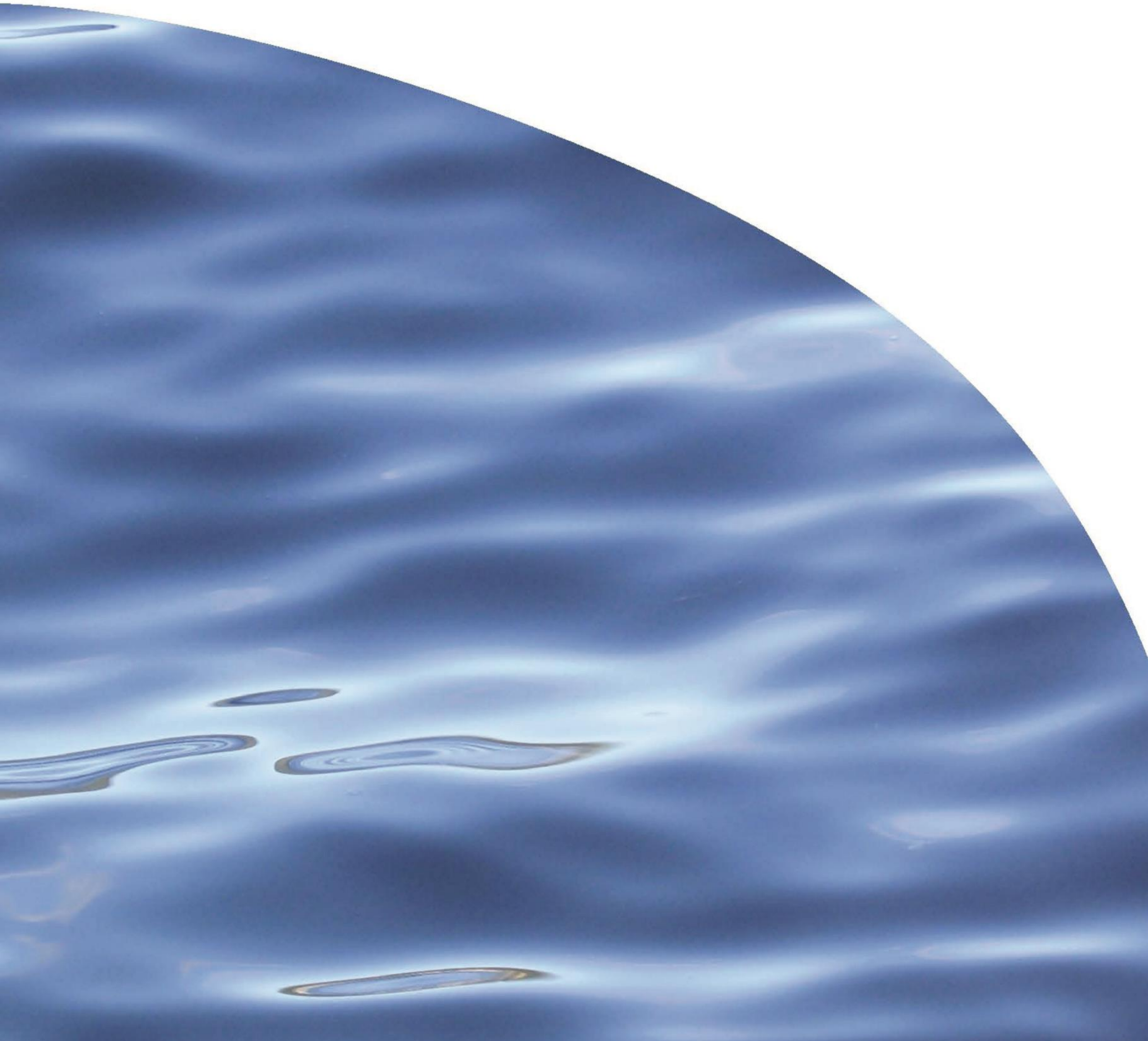
REPORT NO. 3098

EFFECTS OF MOORINGS ON DIFFERENT TYPES OF MARINE HABITAT



EFFECTS OF MOORINGS ON DIFFERENT TYPES OF MARINE HABITAT

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EXECUTIVE SUMMARY

There are over 3,000 swing moorings for boats in the Marlborough Sounds. Some seabed habitats are highly sensitive to any type of disturbance caused by swing moorings while others may be more resilient. Historically, some of Marlborough's swing moorings are likely to have been placed over areas of the seabed that are sensitive to damage. Marlborough District Council (MDC) has identified a need for a review of the effects of swing moorings on different subtidal habitats, and for guidelines to manage effects.

Block-and-chain swing moorings, which represent the large majority of moorings currently present in the Marlborough Sounds, consist of an anchor (usually a concrete block) to which is attached a heavy-gauge ground chain, an intermediate chain and a top ('riser') rope, with a large surface float. MDC's *Mooring construction guidelines* recommend that the length of chain used be equal to the depth of water at mean high water of spring tides, with one third of this chain to be ground chain. Conventional swing moorings can impact the seabed surrounding the anchor via the arc swept by the chain. In situations where a single mooring anchor is used, the mooring chain may be dragged repeatedly across the seabed through an arc of 360º around the anchor with changes in tidal movement and wind direction. Even in areas without conspicuous surface features, chain-scour will loosen sediments, making them more vulnerable to erosion and alteration of texture by water movement.

Habitats and species of particular ecological, cultural or conservation significance that are particularly sensitive to the effects of block-and-chain moorings include:

- rocky reefs and cobble fields (moorings are not likely to be located on these substrata but may be close enough that the reef is within the area swept by the chain)
- macroalgal beds (where these are growing on reef, moorings are not likely to be located within them but may be close enough that the bed is within the area swept by the chain)
- beds of rhodoliths, hydroids, bryozoans, shellfish, brachiopods, burrowing anemones or sea grass (eelgrass)
- sponge and bryozoan gardens
- tubeworm mounds, reefs and beds
- areas of shell hash (shell hash can provide important habitat diversity in soft sediments and chain sweep will enhance rates of breakdown of the hash)
- fish spawning and nursery areas not included in above (through direct destruction and through loss of structures to which eggs are attached and in which juveniles may shelter).

The simplest method for limiting adverse effects of swing moorings on significant seabed habitats and organisms is to restrict them to locations where they are absent, such as areas

of muddy or sandy sediment. However, disturbance to these habitats will impact the animals living within the sediment and could have adverse ecological effects, such as loss of feeding areas for fish. It is also important to note that current absence of significant habitats or species from an area of seabed may reflect the effects of past activities, such as trawling or dredging, and that removal of all these sources of disturbance would allow recovery of valued ecological features.

Alternative types of mooring can be use that are designed to avoid damage to the surrounding seabed. These typically employ an elastic component in the mooring line that takes up slack in the line at low tide or calm conditions, preventing the line/chain from lying on the seabed. Several studies in Australia have shown that these designs can prevent damage to sea grass beds and, when they replace block-and-chain moorings, allow recovery of the habitat.

We suggest the following guidelines for assessing consents for moorings:

1. No consents for new moorings in ecologically significant marine sites (ESMS) where the mooring will adversely affect the values on which the significance of the site is based.
2. Existing moorings in ESMS to be removed or converted to environmentally friendly moorings where the mooring has adversely affected the values on which the significance of the site is based.
3. Applications for all new consents or renewal of existing consents shall include a description of habitats in the vicinity of the mooring and identification of significant habitats or species present (to be documented with, for example, video or drop camera images).
4. New consents in locations outside ESMS but where significant habitats or species are present shall require environmentally friendly moorings.
5. Existing moorings located in areas with significant habitats or species nearby shall be converted to environmentally friendly moorings or removed if damage is occurring. This includes cases where a significant species or habitat, such as eelgrass or horse mussels, is present within the mooring field but outside of the areas of chain sweep, or in areas around the mooring field, when such species or habitats may be expected to recolonise the impacted areas if ground chains are removed.
6. New consents to have moorings preferentially in areas of mud or sand seabed with no specific ecological, conservation or traditional value.

Application of these guidelines requires information on the nature of the seabed in the vicinity of the proposed (or existing) mooring and identification of significant habitats and organisms present. Guideline 3 is intended to ensure that suitable information is provided with the consent application to allow application of the other guidelines and this, and the second guideline, have already been used in recent consent approvals. MDC has recently mapped and classified benthic habitats in Queen Charlotte Sound and Tory Channel using groundtruthed multibeam sonar[1]. This information will inform consent decisions in terms of the physical nature of the seabed environment.

We also recognise that, were larger-scale forms of disturbance (dredging, trawling, etc.) to be reduced in areas of soft-sediment seabed, mooring chain disturbance would appear relatively more important as a driver of seabed health.

Given the higher cost of environmentally friendly moorings (by a factor of two or more), demonstrations of their reliability and effectiveness, both in holding vessels and in protecting the seabed, is likely to be a significant factor in their uptake by vessel owners. Standards and quality-management systems for the manufacture and installation of moorings would provide confidence to vessel owners and insurers. MDC may also wish to consider facilitating demonstrations of potentially suitable moorings, in collaboration with mooring manufacturers and installers, vessel owners and other stakeholders.

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[1] For further information, see: www.marlborough.govt.nz/environment/coastal/seabed-habitat-mapping/totaranuiqueen-charlotte-sound-seabed-mapping

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1. BACKGROUND AND SCOPE

There are over 3,000 swing moorings for boats in the Marlborough Sounds. Some of these are likely to be placed over areas of the seabed that are sensitive to damage, such as biogenic habitats[2]. Some seabed habitats are highly sensitive to any type of disturbance caused by swing moorings while others may be more resilient. There are bays in the Marlborough Sounds containing high concentrations of moorings that, individually, may have relatively minor effects but may be having a significant cumulative effect. Waikawa Bay, for example, has moorings over a predominantly mud substratum. We understand that some local iwi view this as unacceptable and would like these replaced by mooring systems that do not disturb the seabed to reduce perceived cumulative effects from repeated disturbance. Environmentally sensitive moorings are designed to reduce disturbance to the seafloor, protect benthic (seabed) organisms and habitats.

Marlborough District Council (MDC) has identified a need for a review of the effects of swing moorings on different seabed habitats, and for guidelines to manage effects. In some situations, swing moorings may cause localised damage while, at the same time, prevent larger-scale adverse effects from other activities, such as dredging and bottom trawling in the vicinity of the mooring.

