Waikato Regional Council Technical Report Current 2023/04

Impacts of seabed disturbance in the Waikato region

www.waikatoregion.govt.nz
ISSN 2230-4363 (Online)

Prepared by:
Carina Sim-Smith, Shaun Lee and Simon Daniel (Coast and Catchment Ltd)

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

February 2023

Document #: 25653109

Peer reviewed by:

Dr Martin Cryer

Prof Simon Thrush | Date | June 2023

Approved for release by:

Thomas Wilding | Date | June 2023

Disclaimer

This technical report has been prepared for the use of Waikato Regional Council as a reference document and as such does not constitute Council's policy.

Council requests that if excerpts or inferences are drawn from this document for further use by individuals or organisations, due care should be taken to ensure that the appropriate context has been preserved, and is accurately reflected and referenced in any subsequent spoken or written communication.

While Waikato Regional Council has exercised all reasonable skill and care in controlling the contents of this report, Council accepts no liability in contract, tort or otherwise, for any loss, damage, injury or expense (whether direct, indirect or consequential) arising out of the provision of this information or its use by you or any other party.

IMPACTS OF SEABED DISTURBANCE IN THE WAIKATO REGION

Carina Sim-Smith

Shaun Lee

Simon Daniel

March 2022

Client report for Waikato Regional Council

Report Number: 2022-04

Reviewed by: Shane Kelly

CONTENTS

INTRODUCTION

Globally, human activities have disturbed the seabed for thousands of years. Over time, the size and scale of seabed impact has increased with increasing technological developments and dwindling marine resources. The scale and nature of these impacts are not obvious to most people because they lie hidden beneath the waves. This report discusses the main human activities that occur within Waikato's Coastal Marine Area (CMA)[a] that physically impact the subtidal seabed. Stressors that originate from outside of the CMA, but also, and in some cases substantially, impact the seabed, e.g., inputs of sediment, nutrients, and pollutants, and climate change are beyond the scope of this study[b]. The report covers five main activities:

1. Bottom-contact mobile fishing (e.g., trawling, seining and dredging).[c]
2. Sediment dredging and disposal.
3. Coastal developments (e.g., wharves, marinas, and other engineered structures).
4. Shellfish aquaculture.
5. Boat anchoring and swing moorings.

For each activity, the report discusses:

1. The direct and indirect effects on the seabed arising from the activity.
2. The marine species and habitats that are most affected.
3. The spatial scale and intensity of the impact in the Waikato CMA, and the areas that are most affected.
4. The potential for recovery and probable recovery timeframes.

Infographics have been created to illustrate the main impacts of each of the five activities. These are presented at the front of the report to quickly highlight and summarise key effects.

The report focuses on the immediate effects that arise when the activity is conducted. Future, long-term effects from the ongoing presence of a coastal development or marine farm are outside the scope of this report. For example, the effects of constructing a marina on seabed communities and habitats are discussed, but longer-term impacts such as increased biosecurity risk and the accumulation of copper in seabed sediments, are outside the scope of this report.

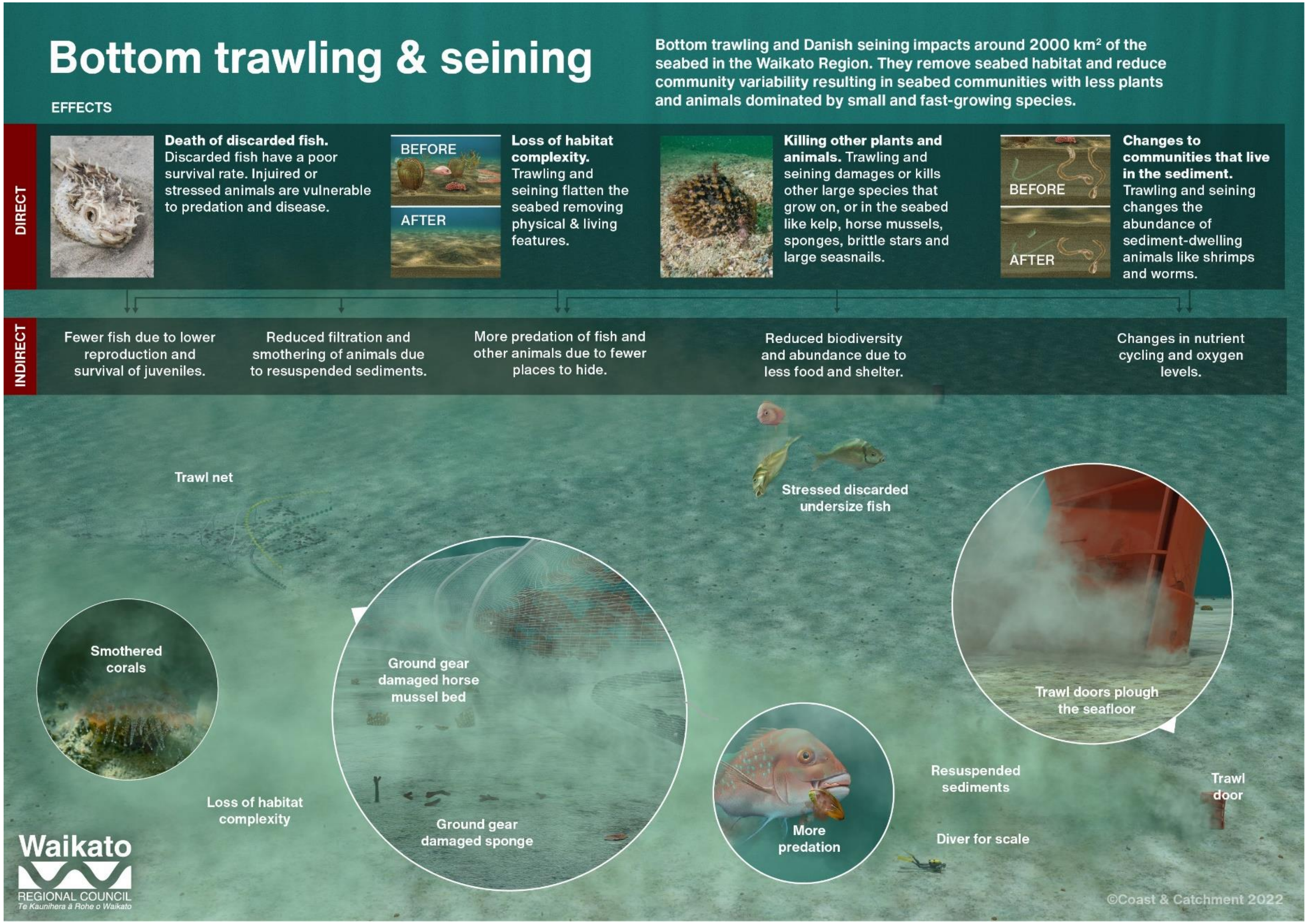
The purpose of the report is to assist Waikato Regional Council's policy development, and therefore information provided is focused on the Waikato Region. However, relevant information from other parts of New Zealand and from around the world are also referenced where applicable.

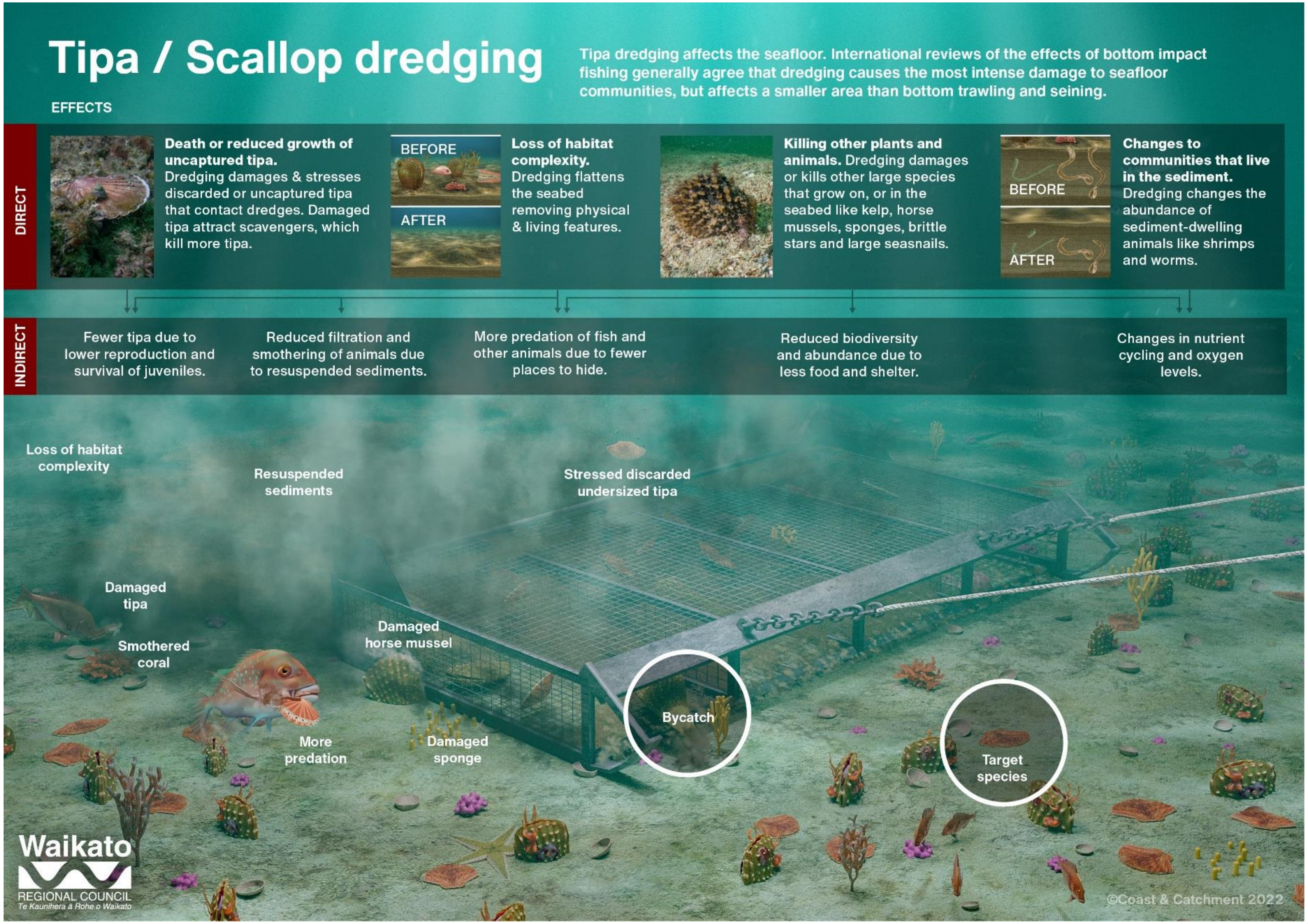
---

[a] This covers the seabed out to 12 nautical miles from the shore.

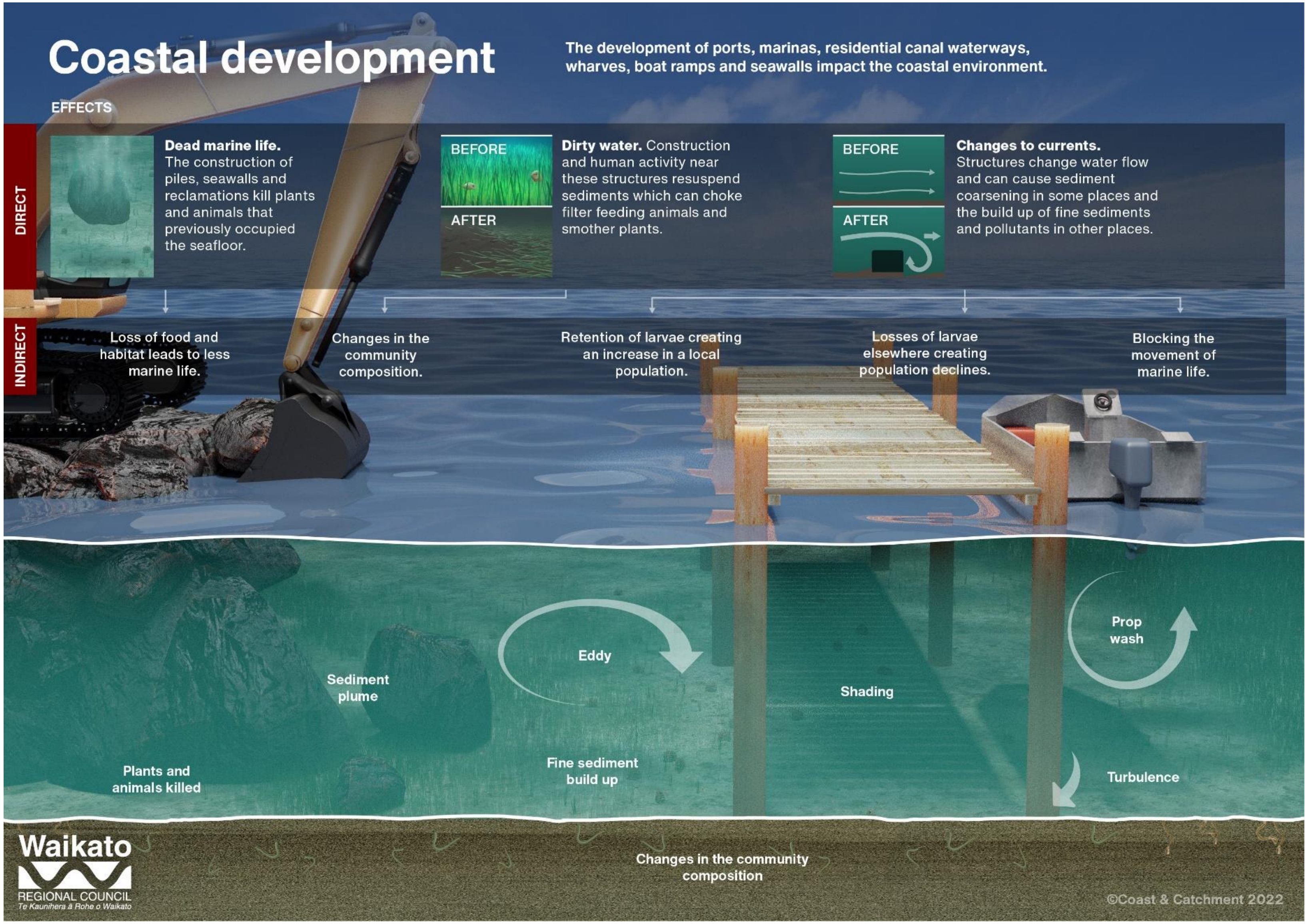
[b] But see the following as an introduction to catchment effects: Coastal Sedimentation: What We Know and the Information Gaps | Waikato Regional Council.

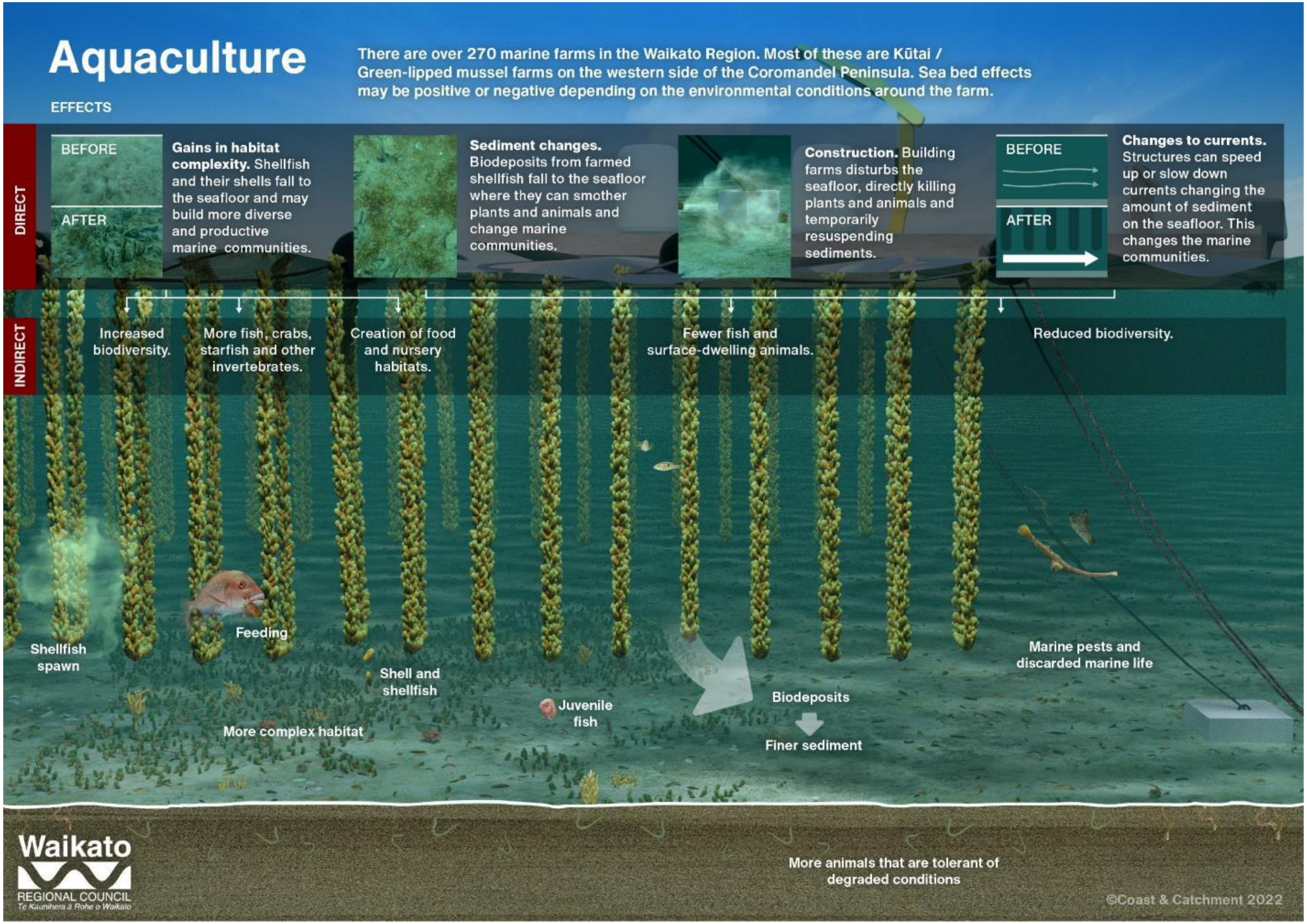
[c] Seabed impacts from static fishing gear e.g., pots and set nets are excluded from this study due to their limited spatial impact and the lack of sufficient information on the topic to provide a robust assessment.


