Effects of Mussel Farming on Reef-building Biogenic Habitats

Serpulid reefs

Prepared for Marlborough District Council

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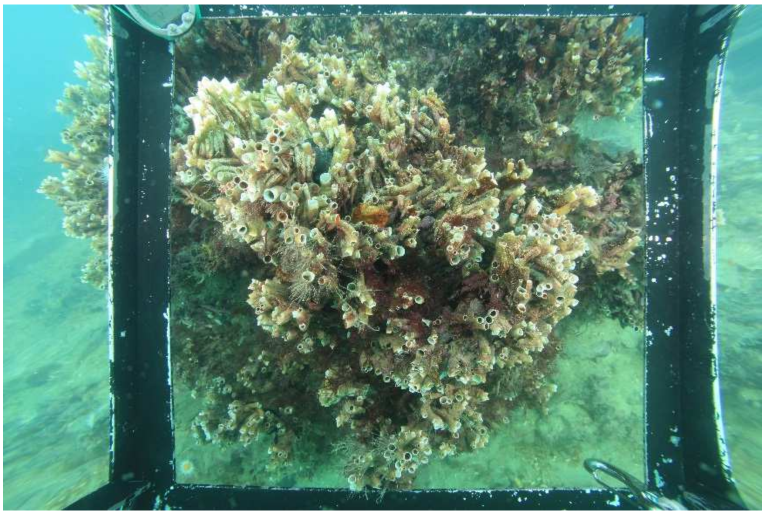

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Executive summary

- The serpulid tubeworm *Galeolaria hystrix* is the main polychaete species that builds biogenic patch reefs in the Marlborough Sounds. There are three major reefs in the region. One is in Queen Charlotte Sound and two are in Port Underwood at the Knobbies and Whataroa Bay.
- The reefs may be older than 50 years and have at least 31 generations of worms forming worm mounds by gregarious larval settlement.
- Environmental variables that cause gregarious settlement are unknown. However, presence of adult worms and food are likely to be significant factors responsible for reef building. Larvae are not attracted to unoccupied worm tubes, therefore dead reefs are unlikely to recover without restoration.
- The Whataroa Bay population is located at the southern headland 80 m from Sanford's mussel farm licence 8444 in 8 -15 m of water. It has been monitored by NIWA since 2011. There has been a decline in the number of live worms on the reef since 2013.
- No data exists on the environmental effects of mussel farms on serpulid biogenic reefs.
- Sediment deposition and phytoplankton depletion are likely to have negative effects on biogenic reefs.
- It is not possible without further study to identify factors responsible for the decline of tubeworms at Whataroa Bay. However, based on historic coexistence with mussels and published research on sediment deposition and phytoplankton depletion, mussel farms are unlikely to be impacting the tubeworms. Factors such as sediment deposition from terrestrial sources, incursion of low salinity water and suspended sediment from Cloudy Bay, and natural decadal variation in populations may play a role in population variability.
- We recommend that both the Knobbies and Whataroa tubeworm reefs in Port Underwood be mapped in detail using side-scan sonar and geo-referenced photoquadrats. Permanent transects should be established for a detailed comparison, in the absence of control sites, to monitor for changes in reef extent and health. Monitoring of sites should be at shorter timescales of 3 – 6 months than presently used for consent conditions.
- Foundation studies on the biology and ecology *G. hystrix* could be used to determine tolerance and behaviour of larvae and adults to sediment and salinity.
- A gradient study in the field could be used to determine; firstly, if there are mussel farm effects and secondly, if restoration is feasible by translocating colonies.
- We suggest sediment trapping concomitant to tubeworm reef monitoring. Deposition rates and proportional contribution of sediment using the CSSI method after (Gibbs 2008) can be correlated with changes in worm health.

