Davidson Environmental Limited

Re-survey of subtidal cockles located at the head of Deep Bay, Tory Channel

Research, survey and monitoring report number 934

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Blenheim 7240
New Zealand

March 2019

Large cockle collected in 2019.

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1.0 Preface

The present study was commissioned by the Marlborough District Council. The aims were to re-survey of a subtidal cockle bed located at the head of Deep Bay, Tory Channel and to report on any impacts associated with recent logging operations in the catchment. A consent to plant trees was granted on 18 January 1994 (U0930914) with a condition stated "(a) that 8.0 metre riparian zones be established on either side of the main watercourse leading down to Deep Bay and that these riparian zones not be planted with exotic forestry species; (b) that a hauler system as opposed to ground based methods be used to harvest logs on slopes greater than 35 degrees. Consent to establish various skid sites, log storage areas, stream crossings, a stream diversion and coastal permits for two barge sites, one in Waikakaramea Bay and the other at Deep Bay (both on Arapawa Island) to enable the applicant to harvest its forest., was granted on 12 May 2004 (U030144).

Note: The consent states the log loading site proposed for Deep Bay was withdrawn.

The Consent stated "the applicant has proposed various mitigation measures in relation to the land disturbance activities which include sowing down all fill batters from roads and landings, sowing harvested areas with grasses, replanting harvested areas with commercial species but ensuring units not replanted remaining sown down with grass, retaining indigenous scrub and trees within the buffer strip fronting the barge site in Waikakaramea Bay, removal of wilding pines from the adjoining foreshore reserve, planting tree species on Sounds Foreshore Reserve in Waikakaramea Bay to screen the road to the causeway and the log marshalling area and the withdrawal of the mid face road between Deep Bay and Ngaruru Bay. This latter would have been highly visible in Tory Channel. Further the decision states "The applicant proposes an extensive network of roads together with skid sites to harvest the trees and carry the logs to the log loading site at Waikakaramea Bay. This network enables all parts of the forest to be harvested even with the log loading site at Deep Bay not proceeding".

The first cockle survey was commissioned prior to logging of the catchment by Sounds of Forest and was reported in a report by Davidson and Richards (2003a).

2.0 Background information

2.1 Deep Bay

Deep Bay (40 ha) is located along the northern coastline of Tory Channel (Figure 1). The bay is approximately 1.2 km in length and up to 350 m wide. The bay is relatively shallow (< 7 m depth) with a shallow bank located at its entrance and a shallow area the head of the bay (Figure 2).

Figure 1. Location of Deep Bay, Tory Channel.

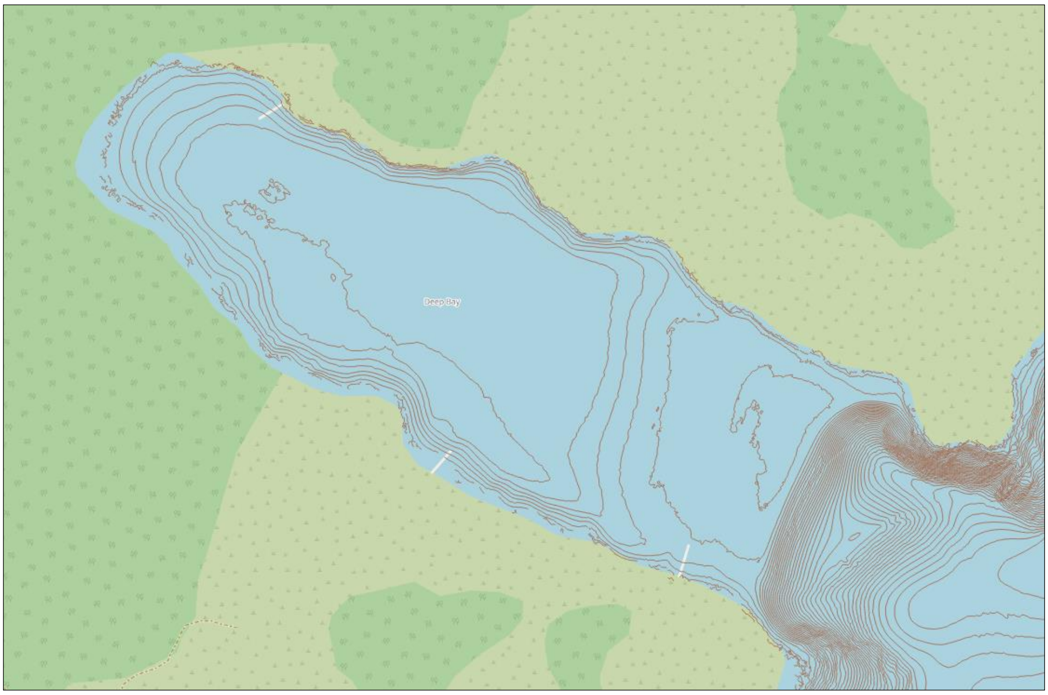

Figure 2. Depth contours (1m) in Deep Bay (NIWA, 2018).

2.2 Catchments and forestry

In 2003 much of the adjacent hillsides were clad in production forestry (Plate 1). Areas of regenerating native vegetation with wilding pines were and still are located towards the bay entrance.

Pine harvesting of the upper slopes and areas adjacent to an access road extending down to the lower slopes near the bay head were initiated between 2004 and 2009 (Plate 2). Logging of the remainder of the plantation occurred in latter, however no aerial photo is available. The consent stated "While not required to do so the applicant has volunteered a condition to be imposed in its consent that it will only harvest the units in its Harvest Units Plan dated August 19, 2003 (as presented to the hearing) such that no one catchment is harvested in its entirety in any one year. "During field work some riparian vegetation remained adjacent to the head of the Bay, with further regeneration of vegetation since logging apparent in disturbed areas (Plate 3).

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Plate 1. Oblique aerial view of Deep Bay catchment taken on 13 August 2004.

