harvested forestry areas suggest that the volume of sediment lost can be significant (DOC 2018; Bright 2021) and soils may contain nutrients and potentially contaminants. Further investigations that could help to determine the characteristics and origins of soils and smaller woody particles could include:

- Sediment source tracing, e.g. Compound Specific Stable Isotope (CSSI) sediment tracers (Swales et al. 2021).
- Estimates of background suspended sediment yield from the Ūawa River to the coastal environments, e.g. Catchment Land Use for Environmental Sustainability (CLUES 2016) and suspended sediment yield modelling (Hicks et al. 2011).
- Benthic and water quality surveys to determine the spatial and temporal effects of additional soil deposition to sediment characteristics (grain size) and chemistry (nutrients, metals, organic content[11] and ash free dry weight) and benthic communities, and to the water quality (turbidity, suspended solids, clarity, colour). These would compare conditions before and after an event and, ideally, compare impacted and unimpacted locations.

There are a few potential contaminants associated with concentrated areas of woody debris and their associated leachates. These are discussed below.

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[11] The organic content of the sediments can be expected to increase if there is an increase in the deposition of smaller wood related debris, and from the subsequent abrasion and break down of woody debris.

Figure 8. Representative examples of large woody debris being discharged from the Ūawa River into the Tolaga Bay coastal area. A) pine log (cut), B) pine log (long-resident), C) pine log (waratah marks from logging, white arrows), D) willow (windthrow), E) pine log (freshly cut for firewood), F) poplar (windthrow). Images and excerpts from Cave et al. (2017).

4.2.1. Potential contaminants associated with logging residues

Resin acids

Resin acids are naturally occurring compounds that can be toxic at high concentrations. Resin acids are derived from the cell tissue and bark of *Pinus radiata* and other commercially-grown timbers. The most common resin acid found in log yard stormwater is dehydroabietic acid (DHAA), which usually accounts for 40–50% of total resin acids. Others commonly found include abietic, isopimaric, and pimaric acids. The toxicity of these compounds to freshwater aquatic organisms is well documented, although there are limited data for marine organisms (Morrisey 2017). For example, DHAA has a 96-hour LC50 (i.e. the concentration required to kill 50% of the test organisms in 96 hours) for trout of 0.7–1.5 mg/L. The other resin acids exhibit similar LC50 concentrations, ranging from 0.4–1.8 mg/L (KMA 1993, Morrisey 2017). It is worth noting, however, that while resin acids may accumulate in sediments, they do not bioaccumulate, nor do they biomagnify through the food chain the way some contaminants do (e.g. mercury). Resin acids have been identified in fish exposed to marine forestry discharges (‘bio-uptake' through ingestion of water, sediment and biological materials) and can be excreted via bile, urine and faeces.

Fungicides and antisapstains

The use of fungicides and antisapstains on debarked logs and sawn timber for export is also a potential source of stormwater contamination. Since *P. radiata* has a high proportion of sapwood to heartwood, it is particularly susceptible to sapstain[12] and is often treated prior to export. Logs are debarked and sprayed with such treatments before they are transported to some ports. In other ports, logs and sawn timber are treated with fungicides or antisapstains on site. We do not know if this is done to the logs in the Ūawa catchment.

As examples, the principal active constituents of the fungicides Busan 30 WB and NP-1 are 2-(thiocyanomethylthio)-benzothiazole (TCMTB) for Busan 30 WB, and didecyl-dimethyl ammonium chloride (DDAC) and iodopropynyl butylcarbamate (IPBC) for NP-1. All are toxic to a range of aquatic organisms including fish (e.g. 96–hour rainbow trout LC50 of 2.81 mg/L and 0.8 mg/L for DDAC and IPBC, respectively), crustaceans and algae (Szenasy 1998, Morrisey 2017). However, both products are resistant to washing off after application. Fungicidal treatments should not pose a significant threat to receiving environments when adequate dilution is available. Morrisey (2017) noted that NP-1 readily disperses in water and is biodegradable once diluted. IPBC has an environmental half-life of two hours while its major degradation product (propynyl butyl carbamate [PBC]) breaks down after approximately four days (Morrisey 2017).

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[12] ‘Sapstain’ is a term used to describe wood that shows stains on its surface, caused by wood-staining fungi.

Tannins (phenolic compounds)

Tannins associated with the logging residues can be considered contaminants in the water column if they are in high concentrations relative to the receiving environment. Tannins are found commonly in the bark of trees, wood, leaves, buds, stems, fruits, seeds and roots, and help to protect the individual plants. For example, tannins stored in the bark of trees protect the tree from being infected by bacteria or fungi (Das et al. 2020), and similar properties are therefore extended to the waterways. While tannins can also affect the colour and clarity of the receiving environment, they can have direct toxic effects by lowering the pH of the water. In confined water bodies this could cause a range of ecotoxic effects from behavioural changes to mortality (Morrisey 2017). However, tannins should not pose a significant threat to receiving environments when adequate dilution is available.

Suspended solids

Suspended solids (SS) associated with the logging residues can be considered contaminants in the water column if they are in high concentrations relative to the receiving environment (DOC 2018). Suspended sediment 'ecotoxicity' is caused by physically damaging (scouring, abrasion and clogging) tissues and organs or by decreasing light penetration and visual clarity in the water, which can cause a range of 'toxic' effects from behavioural changes to mortality (Cavanagh et al. 2014; Morrisey 2017). Freshwater sediment inputs are considered particularly significant to depositional environments such as estuaries (DOC 2018).

Nutrients

Dissolved nutrients (nitrogen and phosphorus) associated with suspended sediments and woody debris can be considered contaminants / toxic if in high concentrations relative to the receiving environment. Increased concentrations of nitrogen and phosphorus in the water column can have direct effects on primary producers (phytoplankton and algae), increasing the biomass production and disturbing the natural ecological balance in the coastal zone (i.e. causing eutrophic conditions). In this way, concentrated nutrient leachates from woody debris and sediment could cause ecotoxic effects through:

- excessive algal blooms (both toxic and non-toxic)
- reduced depth distribution of submerged aquatic vegetation
- increased growth of nuisance macroalgae
- increased sedimentation / suspended sediment (fallout of plankton).

It should be noted that algae will consume oxygen as they grow and, when they die, their decomposition will also use oxygen. Low oxygen concentrations can kill benthic animals and fish, and is also an indirect effect of excessive algal growth and subsequent decomposition.

Organic material

High concentrations of dissolved organic matter (DOM) in leachates associated with logging residues can result in increased oxygen demand from bacteria and phytoplankton. DOM is a large and complex mixture of compounds with source inputs that differ with location, season, and environmental conditions, and is a key component of the carbon cycle and food chain in aquatic settings (Letourneau & Medeiros 2019). It is necessary for bacterial production, biogeochemical transformations and nutrient availability, and it affects bacterial and phytoplankton community structure and function. Intermittent extreme rainfall events causing logging residue discharges can be expected to have short-term impacts on the quantity and quality of DOM reaching the coastal environment, most notably in estuaries (Letourneau & Medeiros 2019). Higher concentrations of DOM supplied by the Ūawa River could result in higher, and / or differently structured bacterial loads in coastal and estuarine environments, due to competition for carbon-rich resources (which fuels bacterial respiration). Indirectly this could increase nutrient availability, through increased bacterial remineralising of dissolved organic matter (Traving et al. 2017), adding to the nutrient-related effects (discussed above).

4.3. Debris and sediment transportation

How long the woody debris remains buoyant (time-dependent buoyancy[13]) is largely controlled by the tree species (which determines volume and specific gravity), its wetting / drying history, and degradation (Murphy et al. 2020). Other key predictors of the mobility of large woody debris in coastal environments are: (i) sea state and wave-induced circulation; (ii) debris length; (iii) debris morphology; and (iv) beaching / wash-off processes (Murphy et al. 2020).

Shorter / smaller woody debris pieces (offcuts, sticks, bark, etc.) are likely to be transported more rapidly alongshore by littoral[14] processes; in contrast, those that are ejected offshore by rip / eddy currents are less likely to be transported back onshore by waves (Murphy et al. 2020). Smooth, cylindrical logs are likely to be more mobile than large tree branches, or logs with root balls. When deposited on the upper beach the smooth logs are more likely to roll back down the beach when meeting a subsequent wave run-up[15], therefore they are mobile in the intertidal area for the longest period. The irregular shape of tree branches tend to inhibit rolling, requiring higher wave run-up events and floatation of the pieces to cause full remobilisation (Murphy et al. 2020). This suggests pine logs will remain mobile for a longer time than the more morphologically complex willow and, to a lesser extent, poplar (assuming the logs are not cut).

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[13] A major factor determining the capacity for driftwood transport (Murphy et al. 2020).

[14] The littoral zone extends from the high-water mark, which is rarely inundated, to shoreline areas that are permanently submerged.

[15] Wave run-up is the maximum onshore elevation reached by waves, relative to the shoreline position in the absence of waves.

Wood floating in water has a limited buoyancy (Häggblom 1982), and this is mainly determined by the properties and basic density of wood when drifting starts. The maximum period of buoyancy for coniferous wood (*Picea* /spruce, *Larix* / larch, *Pinus* / pine) is between 10 and 17 months, and from 6 to 10 months for broadleaves (*Betula* / birch, *Salix* / willow, *Populus* / aspen) (Häggblom 1982). This suggests that pine logs could be more mobile for a longer period of time period than poplar and / or willow logs, and that larger, more buoyant logs are likely to be transported far beyond the Tolaga Bay area by coastal currents.