Marlborough District Council's recently notified Marlborough Environment Plan (MEP) contains two objectives aimed at protecting and enhancing marine biodiversity:

8.1 Marlborough's remaining indigenous biodiversity in terrestrial, freshwater and coastal environments is protected.
8.2 An increase in area / extent of Marlborough's indigenous biodiversity and restoration or improvement in the condition of areas that have been degraded.

The MEP gives effect to Objectives 8.1 and 8.2 in part through a rule (Rule 16.7.5) that prohibits 'fishing activity that uses a technique that disturbs the seabed' (including dredging and bottom trawling) in marine sites assessed as ecologically significant (see Section 3.1.3 of this report for a definition of these sites). However, this prohibition does not include other forms of seabed disturbance, such as anchoring and mooring that may have adverse effects on seabed habitats and organisms.

Following public submissions challenging the MEP, its implementation is awaiting a decision by the Hearings Panel in 2018. Consequently, Rule 16.7.5 has not yet been given legal effect. The Marlborough Sounds Resource Management Plan, which is currently in effect, does not contain any restrictions on seabed disturbance other than through the consenting process. A resource consent is required for a swing mooring

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[2] Biogenic habitats are those formed by living organisms, such as coral, tubeworm mounds, sponge gardens or rhodolith (calcareous red algal) beds.

or stern-tie mooring in the Marlborough District. Under statutory acknowledgement of their association with the area, each of the Te Tau Ihu iwi is informed of all resource consent applications in the Marlborough Sounds. One of the iwi has made submissions in response to recent resource consent applications, suggesting that traditional mooring chains be replaced by moorings that are more environmentally sensitive.

MDC therefore seeks to understand the relative ecological effects of different types of swing moorings. MDC would also like to understand which types of mooring are appropriate or inappropriate in each type of habitat and to identify situations in which more environmentally sensitive mooring systems would be preferable. The findings of such a study are also likely to be of value to other councils.

In summary, the information sought by MDC is as follows:

- An understanding of the relative ecological effects of different mooring technologies and of which types of mooring are appropriate or inappropriate in each type of habitat, i.e., to identify situations in which more environmentally sensitive mooring systems would be preferable.
- A characterisation of seabed habitats based on sensitivity and risk of damage by mooring, including habitat types absent or uncommon in the Marlborough District but present in other areas of New Zealand.

In this report we:

- review the structure of swing moorings and current guidelines on appropriate locations for them
- identify ecological effects of swing moorings
- identify which seabed habitat types are sensitive to which type of swing mooring
- assess the effects of swing moorings relative to other causes of disturbance to the seafloor in the Marlborough Sounds
- identify methods of mitigating and managing effects of swing moorings, including identifying habitats for which traditional moorings may still be appropriate.

2. MOORING STRUCTURE AND INSTALLATION

2.1. Mooring structure

The vast majority of moorings in the Marlborough Sounds are block-and-chain swing moorings (Peter Johnston, pers. comm., MDC). There are also some stern-tie moorings which typically use a block-and-chain mooring for the bow of the vessel, with the stern attached by a rope to an anchor (such as an embedded piece of railway iron or, less commonly, a tree) on the adjacent land. In addition, a relatively small number of moorings in the Sounds use a subsurface, elasticated element to keep the chain above the bed and reduce the swing radius. These are usually attached to concrete-block anchors, although they can be used with screw anchors. These alternatives to block-and-chain moorings are described in more detail in Section 5.3.

Conventional moorings are attached to a mooring block or weight (‘gravity anchor’) that relies on its mass and/or burial into the seabed to secure the mooring. Concrete block anchors are normally used for swing moorings in New Zealand, mainly because their resistance to loads in any horizontal direction and the minimal effects of corrosion on them (OCEL undated). Other anchoring options include mushroom anchors and helical screws, which achieve similar holding strength for lighter mass.

In conventional moorings, one end of a heavy-gauge, ground chain is attached to the anchor and the other end is attached to a lighter-gauge, intermediate chain. The intermediate chain attaches, via a swivel, to a top (‘riser’) rope or chain, with a large surface float and accompanying pendant for securing to the vessel (Figure 1). The catenary curve[3] given by the weight of the chain to the mooring line creates a reduced angle of pull on the anchor, increasing the level of force it will resist before dragging. The greater the excess chain length (and the heavier its weight), the more effective the catenary effect; however, this must be balanced against the increasing arc of vessel swing, which limits mooring density.

There is currently no national or regional marine-industry standard design for moorings in New Zealand (OCEL undated). However, mooring specifications and guidelines have been developed by regional and district councils, including MDC. Northland Regional Council has developed mooring guidelines in collaboration with Auckland Council, Waikato Regional Council and mooring contractors (OCEL undated). The various guidelines developed by councils are consistent in the general design of the moorings (Figure 1) but differ in some details, such as the lengths of the chain components.

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[3] The curve that a hanging chain assumes when supported at its ends.

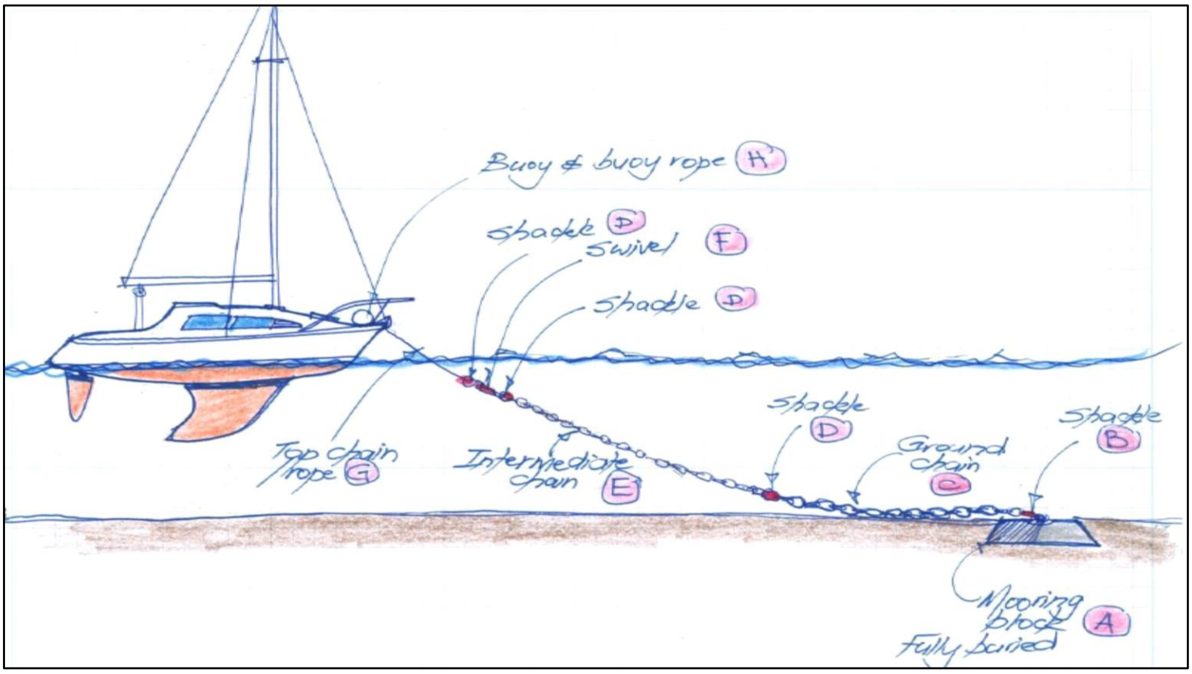

Figure 1. Conventional block-and-chain mooring system for small vessels. The mooring consists of an anchor block (A), shackle and ground chain (B, C), shackle and intermediate chain (D, E), shackles, swivel and top (‘riser’) chain or rope (D, F, G) and buoy and buoy rope (H). Source: OCEL (undated).

MDC’s *Mooring construction guidelines* (see Appendix 1) recommend that the length of chain used be equal to the depth of water at mean high water of spring tides, with one third of this chain to be ground chain. The length of the top rope should also be equal to the depth of water at mean high water of spring tides, making the total length of chain and rope equal to twice the depth of water at mean high water of spring tides. The guidelines also specify the weight of the mooring block and the diameters of chains and ropes, according to the size of vessel.

Screw anchors differ from gravity anchors in that they can accommodate high vertical loads at the anchor position (OCEL undated). Consequently, chain is not required to convert vertical loading at the point where the line attaches to the vessel into horizontal loading at the attachment to the anchor.

Moorings and their anchors may be placed independently or in multiple arrangements to increase holding ability and decrease the vessel’s swing arc, depending on the specific site conditions and required mooring densities.

2.2. Location and installation of moorings

Practicality dictates that swing moorings for small vessels in the Marlborough Sounds are located in sheltered locations with minimal wave exposure, generally near the shore in bays or the fringes of the main reaches of the Sounds. Applicants for a consent to install a mooring in the Marlborough District must provide an assessment of effects of the mooring on the following:

- maritime safety, including location relative to navigational routes, existing moorings, jetties, launching ramps and marine farms
- recreational values and casual anchoring, including location relative to areas used for swimming, kayaking, diving, fishing and water-skiing
- amenity values, including established appearance and uses of the area, presence and types of other moorings, vessels or man-made structures
- utilities, including underwater cables
- land-based facilities, including requirement for a launching ramp, boatshed or similar and the parking of vehicles, dinghies and/or trailer parking on public land
- marine ecology, including whether the vessel to be moored has sewage treatment or holding tanks, whether the mooring is designed to prevent seabed disturbance by the dragging of the mooring tackle, and whether it is located within an identified area of ecological significance (see Section 3.1.3).

Gravity anchors, such as concrete mooring blocks, are lowered to the seafloor from a vessel and must be embedded in the seabed. Gravity anchors derive their resistance to being dragged from a combination of frictional resistance to sliding over the seabed and passive ‘earth pressure’ resistance to lateral movement through the sediment in which it is buried. The block needs to displace sediment and water as it enters the seabed and it may need to be buried by dragging or applying jets of water or air to liquefy the sediment around it to ensure that it is securely embedded. Burial also reduces the risk that the block will be hit by the keels of boats.

Although currently much less commonly used for swing moorings than gravity anchors, screw anchors do not require to be set or dragged to develop their full anchoring potential. They are screwed vertically into the sediment by an installation tool (auger driver) deployed from a workboat or barge.