Bottom trawling & seining
Bottom trawling and Danish seining impacts around 2000 km² of the seabed in the Waikato Region. They remove seabed habitat and reduce community variability resulting in seabed communities with less plants and animals dominated by small and fast-growing species.
EFFECTS
DIRECT
Death of discarded fish. Discarded fish have a poor survival rate. Injured or stressed animals are vulnerable to predation and disease.
BEFORE
AFTER
Loss of habitat complexity. Trawling and seining flatten the seabed removing physical & living features.
Killing other plants and animals. Trawling and seining damages or kills other large species that grow on, or in the seabed like kelp, horse mussels, sponges, brittle stars and large seasnails.
BEFORE
AFTER
Changes to communities that live in the sediment. Trawling and seining changes the abundance of sediment-dwelling animals like shrimps and worms.
INDIRECT
Fewer fish due to lower reproduction and survival of juveniles.
Reduced filtration and smothering of animals due to resuspended sediments.
More predation of fish and other animals due to fewer places to hide.
Reduced biodiversity and abundance due to less food and shelter.
Changes in nutrient cycling and oxygen levels.
Trawl net
Stressed discarded undersize fish
Smothered corals
Ground gear damaged horse mussel bed
Trawl doors plough the seafloor
Loss of habitat complexity
Ground gear damaged sponge
More predation
Resuspended sediments
Diver for scale
Trawl door
Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato
©Coast & Catchment 2022

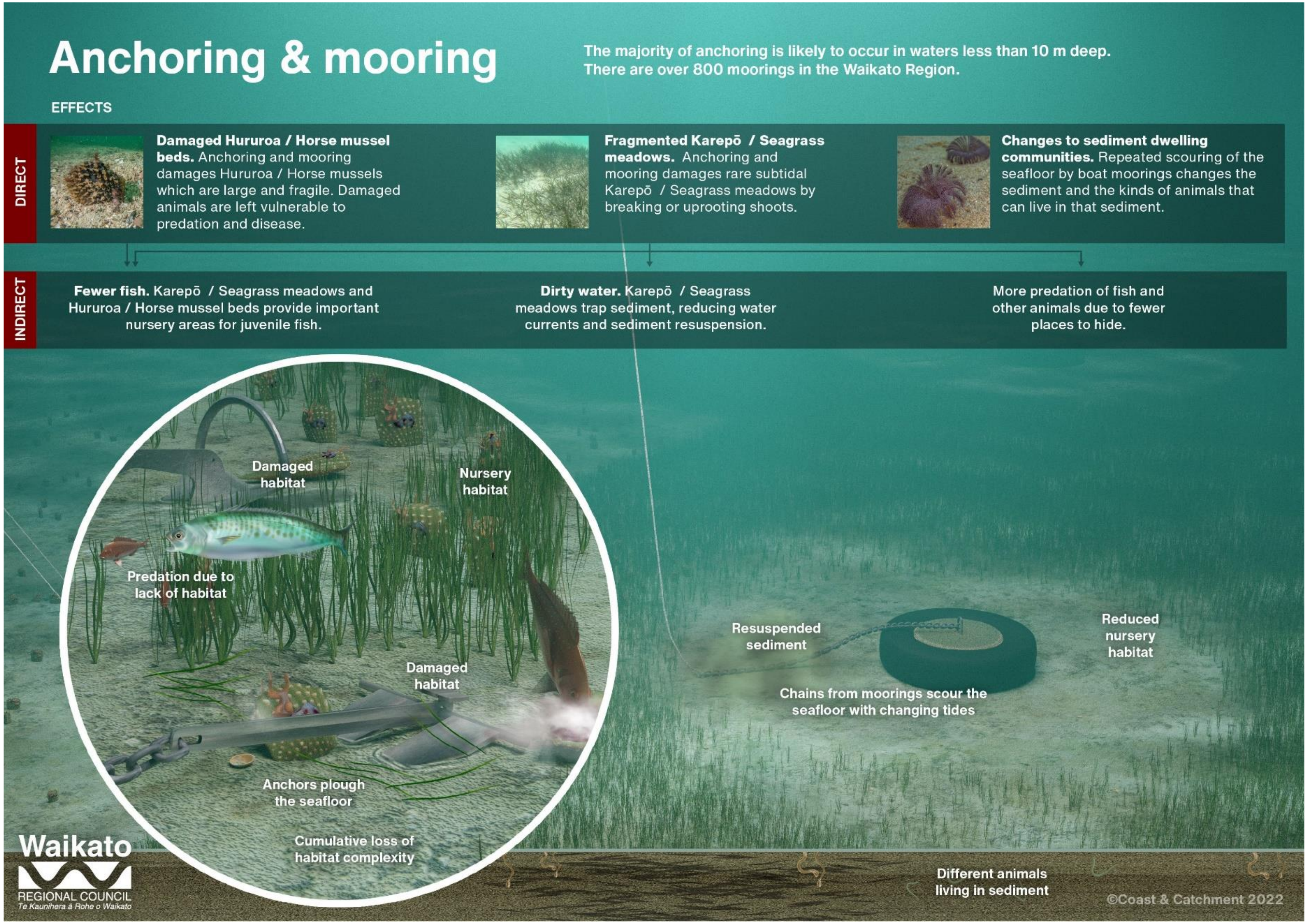

Tipa / Scallop dredging
EFFECTS
Tipa dredging affects the seafloor. International reviews of the effects of bottom impact fishing generally agree that dredging causes the most intense damage to seafloor communities, but affects a smaller area than bottom trawling and seining.
DIRECT
Death or reduced growth of uncaptured tipa. Dredging damages & stresses discarded or uncaptured tipa that contact dredges. Damaged tipa attract scavengers, which kill more tipa.
BEFORE
AFTER
Loss of habitat complexity. Dredging flattens the seabed removing physical & living features.
Killing other plants and animals. Dredging damages or kills other large species that grow on, or in the seabed like kelp, horse mussels, sponges, brittle stars and large seasnails.
BEFORE
AFTER
Changes to communities that live in the sediment. Dredging changes the abundance of sediment-dwelling animals like shrimps and worms.
INDIRECT
Fewer tipa due to lower reproduction and survival of juveniles.
Reduced filtration and smothering of animals due to resuspended sediments.
More predation of fish and other animals due to fewer places to hide.
Reduced biodiversity and abundance due to less food and shelter.
Changes in nutrient cycling and oxygen levels.
Loss of habitat complexity
Resuspended sediments
Stressed discarded undersized tipa
Damaged tipa
Smothered coral
Damaged horse mussel
More predation
Damaged sponge
Bycatch
Target species
Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato
©Coast & Catchment 2022

Sediment dredging and disposal
Dredging is done for development and maintenance of ports, marinas, shipping channels and other coastal developments. Both excavation and disposal impact the seafloor.
EFFECTS
DIRECT
Dead plants and animals. Dredging removes marine life which may die immediately, in transport, or in the new habitat.
BEFORE
AFTER
Burial. Plants and animals buried under disposed material.
Dirty water. Increased turbidity and suspended sediment from sediment plumes made by dredging or disposal. Effects are greater for fine sediment.
BEFORE
AFTER
Changes to the sediment composition.
INDIRECT
Loss of food and habitat leads to less marine life.
Chemical poisoning by released contaminants from polluted locations.
Impaired filter feeding.
Spread of marine pests.
Changes in the community composition.
Dead plants and animals
Poisoning
Discarded marine pests
Impaired feeding
Burial
Loss of habitat complexity
Changes in community composition
Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato
©Coast & Catchment 2022


Coastal development
The development of ports, marinas, residential canal waterways, wharves, boat ramps and seawalls impact the coastal environment.
EFFECTS
DIRECT
Dead marine life. The construction of piles, seawalls and reclamations kill plants and animals that previously occupied the seafloor.
BEFORE
AFTER
Dirty water. Construction and human activity near these structures resuspend sediments which can choke filter feeding animals and smother plants.
BEFORE
AFTER
Changes to currents. Structures change water flow and can cause sediment coarsening in some places and the build up of fine sediments and pollutants in other places.
INDIRECT
Loss of food and habitat leads to less marine life.
Changes in the community composition.
Retention of larvae creating an increase in a local population.
Losses of larvae elsewhere creating population declines.
Blocking the movement of marine life.
Eddy
Prop wash
Sediment plume
Shading
Plants and animals killed
Fine sediment build up
Turbulence
Changes in the community composition
Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato
©Coast & Catchment 2022



Aquaculture
EFFECTS
There are over 270 marine farms in the Waikato Region. Most of these are Kūtai / Green-lipped mussel farms on the western side of the Coromandel Peninsula. Sea bed effects may be positive or negative depending on the environmental conditions around the farm.
DIRECT
BEFORE
AFTER
Gains in habitat complexity. Shellfish and their shells fall to the seafloor and may build more diverse and productive marine communities.
Sediment changes. Biodeposits from farmed shellfish fall to the seafloor where they can smother plants and animals and change marine communities.
Construction. Building farms disturbs the seafloor, directly killing plants and animals and temporarily resuspending sediments.
BEFORE
AFTER
Changes to currents. Structures can speed up or slow down currents changing the amount of sediment on the seafloor. This changes the marine communities.
INDIRECT
Increased biodiversity.
More fish, crabs, starfish and other invertebrates.
Creation of food and nursery habitats.
Fewer fish and surface-dwelling animals.
Reduced biodiversity.
Shellfish spawn
Feeding
Shell and shellfish
More complex habitat
Juvenile fish
Biodeposits
Finer sediment
Marine pests and discarded marine life
More animals that are tolerant of degraded conditions
Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato
©Coast & Catchment 2022


Anchoring & mooring
The majority of anchoring is likely to occur in waters less than 10 m deep.
There are over 800 moorings in the Waikato Region.
EFFECTS
DIRECT
Damaged Hururoa / Horse mussel beds. Anchoring and mooring damages Hururoa / Horse mussels which are large and fragile. Damaged animals are left vulnerable to predation and disease.
Fragmented Karepō / Seagrass meadows. Anchoring and mooring damages rare subtidal Karepō / Seagrass meadows by breaking or uprooting shoots.
Changes to sediment dwelling communities. Repeated scouring of the seafloor by boat moorings changes the sediment and the kinds of animals that can live in that sediment.
INDIRECT
Fewer fish. Karepō / Seagrass meadows and Hururoa / Horse mussel beds provide important nursery areas for juvenile fish.
Dirty water. Karepō / Seagrass meadows trap sediment, reducing water currents and sediment resuspension.
More predation of fish and other animals due to fewer places to hide.
Damaged habitat
Nursery habitat
Predation due to lack of habitat
Damaged habitat
Anchors plough the seafloor
Cumulative loss of habitat complexity
Resuspended sediment
Chains from moorings scour the seafloor with changing tides
Reduced nursery habitat
Different animals living in sediment
Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato
©Coast & Catchment 2022

BOTTOM-CONTACT COMMERCIAL AND RECREATIONAL FISHING

BOTTOM TRAWLING & SEINING

Bottom trawling is the main method used to catch finfish commercially in New Zealand. In northern New Zealand (FMA1 & FMA9), inshore bottom trawling mainly targets snapper/tāmure, tarakihi, gurnard/kumukumu and trevally/araara.[1] There are three main types of bottom-contact nets used commercially in New Zealand:[1,2]

1. **Bottom trawls (otter trawls)**—have an opening comprising multiple floats attached to a headline, and a weighted groundrope or chain at the bottom of the net to maintain contact with the seafloor. Wire ropes (sweeps and bridles) connect the wings (sides) of the net to heavy trawl doors (1–4 m^2 in size, and up to several tonnes in weight),[1,3,4] which keep the mouth of the net open. The net narrows towards either a cod end or a Precision Seafood Modular Harvesting System[d] that traps the fish at the tail end of the net. A typical bottom trawl used in inshore waters in northern New Zealand has a door-to-door distances of 70–200 m (max. = 350 m), and a net width of 10–30 m (max. = 100 m). Trawls are towed at a speed of around 3 kts and cover a typical distance of 12–15 km per tow.[1,5,6]

2. **Bottom pair trawls**—use the same type of net as bottom trawls, but each side of the net is pulled by a separate vessel. Trawl doors are not used because the horizontal opening of the net is maintained by the separation of the vessels. Nets are much larger than those used by single vessel bottom trawls.[7]

3. **Danish seines**—have nets that are similar to bottom trawls but lack the trawl doors. Instead, the wings of the net are attached to very long, weighted ropes that pull the net over the seabed surrounding the fish. An area of several square kilometres may be swept by a single Danish seine shot.[5]

In addition, beam trawls, which have a metal bar across the top of the net to maintain the horizontal opening, and a weighted rope or chain at the bottom, are used for research surveys in New Zealand.[8] Beam trawls are not used commercially in New Zealand.[7]

In New Zealand, most bottom trawling occurs in deep waters. Bottom trawling and Danish seining are prohibited from a large area of the inner Hauraki Gulf and Coromandel Peninsula coastline, and trawling is prohibited within 7.5 km of the west coast of the Waikato Region (Figure 1). However, bottom trawling still occurs in inshore waters, where a much higher percentage of the available seabed is impacted compared to deep waters. Between 2008–2012, about 59% of the seafloor less than 100 m deep in New Zealand was contacted by bottom trawls.[6] In the Waikato Region, the total bottom trawl footprint[e] has been around

---

[d] The traditional cod end is replaced with a cylinder made from PVC that has escape apertures of varying sizes and densities along the cylinder and a solid end.

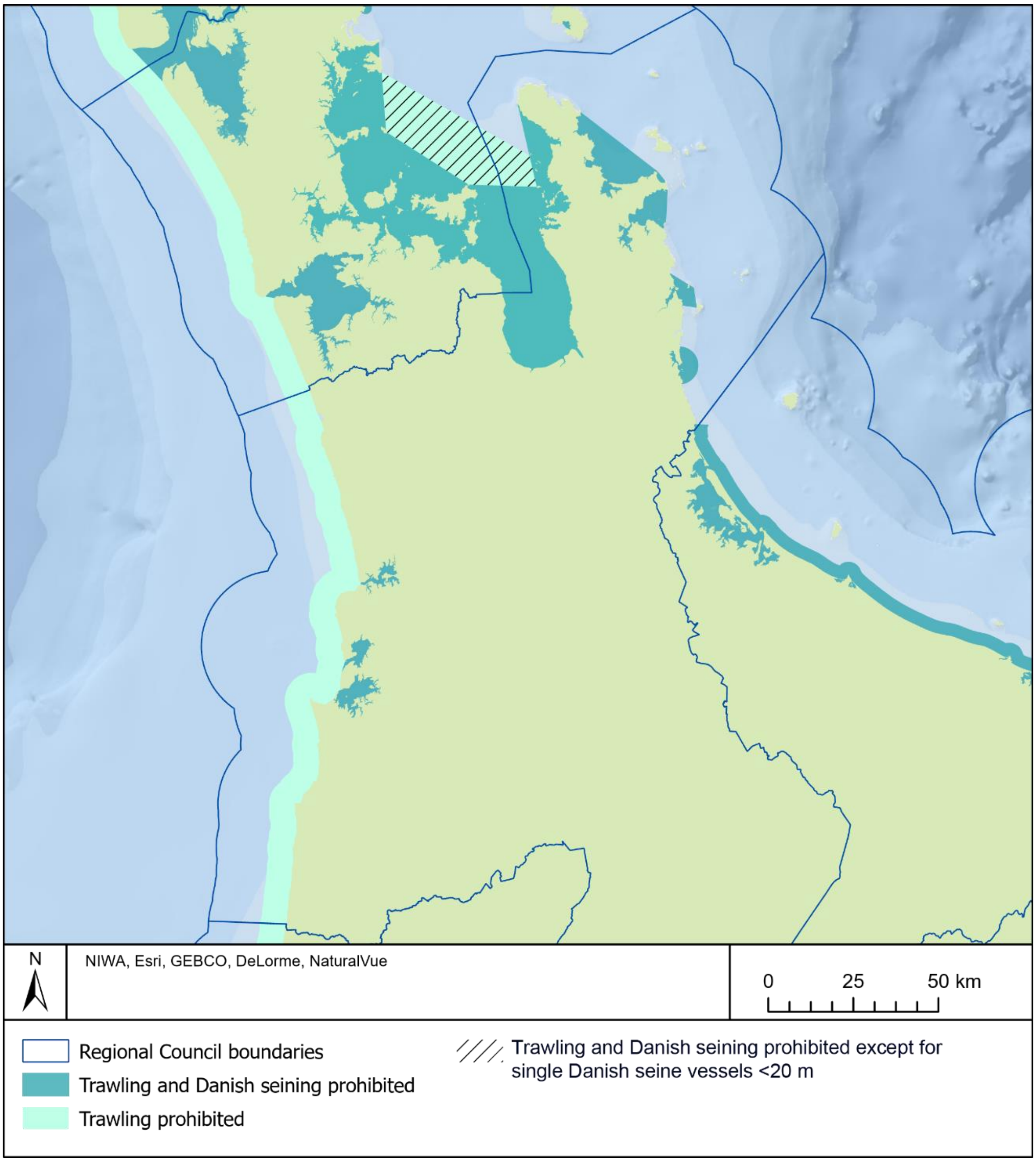
[e] The area of the seafloor estimated to have been contacted by trawl gear.

2000 km^2 per year over the last decade, which is around 27% of the available seabed. This has decreased by 23% from 2,353 km^2 in 2008–09 to 1807 km^2 in 2018–19 (Figure 2 & Figure 3).[9,f]

Danish seining has a smaller footprint than bottom trawling in the Waikato Region. The seining footprint appears to have decreased slightly between 2008–09 and 2018–19 (Figure 4). However, due to the small number of vessels operating in the Waikato Region in recent years, some information on Danish seining in the region is not available. Fishing intensity from seining is also much less than bottom trawling, with around 280 seines conducted in the Waikato Region in 2008–09 compared with around 13,400 bottom trawls conducted in the same fishing year.

[f] Danish seine data was not included in this study.

Figure 1. Areas within Waikato's Coastal Management Area where trawling and Danish seining are prohibited. (Data from the Ministry for Primary Industries (MPI)).[g]



[g] https://catalogue.data.govt.nz/dataset/trawl-prohibitions

Figure 2. Total area of the seabed directly impacted by trawling gear (trawl footprint) in the Waikato Region between 2008–09 and 2018–19. (Data provided by Fisheries NZ from [9] and excludes Danish seining and cells where there are 3 or fewer active fishers or vessels).

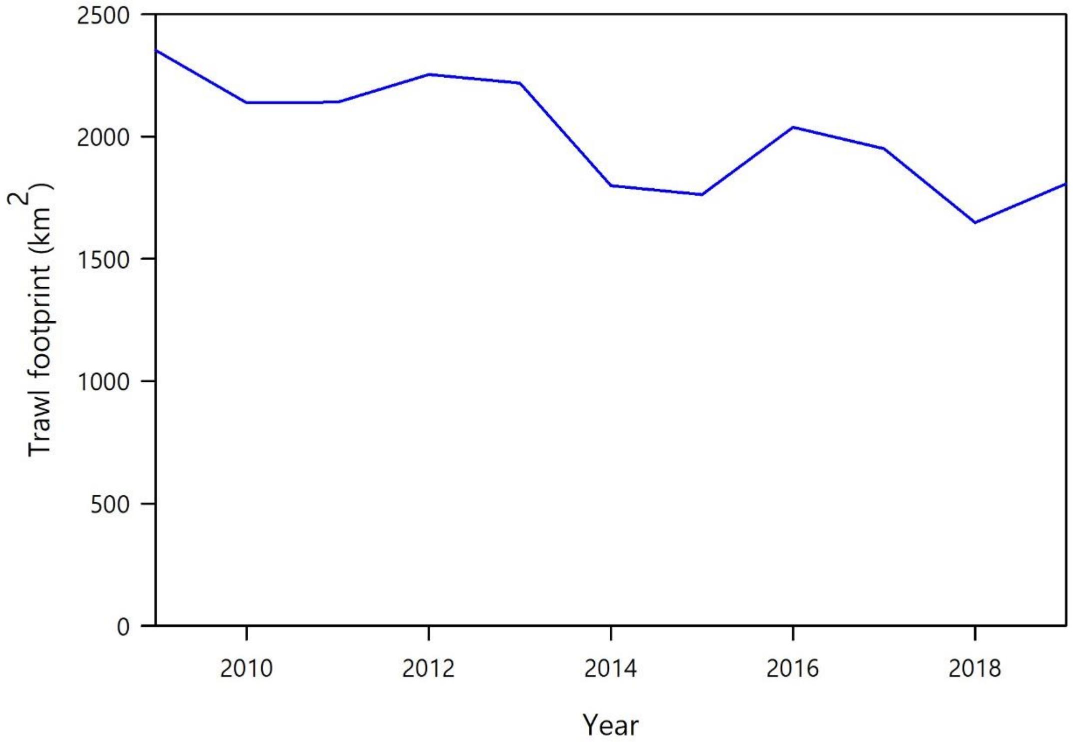


Figure 3. Number of bottom trawls conducted in the Waikato Region in 2008–09 and 2018–19. (Data provided by Fisheries NZ from [9] and excludes cells where there are 3 or fewer active fishers or vessels).