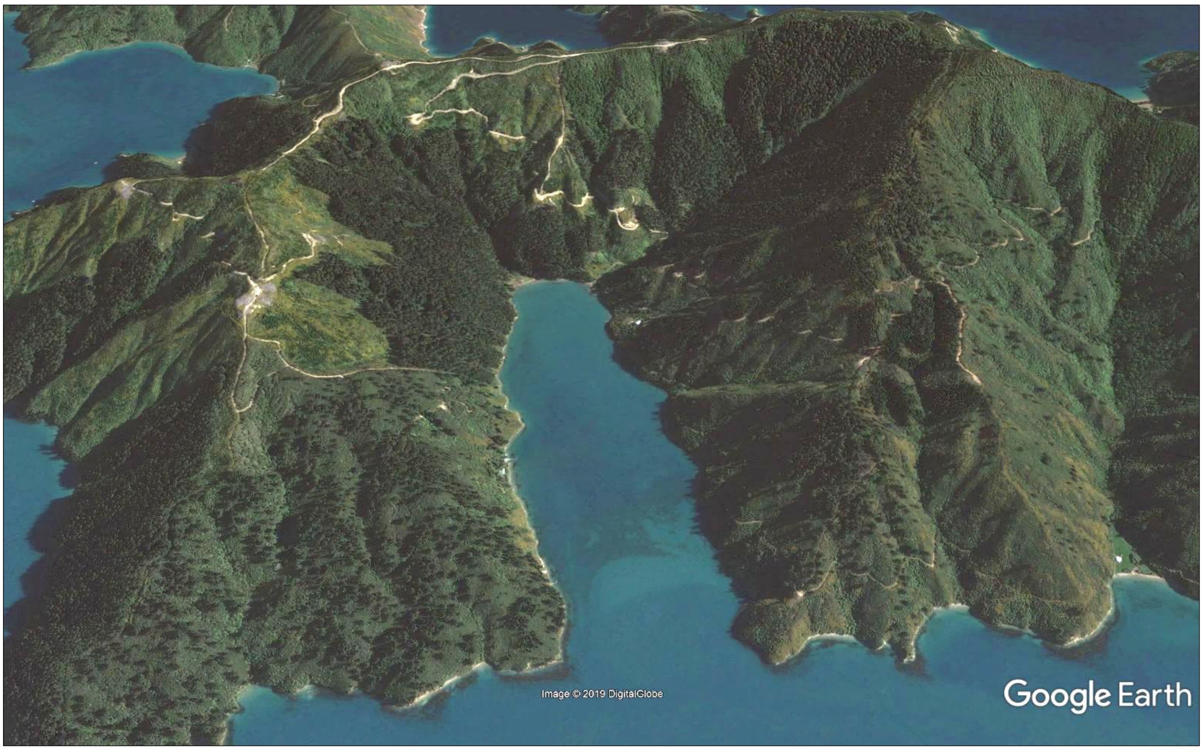

Plate 2. Oblique aerial view of Deep Bay catchment taken on 6 September 2009.

Plate 3. Panoramic photo of the head of Deep Bay, 12 March 2019 (41^o 13.21, 174^o 14.52). Note jetty and house at right of photo.

2.3 Significant sites

Tory Channel has the highest concentration of marine significant sites in Marlborough. (Figure 3). Most sites are located in the main channel and are dominated by current swept biogenic habitats including hydroids, sponges, ascidians and bryozoans or are shallow eelgrass beds (Davidson and Richards, 2015; Rayes and Davidson, 2017; Davidson *et al*., 2017). Two Tory Channel significant sites were located at the heads of side bays (i.e. Hitaua and Deep Bays).

Hitaua Bay significant site (Site 5.5)

Hitaua Bay Estuary was regarded as the best example of an estuarine habitat in the Tory Channel biogeographic area (Davidson *et al*., 2011). Davidson and Richards (2015) resurveyed the site in January 2015 and stated "Although it still supports estuarine habitats, it appears to have recently been influenced by the deposition of fine sediment from the logged catchment. Observations show a build-up of fine sediment over and around intertidal cobbles and a disappearance of some intertidal species compared to a baseline survey conducted for MDC in 2003 (Davidson and Richards, 2003b). Cockles do remain in comparable densities to samples collected in 2003, however their mean size appears to have declined."

Subsequently, the significant site review panel recommended that the Hitaua Bay significant site be downgraded and removed as a significant site due to smothering of intertidal and shallow subtidal habitats after heavy rain events that occurred following logging operations (Davidson *et al*., 2015). The review panel stated "The site is no longer the best example of an estuarine habitat in Tory Channel, however, the intertidal saltmarsh vegetation located around the edge of the site remains intact. We suggest monitoring the recovery of intertidal flats and biota."

Deep Bay significant site (Site 5.7)

The only other within-bay significant site known from Tory Channel is Deep Bay. Deep Bay subtidal cockle bed was ranked as a significant site in Davidson *et al*. (2011). The authors stated "there is a cockle bed at the head of Deep Bay (Davidson and Richards, 2003). It is low density compared to other areas in Tory Channel, but individual cockles are extremely large and therefore of scientific interest."

Until now, the Deep Bay significant site has not been resurveyed since logging events.

