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– ARTICLE –

Middens Historically Significant on a Northland Landscape are Key to Demonstrating Ecological Degradation in an Adjacent Estuary

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ABSTRACT

Cockles (*Austrovenus stutchburyi*) dominate large Māori middens near Hororoa Point, in mid-Kerikeri Inlet, Bay of Islands, New Zealand, essentially all being 27–55 mm long, disarticulated individuals. Additionally, historical records show that significant levels of cockle harvesting were taking place nearby in at least the early-1800s. Today, the cockle stocks in this region are dense but appear degraded despite little or no harvesting for decades: they contain low proportions >30 mm individuals, with few exceeding 35 mm and 4 y of age. In this instance, middens have provided critical insight into the diminished stock-status of a modern cockle population compared with late-historical times. We invoke high and chronic levels of land-derived terrigenous sedimentation, and reduced resistance to parasites and disease, as primary causal factors behind the decline.

Keywords: *Austrovenus,* Bay of Islands, cockles, disease, midden, New Zealand, parasite, sedimentation

INTRODUCTION

Middens are records of human harvests rather than being reflections of natural abundance of taxa in an environment (Anderson 1981), but, nevertheless, their analysis can provide critical insight into ecological change. In New Zealand, middens have been used to learn about species extinctions at one extreme (eg, the northern sealion, a yet-unnamed species distinct from the New Zealand sealion *Phocarctos hookeri*; Smith 1989; Collins 2014), through to less-dramatic changes such as reduced mean size resulting from intense harvesting (eg, Leach 2006).

Some of our most useful, early insights into the characteristics of the cockles (*Austrovenus stutchburyi*) of the Bay of Islands (35° 12' S, 174° 10' E; Figure 1), a northeastern embayment of New Zealand, lie within Māori middens, midden-cockle size, abundance and ubiquity pointing to extensive and particularly rich resources of this bivalve in at least late pre-Contact (pre-1800) times (Booth 2016:78). Moreover, with a documented history going back to the early-1800s, information around the early post-Contact-period cockle resources of the Bay of Islands (and in particular Kerikeri Inlet), by which time cockles were a dietary staple in the north (Allen 2012; Smith 2013), may be among the most detailed available. Yet today, local cockle populations appear degraded, no longer achieving the same sizes or ages they once did.

Cockles are ubiquitous, shallow-burrowing bivalves of soft estuarine and sheltered shores (Morton and Miller 1968). Living from near high-water mark to lowest shores, most abundantly (up to 4500 per m^2) in sediments with ~11% mud (Anderson 2008:19; MPI 2018:233), cockles are ecosystem engineers, creating, modifying and maintaining habitats (Gutiérrez *et al*. 2003). Maturing at around 18 mm shell length (distance between the anterior and posterior ends, the only shell dimension reported here without qualification), spawning is protracted over late-summer, and interannual recruitment is typically highly variable (eg, Adkins *et al*. 2016).

Productivity and vigour in living bivalves is typically assessed using multiple lines of evidence, including data concerning age and size attained, growth rate, condition index (mass of tissue relative to shell), biochemical composition, and levels of parasites and disease (eg, Mann 1978) – but only the first two can be measured for archaeological cockles. Cockle growth rates and condition decline with distance above low-tide level, and along salinity gradients with distance from estuary mouths (Dobbinson *et al*. 1989:197; Marsden 2004:157). Growth in Northland over each of the first two full years is typically 5–10 mm shell height (at these sizes, essentially the same as shell length), cockles reaching ~30 mm height (~33 mm length) by age four (Larcombe 1971:15; MPI 2018:234). Macro-increments visible on shell surfaces are associated with annual growth (eg, Larcombe 1971:14; Coutts 1974:333), a year's growth

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being the distance between the sharp depressions of successive winters. In pristine populations, individuals ~12 y are not uncommon, with ~20 y the maximum age (~60 mm; Stephenson and Chanley 1979: 553). Main predators include shorebirds, finfish (particularly eagle rays *Myliobatus tenuicaudatus* and large snapper *Chrysophrys auratus*) and drilling shellfish such as *Cominella* spp. (Larcombe 1971: 97–112). Parasites can cause cockles to lose burrowing capacity and to 'surface', leaving them prone to predation (Babirat *et al*. 2004; Studer *et al*. 2013) and to temperature extremes. Cockles and other bivalves are also afflicted by disease that can cause mass die-offs (eg, Harvell *et al*. 1999; Guo and Ford 2016; Jones *et al*. 2017), with large losses of cockles noted for Kerikeri Inlet (particularly on the mid-northern side) in the late-1960s, followed by stock rebuild (Booth 1972: 98).