The recurrence, time history and clustering of wave run-up events are important factors controlling the stability of debris accumulations on sandy shores (Murphy et al. 2020). Silica sand may accumulate around debris deposited on the upper beach, or around pieces of debris trapped against or on other structures (e.g. past log deposits and the wharf), potentially resulting in partial burial of the debris (Murphy et al. 2020). Deposited debris may be washed away again if there is a quick succession of wave run-up events in quick succession (Murphy et al. 2020). However, the longer a piece of debris remains beached in areas where sand is mobile and accreting without being remobilised by subsequent wave run-up, the more sediment is likely to accumulate in its vicinity, leading to more stable debris deposits.

Due to the extent of cleared land in the catchment, soils are most likely to become mobile during heavy rainfall events. Given that the soils in the Ūawa catchment comprise unconsolidated fine sediment, there is potential for mobilised (and remobilised) sediments to be relatively buoyant and transported over a wide spatial extent (i.e. beyond the bay) following a heavy rainfall event. This may explain our observations of fine sediment deposits over rocky shore areas. Thus, sedimentation, to some degree, is likely to occur during heavy rainfall irrespective of the presences of logging residues and as part of the natural coastal processes. It is likely that the erosional soils of the Ūawa River catchment are a primary contributor to the poor water clarity and elevated suspended sediments in the wider bay (typical of New Zealand coastal waters that are influenced by river mouths). However, with the limited information currently available[16] for this assessment, it is difficult to determine the origin of the sediments, or the contribution from logging residues (e.g. collapsed river banks or from recently deforested areas).

Aside from the discharge characteristics of logging residues, the extent and shape of the areas affected by logging residue plumes, and the magnitude of sedimentation effects, will also depend on: (1) the quantity and quality of the river outflow, (2) the hydrodynamic characteristics that control plume behaviour and (3) the physical and biological makeup of the seabed habitat (Gillespie 2007).

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[16] See recommendations for sediment tracing investigations (Section 4.2) to understand contribution from logging residues.

4.4. Extent and persistence of deposition

Tolaga Bay beach appears to be the ultimate receiving environment for logging residues mobilised in the Ūawa Catchment (Cave et al. 2017) and it is a contentious issue for locals and the wider community because of the beach's values (Table 2). The distribution of debris on the Tolaga Bay beach is discussed in several post-event assessments / reports (Cave et al. 2017; GDC 2018; Cave 2019; Rosser et al. 2019; Cave 2020). In more recent years, drone and satellite imagery has been collected following weather events (Murry Cave, pers. comm.). However, calculations of the spatial extent of the logging residues over time, in the Bay or wider surrounds, has not yet been completed. Given this, the site visit to Tolaga Bay on 27–28 April 2022 allowed a preliminary estimate of the characteristics and extent of logging debris deposition in relation to the distribution of subtidal and intertidal kaimoana habitats and taxa (see Section 3 for more detail).

Side-scan images collected during the site visit showed little evidence of large woody debris in the subtidal (sand or reef) areas of the bay, with two features that may represent logs or debris to the northwest of the bay (see 'hummocky seabed' and 'lines' feature, Figure 6). There were also large numbers of logs and amounts of smaller woody debris (sticks and bark) at the high tide mark predominantly on the sandy beach, the upper rocky shore at the northern Tolaga Bay cliffs and, to a lesser extent, the southern cliffs coastline (pockets of driftwood entrained in caves) and estuary / river mouth. Fine sediment deposits (including shell hash) were also observed covering sessile intertidal organisms on the northern reef substrates.

While larger logs can travel great distances, it appears most of the woody debris within the bay eventually deposits at the high tide mark along the sandy beach or the rocky shore, particularly to the north, with some evidence of woody debris remaining in the estuary / river mouth. Given this, the extent of logging debris following an Ūawa River flooding event can be assumed to extend (eventually) to the beach, estuary, intertidal / subtidal and surrounding rocky reefs within Tolaga Bay, particularly along the northern coast (following predominant current patterns). It's also probable that some larger more buoyant logs travel far beyond the Bay.

As there was a logging residue mobilisation event in the month preceding the site visit, the larger woody debris in the Bay appeared to only persist in the high tide areas, with little / no evidence of sunken or floating log rafts (the exception being the features identified in Figure 6). Smaller woody debris (sticks and bark) were spread on the sandy and rocky shore between high and low tide zones and appear to remain mobile for longer in these locations. The persistence of the larger beached wood (logs) on the upper shorelines depends on a number of factors, including the decomposition timeframe, whether it is removed, whether it is smothered by sand (incorporated into sand dunes) and / or if it is remobilised during subsequent storm events. It is also recognised that some of the woody debris is likely to reach areas outside of the Bay, given pine has the potential to retain buoyancy for a number of months (Section 4.3).

Although the estuary of the Ūawa River and Kaitawa Stream was not investigated during our visit (Section 3), it was visited by Professor Conrad Pilditch (University of Waikato) about two months after the Queen’s Birthday rainfall event in June 2018 (Appendix 6). Visiting in mid-August, Professor Pilditch made qualitative observations of sediments, animals and plants, and noted ‘the number of large logs stranded in estuary’ (he did not report numbers of logs). This suggests that logs can persist there for at least two months following a mobilisation event. There were no obvious or large amounts of fresh mud evident in the areas of the estuary visited by Professor Pilditch that might have suggested large-scale smothering of intertidal areas and the animals living in them. However, without physical data on the sediment profile and wider scale searching in the estuary, it is difficult to know how and when the estuary sediment structure responded to mobilisation events over time. Professor Pilditch suggested a study of sediment cores from the estuary to identify historical changes in sediments and relate them to changes in catchment land use. We support this suggestion.

It is reasonable to assume that fine sediment deposition to the coastal environment from the Ūawa River is persistent and widespread. Fine sediment deposits in Tolaga Bay appear to have a greater extent than woody debris, with observations made during the site visit showing that fine sediment deposits appear to extend over rocky shore areas. Whether the additional sediment inputs from logging residues following a mobilisation event cause a detectable increase in the extent of a sediment plume is difficult to say (compared to background levels). However, it is reasonable to assume, given the additional volume of sediments and the buoyancy and transportation characteristics of sediments discussed in Section 4.3, that there will be some increase in potential spatial extent (i.e. within and beyond the Bay). The majority of sediments will eventually be deposited on soft mud / sand habitats in deeper waters or semi-protected coastal embayments (Gillespie 2007).

5. POTENTIAL EFFECTS OF LOGGING RESIDUES ON COASTAL ECOSYSTEMS AND BIOLOGY

The following section discusses the available literature on the effects to coastal ecosystems from frequent and high volumes of logging residues (woody debris and mobilised soils) during high rainfall events. Using the information gleaned from the literature review, this section will describe the 'benefits' and 'costs' of these effects to coastal environments, specifically:

1. smothering of benthic ecosystems
2. physical abrasion on reefs and coastal ecosystems
3. increased suspended materials in the water column (potentially reducing water clarity, increased number of large floating items (logs, sticks, bark), increased concentrations of suspended nutrients and/or reducing food quality for filter feeding animals)
4. leaching of toxic compounds
5. deoxygenation of waters.

Other effects that are out of scope of this assessment, but likely to be of relevance to the community: the spread of invasive species, coastal hazards to shipping and navigation, and the overall societal cost.

5.1. Smothering of benthic ecosystems

5.1.1. Benefits

Woody debris was more often seen historically on coastlines but now is often removed to improve beach access, navigation and reduce fishing snags (Gonor et al. 1988; Payton 2018). Biologically, the deposition and smothering of woody debris has several important functions in marine ecosystems.

Fine woody material may be deposited and incorporated into seabed sediments, providing a source of carbon and other nutrients for organisms living there (West et al. 2011). The major degraders of marine wood are wood-boring shipworms (actually shellfish, not worms, that burrow into wood) and gribbles (sea lice that specialise in boring into wood) (Gonor et al. 1988). Marine fungi and bacteria appear to play minor roles in the initial invasion and degradation of wood in the sea. These animals burrow, live in and ingest wood as a food source, processing the wood and making it available as food or shelter for other marine organisms, and adding carbon and nutrients to the seabed (Murphy et al. 2021). Larger woody material (floating trees) can travel long distances and is quickly colonised by shipworms, gribbles and barnacles. When this moving wood sinks to the bottom of the ocean, it forms the primary energy base for a diverse community of animals and functions as an island of productivity in an otherwise stable, low diversity, low productivity environment (Gonor et al. 1988; Murphy et al. 2021).

In windy areas, woody debris can trap appreciable amounts of windblown sand in the backshore, which can alter beach–foredune sediment budgets and initiate dune formation (Eamer & Walker 2010). In this respect, woody debris provides an important buffer that reduces erosion of established foredunes. The wood not only traps sediment but provides decaying organic matter for pioneering plant and dune grass species to take root in (Doong et al. 2011). Thus, woody debris can help stabilise and contribute to accretion of soft sediment and pebble / cobble beaches (Gonor et al. 1988; Kennedy & Woods 2012; Payton 2018).

In coastal areas where erosion is occurring, coastal accretion (where sediment is carried down by streams and the shoreline builds out, see ’credits’ in Figure 9) can help offset erosional losses (when the shoreline retreats), either temporarily or permanently (MfE 2017).