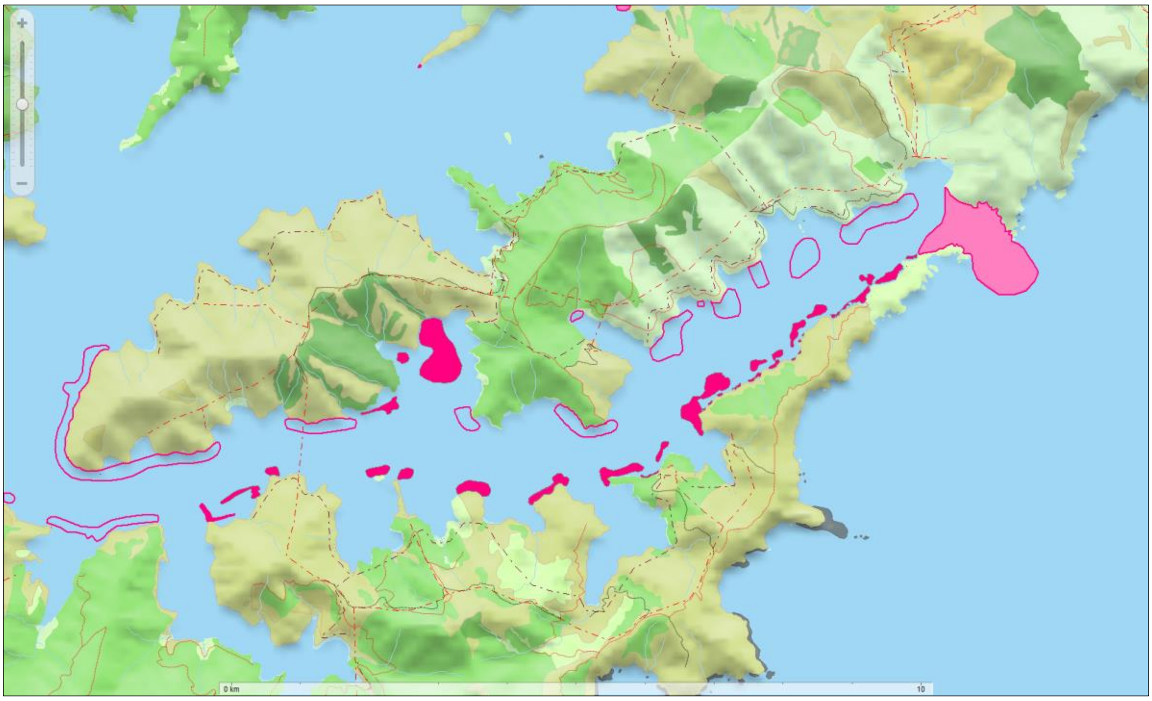

Figure 3. Known significant sites in Tory Channel including Deep Bay.

2.4 Cockle biology

The endemic cockle (tuanga) (*Austrovenus stutchburyi*), formerly known as *Chione stutchburyi*, is a shallow-burrowing suspension feeder found in soft mud to fine sand on protected beaches and enclosed shores around the North and South Islands, Stewart Island, the Chatham Islands and the Auckland Islands (Morton and Miller, 1973; Spencer *et al*., 2002). Although predominantly found in the intertidal, it is also found in subtidal sediments.

Infaunal bivalves are considered biologically important, and often critical, functional species that can improve water quality, stabilise sediments, oxygenate sediments as active bio-engineers, and can provide critical-habitat, both as living bivalve beds and through the accumulation of biogenic shell debris that can support highly diverse benthic assemblages (Barrett *et al*., 2017).

Sexes are separate and the sex ratio is usually close to 1:1. Size at maturity has been estimated at about 18 mm shell length (Larcombe, 1971). Spawning extends over spring and summer, and fertilisation is followed by a planktonic larval stage lasting about three weeks.

Considerable variability in cockle growth occurs around New Zealand. At Snake Bank (Whangarei) growth to 30 mm was estimated between 2 and 5 years (Martin, 1984; Cryer, 1997) with cockles reaching maturity at 18 mm (Larcombe, 1971) in their second year of growth. Stephenson (1981) suggested that cockle may live up to 20 years of age and this was confirmed in Otago (McKinnon, 1996).

Movement of juveniles have been documented, but individuals over 25 mm shell length remain largely sessile, moving only in response to disturbance. Mortality from predation, particularly birds and invertebrate predators is a regular occurrence.

Cockles can be harvested all year round, and New Zealand manages the harvest with quotas and recreational bag limits. Cockles are commercially harvested in several locations including Whangārei Harbour, Golden Bay and Otago Peninsula.

2.5 Threats to cockles

Threats to cockles from human activities comes in form of over fishing, sedimentation, reclamation, dredging and pollution.

Studies examining sedimentation effects in intertidal soft-sediment infaunas have identified negative relationships between the health of bivalve populations and sedimentation, especially for functional species associated with low- or moderate- depositional environments (Norkko *et al*., 2002; Anderson *et al*., 2004; Lohrer *et al*., 2004). For example, terrigenous deposition in excess of 3 cm on sandflats has been shown to cause a decrease in macrofaunal populations by 90% after 10 days (Norkko *et al*., 2002). Norkko *et al*. (2006) found that storm events that increased turbidity and sedimentation over a short time frame (<10 days) did not have significant direct-impacts on the associated bivalve population, but repeated turbidity and sedimentation events over 3–5 months led to increased muddiness in estuaries and a significant negative impact on bivalve physiology.

As part of a series of laboratory experiments, cockles were found to be resilient to particular sediment smothering (Barrett, *et al*., 2017). Authors reported "cockles were found to be highly mobile and capable excavators, able to resurface within days (often hours) from under 2, 5 and 10 cm, and even 25 cm, of native sediment where no physical disturbance to their natural (in situ) orientation had occurred. Cockles repeatedly re-surfaced following daily reburial, indicating they were resilient to at least low levels of repeated deposition."

Barrett, *et al.* (2017) reported “cockles were much slower to re-orientate following disturbance to their natural orientation (inverted at the time of burial), and while able to resurface from an inverted position under low levels of deposited sediment they were significantly impeded in their ability to resurface when buried under greater sediment loads (5 and 10 cm), with significantly fewer adults resurfacing than sub-adults.”

The authors cautioned that “based on previous studies, finer grained sediments (e.g., silts) or those that contain even small compositions of terrestrial clays are likely to have much more significant effects, with potential changes in community structure and loss of critical species likely to occur.”