1 Introduction

Long-line culture of Greenshell™ mussels *Perna canaliculus* began in New Zealand in 1975, expanding in sheltered waters of the Marlborough Sounds to occupy 3,061 ha of water space in 2009. The ecological effects of intensive aquaculture of farming shellfish was reviewed extensively by Keeley et al. (2009). Their review was primarily based on the grow-out stage of mussel cultivation both from New Zealand and overseas. The scope of their study on ecological issues of mussel farming was focused in three main areas; (1) those associated with effects on the seabed, (2) those associated with effects on the water column, and (3) wider ecological issues such as effects on fish, mammals and the spread of invasive species. The primary effects identified on benthos were organic enrichment, smothering of the seabed by deposition of pseudo-faecal and faecal material, shell drop and biofouling organisms living in soft sediments below or near farm foot-prints. Water column effects reported on the 'ecological carrying capacity' of bays and regions, driven by phytoplankton production and the depletion by cultured mussels.

Hartstein and Stevens (2005) determined that the majority of biodeposits from mussel farms under average conditions of water depth and tidal velocity, reduce to natural levels between 30 – 50 m beyond the farm boundary, and that live mussel drop, and associated biofouling is typically confined to within 10 m of farming structures (Keeley et al. 2009). Studies have found higher abundance of polychaete species beneath farms, but no difference between other major macrofaunal groups (molluscs, crustaceans, echinoderms) inside and outside farms.

Little attention, however, has been given to the impact of mussel farming on adjacent reef habitat assemblages. Mussel farm resource consents and renewals in the Marlborough Sounds are granted beyond 30 - 50 m distance from shore on the assumption that no impact occurs to reef communities. To our knowledge there have been no empirical studies on impact of mussel farms on adjacent reef assemblages. Further, studies to monitor and determine causes of changes in community assemblages or abundance of key species are likely to be complex and expensive.

The reef species bryozoans, rhodoliths and tubeworms are considered of scientific and ecological importance in the Marlborough coastal marine area (Davidson et al. 1995). These biogenic reef-forming species were relatively common and widespread in the region (S. Urlich, MDC, pers. comm.). Of the reefs built by aggregations of individual polychaete tubeworms *Galeolaria hystrix*, only three are known in the Marlborough Sounds. The worms can form mounds of aggregating individuals up to 1 - 5 m in diameter and 1.5 m high in depths ranging from 6 to 30 m. These patch reefs are important habitat for associated sessile and mobile species including invertebrates and fish (Smith et al. 2005). Two such reefs are located in Port Underwood in the vicinity of mussel farms at The Knobbies (3.4 ha) and on the southern headland of Whataroa Bay (0.9 ha) (Davidson et al. 2010) and Fig 1-1.

Mussel farms have been operating in Whataroa Bay since about 1990 (Z. Charman, Sanford, pers. comm.). The closest farm to tubeworms is Sanford's 8444 farm, located inside the bay approximately 80 m distant from the reef (Fig 1-2). A baseline study as part of the consent conditions first done by NIWA in September 2011 (Page et al. 2011) mapped and recorded healthy worm mounds. Monitoring two years later in 2013 showed no significant change in reef health (Page 2013). However, a subsequent monitoring survey of the tubeworm reef in July 2016 has identified

Figure 1-1: Map of the eastern side of Port Underwood showing location of tubeworm reefs at the Knobbies (6.1) and the southern headland of Whataroa Bay . Figure adapted from Davidson et al. (2011).