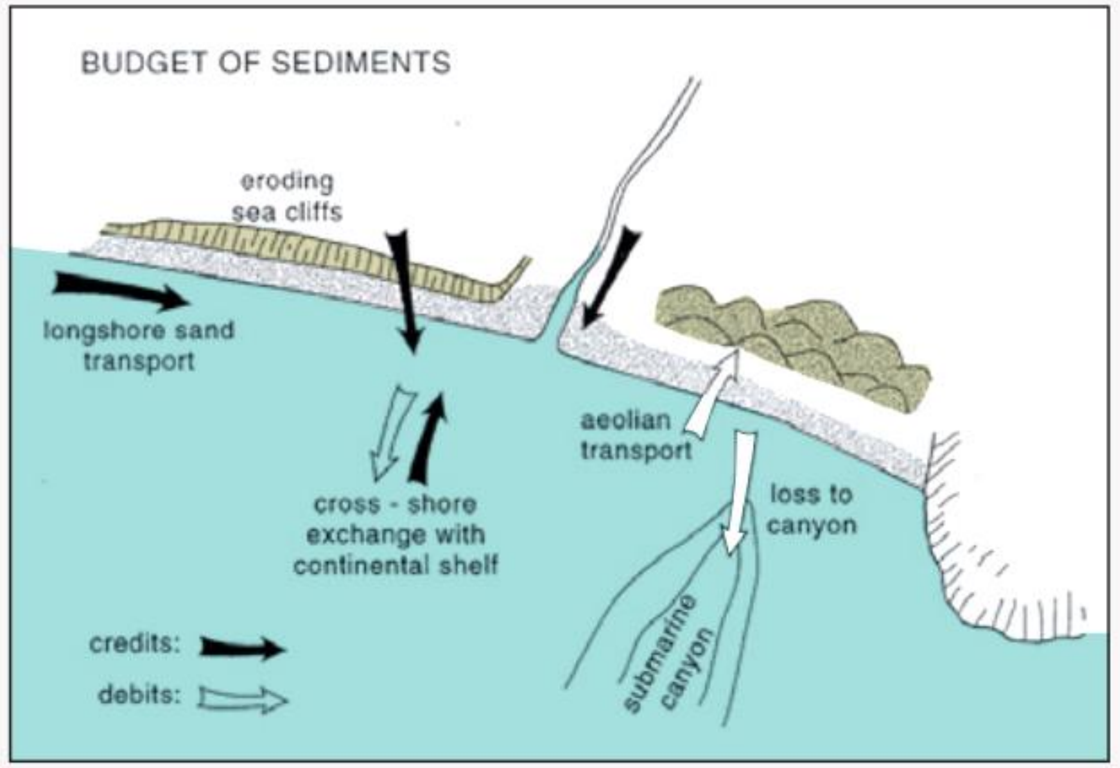

Figure 9. Components of a typical coastal sediment budget (from MfE 2017). ‘credits’ represent deposition of sediment, ‘debits’ represent erosion.

5.1.2. Costs

During major flooding events, sediment-laden plumes from East Coast rivers can extend over large areas of coastline (10 km +) alongshore and offshore by wave action and tidal currents (Gillespie 2007). The additional volume of sediment attributable to logging activities in the Ūawa catchment during these events could be in the order of 2 million m^3 with an additional 47,000 m^3 of woody debris (see Section 4.1).

Accumulation of fine woody material, such as bark and wood chips, and deposition of sediment derived from soil erosion, can smother the seabed, depriving it of oxygen and burying animals and plants. If deposition occurs rapidly and / or frequently, as is experienced during Ūawa River flooding events (Section 4.1), animals and plants attached to the seabed will be buried, as will motile animals that are unable to burrow up through the material (Bright 2021). While some localised areas at the river mouth and possibly in the north-east of the Bay appear to have single sunken logs, there was little evidence of widespread woody debris (either sunken or floating) in the vast majority of the intertidal, subtidal or river mouth areas we investigated, suggesting this is not a persistent issue following a mobilisation event. It is recognised that accumulations of smaller woody material (like bark and sticks) on the seabed are likely to be harder to detect using sidescan compared to an object with a larger 3D profile (Kaeser & Litts 2008) and the ground truthing of sidescan outputs may help to identify these features (e.g. using video or dive surveys).

Two months following the Queen's Birthday logging residue mobilisation event (June 2018), qualitative observations of the estuary were undertaken by Professor Pilditch (Appendix 6). He reported many logs stranded in Kaitawa estuary (unquantified), with no obvious or large amounts of fresh mud evident in the areas searched. The sediment in the upper reaches of the estuary was quite muddy, supporting high densities (unquantified) of mud crab (*Austrohelice crassa*) and mud snails (*Amphibola crenata*), indicative of a ‘healthy population’. The sediment surface also had other indicators of animal activity (holes, feeding tracks, tubes), most like due to polychaete worms, consistent with sediment of similar composition in other estuaries. Professor Pilditch noted, however, that without quantitative sampling of the sediment animal community it is difficult to assess the status overall health of the Kaitawa Estuary.

Sediment inputs from the Ūawa River in general are likely to be causing sedimentation and smothering of marine organisms in Tolaga Bay coastal areas on a more regular basis (compared to woody material). Increased levels of sedimentation can potentially alter the nature of the seabed by making the sediment muddier and less stable (and therefore prone to remobilisation), which could be exacerbated in areas dominated by mobile woody debris (Kirkpatrick et al. 1998). For example:

1. During major flood events (e.g. Cyclone Bola, March 1988) riverine sediment plumes resulted in the creation of near-bottom, high turbidity (fluid mud) layers

that extended out over most of the continental shelf and had catastrophic smothering effects on benthic communities. Recovery rates after such an event were thought to be in the order of years (Gillespie 2007).

2. In Onapua Bay in the Marlborough Sounds, coastal logging contributed to sediment smothering the seabed between 4 m and more than 30 m seawards of the stream mouth (Gillespie & Asher 1993; Gillespie et al. 1993; Gillespie & Asher 1994, 1995; Fransen et al. 1998). There was relatively little pine debris present, and most of it had settled 65–100 m from shore (10–12 m water depth). Changes were small after typical rainfall events but after major storms the effects were more noticeable, with a small delta developing in the mouths of the streams draining the logged area and gravel and silt deposited on the shore. The deposited sediment was reworked and dispersed by wave action over time and effects were no longer present after six months. However, the lack of strong or lasting effects detected in the coast below the logged catchment (vs the coast below the reference catchments) may have been due to the low frequency and intensity of rainfall events over the 5-year monitoring time frame (Gillespie & Asher 1995). Higher intensity and more frequent rainfall events could have produced more pronounced effects.

Some near-shore sedimentation was noted at the northern rocky reef intertidal areas in Tolaga Bay (Section 3.1.2) that could cause adverse impacts to the existing intertidal reef biota, including kaimoana (listed in Table 1). However, most sediments derived from the Ūawa catchment appear to be rapidly flushed away from potentially sensitive near-shore rocky reef habitat in the Bay, and are likely to be deposited eventually in soft mud / sand habitats in deeper waters or semi-protected embayments (Gillespie 2007). Thus, while some rocky reef kaimoana species within the bay, such as Kuku beds (mussel beds), can be expected to be adversely impacted by chronic and even episodic sedimentation events, so too can the animals and algal communities in more distant depositional zones (Gillespie 2007).

Coarse-grained gravels and sandy materials deposited close to the river mouths may form estuaries or deltas or be transported along shore to beaches (Gillespie 2007). In some contexts this is a benefit (e.g. for nourishing eroding beaches), as discussed in Section 5.1.1. However, smothering by terrigenous (land-derived) sediment is also a major threat resulting in intertidal and estuarine habitats being modified or lost (Thrush et al. 2004; Gillespie 2007). While there are no quantitative data on the Kaitawa Estuary (Table 2) biota, kaimoana species identified in Table 1 that could be present, include; Īnanga (whitebait), Pātiki (flounder), Tuna (eels), and a range of native freshwater fish. Soft sediment invertebrates in the estuary are likely to include the kaimoana; Tuangi (the cockle *Austrovenus stutchburyi*, Appendix 6); and Whetiko (the mud snail *Amphibola crenata,* Appendix 6), both of which are mobile under depositional conditions (Barrett et al. 2017).

Observations made following the June 2018 logging residue mobilisation event (Appendix 6) noted the presence of mangroves fringing the channel edge at the upper end of the estuary where the Kaitawa Stream enters. Mangroves do not naturally occur this far south and the Tolaga mangroves were transplanted from Ohiwa Harbour in 1980 (Crisp et al. 1990). While mangroves play an important role in estuaries trapping sediment and providing habitat, they can expand rapidly, due to increased sediment supply and altered water flow patterns, resulting in habitats being modified or lost (Appendix 6). If estuary monitoring is to be undertaken in the future, it would be pertinent to include provision for monitoring mangrove extent.

Riverine plumes can also lead to the deposition of contaminated sediments, depending on the catchment characteristics. For example, investigations on the Motueka River plume in western Tasman Bay showed high nickel and chromium concentrations in sediments, traced to a natural upper catchment mineral belt. Concentrations in the sediment greatly exceeded guidelines for the protection of aquatic life (Gillespie 2007).

There is potential for adverse smothering effects from logging residues for some reef and estuarine kaimoana taxa resulting from the increasingly frequent Ūawa River flooding events and increasing levels of log harvesting, adding to the cumulative effects legacy in the coastal environment (Figure 10). Further investigation[17] is warranted of the spatial extent, persistence and the contribution from logging, of sediment inputs to kaimoana taxa on the rocky reef in Tolaga Bay and Kaitawa estuary. Furthermore, while smaller accumulations of woody material (like bark and sticks) and large accumulations of logs (that might also cause smothering) were not detected in the sidescan outputs, ground-truthing of sidescan outputs is advisable to provide a weight of evidence.