3. ECOLOGICAL EFFECTS OF MOORINGS ON SEABED HABITATS

3.1. Direct physical disturbance

Direct physical disturbance has been identified as one of the principal threats to New Zealand marine habitats (MacDiarmid et al. 2012). In the Marlborough Sounds, the total area of significant marine sites has declined by c. 215 ha between 2011 and 2016 (Davidson & Richards 2016: it should be noted that much of the information used to assess the significance of sites was collected in the 1980s, so the period of change is likely to be longer than 2011–2016). Some of these losses were the result of the partial or complete removal (i.e. loss of those values that conferred significance) of an entire site (namely loss of a horse mussel bed), and loss of status as the best example of an estuary due to sedimentation from the catchment. In addition, the areas of some individual sites have declined by 27%–96% (Davidson & Richards 2015). Davidson and Richards (2015) suggested that much of this loss was due to anthropogenic effects such as trawling, dredging and sedimentation and that remaining areas are remnants of larger areas reduced or lost due to previous anthropogenic activities.

Physical disturbance of subtidal marine habitats can be characterised in terms of both intensity and severity. The intensity of a disturbance may be defined as the physical force of an event per unit area, per unit time. The severity is the impact on a particular organism, community or ecosystem; at the individual level this might be expressed as the energetic costs of rebuilding a burrow, at the population level as the proportion of individuals killed or at the community level, by a change in species diversity (Hall 1994).

Sources of physical disturbance and sediment transport include natural hydrodynamic processes, biological activities of the animals that live in, on or close to the sediment, and anthropogenic disturbances. The hydrodynamic regime (mainly tidal and wind-driven currents) of an area largely determines its sedimentary characteristics and consequently its broad-scale community patterns (Hall 1994). The physical nature and resulting community structure may be further disturbed or influenced by the organisms that live there through activities such as burrowing, grazing and the formation of biogenic habitats such as tubeworm and bryozoan reefs and shellfish beds (Wright & Jones 2006).

Impacts of anthropogenic disturbance can often be high in terms of both their intensity, severity and extent (Tuck et al. 2017). Many of the structure-forming species, as well as other species that serve important functional roles on the seafloor, are sensitive to physical disturbance. Biological traits (e.g., morphology, life history, dispersal characteristics) can determine both the sensitivity of different species to the disturbance impact, and to their ability to recolonise disturbed habitats (Lundquist et al. 2013).

In general, high rates of disturbance to benthic communities reduce habitat structure, resulting in homogenous, simple, low diversity communities, the loss of large and long-lived sedentary species that create habitat structure, and associated reductions in primary production and ecosystem function (Handley et al. 2014). Estimating the relative impact of a particular physical disturbance on seabed habitats requires a prior understanding of co-occurring natural and anthropogenic processes of disturbance. These dynamics are rarely well understood.

3.1.1. Disturbance caused by installation of moorings

Installation of anchors, particularly gravity anchors such as concrete blocks, will cause temporary disturbance of the seabed at and immediately around the mooring location. Some of this disturbance will be short-lived (weeks or months) but there will be a small, permanent loss of soft sediment habitat. This loss will be slightly larger for gravity anchors than for screw anchors.

Irrespective of type, installation of an individual anchor will directly impact a relatively small area of the seabed, and the accompanying biological communities. Even at maximum mooring densities, the anchors themselves will have a small benthic footprint.

Their relatively small size, low profile, and low density, coupled with moderate water depths, also means that mooring anchors will likely have only very localised and negligible influences upon water circulation.

3.1.2. Direct disturbance caused by mooring-chain scour

Conventional swing moorings can impact the seabed surrounding the anchor via the arc swept by the chain (Demers et al. 2013; Unsworth et al. 2017). Chains are necessarily long to allow for tidal rise and fall and to form a catenary against lift and shock loading from the moored vessel under the influence of wave action. In situations where a single mooring anchor is used, the mooring chain may be dragged repeatedly across the seabed through an arc of 360º around the anchor with changes in tidal movement and wind direction. With repeated scouring, the mooring chain can clear a circular mooring scar in the surrounding seabed (Figure 2).

Figure 2. Areas of sea grass (*Posidonia* / *Zostera* / *Halophila*) damaged by swing moorings in Manley Cove, New South Wales. Source: Bowman (2008).

Previous Cawthron studies have identified physical mooring scars associated with swing moorings in Waikawa Bay, in the Marlborough Sounds (Figure 3). Based on the construction guidelines for moorings in Marlborough, the radius of the area swept by the ground chain will be one third of the water depth at mean high water springs. In 10 m water depth, the area swept will be c. 35 m^2, c. 79 m^2 in 15 m depth, and c. 140 m^2 in 20 m depth. These areas may, however, be underestimates. Demers et al. (2013) estimated that the area of damaged seagrass around each mooring was 254 m^2 at a location in New South Wales where swing moorings had been in place for 30 years in water of 3–6 m deep. Further information on the scale of effects of moorings in Queen Charlotte Sound is likely to be provided by the recent multibeam survey commissioned by MDC[4].

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[4] www.marlborough.govt.nz/environment/coastal/seabed-habitat-mapping/totaranuiqueen-charlotte-sound-seabed-mapping

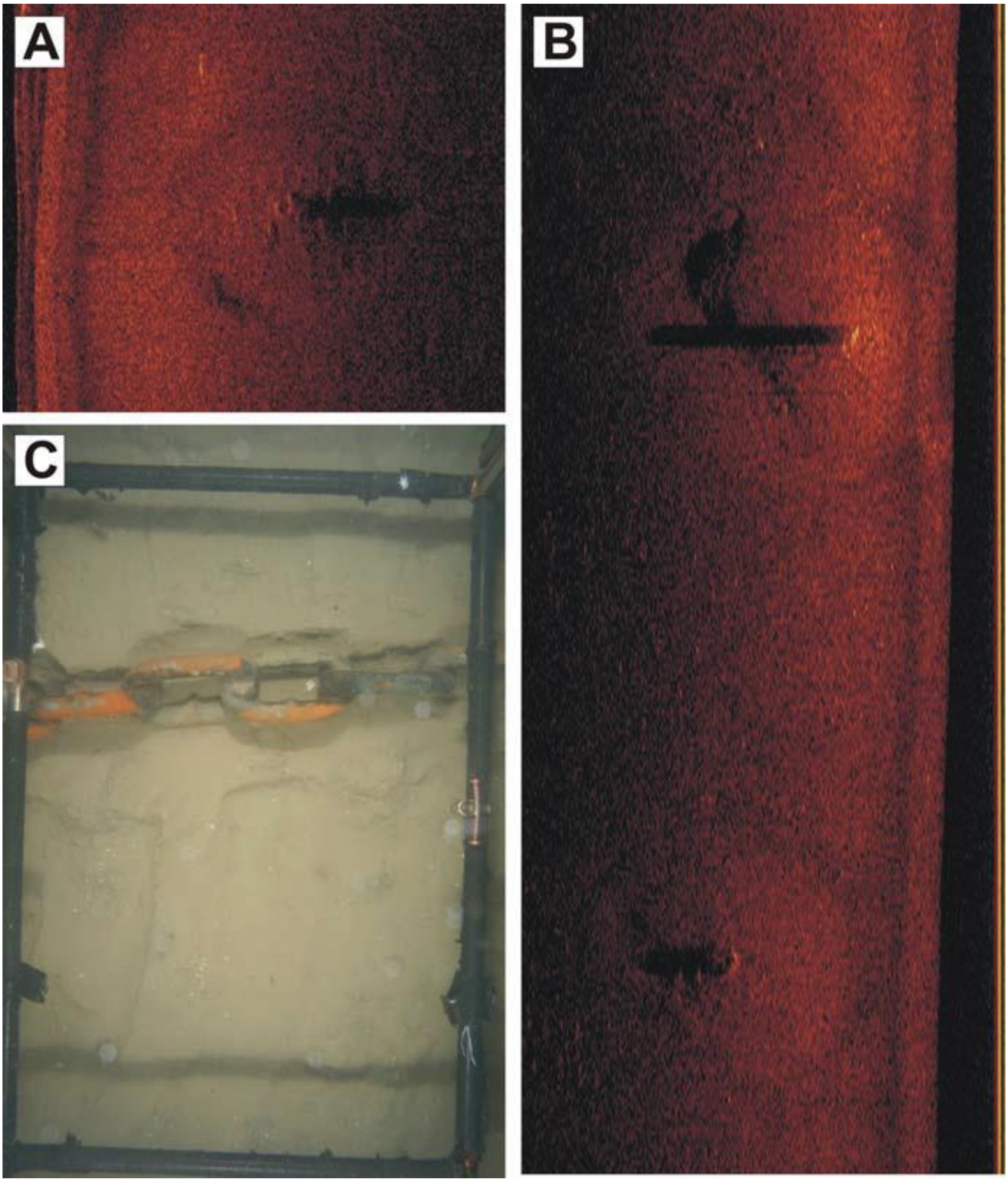

Figure 3. Chain sweep effects of moorings in Waikawa Bay. Images A and B show side-scan sonar images of circular seabed mooring scars and sonar shadows cast by the central mooring blocks. Scars are 14–20 m in diameter in water depths of 8-14 m. Image C shows a drop-camera image of an *in situ* mooring chain, illustrating the sweep imprint in soft mud / sand substrate. Source: Sneddon (2010).

The formation of mooring scars has been identified as an issue of concern overseas for benthic areas characterised by high conservation value biogenic features (e.g. sea grasses, corals, shellfish beds: Demers et al. 2013; Unsworth et al. 2017). Frequent scraping of the surface sediments by mooring chains may directly damage organisms and also remove biogenic structures such as burrows, mats of benthic microalgae and beds of tubeworms.

3.1.3. Habitats and species vulnerable to direct disturbance by moorings

Work commissioned by MDC identified and described the ecological value of significant marine sites around the Marlborough Sounds area from Cape Soucis (Tasman Bay) to Willawa Point (East Coast) (Davidson et al. 2011)[5]. In addition to highlighting important species and specific environmental issues and threats across the region, the report also evaluated the ecological significance of various sites across nine biogeographic areas[6], based on an assessment of the following seven criteria:

1. representativeness – a good example of biological features
2. rarity – status of plants and animals and communities / habitats
3. diversity – a wide range of species and habitats
4. distinctiveness – ecological features that are unique or outstanding
5. size – how large the site was
6. connectivity – proximity to other significant areas
7. adjacent catchment modifications – protected native vegetation preferred.

A total of 129 ecologically significant sites were recognised and described in the report, based on the presence of ecologically important or rare species, or commercially or culturally valuable species.

