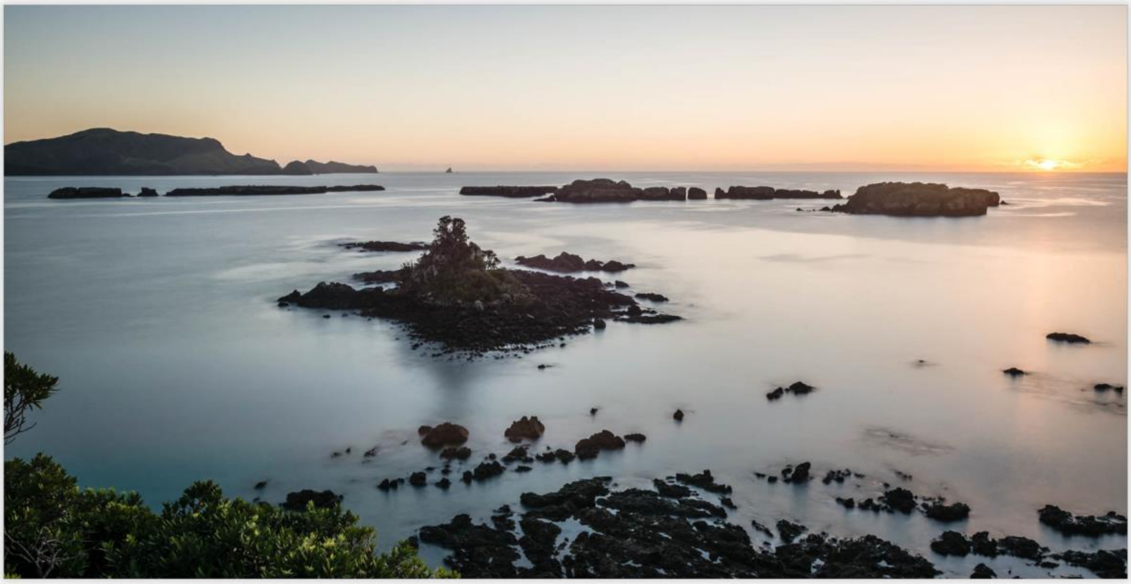
# Water quality, shellfish disease and harvesting pressure in northwest Bay of Islands: implications for kutai (green-lipped mussel) recruitment, survival and abundance



A desk-top review prepared by *Fish Forever* for
Te Komiti Kaitiaki Whakature i nga Taonga o Tangaroa

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May 2020

Black Rocks from Moturoa Island, Mataka maunga at left background
(Image: Dean Wright Photography)

# My conclusions for Black Rocks kutai, at a glance

### Has there been significant decline in kutai abundance since ~2015?
Yes, almost certainly, among both intertidal and subtidal populations – although there has been insufficient formal surveying to quantify the level of reduction.

### Has poor water quality contributed to this decline?
Most unlikely – no key water-quality indicators have failed categorically to meet Australasian guidelines.

### Has lack of food (phytoplankton) contributed to this decline?
Possibly – but unlikely. Food *does* limit other kutai populations, but for the Black Rocks:
- No known accounts of reduced condition ('watery' flesh, with little or no roe development);
- No evidence of reduced condition among other filter feeders nearby.

### Have low numbers of settlers contributed to this decline?
Yes, almost certainly, but supporting observations are sparse:
- Poor recruitment has been invoked for decline in kutai populations elsewhere in New Zealand;
- Recent pictures and observations of intertidal and subtidal populations at Black Rocks suggest sparse – if any – ongoing recruitment.

### Have increased levels of predation, or competition, contributed to this decline?
Most unlikely: no evidence for increased abundance of key predatory fish, starfish or crabs, nor of competitors such as little black mussels.

### Have increased levels of parasitism contributed to this decline?
Most unlikely:
- Parasites (most commonly pea-crabs) infest kutai at low levels nationally;
- No known reports of heavy parasite infestation at the Black Rocks.

### Has disease contributed to this decline?
Possibly, but needs further investigation:
- There are reports of large quantities of dead shells on the seafloor (although there are no reports of significant numbers of dead kutai among living intertidal or subtidal populations);
- Certain divers familiar with the area suggest that the kutai beds were recently so extensive not to have been knocked over in such short time.