Kerikeri Inlet is an 8 km long shallow, drowned river valley that narrows near Skudders Beach into two tidal rivers, the Kerikeri (upstream catchment area 99 km^2) and Waipapa (34 km^2), with tidal mudflats occupying around half the surface area today – just as they have over recent geological times (Figure 1). Bay of Islands sediment accumulation rates are presently 10–20 times higher than before European settlement (Swales *et al*. 2012: 63), being greatest in upper estuaries. Accordingly, sedimentation has led to nearshore areas of Kerikeri Inlet becoming infilled with fine silt to depths of 15 cm or more that prevents cockles establishing altogether; this has been particularly noticeable along its mid- and upper-reaches (eg, Griffiths 2011) where around 50% of cockle habitat has been lost. Nevertheless, cockles today are abundant near the mid-Inlet channels, indicating that, in places, conditions remain biologically and physically suitable for settlement and at least early growth.

In this paper we use shell characteristics of cockles in Māori middens at Hororoa Point, a north-facing headland on the mid-south shore of Kerikeri Inlet, compared with those of the living cockles available nearby today, to conclude that there has been catastrophic decline in the status of this shellfish stock. We associate this degradation with high and chronic levels of land-derived terrigenous sedimentation, together with reduced resistance to parasites and disease.

METHODS

Historical information around beds of living cockles near Hororoa Point was gleaned from early missionary and explorer accounts, with midden-cockle presence and size taken from Site Record Forms (SRFs) on ArchSite, New Zealand Archaeological Association's Site Recording Scheme website and from examination of surface cockles. Although proportions of pure shell to organic material in middens typically vary a lot, standardised estimates of cockle volumes were derived from the SRFs by assuming 1 m width and 0.2 m depth for each reported metre-length of midden. The size data for midden cockles provided by the archaeologists on the SRFs will generally have resulted from little more than overview of surface shell material, but nevertheless they do provide valid and relevant insight into individual-size of the cockles available for harvest at the time.

Two middens directly associated with Hororoa Point were recorded on SRFs by Glenis Nevin, in 1984: the 300 m long midden-complex P05/464 and, to the east, the smaller P05/465 (Figure 1; Supplementary Material [SM] 1 & 2). At the time, P05/464 had an estimated volume of 1660 m^3: the western portion was a low-lying cockle-shell spit (cockles 35–51 mm) and to the east, on the face of a bluff, a midden-scree remnant contained cockles that were predominantly 29–47 mm (SRF). Later, at least one kiln produced burnt-lime, the shell for this agricultural dressing coming not only from the area of the spit, but possibly too from huge (now covered/excavated) middens on the banks of nearby Ōkura River (NAR 2004: 11,16). Many tonnes of both whole cockles and machine-crushed cockles were trucked from here to nearby properties in the mid-1900s, most shells having been whole (or nearly so) and identifiable when mined.

Hororoa Point middens were examined in December 2018 for the size-range of cockles present: at P05/464, sampling was near the base of the midden scree, and at P05/465 at the midden face. In order not to disturb the middens, cockle valves were haphazardly located on the *surface* in approximate proportion by size to the shells present. For the smaller cockles, the second and third full-years' growths were estimated based on winter depressions on the external shells; the first full-year's growth was not estimated because of frequent difficulty in determining the first winter depression, laid down shortly after settlement, it lying close to the umbo and often faint. Age of some of the larger cockles was also estimated, although crowding of the outer growth rings meant that this could not be precise.

The shell spit on the west side of P05/464 was not sampled in this study because it appears to be both natural and anthropogenic in nature. Degrading whole, dead cockles of all sizes, as well as shell fragments, naturally accumulate on the margins of cockle beds (eg, Morrison *et al*. 2014: 58), having been transported and sorted by the nearshore water movements. Nevertheless, mainly large cockles were once present on the spit in enormous quantities: in the early-1960s, remnant faces of previously-quarried deposits were 2–3 m high comprised of opened but otherwise whole cockles, interspersed with organic material (Greg Imms, pers. comm., 2019). Almost certainly, therefore, this spit represents – for the most part – a midden (as suggested in the SRF), which was subsequently mined and which, as a result, became much reduced in size (SM 1).

The midden-scree on the east side of P05/464 (SM 3; 35° 12' 30.0" S, 173° 59' 50.0" E), almost certainly one of the 'Huge pipi-shell middens' referred to by Ferrar and Cropp (1922) (SM 4), was not mined. (In this part of the country, cockles are frequently referred to as 'pipi' by local Māori,

'kōkota' being the more-commonly used term for *Paphies australis* [eg, Strickland 1990]). In 2018–19, the eroding scree covered much of the 8 m height of the bluff, showed no obvious layering, and was comprised almost solely of 'clean', often tightly-packed, disarticulated but whole and unburnt, medium to large (30–50 mm) cockle valves, although the base where it was being eroded by the sea was dominated physically by large cockles. Similarly, parts of nearby P05/465 (~330 m^3) remain, up to 3 m high with densely packed, mainly large cockles. Each cubic metre of both midden surfaces contained approximately 134,000 cockle valves, with almost no other shellfish being present, the most common exception being an occasional pipi *P. australis*. Few stones and little of the charcoal normally associated with day to day cooking were apparent within the middens.