A number of habitat types and species found in the Marlborough region are likely to be particularly vulnerable to physical disturbance from mooring structures due to their life history traits or proximity to suitable mooring areas. Davidson et al. (2015) identified 11 sites within the Marlborough region that they considered highly vulnerable with such low natural tolerance for disturbance as to require complete protection. A further 60 sites were identified as vulnerable but could tolerate minor levels of disturbance such as occasional anchoring activity. Three more sites were identified that had lost their particular benthic values since surveys were carried out in 2011 and required rehabilitation. Davidson and Richards (2016) identified a further 11 significant marine sites across the Marlborough region, for five of which they have made recommendations for complete protection from all forms of physical disturbance.

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[5] The maps can be found at: https://maps.marlborough.govt.nz/smaps/?map=4f01102c6f934418a54a0b23ceddcb1f, accessed 2 November 2017.

[6] Area 3 represents Pelorus Sound, Area 4 Queen Charlotte Sound, Area 5 Tory Channel and Area 6 Port Underwood.

Biogenic habitats found in areas of soft sediments in Marlborough include red algal beds, rhodolith beds, sea grass beds, sponge gardens, hydroid beds, bryozoan gardens, tubeworm beds and mounds, and horse mussels and other shellfish beds. These are considered to be ecologically significant by Davidson et al. (2011) and their presence contributes to the recognition of ecologically significant sites. Individual soft-sediment species considered to be of ecological, cultural or conservation significance include the endemic red alga *Adamsiella chauvinii*, burrowing anemones, giant lampshells and scallops. These habitats and species are described below, including their significance in the Marlborough District (Davidson et al. 2011).

Swing moorings for small vessels are usually located in areas subject to low wave exposure. Such areas tend to support species, habitats and communities that are vulnerable to physical disturbance, are slow growing and/or are limited in spatial extent (Davidson et al. 2015). The predominant type of mooring used in the Marlborough District—gravity anchors with chains and rope—is usually placed on soft sediments so that the anchor can embed itself in the seafloor. Any biogenic structures or individual organism protruding above the sediment surface within the area swept by the ground chain of a swing-mooring is likely to be destroyed. The continued presence of the mooring will also prevent recolonisation.

Although moorings are unlikely to be located on areas of rocky reef or cobble (because of their reduced holding capacity on these substrata), they could be positioned close enough that adjacent hard substrata are swept by the ground chain. In this case any organisms present are likely to be destroyed and recolonisation prevented. This will include habitat-forming species such as macroalgae and turfing algae, and encrusting species such as sponges, anemones, ascidians, tubeworms, oysters and mussels. Mobile species, such as crayfish, gastropods, kina and starfish will be excluded for at least part of the time.

Red algal beds

The red algae *Adamsiella chauvinii* and *Rhodymenia* spp. can form dense beds 15-20 cm in height. They occur on a variety of substrata including rock, tube worm colonies, horse mussel shells, sand and mud. In Marlborough, particularly dense beds exist in areas of Port Underwood, East Bay, Grove Arm and inner Queen Charlotte Sound.

A. chauvinii is regarded as a significant species in Marlborough because its dense beds provide biogenic habitat for a variety of species including bivalves, holothurians and fish, and spawning areas for rough skate and elephant fish. Beds of *Rhodymenia* spp. provide an important food source for a variety of species including urchins and herbivorous fish. Red algal beds likely also affect sediment stability and the cycling of nutrients between seabed and water column.

Specific threats to these species are unknown but the local direct impacts of physical disturbance may be significant.

Rhodolith beds

Rhodoliths (*Lithothamnion* spp.) are free-living growths of calcareous algae which form distinct beds on hard substrate interspersed across soft sediments. Open-branching growth forms are common in sheltered environments. In Marlborough, significant rhodolith beds are known from a small number of locations including Picnic Bay, in Pelorus Sound and Ponganui Bay and Catherine Cove on D'Urville Island. Rhodoliths beds enhance local biodiversity by increasing habitat complexity and providing biogenic habitat for algae and invertebrates.

Specific threats to these species are unknown but, due to the delicate structure and relatively slow growth of rhodoliths, the local direct impacts of physical disturbance may be significant.

Sea grass beds

Sea grass, or eelgrass, *Zostera muelleri* grows in intertidal and shallow subtidal areas on silty or sandy tidal flats, channels and river mouths in estuaries and, less commonly, coastal beaches and rocky reef platforms (Matheson et al. 2009). Sea grass meadows have been recorded throughout New Zealand, from Parengarenga Harbour in Northland to Cooks Inlet on Stewart Island (the southern limit for sea grass worldwide) (Green & Short 2003). The distribution of sea grass beds has not been surveyed in the Sounds but the beds are apparently more common and larger in Queen Charlotte Sound than in other areas (Davidson et al. 2010). However, Stevens and Robertson 2014 reported that extensive beds are now only present in the well-flushed areas of the lower Havelock estuary, between Cullen Point and Shag Point. Most beds occur in intertidal estuaries and gently sloping shores of sheltered parts of the Sounds. There is also a shallow subtidal bed in Tipi Bay in Tory Channel (Davidson et al. 2010).

Sea grass plays an important role in coastal environments, stabilising sediments, reducing erosion and improving water clarity. Sea grass absorbs nutrients from the water and seabed, releases oxygen and is an important constituent of nutrient cycling in the marine environment (Hailes 2006). It also provides important nursery habitats for snapper and leatherjacket juveniles and other species of fish (Morrison et al. 2014), as well as habitat for numerous small crustaceans and worms that are important sources of food for wading birds and fish (Woods & Schiel 1997).

Sea grass faces a range of major threats including the impacts of climate change, terrestrial sources of pollution, introduced species and direct physical damage from human activities. It is particularly susceptible to local physical disturbance and anything that reduces water clarity and light penetration for photosynthesis or increases sedimentation and eutrophication (Matheson et al. 2009). Damage from swing mooring chains exposes areas of bare sediment within sea grass beds, fragmenting the sea grass habitat and allowing increased erosion by water movement, potentially exacerbating loss of sea grass (Bowman 2008; Unsworth et al. 2017).

Damage to sea grass beds from swing moorings had been documented in Australia (e.g., Walker et al. 1989; Hastings et al. 1994; Demers et al. 2013) and various governmental and non-governmental programmes have been initiated there to reduce these impacts. These programmes involve assessments of the efficacy, and encouragement of the use, of alternatives to block-and-chain moorings[7].

Sponge gardens

Sponges are an important component of many coastal environments on rocky reefs and coarser soft sediments in higher current areas. Sponge habitats appear to play an important nursery function for juvenile snapper on reef and soft sediment habitats (Battershill 1987) and likely provide an important habitat for a wide variety of other fish species (Morrison et al. 2014). Their relative dominance increases with depth, as kelps, which dominate shallower areas, reach the limit of their light tolerance (Morrison et al. 2009). Multispecies 'biogenic clumps', consisting of combinations of sponges, bryozoans, ascidians, hydroids, horse mussels and whole, dead shells have been recorded at 14 sites throughout the Sounds in water depths from 10–60 m (Davidson et al. 2010). Locations included Tawhitinui Reach in Pelorus Sound, several locations in Tory Channel, and Trio Islands (east of D'Urville Island), where two relatively large areas of soft sediment support what appear to be the remnants of once abundant and higher-quality biogenic habitat that has been reduced by dredging and trawling.

As filter feeders, sponges are sensitive to increased suspended sediment loads (Lohrer et al. 2006) and the effects of physical disturbance are likely to be significant in many coastal areas (Morrison et al. 2014). Very little else is known about the specific threats to sponge habitats around New Zealand but, due to sponges' delicate structure and relatively slow growth, direct impacts of physical disturbance from other sources of physical disturbance are likely to be locally significant.

Hydroid beds

The tree hydroid *Solanderia ericopsis* is found all around New Zealand, at depths from 2–200 m. It occurs on boulders, cobbles and fine sediments throughout the Sounds, including the headlands of Tapapa Point, Tawero Point and Kauauroa Bay where there are strong tidal currents (Davidson et al. 2011). It provides habitat for a variety of invertebrate and fish species, including acting as a substratum for the 'primary settlement' phase of mussel larvae (Handley 2015).

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[7] See, for example (all accessed 31 October 2017):
http://www.seqcatchments.com.au/case-studies/mooring-trial-to-end-crop-circles-in-moreton-bay
https://www.dpi.nsw.gov.au/fishing/habitat/threats/traditional-boat-moorings-in-sensitive-habitats
http://sims.org.au/research/current-projects/sea grass-friendly-moorings/

As filter feeders, hydroids are sensitive to increased suspended sediment loads. Specific threats to this species are unknown but, due to the delicate structure and relatively slow growth, local direct impacts of physical disturbances are likely to be considerable.

Bryozoan gardens

Cellaporaria agglutinans, *Galeopsis* spp. and other species of colonial bryozoans have delicate, stony skeletons of calcium carbonate, similar in appearance to coral. In New Zealand *C. agglutinans* is also commonly known as Separation Point coral, Tasman Bay coral or hard coral. Bryozoan gardens occur between 3–220 m depth and can form reefs commonly up to half a metre in height. These species are relatively widespread across Marlborough and grow on rocky and soft sediment substrata in high current areas. Large, conspicuous colonies are known from areas in Current Basin, off Separation Point and Chetwode and the Titi islands.

They are important habitat-forming species, forming structurally complex reefs that provide habitat for a variety of species and nursery areas for commercially important fish species such as snapper, terakihi and John Dory. It is also likely that large reefs secure the substrate and modify flow, affecting local sediment composition and resulting ecological relationships.

Colonies are very brittle and vulnerable to damage and associated sedimentation from physical disturbance.

Tubeworm beds and mounds

A range of worm species create an amalgam of calcareous tubes of sufficient size and density to form biogenic mound or reef habitats (Morrison et al. 2014). Reefs can form over areas in excess of 100 m diameter and be relatively long-lived, in excess of 50 years (Morrison et al. 2009). A high diversity and abundance of algae, invertebrates and fish associate closely with healthy tubeworm reefs (Smith et al. 2005). Although the occurrence and extent of tubeworms mounds and reefs in Marlborough is largely unknown, tubeworm reefs have been identified at sites across the Sounds on both soft and hard seafloor, including areas of Perano Shoal, Queen Charlotte Sound and Port Underwood (Estcourt 1967; Davidson et al. 2010).

Tubeworms are suspension feeders, and excessive sedimentation may lower their fecundity, cause damage, or even kill them (Smith et al. 2005). Specific threats to this species are unknown but, due to the delicate structure and relatively slow growth of mound or reef formation, local direct impacts of physical disturbance are likely to be considerable.