3.0 Methods

Cockles were sampled in Deep Bay in the afternoon of 5th March 2019. All core samples were collected within the area identified by Davidson and Richards (2003) as supporting cockles. Divers collected core samples (15 cm diameter by 13 cm deep) in a haphazard sampling regime within the survey strata. Divers were instructed to collect cores from a variety of water depths and throughout the known cockle strata. GPS coordinates were plotted onto Tumonz 8 by placing the survey vessel over the divers position when cores were taken.

Each core was brought to the surface and transferred to the survey vessel where live cockles were measured and counted. Two measurements were collected (i.e. maximum length and maximum width). Maximum width was used in the present report as it enabled comparison with other cockle data collected in the Marlborough Sounds. Photos of selected representative core samples were also collected onboard the survey vessel.

Once all samples had been processed cockles were returned to the benthos by divers. Cockles were partially buried to ensure their survival.

4.0 Results

Diver collected core samples were collected to investigate cockle density and size from the head of Deep Bay (Figure 4). Core sample depths were adjusted to datum and ranged from 1.2 m to 5.6 m. A total of 16 core samples were collected in 2019 compared to 24 cores in 2003. Core samples in both sample years were collected in a haphazard sampling regime from the same area using the same corer.

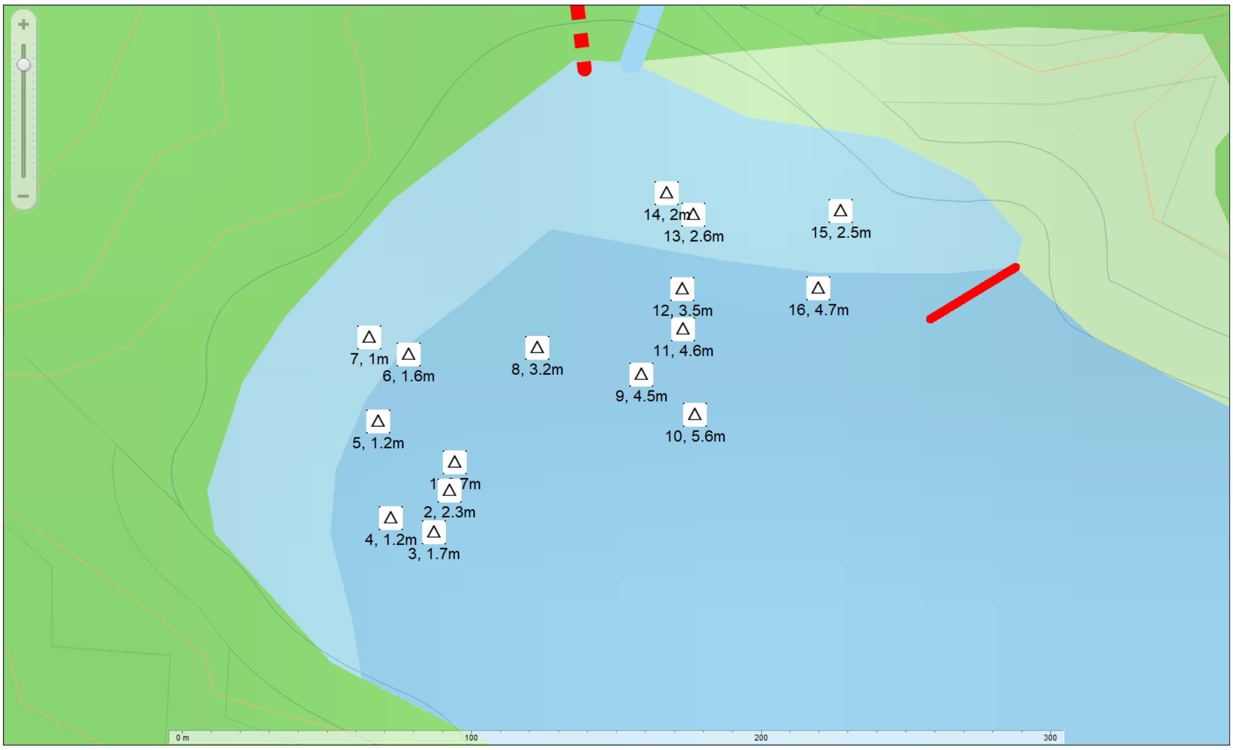

Figure 4. Location of cockle core samples in Deep Bay with depths adjusted to datum

4.1 Cockle density

In 2019, cockle density ranged from 0 to 4 individuals per core sample or 0 to 226 individuals per m^2 (Table 1). In the previous 2003 survey, cockle density ranged from 0 to 5 individuals per core sample or 0 to 283 individuals per m^2.

Mean density in 2003 was 63.7 individuals per m^2 compared to 74.3 individuals per m^2 in 2019 (Figure 5). This represented a small increase, but the increase was not significant (Mann-Whitney U statistic =169, P = 0.516) (Table 1).

The density from another bay in Tory Channel and several bays in Pelorus Sound, showed Deep Bay supported a low density of cockles, however, all sites sampled in Pelorus were intertidal and the Hitaua Bay site was a combination of intertidal and shallow subtidal (Figure 5).