Current cockle sizes and densities were derived from field sampling (Figure 1, SM 5) in 2018–19. GPS-located samples (each 0.03 m^2 of surface substrate, to a depth of 5 cm) from Middle Bank (MB; seven samples separated by ~50 m, sampled in December 2018), South Shore (SS; six samples, ~50 m, January 2019) and Pickmere Channel (PIC; five samples, ~30 m, April 2019) were sieved to 2 mm, and the cockles measured to the nearest millimetre using vernier callipers. Again, not only was age estimated, but for representative live samples, the second and third full-years' growths were determined. Size and age of the *recently dead* cockles were also recorded for particular samples.

RESULTS

Pre-Contact/early post-Contact cockles

The Mid-Kerikeri Inlet presents an archaeologically-rich landscape. The density of recorded shoreline middens approaches 4 per km of coast, being among the highest for the Bay of Islands (Booth 2016:78; SM 6). Cockles dominate the middens, and essentially all shells recorded on the SRFs were 30–55 mm, opened individuals (SM 2).

The first written records concerning a significant cockle fishery near Hororoa Point (and upstream to at least Skudders Beach) date from the early-nineteenth century. At that time, people of (or closely allied to) Taiamai (near Ohaeawai, 18 km inland) had land, access and fishing rights on the south side of Kerikeri Inlet, and particularly near Ōkura River (eg, Sissons *et al.* 2001:28), where summer months were usually spent harvesting and preparing cockles for transport inland, and in other fishing activities.

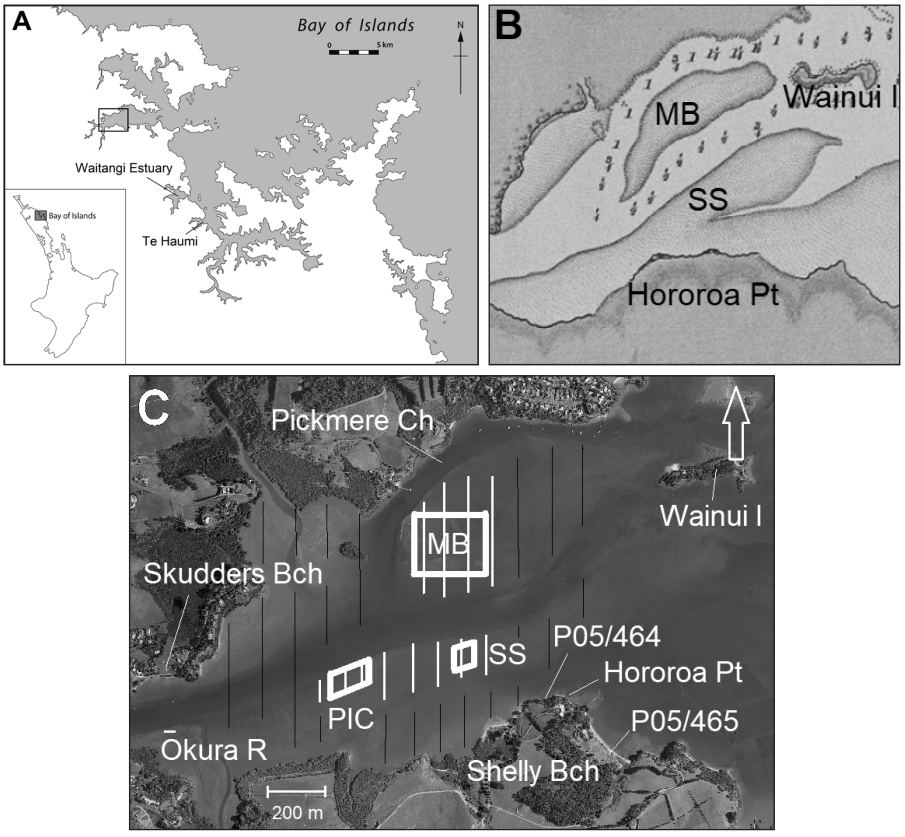

Figure 1. A) Mid-Kerikeri Inlet in the Bay of Islands (North Island, New Zealand); B) off Hororoa Point in 1849 (Stokes 1849); and C) the same place today (based on Booth 2020). The main extent of the cockle beds in 2018–19 are indicated by white vertical lines; black vertical lines denote areas of deep mud essentially devoid of cockles. Boxed areas are cockle-sampling sites (MB, Middle Bank; PIC, Pickmere Channel; SS, South Shore).