Horse mussels beds

Horse mussels (*Atrina zelandica*) inhabit muddy and soft sand sediments from extreme shallow water to 70 m depth and will often form dense beds in excess of

10 individuals/m^2. Davidson et al. (2011) define a horse mussel bed as an area 'with high densities of horse mussels forming a bed or zone (> 4/m^2)'. Individuals can live up to 15 years, and established beds provide complex biogenic habitat for a wide array of algae, invertebrates and commercially important fish species such as snapper and scallops. Beds have been recorded in many areas of the Sounds including Grove Arm, Wet Inlet and Port Gore.

Direct impacts of physical disturbance are likely to be considerable. Horse mussels are particularly vulnerable to physical disturbance because of their size, delicate shells and inability to re-bury themselves to the substrate after disturbance. They are also sensitive to increased levels of suspended sediments. Large areas of horse mussels have been lost from areas of the Marlborough Sounds, including Pelorus Sound, Guard's Bay and Port Gore due to anthropogenic activities (Davidson et al. 2011).

Burrowing anemones

Burrowing anemones (*Cerianthus* sp.) inhabit silty, shell and sand substrata with low to moderate tidal flows. This is a significant species in the Marlborough Sounds due to its relative rarity and low abundance. Burrowing anemones have been recorded from a number of locations in Marlborough and are most common from Oke Rock to Pelorus Sound but also known from Port Ligar and East Cape to Arapawa Island.

Specific threats to this species are unknown but due to their soft bodies and delicate feeding structures, the local direct impacts of physical disturbance are likely to be significant. Their abundance and distribution is thought to be limited in the region by increasing sedimentation and physical disturbance.

Giant lampshell

The giant lampshell (*Neothyris lenticularis*) is endemic to New Zealand and sub-Antarctic waters and is widespread across the deeper waters of Cook Strait. It is a significant species of conservation value in Marlborough due to its occurrence at relatively shallow depths in areas of East Bay, Arapawa Island and Queen Charlotte Sounds. At high densities it can form a biogenic habitat, enhancing benthic biodiversity and productivity.

Specific threats to this species are unknown but the local direct impacts of physical disturbance are likely to be considerable.

Scallop beds

The scallop *Pecten novaezelandiae* is endemic to New Zealand and is found throughout the Marlborough Sounds. They are particularly abundant in Croisilles Harbour entrance, Queen Charlotte Sound and some outer Sound locations.

Scallops are found on a variety of soft substrata from mud to fine gravel and are most abundant in areas of tidal flow. It is an important recreational and commercial catch species in the Sounds. In their adult phase scallops are mobile but their movements are limited to a range of a few tens of metres. They are sessile in their juvenile stage and their development is highly variable, influenced by local environmental conditions and hydrodynamics. In Marlborough, scallop abundance fluctuates but is considered largely stable. They are primarily caught using dredges, which have a significant negative impact on the surrounding biogenic habitat and broader ecology of the area. Local impacts of physical disturbance and associated sedimentation are likely to be significant.

Fish spawning and nursery areas

The sheltered bays of the Marlborough Sounds are an important spawning and nursery area for the rough skate (*Zearaja natuta*) and the elephant fish (*Callorhinchus milii*), and likely many other species of fish.

The rough skate is an endemic species to New Zealand, found primarily around the South Island down to depths of around 500 m. Inner Queen Charlotte Sound and Port Underwood are important spawning and nursery areas. Females lay eggs directly onto the seabed, which makes them particularly vulnerable to direct physical disturbance and smothering by sediments.

Elephant fish occur throughout New Zealand and Australia to a depth of around 230 m. Historically they have been a commercially important food fish and their numbers have been recovering following overfishing in the 1970s and early 1980s. Adults migrate to inshore waters in summer to breed and significant spawning grounds have been identified in areas of Garne Bay, Pelorus Sound, Saville Bay, Kumutoto Bay and Grove Arm. Females lay their eggs directly onto the substratum in shallow water, less than 25 m in depth. The eggs have a relatively long incubation period (up to 8 months) making them vulnerable to direct physical disturbance and smothering by sediments.

3.2. Indirect effects of disturbance of the seabed

3.2.1. Erosion and resuspension of sediments

Even in areas without conspicuous surface features, chain-scour will loosen sediments, making them more vulnerable to erosion and alteration of texture by water movement. In general, levels of sediment destabilisation and erosion will be highest in areas of high natural and anthropogenic physical disturbance. Erosion and resuspension of sediments may, in turn, have direct or indirect ecological effects. Gradual modification of the particle size distribution of the sediments inside the swing radius of the mooring may alter the chemical and physical properties of the sediment, such as the degree and depth of anoxia and changes in organic content. These changes may, in turn, cause changes in the abundance and distribution of animals and plants living in and on the sediment (Hall 1994). Furthermore, organisms such as tube-building worms and mat-forming micro-organisms can have a strong stabilising effect on the sediment, so that damage to these communities is likely to result in a further increase in erodibility.

Disturbances such as mooring scour will re-suspend sediments and alter surface roughness and infaunal community structure and activity. This will further influence sediment structure and rates of erosion. These structures naturally stabilise sediments and protect them from erosion and re-suspension. Sediment destabilisation and resuspension result in the loss of fine sediments and organic content, and changes in sediment and faunal community structure. Re-suspended benthic sediments may have a range impacts on the wider marine environment, including benthic habitat smothering, release of contaminants and pollutants, increased nutrient availability, reductions in dissolved oxygen and water clarity, and effects on fish health.

Sediment deposition has been shown to greatly affect the composition and the ecology of corals (Wittenberg & Hunte 1992) sea grass habitats (Marbà & Duarte 1994) and temperate algal reef communities (DeVinney & Volse 1978; Stewart 1983). It can reduce kelp survival and reproduction (DeVinney & Volse 1978) and it has been suggested that the dominance of algal turfs in many intertidal and subtidal rocky habitats may be related to prolonged high levels of sedimentation and scour (Stewart 1989).

Fine-grained sediments tend to accumulate contaminants by adsorption to the surfaces of the sediment particles, and thus can act as an important pollutant reservoir, reducing the availability of toxicants to aquatic organisms. Changes in sediment chemistry, due to seabed disturbance and resuspension, can result in contaminant re-mobilisation into the surrounding environment and transformation of contaminants into more bioavailable or toxic chemical forms (Simpson et al. 1998).

Sediment resuspension and the resulting release of nutrients and organic matter can enhance the growth of water column bacteria and protozoa, increase benthic and pelagic photosynthesis, impact carbon and nitrogen cycling and increase pelagic and benthic respiration rates and dissolved oxygen demands (Sloth et al. 1996; Wainright & Hopkinson Jr 1997) leading to changes in turbidity and water clarity.

Reduction in the amount of available light caused by suspended particles has a number of consequences. It affects the visual range of organisms and the light energy available for photosynthesis. Reduced visual clarity may affect the behaviour and success of visual predators such as fish and aquatic birds (Lythgoe 1979). Prolonged and increased sediment loading and turbidity are probably a direct and critical source of stress for marine algal and invertebrate communities as a result of reduced availability of light, oxygen, nutrients and firm substratum for settlement and recruitment and an increase in physical scouring (Daly & Mathieson 1977; DeVinney & Volse 1978; Shaffer & Parks 1994). Filtration by biogenic habitat-forming bivalve species, such as oysters, has been shown to be important in reducing turbidity, thereby improving light conditions for the recovery of sea grass beds and consequently having a further stabilising effect on sediments and improving water clarity (Newell & Koch 2004).

3.2.2. Introduction of hard substratum

The installation of mooring anchors, such as concrete blocks, will produce a slight alteration of the local habitat and community structure due to the small amount of introduced hard substrate they represent in otherwise fairly uniform areas of soft sediments. The area of hard surface available for colonisation will depend on the size of the block and the degree to which it is embedded in the surrounding sediment. It will also be reduced by chain-sweep across the block’s surface.

Any biological assemblages that develop on mooring anchors may not be the same as those found on nearby natural hard substrata. Assemblages on other types of artificial structures in harbours (such as wharf piles and pontoons) have been found to differ from those on natural substrata (Connell & Glasby 1999; Connell 2001; Chapman & Clynick 2006; Chapman & Underwood 2011). When assessing the potential for constructed breakwaters to compensate for lost hard substratum associated with the proposed extension of Waikawa Marina, Sneddon et al. (2008) noted that there were differences between the existing breakwater and natural reef habitats in terms of the animals and plants present. There is also a significant risk that artificial hard surfaces will provide a site for colonisation by non-indigenous pests, such as the macroalga *Undaria pinnatifida*, the tubeworm *Sabella spallanzanii* and the ascidians *Didemnum vexillum* and *Styela clava*. All of these species are already present in the Sounds and often occur first on artificial substrata before colonising nearby natural habitats (Russell et al. 2008; Dafforn et al. 2015).

3.2.3. Predator-prey interactions and provision of refugia

In addition to direct mortality of benthic organisms caused by the movement of the ground chain, disturbance to the seabed around moorings may attract predatory and scavenging fish and invertebrates. Larger, deeper-burrowing organisms, normally protected from their predators, may become exposed to predation. Fish, birds and marine mammals may, thus, be affected indirectly by a reduction in the diversity and abundance of their prey or physical disruption to their feeding grounds around moorings, but the total area involved will be relatively small. For example, Herbert et al. (2009) found a reduction in the abundance of infauna around intertidal moorings in southern England, including species that are important prey for birds.

Mooring structures may directly affect competition and predation among and within species, potentially leading to differences in the structure of marine benthic communities (Herbert et al. 2009). For example, avoidance of areas of moorings by marine mammals may reduce predation pressure on local populations of some prey species. The presence of moorings also reduces fishing pressure by excluding some fishing practices, notably dredging and trawling.

However, the presence of moorings and vessels may act as attractants for some predators, because of the physical structures provided, by increasing abundances of their prey, or by reducing abundances of their own predators. For example, fur seals and sea birds often use moored vessels (including those in Waikawa Bay, pers. obs.) for hauling out and roosting, which may increase predation pressure locally. Spotties (*Notolabrus celidotus*) can be ten times more abundant beneath mussel farms than on adjacent reefs, apparently attracted to the vertical surfaces of anchor blocks (Carbines 1993). Young spotties settle on coastal reefs and subsequently move to farms, where they tend to remain. Their presence presumably consumption of their prey species and, in turn, may attract their own predators (fish, birds, marine mammals) to the local area.