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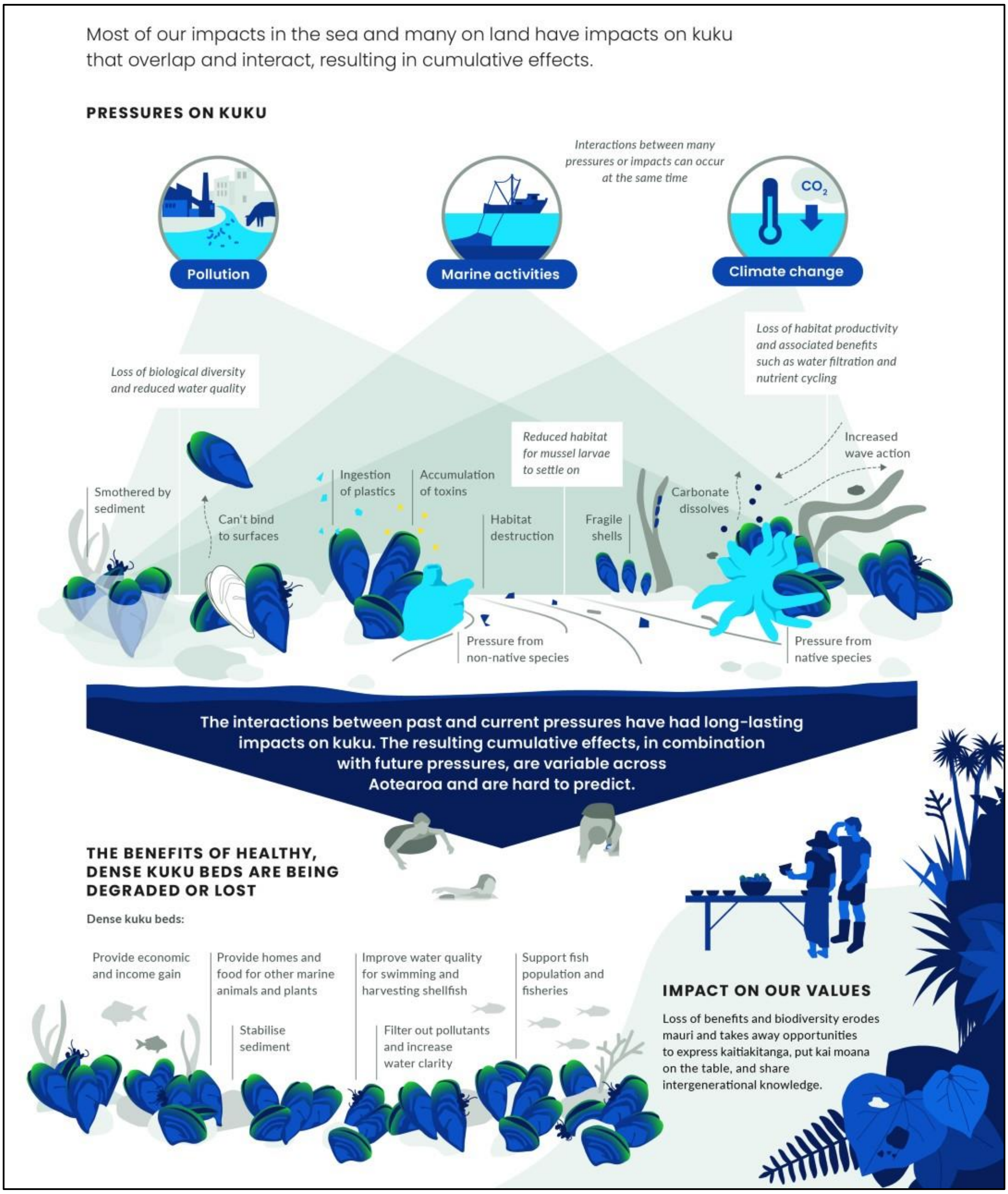
[17] For example, a forensic compound specific stable isotope (CSSI) technique and more extensive intertidal / estuary surveys.



Most of our impacts in the sea and many on land have impacts on kuku that overlap and interact, resulting in cumulative effects.

PRESSURES ON KUKU

The interactions between past and current pressures have had long-lasting impacts on kuku. The resulting cumulative effects, in combination with future pressures, are variable across Aotearoa and are hard to predict.

THE BENEFITS OF HEALTHY, DENSE KUKU BEDS ARE BEING DEGRADED OR LOST

Dense kuku beds:

IMPACT ON OUR VALUES

Loss of benefits and biodiversity erodes mauri and takes away opportunities to express kaitiakitanga, put kai moana on the table, and share intergenerational knowledge.

Figure 10. Cumulative pressures that affect kuku. Excerpt from The Ministry for the Environment, Our marine environment 2019 https://environment.govt.nz/publications/our-marine-environment-2019/all-our-activities-put-cumulative-stress-on-the-marine-environment/

5.2. Physical abrasion to reefs and coastal ecosystems

5.2.1. Benefits

The battering of intertidal and shallow subtidal areas by woody debris during storms has an important role in structuring rocky shore and intertidal communities (Gonor et al. 1988). Sessile plants and animals in this community compete for attachment space, with the more successful or dominant species gradually excluding others and occupying all surface space. This can result in decreased community diversity. The physical impact of woody debris during storms can dislodge animals and plants and create patches of open space that can then be occupied by other species. This process creates a mosaic of patches at different stages of development, and may result in higher diversity overall (Gonor et al. 1988).

5.2.2. Costs

Frequent and excessive abrasion by floating woody debris may remove existing organisms, preventing new assemblages of species from developing. This can result in permanent bare areas or areas occupied only by species that can recolonise rapidly between abrasion events (Murphy et al. 2020).

Large floating woody debris in particular, is recognised as an important geomorphic agent on New Zealand coastlines (Kennedy & Woods 2012), offering a powerful force for erosion by battering and abrading cliffs (similar to Tolaga Bay's Tatarahake Cliffs, Table 2), especially when driven by storm waves (Doong et al. 2011). Shorelines along the North Island between East Cape and Hawke Bay contribute high sediment loads due to the soft rock and erosion-prone hill country (Gillespie 2007), but additional battering forces from logging debris could increase the rate of erosion further.

There was little evidence of large woody debris from logging residue in the deeper subtidal areas or the river mouth noted from the sidescan survey (Section 3.2). Two single logs were noted in the river mouth / estuary (Figure 7); however, the only feature detected by the sidescan that could represent an accumulation of sunken logs was detected in the inner part of the north-west bay, between a 10–15 m depth range (Section 3.2.2). This area / feature warrants further investigation when water clarity improves.

Potential evidence of woody debris abrasion occurring were noted in the intertidal areas inspected during the rocky shore intertidal survey (Section 3.1.2). These included, large accumulations of logs and woody debris at the extreme high tide / storm surge area, possible scouring or scrape marks on high tide rocky shore, empty limpet attachment points and large sections of clear bedrock (patchy communities) on the northern shoreline. Additionally, most taxa were present in cracks and areas of protected reef. Exposed reef was either bare or only had biofilm present. Overall, very few kaimoana taxa were observed in the intertidal survey locations. These were (total count over the 5 transects):

- Kuku (green-lipped mussel, 2 individuals)
- Pōrohe (blue mussels, 'present'[18]),
- Ngākihi (limpets, 26 individuals)
- Kaikai tio (oyster borer, 6 individuals)
- Pupu (top snails and cats eyes, 6 individuals)
- Karengo (sea lettuce/ *Ulva* sp., 'present').

These kaimoana were generally more prevalent in the low shore transects. Kuku and Pōrohe in particular were observed only on the northern shoreline transects; none were present on the southern shoreline transects.

It's unclear whether our observations of community composition and distribution were the result of abrasion from woody debris or if they were caused by other pressures such as kaimoana gathering at easy access intertidal sites or other environmental pressures (e.g. long-term sedimentation). However, if we also consider the prevalence of woody material at the high tide mark and entrained in boulders, it suggests physical abrasion due to woody debris may be occurring on the rocky reef kaimoana habitat, most notably on the northern shorelines, but possibly in some of the subtidal reef and river mouth areas as well (see Section 3.2.2). While it's probable that some larger, more buoyant logs travel far beyond the Bay (Section 4.3), the extent of abrasion from woody debris in Tolaga Bay is unclear. Further investigation into the intertidal areas to the north and south of Tolaga and the surrounding coastline would help to clarify whether these characteristics are typical reef community in the area, and / or the extent of the abrasive effect to the intertidal kaimoana.

Wood-related physical abrasion from each mobilisation event is likely to persist for a matter of weeks or months within the Bay, as evidenced by the decomposition rate and the progressive loss of buoyancy of woody debris in the ocean (Section 4.2 and 4.3). In the longer term, the abrasion effects are likely to occur intermittently during subsequent storm events (assuming there is no change to harvest management practices, Section 4.1), with remobilisation from storm surge possibly causing compounding effects, as more woody debris is added to the system. This timeframe / frequency is also supported by site visit observations where: 1) the vast majority of logging residue appeared to be restricted to the high tide and storm surge zones, 2) there was no evidence of floating logs, and 3) little evidence of sunken logs in the subtidal areas (Section 3.2.2) following the preceding month's flooding event.

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[18] Kaimoana taxa that were noted as 'present' (P) were present in the quadrat, but not under a grid-point so could not be included in the enumeration due to low abundances.

While large woody debris appears to have intermittent abrasive effects locally, further investigation into the abrasive potential of the smaller woody debris entrained in crevasses and boulders in the intertidal areas would help to clarify how long the potential for abrasion persists. Monitoring of movements of the two sunken logs observed in the river mouth (Figure 7) and the sidescan features identified (Section 3.2.2) would provide an indication of the rate of transport of such large debris.

5.3. Increased sediments and other materials in the water column

5.3.1. Benefits

None.