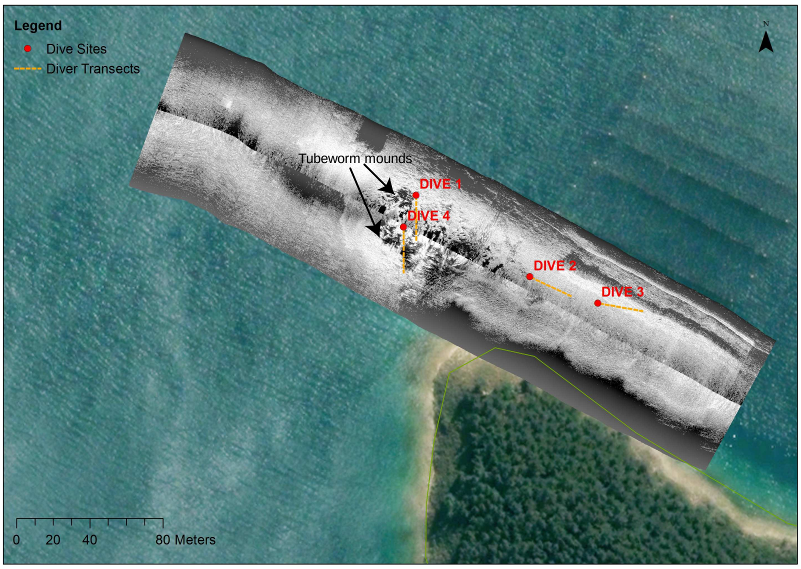

Figure 1-2: Side-scan sonar map of tubeworm mounds at Whataroa Bay.

significant change in the health of the mounds (Page and Olsen 2016), a decrease in occupancy of live worms in tubes from ~96% in 2011 and 2013 to ~48% in 2016.

In this context, the scope of our review is limited to literature and anecdotal information in New Zealand and overseas on the ecology of *Galeolaria hystrix* or similar species, and the potential effect of mussel farms and other anthropogenic and natural sources of disturbance on these biogenic reef-building species. Based on this summary, we give advice to the Marlborough District Council and other councils on how best to monitor changes in the health and extent of the reefs.

2 Ecology of reef building serpulid worms

Our review is not intended to be an exhaustive coverage of the literature on this Family of reef-building tubeworms, but rather a summary of what is known relevant to a discussion of the potential environmental impacts of mussel farms on *G. hystrix* reefs.

Galeolaria hystrix occurs from Taranaki to Stewart Island, including New South Wales and South Australia. It forms calcareous magnesium calcite double-keeled tubes up to 21 cm long, and is estimated to live for up to 12 years (Riedi 2012). On subtidal bedrock, worms generally occur singly or in small groups. However, under certain environmental conditions they become gregarious and form reefs (Kupriyanova et al. 2001). The mechanism of reef formation in *G. histrix* is unknown, individuals form aggregations most likely in response to food and hydrodynamic conditions. Larvae are planktotrophic, usually spending hours to several weeks in the water column, and then settling on adult tubes in response to chemical and physical cues to build a reef over time (Hughes 2011). Settlement of polychaete worms can be in response to microbial films, the presence of conspecifics, sympatric species, and habitat (Qian 1999). Larval settlement of a closely related gregarious serpulid species, *Hydroides elegans* is in response to chemical cues from live conspecifics (Bryan et al. 1997).

Mass occurrences of serpulid tubeworms have been described in approximately 10% of species in the Family (ten Hove 1979). Reef structures of densely intertwined calacerous tubes modify the physical environment by entraining sediment (Schwindt et al. 2004) and increase habitat complexity and biodiversity (Bianchi and Morri 1996; Smith et al. 2005). *G. hystrix* reefs are estimated to be as old as 50 years (Smith et al. 2005), made up of an estimated 31 generations of worms (Riedi 2012). Patch reefs made up of worm mounds can cover extensive areas of seafloor, often over subtidal mud or sand, providing islands of hard substrate microhabitat for other organisms. Big Glory Bay, Stewart Island has the most extensive *G. hystrix* reefs, first identified in 1995 and mapped by Smith et al. (2005) in 2002. Several reefs were in close proximity to salmon and mussel farms in the inner parts of the bay. Authors noted that “Healthy and numerous reefs in the inner parts of Big Glory Bay imply that nutrient enrichment and sedimentation from nearby mussel farming… have had little effect so far”. However, they then noted that the number of live worms in their mid-winter survey was low and suggested reefs may degrade over time. A revisit of the Big Glory Bay sites in 2004 was not able to find any reefs at the head of the bay (A. Smith, pers. comm.), suggesting the reefs had died out in response to enrichment or sedimentation from marine farming.