3.3. Recovery and the frequency of disturbance

The magnitude of effects of disturbance on benthic communities, and rates of recovery from it depend, among other factors, on the type of substratum, hydrodynamic factors and supply of adult and larval recolonisers. Chain scour from moorings provides an ongoing (‘press’) disturbance, periodically (or even continuously if wind and water movements dictate) raking the surface of the sediment and dislodging any organisms projecting above it. This will inhibit or prevent recovery of the animal and plant assemblages, and also prevent stabilisation of the sediment, within the swept area, other than in the very short term. Once sediments have been destabilised by the movement of the ground chain and by the removal of organisms that protect the sediment surface (microalgal mats, tubeworm and shellfish beds and sea grasses), they are likely to continue to erode if water currents are sufficiently strong. Consequently, the indirect ecological effects caused by increased suspended-sediment load will also persist.

Herbert et al. (2009) demonstrated that the recovery of benthic assemblages after removal of intertidal moorings in southern England was incomplete after 15 months, suggesting a relatively long-term impact resulting from changes to particle size distributions (greater prominence of larger particles of gravel and shell). An experimental study (Dernie et al. 2003) showed that the full recovery of soft sediment assemblages from physical disturbance could take between 64 and 208 days following physical disturbances of different intensities. In the case of sea grass beds, Demers et al. (2013) recorded recolonisation of areas previously swept by mooring chains following replacement with sea grass-friendly moorings[8]. These studies suggest that although recovery of benthic communities is likely to occur after the removal of block-and-chain moorings, it may take many months or even years.

Recovery from other sources of disturbance may be possible in areas within the mooring field that are not actually swept by chains. Additionally, colonisation of mooring blocks by encrusting organisms will potentially create a network of mini-reefs that, while not replacing lost soft-sediment habitat, may increase the biological diversity of the local area. The risk that these new surfaces may provide substrata for non-indigenous species was discussed in Section 3.2.2.

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[8] Demers et al. (2013) did not specify the time-scale of this recovery, but it was apparently less than four years.

4. EFFECTS OF MOORINGS RELATIVE TO OTHER SOURCES OF DISTURBANCE

There are numerous sources of natural and human physical disturbance that have the potential to detrimentally impact the marine habitats and communities of the Marlborough Sounds (Davidson et al. 2011). In the absence of detailed empirical investigations, an accurate estimation of the contribution of mooring disturbance to the overall impacts on the marine environment of the Marlborough Sounds is impossible. However, it is assumed that, relative to existing sources of physical disturbance, the environmental impacts of moorings are likely to contribute a relatively small proportion of total disturbance in the Sounds. This assumption is reflected in the common perceptions of visitors to the Sounds. Most visitors believe moorings and jetties were unlikely to create adverse effects on the environmental value of the Sounds beyond minor concerns over their visual impact (Corydon Consultants 2012).

As mooring numbers in the Sounds continue to rise, and existing impacts are reduced in response to improved management approaches and predicted land use changes, their relative contribution to disturbance of the marine environment may well increase. Therefore, in trying to evaluate present and future impacts of moorings, it is important to consider them in relation to the scale, extent and expected continuation of existing sources of physical disturbance.

4.1. Natural disturbances and storms

Storms provide an unpredictable, episodic source of natural disturbance and mortality for benthic organisms and may strongly influence community composition (Posey et al. 1996). However, in many cases these effects may be less than background annual variability. Increased natural sediment run-off from land, following extreme rainfall event, flooding and landslides, etc. poses a threat to the biodiversity of shallow estuarine and coastal areas. Storms can result in rapid deposition of fine terrestrial sediments into the marine environment and have serious impacts on benthic communities (Norkko et al. 2002). The role of wind-wave disturbance and transport of sediments and macrofauna, and the importance of bioturbation by benthic organisms, are all important factors in facilitating the recovery of benthic habitats after large natural disturbances.

Climatic change is expected to cause an increase in ocean acidification, rates of sea-level rise and intensity and frequency of extreme coastal storms over the next decades (Scavia et al. 2002; Stocker 2014). Much of the Marlborough Sounds is sheltered from offshore swells and waves due to its topography but in many places disturbance from tidal currents can be high. Relatively minor, local impacts and disturbances to sheltered marine environments, such as the Sounds, have the potential to be compounded and exacerbated by climate change.

Impacts of erosion and resuspension of benthic sediments due to direct human disturbance must be considered in relation to the scale, extent and flux of existing natural and external factors influencing coastal areas. Habitat types, rates of primary production, terrestrial sources of erosion and pollution and wind-wave and/or tidal resuspension are all highly variable throughout the Marlborough Sounds. Many localised areas are subject to high tidal or land run-off influences and are therefore depositional environments with naturally occurring low water clarity. Levels of physical, human disturbance and pollution will vary throughout the Sounds and in many locations, relative to existing human and natural sources of disturbance, the impacts of mooring structures are likely to be minor and localised in their scale and extent.

4.2. Dredging and trawling

Bottom trawling and dredging can inflict chronic and widespread disturbance on the seabed, causing dramatic reductions in the biomass of infauna and epifauna and possible changes in the trophic structure and function of benthic communities. This can, in turn, have important implications for the processing of primary production and the wider functioning of marine ecosystems (Jennings et al. 2001). Trawling has been shown to reduce the abundance of bioturbating species, important for oxygenating benthic sediments (Widdicombe et al. 2004). The precise consequences of long-term trawling and dredging on the marine environment are often difficult to ascertain due to the widespread, historical extent of these activities. The impact of bottom trawling and dredging on benthic infauna will depend on the natural disturbance levels to which benthic communities are already adapted (Queirós et al. 2006), the types, size and weights of gear, and the frequency of disturbance (Jones 1992). The impacts of trawling can be severe and widespread and studies have revealed that impacts such as the re-suspension of sediment can occur in magnitudes comparable to those caused by storms (Hall 1994).

Various significant marine sites in the Marlborough region are vulnerable to dredging and trawling damage. There are currently a number of commercial and recreational fishing restrictions on the use of trawls and dredges in the Marlborough Sounds based on gear type and seasonal restrictions[9]. As noted in Section 1, MDC has proposed a prohibition on bottom trawling and dredging in most of the ecologically significant marine sites, based on the findings and recommendations of MDC reports (Davidson & Richards 2015; Davidson & Richards 2016) that marine ecosystems in the

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[9] http://www.legislation.govt.nz/regulation/public/1986/0218/latest/whole.html?search=qs_act%40bill%40regulation%40deemedreg_challenger_resel_25_h&p=1#DLM107955

Marlborough Sounds are being degraded or lost (Simpson 2016). A review of historical changes in benthic habitats in Pelorus Sound (Handley 2015) found a lack of information on the extent of shellfish beds before the arrival of Europeans. However, there were reports of over-exploitation of mussel stock by the early 1970s, with consequent exposure of the underlying soft sediments.

4.3. Land runoff

Runoff of sediments and other contaminants has historically been high in the Marlborough Sounds due to land clearance and the associated runoff caused by forestry, agricultural and other land use activities (Davidson et al. 2011). Historic and ongoing sources of anthropogenic contamination include meat-processing facilities, boat building, maintenance and berthage, urban stormwater, and treated and untreated sewage discharges. Due to a lack of baseline data the full scale of these effects on the local marine environment over the last two hundred years is largely unknown (Handley 2015, 2016). There have been patchy improvements in land use practices since the 1990s, which have overall not been effective in mitigating the persistent, episodic impacts of forestry activities in the area continue to cause significantly elevated levels of sedimentation into the surrounding marine environment (Urlich 2015, Handley et al. 2017).

4.4. Vessel disturbance and anchoring

Much of Queen Charlotte Sound between Cooks Strait and Picton is affected by regular vessel traffic (Davidson et al. 2017). High-speed ferries between the North and South islands were introduced in the 1990s with little prior understanding of the environmental effects that might result (or of the baseline conditions that would allow adequate assessment of effects). It is known that increased wave energy from high-speed vessel wakes can cause significant changes to beach and shoreline morphology through erosion, deposition and reorientation, particularly in confined coastal waters with low natural wave energy (Parnell et al. 2007). Implementation of protective management strategies has been hindered by a frequent lack of baseline data and the rapidity at which high-speed vessels have been introduced to near-shore, low energy environments

The introduction of large, high-speed ferries to the Marlborough Sounds caused initial rapid and significant sediment transport and accretion on beaches and coastal environments up to 10 km from the sailing route. This has persisted in many places despite speed restrictions to below 18 knots, imposed on operators in 2000 (Parnell et al. 2007). There are likely to be significant interactions between sediment supply from land runoff and vessel wake erosion in the Sounds (Parnell et al. 2007). Sites along ferry routes in Queen Charlotte Sound have been monitored since 1995, identifying responses in the biological communities and subsequent recoveries following the implementation of speed restrictions (Davidson et al. 2017).

Management of the impacts of recreational boating is typically based on measures of numbers of boats (e.g. marina berths, vessel registrations) but the potential environmental impacts are also a function of boat usage and activity (Widmer & Underwood 2004). In the Marlborough Sounds, a significant proportion of boat activity includes small vessels moving between harbours and bays, and anchoring. The intensity of these vessel movements varies widely in intensity among locations and seasons. Correspondingly, any environmental impacts associated with vessel anchoring will likely be highly variable depending on location, season and habitat type. Anchoring on delicate habitats such as sea grasses, even by small boats using low-impact anchors, can have detrimental impacts (Milazzo et al. 2004) but moderate levels of anchoring may only inflict minor and short term impacts on soft-sediment communities (Backhurst & Cole 2000).

The specific effects of other forms of boating impacts including noise, chemical and organic contamination, are largely unknown in the Marlborough Sounds.

5. MITIGATING THE EFFECTS OF MOORINGS

5.1. Low sensitivity habitats

The simplest method for limiting adverse effects of swing moorings on significant benthic habitats and organisms is to restrict them to locations where these features are absent. As noted in Section 2.2, most swing moorings for small vessels in the Marlborough Sounds are located in sheltered locations with minimal wave exposure, generally near the shore in bays or the fringes of the main reaches of the Sounds. The benthic habitats in these areas often consist of sands and muds, with sediments becoming finer further into bays, where water movement is weakest. Sedentary, surface-living organisms tend to be relatively scarce in these areas, particularly in deeper water, partly because of the lack of substratum to attach to and partly because, in the case of the fauna, many are filter feeders and intolerant of high concentrations of suspended sediment often present in these environments. Biogenic habitats are usually absent for the same reason. The fauna living within the sediment (the 'infauna') is often resilient to disturbance, characterised by relatively high mobility, short generation times and high rates of recruitment and migration. Nevertheless, the infauna can be impacted by the presence of swing mooring, either directly or by alteration of the texture of the sediment (Herbert et al. 2009).