At such shellfishing camps, shellfish were usually steamed-open, threaded on flax string, then hung to harden before transport/storage (eg, Best 1929: 58), large individuals presumably being preferred. It appears, however, that by about 1830 the area was being little used any longer for summer fishing (Shawcross 1967: 210–212).

For 1819–26, there are three independent commentaries regarding the significance of cockle stocks in the area. 1) Early in 1819, missionary Samuel Marsden found, in the middle of Kerikeri Inlet, a very large cockle bed dry at low water where 'about a hundred women were busy collecting cockles for food' (Elder 1932: 180). 2) In August 1823, also near Hororoa, missionary Henry Williams was 'struck with the appearance of vast quantities of wild duck…. but upon drawing nearer, we discovered that it was a considerable quantity of children in the water collecting cockles' (Easdale 1991: 22). 3) And in 1826, 'opposite Skudders Beach', Colonial Botanist of New South Wales Alan Cunningham found '…whilst we were passing the narrows bounded by mudflats covered with a Cockle (Cardium) which the natives & more especially those often females were gathering together in baskets for food.' (Easdale 1991: 22).

Midden cockles (P05/465 and P05/464; Figure 2) averaged 38 mm and 37 mm respectively ($N = 126, 150$), reached 56 mm and 54 mm shell length, and lived to a considerable age (at least 12 y); the second full-year's average increments were 4.2 mm and 3.9 mm shell height respectively, and the third full-year's growths 3.7 mm and 3.6 mm shell height.

Recent cockles

Today, small live cockles are numerous on the tidal flats away from the immediate shores of Hororoa Point, these margins now being deep, fine mud and essentially bereft of shellfish (Figure 1). Although there has been no significant harvesting of cockles in mid-Kerikeri Inlet for decades now according to residents with expansive views over the tidal flats (eg, Adrian Walker, Department of Conservation, Kerikeri, pers. comm., 2019), 1) long-time local Richard Civil (21 Rangitane Rd, Kerikeri, pers. comm., 2018) recalled harvesting high proportions of plentiful, *large* cockles here in the 1940s–1950s; 2) Booth (1972: 100,224) reported that living bivalves significant on the nearshore intertidal and shallow-subtidal flats at Shelly Beach (and Skudders) in 1971–72 included abundant cockles and pipi, as well as wedge shells *Macomona liliana* (with essentially none of these shellfish now present); and 3) long-term locals report 'harvestable' cockles (where ≥30 mm individuals are present at ≥25 per m^2; Pawley and Smith 2014: 7) being present at Skudders Beach only until the early-1970s.

Cockles today are widespread and abundant (up to at least 2400 per m^2) at and near the surface at MB, SS and PIC – but they are barely harvestable (averaging 24 mm across all 18 samples, the largest individual being 36 mm; Figures 2 & 3), and the largest recently-dead cockles in the samples were no larger than the living ones. Moreover, cockles >30 mm have been rare at PIC since at least 2009, when sampling began there (Figure 3). Cockles (MB, SS and PIC) averaged 26.6 mm, 24.0 mm and 17.3 mm respectively ($N = 392, 142, 108$), reached 36 mm, 34 mm and 28 mm shell length, and lived only 3-5 y. Growth rates were similar to the midden cockles of the same size: the second full-years' average increments were 4.9 mm, 4.1 mm and 3.7 mm shell height for MB, SS and PIC respectively; and the third full-years' growth 3.3 mm shell height for MB (Figure 2 and SM 5).

Significant numbers of the live cockles at all three sampling areas were not completely buried in the substrate, instead appearing as scatters on top of the sediment surface, and in places they were present partially exposed in large numbers (SM 7). There had been no recent flooding, and none of these areas showed any evidence of erosional processes that might account for the exposure of these cockles.