5.3.2. Costs

Seaweed and microalgae could be subject to reduced levels of photosynthesis and die. Seaweeds and microalgae are the basis of the food web on shores and shallow seas and depend on sunlight for photosynthesis to produce food and to grow. Suspended material in the water column reduces their ability to photosynthesise (Murphy et al. 2020), so the seaweeds grow more slowly and eventually are unable to survive. This, in turn, deprives animals of their food and, in many cases, their shelter.

If concentrations of nutrients (phosphorus / nitrogen, Section 5.4.2) are also high, this can potentially cause nuisance growths of seaweeds of microalgae (including toxic species). However, it is noted that no evidence of nuisance algal growth was identified in the preliminary surveys undertaken (Section 3).

As discussed in Section 5.1, riverine plumes can mobilise contaminated sediments (depending on the catchment characteristics) that may cause adverse effects to aquatic life in the water column (Gillespie 2007). Higher levels of turbidity and poorer water clarity can lead to behavioural (avoidance) and foraging efficiency changes for visual predators such as macroinvertebrates, fish (such as snapper) and marine mammals.

Suspension-feeding animals could potentially lose condition and die. The impact of elevated suspended sediment to suspension feeding kaimoana (such as mussels) depends primarily on two factors: the size range of the sediment particles, and the food content of the suspended sediment[19]. For example, if the particles are above approximately 20 mm diameter (the maximum size used by most suspension feeders) then effects will probably be minimal. If the food content in sediment increases, animals may get more nutrition for time spent feeding. If the food content decreases,

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[19] https://niwa.co.nz/publications/wa/vol10-no4-december-2002/effect-of-increased-suspended-sediment-on-suspension-feeding-shellfish

animals will have to work harder for their food and could potentially lose condition and die.

While background level of suspended sediment and woody materials during a mobilisation / rainfall event are likely to be high, it is reasonable to assume an increase in potential spatial extent, and persistence of typical riverine sediment plume (i.e. within and beyond the bay), especially considering the estimate volume of mobilised sediment from logging residues is in the order of millions of cubic metres (Section 4.1). The uncertainty around the spatial extent, persistence, and the contribution from logging to the Ūawa River's suspended sediment / woody materials inputs would likely be improved following the 'further investigations' described in Section 5.1.2.

5.4. Leaching of toxic compounds

5.4.1. Benefits

None.

5.4.2. Costs

There are a few potential contaminants associated with concentrated areas of woody debris and their associated leachates (described in Section 4.2). The leachable constituents from high volumes of logging residues that are of most concern in terms of ecotoxic effects to kaimoana species (e.g. fish, shellfish and seaweeds) are resin acids and suspended solids. There may also be cumulative or interactive effects from two or more of the stressors described in Section 4.2.1 (Morrisey 2017).

Any leachates derived from logging residues will probably have little effect due to the high assimilative capacity and buffering potential in the coastal receiving environment (Pease 1974), irrespective of their ecotoxicity under laboratory conditions. For example, in an experiment by Pease (1974) organic compounds leached rapidly from logs in laboratory studies (via water condensate), but were readily precipitated in salt water, suggesting that the buffering potential of saltwater inhibits toxic effects in the water column. This is particularly so in the highly dispersive and energetic intertidal and subtidal reef systems occupied by the Tolaga Bay kaimoana taxa of interest (Table 2).

Any ecotoxic effects from logging residue leachates are more likely to be detectable in poorly flushed, lower salinity areas (where the leachate / debris might be concentrated), such as estuarine pools and channels (Pease 1974; Letourneau & Medeiros 2019). While there are currently no quantitative data on the Kaitawa estuary biota, it is considered a habitat of significant conservation value (Table 2). Following the June 2018 storm and deposition event, Professor Pilditch (see Section 4.4 and

Appendix 6) reported that many logs were stranded in Kaitawa estuary and that the sediment in the upper reaches of the estuary was quite muddy. Nevertheless, the area appeared to support an assemblage of animals consistent with similar sediments in other estuaries. Professor Pilditch noted, however, that without quantitative sampling of the sediment animal community, it is difficult to assess the overall health of the Kaitawa Estuary.

Some of the potential kaimoana taxa that may be present in an estuarine or brackish habitat (as identified in Table 1) include mobile fish such as Īnanga (whitebait), Pātiki (flounder), Tuna (eels), and a range of native freshwater fish (Table 1). Soft sediment invertebrates may include, Whetiko (mud snails) and Tuangi (cockles), which are considered to be highly mobile under depositional conditions (Barrett et al. 2017). While there is potential for adverse effects for localised estuarine taxa in the short term (e.g. during low tide), mobile estuarine aquatic taxa generally have the ability to move away from undesirable environmental conditions and to a certain degree are naturally adapted to manage fluctuating environmental conditions (e.g. desiccation, temperature, salinity). It was also observed during the brief sidescan survey of river mouth that large accumulations of bark and wood appeared to be restricted to the shore between the low and (especially) high tide mark, with no evidence of mass debris accumulations in the tidal channels or pools. It is noted, however, ground-truthing of sidescan outputs is advisable to provide a weight of evidence, and that no quantitative survey of the Kaitawa estuary was undertaken during the site visit. Investigation and characterisation of the valued Kaitawa estuary (Table 2) and its resident kaimoana taxa, would help to clarify the risk of toxicity posed from logging residue leachates (specifically, suspended sediments and resin acids).

5.5. Deoxygenation of waters

5.5.1. Benefits

None.

5.5.2. Costs

The reduction of oxygen in water is a secondary effect that can be caused by leaching of oxygen-demanding substances and the decomposition of logging residues (discussed in Sections 4.2.1, 5.1.2 and 5.4.2). This depletion of oxygen in receiving waters can have adverse effects on aquatic biota.

Intermittent extreme rainfall events causing logging residue discharges can be expected to have short-term impacts on the quantity and quality of dissolved organic matter (DOM) and nutrients (nitrogen and phosphorus) in the coastal environment, most notably in estuaries (Letourneau & Medeiros 2019). Higher concentrations of DOM supplied by the Ūawa River could result in higher, and / or differently structured bacterial loads in coastal and estuarine environments, due to competition for carbon-rich resources (which fuels bacterial respiration). Indirectly this could increase nutrient availability, through increased bacterial remineralising of dissolved organic matter (Traving et al. 2017).

Increased concentrations of nitrogen and phosphorus in the water column can lead to increased production by primary producers (phytoplankton and algae), disturbing the natural ecological balance in the coastal zone. In this way, concentrated nutrients could lead to excessive algal blooms and growth, which when decomposing, consumes additional oxygen from the water column (potentially killing benthic animals and fish).

The severity of the deoxygenation effect will depend on the nature of the receiving environment and the characteristics of the logging residues (e.g. volume, persistence). Oxygen demand is rarely an issue with high energy coastal discharges given the high assimilative capacity of these receiving environments. However, as discussed in Section 5.4.2, poorly flushed, brackish (lower salinity) areas such as estuary pools and channels where logging residues (e.g. sunken log rafts and bark layers) might be concentrated could be at higher risk of short-term, localised effects from deoxygenation (Pease 1974; Letourneau & Medeiros 2019). Decomposition of large debris, such as logs, will not contribute much to the nutrient load even in a sheltered estuary, because wood is low in nitrogen (Appendix 6).

6. SUMMARY

Woody debris and sediment are important inputs to estuarine and oceanic habitats, from the tidal limits of coastal rivers to the open ocean surface and the deep-sea floor. While it may be natural and beneficial to have reasonably high levels of large woody debris and sediment deposited on beaches, for example after rainfall events, the frequency of these events is on the rise. It is clear that the volume and frequency of wood deposited on the beaches and floating in Tolaga Bay have increased[20] since local plantation forests began harvesting in 2010 (see Table 6).

There are a number of potential effects resulting from logging residues that could, either directly, indirectly or cumulatively, have an adverse impact on kaimoana taxa and habitats in the Tolaga Bay coastal area. The adverse effects identified were smothering of benthic ecosystems, physical abrasion / scouring, increased sediments and other materials in the water column, leaching of toxic compounds and deoxygenation of water. Based on the findings of the literature review and the site visit, it appears that the mostly likely effects to the intertidal and wider bay are physical abrasion and sedimentation (smothering and reduced water clarity) from the logging residues. There were also a number of potentially beneficial effects identified, notably; providing a source of carbon and other nutrients for sediment and dune dwelling organisms and initiating dune formation (buffering coastal erosion). In the context of increased storminess and sea-level rise, increased rates of coastal sediment accretion may help offset their effects, and woody debris can contribute to this (Eamer & Walker 2010; Falkenrich et al. 2021).

The extent and persistence of the potential woody debris abrasion effects is not fully understood, but the vast majority of woody material in the Bay observed during the April 2022 site visit appeared to be restricted to the high tide and storm surge zones following the preceding month’s flooding event (Table 6). There was no evidence of floating logs in the Bay and little evidence of sunken logs in the soft sediment, rocky reef subtidal or Ūawa river mouth areas (sidescan survey results, Section 3.2.2). The exception to this was the accumulation of smaller woody debris entrained in crevasses and boulders in the lower intertidal areas, the presence of ‘hummocks’ and ‘lines’ in sidescan images from the north-west of the inner Bay subtidal area, and two sunken logs in the river mouth.

While it is known that larger logs can travel great distances, the persistence of the abrasion effects in the immediate intertidal and subtidal areas of Tolaga Bay appear to be a matter of months following a mobilisation event, and of intermittent frequency (due to possible remobilisation during subsequent storm events). Further investigation into the abrasive potential of the smaller woody debris entrained in crevasses and

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[20] Although we do note that historically the greatest increase in debris to the Ūawa River was likely to be caused by land clearing following human settlement.

boulders in the intertidal areas, and characterisation of the features identified in the sidescan outputs, would help to clarify how long the potential for abrasion persists and its extent.