**YET**
- Kutai are unknown elsewhere in New Zealand to be massively afflicted by disease;
- No known accounts of reduced condition among kutai at the Black Rocks;
- Certain close-by kutai populations appear to remain populous and intact, and there is ongoing kutai recruitment elsewhere in the Bay of Islands.

### Has overharvesting contributed to this decline?
Almost certainly:
- The intertidal populations - highly-visible - appear to have been steadily declining through (sometimes bulk and destructive) harvesting;
- Subtidal populations are known to have been harvested heavily for community events;
- But, at least certain intertidal populations nearby still appear relatively intact.

### *BUT, for greater certainty, further observations, data and biological material are required:*
- What is the depth, extent and biological characteristics of the remaining subtidal mussels?
- Is there evidence for new recruits amongst either the intertidal or subtidal mussels?
- What are the characteristics (size, erosion) of the dead kutai on the seafloor below the rock faces?
- Are there moribund kutai that can be sent to MPI Biosecurity Surveillance for pathology?

# Contents

# Water quality, shellfish disease and harvesting pressure in northwest Bay of Islands: implications for kutai (green-lipped mussel) recruitment, survival and abundance

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## Summary

Kutai (green-lipped mussels *Perna canaliculus*) are choice kai moana for many of us, 'getting a feed' often an integral part of a day's fishing; and at the same time they are the basis of a half-billion dollar per year aquaculture industry. In the Bay of Islands the Black Rocks, within Te Puna Mātaitai, have long been known for their rich source of kutai, but in recent times the mussel's abundance – both intertidally and subtidally – has declined alarmingly, possibly over just a few years. One explanation for such a decline is that water quality - some combination of physical (eg, terrigenous silt), chemical (eg, pesticide) or biological (eg, insufficient food) condition - has led to widespread morbidity and mortality among adult shellfish. Other possible contributors to decline in kutai include disease/parasite outbreak, recruitment failure (insufficient small juveniles reaching/surviving on the beds to replace adult mussels that have gone), and overharvesting.

There is no evidence that waters in the region of the Black Rocks have, within the past 5 y, been contaminated badly enough to bring about widespread mortality among the kutai; for key variables/parameters, the waters more than meet the Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines. Further, based on what is known of kutai in other parts of Aotearoa, a widespread and catastrophic disease outbreak is unlikely – yet there have been reports of large quantities of dead shells on the seafloor beneath Black Rocks' beds. Critically, the Black Rocks kutai population appears to be recruitment-limited – new, small mussels are not immediately evident in either the intertidal or in the (much less-well observed) subtidal populations. Finally, overharvesting has almost certainly contributed to the decline.

These conclusions cannot be locked in until further sampling is undertaken: 1) determine the shell-size, condition and mortality of kutai within the remaining intertidal and subtidal populations, with any moribund individuals collected for disease diagnostics; and 2) define the characteristics of the dead shells present, both within beds as well as on the seafloor nearby. It is also important that formal recording of peoples' experiences around the distribution, availability and harvesting of kutai at the Black Rocks be expanded, the weight given to the various narratives categorised (even prioritised) according to established criteria.

This report was researched and written by John Booth on behalf of *Fish Forever* for Te Komiti Kaitiaki Whakature i nga Taonga o Tangaroa, it was reviewed by four *Fish Forever* scientists (alphabetically, Dr Vicky Froude, Derry Godbert, Dr Ken Grange and Chris Richmond), and it was authorised for release by the Chair of *Fish Forever*.