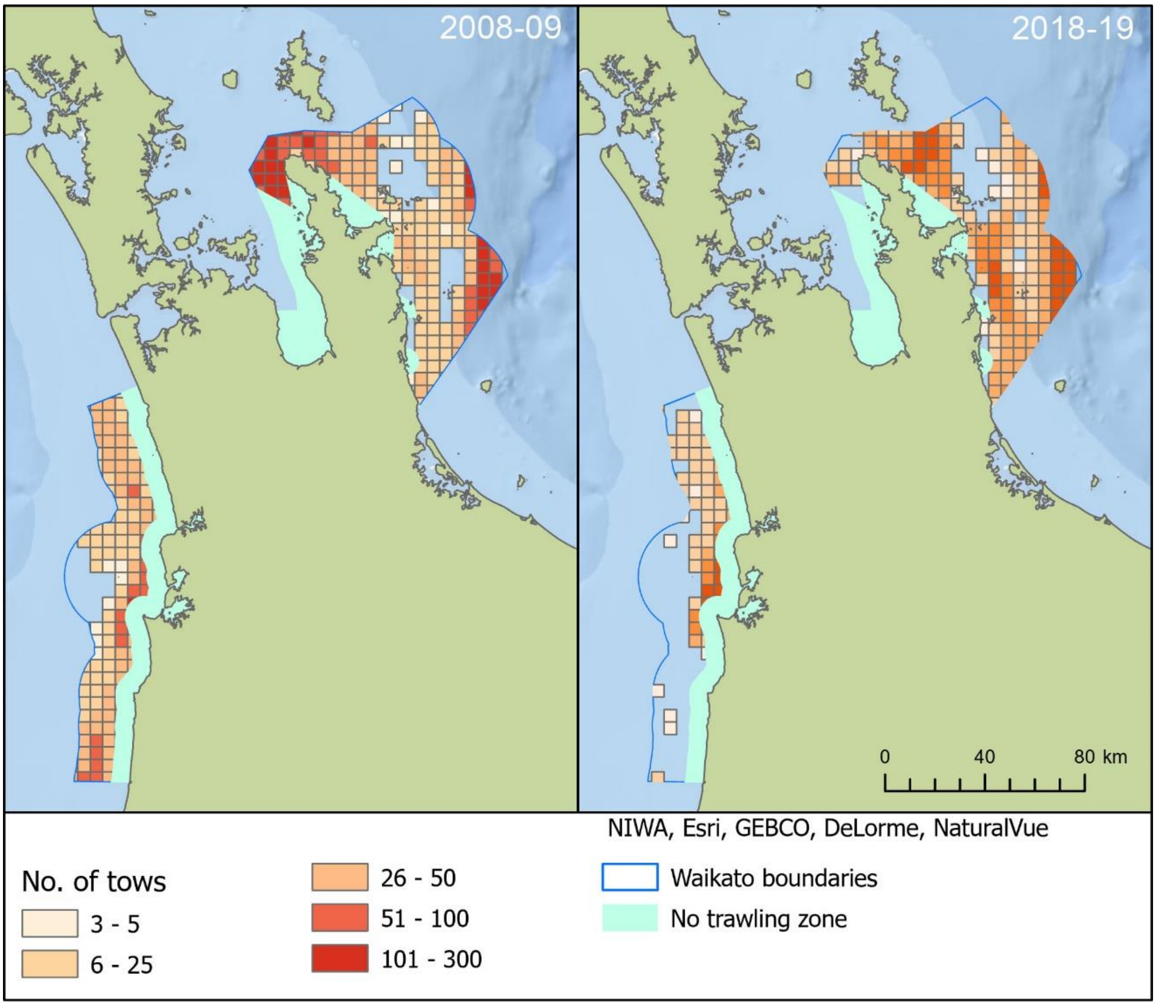
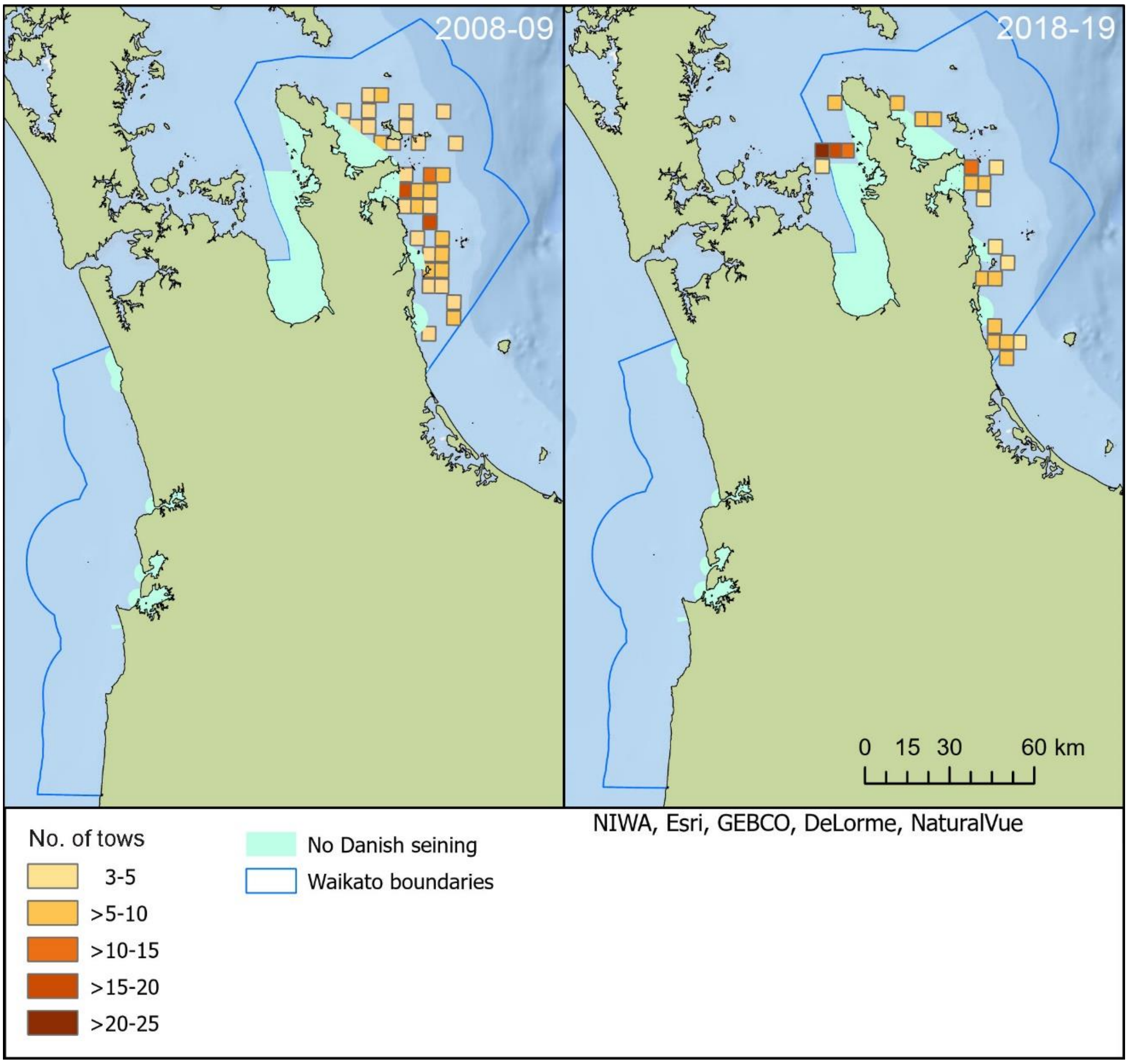


Figure 4. Number of Danish seines conducted in the Waikato Region in 2008–09 and 2018–19. (Data provided by Fisheries NZ and excludes cells where there are 3 or fewer active fishers or vessels).



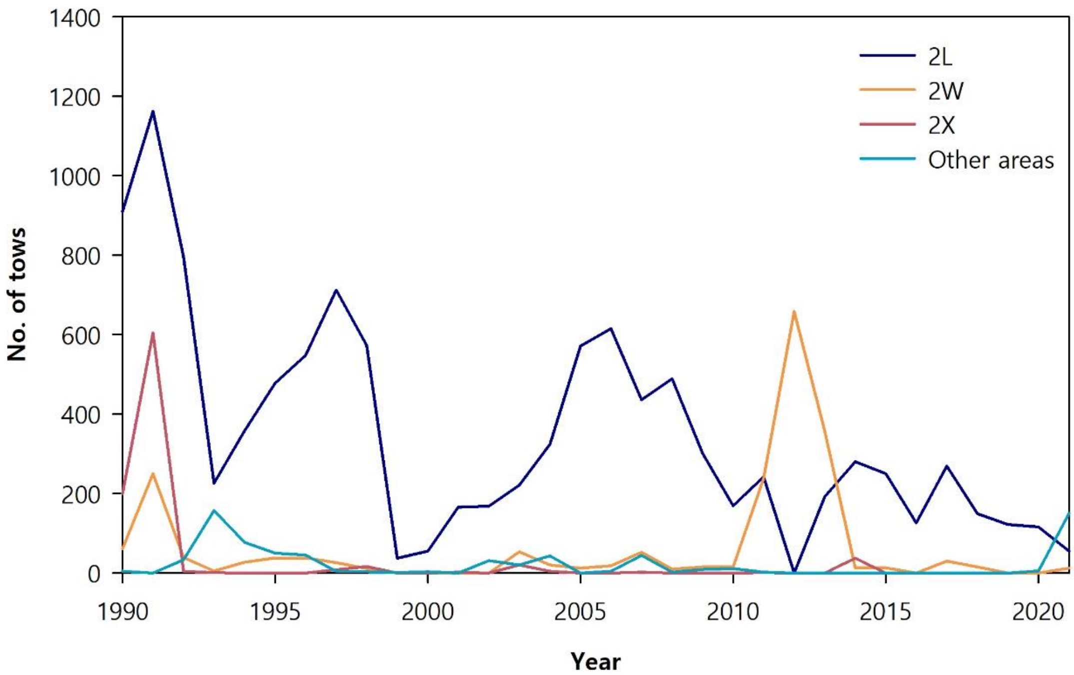
SCALLOP DREDGING

Scallops/tipa (*Pecten novaezelandiae*) are a popular delicacy and are commercially and recreationally harvested in the Waikato Region. Commercial fishing for scallops in the Coromandel started in 1968 and all commercial harvest is collected by dredge.[10] The most common commercial scallop dredge used by the Coromandel fishery is a self-tipping box dredge. These dredges are around 1.5–2.5 m wide, weigh around 150–200 kg, and are basically a three-sided mesh box on runners with a rigid tooth bar fitted to the lower leading edge of the dredge.[10-12] The tooth bar has tines that are spaced about 90 mm apart that dig into the sediment to a depth of about 2–6 cm,[13] dislodging scallops and any other unattached, fragile, or loosely attached animals or seaweed within its path. Dredges are typically towed for 5–30 mins (approximately 400 m to 3 km[h]) depending on the fullness of the dredge.[14]

Historically, scallops were harvested from many discrete beds scattered around the Hauraki Gulf and eastern Coromandel, but over time, both the total commercial landings and areas fished have been reduced due to dwindling populations.[10,15] The total number of tows conducted in commercially dredged areas that are within, or partially within, the Waikato Region has decreased nearly 10-fold over the last 30 years from 1175 tows per year in 1990 to 121 tows in 2020 (no information is available on the length of each tow, which is likely to increase as scallop densities decrease; data provided by Fisheries NZ). Most of the commercial scallop dredging in the Waikato Region has occurred in three areas around the Coromandel Peninsula (2L, 2W and 2X), though in recent years most of the harvest has come from the Mercury Bay area (2L) (Figure 5 & Figure 6).

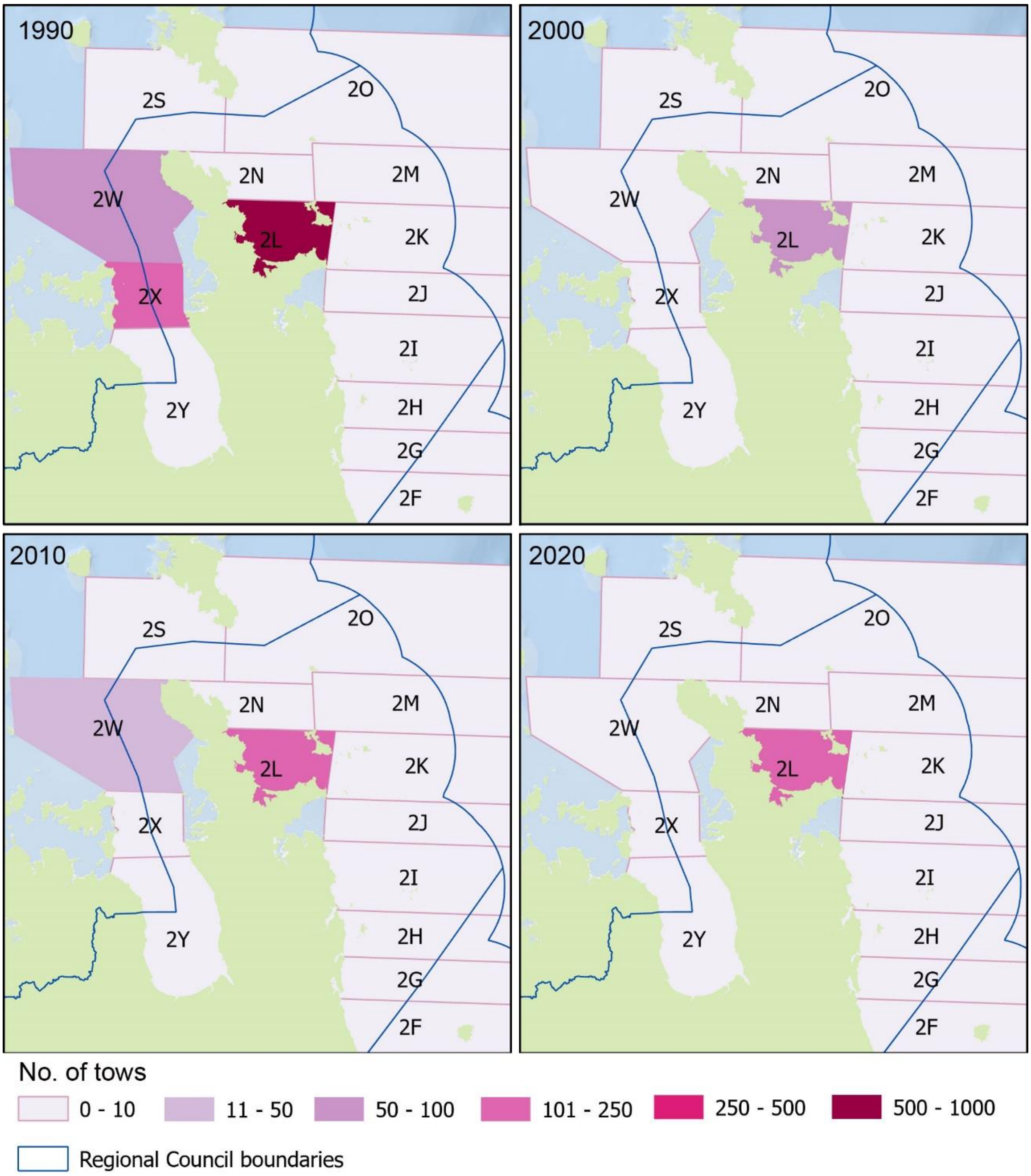
Recreational scallop dredges work on the same principle as commercial dredges but are much smaller—typically 60–70 cm long and less than 10 kg, with either a net or metal cage to catch the scallops. Around 37 tonnes (greenweight) of scallops were estimated to be recreationally harvested from the Coromandel region in 2017–18, which accounted for 60% of the national recreational scallop harvest.[16] However, most recreationally harvested scallops in the Coromandel are collected by divers, with only around 12% of the recreational catch estimated to be collected by dredging.[14]

Figure 5. Number of commercial scallop tows per year between 1990 and 2021 conducted in statistical areas that fall wholly or partially within the Waikato Region (data provided by Fisheries NZ). Note that the length of each tow (and the area impacted) are unknown.



[h] Based on a tow speed of 2.5–3 knots.

Figure 6. Commercial scallop dredging statistical areas that fall wholly or partially within the Waikato Region, and number of scallop tows conducted in each area in 1990, 2000, 2010 and 2020 (data provided by Fisheries NZ).



EFFECTS OF BOTTOM-CONTACT MOBILE FISHING GEAR

The general effects of bottom trawling, Danish seining and scallop dredging are similar, and are therefore discussed together. Bottom trawling and dredging were ranked as the 3rd equal and 7th greatest human-induced threat to marine habitats in New Zealand, respectively.[17]

Scraping and ploughing of the seabed is caused by the entire lower surface of scallop dredges, and the trawl doors, ground ropes, sweeps, lower bridles, and sometimes the cod end of bottom trawls.[7] Trawl doors are particularly damaging due to their weight, and doors may plough deep furrows up to 30 cm deep and 2 m wide, with penetration depth affected by sediment type, gear type, and vessel usage.[3,7,18,19]

International reviews of the benthic effects of fishing generally agree that dredging causes the most intense damage to benthic communities (per area) as dredges tend to penetrate deeper into the sediment than trawls.[20-22] However, while bottom trawling causes less intense damage per area, it affects a substantially larger area than dredging in the Waikato Region.

DIRECT EFFECTS

The scale and type of effects are dependent on the fishing method, gear configuration (e.g., dredge/trawl design, length of towing wire, tow speed, warp: depth ratio etc.), seabed habitats and environmental conditions, and the sensitivity of the species present.[6] Direct effects caused by bottom trawling and dredging include:

1. **Loss of habitat complexity**—trawling and dredging flattens the seabed removing physical features such as ripples, mounds, and accumulations of shell or gravel, and erect marine life such as sponges, horse mussels, bryozoans and seaweed.[13,21-25] Sediment that is resuspended by the trawl or dredge may also bury shell/gravel substrates. This loss of habitat complexity may lead to indirect effects on the animals that use these habitats (see section on Indirect Effects for more detail). The once highly productive Tasman/Golden Bay scallop fishery has been closed since 2016, yet recruitment to this area remains very low, and it is thought that the lack of recovery is due to the degradation of the benthic habitat by sedimentation, dredging/trawling disturbance to the seabed, and over-enrichment of nutrients.[26-28]

2. **Mortality or reduced growth of discarded target animals**—bottom fishing affects discarded or uncaptured animals that encounter the trawl or dredge. Undersized target fish that are landed by commercial trawling in New Zealand are currently returned to the sea (alive or dead).[i] Discarded fish captured by bottom trawls with a traditional cod end have a poor survival rate,[29] though around 50% of commercial fishing vessels in north-eastern New Zealand (FMA1) now use the Precision Seafood Modular Harvesting System,[1] which has been shown to have a higher survival rate for discarded snapper.[30]

   Scallops may be damaged by the dredge or stressed by being removed from the water, which increases their mortality rate.[22,31] Instantaneous mortality for damaged scallops (undersized or not captured) in the Coromandel fishery was estimated to be up to 18% depending on the size of the scallop.[32] Injured scallops that are not killed immediately attract predators and scavengers, which increases losses.[31,33-35] The abundance of predatory crabs and fish has been found to markedly increase 15 hours after dredging.[35] Overall, estimated total scallop mortality from the Coromandel fishery one month after dredging was between 14 and 52% for undersized, discarded scallops, and between 1 and 25% for uncaptured scallops that were hit by the box dredge.[36]

   The growth of animals may also be reduced as energy is diverted towards recovery from stress and injury.[22] For example, the growth rate of scallops captured or hit by a dredge

[i] A bill is currently under consideration at parliament to prohibit the discard of undersized fish (https://www.mpi.govt.nz/dmsdocument/45763-Fisheries-Amendment-Bill-Strengthening-fishing-rules-and-policies-landings-and-discards-Cabinet-paper).

were found to grow 33–66% slower in the month after capture, compared to undisturbed scallops.[12,36]

3. **Mortality of other animals and plants growing on the seabed**—trawling and dredging damages or kills other large species that grow on, or in the seabed, with the most vulnerable species being those that grow on top of the seabed (e.g., horse mussels, bryozoans, sponges and tube-building polychaetes), fragile species (e.g., sea urchins, anemones and sea cucumbers), species that may get smothered (e.g., other bivalves and rhodoliths) and species that become more vulnerable to predation after dredging (e.g., brittle stars, large gastropods and hermit crabs).[24,37-43]

The main by-catch caught by dredges during a 2009 scallop survey of the key Coromandel fishing areas were seaweed (11% of catch volume), starfish (*Astropecten* sp., *Coscinasterias* sp. and *Luidia* sp.) (4%), and other live bivalves (4%), which included large dog cockles/kuhakuha (*Glycymeris laticostata*), horse mussels/hururoa (*Atrina zelandica*) and the clam *Tawera* sp. (Figure 7).[44] Starfish and seaweed were caught in over 85% of the tows. Various sponges were captured in 57% of the tows, but only made up 0.4% of the catch volume. Horse mussels were only caught in 2% of the tows and accounted for 0.3% of the total catch.[44] Of these by-catch species, horse mussels and sponges are particularly vulnerable to dredging.[15]

No information is available on the seabed species caught as by-catch by the New Zealand inshore fisheries.[45] Common species caught as by-catch by snapper research trawls in the Hauraki Gulf include sponges (particularly *Callyspongia ramosa* and *Suberites affinis*), starfish (*Astropecten* sp. and *Coscinasterias* sp.) and fan worms (Sabellidae).[46]

Current by-catch species and amounts do not necessarily reflect historical by-catch, as the current abundance of some species is significantly lower than historic levels, particularly in frequently dredged areas. Historically, horse mussels were widespread throughout the Hauraki Gulf, particularly around northwest Coromandel and south of Great Mercury Island.[47,48] Horse mussels were likely to have comprised a much higher percentage of by-catch in the past, however, their large, fragile shells protrude above the seabed, making them particularly vulnerable to dredges and trawls. A study on a closely-related species, the fan mussel *Atrina fragilis*, found that scallop dredging reduced their average abundance by 87%.[35] Similarly, studies conducted in the Hauraki Gulf and Tasman and Golden Bays found that the abundance of erect animals, including horse mussels, decreased with increasing bottom-fishing intensity.[37,41]

Sponges are commonly found in habitats that are dredged for scallops, and are one of the most vulnerable species to trawling and dredging.[44,49] For example, effects on sponges were demonstrated in a Mediterranean study, which found that sponge abundance (-54%) and the number of sponge species (-30%) decreased substantially after an area closed to bottom-contact fishing for three years was reopened for scallop dredging.[50] Similar comparisons of fished and non-fished areas have found higher abundances of sponges, bryozoans and other fragile erect animals in the non-fished areas.[49,51] Many sponges are slow-growing, particularly those found in deeper waters, which prevents recovery between fishing events.[52]

Rhodoliths (maerl) are slow-growing, unattached coralline algae that support highly diverse seabed communities. Very few rhodolith beds are known to occur in the Waikato Region—a relatively large bed has been recorded north of Ohinau Island and small beds have been recorded west of Great Mercury Island.[53] Trawling and dredging overturns and buries rhodoliths. Dredging in previously unfished rhodolith beds in Scotland was found to kill more than 70% of the rhodoliths present, with no sign of recovery after 4 years.[24]

Large, slow-moving animals are also vulnerable to trawling and dredging. A study conducted in the Irish Sea found that a high proportion of uncaptured and by-catch animals were immediately damaged or killed by scallop dredges, with the most affected species being starfish (*Luidia ciliaris* (-74%) and *Astropecten irregularis* (-33%)), crabs (*Cancer pagurus* (-63%) and *Liocarcinus* spp. (-50%)), and sea urchins (*Echinus esculentus* (-47%)).[38] Similarly, a study on the effects of trawling in 200–600 m deep waters in the deeper portion of Waikato's CMA found that trawling activity was negatively associated with invertebrate species richness and diversity, with the abundance of urchins (*Ogmocidaris benhami* and *Phormosoma bursarium*), basket stars (*Gorgonocephalus dolichodactylus*), gastropods (*Penion sulcatus* and *Alcithoe lutea*) and hermit crabs (*Paguristes barbatus*) negatively correlated to trawling activity.[43]

4. **Changes in sediment-dwelling communities**—trawling and dredging can also affect small, sediment-dwelling animals (infauna) that are not likely to be crushed or captured. A short-term study conducted in Coromandel found that dredging caused significant reductions in the abundance of many common species including small crustaceans (phoxocephalids, tanaid shrimps, and amphipods) and worms (polychaetes), both 2 hours and 3 months after dredging. Effects were greater in the site that was not commercially dredged (Hahei), compared to the site that was regularly commercially dredged (Opito Bay), which was probably because Opito Bay had a community that was already adapted to dredge disturbance. Some polychaete and bivalve species showed a significant increase in abundance 3 months after dredging, which may be due to preferential settlement in the dredged area, or attraction of scavengers/predators.[31]

   Similarly, higher trawling and dredging intensity in Golden and Tasman Bays was found to be correlated to a decreasing number of sediment-dwelling species, with shellfish (*Corbula zelandica, Theora lubrica, Ennucula strangei* and *Nozeba emarginata*), tube-building polychaete worms and hermit crabs the most affected species.[37]

   These changes in community are likely due to changes in habitat, increased exposure to predators, and suspension and transport away from the area by water currents.[13,31] Fine nets placed behind scallop dredges have demonstrated that a large percentage of sediment-dwelling animals are dislodged from the sediment by the dredges and briefly suspended in the water column.[13]

Overall, trawling and scallop dredging removes habitat variability and makes seabed communities more similar with lower species abundances. Trawling and dredging also causes a community shift from one that is dominated by erect, slow-growing and/or fragile species, to one dominated by small, encrusting and fast-growing species.[25,41,43,54,55]

Figure 7. Examples of by-catch caught by scallop dredging within the Coromandel fishery area. A) Horse mussels. B) Dog cockles. Note that these images are from random stratified surveys[15] so may not represent the catch of the commercial fishery, and that many of the shells pictured did not contain live animals (photos reproduced with permission from MPI).