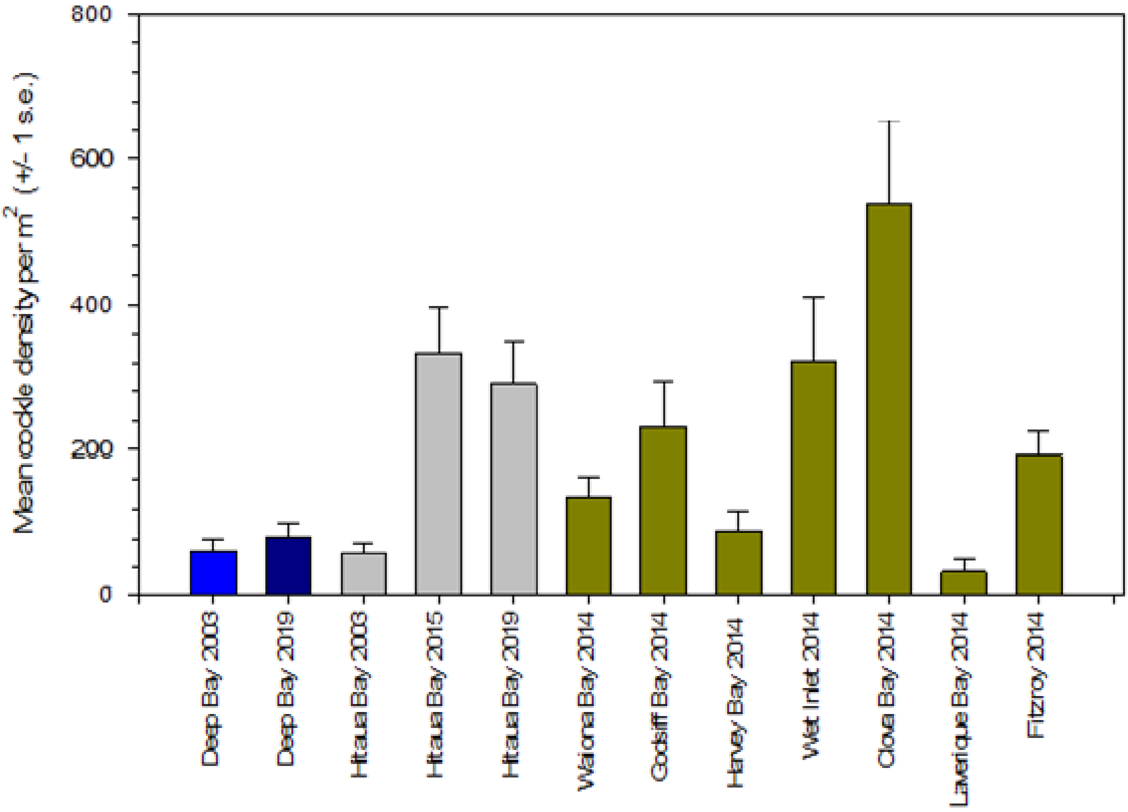

Figure 5. Mean cockle density (per m²) from Deep Bay in 2003 and 2019, compared to other bays in the Marlborough Sounds.

4.2 Cockle size (width mm)

A total of 21 cockles were measured in 2019 compared to 31 in 2003 (Table 2). Cockle width in 2019 ranged from 46 to 69 mm compared to 45 to 65 mm in 2003 (Plate 4). Mean cockle width was highest in 2019 with a mean of 59.2 mm, compared to 59 mm width in 2003 (Figure 6, Table 2). This increase was small and not statistically different (Mann-Whitney U statistic =305, P = 0.416).

Mean cockle size from another bay in Tory Channel and several bays in Pelorus Sound, showed Deep Bay supported the largest cockles (Figure 6). No small cockles were recorded from cores collected in Deep Bay.

Plate 4. Representative range of cockles collected from Deep Bay in 2019.

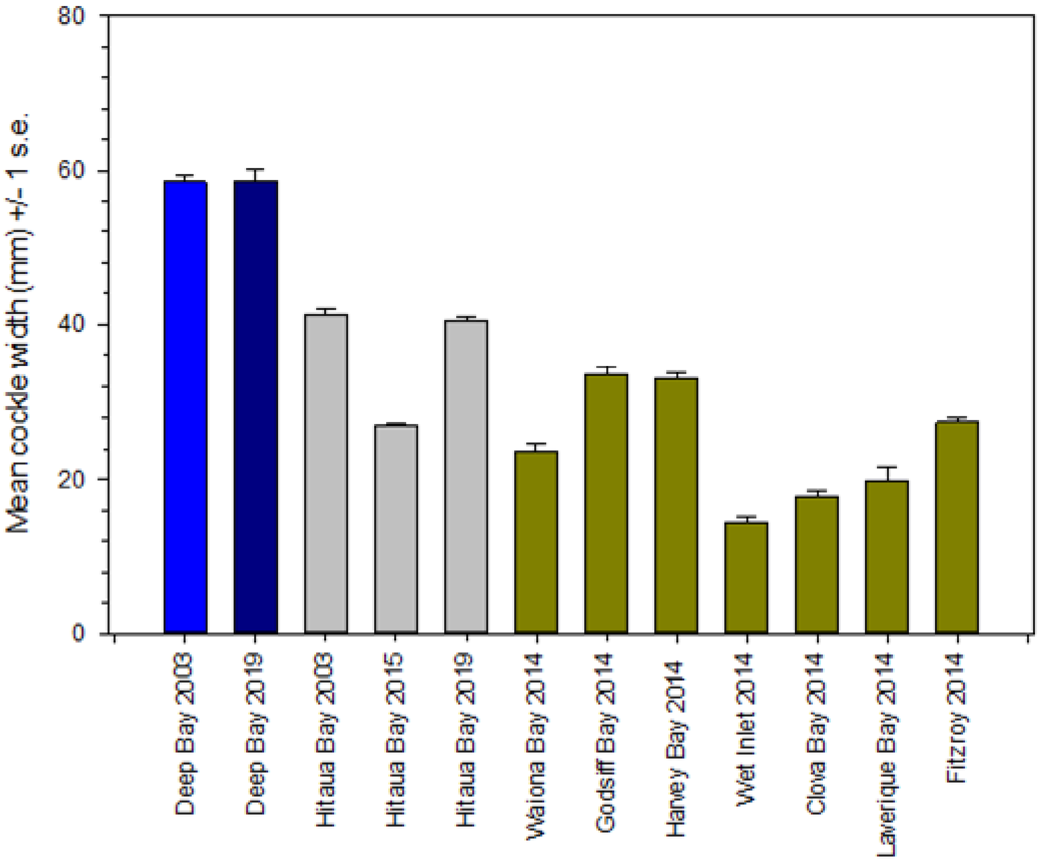

Figure 6. Mean cockle width (mm) from Deep Bay in 2003 and 2019, compared to other bays in the Marlborough Sounds.