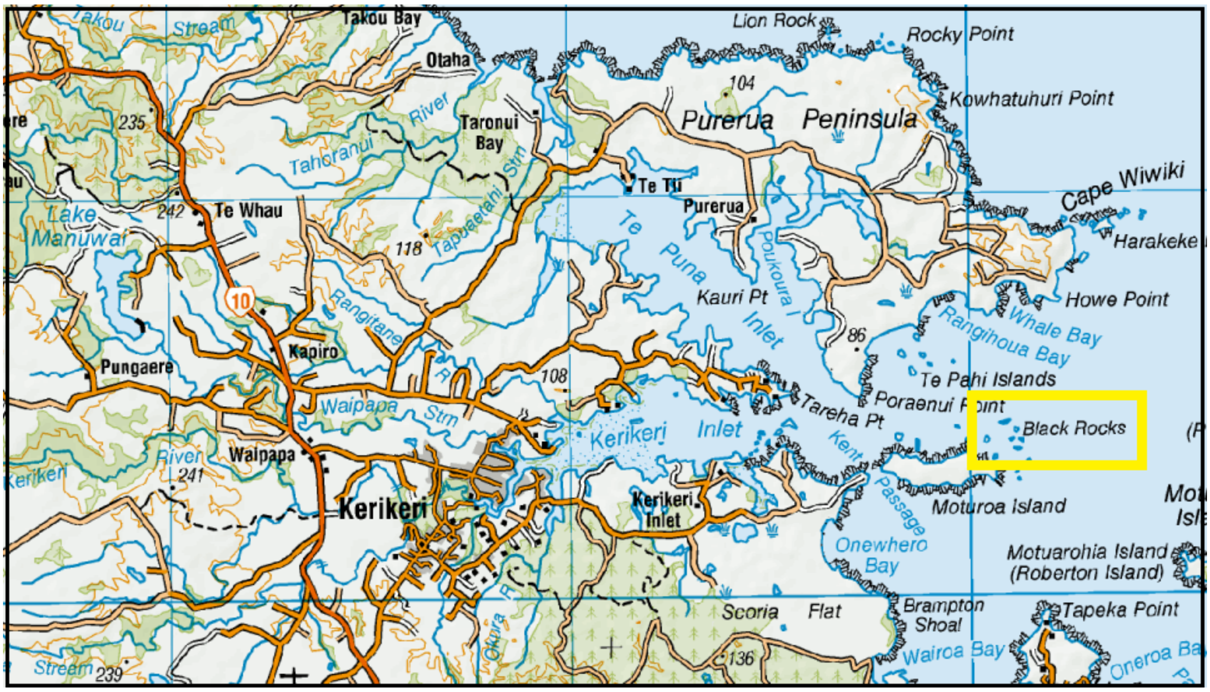


**Figure 1. Waters from two inlets (Te Puna and Kerikeri) combine to flow eastward, north of Moturoa Island, and past the Black Rocks (boxed) out into the main basin of the Bay of Islands.**

## 1. Introduction

Kutai (the green-lipped mussel, *Perna canaliculus*) are found throughout the main basin of the Bay of Islands (eg, Morley & Hayward 1999), the Black Rocks stock for a long time having been perhaps the best-known in the Bay. The Black Rocks lie within Te Puna Mātaitai (*see* Figure 8), with various other kutai populations also present within this rohe – both on the mainland as well as on various islets and semi-submerged rocks.

Soon after establishment of Te Puna Mātaitai, in 2013, the state of Black Rocks kai moana stocks came under scrutiny, there being particular concern over the seemingly-rapid reduction in availability of the kutai. The possible causes – and particularly the action that might be taken to address this decline – were the subject of hui at Waimate North's Tauwhara Marae in December 2018 (*Kaimoana ake tonu atu – seafood forever*) and December 2019 (*Community consultation hui for the 'Proposed Bylaw for the Te Puna Mātaitai Reserve, Bay of Islands – November 2019' Te Komiti Kaitiaki Whakature I nga Taonga o Tangaroa*), each led by TeRau Allen and Hugh Rihari and with wide community participation that included Hapu, Bay of Islands Swordfish Club, Spearfishing New Zealand, *LegaSea* and *Fish Forever*.