INDIRECT EFFECTS

Bottom trawling and dredging are also likely to cause a range of indirect effects, though these effects are not well-understood. Likely indirect effects include:

1. **Reduction in reproductive success of the target animal**—all fishing methods reduce reproductive success by removing large numbers of breeding individuals from a population. However, this impact is exacerbated for animals such as scallops that have no, or limited mobility and require dense aggregations to achieve high fertilisation rates during spawning.[22] Commercial dredging targets dense scallop aggregations, causing a disproportionally high reduction in reproductive success.

2. **Reduction in shellfish and fish recruitment due to loss of biogenic habitat**—biogenic habitats are habitats that are created by plants and animals such as mussel reefs, seagrass/karepō beds and sponge gardens. Biogenic habitats provide important nursery areas for juvenile fish such as snapper and blue cod, and the loss of these habitats is likely to reduce the subsequent fish population.[56-58] For example, in Australia closure of an area to bottom trawling for 5 years was found to increase the amount of erect animals present and the catch rate of two snapper species, compared to a nearby trawled area.[59]

   Scallops and mussels prefer to settle on plants and animals with fine, highly branched growth forms such as hydroids and bryozoans.[22,60] The removal of such features by dredges has been shown to reduce the recruitment success and survival of juvenile scallops.[61]

3. **Reduced diversity**—areas of high habitat complexity and biogenic habitat tend to have seabed communities with greater diversity (number of different species) and abundance (number of animals),[58,62-65] though some disturbed environments can have very high abundances of a few species. Smothering of gravel/shell by disturbed or resuspended sediment may prevent colonisation by animals that require a hard substrate. [24,51] Loss of these habitats results in lower fish and invertebrate diversity and abundance, which leads to cascading changes in community structure and abundance up the food chain.[66]

4. **Increased predation**—Trawling and dredging damages animals, which attracts predators and scavengers to the area.[35,67,68] For example, one study found that average abundances of predatory fish increased by 1.6 times shortly after trawling, and fish in the trawled area were found to consume over twice the normal amount of food as fish in nearby untrawled areas.[67]

   Trawling and dredging also removes habitat complexity, reducing available predator refuge areas for juvenile fish and invertebrates. Juvenile fish and crustaceans have been shown to take refuge from predators in complex and biogenic habitats, and predation rates have been found to be lower in those habitats compared to areas of bare sediment.[69-73] For example, mortality rates of tethered juvenile scallops (15–30 mm) in Kawau Bay and Tasman Bay were found to be up to four times higher (15% vs 59%) in areas that had been commercially dredged and contained few biological features, than undredged areas that contained higher numbers of sponges, horse mussels and ascidians. Most of the mortality was attributed to predation by starfish and gastropods, which mainly rely on their sense of smell to detect prey. It is unclear how the presence of biological features reduces predation, but it may be due to alteration of boundary flows that transport chemical cues.[23]

5. **Resuspension of sediments and release of contaminants**—dredging and trawling, particularly trawl doors, disturbs and resuspends sediments creating a plume behind the fishing gear. The size and duration of this plume depends on the gear used, current speeds, depth and substrate type, with fine, muddy sediments staying in suspension for longer. Scallop dredging in sandy sediments in Port Philip Bay, Australia, was found to increase the suspended sediment concentration by 2–3 times immediately behind the dredge, with the concentrations returning to background levels within 30 mins. [74,75] In contrast, the effects of trawling in muddy sediment in a shallow sheltered area of the Baltic Sea were much larger. A 12 m inshore vessel towing a bottom trawling net with 230 kg doors was found to create a 36 m wide track and resuspend 9.5 t of sediment per km towed[j]. This suspended sediment remained in the water column for 3–4 days and spread more than 1 km away from the trawl track.[19] Resuspended sediments may smother fauna living on the seabed or negatively affect the feeding and filtration abilities of animals,[67,76] however these effects depend on the species present and their tolerance of high suspended sediment concentrations.

   Flow-on effects on marine life are also poorly understood due to multiple complex relationships between marine life and their environment. For example, the release of nutrients from the sediment may increase growth of phytoplankton and seaweeds, but this benefit may be counteracted by the increase in turbidity that decreases light availability required for their growth.[67]

6. **Alteration to natural biogeochemical processes**—bottom trawling and dredging have been shown to:

   a. Disrupt the natural exchange of nutrients, gases and particulates between the seabed and the water—physical disturbance of sediments by trawls and dredges also releases nutrients, gases and particulates that are contained within the seabed. A Baltic Sea study found that trawling resulted in the short-term (hours) release of a large pulse of dissolved nitrogen, phosphorus, manganese, and methane, within a few hundred metres of the track. Two days after trawling, the movement of nutrients and oxygen between the sediment and bottom water had not completely returned to normal.[19] At present, the implications of the release of seabed nutrients and particulates are poorly understood. It is not known whether trawling and dredging simply accelerates the release of nutrients from the sediment that would have gradually occurred naturally, or whether it causes a long-term, step change.[19,77-79] The magnitude of impact is likely to be dependent on the frequency of the impact, the organisms present, and the existing biogeochemistry of the seabed. Effects of low disturbance frequencies were found to be similar to that of natural bioturbators[k] but at high disturbance frequencies, disruptions were too frequent to allow the system to reach an equilibrium.[79]

---

[j] This is equal to a resuspension rate of 0.25 kg/m^2 across the whole trawl track.

[k] Burrowing animals that mix and oxygenate the sediment.

b. Reduce the ecosystem services provided by benthic species—erect and sediment-dwelling species provide a range of natural processes (ecosystem services) such as stabilising the sediment, bioturbation, filter feeding to convert suspended nutrients and plankton to seabed deposits, nutrient cycling, and alteration of the boundary flow conditions near the seabed.[18,66] Bottom trawling and dredging have been found to decrease the abundance of benthic species that provide ecosystem services.[37,41,80] For example, densities of heart urchins (*Echinocardium cordatum*), which are one of the most vulnerable species to trawling and dredging, were found to be positively correlated to nitrogen[l] release from the seafloor.[81] Nitrogen is important for the growth of plankton, which forms the basis of the food chain, but the implications of reduced nitrogen release by affected benthic species will depend on the disturbance frequency and whether the affected community is nitrogen-limited. The loss of species that provide these ecosystem services may have important flow-on effects on the marine environment, but further research is required on the scale of these impacts and their potential significance.

c. Change the remineralisation[m] rate of organic carbon from the seabed—bottom trawling and dredging may affect the remineralistion rate of organic carbon stored in the seabed through increased sediment resuspension, increased mixing and oxygenation of the sediment, reduced bioturbation, reduced respiration of animals, and increased primary production from resuspended nutrients. A recent review of the impacts of bottom-trawling on carbon storage found mixed results: 61% of 49 studies found no significant effect; 29% of studies reported reduced organic carbon storage; and, 10% of studies reported increased organic carbon storage.[82] More research is required to improve our understanding on the impacts of bottom-contact fishing on the carbon cycle.

In general, the size of the fishing effect depends on several factors, with impacts generally increasing with:

- increasing substrate hardness, with the least impact on sandy and muddy sediments and the highest impact on reef, gravel and biogenic habitats;[20,21,24,40]
- increasing fishing intensity (in previously trawled areas),[37,83] though the greatest impact on biogenic habitats occurs on the first tow through a pristine area;[24,52]
- increasing penetration depth of fishing gear;[84]
- decreasing waves and currents and storm disturbances due to the communities present being less adapted to physical disturbance;[40,83,85,86]
- higher abundances of slow-growing, emergent and fragile animals, such as rhodoliths, sponges and bryozoans;[24]

---

[l] Ammoniacal nitrogen, NH_4-N.

[m] The breakdown of organic carbon by bacteria and algae into dissolved inorganic carbon.

- increasing distance between the impacted area and reproductive populations of the species affected.[85]

RECOVERY

Complete recovery of a community is difficult to assess as there are no pristine reference areas that provide a baseline. Recovery times also depend on the factors listed above that influence the size of the effect, and there is a very wide range in estimated times. A global meta-analysis of bottom-contact fishing studies that covered a gradient of fishing impact found that the median recovery time for sedimentary seabed communities to return to between 50–95% of the theoretical unfished abundance (assuming logistic population growth) was between 1.9 and 6.4 years.[87] Recovery time increased with increasing percentages of gravel in the substrate. Note that the above recovery times excluded biogenic habitats, and only measured recovery of total community biomass or abundance. Recovery of individual species can be highly variable depending on their life history characteristics. Small mobile fauna such as polychaetes and malacostracans can recover to unimpacted levels within 1 year, while large, erect, and slow-growing species such as sponges and bryozoans are likely to take more than 10 years to recover.[15,59,84,85] Therefore, relatively large gains in recovery may be made initially due to the recovery of small, fast growing species, but there may be a long ‘tail’ period when the community is still recovering. For example, even after 17 years of fishing closure around the Isle of Man, UK, several species were found to be still increasing in abundance.[88]

If an area is impacted more frequently than the recovery time, then the community will remain in a permanently altered state.[66] Furthermore, if fishing results in the decrease of a species or population to below the minimum density required for reproduction, or dramatically changes the seabed substrate, then the original benthic communities may never recover. There is evidence that rhodolith and soft-sediment mussel beds that have been impacted by dredging are unable to recover in human-relevant time scales.[22,24,89] For example, soft-sediment mussel beds used to cover >500 km^2 of the Firth of Thames and inner Hauraki Gulf, but were dredged to near-extinction in the first half of the 20th century.[89] Despite the lack of commercial dredging or bottom-trawling in much of this area for decades, soft sediment mussel beds have never returned. Fishing impacts were exacerbated by the very high levels of terrestrial sediment inputs into the Firth, which is likely to be a major factor in the lack of recovery of soft-sediment mussel beds. The dense mussel beds and attached biogenic habitat that would have provided a favourable settlement surface for mussel spat have been replaced by a deep layer of soft, muddy sediment that is unfavourable for mussel settlement and survival, resulting in a fundamental shift in the habitat in the Firth and inner Gulf.

SEDIMENT DREDGING AND DISPOSAL

DREDGING

Dredging of the seabed is often required for the construction of coastal developments such as ports, marinas and wharves, and to allow and maintain ship access to these developments. In shallow waters (<30 m) that are affected by wave action and land sedimentation, repeated dredging is typically required to maintain the desired depths, whereas, in deeper waters dredged areas are likely to be relatively stable features.[90,91]

Dredgers are either mechanical (grabs and excavators) or hydraulic (via suction). The four main types of dredgers used are:

1. **Backhoe dredgers**—have an open bucket at the end of the crane arm that scoops up material and places it in a barge for transport off site. Backhoe dredges produce relatively high turbidity as sediment is resuspended when the dredge hits the seabed and lost as the bucket is pulled through the water column and drained above the surface.[92]

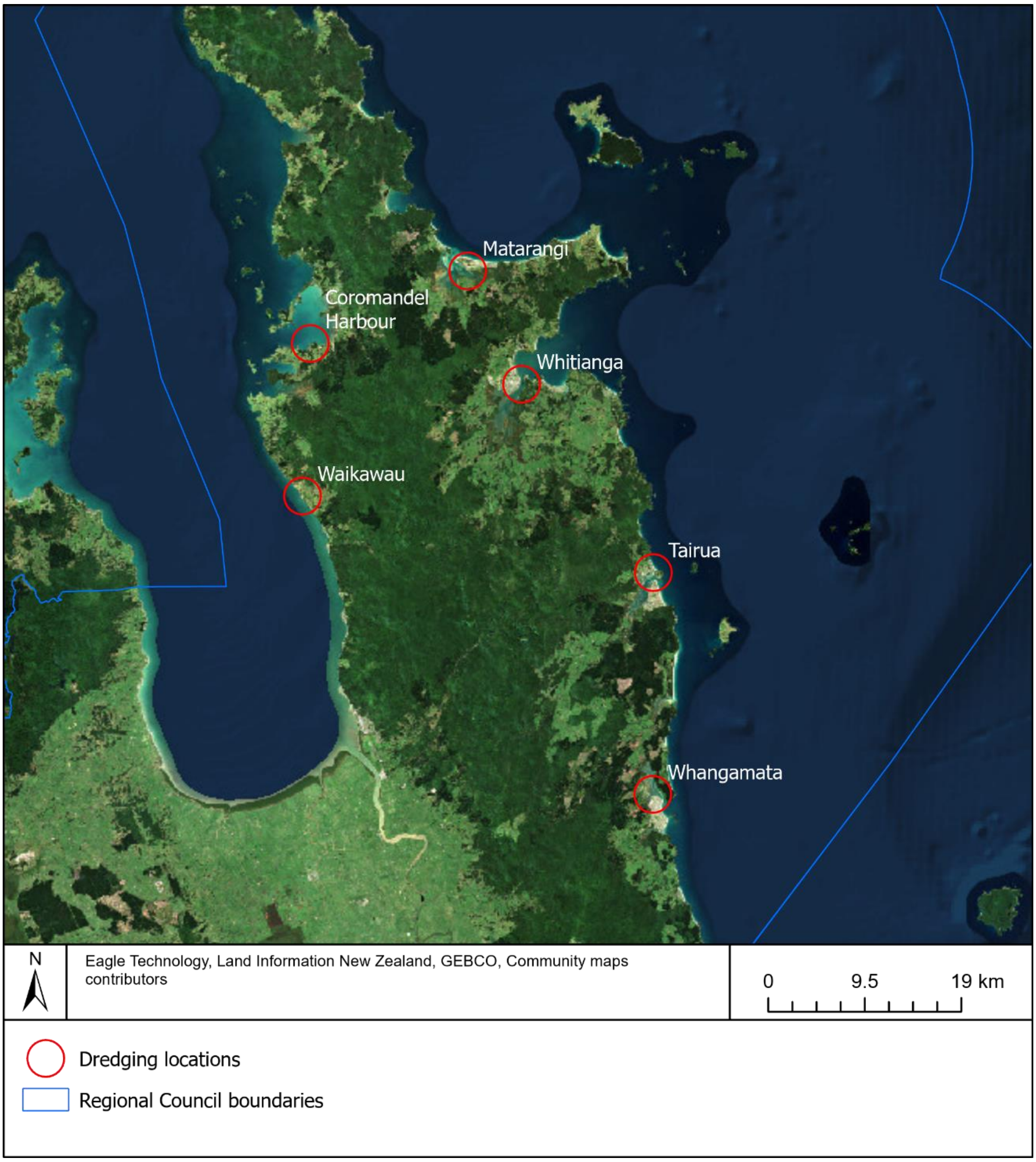
2. **Grab dredgers**—have a closing clam shell bucket at the end of the crane arm that closed around the sediment. They can produced relatively high turbidity, but specialised grabs can be used that generate less suspended sediment than other types of dredgers.[92]

3. **Cutter suction dredgers**—have a rotating cutter at the end of a suction line that is suitable for cutting a wide range of materials. The basket shaped cutter cuts the material creating a cloud of dredged material in the water, which is then sucked up the line to a barge. Suction is not 100% efficient and up to 5% of all disturbed solids are not sucked up.[93] Overflow from the barge can also generate high levels of turbidity.[92]

4. **Trailing suction hopper dredgers**—are suitable for relatively soft, unconsolidated material. The dredge is pulled along the seabed by a vessel and the drag head loosens the sediment, which is sucked up the pipe along with water and pumped into a hopper where the water overflows out the top. The dredge generates relatively low levels of turbidity, but suspended sediment in the overflow from the hopper can be high (5–30% of the total volume pumped into the hopper), depending on the processing speed.[91,93,94]

Based on consenting information provided by WRC, over 45,000 m^3 of sediment may have been dredged from the Waikato Coastal Marine Area for coastal developments (capital dredging), and up to approximately 18,000 m^3 per year is currently authorised to be removed for ongoing maintenance dredging, though the quantity dredged in any given year may be much less than this. Most of the dredging activity that has been conducted in the Waikato Region has been required for the construction of various marinas and waterway developments, and for maintaining access to Sugar Loaf Wharf in Coromandel Harbour, and Tairua Harbour (Figure 8).

Figure 8. Locations where dredging has been conducted in the Waikato Region.



DISPOSAL OF DREDGED MATERIAL

Dredged material is often disposed of in the sea due to disposal costs and logistics. Based on consenting information provided by WRC, most dredge disposals that occur in the Waikato Coastal Marina Area occur on beaches or in the intertidal area for the purposes of beach replenishment[n]. The only subtidal deposition was for approximately 40,000 m^3 of sand dredged from Tairua Harbour, which was consented to be deposited approximately 1 km offshore from Pauanui Beach.

[n] Description of the effects of sediment disposal on intertidal and beach habitats is outside of the scope of this report.

EFFECTS OF DREDGING & DISPOSAL

Dredging causes the unavoidable loss of surface sediment and marine life that are present within the dredge footprint, while disposal may smother attached or sedentary marine life present at the disposal site. Dredging and disposal were assessed as the 27th and 8th greatest human-induced threats to marine habitats, respectively.[17] Dredging often occurs in harbours and estuaries that are important nursery and feeding areas for a range of fishes, birds and other animals. The size of the impact caused by dredging and disposal depends on the:

- quantity of material dredged and disposed;
- frequency and duration of dredging;
- dredging methods;
- depth, current speeds, waves and water quality at the site;
- sediment composition;
- presence of any contaminants in the sediment;
- distance from ecologically sensitive habitats and the tolerance of plants and animals to suspended sediments.[95]

DIRECT EFFECTS

1. **Changes to the seabed**—dredging lowers the seabed height while disposal may increase the seabed height (depending on current speeds and the spread of material). Both activities may change the sediment composition (if the sediment composition varies with depth at the dredge site, or varies between the dredge and disposal site), which leads to indirect impacts on the seabed community (see Section on Indirect Effects for more details).

2. **Removal of marine life**—dredging removes all marine life present within the extracted sediment. This marine life may not survive the dredging and transport process, or conditions at the disposal location may be unsuitable for their survival.[91]

3. **Smothering by disposed or mobilised sediment**—smothering of the seabed by the disposed sediments is likely to cause the loss of marine life growing in or on the seabed under the disposed sediment. Mobile animals such as worms may be able to burrow to the surface, but attached and sedentary animals are likely to be smothered. A review of the effects of dredge spoil disposal in New Zealand concluded that the majority of studies found that any negative ecological effects caused by disposal were limited to the disposal footprint and were short-lived. This conclusion is likely to be due (in part) to the relatively uncontaminated spoil deposited, high currents at disposal sites, and similarity between the dredged spoil and the sediment at the disposal site.[96]

   Monitoring studies generally indicate that disposal effects are relatively minor and short-lived. Effects are generally related to minor changes in community composition,[97,98] and are small compared with changes that occur over time.[98] For example, disposal of muddy spoil in a high energy area off Otago was found to result in a change in community composition and a decrease in abundance but, within a month, the fine sediments were dispersed and the macrofaunal community recovered to the preexisting state.[96] Similarly, macrofaunal communities subjected to spoil disposal in Nelson recovered within six months, and no long-term, cumulative effects were discernible.[99]

Many other dredge disposal studies have not found any significant difference between disposal and control sites,[98,100-104] which may be due to the temporary nature of any impact and the time elapsed between disposal and monitoring.