Table 1. Sample event data in 2003 and 2019 from Deep Bay. Data are number of cockles per core and number of cockle per m^2.

25-Nov-03

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean	SD	SE
Number of cockles (per core)	3	3	2	1	1	2	1	0	0	0	0	0	0	0	2	1	2	0	1	5	0	0	2	1	1.13	1.30	0.26
Number per m^2	169.8	169.8	113.2	56.6	56.6	113.2	56.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	113.2	56.6	113.2	0.0	56.6	282.9	0.0	0.0	113.2	56.6	63.66	73.33	14.97

05-Mar-19

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Mean	SD	SE
Depth (m)	2.7	2.3	1.7	1.2	1.2	1.6	1	3.2	4.5	5.6	4.6	3.5	2.6	2	2.5	4.7			
Number of cockles (per core)	1	0	0	3	1	3	3	1	2	0	4	1	0	0	1	1	1.31	1.30	0.27
Number per m^2	56.6	0.0	0.0	169.8	56.6	169.8	169.8	56.6	113.2	0.0	226.4	56.6	0.0	0.0	56.6	56.6	74.27	73.69	15.04

Table 2. Cockle width (mm) collected in 2013 and 2019 from Deep Bay.

	Deep Bay 25 November 2003	Deep Bay 05 March 2019
N	31	21
Mean length (mm)	59.00	59.24
SD	4.43	7.25
SE	0.80	1.58

4.3 Sediment

Benthic core samples were dominated by fine soft sediments (Plate 5). Sediment was characterised by silt and clay with a component of very fine sand as indicated by a minor gritty texture. Very little shell material was observed apart from the presence of whole dead cockle shells. Deep sediments were a light grey indicative of aerobic sediments to the bottom of each core. Surface sediments were fluffy and yellowish in appearance indicating their recent terrestrial origin (Plate 5).

Plate 5. Core samples collcted from Deep Bay (March, 2019). Left sample 2.6 m depth, right sample 4.5 m depth.

5.0 Discussion

Subtidal cockles at the head of Deep Bay are very large but found in low densities compared to other cockle beds in the Marlborough Sounds and New Zealand.

5.1 Cockle density

Traditionally, cockles are usually intertidal and are most common on sandy or coarse sediment below 12 percent mud (Thrush *et al*., 2003; Anderson, 2008). Cockles are often a dominant species and densities as high as 4500 per m^2 have been reported in some areas of New Zealand. Considerable variability in cockle growth occurs around New Zealand. At Snake Bank (Whangarei) growth to 30 mm was estimated between 2 and 5 years (Martin, 1984; Cryer, 1997) with cockles reaching maturity at 18 mm (Larcombe, 1971) in their second year of growth.

Sediment, both suspended and deposited is regarded as a threat to cockles as it can impact cockle fitness or survival, with terrestrial sediments having greater effects than marine sediments (Gibbs & Hewitt, 2004). Increasing suspended sediment concentrations can induce increased physiological stress, decreased reproductive status and decreased juvenile growth rates (Nicholls *et al*., 2003; Gibbs & Hewitt, 2004). Sediment deposition has also been shown to negatively impact upon densities of cockles (Lohrer *et al*., 2004). The impact of mudiness has been documented with a decline in abundance across sites with increasing mud content (Thrush *et al*., 2003; Anderson 2008).

5.2 Cockle size

Presently in New Zealand, cockles seldom reach sizes greater than 55 mm length or approximately 58 mm width. In a large survey of Pauatahanui Inlet, Michael and Wells (2016) stated the largest cockle measured was 52 mm in length (approx. 55 mm width). Comparison of cockle data collected from Deep Bay and intertidal samples from other sites in the Marlborough Sounds shows cockles were relatively small especially in Pelorus Sound. The closest sizes to Deep Bay were recorded from Hitaua Bay in Tory Channel with the largest cockle being 54 mm width (51 mm length).

Archeological studies in New Zealand have shown middens can be populated by very large cockles up to and over 60 mm (Anderson, 1981). Anderson (1981) suggested that the infrequent use of the area by Maori ensured size-frequencies remained high.

Maxwell and MacDiarmid (2016) conducted interviews with Maori families living in the Otago region. Interviews revealed that one bed in Otahou near the entrance to Otago Harbour was knee deep and the other was over a sand bar further out in the harbour where children weren't allowed to go without an adult. The respondent stated biggest cockles (6–8 cm) were further out and that four or five would be enough to feed a child. One Otago family reported that in the 1980s the average size of cockles was 59 mm and it would take 5 minutes to get a bucket load. At 59 mm you can get 300 in a 10 litre bucket. Now (2008), the 59 mm cockles are rare and the average size is 45 mm; at this size 300 cockles fills only half a bucket. In the 1960s one family reported that the average size of cockles collected was the size of your hand and in 2008 the average size was 70 mm when it took an hour to collect 150 cockles.

Based on these anecdotal accounts it is plausible that subtidal cockle beds supporting lower density large cockles were once more widespread in New Zealand. Their decline is likely due to anthropogenic activities such as land clearance and associated sedimentation combined with over fishing.

5.3 Significance of the Deep Bay cockle bed

The Deep Bay cockle bed was ranked as significant by Davidson *et al*. (2011). The authors regarded it of scientific interest due to the bed being subtidal (which is unusual in Marlborough) and the cockles being larger than any other bed in the region.

Based on a literature search of cockle studies throughout New Zealand, it is likely these are some of, if not the largest cockles remaining from New Zealand waters (Professor Thrush, pers comm.). These cockles are certainly the largest known from the top of the South Island. This combined with the fact these cockles are subtidal makes it the only one of its kind in Marlborough and Nelson/Tasman. It is also representative of a biological feature (i.e. a cockle bed with very large individuals) once more widespread in parts of New Zealand.