3 Potential ecological impacts on *Galeolaria hystrix* reefs

3.1 Competition for food: ecological carrying capacity

Bivalves and tubeworms feed on overlapping size fractions of phytoplankton. Serpulids are suspension feeders, using oral tentacles to filter phytoplankton from the water column (Riisgard and Ivarsson 1990). The food size utilised by *G. hystrix* is unknown. However, a closely related species of reef-building tubeworm *Ficopomatus enigmaticus*, filters food particles in the 2 – 16 µm size fraction (Davies et al. 1989). Whereas mussels, *Perna canaliculus*, feed on the same food, but a broader range of plankton from 5 – 600 µm in size (Zeldis et al. 2004). The effect of introducing additional mussels on farms increases the flushing time in bays by interrupting water flow, and mussels may out-compete other suspension feeders such as polychaetes and sponges to exceed the ecological carrying capacity of the farmed area (Keeley et al. 2009). Competition for food among suspension feeding polychaetes and bivalves should not be underestimated (Bruschetti et al. 2008). Serpulid aggregations can significantly enhance water quality by suspension feeding (Davies et al. 1989). An overseas study also suggests that the filtration pressure of large gregarious reef-building polychaetes could reach ecological carrying capacity in a semi enclosed embayment when cultured mussels and oysters are added to the system (Dubois et al. 2009).

Water column surveys as part of the FRIA marine farming surveys provide evidence of phytoplankton depletion around existing mussel farms. The snapshots of Chlorophyll *a* concentrations suggest that small New Zealand farms have relatively little influence on the overall concentration of phytoplankton in the water column (Keeley et al. 2009).

Modelling of phytoplankton depletion in Port Underwood also suggests mussel farms remove no greater than 10 – 14% of phytoplankton, and that these effects extend little beyond the footprint of the farm (Hadfield 2014). It is unlikely therefore, that food depletion is a factor limiting populations or causing observed mortality of tubeworms in the mounds at Whataroa. Further, the mussel farms in the bay have been operational since 1990, and the worm mounds have been known to exist, and have survived sharing embayments with mussels since 1995 (Davidson et al. 1995).

3.2 Sediment Effects

Filter feeders such as sponges are known to be particularly sensitive to increased levels of suspended sediment (Roberts et al. 2006). Little is known about the effects of increased sediment on tube-building polychaetes. Miller et al. (2002) suggested the need to define the natural norms of suspended sediment to be able to quantify the adaptive envelope of a species. If the maximum concentration of resuspended fine material is low compared to near-bottom seston concentration, then resuspension will have little or no impact. There is, however, no data or time series on suspended sediment concentrations in Port Underwood to compare changes with background concentrations. At some concentration, suspended sediment will interfere with *G. hystrix's* ability to feed effectively. A closely related species of tube dwelling polychaete, *Sabellaria alveolata* is tolerant of relatively high levels of suspended particulate matter (SPM) (Dubois et al. 2009). In experiments mimicking tidal resuspension, food clearance rates decreased exponentially in response to increased SPM from 6.5 to 45 mg l^{-1}. However, the number of feeding individuals remained stable up to 55 mg l^{-1}. Tidal mixing is periodic in intensity, so tubeworms may tolerate variation in SPM. However, extended periods of high SPM from marine farm or terrestrial sources could compromise reproductive success and larval settlement to live adult tubes. It is unlikely that cultured mussels at current stocking levels in Port Underwood are impacting tubeworms by increased sediment in

Whataroa Bay. Sediment dispersal models of mussel bio-deposits demonstrate that little deposition occurs beyond 30 – 50 m of a typical farm site in the Marlborough Sounds (Hartstein and Stevens 2005). Further, recent modelling for ecological assessments of marine farm extensions in Port Underwood supports this conclusion (Grange and Hadfield 2012). In addition, as described earlier, mussel farms and tubeworm reefs have coexisted since at least 1995. Changes in tubeworm health have occurred only over the last 2 years.