Disposal of spoil in nearshore areas sometimes occurs for beach replenishment, which may affect intertidal and beach communities. However, monitoring of the effects of spoil disposal in a nearshore site off Taranaki found no negative effects on intertidal communities or kai moana species (paua, kina and Cook's turban).[104] Similarly, spoil disposal off Westshore Beach, Napier, was found to only have a small, temporary effect on the seabed communities, becoming indiscernible from control sites after a period of months.[98]

4. **Increased turbidity and suspended sediment concentrations**—resuspended sediment and increased turbidity generated by dredging and disposal have the potential to negatively affect marine life across a broad area. High levels of suspended sediment can cause several negative effects on marine life including:

   - Reduced growth or mortality or a depth restriction of subtidal macro- and microalgae and seagrass due to reduction in light levels.[95,105,106]
   - Negative effects on health, behaviour, feeding ability and survival of fish by clogging gills, elevating stress levels, promoting avoidance behaviour, and reducing feeding success. For example, total suspended sediment (TSS) concentrations of >23 mg/l were correlated with higher levels of gill deformation, lower body condition, and a diet shift from swimming prey to prey living on/near the seabed in baby snapper.[107,108] Tolerance to suspended sediment depends on the species, with some species experiencing increased mortality at TSS concentrations of 25 mg/L, while other species can withstand concentrations of 28,000 mg/L with no increase in mortality.[109] In general, coastal species are more vulnerable to suspended solids than estuarine species, and larval stages are particularly vulnerable.[109-111]
   - Reduced filtration rates, growth and survival of shellfish and other filter feeders. For example, adult pipis, cockles and scallops can continue to feed at high concentrations of suspended sediment for short durations (<1 week) but. in the long term, show negative effects at TSS concentrations of more than 60–70 mg/l, 300–350 mg/l, and 100 mg/l, respectively.[108,112-114] Horse mussels appear to be more sensitive to suspended sediment and show negative effects at 80 mg/l.[115]
   - Negative effects on deposit feeders. Concentrations above 300 mg/l for 9 days negatively affected the intertidal wedge shell *Macomona liliana*. After 14 days of high exposure, most wedge shells had died or were lying exposed on the surface.[116]

   The size of the effect will depend on the increase in TSS generated by the activity, the duration of the increased TSS, and the tolerance of animals present to suspended sediments.

5. **Release of toxic contaminants**—the impacts of dredging and disposal on marine life are likely to be more severe if the dredged material contains contaminants such as heavy

metals, polycyclic aromatic hydrocarbons or polychlorinated biphenyls. Agitation and disposal of sediment can release contaminants back into the environment making them available for uptake by marine animals.[108] Monitoring of metal contaminants in marine sediments from around the Waikato Region showed that several sites in the Firth of Thames, Whitianga Estuary and Port Waikato exceeded default guideline values[117] for certain metals, while Tairua Estuary and Raglan Harbour did not.[117,118]

6. **Introduction of new species**—changes in community composition may occur if plants or animals are present in the dredge spoil that are not present at the disposal site (depending on whether they survive the dredging and disposal process). In particular, the presence of marine pests in the dredge spoil poses a risk of transmitting pests to the disposal site.

Some habitats, such as seagrass beds, are particularly vulnerable to the effects of dredging. A global review of the impacts of dredging on seagrass found that over 21,000 ha of seagrass was lost due to direct removal and increased turbidity from 45 dredging projects.[95]

INDIRECT EFFECTS

1. **Reduction in marine life**—dredging and disposal will cause the loss of plants and animals living on or in the seabed within the affected area. Those organisms provide food and/or habitat for other animals, and their loss may result in cascading changes in community structure and abundance up the food chain.

2. **Changes to seabed community**—dredging and disposal may alter the habitat causing changes in the seabed community. These include:

    a. changes in sediment composition (particularly if the dredge spoil has a higher concentration of fine sediment, organic content or heavy metals than the disposal site), which leads to a change in the composition of sediment-dwelling animals;

    b. changes to currents due to alteration of the seabed height, which may affect the transport and settlement of sediment and larvae.

RECOVERY

Recovery times of benthic communities following the completion of dredging depends on the substrates and communities present. The rate of recovery is highly variable and depends on:

- the size of the impact;
- the physical characteristics of the sites;
- the type of communities present in the dredged and disposal areas;
- the tolerance of marine life present to suspended and deposited sediment.[90]

Reported rates of recovery for dredged communities following a single dredge event are: 6–8 months for muddy communities; 1–4 years for sandy/gravelly communities; and 5–10 years for coarser sediment communities.[90,91,119,120] However recovery rates are much longer for high dredge intensity sites, such as those dredged for sand extraction, with reported recovery times of 7–20+ years.[91,121-123]

COASTAL DEVELOPMENTS

Coastal developments in the Coastal Marine Area include structures such as ports, marinas, residential canal waterways, wharves, and seawalls. Coastal developments in the Waikato Region include the Whitianga Marina, Whitianga Waterways, Pauanui Waterways[o], Tairua Marina, Whangamata Marina, Thames Marina, and various wharves and boat ramps (Figure 9).

EFFECTS OF COASTAL DEVELOPMENTS

DIRECT EFFECTS

Coastal developments permanently occupy the seabed, cause temporary disturbance during construction (which often requires reclamation and dredging), and can cause changes to the hydrodynamics of an area. The scale and type of effects are highly dependent on the size of the development, construction methods, current speeds and wave energy, and the communities and habitats that are present in the area.[124] Coastal development often occurs in harbours and estuaries that are important nursery and feeding areas for a range of fishes, birds and other marine animals. Effects associated with dredging and disposal are discussed in the section above. Other direct effects include:

1. **Occupation and reclamation**—structures such as piles, reclamations, and seawalls that directly occupy the seabed will destroy all sedentary or slow-moving marine life present directly beneath them. In addition, the presence of elevated structures may cause environmental changes that will affect seabed communities. For example, the placement of a wharf or pontoon over a seagrass or seaweed bed will increase shading, which may result in the reduction or loss of vegetation underneath.[124-127]

2. **Increased sediment resuspension and turbidity**—disturbance of the sediment during construction causes sediment resuspension and increases in turbidity, which may result in a range of impacts on marine plants and animals (see Direct Effects of Dredging and Disposal for more information). These impacts are likely to occur mainly during the construction phase, though on-going disturbances arising from the presence and use of the facility may also cause increases in suspended sediments and turbidity e.g., disturbance caused by propeller wash or turbulence around artificial structures.[128]

3. **Changes to water flow and wave energy**—the placement of a large structure in the sea will affect the hydrodynamics of the area. This may cause:

    a. increased erosion and scour in high energy environments or down-current of the structure, leading to a coarsening of the sediments;[129-131]

    b. decreased currents and the creation of eddies, particularly up-current or shoreward of the structure, resulting in the accumulation of fine sediments;[129-131]

    c. retention of water within semi-enclosed structures such as marinas, resulting in reduced flushing and accumulation of fine sediments and pollutants.[128,132,133]

---

[o] Whitianga and Pauanui Waterways were constructed by excavating canals from the land, and therefore did not directly impact the seabed apart from dredging of the access channel.

Effects are highly site-specific and typically require hydrodynamic modelling and field measurements to predict the size and nature of likely effects. [129,132,134]

INDIRECT EFFECTS

Indirect effects arising from coastal development are mainly due to changes in the habitat caused by developments. These include:

1. **Reduction in food and habitats**—the loss or modification of large areas of the seabed will reduce the area available for marine animals to utilise. In particular, the loss of biogenic habitats or critical foraging areas may result in a reduction of invertebrate, bird and fish populations.[124,135]

2. **Changes in the seabed community**—changes in the sediment composition due to the deposition or erosion of sediments, or changes in water currents around a structure may cause changes in the seabed community composition. These include:

    a. changes in community composition resulting from a change in grainsize and/or currents and wave energy;[130,131,136]

    b. retention of larvae due to eddies or reduction of currents generated by a structure, which may result in an increase in the population near the structure (depending on whether suitable settlement habitats are present);[128,133]

    c. reduced transport of larvae to down-current areas due to interruption of water flows, resulting in a decrease in populations in those areas.[125,137]

3. **Blocking movement**—coastal developments can act as physical barriers, preventing or hindering the movement of marine life around the coast. For example, groynes were found to hinder the transport of fish larvae to favourable settlement areas.[137] This can result in a loss of connectivity between populations and lower reproductive success.

RECOVERY

Changes caused by coastal developments are generally permanent (with the exception of construction-related effects) as long as the development remains in place. Recovery may be possible following the removal of the structure from the sea, but removal rarely occurs.

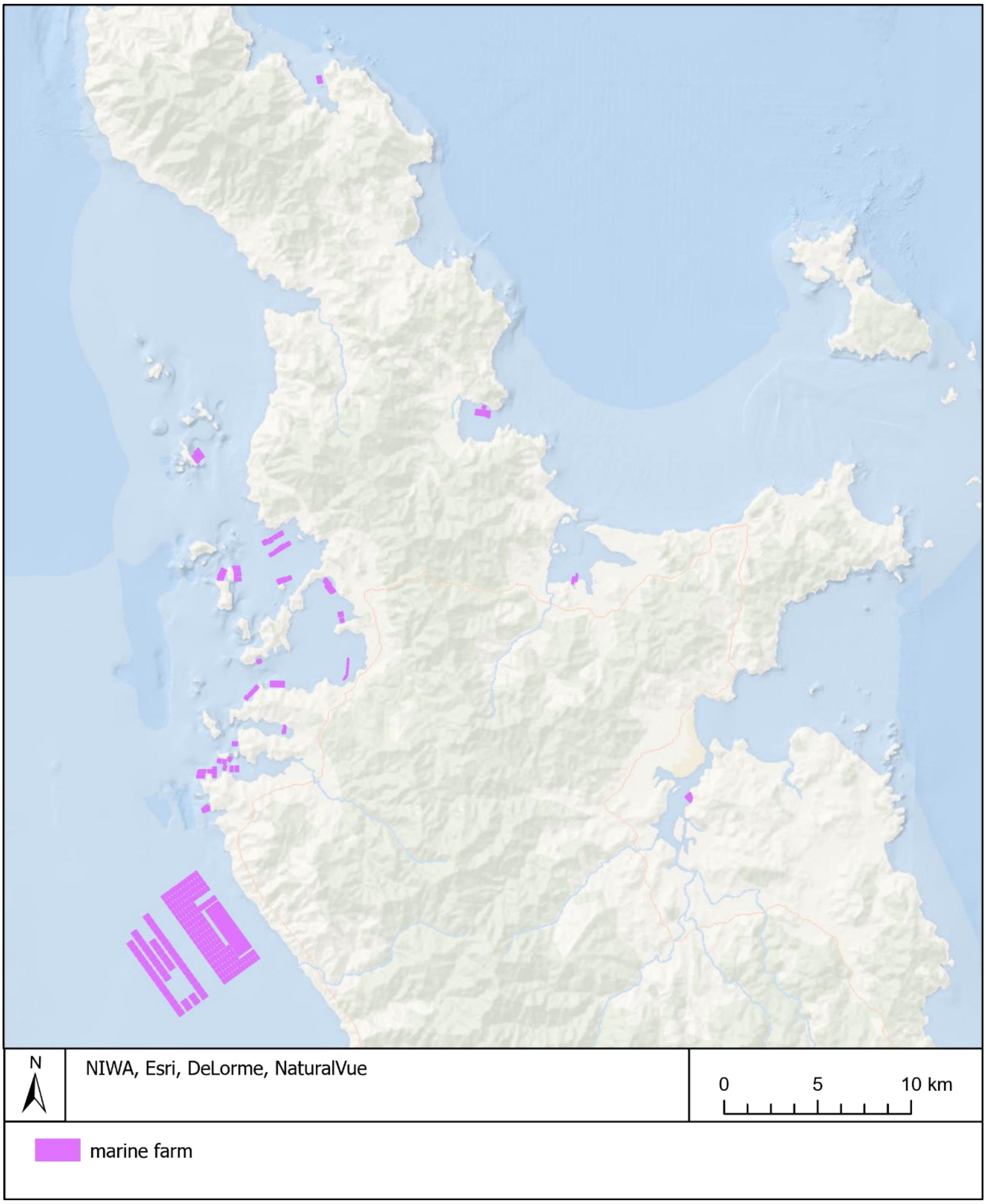
Figure 9. Large coastal developments in the Waikato Region: A. Whitianga Waterways and Whitianga Marina. B. Pauanui Waterways. C. Tairua Marina. D. Whangamata Marina.

Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

SHELLFISH AQUACULTURE

Commercial aquaculture in New Zealand started in the 1960s and rapidly increased over the following three decades. Today, the Waikato Region contains over 270 marine shellfish farms that cover around 1,500 ha and produce 23% of New Zealand's green-lipped mussels and 28% of New Zealand's Pacific oysters.[138] The vast majority of these farms are located on the western side of the Coromandel Peninsula (Figure 10), though a few spat catching farms are present in Kawhia and Aotea Harbours.

Figure 10. Location of marine farms around the Coromandel Peninsula.



In the Waikato Region, green-lipped mussels are grown on longlines in subtidal areas, while Pacific oysters are grown on sticks or in bags or baskets in intertidal areas. Currently, no marine finfish farming occurs in the Waikato Region. The focus of this report is on impacts to subtidal areas, therefore, this section focuses on the effects of mussel farming.

Mussel farms have rows of double longlines or backbones that are typically around 100–150 m long and are held up by a series of floats. The longlines are anchored to the seafloor at either end by concrete or screw anchors. Grow ropes hang in loops from the longlines that extend down to 7–10 m depth.[139] Rows of longlines are typically spaced around 25 m apart.

EFFECTS OF SHELLFISH AQUACULTURE

DIRECT EFFECTS

Aquaculture has numerous physical and biological effects on the environment.[140] Direct effects of mussel farming on the seabed include:

1. **Deposition of mussels, shell and fine particles**—the benthic effects of mussel farming are well understood and are mainly related to the ongoing deposition of mussels, shell, biodeposits (mussel faeces and pseudofaeces[p]), and other marine life below the farm, which alter the physical, chemical and biological characteristics of the seafloor. These effects are well-described in other reports[141-144] and are outside of the scope of this report, so are only briefly summarised here. Typical responses include:

   a. Increased sedimentation leading to reduced grainsize, minor enrichment and changes to sediment chemistry within and slightly beyond farm boundaries (i.e., up to 100 m). This may lead to smothering of the seabed community and changes in the composition of sediment-dwelling communities. Minor enrichment typically increases the abundance and diversity of sediment-dwelling communities. However, increasing levels of enrichment causes decreases in diversity and the dominance of a few tolerant species.

   b. The accumulation of live shellfish and shell material under the farm, which can provide food and a hard substrate for other animals (e.g., starfish, sea cucumbers, crabs, sponges and tube worms), which typically leads to a more diverse and productive community on top of the seabed than what was originally present.

   c. The deposition of other marine life, including marine pests, that either fall naturally to the seabed, or which are deliberately or incidentally removed during farm operations (Figure 11).

   These effects are dependent on the location of the marine farm, the environmental conditions, and the intensity of farming conducted at the site.

2. **Occupation**—anchors placed at the end of each row will directly occupy the seabed, destroying all sedentary or slow-moving marine life present under them. In addition, disturbance of the sediment during construction or maintenance of the farm will temporarily cause sediment resuspension and increases in turbidity, which may result in

[p] Filtered material rejected by mussels during feeding.

a range of impacts (see Direct Effects of Dredging and Disposal for more information), though these effects are likely to be very limited in extent, short-lived and infrequent.

3. **Changes to water currents**—the placement of a large structure in the sea will affect the hydrodynamics of the area. Current speeds through the farm are generally reduced, while current speeds around and underneath the farm may increase, depending on the farm placement, layout and the environmental conditions (e.g., farms that occupy most of the water depth in a high current area are likely to cause a larger increase in currents beneath and around the farm).[144,145] In addition, anchor blocks will increase scouring near the blocks in high current areas,[144] while oyster racks reduce currents speeds causing the build-up of sediment underneath the racks.[146] These changes in water currents will increase or decrease the accumulation of fine sediment, which will indirectly lead to changes in sediment-dwelling communities.

4. **Increased shading**—shellfish farms increase shading, which may reduce the growth of any seaweed or seagrass growing below the farm.[145,147] For example, seagrass within a subtidal oyster farm in the Kaipara Harbour was found to be less dense and less abundant directly underneath the lines of baskets compared to between the lines.[148]

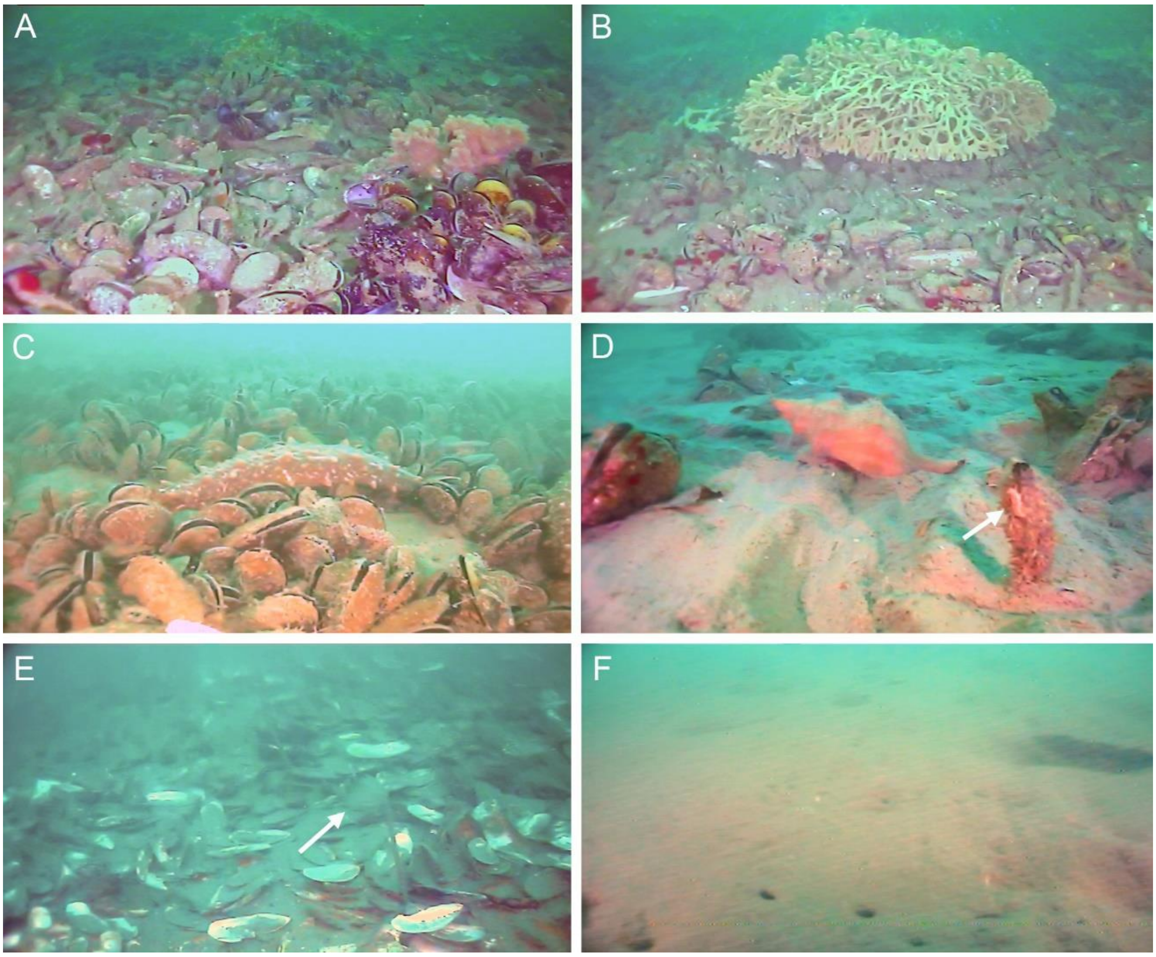
INDIRECT EFFECTS

The indirect effects of aquaculture mainly arise from the changes in the seabed community caused by farm impacts. These effects may be positive or negative. Accumulation of live mussels and associated marine life under mussel farms can provide important nursery habitats, food and shelter for fish and invertebrates, which will lead to increases in populations. For example, soft sediment mussel beds were estimated to support ten times the density of small fishes such as juvenile snapper, and 2–8 times the density of invertebrates such as crabs and sea snails.[58] However, other mussel farms may result in the loss of seabed communities due to smothering and enrichment, resulting in less food and habitats.