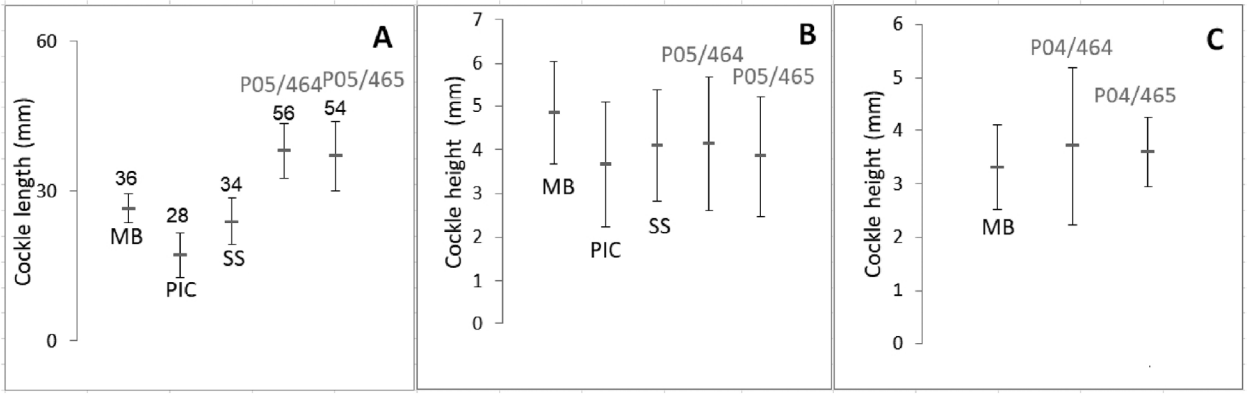

Figure 2. A) Hororoa cockles in 2018–19, mean size (mm length ±1 SD; 2 mm seive), with largest cockle-size given above each; B) mean second full-year's growth (mm height ±1 SD); and C) mean third full-year's growth (mm height ±1 SD). MB, Middle Bank; PIC, Pickmere Channel; SS, South Shore; Midden (P05/465 and P05/464) growth increments were for cockles 25–35 mm long.

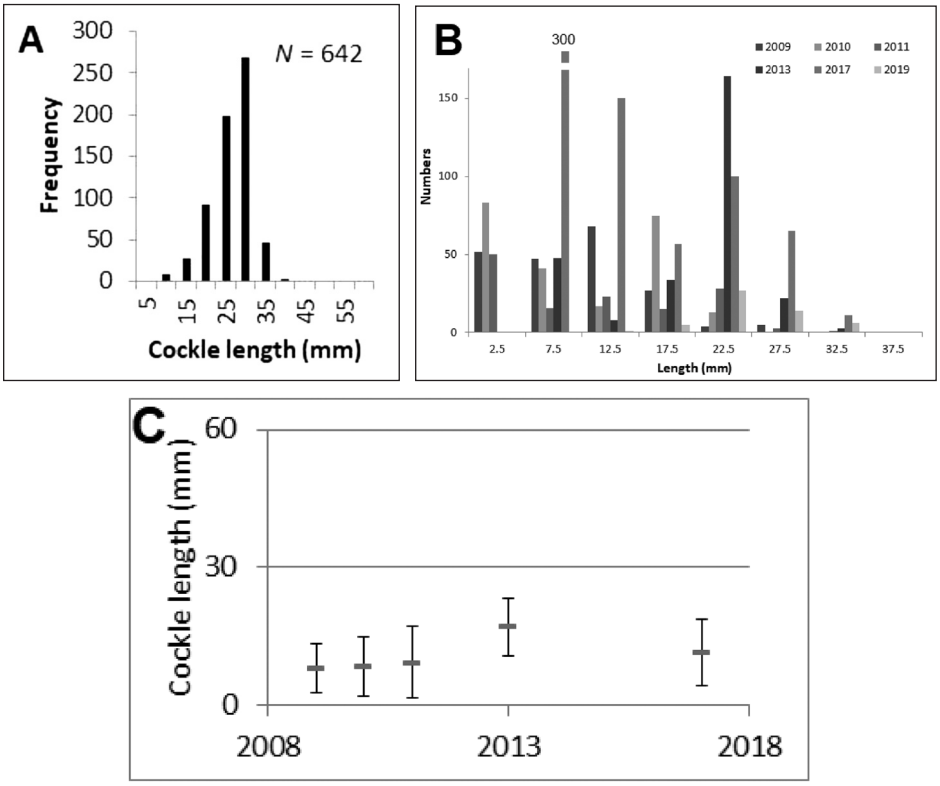

Figure 3. A) 2018–19 length-frequency distribution of living Hororoa cockles from Middle Bank, Pickmere Channel and South Shore combined (2 mm sieve); B) Length frequencies of Pickmere Channel cockles sampled during April (0.5 mm sieve), by year, 2009–17; and C) their summary size-statistics (mm mean length ±1 SD) (Richard Griffiths, Northland Regional Council, pers. comm. 2019).

DISCUSSION

Middens have been key in identifying change in the characteristics of mid-Kerikeri Inlet cockle populations. Not only has recent sedimentation of the Inlet (apparently since the mid-1900s; Booth 2020) led to ~50% loss of cockle habitat, mostly nearshore, but also the cockles present today are small. Although other indices of shellfish vigour, such as relative condition index, could not be examined, the cockles today are apparently as productive over the first few years of their lives as they were 200 y ago, their early annual growth-increments being indistinguishable. And yet they do not come close to the sizes or ages of cockles seen in the middens. Furthermore, small cockles have predominated at Hororoa for at least a decade, with successful (albeit annually variable) recruitment, and few individuals survive to exceed 30 mm (Figures 2 & 3); their die-off is apparently more age or size-related than episodic. And, notably, there have also been unnaturally high numbers of living cockles at the very surface of the substrate, where they are prone to predation.