The extent and persistence of sedimentation effects in the region are likely to be long term and can be expected to combine with existing sedimentation effects from other land use practices to cover a wide coastal area. This may be evidenced by the shell and sand deposited on the intertidal species assemblages surveyed. Whether the increase in sediment from logging residues causes a detectable increase (compared to background levels) in the spatial extent of a sediment plume following a mobilisation event is difficult to say. However, it is reasonable to assume the potential spatial extent includes the Bay and the adjacent coast, with the majority of sediments eventually being deposited in soft mud / sand habitats in deeper waters or semi-protected coastal embayments. Regardless of the source of the sediment, there is potential for adverse smothering effects for some reef and estuarine kaimoana taxa resulting from the increasingly frequent Ūawa River flooding events, adding to the cumulative effects legacy (Section 5.1.2).

There were very few kaimoana taxa identified in the preliminary intertidal survey (Section 3.1.2). These were; Kuku (green-lipped mussel, 2 individuals), Pōrohe (blue mussels, ‘present’), Ngākihi (limpets, 26 individuals), Kaikai tio (oyster borer, 6 individuals), Pupu (top snails and cats eyes, 6 individuals) and Karengo (sea lettuce/ *Ulva* sp., ‘present’). These kaimoana were generally more prevalent in the low shore areas. Kuku and Pōrohe in particular were only observed on the northern shoreline transects; none were present on the southern shoreline transects. It is unclear with the current amount of information available whether the apparent dearth of kaimoana taxa is due to logging residue effects, or if it is typical of easily accessed (and harvested) rocky intertidal areas in the wider coastal area, and / or it is simply a result of the small-scale survey undertaken. Further investigation into the wider kaimoana diversity of coastlines in the area would improve this understanding.

Some potential for localised, short-term effects from the leaching of organic compounds (toxicity and deoxygenation) was also identified in less well-flushed, lower salinity locations, such as the Kaitawa estuary (Section 5.4.2). While the site visit surveys did not include a specific investigation into the estuarine species assemblages in the area, kaimoana taxa that may be present and / or impacted (as identified in Table 1) might include mobile fish, such as Īnanga (whitebait), Pātiki (flounder), Tuna (eels), Whetiko (mud snails) and Tuangi (cockles).

Investigation of the following topics would help to clarify the level of risk associated with the potential effects identified here (in terms of magnitude and consequence, spatial extent, persistence and likelihood of an effect) and help to understand the current state of kaimoana species and habitats in Tolaga Bay:

- comprehensive quantitative intertidal surveys (characterisation of intertidal communities and habitats)
- video survey of identified sidescan features and subtidal reef systems (Section 3.2.2)
- tracking of the potential transportation / movements over time of the two sunken logs observed in the river mouth (Figure 7)
- characterising the Kaitawa estuary ecosystem including, but not limited to, physicochemistry, habitat change (e.g., broadscale mapping of dominant estuary features, such as mangrove extent), and its species assemblages (including kaimoana taxa)
- investigating the source and extent of the sediment in the Ūawa River (see Section 4.1)
- potential monitoring of extent of logs through satellite or aerial imagery.

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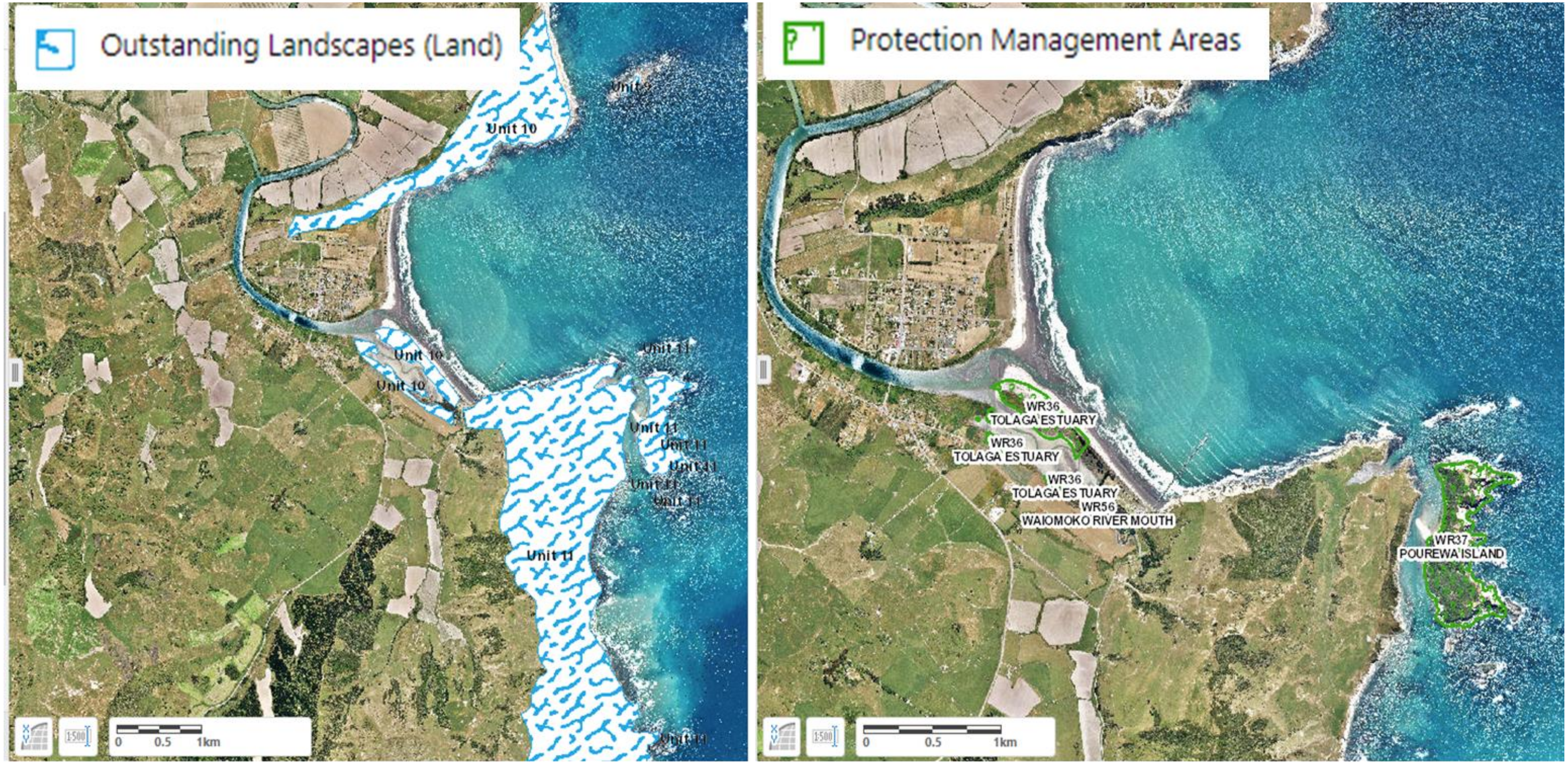
Appendix 1. Outstanding landscapes (land) and protection management areas in the Tolaga Bay / Ūawa coastal area (extracted from the online Tairāwhiti Plan[21]).



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[21] Tairāwhiti Plan is a free mapping application that enables viewing of planning data from the Tairāwhiti Resource Management Plan (https://maps.gdc.govt.nz/H5V2_12/).

Appendix 2. Geological sites and coastal environment management areas in the Tolaga Bay / Ūawa coastal area (extracted from the online Tairāwhiti Plan[22]).

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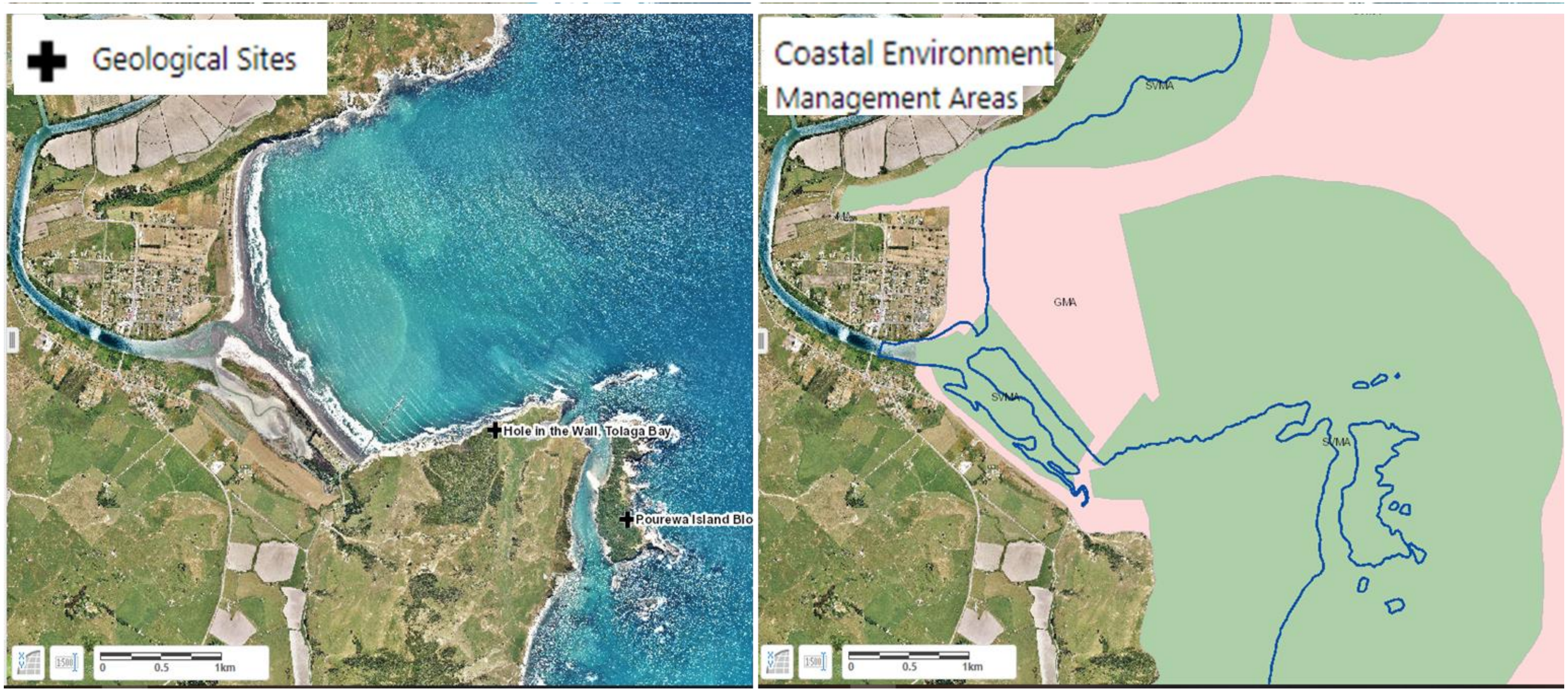