RECOVERY

The seabed community and habitat would gradually recover upon removal of the marine farm.[141] Recovery times are highly dependent on the farm location and environmental conditions, but biological recovery of sediment-dwelling communities to become similar to those in the surrounding area is likely to take months to years,[142,149] while physical recovery of the substrate (i.e., the decomposition of shell and other debris) is likely to take decades.[146,150]

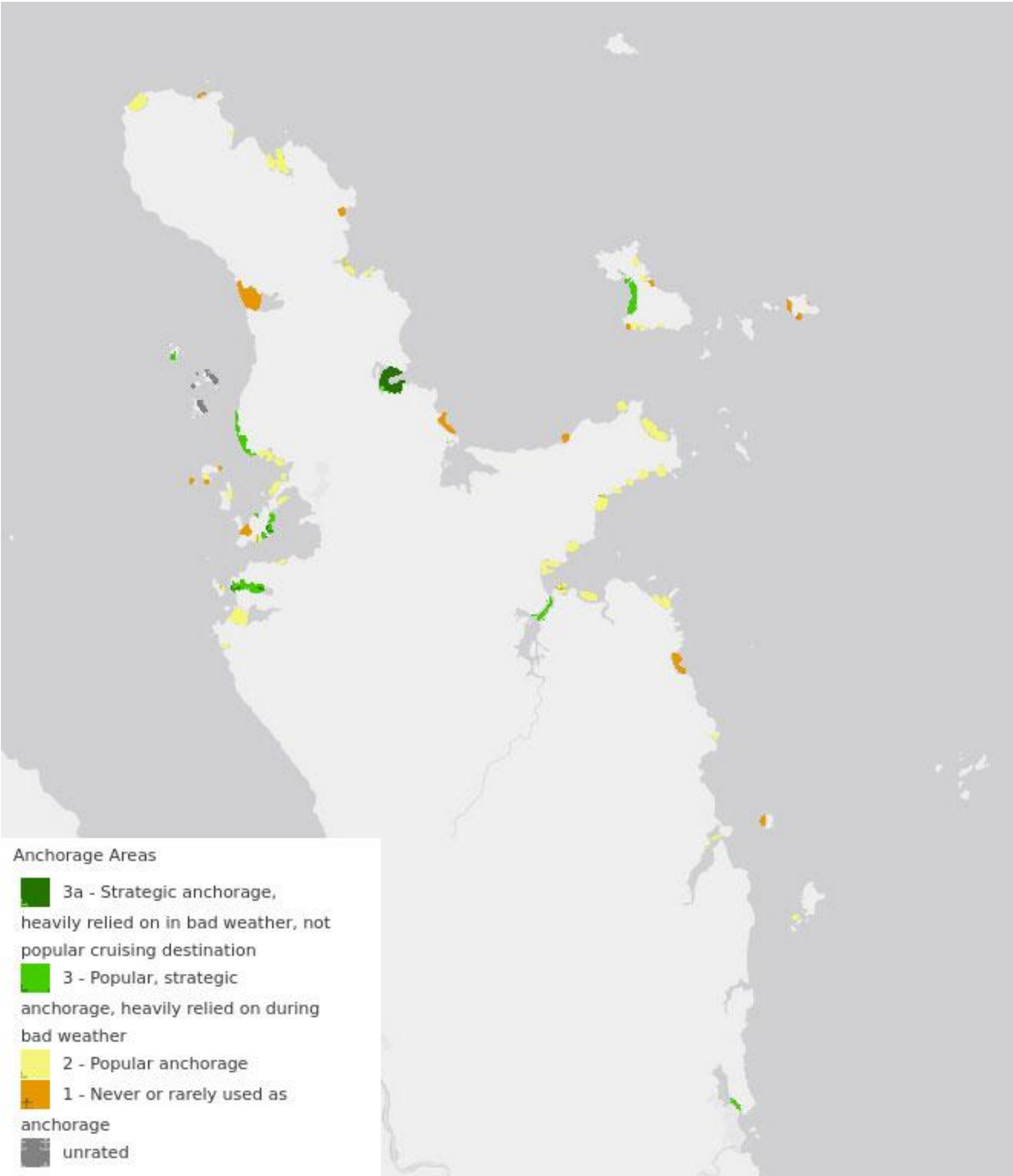
Figure 11. Examples of seabed communities under Coromandel mussel farms: A & B. Dense live mussels and sponges. C. A sea cucumber amidst live mussels. D. A sea snail and the clubbed tunicate (arrow), a marine pest. E Dense mussel shells and the Mediterranean fan worm (arrow), another marine pest. F. Bare soft sediment with crustacean burrows.



BOAT ANCHORING AND SWING MOORINGS

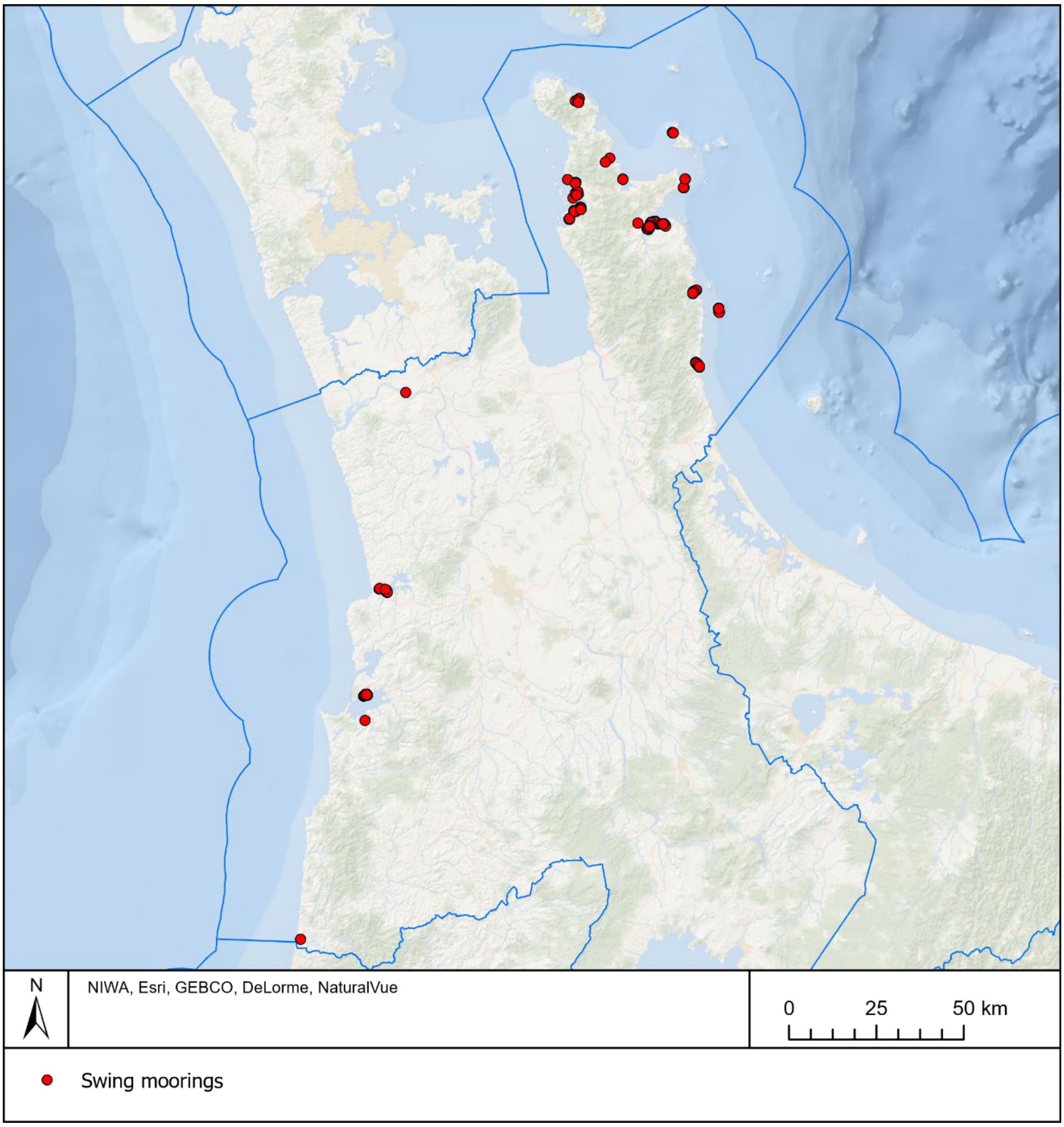
The Waikato/Taupo region is the second most popular recreational boating destination in New Zealand, with 10% of Waikato's population participating in recreational boating activities.[151] Many of the bays around the upper half of the Coromandel Peninsula are popular anchorages (Figure 12), with the majority of anchoring likely to occur in waters less than 10 m deep.[152] There are also around 830 swing moorings in the Waikato Region.

Figure 12. Locations of popular anchorages around the Coromandel Peninsula (Figure from Sea Change – Tai Timu Tai Pari[q]).



[q] https://www.seasketch.org/#projecthomepage/52322dd05d3e2c665a00d119

Figure 13. Location of swing moorings in the Waikato Region (data from WRC).



EFFECTS OF ANCHORING AND MOORING

Anchor and chain damage are caused by deployment and retrieval of the anchor and movement of the rope/chain over the seabed. The process of anchoring may create an anchor pit on the seabed and/or long furrows from anchor or chain drag. A 20 kg anchor suitable for a large recreational vessel penetrates 10 cm into the sediment, while anchors used by large commercial vessels penetrate 50–550 cm into the sediment depending on the anchor size and substrate.[153] Anchoring was assessed as the 30th largest human-induced threat to marine habitats.[17] The movement of the chain/rope from swing moorings can cause similar damage to the seabed, though the mooring location is fixed, so the same area of the seabed is repeatedly affected. For simplicity, these processes are collectively referred to as ‘anchor scour’.

DIRECT EFFECTS

Direct effects caused by anchor scour increase with increasing vessel size, and depend on the habitats and communities present, with fragile plants and animals the most affected by anchoring. The main studies on anchor scour in temperate regions have focused on impacts on seagrass and horse mussels.

1. **Impacts on seagrass**—Numerous international studies have shown that boat anchors and swing moorings cause damage to seagrass beds by breaking or uprooting shoots and creating anchor pits that contain few shoots and have damaged rhizomes (roots).[153-155] Individual recreational anchors were found to cause an anchor pit with an average size of 0.16 m^2 (i.e., 40 × 40 cm) and up to 4 m^2.[156-158] Over time, impacted seagrass beds became less dense and fragmented. Comparison on anchoring and no-anchoring areas found that seagrass beds were less dense in areas where anchoring is allowed.[159]

   Similarly, boat moorings located over seagrass beds were found to scour all the seagrass from a circular area around the mooring within a radius of 1–10 m.[158,160,161] The sediment within this area was also excavated by 0.5–1 m by the chain.[160] Estimated seagrass losses from around the scour area of boat moorings in some bays was up to 13% over a decade.[162]

   Anchor scour can also reduce the diversity and abundance of small animals that live in and under the seagrass. In one study on *Zostera marina* in the United Kingdom, anchor scour was found to reduce the abundance (number of animals) by 70% and reduce the diversity (number of species) by 24% within the scoured area compared to adjacent patches of unimpacted seagrass.[158]

   Subtidal seagrass (*Zostera muelleri*) beds in New Zealand are a rare habitat, with only three large subtidal beds known to occur in the Waikato Region: Huruhi Harbour (Great Mercury Island), South Bay (Slipper Island) and Whangapoua Harbour.[163] Both Huruhi Harbour and South Bay are popular anchorages[163] and permanent swing moorings also are present in both areas, near or within the seagrass beds (Figure 14). A recent survey of the beds found that the seagrass around the moorings at South Bay had been scoured off by the chains (Figure 15).[163]

2. **Impacts on horse mussels**—Horse mussels are large fragile bivalves that protrude well above the seabed making them vulnerable to anchor scour. Experimental anchoring off Kawau Island using a 20 kg anchor was found to increase the number of damaged horse mussels and decrease the total number of horse mussels present. Predators were attracted to the scent of damaged shellfish and the number of starfish (*Patiriella regularis*) and predatory whelks (*Cominella* sp.) also increased with increasing numbers of damaged horse mussels.[164]

   Similarly, densities of the closely related fan mussel, *Pinna nobilis*, was found to be significantly higher in areas around the Mediterranean where anchoring is not allowed compared to areas where anchoring is permitted.[159,165]

3. **Impacts on sediment-dwelling animals**—most anchoring and mooring occurs over bare soft sediment that is inhabited by small sediment-dwelling animals, however, very little information is available on the effects of anchor scour on soft sediment communities.

Infrequent anchoring is unlikely to cause detectable changes to soft sediment communities at broad scales, however moorings have more of an impact because they repeatedly affect the same area. A UK study on intertidal moorings found that those impacts included the chain scraping away finer sediments leaving greater percentages of gravel and shell fragments, and a significantly different community composition from the surrounding area.[166]

Figure 14. Overlap between 2019 subtidal seagrass beds and swing moorings in A) Huruhi Harbour, Great Mercury Island, and B) South Bay, Slipper Island (data from WRC).

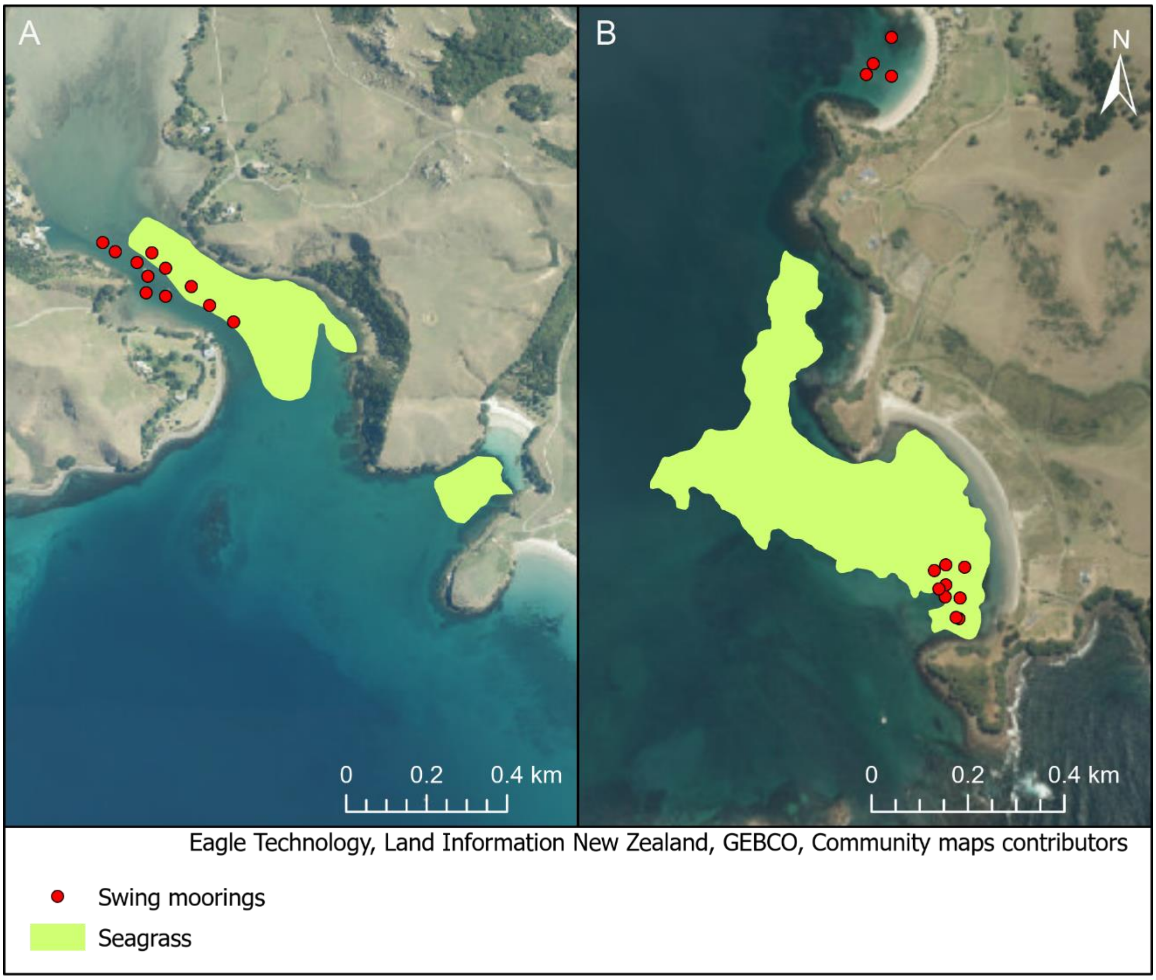


Figure 15. Scouring of the seagrass around swing moorings at South Bay, Slipper Island (Figure from [163]).

INDIRECT EFFECTS

1. **Reduction in fish recruitment due to loss of biogenic habitat**—biogenic habitats provide important nursery areas for juvenile fish. For example, the abundance of juvenile fish, particularly snapper and trevally, were much higher within seagrass beds and horse mussel beds around northern New Zealand than the surrounding unvegetated areas.[56,57,65,167] Presumably juvenile fish favour these areas because they confer some competitive advantage (i.e. more food, shelter, or protection from predation), so the reduction of these habitats by anchor scour is likely to reduce the subsequent fish population, though the relationship between habitat loss and reduction in recruitment has not been measured.

2. **Increased predation**—seagrass beds provide a refuge from predation for small fish and invertebrates, reducing predation rates.[168] The reduction and fragmentation of this habitat by anchor scour has the potential to reduce subsequent fish populations.

3. **Increased sediment resuspension and turbidity**—seagrass acts as a sediment trap, reducing water currents and sediment resuspension within the bed, which reduces turbidity.[169,170] The loss of seagrass can indirectly increase erosion, resuspension of sediments and organic material, and turbidity,[158] which has negative effects on seagrass and seaweed, filter feeders such as bivalves and sponges, and visual predators such as baby snapper.[107]

RECOVERY

Little is known about the recovery rates of seabed communities from anchor scour, but at popular anchorages the rate of damage is likely to exceed the recovery rate for fragile and slower growing plants and animals.[153]

1. **Seagrass**—recovery rates of seagrass depend on the species present and their growth rates.[153] For example, the fast-growing Caribbean species, *Halodule wrightii*, was found to recover within 9 months from simulated anchor scour, whereas the slower growing *Thalassia testudinum* had not recovered after 7 months, and *Posidonia* spp. had only partially recovered after 12 months, and may take years to decades to fully recover.[155-157,171,172] Intertidal beds of the New Zealand seagrass, *Zostera muelleri*, recovered from small-scale seagrass transplants after 9 months,[173] but no studies have been conducted on the recovery of subtidal beds following anchor damage.

1. **Horse mussels**—no specific studies have been conducted on the recovery rates of horse mussel beds from anchor scour, however this is likely to take years as New Zealand horse mussels are estimated to take around 3 years to grow to around 25 cm in length.[174]

2. **Sediment-dwelling animals**—recovery of soft sediment communities from mooring impacts may take years, depending on the substrate, wave energy and tidal currents. For example, communities within the scour zone of mooring chains had not recovered 15 months after the moorings had been removed.[166]

SUMMARY & CUMULATIVE EFFECTS

All the activities discussed can cause a range of negative effects on seabed habitats and communities, many of which are similar. These include:

- loss of complex habitats and communities;
- direct loss of marine life and reduced biodiversity;
- changes to sediment-dwelling communities;
- reduced reproduction and recruitment of some species (although some benefits for scavengers and opportunistic species);
- negative effects from increased suspended sediments;
- changes in sediment chemistry and natural processes; and
- changes in water currents and the dispersal of sediment and larvae (Table 1).

The area of seabed affected by these activities varies greatly. The total footprint[r] of bottom-contact fishing in the Waikato Region is around 2000 km² per year, with some areas repeatedly trawled each year. Cumulatively, the area impacted is much greater than this, as there are differences in the areas trawled between years, and some areas around the northern Coromandel Peninsula are impacted by both bottom trawling and scallop dredging. Recovery from trawling and scallop dredging is estimated to take up to 8+ years, depending

[r] The area of the seafloor estimated to have been contacted by trawl gear.

on the habitats and communities impacted. Therefore, it is likely that certain areas of the seabed are impacted too often to allow for recovery and these are in a permanently altered state.

The scale bottom-contact fishing impact dwarfs the area affected by all other activities in the Waikato Region, with shellfish aquaculture occupying around 15 km^2, and dredging, disposal, and coastal developments each estimated to impact less than 1 km^2 of the subtidal seabed. The spatial extent of anchoring and mooring is unknown but it is unlikely to be large (Table 1).

For the most part, the area impacted by bottom-contact fishing does not overlap with areas impacted by other activities—bottom trawling is prohibited from most of the nearshore areas directly adjacent to the coast, while the other activities currently occur very close to the coast. Apart from dredging and coastal development, which often occur together, there is also unlikely to be much direct overlap in the areas affected by dredging, disposal, coastal development, aquaculture, anchoring and mooring.

Despite the relatively small area affected by dredging, coastal developments, aquaculture, anchoring and mooring on a regional scale, the impacts of these activities can be significant in certain locations. These activities are often concentrated in harbours, bays and estuaries that contain biogenic habitats that provide important nursery and feeding areas for a wide range of fishes, birds and invertebrates. Added together, these impacts can collectively cause negative impacts that may be substantial on an estuary or bay scale. For example, Figure 16 shows the biogenic habitats present in Tairua Harbour and the range of activities conducted in the harbour that disturb the seabed. Management of these impacts should consider the wider cumulative impacts on the bay or estuary, as well as the localised impacts of a particular activity.

Figure 16. Biogenic habitats present in Tairua Harbour and activities conducted in the harbour that disturb the seabed. (Data on biogenic habitats from DOC,[53] data on consented activities provided by WRC).