The shells on the surface of the Hororoa middens today appear to represent large-scale, more-or-less sustained cockle harvests over some number of years of the late pre-Contact/early post-Contact eras, derived from healthy and productive stocks that contained sizeable numbers of large individuals; the stocks being ancient and pristine are unlikely, given the early narratives.

In contrast, the much-smaller cockles near Hororoa (or their absence altogether) today represent the current, more-or-less steady state – an apparently depressed stock, with barely-harvestable cockles despite little gathering. This suggests a massive status-change in the resource, but in order to secure this conclusion, there are certain key questions.

Did P05/464 cockles come from the Hororoa beds?

Because of the sheer volume of cockles indicated, consistent with large-scale harvesting and processing for transport inland, it seems likely most of the shellfish came from nearby rather than from distant sources. The sand/mud flats off Hororoa have almost certainly been the largest intertidal area for Kerikeri Inlet for centuries (Figure 1).

How representative in size are the P05/464 cockles of the broader Hororoa beds at the time of harvesting?

The presence of mainly large cockles (>40 mm) on the surface of midden P05/464 today suggest there were significant numbers/proportions of large cockles available nearby in the past; furthermore, most other mid-Kerikeri

middens with associated cockle-size data also show the presence of large individuals (SM 2).

How representative was the sampling of P05/464 in 2018?

The sampling was comprised of haphazard but, nevertheless, representative *surface* observations, and they yielded a size range (29–56 mm) not dissimilar to what archaeologists had recorded there 34 years previous (29–47 mm). However, the sizes of cockles beneath the midden surface are unknown.

Without dates, how can P05/464 cockles be linked to late pre-Contact/early post-Contact harvesting?

The cockles investigated were on the *surface* of the midden spill, so will – intuitively – be among the more recent harvestings, and there has been no large-scale cockle collecting in living memory, or in the historical record, since those of the early nineteenth century.

Evidence from midden-complex P05/464 points to a scale of cockle harvesting well beyond the artisanal, given 1) the sheer volumes of cockles today still spilling down the bluff; 2) the many tonnes of midden cockle-shell mined from the spit nearby; 3) the early-European reports of large-scale cockle harvesting here, with significant populations being present at least as far up Kerikeri Inlet as Skudders Beach; and 4) the traditional Taiamai accounts of Hororoa being a principal summer fishing camp with a focus on cockles for inland supply. Because it is most unlikely small cockles were absent from the beds when harvesting took place, it appears the larger ones were targeted. As there are few stones and little charcoal present within the midden, the cockles were presumably steamed open in great quantities on the bluff above. Furthermore, other archaeological features in the immediate vicinity are indicative of a well-peopled landscape at certain times of the year: 1) there is a cluster of kumara storage pits, each ~8 m^2, on the bluff near the eastern midden scree (SM 1); 2) cultivation and drainage lines are visible in early aerial photography on the flat near the spit (SM 1); and 3) adzes and adze fragments, hoanga and hammerstones, and chert flakes suitable for fish-processing have been found on the beach nearby (Booth Whanau Collection, housed at Te Kōngahu Museum of Waitangi). However, any temporal coincidence between these lines of evidence is untested.

The Hororoa middens are also interesting from the point of view of foraging models and foraging efficiency (FE) (eg, Allen 2012): the assumption is that harvesting initially targets high-return resources, but as these are depleted FE declines and lower-value resources are sought. Given the overwhelming dominance and sheer abundance of large cockles, it appears that foraging success associated with the Hororoa middens remained high, and lower return resources were not required. This may suggest management was particularly effective, the beds containing sizeable proportions of large individuals over time, despite the levels of harvesting taking place.

On the margins of Kerikeri Inlet today, deep, fine silt appears to altogether prevent cockles establishing, while presumably-compromised cockles further offshore succumb within ~4 y (and ~35 mm) despite annual growth-increments being indistinguishable from those of similar size among the midden cockles (Figure 2). Further, the significant numbers of surfaced cockles present possibly suggest high parasite infestation, or the effects of some other contagion or debilitating contaminant. Surfacing can be characteristic of trematodes: cockles serve as second intermediate host for several echinostome species, some of which prevent cockles from burrowing. With infection rates positively cockle-size-dependent, parasites infect (albeit at relatively low densities per individual shellfish) all cockles in certain parts of the Bay of Islands (Studer *et al*. 2013: 127). Large numbers of surfaced cockles may be recent because neither Larcombe (1971) nor Hewitt *et al*. (2010; pers. comm., 2019) appear to have encountered them in their ecological observations of Bay of Islands cockles, and, because surfacing is disadvantageous, it appears many cockles are compromised. These presumably-challenged cockles may be less-resilient to other infection, leading most to succumb when they are small and young.