Terrestrial input of fine sediment cannot be excluded, or separated from mussel farm effects on the tubeworm mounds in Whataroa Bay. Google Earth images show forest harvesting occurred in part of the catchment of the bay between December 2014 and December 2016 (Fig. 3 -1).

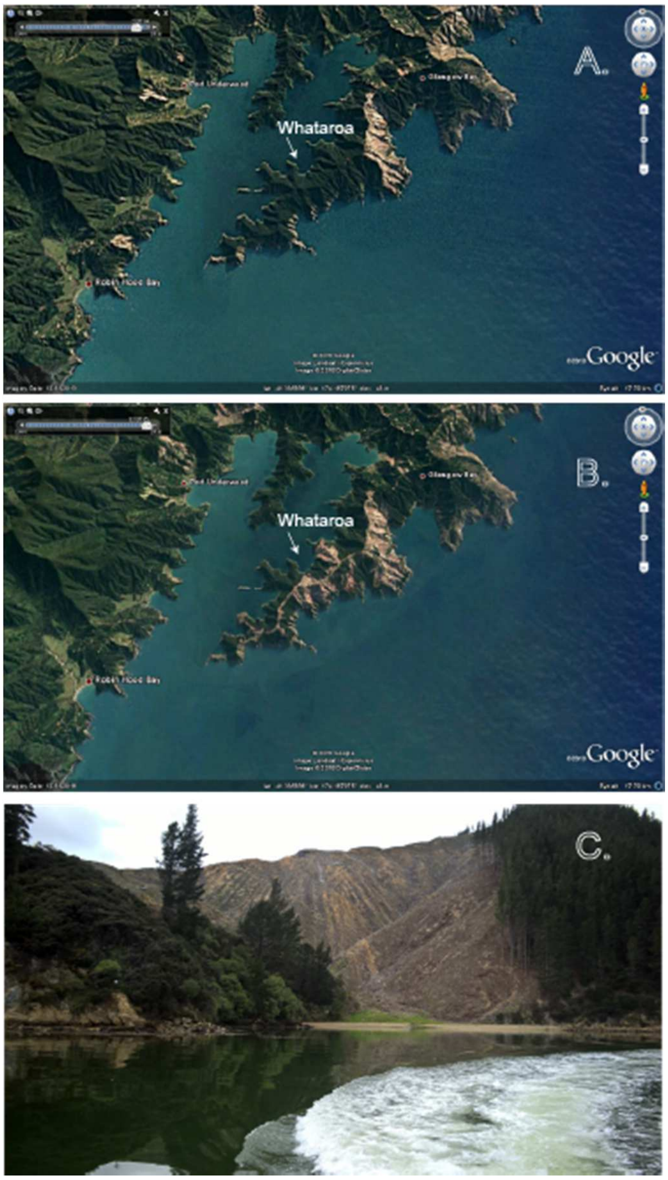

Figure 3-1: Google earth images showing harvesting at the head of the bay. A) Image date: 31 December, 2014; B) image date: December 2016; C) forestry harvesting in the bay, 28 September, 2016.

Most of the forest harvesting activity that occurred close to the sea was during January to March, 2016 (Tamati Smith, Tasman Forest Management, pers. comm.). Rainfall data from the NIWA rain gauge in Ocean Bay at 9 m elevation (Fig. 3-2) shows an average year for rainfall, but heavier rain occurred during the months of May to September 2016, after vegetation had been removed.