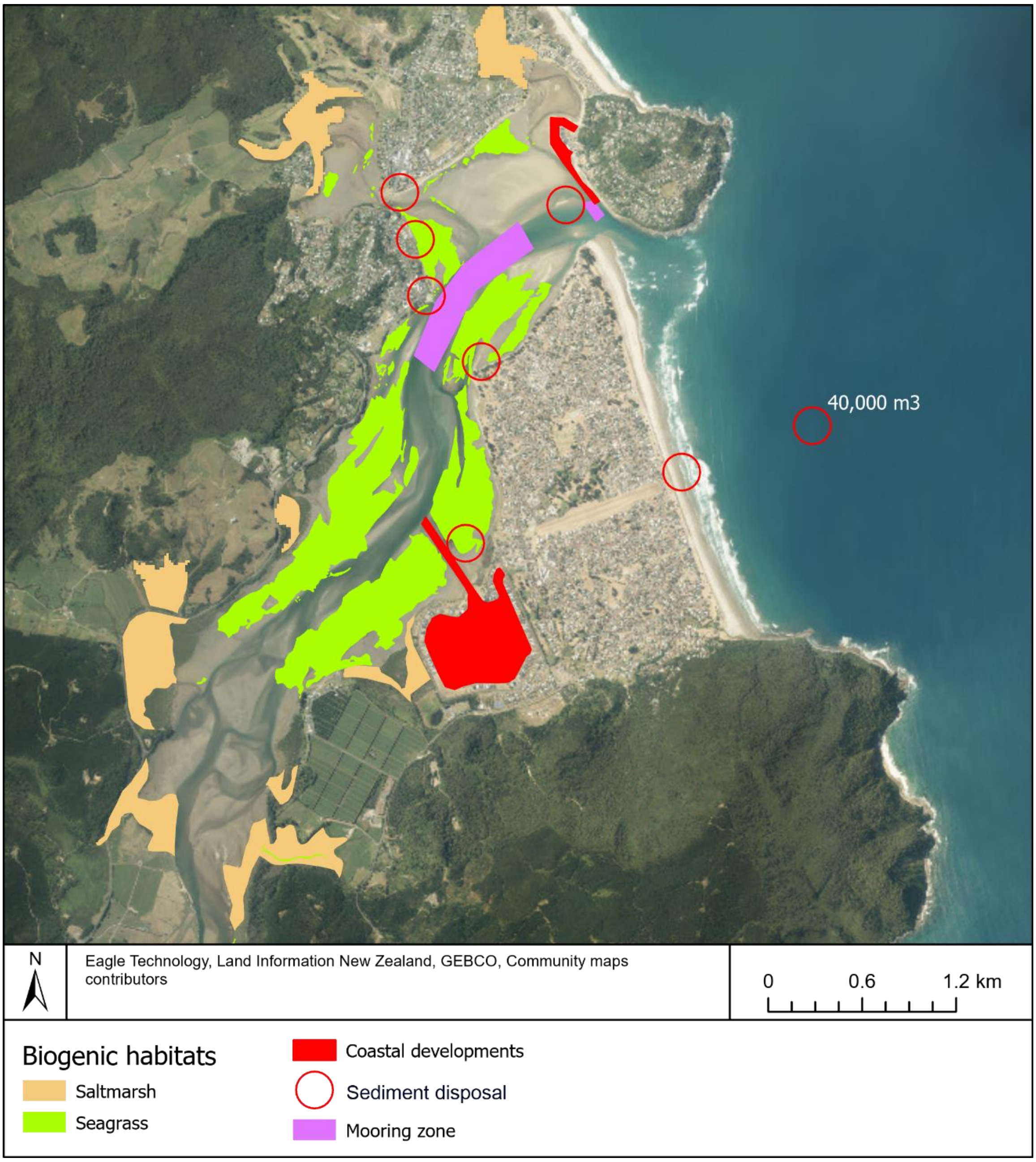


Table 1. Summary of the main effects of activities in the Waikato Region that disturb the seabed.

Activity	Approximate Waikato area impacted (km^2)	Loss of complex and biogenic habitat	Direct loss of marine life	Changes to sediment dwelling communities	Reduction in reproduction and recruitment	Increased predation	Effects from suspended sediments	Changes to sediment chemistry	Changes to currents and dispersal	Recovery time (years)
Bottom-contact fishing	2000[s]	✓	✓	✓	✓	✓	✓	✓		2–10+
Dredging	<1	Possible	✓	✓	Possible		✓	✓	✓	2–10+
Disposal	<1	Possible	✓	✓			✓	✓	✓	<1
Coastal developments	<1	Possible	✓		Possible		✓		✓	Unlikely
Shellfish aquaculture	15	Possible, may also increase	✓from anchors only	✓	Possible, may also enhance			✓	✓	1–10+
Anchoring and mooring	?	Possible	✓	✓		✓	✓			1–3

[s] Trawl footprint per year.

ACKNOWLEDGEMENTS

We thank Michael Townsend, Martin Cryer and Simon Thrush for their helpful review of an earlier version of this report. Data used in this report was provided by Fisheries New Zealand and Waikato Regional Council.

REFERENCES

1. Jones EG, MacGibbon DJ, Baird SJ, Hurst R. 2021. Gear use in New Zealand inshore trawl fisheries. New Zealand Fisheries Assessment Report 2021/30 Wellington, New Zealand: Fisheries New Zealand, 85 pp.
2. Fisheries NZ. 2009. Fishing methods. Fisheries Infosite. Available at: https://fs.fish.govt.nz/Page.aspx?pk=63 (Accessed
3. Jones JB. 1992. Environmental impact of trawling on the seabed: a review. *New Zealand Journal of Marine and Freshwater Research.* 26(1):59–67.
4. Drury J, Hartill B. 1993. Summary findings from the 1992 R. V. Kaharoa trawl survey of the Bay of Plenty (KAH9202). Northern Fisheries Internal Report no. 16. Auckland: Ministry of Agriculture and Fisheries.
5. Boyd R. 2017. Commercial fishing in Whangarei Harbour and Bream Bay. Report prepared for Refining NZ. 43 pp.
6. Baird SJ, Hewitt J, Wood BA. 2015. Benthic habitat classes and trawl fishing disturbance in New Zealand waters shallower than 250 m. New Zealand Aquatic Environment and Biodiversity Report no. 144. Wellington, New Zealand: Ministry for Primary Industries, 184 pp.
7. Eayrs S, Craig T, Short K. 2020. Mitigation techniques to reduce benthic impacts of trawling. Report prepared for the Department of Conservation. Wellington, New Zealand: Terra Moana, 125 pp.
8. Morrison MA, McKenzie J, Bian R. 2019. Pre-recruit (0+) snapper (*Chrysophrys auratus*) beam trawl and beach sein surveys of East Northland and the Hauraki Gulf. New Zealand Fisheries Assessment Report 2019/72. Wellington, New Zealand: Fisheries New Zealand, 50 pp.
9. Baird SJ, Mules R. 2021. Extent of bottom contact by commercial trawling and dredging in New Zealand waters, 1989–90 to 2018–19. New Zealand Aquatic Environment and Biodiversity Report no. 260. Wellington: Fisheries New Zealand, 157 pp.
10. Fisheries New Zealand. 2021. Fisheries Assessment Plenary, November 2021: stock assessments and stock status. Complied by the Fisheries Science and Information Group. Wellington, New Zealand: Fisheries New Zealand, 663 pp.
11. McLoughlin RJ, Young PC, Martin RB, Parslow J. 1991. The Australian scallop dredge: estimates of catching efficiency and associated indirect fishing mortality. *Fisheries Research.* 11:1–24.
12. Beentjes MP, Baird SJ. 2004. Review of dredge fishing technologies and practice for application in New Zealand. New Zealand Fisheries Assessment Report 2004/37. Wellington: Ministry of Fisheries, 40 pp.

13. Currie DR, Parry GD. 1996. Effects of scallop dredging on a soft sediment community: a large-scale experimental study. *Marine Ecology Progress Series.* 134(1–3):131–150.

14. Ministry of Fisheries. 2007. Draft Coromandel scallop fisheries plan. Appendix 1: information summary. Wellington: Ministry of Fisheries.

15. Tuck ID, Parkinson D, Dey K, Oldman J, Wadhwa S. 2006. Information on benthic impacts in support of the Coromandel Scallops Fishery Plan. Final Research Report. Wellington, New Zealand: Ministry of Fisheries, 64 pp.

16. Wynne-Jones J, Gray A, Heinemann A, Hill L, Walton L. 2019. National panel survey of marine recreational fishers 2017–18. New Zealand Fisheries Assessment Report 2019/24. Wellington: Fisheries New Zealand, 104 pp.

17. MacDiarmid AB, McKenzie A, Sturman J, Beaumont J, Mikaloff-Fletcher S, Dunne J. 2012. Assessment of anthropogenic threats to New Zealand marine habitats. New Zealand Aquatic Environment and Biodiversity Report no. 93. Wellington, New Zealand, 255 pp.

18. Thrush SF, Dayton PK. 2002. Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. *Annual Review of Ecology and Systematics.* 33(1):449–473.

19. Bradshaw C, Jakobsson M, Brüchert V, et al. 2021. Physical disturbance by bottom trawling suspends particulate matter and alters biogeochemical processes on and near the seafloor. *Frontiers in Marine Science.* 8(1127):683331.

20. Kaiser MJ, Clarke KR, Hinz H, Austen MCV, Somerfield PJ, Karakassis I. 2006. Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series.* 311:1–14.

21. Collie JS, Hall SJ, Kaiser MJ, Poiner IR. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology.* 69(5):785–798.

22. Stewart BD, Howarth LM. 2016. Quantifying and managing the ecosystem effects of scallop dredge fisheries. In: Shumway SE, Parsons GJ, eds. *Scallops: biology, ecology, aquaculture, and fisheries*. Oxford: Elsevier Science:585–610.

23. Talman SG, Norkko A, Thrush SF, Hewitt JE. 2004. Habitat structure and the survival of juvenile scallops *Pecten novaezelandiae*: comparing predation in habitats with varying complexity. *Marine Ecology Progress Series.* 269:197–207.

24. Hall-Spencer JM, Moore PG. 2000. Scallop dredging has profound, long-term impacts on maerl habitats. *ICES Journal of Marine Science.* 57:1407–1415.

25. DFO. 2006. Impacts of trawl gears and scallop dredges on benthic habitats, populations and communities. Canadian Science Advisory Secretariat Science Advisory Report 2006/025. Ottawa, Ontario: Fisheries and Oceans Canada, 13 pp.

26. Newman T. 2021. Scallop recovery in top of the south still clouded by uncertainty. *Stuff.* 20 Feb 2021.

27. Williams JR, Hartill B, Bian R, Williams CL. 2014. Review of the southern scallop fishery (SCA7). New Zealand Fisheries Assessment Report 2014/07. Wellington: Ministry for Primary Industries, 71 pp.

28. Williams JR, Bian R, Olsen L, Stead J. 2021. Survey of scallops in SCA7, May 2020. New Zealand Fisheries Assessment Report 2021/09. Wellington: Fisheries New Zealand, 54 pp.

29. Suuronen P. 2005. Mortality of fish escaping trawl gears. FAO Fisheries Technical Paper 478. Rome: Food and Agriculture Organization of the United Nations.

30. Wietheger A. 2015. Precision Seafood Harvesting by-catch reduction. Available at: https://apec-flows.ntu.edu.tw/category-detail.aspx?seq=20 (Accessed

31. Thrush SF, Hewitt JE, Cummings VJ, Dayton PK. 1995. The impact of habitat disturbance by scallop dredging on marine benthic communities: what can be predicted from the results of experiments? *Marine Ecology Progress Series.* 129:141–150.

32. Cryer M, Morrison M, Davies NM, Ford RB. 2009. Including incidental effects in fisheries models can have major implications for management advice: an example based on scallop dredging. 21–25 Sep 2009, Berlin, Germany. Available from https://www.ices.dk/sites/pub/CM%20Doccuments/CM-2009/K/K0409.pdf

33. Jenkins SR, Mullen C, Brand AR. 2004. Predator and scavenger aggregation to discarded by-catch from dredge fisheries: importance of damage level. *Journal of Sea Research.* 51(1):69–76.

34. Veale LO, Hill AS, Brand AR. 2000. An in situ study of predator aggregations on scallop (*Pecten maximus* (L.)) dredge discards using a static time-lapse camera system. *Journal of Experimental Marine Biology and Ecology.* 255(1):111–129.

35. Hall-Spencer JM, Froglia C, Atkinson RJA, Moore PG. 1999. The impact of Rapido trawling for scallops, *Pecten jacobaeus* (L.), on the benthos of the Gulf of Venice. *ICES Journal of Marine Science.* 56(1):111–124.

36. Cryer M, Morrison A. 1997. Incidental effects of commercial scallop dredges. Final report for Ministry of Fisheries Research Project AKSC03. Auckland: National Institute of Water and Atmospheric Research, 29 pp.

37. Tuck ID, Hewitt JE, Handley SJ, Lundquist C. 2017. Assessing the effects of fishing on soft sediment habitat, fauna and process. New Zealand Aquatic Environment and Biodiversity Report no. 178. Wellington: Ministry for Primary Industries, 143 pp.

38. Jenkins SR, Beukers-Stewart BD, Brand AR. 2001. Impact of scallop dredging on benthic megafuana: a comparison of damage levels in captured and non-captured organisms. *Marine Ecology Progress Series.* 215:297–301.

39. Veale LO, Hill AS, Hawkins SJ, Brand AR. 2001. Distribution and damage to the by-catch assemblages of the northern Irish Sea scallop dredge fisheries. *Marine Biological Association of the United Kingdom Journal of the Marine Biological Association of the United Kingdom.* 81(1):85–96.

40. Grabowski JH, Bachman M, Demarest C, et al. 2014. Assessing the vulnerability of marine benthos to fishing gear impacts. *Reviews in Fisheries Science & Aquaculture.* 22(2):142–155.

41. Thrush SF, Hewitt JE, Cummings VJ, et al. 1998. Disturbance of the marine benthic habitat by commercial fishing: impacts at the scale of the fishery. *Ecological Applications.* 8(3):866–879.

42. Fisheries New Zealand. 2022. Aquatic Environment and Biodiversity Annual Review 2022. Compiled by the Aquatic Environment Team, Fisheries Science and Information. Wellington, New Zealand: Fisheries New Zealand, 779 pp.

43. Cryer M, Hartill B, O'Shea S. 2002. Modification of marine benthos by trawling: toward a generalization for the deep ocean? *Ecological Applications.* 12(6):1824–1839.

44. Williams JR, Parkinson DM, Tuck ID. 2010. Biomass survey and stock assessment for the Coromandel scallop fishery, 2009. New Zealand Fisheries Assessment Report 2010/33. Wellington: Ministry of Fisheries, 40 pp.

45. Fisheries NZ. 2020. Aquatic environment and biodiversity annual review 2019–20. Wellington: Fisheries Science Team, Ministry for Primary Industries, 750 pp.

46. Parsons DM, Bian R, Parkinson D, MacGibbon DJ. 2021. Trawl surveys of the Hauraki Gulf and Bay of Plenty in 2019 and 2020 to estimate the abundance of juvenile

snapper. New Zealand Fisheries Assessment Report 2021/08. Wellington: Fisheries NZ, 127 pp.

47. Jones EG, Morrison MA, Davey N, Hartill BW, Sutton C. 2016. Biogenic habitats on New Zealand's continental shelf. Part I: Local ecological knowledge. New Zealand Aquatic Environmental and Biodiversity Reprot no. 174. Wellington: Ministry for Primary Industries, 95 pp.

48. Morrison MA. 2021. Hauraki Gulf Marine Park habitat restoration potential. New Zealand Aquatic Environment and Biodiversity Report no. 265. Wellington: Fisheries NZ, 132 pp.

49. Asch RG, Collie JS. 2008. Changes in a benthic megafaunal community due to disturbance from bottom fishing and the establishment of a fishery closure. *Fishery Bulletin.* 106(4):438–456.

50. Kefalas E, Castritsi-Catharios J, Miliou H. 2003. The impacts of scallop dredging on sponge assemblages in the Gulf of Kalloni (Aegean Sea, northeastern Mediterranean). *ICES Journal of Marine Science.* 60:402–410.

51. Handley S, Willis TJ, Cole RG, et al. 2014. The importance of benchmarking habitat structure and composition for understanding the extent of fishing impacts in soft sediment ecosystems. *Journal of Sea Research.* 86:58–68.

52. Morrison KM, Meyers HK, Roberts EM, Rapp HT, Colaco A, Pham CK. 2020. The first cut is the deepest: trawl effects on a deep-sea sponge ground are pronounced four years on. *Frontiers in Marine Science.* 7:605281.

53. DOC. 2014. MPA policy habitat classification, Hauraki Gulf Marine Park. Hauraki Gulf Marine Spatial Plan. Available at: https://seasketch.doc.govt.nz/seas_metadata/haurakigulf/HGMSP_habitats_classification.html (Accessed

54. Bradshaw C, Veale LO, Hill AS, Brand AR. 2001. The effect of scallop dredging on Irish Sea benthos: experiments using a closed area. *Hydrobiologia.* 465(1):129–138.

55. Lambert GI, Jennings S, Kaiser MJ, Hinz H, Hiddink JG. 2011. Quantification and prediction of the impact of fishing on epifaunal communities. *Marine Ecology Progress Series.* 430:71–86.

56. Morrison MA, Jones EG, Consalvey M, Berkenbusch K. 2014. Linking marine fisheries species to biogenic habitats in New Zealand: a review and synthesis of knowledge. New Zealand Aquatic Environment and Biodiversity Report no. 130. Wellington, New Zealand: Ministry for Primary Industries, 156 pp.

57. Parsons DM, Buckthought D, Middleton C, Mackay G. 2016. Relative abundance of snapper (*Chrysophrys auratus*) across habitats within an estuarine system. *New Zealand Journal of Marine and Freshwater Research.* 50(3):358–370.

58. McLeod IM, Parsons DM, Morrison MA, Van Dijken SG, Taylor R. 2014. Mussel reefs on soft sediments: A severely reduced but important habitat for macroinvertebrates and fishes in New Zealand. *New Zealand Journal of Marine and Freshwater Research.* 48(1):48–59.

59. Sainsbury KJ, Campbell RA, Lindholm R, Whitelaw AW. 1997. Experimental management of an Australian multi-species fishery: examining the possibility of trawl-induced habitat modification. In: Pikitch EK, Huppert DD, Sissenwine MP, eds. Global trends: fisheries management: proceedings of the symposium; 14-16 June, 1994, Seattle. Washington, Maryland: American Fisheries Society. pp. 107-112. Available

60. de Jong NE. 2013. *Reproduction and larvael development of the New Zealand scallop, Pecten novaezelandiae* [MSc]. Auckland, Auckland University of Technology.

61. Kamenos NA, Moore PG, Hall-Spencer JM. 2004. Maerl grounds provide both refuge and high growth potential for juvenile queen scallops (*Aequipecten opercularis* L.). *Journal of Experimental Marine Biology and Ecology.* 313(2):241–254.

62. Compton TJ, Morrison MA, Leathwick JR, Carbines GD. 2012. Ontogenetic habitat associations of a demersal fish species, *Pagrus auratus*, identified using boosted regression trees. *Marine Ecology Progress Series.* 462(219–230).

63. Parsons DM, Morrison MA, Thrush SF, et al. 2013. The influence of habitat structure on juvenile fish in a New Zealand estuary. *Marine Ecology.* 34(4):492–500.

64. Diaz RJ, Cutter GR, Jr., Able KW. 2003. The Importance of physical and biogenic structure to juvenile fishes on the shallow inner continental shelf. *Estuaries.* 26(1):12–20.

65. Lohrer AM, McCartain LD, Buckthought D, MacDonald I, Parsons DM. 2018. Benthic structure and pelagic food sources determine post-settlement snapper (*Chrysophrys auratus*) abundance. *Frontiers in Marine Science.* 5:427.

66. National Research Council. 2002. Effects of trawling and dredging on seafloor habitat. Washington, DC: The National Academies Press, 126 pp.

67. Collie J, Hiddink J, van Kooten T, et al. 2017. Indirect effects of bottom fishing on the productivity of marine fish. *Fish and Fisheries.* 18(4).

68. Kaiser MJ, Spencer BE. 1994. Fish scavenging behaviour in recently trawled areas. *Marine Ecology Progress Series.* 112:41–49.

69. Ryer CH, Stoner AW, Titgen RH. 2004. Behavioral mechanisms underlying the refuge value of benthic habitat structure for two flatfishes with differing anti-predator strategies. *Marine Ecology Progress Series.* 268:231–243.

70. Tupper M, Boutilier RG. 1995. Effects of habitat on settlement, growth, and postsettlement survival of Atlantic cod (*Gadus morhua*). *Canadian Journal of Fisheries and Aquatic Sciences.* 52(9):1834–1841.

71. Laprise R, Blaber SJM. 1992. Predation by Moses perch, *Lutjanus russelli*, and blue-spotted trevally, *Caranx bucculentus*, on juvenile brown tiger prawn, *Penaeus esculentus*: effects of habitat structure and time of day. *Journal of Fish Biology.* 40(4):627–635.

72. Parsons DM, MacDonald I, Buckthought D, Middleton C. 2018. Do nursery habitats provide shelter from flow for juvenile fish? *PLoS ONE.* 13(1):e0186889.

73. Pirtle JL, Eckert GL, Stoner AW. 2012. Habitat structure influences the survival and predator-prey interactions of early juvenile red king crab *Paralithodes camtschaticus*. *Marine Ecology Progress Series.* 465:169–184.