The Hororoa length-frequency distributions (Figure 3, SM 5), with poor representation of cockles <20 and >30 mm, are similar to recent observations in Waitangi Estuary (Figure 1) (Griffiths 2013: 23). These patterns are consistent with one or more possible explanations: 1) poor recent larval recruitment; 2) larval recruitment taking place elsewhere, juveniles migrating onto the bed within a year; 3) high mortality/predation of very small cockles; 4) particularly high larval recruitment ~2 y earlier, with good survival; and 4) death after ~4 y or sooner. Poor recent larval recruitment, and high mortality once the shellfish reach round 30 mm, appear to be the most likely explanations for these size distributions. In contrast, stronger early cohorts have recently been present at Te Haumi (Berkenbusch and Neubauer 2015: 70), and in other parts of the Bay in 2009 (Judi Hewitt, NIWA, pers. comm. 2019) – but few cockles anywhere grew to exceed 35 mm. Accordingly, the impression is that although levels of larval recruitment may be spatially and temporally variable, the one constant is that cockles seem to no longer achieve large sizes.

There are many competing and/or compounding potential explanations for significant and enduring reduction in the size of Hororoa Point cockles today compared with in late pre-Contact/early post-Contact times. 1) *Recent suboptimal seawater temperatures associated with ocean-climate variation*: however, although the Hororoa middens probably derive from times when average air temperatures were up to 1° C cooler than today (Little Ice Age; Anderson *et al*. 2014: 121), cockles, until at least the 1960s, reached large sizes (~50 mm) in warm northern waters (Larcombe 1971: 43; author's and others' unpubl. obs.), and, anyway, northeast-New Zealand coastal sea temperatures have risen little since the 1970s (Shears and Bowen 2017). 2) *Game-changing rises in sea level*: however, northern-New Zealand sea-level rise has averaged only ~1.3 mm per yr since 1899

(Hannah 1990), and the intertidal of mid-Kerikeri Inlet today appears geomorphologically similar to that of the mid-1800s (Figure 1). 3) *Diminished growth rates today*: however, at least early annual growth increments are indistinguishable from midden cockles of similar size (overlapping SDs; Figure 2). 4) *Recent overharvesting*: however, according to locals there has been no significant harvesting here for decades. 5) *Previous heavy exploitation of large individuals has profoundly altered population genetics*: however, this seems most unlikely, based on the international literature reviewed. 6) *Māori translocated and manipulated cockles on such a scale that natural size-distributions were supplanted*: however, evidence for transplantation of cockles at *large* scale has proved elusive. 7) *Loss of interest in cockles as seafood has led to overcrowding and slower growth*: however, early growth increments are indistinguishable from midden cockles, and we know densities can reach values much higher (~4500 per m^2; MPI 2018: 233) than the maximum of ~2400 per m^2 (average ~1100 per m^2) found in this study. 8) *Chronic and intolerably-high levels of organic or inorganic contaminants*: however, at least since 2008, enrichment in the water column and surficial sediments in Kerikeri Inlet has been at most low to moderate, with no lethal levels of bivalve toxins reported (Cornelisen *et al*. 2011; Griffiths 2011, 2014; Bamford 2016). 9) *Chronic food-limitation brought about by low productivity*: however, tidal flushing is fulsome, and conditions are not unproductive (Griffiths 2011). 10) *Greater numbers of large-cockle predators, and/or fewer predators of small cockles*: however, there is no evidence for noteworthy changes in abundance of these. 11) *Chronically insufficient larvae*: however, breeding-sized cockles are still numerous in the broader Kerikeri Inlet. 12) *Highly-variable recruitment success, with long intervals between cohorts of large cockles*: however, there is no evidence for quantities of *large* dead-shells present on the beds or adjacent shores. 13) *Periodic and damaging environmental episodes (eg, eutrophication, harmful algal-blooms, viral outbreaks) have led to mass mortalities of large cockles*: however, no quantities of recently-dead, *large* cockles are known here. 14) *Greater prevalence of parasites and disease-causing organisms, with parasite impact typically positively age-related*: this is a strong possibility. 15) *Chronic stress, perhaps brought about by persistent, and at times catastrophic, deposition of terrigenous silt, has left cockles less-resistant to parasites and disease*: this is also a strong contending explanation for much smaller cockles off Hororoa Point cockles today compared with 200 or so years ago. In summary, generally low densities of harvestable cockles in Kerikeri Inlet today probably result from multiple stressors underpinned by chronic levels of fine terrigenous-silt accumulation – a well-known inhibitor of cockle vigour (eg, Lohrer *et al*. 2004). Further, it is possible some crucial tipping point in sedimentation levels has been reached – or some level of prevalence and persistence of a disease or parasite attained (Harvell *et al*. 1999) – whereby re-attainment of a full size range, with substantial proportions of older cockles, is presently not possible.