There are, however, exceptions to this lack of surface-living organisms and biogenic habitats in the types of habitat favoured for swing moorings. Horse mussels, scallops, tubeworms (including species that form reefs and beds) and burrowing anemones are characteristic of muddy and muddy sand habitats in the Sounds and other regions of New Zealand. Even where such features are not currently present at a location where swing moorings occur or are proposed, they may have been present historically but were lost because of the presence of moorings or other forms of anthropogenic disturbance, such as dredging and bottom-trawling. For example, Handley (2015, 2016) documented the loss of beds of green-lipped mussels, blue mussels and scallops from soft-sediment areas of the Sounds as a result of human activities (mainly fishing).

A simple method for assessing whether removal of existing moorings or refusal of new ones would allow recovery of significant species or habitats would be to determine whether they already occur within the mooring field (outside of the areas swept by ground chains) or in the area immediately around it.

5.2. Appropriate mooring densities

The longer the ground chain on a mooring, the greater the elasticity provided to counter the force of waves, currents and wind but also the greater the area of the seabed swept by the chain. It may be possible to reduce the length of ground chain in order to decrease the total area of seabed impacted by a given number of moorings in an area. The length of ground chain required for a given size of boat, depth of water, tidal range and sea conditions experienced at a mooring is, however, an engineering question. We are not qualified to determine whether the area impacted by individual moorings could be reduced by altering the length or weight of the ground chain specified in the MDC mooring construction guidelines.

Although the area impacted by a single mooring may be small relative to the total area of similar habitat within a bay or wider area, the total area impacted will obviously increase as the number of moorings in the bay increases. There is no simple answer to the question of what proportion of the total area can be impacted without causing a significant, adverse effect. Sneddon (2010) concluded that mooring scars in Waikawa Bay represented only a minor ecological impact to soft sediment habitat due, in part, to the small benthic areas affected relative to the amount of similar soft sediment habitat in the wider area. The recent multibeam survey of benthic habitats in Queen Charlotte Sound and Tory Channel will show the scale of swing circles, and allow the relative areas of disturbed and undisturbed seabed to be calculated, for any bay in the region. It will also identify places where swing circles intrude into cobble or reef habitat.

5.3. Alternatives to block-and-chain mooring systems

Pole moorings, with the vessel fasted both at the bow and stern, avoid the need for ground chains. They are still likely to exert some impact on the seabed around them, through deposition of fouling organisms that fall off the pole and scour around the base of the pole by water currents. By preventing the vessel from swinging to face winds and currents, pole moorings increase the strain on the mooring. Consequently they are more suited to relatively sheltered environments.

Stern-tie moorings (see Section 2.1) reduce the swing of the vessel by fastening the stern to a fixed point on the adjacent shore. The area of seabed affected by the mooring line is therefore limited to a sector of the circle rather than the full circle swept by a block-and-chain mooring.

Holding boats in line between fixed buoys attached to a fixed ground line (a ‘trot’ type mooring) may reduce scour effects because, being fixed at both ends, the ground line is less free to travel over the seabed (Herbert et al. 2009). However, the ground line is not intended to be taut on these moorings and, consequently, there may be some movement of the ground line over the seabed in response to changes in the direction of the forces created by waves, currents and wind. The mooring line attached to the ground chain also consists of chain and this may lie on the seabed at low tide, potentially causing scour.

Chain-sweep effects can be minimised or avoided by employing mooring systems that have a smaller footprint and keep the mooring tackle off the bottom (e.g. moorings that incorporate an elastic component in the line) (Figure 4). Instead of using a length of chain to absorb the vertical and horizontal forces created by waves, currents and wind, an elastic 'rode' (line) is used to attach the mooring line to the anchor. The elastic rode can be attached to a conventional mooring anchor and the length of the rode designed such that it is short enough to remain suspended off the seabed by the mooring float during low water conditions, but can stretch to accommodate an increase in tide height and the strain of the moored vessel. They can also be used with screw anchors. Due to their expense, such systems are normally only used to reduce vessel swing radii and enable greater mooring densities or to conserve particularly sensitive benthic environments.

Figure 4. Traditional (left) versus elastic (right) mooring ropes. Source: http://www.atlanticfishhabitat.org/Documents/21981ProtectingEelgrassHabitat-2_000.pdf, accessed 25 October 2017.

The New Zealand Marine Flex[10] , United States Eco-mooring[11] and the Swedish Seaflex® [12] mooring systems are examples of elastic moorings designed to provide progressive resistance to water motion, both vertically and horizontally. These designs consist of a set of elastic hawsers (Figure 5), and the size of the mooring depends on tidal range, wind, waves, currents, water depth and the vessel's air resistance. The inherent elasticity in the line provides greater reduction of shock-loading than a chain.

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[10] http://www.marineflex.com/

[11] http://www.boatmoorings.com/eco-mooring.php

[12] http://www.seaflex.net/

The mooring can be attached to an embedded anchor (e.g. a screw anchor) or a gravity anchor.

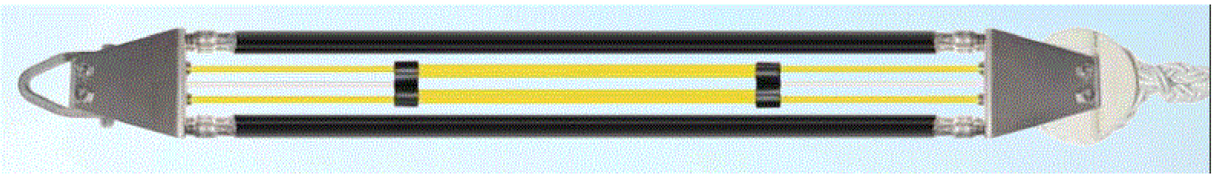

Figure 5. Seaflex® mooring, consisting of a parallel series of elastic hawsers. Source: http://seaflex.s-dev.se/wp-content/uploads/2013/03/Seaflex_product_sheet_English.pdf, accessed 25 October 2017.

The Australian Seagrass Friendly Mooring System[13] uses a screw anchor, to which the mooring line attaches via a shock absorber. The top of the anchor protrudes ca 30 cm above the seabed and the shock absorber is attached to it by a swivel-head. The shock-absorber consists of a spring inside a cylinder—water is forced out of the cylinder as the spring is compressed, adding further damping. When not under strain, the shock absorber lies horizontally, c. 30 cm above the seabed.

The EzyRider Mooring[14] (also Australian) is made up of a chain connected to an anchor (concrete block or an offset system consisting of three steel stakes driven into the seafloor) and held of the seabed by a large displacement surface buoy. The chain is attached to the buoy by elastic hawsers that absorb the force created by waves, currents and wind and also keeps the chain off the seabed with changing tidal height.

5.4. Habitat change after installation of environmentally friendly moorings

The response of sea grass beds in New South Wales to replacement of block-and-chain moorings with Seagrass Friendly Moorings (see Section 5.3) was studied between 2009 and 2013[15]. This form of mooring allowed sea grass to recolonise previously bare areas created by chain scour (Figure 6). Failure to recolonise in some areas was attributed to higher wave action and sediment movement.

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[13] http://www.sea grassmooring.com.au/, accessed 25 October 2017.

[14] http://www.gageroadsdiving.com.au/projects/ezyrider-mooring-and-offset-anchor-system, accessed 25 October 2017.

[15] http://www.dpi.nsw.gov.au/fishing/habitat/threats/traditional-boat-moorings-in-sensitive-habitats, accessed 25 October 2017.

Figure 6. Photographs of a sea grass-friendly mooring taken in 2009 (left) and 2010 showing recovery of sea grass. Source: https://www.dpi.nsw.gov.au/fishing/habitat/threats/traditional-boat-moorings-in-sensitive-habitats [credited to Bill Gladstone], accessed 25 October 2017.

A trial of three types[16] of sea grass-friendly moorings in southern Queensland (DEEDI 2011) reported some evidence that the replacement of traditional moorings at four trial locations was 'associated with an overall decrease in the patchiness of the benthic communities'. Fragmentation and increased patchiness of habitats, and the biological assemblages they support, is a general consequence of disturbances such as those caused by chain scour. The short period of the reported study (6–9 months) was not sufficient to determine whether recovery of sea grass, microalgal or microbial cover, and their stabilising effect on the sediment, was likely to occur.

Demers et al. (2013) compared sea grass (predominantly *Posidonia australis*) cover and density in the vicinity of block-and-chain, cyclone and Seagrass Friendly® moorings and nearby reference areas without moorings in New South Wales. The cyclone moorings consisted of a central anchor weight with three ground chains radiating out from it to anchors. The Seagrass Friendly® mooring had similar sea grass cover to the reference areas, whereas cover was denuded from an area of radius c. 9 m around block-and-chain moorings and c. 18 m around cyclone moorings. There was evidence of recolonisation of denuded areas by the sea grasses *Halophila ovalis* and *Zostera* spp. where Seagrass Friendly® moorings had replaced traditional moorings. These taxa are faster to recover from disturbance than the larger, slower-growing *Posidonia*.

As noted in Section 3.1.2, in a study focussed on species that are important prey for wading birds, Herbert et al. (2009) found that recovery of the animals living in the sediment was not complete 15 months after the removal of the surface buoys on swing moorings in southern England. They suggested that this was due to alteration

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[16] The three types were the Seagrass Friendly® Mooring System, EzyRider Mooring and Seaflex® Mooring.

of the sediment by chain sweep. In sheltered environments, deposition of fine sediments is likely to restore the original sediment texture and, in turn, the composition of the infauna.

5.5. Expected effects of changes in mooring type in the Marlborough Sounds

Only one species of sea grass (eelgrass, *Zostera muelleri*) occurs in New Zealand and may show similar recovery ability to those members of the genus found in New South Wales (*Z. muelleri* also occurs from Tasmania to southern Queensland) (Demers et al. 2013). Where damage to sea grass by block-and-chain moorings has occurred in the Sounds (if such locations exist), a change to sea grass-friendly moorings may, therefore, result in recovery. If water clarity in the Sounds improves in the future as a consequence of management of other forms of disturbance, the use of sea grass-friendly moorings in areas adjacent to existing beds may allow expansion and (re)colonisation of previously unvegetated areas.

A study of the recovery of benthic biota following the removal of moorings suggests that the process may take some time (more than a year: Herbert et al. 2009). However, studies of areas of seabed beneath mussel farms in Tasman Bay have shown that horse mussels can recolonise previously dredged areas within a year or two (D. Morrisey, pers. obs.). The presence of such habitat-forming species may accelerate the development of associated biological assemblages.