74. Black KP, Parry GD. 1994. Sediment transport rates and sediment disturbance due to scallop dredging in Port Phillip Bay. *Memoirs of the Queensland Museum.* 36(2):327–341.

75. Black KP, Parry GD. 1999. Entrainment, dispersal, and settlement of scallop dredge sediment plumes: field measurements and numerical modelling. *Canadian Journal of Fisheries and Aquatic Sciences.* 56(12):2271–2281.

76. Kaiser MJ, Collie JS, Hall SJ, Jennings S, Poiner IR. 2003. Impacts of fishing gear on marine benthic habitats. In: Sinclair M, Valdimarsson G, eds. *Responsible Fisheries in the Marine Ecosystem*. Wallingford: CABI Publishing:197–218.

77. Blackburn TH. 1997. Release of nitrogen compounds following resuspension of sediment: model predictions. *Journal of Marine Systems.* 11(3–4):343–352.

78. Sloth NP, Riemann B, Nielsen LP, Blackburn TH. 1996. Resilience of pelagic and benthic microbial communities to sediment resuspension in a coastal ecosystem, Knebel Vig, Denmark. *Estuarine, Coastal and Shelf Science.* 42(4):405–415.

79. Duplisea DE, Jennings S, Malcolm SJ, Parker R, Sivyer DB. 2001. Modelling potential impacts of bottom trawl fisheries on soft sediment biogeochemistry in the North Sea. *Geochemical Transactions.* 2:112.

80. Tsikopoulou I, Smith CJ, Papadopoulou KN, Austen MC. 2022. Linking species functional traits to specific biogeochemical processes under trawling pressure. *Biology.* 11(10):1378.

81. Lohrer AM, Thrush SF, Gibbs MM. 2004. Bioturbators enhance ecosystem function through complex biogeochemical interactions. *Nature.* 431(7012):1092–1095.

82. Epstein G, Middlelburg JJ, Hawkins J, Norris C, Roberts CM. 2022. The impact of mobile demersal fishing on carbon storage in seabed sediments. *Global Change Biology.* 28(9):2875–2894.

83. Lambert GI, Murray LG, Hiddink JG, Hinz H, Salmononsen H, Kaiser MJ. 2015. Impact of scallop dredging on benthic communities and habitats in the Cardigan Bay Special Area of Conservation. Part I – impact on infaunal invertebrates. Fisheries & Conservation report no. 59. Bangor Univeristy, 73 pp.

84. Sciberras M, Hiddink JG, Jennings S, et al. 2018. Response of benthic fauna to experimental bottom fishing: A global meta-analysis. *Fish and Fisheries.* 19(4):698–715.

85. Lambert GI, Jennings S, Kaiser MJ, Davies TW, Hiddink JG. 2014. Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing. *Journal of Applied Ecology.* 51(5):1326–1336.

86. Stokesbury KDE, Harris BP. 2006. Impact of limited short-term sea scallop fishery on epibenthic community of Georges Bank closed areas. *Marine Ecology Progress Series.* 307:85–100.

87. Hiddink JG, Jennings S, Sciberras M, et al. 2017. Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. *PNAS.* 114(31):8301–8306.

88. Bryce DB-S, Belinda JV, Matthew WJM, Helen LR, Andrew RB. 2005. Benefits of closed area protection for a population of scallops. *Marine Ecology Progress Series.* 298:189–204.

89. Paul LJ. 2012. A history of the Firth of Thames dredge fishery for mussels: use and abuse of a coastal resource. New Zealand Aquatic Environment and Biodiversity Report no. 94. Wellington, New Zealand: Ministry of Agriculture and Forestry, 27 pp.

90. Newell RC, Seiderer LJ, Hitchcock. 1998. The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. *Oceanography and Marine Biology: An Annual Review.* 36:127–178.

91. ICES. 2016. Effects of extraction of marine sediments on the marine environment 2005–2011. ICES Cooperative Research Report no. 330. Copehagen, Denmark: International Council for the Exploration of the Sea, 206 pp.

92. Pullar A, Hughes S. 2009. Project Next Generation: dredging methodology and disposal alternatives. Client report prepared for Port Otago Ltd. 53 pp.

93. van Rijn LC. 2019. Turbidity due to dredging and dumping of sediments. Available at: https://www.leovanrijn-sediment.com/papers/Turbiditydredging2020.pdf (Accessed

94. Pitcher CR, Hiddink JG, Jennings S, et al. 2022. Trawl impacts on the relative status of biotic communities of seabed sedimentary habitats in 24 regions worldwide. *Proceedings of the National Academy of Sciences.* 119(2):e2109449119.

95. Erftemeijer PLA, Lewis RRR, III. 2006. Environmental impacts of dredging on seagrasses: a review. *Marine Pollution Bulletin.* 52(12):1553–1572.

96. Paavo B. 2007. *Soft-sediment benthos of Aramoana and Blueskin Bay (Otago, New Zealand) and effects of dredge-spoil disposal* [PhD]. Dunedin, New Zealand, University of Otago.

97. Halliday J, Hailes S, Hewitt J. 2008. Effect of dredge disposal on the benthic fauna of the Eastland Port offshore disposal ground, Poverty Bay. NIWA client report HAM2008-177 prepared for Eastland Port Ltde. Hamilton, New Zealand: National Institute of Water and Atmospheric Research Ltd, 34 pp.

98. Sneddon IR, Atalah J. 2018. Monitoring of benthic effects from dredge spoil disposal at sites offshore from Napier Port: 2018 survey. Nelson, New Zealand: Cawthron Institute, 62 pp.

99. Roberts RD, Forrest BM. 1999. Minimal impact from long-term dredge spoil disposal at a dispersive site in Tasman Bay, New Zealand. *New Zealand Journal of Marine and Freshwater Research.* 33(4):623–633.

100. West SA. 2010. Subtidal benthic biology monitoring of the 2009 dredgings disposal – post disposal report. Auckland, New Zealand: Bioresearches, 99 pp.

101. Edhouse S, Hailes SF, Carter KR. 2014. Effects of dredge spoil disposal on benthic fauna of the Eastland Port offshore disposal ground. NIWA report HAM2014-065 for Eastland Port Ltd. Hamilton: National Institute of Water and Atmospheric Research, 48 pp.

102. Smith S. 2008. Monitoring of benthic effects of dredge spoil disposal at sites offshore from the Port of Napier: 2007 survey. Environmental Assessments & Monitoring Ltd.

103. Smith S. 2013. Monitoring of benthic effects of dredge spoil disposal at sites offshore from the Port of Napier: 2012 survey. Napier, New Zealand: Triplefin Environmental Consulting, 41 pp.

104. Taranaki Regional Council. 2015. Port Taranaki Limited maintenance dredging monitoring report 2009–2014. Stratford, New Zealand.

105. Chartrand KM, Bryant CV, Carter AB, Ralph PJ, Rasheed MA. 2016. Light thresholds to prevent dredging impacts on the Great Barrier reef seagrass, *Zostera muelleri* ssp. *capricorni*. *Frontiers in Marine Science.* 3:106.

106. Essink K. 1999. Ecological effects of dumping of dredged sediments; options for management. *Journal of Coastal Conservation.* 5:69–80.

107. Lowe M, Morrison M, Taylor RB. 2015. Harmful effects of sediment-induced turbidity on juvenile fish in estuaries. *Marine Ecology Progress Series.* 539:241–254.

108. Wilber DH, Clarke DG. 2001. Biological effects of suspended sediments: a review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. *North American Journal of Fisheries Management.* 21(4):855–875.

109. Wenger AS, Harvey E, Wilson S, et al. 2017. A critical analysis of the direct effects of dredging on fish. *Fish and Fisheries.* 18(5):967–985.

110. Appleby JA, Scarratt DJ. 1989. Physical effects of suspended solids on marine and estuarine fish and shellfish, with special reference to ocean dumping: a literature review. Canadian Technical Report of Fisheries and Aquatic Sciences no. 1681. Nova Scotia, Canada: Department of Fisheries and Oceans, 33 pp.

111. Partridge GJ, Michael RJ. 2010. Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper *Pagrus auratus*. *Journal of Fish Biology.* 77(1):227–240.

112. Coppede Cussioli M. 2018. *Ecological effects of turbidity variations in and around dredging areas in the Port of Tauranga* [PhD]. Hamilton, New Zealand, The University of Waikato.

113. Hewitt JE, Norkko J. 2007. Incorporating temporal variability of stressors into studies: An example using suspension-feeding bivalves and elevated suspended sediment concentrations. *Journal of Experimental Marine Biology and Ecology.* 341(1):131–141.

114. Nicholls P, Hewitt J, Halliday J. 2003. Effects of suspended sediment concentrations on suspension and deposit feeding marine macrofauna. NIWA client report HAM2003-077 for Auckland Regional Council. Hamilton: National Institute of Water and Atmospheric Research.

115. Ellis J, Cummings V, Hewitt J, Thrush S, Norkko A. 2002. Determining effects of suspended sediment on condition of a suspension feeding bivalve (*Atrina zelandica*): results of a survey, a laboratory experiment and a field transplant experiment. *Journal of Experimental Marine Biology and Ecology.* 267(2):147–174.

116. Gibbs M, Hewitt J. 2004. Effects of sedimentation on macrofaunal communities: a synthesis of research studies for ARC. Auckland Regional Council Technical Publication 264. Auckland: Auckland Regional Council, 48 pp.

117. ANZG. 2018. Australian and New Zealand guidelines for fresh and marine water quality. Canberra, ACT, Australia: Australian and New Zealand Governments and Australian state and territory governments.

118. WRC. 2020. Pollutants in sediments. Available at: https://www.waikatoregion.govt.nz/environment/coast/coast-monitoring/pollutants-in-sediments-report/ (Accessed

119. van Dalfsen JA, Essink K, Madsen HT, Birklund J, Romero J, Manzanera M. 2000. Differential response of macrozoobenthos to marine sand extraction in the North Sea and the Western Mediterranean. *ICES Journal of Marine Science.* 57(5):1439–1445.

120. Sardá R, Pinedo S, Gremare A, Taboada S. 2000. Changes in the dynamics of shallow sandy-bottom assemblages due to sand extraction in the Catalan Western Mediterranean Sea. *ICES Journal of Marine Science.* 57(5):1446–1453.

121. Cooper K, Boyd S, Eggleton J, Limpenny D, Rees H, Vanstaen K. 2007. Recovery of the seabed following marine aggregate dredging on the Hastings Shingle Bank off the southeast coast of England. *Estuarine, Coastal and Shelf Science.* 75(4):547–558.

122. 1964. Toheroa farming possible. *Commercial fishing.* 3(2):23.

123. Boyd SE, Limpenny DS, Rees HL, Cooper KM. 2005. The effects of marine sand and gravel extraction on the macrobenthos at a commercial dredging site (results 6 years post-dredging). *ICES Journal of Marine Science.* 62(2):145–162.

124. Heery EC, Bishop MJ, Critchley LP, et al. 2017. Identifying the consequences of ocean sprawl for sedimentary habitats. *Journal of Experimental Marine Biology and Ecology.* 492:31–48.

125. Bishop MJ, Mayer-Pinto M, Airoldi L, et al. 2017. Effects of ocean sprawl on ecological connectivity: impacts and solutions. *Journal of Experimental Marine Biology and Ecology.* 492:7–30.

126. Iannuzzi TJ, Weinstein MP, Sellner KG, Barrett JC. 1996. Habitat disturbance and marina development: an assessment of ecological effects. I. Changes in primary production due to dredging and marina construction. *Estuaries.* 19(2):257–271.

127. Burdick DM, Short FT. 1999. The Effects of boat docks on eelgrass beds in coastal waters of Massachusetts. *Environmental Management.* 23(2):231–240.

128. Rivero NK, Dafforn KA, Coleman MA, Johnston EL. 2013. Environmental and ecological changes associated with a marina. *Biofouling.* 29(7):803–815.

129. McKenzie JS. 2014. *Predicted hydrodynamic and sediment transport impacts of breakwater construction in Tauranga Harbour, New Zealand* [MSc]. Hamilton, New Zealand, University of Waikato.

130. Munari C, Corbau C, Simeoni U, Mistri M. 2011. Coastal defence through low crested breakwater structures: jumping out of the frying pan into the fire? *Marine Pollution Bulletin.* 62(8):1641–1651.

131. Bertasi F, Colangelo M, Abbiati M, Ceccherelli V. 2007. Effects of an artificial protection structure on the sandy shore macrofaunal community: the special case of Lido di Dante (Northern Adriatic Sea). *Hydrobiologia.* 586(1):277–290.

132. Reeve G. 2008. *Sedimentation and hydrodynamics of Whitianga Estuary* [MSc]. Hamilton, University of Waikato.

133. Floerl O, Inglis GJ. 2003. Boat harbour design can exacerbate hull fouling. *Austral Ecology.* 28(2):116–127.

134. Reinen-Hamill R. 2021. Vision for growth port development: coastal process assessment. Tonkin and Taylor report prepared for Northport Ltd.

135. 1974. Toheroa populations show increases *Catch.* 1(3):4-5.

136. Martin D, Bertasi F, Colangelo MA, et al. 2005. Ecological impact of coastal defence structures on sediment and mobile fauna: evaluating and forecasting consequences of unavoidable modifications of native habitats. *Coastal Engineering.* 52(10):1027–1051.

137. Lechner A, Keckeis H, Schludermann E, et al. 2013. Shoreline configurations affect dispersal patterns of fish larvae in a large river. *ICES Journal of Marine Science.* 71(4):930–942.

138. AQNZ. no date. Aquaculture New Zealand. Available at: https://www.aquaculture.org.nz/ (Accessed

139. Fisher E. 1993. Mussel power. New Zealand Geographic. Available at: https://www.nzgeo.com/stories/mussel-power/ (Accessed Feb 2022).

140. MPI. 2013. Literature review of the ecological effects of aquaculture. Nelson, New Zealand: Ministry for Primary Industries.

141. Keeley N. Benthic effects. Nelson, New Zealand: Ministry for Primary Industries; 2013:3-1–3-33.

142. Keeley N, Forrest BM, Hopkins G, et al. 2009. Sustainable aquaculture in New Zealand: reivew of the ecological effects of farming shellfish and other non-finfish species. Cawthron Institute report no. 1476 prepared for the Ministry of Fisheries. Nelson, New Zealand: Cawthron Institute, 150 pp.

143. Forrest BM, Elmetri I, Clark K. 2007. Review of the ecological effects of intertidal oyster aquaculture. Nelson: Cawthron Institute.

144. Plew D. Hydrodynamic effects. Nelson, New Zealand: Ministry for Primary Industries; 2013:11.01–11.23.

145. McKindsey CW, Archambault P, Callier MD, Olivier F. 2011. Influence of suspended and off-bottom mussel culture on the sea bottom and benthic habitats: a review. *Canadian Journal of Zoology.* 89(7):622–646.

146. Forrest BM, Creese RG. 2006. Benthic impacts of intertidal oyster culture, with consideration of taxonomic sufficiency. *Environmental Monitoring and Assessment.* 112(1–3):159–176.

147. Everett RA, Ruiz GM, Carlton JT. 1995. Effect of oyster mariculture on submerged aquatic vegetation: an experimental test in a Pacific Northwest estuary. *Marine Ecology Progress Series.* 125:205–217.

148. Bulmer RH, Kelly S, Jeffs A. 2012. Hanging basket oyster farming: assessing effects on seagrass using aerial photography. *Aquaculture Environment Interactions.* 2:285–292.

149. Matisson J, Lindén O. 1983. Benthic macrofauna succession under mussels, *Mytilus edulis* L. (Bivalvia), cultured on hanging long-lines. *Sarsia.* 68(2):97–102.

150. Davidson RJ, Richards LA. 2014. Monitoring of a relocated mussel farm in Otanerau Bay, East Bay, Marlborough Sounds: 2002–2014. Survey and monitoring report no. 788 prepared for Marlborough District Council. Nelson: Davidson Environmental Ltd, 57 pp.

151. Dodd J, Griffiths R, le Roux H, Russo M. 2020. Recreational boating and marketing monitor research June 2020. Maritime NZ, 35 pp.

152. Deter J, Lozupone X, Inacio A, Boissery P, Holon F. 2017. Boat anchoring pressure on coastal seabed: quantification and bias estimation using AIS data. *Marine Pollution Bulletin.* 123(1):175–181.

153. Broad A, Rees MJ, Davis AR. 2020. Anchor and chain scour as disturbance agents in benthic environments: trends in the literature and charting a course to more sustainable boating and shipping. *Marine Pollution Bulletin.* 161:111683.

154. Milazzo M, Badalamenti F, Ceccherelli G, Chemello R. 2004. Boat anchoring on *Posidonia oceanica* beds in a marine protected area (Italy, western Mediterranean): effect of anchor types in different anchoring stages. *Journal of Experimental Marine Biology and Ecology.* 299(1):51–62.

155. Francour P, Ganteaume A, Poulain M. 1999. Effects of boat anchoring in *Posidonia oceanica* seagrass beds in the Port-Cros National Park (north-western Mediterranean Sea). *Aquatic Conservation: Marine and Freshwater Ecosystems.* 9(4):391–400.

156. Creed JC, Amado Filho GM. 1999. Disturbance and recovery of the macroflora of a seagrass (*Halodule wrightii* Ascherson) meadow in the Abrolhos Marine National Park, Brazil: an experimental evaluation of anchor damage. *Journal of Experimental Marine Biology and Ecology.* 235(2):285–306.

157. Williams SL. 1988. *Thalassia testudinum* productivity and grazing by green turtles in a highly disturbed seagrass bed. *Marine Biology.* 98(3):447–455.

158. Collins KJ, Suonpää AM, Mallinson JJ. 2010. The impacts of anchoring and mooring in seagrass, Studland Bay, Dorset, UK. *International Journal of the Society for Underwater Technology.* 29(3):117–123.

159. Vázquez-Luis M, Borg JA, Morell C, Banach-Esteve Ga, Deudero S. 2015. Influence of boat anchoring on *Pinna nobilis*: a field experiment using mimic units. *Marine & Freshwater Research.* 66(9):786–794.

160. Walker DI, Lukatelich RJ, Bastyan G, McComb AJ. 1989. Effect of boat moorings on seagrass beds near Perth, Western Australia. *Aquatic Botany.* 36:69–77.

161. Ouisse V, Marchand-Jouravleff I, Fiandrino A, Feunteun E, Ysnel F. 2020. Swinging boat moorings: spatial heterogeneous damage to eelgrass beds in a tidal ecosystem. *Estuarine, Coastal and Shelf Science.* 235:106581.

162. Hastings K, Hesp P, Kendrick GA. 1995. Seagrass loss associated with boat moorings at Rottnest Island, Western Australia. *Ocean & Coastal Management.* 26(3):225–246.

163. Clark D, Crossett D. 2019. Subtidal seagrass surveys at Slipper and Great Mercury Islands. Waikato Regional Council Technical Report 2019/29. Hamilton: Waikato Regional Council, 54 pp.

164. Backhurst MK, Cole RG. 2000. Biological impacts of boating at Kawau Island, north-eastern New Zealand. *Journal of Environmental Management.* 60:239–251.

165. Hendriks IE, Tenan S, Tavecchia G, et al. 2013. Boat anchoring impacts coastal populations of the pen shell, the largest bivalve in the Mediterranean. *Biological Conservation.* 160:105–113.

166. Herbert RJH, Crowe TP, Bray S, Sheader M. 2009. Disturbance of intertidal soft sediment assemblages caused by swinging boat moorings. *Hydrobiologia.* 625(1):105–116.

167. Morrison MA, Lowe ML, Grant CM, et al. 2014. Seagrass meadows as biodiversity and productivity hotspots. Wellington: Ministry for Primary Industries, 147 pp.

168. Heck Jr KL, Orth RJ. 2006. Predation in seagrass beds. In: Larkum AWD, Orth RJ, Duarte C, eds. *Seagrasses: Biology, Ecology and Conservation*. Netherlands: Springer:537–550.

169. Widdows J, Pope ND, Brinsley MD, Asmus H, Asmus RM. 2008. Effects of seagrass beds (*Zostera noltii* and *Z. marina*) on near-bed hydrodynamics and sediment resuspension. *Marine Ecology Progress Series.* 358:125–136.

170. Reidenbach MA, Thomas EL. 2018. Influence of the seagrass, *Zostera marina*, on wave attenuation and bed shear stress within a shallow coastal bay. *Frontiers in Marine Science.* 5:397.

171. Ceccherelli G, Campo D, Milazzo M. 2007. Short-term response of the slow growing seagrass *Posidonia oceanica* to simulated anchor impact. *Marine Environmental Research.* 63(4):341–349.

172. Montefalcone M, Chiantore M, Lanzone A, Morri C, Albertelli G, Bianchi CN. 2008. BACI design reveals the decline of the seagrass *Posidonia oceanica* induced by anchoring. *Marine Pollution Bulletin.* 56(9):1637–1645.

173. Matheson FE, Reed J, Dos Santos VM, Mackay G, Cummings VJ. 2017. Seagrass rehabilitation: successful transplants and evaluation of methods at different spatial scales. *New Zealand Journal of Marine and Freshwater Research.* 51(1):96–109.

174. Hopkins GA. 2002. *Aspects of the biology of the horse mussel Atrina zelandica Gray in Doubtful Sound and off the Otago Coast, New Zealand* [MSc]. Dunedin, University of Otago.