Much-lowered stock status among cockles today compared with in the past is not confined to Kerikeri Inlet. Although limited weight can be placed on cockle-length ranges from middens where length distributions were *not* the main point of the archaeologists' mahi, and size-range is an extremely coarse metric, both the reduction in areal extent of cockle beds brought about mainly through nearshore sedimentation at Hororoa, as well as low proportions of large cockles there, are echoed throughout much of the Bay of Islands today (Booth 2020). Cockles dominate the Bay's middens (some dated; Booth 2016: 80), most almost certainly resulting from many years of harvesting, particularly during late pre-Contact/early post-Contact times. Despite large local human populations capable of intense fishing pressure (Booth 2016: 75–76), and strong dependence by northern Māori on estuarine shellfish by late-pre-Contact times (Allen 2012; Smith 2013), most middens with associated size data contain large to very large cockles (≥40 mm) (Figure 4A). Yet the largest cockles throughout the broader Bay of Islands today are, like off Hororoa Point, typically much smaller (usually ≤33 mm; Figure 4B–4C), even though the beds are essentially unfished. Moreover, both scatterings and concentrations of living, surfaced individuals were widespread on Bay of Islands cockle beds during the 2018–19 sampling on which Figure 4B–4C is largely based, their shells proud of the substrate surface.

This contribution has compared and contrasted the size and early-growth characteristics of living cockles with archaeological cockles, the results suggesting that cockle stocks of Kerikeri Inlet – and probably much of the rest of the Bay of Islands too – are compromised today compared with ~200 y ago. Although the cockle length-frequency distributions (Figures 2 & 3) are consistent with low recent levels of new recruits to the Hororoa beds, other data from the Bay of Islands point to temporally variable recruitment – the one constant being the apparent inability of cockles to any longer achieve even 40 mm length, let alone the larger sizes of earlier times. The full story behind this catastrophic change has yet to be made clear.

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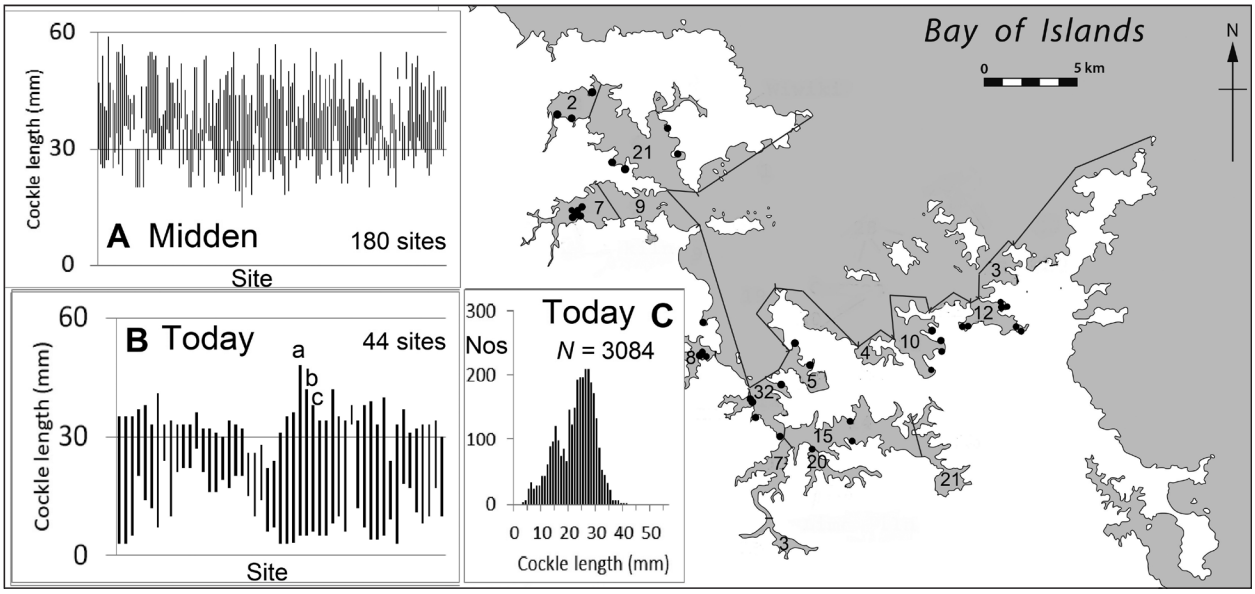

Figure 4. A) Length ranges of midden cockles reported on archaeological Site Record Forms, with numbers of middens shown on the map according to Booth's (2016) archaeological compartments; B) and C) recent (since 2009) living cockles, with sampling sites indicated on map by dots, the author sieving to 2 mm (but others' mesh sizes varying) for the Bay of Islands (based on Booth 2020). In A and B, each vertical line denotes maximum and minimum cockle lengths for a particular locality. In B, designations a, b and c are beach-wide maximum and minimum values.

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