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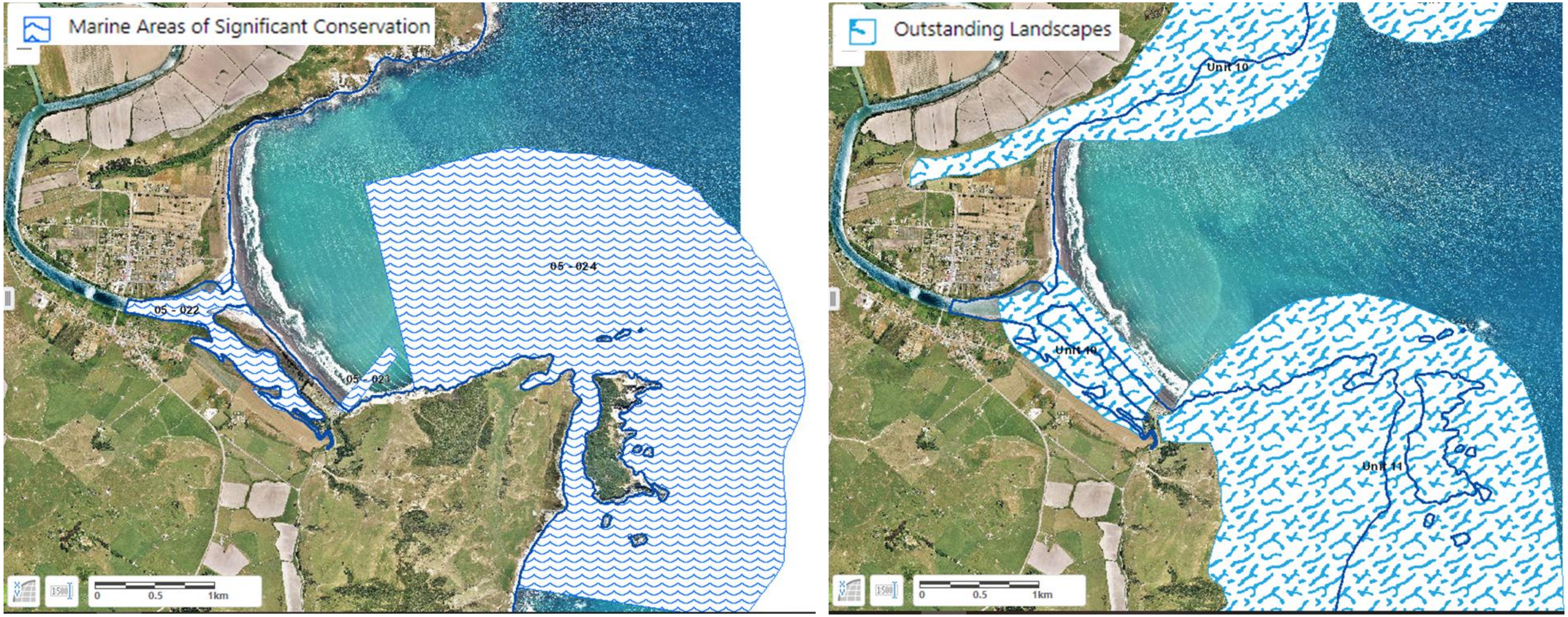
[22] Tairāwhiti Plan is a free mapping application that enables viewing of planning data from the Tairāwhiti Resource Management Plan (https://maps.gdc.govt.nz/H5V2_12/).

Appendix 3. Marine areas of significant conservation value and outstanding marine landscapes in the Tolaga Bay / Ūawa coastal area (extracted from the online Tairāwhiti Plan[23]).



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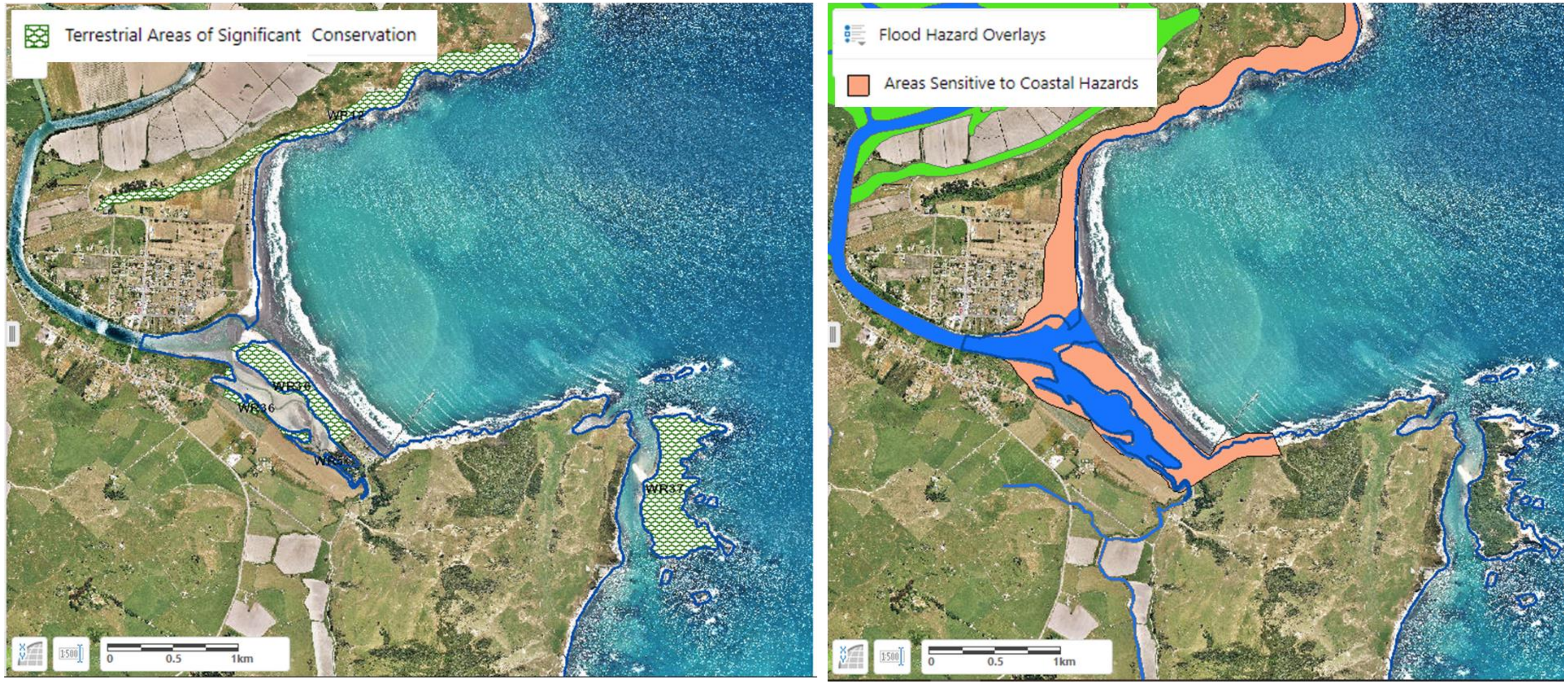
[23] Tairāwhiti Plan is a free mapping application that enables viewing of planning data from the Tairāwhiti Resource Management Plan (https://maps.gdc.govt.nz/H5V2_12/).

Appendix 4. Terrestrial/coastal areas of significant conservation value and areas sensitive to coastal hazards in the Tolaga Bay / Ūawa coastal area (extracted from the online Tairāwhiti Plan[24]).