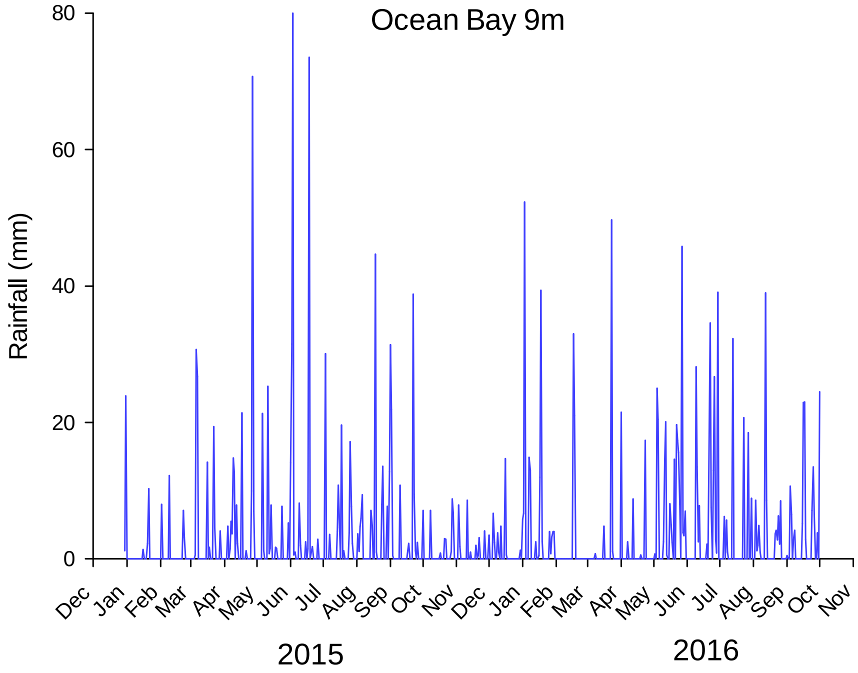

Figure 3-2: Rainfall for 2015 and 2016 measured by the Ocean Bay NIWA rain gauge

Photoquadrats of mounds with predominantly dead tubeworms do not, however, show clear evidence of smothering by sediment. Sediment present may have accumulated on already dead mounds, with subsequent fouling by turfing red algae.

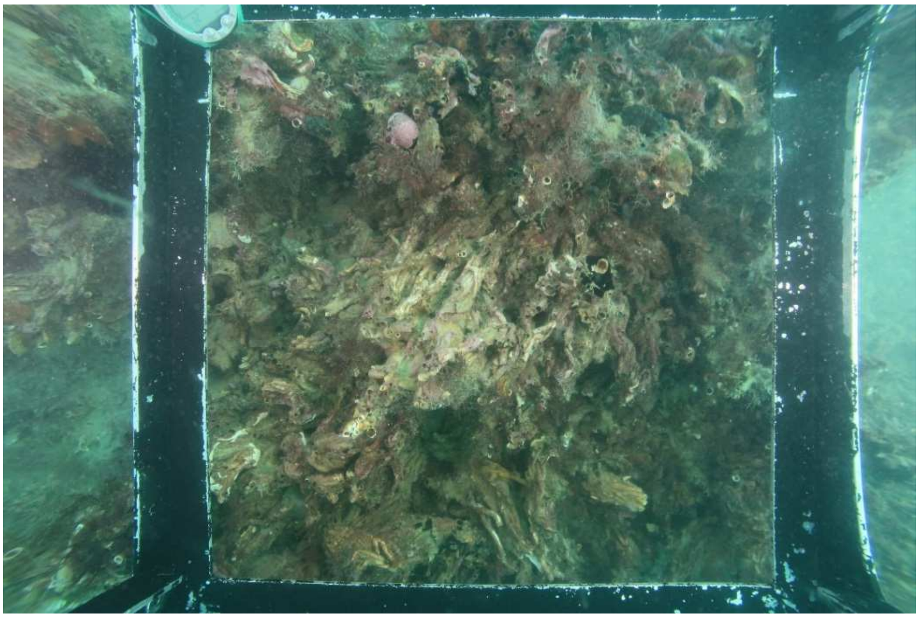

Figure 3-3: Example of a tubeworm mound in 0.25 m^2 photoquadrat in transect 4, largely composed of dead worms (Page and Olsen 2016).