The effects of larger-scale forms of disturbance (dredging, trawling, etc.) may be minimised in the immediate area of the mooring field due to the difficulty of operating equipment near moored vessels and/or the mooring equipment. Nonetheless, the larger-scale forms of disturbance are still expected to have some degree of impact in the mooring field. Where mooring-associated disturbance is reduced or removed, but large-scale disturbance is persistent, seabed recovery may be minimal. However, if larger-scale forms of disturbance were reduced or removed in areas of soft-sediment seabed, mooring chain disturbance would be expected to become relatively more important as a driver of seabed health. Mooring disturbance would then potentially be an important factor to consider with respect to the Marlborough Environment Plan (MEP) objective 8.2: ‘An increase in area / extent of Marlborough’s indigenous biodiversity and restoration or improvement in the condition of areas that have been degraded’.

6. MANAGEMENT GUIDANCE AND RECOMMENDATIONS

MDC would like to understand within which habitat types moorings are appropriate or inappropriate, and situations where more environmentally sensitive mooring systems would be preferable.

6.1. Habitats and species sensitive to the effects of different types of mooring

6.1.1. Block-and-chain moorings

Any type of habitat or organism that projects above the surrounding seabed is vulnerable to damage by the movement of mooring chains across the bed. Even in areas of soft sediments where organisms living on the surface are predominantly mobile (such as crabs, gastropods, sea stars and sea cucumbers) and therefore able to avoid areas affected by chains, there will be disturbance of the sediment, at least surficially. This disturbance is likely to kill organisms living near the sediment surface and prevent their recolonisation. It may also affect deeper-burrowing species by disrupting their contact with the surface for respiration and feeding. Consequently, block-and-chain moorings are likely to have an adverse effect on all habitats in which they are located, particularly where frequent winds and regular changes in the direction of tidal currents cause the moored vessel to swing on the mooring.

In addition to those discussed in Section 3.1.3, other habitats and species considered to be of particular ecological, cultural or conservation significance and that are likely to be particularly sensitive to the effects of block-and-chain moorings are:

- rocky reefs (moorings are not likely to be located on these substrata but may be close enough that the reef is within the area swept by the chain)
- cobble fields (moorings are not likely to be located on these substrata but may be close enough that the cobble field is within the area swept by the chain)
- macroalgal beds (where these are growing on reef, moorings are not likely to be located within them but may be close enough that the bed is within the area swept by the chain)
- areas of shell hash (shell hash can provide important habitat diversity in soft sediments and chain sweep will enhance rates of breakdown of the hash).

6.1.2. ‘Environmentally friendly’ and other types of moorings

Trials in Australia indicate that moorings such as the Marine Flex®, Eco-mooring, Seaflex®, Seagrass Friendly Mooring® and EzyRider Mooring® will minimise damage to seabed habitats and organisms providing that the shock-absorbing component (elastic hawsers or spring) is of an appropriate length to keep the mooring line off the seabed.

Stern-tie moorings limit the swing of the vessel and, thereby, reduce the area of the seabed swept by the ground chain to a sector of a circle with a radius equal to the length of the chain, rather than the full circle.

Pole moorings will also reduce the area of impacted seabed. In this case, the impact will be limited to the area around the pole that is scoured by water movement, the extent of which will depend on local current patterns.

6.2. Recommendations for assessing consent applications for moorings

We suggest the following guidelines for assessing consents for moorings:

1. No consents for new moorings in ecologically significant marine sites (ESMS) where the mooring will adversely affect the values on which the significance of the site is based (Davidson et al. 2011).
2. Existing moorings in ESMS to be removed or to be converted to environmentally friendly moorings where the mooring is adversely affecting the values on which the significance of the site is based.
3. Applications for all new consents or renewal of existing consents shall include a description of habitats in the vicinity of the mooring and identification of significant habitats or species present (see list in Section 6.1.1, to be documented as, for example, video or drop camera images).
4. New consents in locations outside ESMS but where significant habitats or species are present shall require environmentally friendly moorings.
5. Existing consents in locations with significant habitats or species shall be converted to environmentally friendly moorings or removed if damage has occurred. This includes cases where a significant species or habitat, such as sea grass or horse mussels, is present within the mooring field but outside of the areas of chain sweep, or in areas around the mooring field, when such species or habitats may be expected to recolonise the impacted areas if ground chains are removed.
6. Moorings to be consented preferentially in areas of mud or sand seabed with no specific ecological, conservation or traditional value.

Application of these guidelines requires information on the nature of the seabed in the vicinity of the proposed (or existing) mooring and identification of significant habitats and organisms present. At present, the information provided with applications for mooring consents is variable (Peter Johnson, pers. comm., MDC). Some applications provide information derived from dive surveys of the seabed, including photographs to document the nature of the bed and features present. Guideline 3 is intended to ensure that suitable information is provided with the consent application to allow application of the other guidelines.

Consideration will need to be given to the time frame for implementing the guidelines. Initial efforts should focus on moorings in areas with high-value or rare habitats and species (Guidelines 2 and 3). In locations where damage from moorings has already occurred but recovery or recolonisation may be expected (Guideline 3), replacement with environmentally friendly moorings could be delayed until the consent is due for renewal. The legislative mechanisms available for achieving changes are, of course, also relevant but are beyond the scope of this report.

Guidelines 2 and 3 have already been used in at least one consent decision by MDC. An application for replacement of a mooring consent in Cherry Tree Bay (Catherine Cove, D'Urville Island) sought to increase the swing circle of the mooring, allowing larger vessels to be moored. The mooring lies within ESMS 2.13 (Davidson et al. 2011), which contains dense rhodolith beds in shallow areas from 6–26 m water depth. The consent was granted with the conditions that (among others) the mooring line should include an elastic tackle, and that the applicants should survey the seabed within the new swing circle for the presence of rhodoliths. The use of an elastic tackle is to allow the line to be detached from the block for inspection without the need to lift and replace the mooring block, which is likely to extend the area of impact on the rhodoliths. The applicants must provide a report (including photographs) of the extent, location and health of the rhodolith beds to MDC.

6.3. Encouraging the use of environmentally friendly moorings

Interviews with mooring owners and mooring manufacturers conducted as part of the trial of sea grass-friendly moorings in Queensland (DEEDI 2011) suggested, among other things, that accreditation and/or standards for the design of these moorings, and government intervention or facilitation in uptake, would be beneficial. Cost was a key factor in uptake and demonstration of effectiveness and reliability is important to vessel owners. Standards and quality-management systems for the manufacture and installation of moorings would provide confidence to vessel owners and insurers.

A feasibility assessment of environmentally friendly moorings in New South Wales (Bowman 2008) noted that these moorings are expensive compared with block-and-chain moorings. Even the cheapest type included in the assessment (the Seagrass Friendly Mooring® System, described in Section 5.3) was twice the price of a traditional mooring (A$1,500 versus A$750 for supply and installation in 2008). Bowman (2008) reported that all of the five proprietary sea grass-friendly moorings reviewed have generally performed well, although there were differences in ease of use.

In the New South Wales context, Glasby & West (2015) pointed out that state government policy generally does not support proposals to install new, replace or relocate existing moorings in sea grass beds larger than 5 m^2. However, in situations where damage to sea grass is permitted, adequate compensation measures are required. Monetary habitat compensation is calculated on a minimum 2:1 basis for sea grasses, which equates to a cost of A$112/m^2. Using this monetary value, the average environmental cost of a new block-and-chain mooring in sea grass in estuaries in the Hunter region would be A$18,368 (based on an average scar area of 164 m^2, equivalent to 7 m radius). The cost of an effective environmentally friendly mooring (c. A$3,500 including purchase price and annual maintenance costs) is therefore considerably less than the cost of damage to sea grass based solely on monetary values for habitat compensation.

Glasby and West (2015) suggested that strategies to reduce adverse effects of moorings on sea grass beds, including encouraging the use of sea grass-friendly moorings, could include:

1. Ensuring that block-and-chain moorings are not (accidently or otherwise) deployed in sea grass beds, which requires accurate positioning of moorings and use of up-to-date maps of sea grass beds.
2. Ensuring that existing block-and-chain moorings are not moved within sea grass beds, either by contractors during maintenance or due to inadequate weight for the size of a vessel or exposure of the mooring site. This would require minimum standards for moorings and accurate co-ordinates for the position of the blocks.
3. Relocating existing block-and-chain moorings out of sea grass beds wherever possible.
4. Where moorings must be in sea grass beds, ensuring that they be environmentally friendly swing moorings that do not scour the seabed.
5. Phasing out of the lawful use of traditional block-and-chain moorings in other sensitive aquatic habitats.
6. Creating the appropriate regulatory and market environment to reduce (or subsidise) the purchase and ongoing cost of environmentally friendly moorings and increase the demand for their use.

As these studies indicate, demonstrating the effectiveness and safety of environmentally friendly moorings in a range of environments and sea conditions is likely to be important in encouraging their use. MDC may wish to consider facilitating the initial use of potentially suitable moorings, in collaboration with mooring manufacturers and installers, vessel owners and other stakeholders.

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9. APPENDICES

Appendix 1. MDC Mooring construction guidelines[17]

Construction Specifications

Mooring Class	Vessel Length	Block Weight	Ground Chain Diameter (mm)	Mooring Chain Diameter (mm)	Rope Diameter (mm)
Class A	Up to 6 metres	1 tonne	24	16	20
Class B	6 – 12 metres	2 tonnes	32	20	20
Class C	12 – 16 metres	3 tonnes	38	20	24
Class D	16 – 18 metres	4 tonnes	38	20	28
Class E	> 18 metres	Vessel specific design by a chartered professional engineer with experience in mooring structures.			

1. Shallow water moorings in a depth of 5 metres or less to be designed to suit with respect to these guidelines.
2. Total length of the chain to be the depth of water at mean high water springs with one third of this chain to be ground chain. (*see below*)
3. Length of the rope to be equal to the depth of water at mean high water springs. (*see below*)
   The total length of the mooring tackle should be equal to twice the water depth at Mean High Water Springs at the mooring site. Generally, mooring tackle consists of a combination of chain and rope totalling twice the water depth.
4. All shackles must be welded.
5. Swivels may be used at the mooring provider's discretion, but where these are used, the size of the swivel must be commensurate with that of the chain.
6. Anodes may be used at the mooring provider's discretion.
7. All mooring blocks must be designed by a Chartered Professional Engineer with expertise in mooring structures and be made to those specifications.
8. Similar metals are to be used throughout.
9. Moorings of different design and/or manufacture will be considered on a case by case basis. As a minimum, such moorings must be supported by appropriate Chartered Professional Engineer design drawings and certification.

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