5.4 Impact of forestry on cockles in Deep Bay

As part of a series of laboratory experiments, Barrett, *et al*. (2017) reported that , cockles were found to be resilient to sediment smothering with most cockles able to excavate themselves to the surface within days (often hours) from under 2, 5 and 10 cm, and even 25 cm, of native sediment where no physical disturbance to their natural (in situ) orientation had occurred.

Barrett, *et al*. (2017) noted that cockles were slower to re-orientate following disturbance to their natural orientation (inverted at the time of burial), and while able to resurface from an inverted position under low levels of deposited sediment they were significantly impeded in their ability to resurface when buried under greater sediment loads (5 and 10 cm), with significantly fewer adults resurfacing than sub-adults."

The authors cautioned that silts and clays were likely to have much more significant effects, with potential changes in community structure and loss of critical species likely to occur. For example, it would rely upon the level of sediment deposition being sub-lethal to bivalve populations.

Heavy rain events often result in very large fine sediment input into coastal environments (Davidson, 2018). Various authors have also documented smothering of bivalve beds due to sedimentation events (Stephenson, 1981; Morrison *et al*., 2009; Grange, 1996). Some estuaries that are now dominated by mud/silt, have been found to have layers of dead cockle shell several feet below the surface, highlighting how vulnerable coastal populations can be to sedimentation events (Marsden and Adkins, 2010; Morrison *et al*., 2009).

Gibbs and Woodward (2018) investigated sources of sediment in the Moutere and Waimea Rivers. It was found that:

(a) native forest and mature pine forest plantations were found to produce very little sediment,
(b) a substantial proportion of fine sediment was found to originate from forest harvesting, (c) harvested production forest that becomes colonised by gorse, broom and other weed species if not replanted are less efficient at protecting soil from rainfall than a closed canopy forest,
(d) bank erosion is a major source of fine sediment,
(e) the Waimea Estuary received a high proportion of legacy sediment from bank erosion but was also receiving sediment from harvested pine forest at various locations, and
(f) Moutere Estuary received a high proportion of sediment directly attributable to pine forest harvesting.

Gibbs and Woodward (2018) stated that this sediment may be travelling through the Moutere River system rapidly and being flocced out at the river mouth when it contacts the more saline sea water.

Much of the Deep Bay catchment was logged over a long period thereby reducing the scale of sediment run-off events. No data on sediment inputs in Deep Bay have been collected, however, visual observations of the subtidal cores collected during the present investigation revealed what appeared to be terrestrially derived sediments at the surface. These sediment cores showed marine sediment were dominant (silts, clays and very fine sand). The surface layer was soft and fluffy in appearance suggesting recent deposition of very fine sediment. It is unknown how much of this terrestrial surface layer is brought into Tory Channel from the Wairau and Awatere catchments versus sediment deposited from the Deep Bay catchment.

Cockle data collected in 2003 prior to logging and in 2019 after logging show cockle abundance and mean size have changed little over this period. Barrett, *et al.* (2017) showed that cockles can move to the surface following sediment deposition. Sediment deposition from Tory Channel waters is likely to be at a low rate but relatively consistent throughout the year. Cockles are therefore likely to cope with this slow deposition. Sediment from the Deep Bay catchment is likely to be sporadic and highest after land clearance combined with heavy rain. The ability of cockles to cope with a pulse of fine sediment is a dependent on scale of rain events relative to cleared land. Once land cover re-establishes and the forest grows, sedimentation from the Deep Bay catchment is likely to return to and remain at low levels until future harvests.

The survival of this cockle bed is therefore vulnerable to a combination of forest harvest and heavy rain events.

6.0 Conclusions

The important questions and risks analysis required in relation to the Deep bay cockle bed and the forestry activity include:

1. How important is the cockle bed?
2. What is the level of threat from sediment smothering?
3. If logging is continued, will cockles survive or recover from a large-scale sediment event?
4. Are there any actions that would minimize impacts? (e.g. staged harvesting, riparian zones, sediment traps, aerial hauling).

Possible answers:

1. It is the only know feature of its kind in Marlborough and a representative example of cockle beds once more widespread around New Zealand.
2. The level of threat from sedimentation is high after and during logging events, but low for the remainder of the forest cycle.
3. Cockles will likely survive small to moderate sedimentation events; however, a major rainfall event may have an adverse impact on cockles. It is unknown if the subtidal cockle bed would recover from a major event. If it did, the period required is also unknown.
4. There are a variety of actions that could reduce the threat to cockles (see Urlich, 2015). It may also be considered appropriate to augment suggested measures due to the importance of the Deep Bay significant site.

References

Anderson, A.J. 1981. A fourteenth-century fishing camp at Purakanui Inlet, Otago, Journal of the Royal Society of New Zealand, 11:3, 201-221, DOI: 10.1080/03036758.1981.10421837.

Anderson, M. J. 2008. Animal-sediment relationships re-visited: Characterising species' distributions along an environmental gradient using canonical analysis and quantile regression splines. Journal of Experimental Marine Biology and Ecology 366(1–2): 16–27.

Barrett, H.; Anderson, T. Morrissey, D. 2017. Effects of sediment deposition on the New Zealand cockle, *Austrovenus stutchburyi*. Prepared for Marlborough District Council Prepared for Marlborough District Council Marlborough District Council by NIWA, report 2017214NE.

Cryer, M. 1997. Assessment of cockles on Snake Bank, Whangarei Harbour, for 1996. New Zealand Fisheries Assessment Research Document 97/2. 29 p. (Unpublished report held in NIWA library, Wellington.)

Davidson, R.J. 2018. Qualitative description of estuarine impacts in relation to sedimentation at three estuaries along the Abel Tasman coast. Prepared by Davidson Environmental Ltd. for Sustainable Marahau Incorporated. Survey and monitoring report no. 882.