4 Natural population variability

Mass mortality of serpulid reefs may occur in response to natural events. *Serpula vermicularis* reefs in the United Kingdom are rare, and have been observed to die-off in some lochs (Hughes et al. 2008), but it is uncertain if this is a natural periodic phenomenon. Recent evidence on reef formation in Scottish sea lochs suggests *S. vermicularis* reefs may be relatively transient features, forming and disappearing at decadal timescales (Hughes 2011). Mortality could also be correlated with increased climate variability due to global warming. A seemingly natural occurrence of mortality has been observed for small *G. hystrix* reefs surrounding Dart Rock in Pelorus Sound (Fig. 4-1) (personal observation) in response to smothering by a filamentous brown alga. This alga occurred throughout Tennyson Inlet (an area with no adjacent mussel farms) during spring 2005 and lasted a month. It smothered and killed sponges and *G. hystrix* worms. No such bloom events have been recorded in Port Underwood apart from seasonal growth of turfing red algae (R. Davidson, pers. comm.).

Recovery of dead or dying *Galeolaria hystrix* reefs appears unlikely, although unstudied. Healthy reefs grow healthy worms. For example, gregarious recruitment of a sister species *Galeolaria caespitosa*, larvae only occurs in the presence of live adults (Andrews and Anderson 1963). Similarly, relatively recent chemical ecology studies confirm adult extracts to be an attractant for larval settlement of *Hydriodes elegans*, a closely related species (Bryan et al. 1997). The death of worms on mounds in Whataroa Bay may therefore be totally unrelated to anthropogenic disturbance from mussel farming. Further, periodic incursions of turbid water from the Wairau River in Cloudy Bay can be dragged into Port Underwood by strong northerly or southerly winds (M. Hadfield, pers. comm.). Hydrographic events such as this could also explain the relatively sudden decline in tubeworm population health.

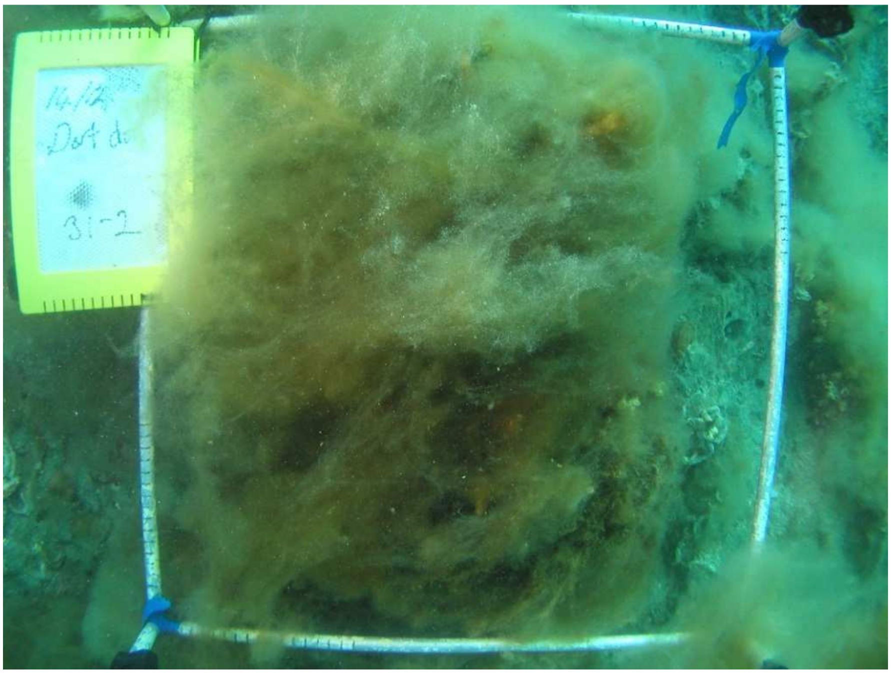

Figure 4-1: A 0.25m^2 photoquadrat of a small *G. hystrix* mound taken on Dart Rock, Pelorus Sound in December 2005.