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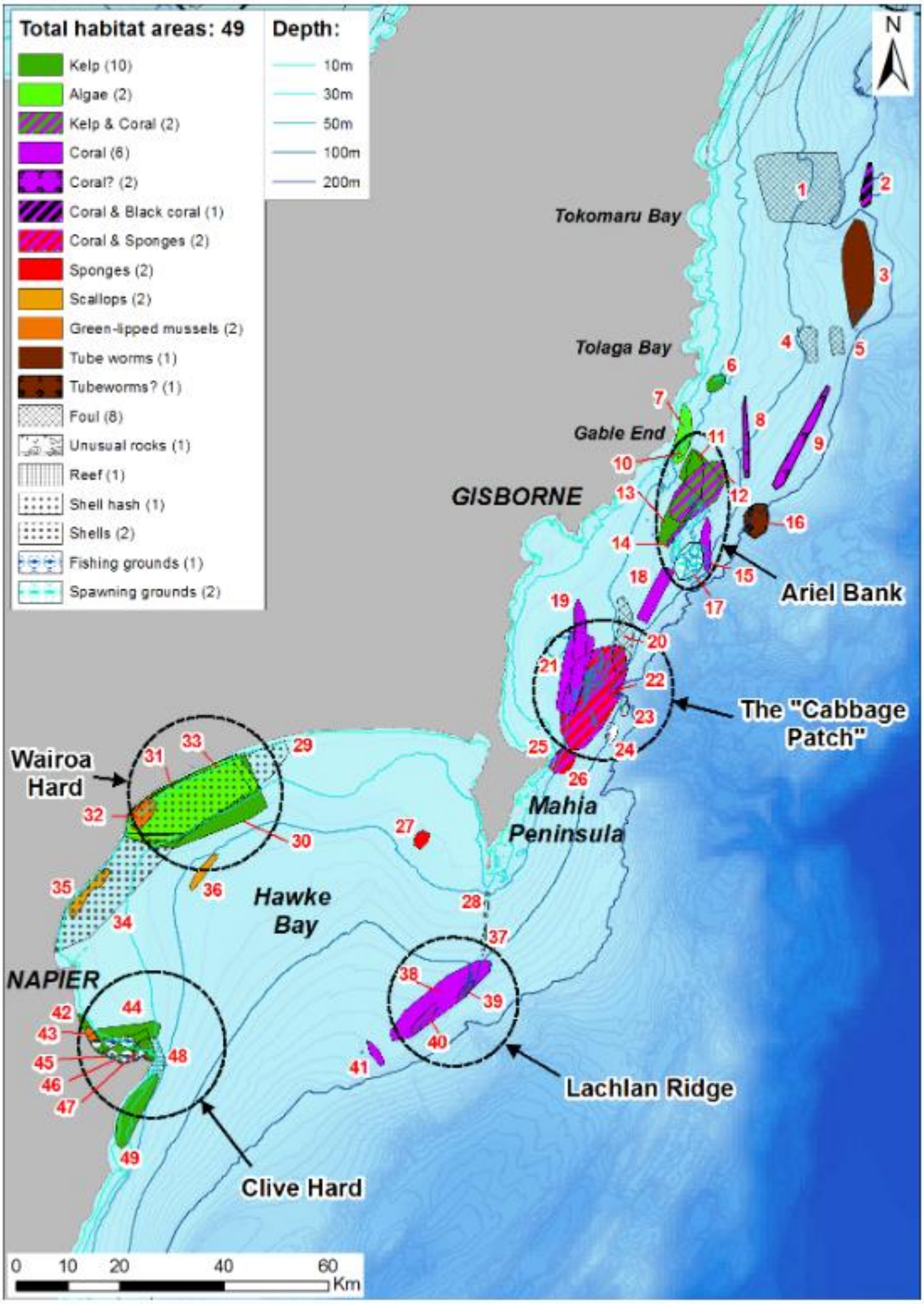
[24] Tairāwhiti Plan is a free mapping application that enables viewing of planning data from the Tairāwhiti Resource Management Plan (https://maps.gdc.govt.nz/H5V2_12/).

Appendix 5. Hawke's Bay / Gisborne region local ecological knowledge (LEK) map from Jones et al. (2016). Map displays knowledge of biogenic marine habitat derived from existing literature and LEK of commercial fishers.



Appendix 6. Kaitawa Estuary observations made by Professor Conrad Pilditch (University of Waikato) following the June 2018 logging residue mobilisation event, 28 August 2018 (Pilditch 2018).

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THE UNIVERSITY OF
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Te Whare Wānanga o Waikato

28 August 2018

Kai ora Alison,

Once again thank you for your hospitality and very warm welcome to Tolaga Bay during my visit in mid-August. I got a lot out of talking with you and the others that I met, it is clear you all share a passionate for improving the environment and are making an active difference. In particular, I found the work you are doing with the local high school on riparian planting inspirational. Below I have briefly summarised a few thoughts based on our conversations and my observations of the Kaitawa Estuary, which I will hope, will be of use to you. If you have any further questions please do not hesitate to ask.

Noho ora mai

Prof Conrad Piditch

Kaitawa Estuary

Below is a summary of my observations of the Kaitawa Estuary from spending several hours walking along the seaward shore of the estuary from the campground toward the Uawa River.

1. The estuary has expansive intertidal flats bisected at low tide by the Kaitawa stream/channel. The sediment is the upper reaches is quite muddy supporting high densities of mud crab (*Austrohelice crassa*) and mud snails (*Amphibola crenata*). At the time of my visit, crabs were not visible on sediment surface, which may have led people to believe their numbers had been reduced by the recent storms. However, crab activity is low when temperatures are cooler and inspection of the burrows revealed many were occupied. The large number of burrows over extensive areas of the intertidal flats indicated a healthy population.
2. In addition to the crab burrows the sediment surface also had other indicators of animal activity (holes, feeding tracks, tubes) most like due to polychaetes (worms) consistent with what I would expect in a sediment of similar composition (mud content) from other estuaries. Without quantitative sampling of the sediment animal community however it is difficult to assess the status overall health of the Kaitawa Estuary.
3. The Kaitawa Estuary does have a fair portion of mud in the sediment, which is expected given the surrounding catchment, soil type, and historical and current land use practices. On my visit I did not see evidence of large amounts of fresh mud deposits (ie related to the June storms) capable of burying and killing off organisms. This is not to stay mud did not enter the estuary, only that it was not obvious because the amounts were low and spread thinly or that water movement within the estuary flushed it back out to sea or concentrated it in other parts not visited. At some stage it would be interesting to core the estuary to try and get some indication of sediment grain size distribution pre-colonisation which would provide some bench mark for how the estuary has altered through time.
4. The most obvious and visible effect of the June storms was the number of large logs stranded in the estuary. Because these logs are untreated they are unlikely to have any long-term effect on the ecology of the estuary apart from excluding sediment dwelling animals from the area directly underneath them. Given time, the logs will decay especially if they are exposed on the sediment surface, bacteria and other organisms will colonise the wood speeding up the decomposition process. The wood is low in nitrogen so its decomposition will not substantially add to the nutrient load in the estuary so is unlikely to promote macroalgal blooms. If removal of logs is warranted (for perhaps aesthetic reasons) I would strongly suggest avoiding the use of heavy machinery which will compress the sediment and likely do more damage than the logs themselves. The logs could be floated off at high tide but this might not be worth the effort.

5. At the upper end of the estuary where the Kaitawa Stream enters the estuary mangroves fringe the channel edge and appear to be colonising the downstream banks (as evidenced by seedings). It would be useful to know (perhaps from aerial photographs) whether this area of mangroves are expanding. Mangroves play an important role in the ecology of northern New Zealand estuaries trapping sediment and providing habitat. However, they can expand rapidly due to feedbacks between increased sediment supply and altered water flow patterns by the mangroves themselves and in some places management has been implement. Given the extensive riparian planting alongside the Kaitawa Stream the sediment supply from this source, in time, will be greatly reduced which should help limit the expansion potential of the mangrove area.
6. Walking down the channel at low tide the bed consisted of the bivalve shells, primarily the cockle *Austrovenus stutchburyi*. It was difficult to assess whether these shells were the result of a recent mortality event or just the natural accumulation over time. The channel did have a fair bit of mud in it which is not great for suspension feeders such as cockles, however when grabbing handfuls of sediment there were good numbers of live adult cockles which is a positive sign. The numbers are likely to decrease as you move up the estuary naturally due to low salinity (freshwater) however if the water/sediment contains too much mud their gills will clog and they will die.

Some suggestions

Knowledge is power and the best way to robustly document change in your estuary is to begin a monitoring program. There is never a bad time to start a monitoring program, only a bad time to stop. I know NIWA has developed community/iwi based monitoring programs, which with little training/cost people can become involved in assessing the ongoing health of their estuary. If you need help connecting with people at NIWA please let me know. Sandy at GDC should also be able to advise on what to monitor and the best way to do it in a scientifically defensible way. There is a lot of information/literature on estuary monitoring programs undertaken by regional councils elsewhere in the country which is freely available. The most important factors are consistency in method (so data from year to year is comparable), ensuring you have adequate sampling effort and measuring things that matter. Some easy things that could be done within the community and/or with school aged children could include:

1. Monitor your shellfish populations. You need to find out first where the cockles and pips are then once a year sample the beds recording density and size. Shellfish are important to the overall health of the estuary because they keep the water clean, a good indicator of health and people like to eat them. They are easy to sample/measure and the data over time will tell you if new shellfish are arriving and growing.

2. I would also consider finding out where the mud snails exist in high densities and carrying out a similar survey of size/density. You can include as many sites as is manageable, the key thing is going back to the same place to sample at the same time of year and using the same method.
3. The logs in the estuary could make an interesting project for the high school children documenting where they are, if they are moving and how long they are taking to break down. The Kaitawa Estuary is small enough that the location of the big logs could be recorded using the GPS in a smart phone and a photograph taken. The locations could be logged in google earth and over time this could be used to visualise the fate the logs answering questions like where do they go? Do they get flushed out of the estuary? Are new ones coming in? This sort of information will be great to have in conversations about their impact, and whether interventions are necessary if the logs continue to arrive clogging up the estuary and altering flow patterns.
4. In conjunction with GDC it would be useful to get accurate bathymetry information (via LiDAR) and have this updated approximately every 10 years to see if the estuary morphology is changing. In conjunction with this, rapid habitat assessment methods developed by Waikato Regional Council (contact Michael Townsend) provide a useful way of quickly assessing areas of mud/sand, major faunal groups/habitats and if done through time will document how things are changing. This obviously require more expertise both in terms of data acquisition and storage/presentation (GIS).