Davidson, R.J.; Richards, L.A.; Rayes, C. 2017. Benthic biological survey of central and south-eastern Tory Channel, Marlborough Sounds. Prepared by Davidson Environmental Limited for New Zealand King Salmon Limited. Survey and monitoring report no. 857.

Davidson, R. J.; Baxter, A. S.; Duffy, C. A. J.; Gaze, P.; du Fresne, S.; Courtney, S.; Brosnan, B. 2015. Reassessment of selected significant marine sites (2014-2015) and evaluation of protection requirements for significant sites with benthic values. Prepared by Davidson Environmental Limited for Marlborough District Council and Department of Conservation. Survey and monitoring report no. 824.

Davidson, R.J. and Richards, L.A. 2015. Significant marine site survey and monitoring programme: Summary 2014-2015. Prepared by Davidson Environmental Limited for Marlborough District Council. Survey and monitoring report number 819.

Davidson, R.J.; Duffy, C.A.J.; Gaze, P.; Baxter, A.; Du Fresne, S.; Courtney, S. 2011. Ecologically significant marine sites in Marlborough, New Zealand. Co-ordinated by Davidson Environmental Limited for Marlborough District Council and Department of Conservation.

Davidson, R. J.; Richards L. 2003a. Biological report on a cockle bed located at the head of Deep Bay, Tory Channel, in relation to log harvesting activities. Prepared by Davidson Environmental Limited for Sounds of Forest. Survey and Monitoring Report No. 449.

Davidson, R. J.; Richards L. 2003b: Biological report on three sites in Tory Channel in relation to recent or proposed forestry activities. Prepared by Davidson Environmental Limited for Marlborough District Council. Survey and Monitoring Report No. 444.

Gibbs, M.M.; Woodward, B. 2018. Waimea and Moutere sediment sources by land use. Prepared for Tasman District Council by NIWA, NIWA client report No: 2018026HN.

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

Grange, K.R., Cole, R.G., Parker, N.R. 1996. Distribution, abundance, and population size structure of cockles (Austrovenus stutchburyi) in Pauatahanui Inlet. NIWA Client Report NEL60416, prepared for Guardians of the Inlet, Pauatahanui. 18p.

Larcombe, M. 1971. The ecology, population dynamics, and energetics of some soft shore molluscs. Department of Zoology, University of Auckland. PhD. 250 p.

Lohrer, A.; Thrush, S.; Hewitt, J. E.; Berkenbusch, K.; Ahrens, M.; Cummings, V. J. 2004. Terrestrially derived sediment: response of marine macrobenthic communities to thin terrigenous deposits. Marine Ecology Progress Series 273: 121–138.

Marsden, I.D., Adkins, S.C. 2010. Current status of cockle bed restoration in New Zealand.Aquaculture International, 18(1): 83-97

Martin, N. D. 1984. *Chione stutchburyi* population responses to exploitation. Unpublished MSc Thesis, University of Auckland, Auckland.

Maxwell, K.; MacDiarmid, A. B. 2016. Taking stock: Oral histories about changes in marine fauna observed locally in the Hauraki Gulf and along the Otago-Catlins coast, New Zealand, 1926–2008. New Zealand Aquatic Environment and Biodiversity Report No. 173.

McKinnon, J.F. 1996. Studies of the Age, growth and shell increment patterns in the New Zealand cockle (*Austrovenus stutchburyi*). A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Marine Science at the University of Otago, Dunedin, New Zealand.

Michael, M; Wells, J. 2017. Community survey of cockles (*Austrovenus stutchburyi*) in Pauatahanui Inlet, Wellington, December 2016 Prepared for the Guardians of Pauatahanui Inlet by NIWA report 2017077WN.

Morrison, M.A., Lowe, M.L., Parsons, D.M., Usmar, N.R., Macleod, I.M. 2009. A review of land-based effects on coastal fisheries and supporting biodiversity in New Zealand. New Zealand Aquatic Environment and Biodiversity, Report No. 39.

Morton, J.; Miller, M. 1973. The New Zealand Sea Shore. Collins, Auckland. 653 p.

Norkko, A., Thrush, S.F., Hewitt, J.E., Cummings, V.J., Norkko, J., Ellis, J.I., Funnell, G.A., Schultz, D., MacDonald, I. 2002. Smothering of estuarine sandflats by terrigenous clay: the role of wind-wave disturbance and bioturbation in site-dependent macrofaunal recovery. Marine Ecology Progress Series, 234: 23-41

Spencer, H. G.; Willan, R. C.; Marshall, B. A.; Murray, T. J. 2002 Checklist of the Recent Mollusca described from the New Zealand Exclusive Economic Zone. http://toroa.otago.ac.nz/pubs/spencer/Molluscs/index.html

Stephenson R. L.1981. Aspects of the energetics of the cockle Chione (*Austrovenus stutchburyi*) in the Avon-Heathcote Estuary, Christchurch, New Zealand. Unpublished PhD thesis. Zoology. University of Canterbury, Christchurch New Zealand. 165 pp

Thrush, S. F.; Hewitt, J.E.; Norkko, A.; Nicholls, P. E.; Funnell, G. A.; Ellis, J. I. 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. Marine Ecology-Progress Series 263: 101–112.

Thrush, S.F., Hewitt, J.E., Norkko, A., Cummings, V.J., Funnell, G.A. 2003. Macrobenthic recovery processes following catastrophic sedimentation on estuarine sandflats. Ecological Applications, 13(5): 1433-1455.

Rayes, C.; Davidson, R. J. 2016. Summary of known benthic biological information for Tory Channel, Marlborough Sounds. Prepared by Davidson Environmental Limited for New Zealand King Salmon Limited. Survey and monitoring report no. 838.

Urlich, S.C. 2015. Mitigating fine sediment from forestry in coastal waters of the Marlborough Sounds. MLDC Technical Report No: 15-009: 61.