5 Monitoring and management recommendations

5.1 Mapping reefs

The data collected by NIWA as part of the tubeworm monitoring for consent of Sanford licence 8444 consists of a side-scan sonar survey of the reef and tubeworm mounds, four 25 m long dive transects recording extent of the mounds, and five photoquadrats are randomly assigned within each transect. The health of the mounds is determined both qualitatively and quantitatively, subsampling within each quadrat to determine the number of live versus dead worms. Monitoring is every two years to determine if change has occurred. While adequate to detect change in this timeframe, the study is not rigorous enough, comparative, or able to ascribe change to any particular source or event.

The first step to monitoring the reef at Whataroa Bay should be to make a geo-referenced map of the tubeworm mounds. The extent of the mounds should be resurveyed and the area delimited using side-scan sonar, or preferably multi-beam sonar for accurate geo-referencing. Greater replication of dive transects using geo-referenced start and end points following methods in Moore et al. (2009) should be used. The map produced for overlaying data can then be used to select permanent quadrats *a priori* for measuring change. All dive transects and photoquadrats can be geo-referenced using the new NIWA MicronNav - USBL Tracking System. Ideally, sites should be resurveyed every 3-6 months to monitor tubeworm health. The Knobbies tubeworm reefs should also be surveyed in the same way as a comparative site to determine if any changes occurring are bay-wide or alternatively there is some point-source impact.

5.2 Accumulation and tracing of sediment

Sediment is likely to be one the greatest threats to tubeworm health. We suggest deployment of sediment traps to measure sedimentation rates over the reefs. These can be run consecutively with monitoring surveys. Sediment samples can then be further analysed using the CSSI method developed by Gibbs (2008) for determining sources of sediment input. Sample size for analysis requires a minimum of 15 -20 g and additional reference samples taken from marine farms and nearby reference soils from terrestrial land-uses. The CSSI method uses compound-specific isotopic analysis of naturally occurring biomarkers (fatty acids) derived from plants to link source soils to land use within a single catchment (Gibbs 2008). The results are given as a “best estimate”, within definable limits, of the proportional contribution of each potential source soil. Information obtained using this method will allow development of management strategies to alter land use practices to reduce sediment loading to streams, rivers and the coast, and thus, the impact on the aquatic ecosystems downstream in estuaries and in sheltered coastal waters.

5.3 Gradient/restoration study

A manipulative study to determine survival of *G. hystrix* aggregations from mussel farm effects using methods similar to Hughes (2011) could be run by rafting colonies at an increasing distance from the farm. Clearly, this kind of study would need to trialled and have suitable controls in the experimental design. Results from this study could also be used to determine the efficacy of restoring damaged *Galeolaria* reefs by seeding adult colonies to reefs. The assumption that there is a pool of larvae to re-recruit to seeded reefs would need to be tested using settlement panels. However, NIWA monitoring results (Page 2013) and observations of tubeworm recruitment to floats at the Knobbies (Z. Charman, pers. comm.) suggest there are enough *Galeolaria* in the Port Underwood larval pool.

5.4 Ecology and Life History

Our review and conclusions of other studies (Smith et al. 2005; Hughes et al. 2008; Smith et al. 2013) show the need for foundation research on the biology and ecology of serpulid reef builders. For example, little is known about the reproductive and larval ecology of *G. hystrix*, or tolerance to environmental variables such as sediment and salinity. There is no information describing the biological assemblages of these 'biodiversity hotspots'. Managing and conserving these is dependent on knowledge from studies, both field and laboratory that could be funded by post-graduate and diploma studies.

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