At the December 2019 hui, there was a range of views on what was causing the mussel depletion – from natural causes to land runoff, with overharvesting a primary candidate. One diver's report of 'a metre-depth' of dead shells on the seafloor beneath certain of the Black Rocks kutai faces (NZ Fishing News 2020) raised the possibility that water quality issues and/or disease had had a part to play in declines among the kutai. This was not an unreasonable proposition, given – for example - that mortalities associated with disease have recently led to the closing of Pacific oyster (*Crassostrea glomerata*) farms upstream of the Black Rocks, in Kerikeri Inlet (eg, Anon 2014), and cockle (*Austrovenus stutchburyi*) populations in Kerikeri Inlet appear today highly compromised through water quality and/or disease issues (Booth 2020). Accordingly *Fish Forever* (https://www.fishforever.org.nz/), a community group focused on promoting, advocating, and supporting marine conservation in the Bay of Islands, offered to provide Te Komiti Kaitiaki Whakature i nga Taonga o Tangaroa a background paper on water quality (and – specifically underscored retrospectively – the possibility of disease/parasites) and any likely impacts on kutai productivity at the Black Rocks. Te Komiti formally requested that *Fish Forever* follow through with this background paper in subsequent correspondence.

The December 2019 hui in course led to a formal application to MPI for a temporary ban on the harvesting of mussels in Te Puna Mātaitai. A bylaw prohibiting the taking of green-lipped mussels (as well as blue mussels *Mytilus galloprovincialis* and the little black mussel *Xenostrobus pulex*) within the Mātaitai came into effect on 23 March 2020 ([Fisheries] Notice No. MPI1120), to be revisited after three years. (The solely-intertidal blue mussel and little black mussel are not considered here because neither is anywhere near as much sought as the kutai.)

Kutai are widely if patchily distributed, and were once abundant, throughout much of northern New Zealand on exposed shores through to those more-sheltered but with adequate turn-over of high-salinity seawater. However, by the close of the last millennium it was already clear that harvesting (mainly commercial at the start, and then recreational and customary) had greatly diminished – even entirely removed – many wild populations, and the status of others had become of concern to managers (*see*, for example, Jeffs et al. [1999], removal in 2005 of the ban on use of scuba to harvest mussels exacerbating the situation). Commercial dredging (later augmented by reasonably large-scale, illegal commercial harvesting – eg, Chisholm 2005) had largely extinguished the extensive (many $km^2$), mainly subtidal Firth of Thames kutai beds (Greenway 1969), where mussels had been present mainly on soft sediments to depths of 30 m or so (Paul 2012). The Firth of Thames reefs have not recovered since commercial fishing there ceased in 1968, low recruitment and survivorship of juvenile mussels probably the main reason (McLeod et al. 2011), and many recreational/customary beds elsewhere remain imperilled.

In this desk-top contribution, I consider first the main biological features of kutai key to our understanding of their presence and persistence at the Black Rocks; I then provide a physical setting to the Black Rocks, with emphasis on the sources of the waters that surround them; next I create a preliminary history around recent (past decade or so) kutai harvesting/availability, as evidenced by divers and intertidal harvesters – to be added to in due course through others' accounts; and then I address the evidence around the extent of reduction in kutai abundance in the area of the Black Rocks in recent times. The main body of this contribution considers whether water quality and/or disease/parasite issues are contributing to any decline in kutai abundance. 'Water quality' here takes in the physical, chemical and biological characteristics of the seawater in the Black Rocks region that might impede or prevent kutai reproduction, settlement or survival – in turn influenced primarily by the features of the fresh and marine waters flowing into the area from the catchments of the Kerikeri and Te Puna inlets, but also by the quality of marine waters further out in the Bay, beyond the Mātaitai. Diseases (eg, bacterial, viral) and parasites in shellfish in the northwest Bay of Islands may be associated with poor water quality too – although disease can also establish even in the context of high water-quality.

## 1.1 Essential biology

Certain aspects of the biology of kutai are key to our determining whether water quality issues might be affecting this shellfish at the Black Rocks, especially their settlement success (cues to settle, primary settlement, secondary settlement) and survival; and their susceptibility to disease and parasites. Kutai require productive waters for sustenance, and, in turn, they are subject to predation.

Kutai are most common in northern and central parts of Aotearoa, where they frequently form dense beds (Morton & Miller 1968). They are found from the midtide zone down to depths >50 m, the physiological inability of small mussels to survive aerial exposure appearing to restrict their occurrence on upper shores (Kennedy 1976), whereas the lower limits – at least of the strictly intertidal populations – are thought to be regulated mainly by predation (Jeffs et al. 1999; Rilov & Schiel 2006). They are found on firm surfaces, but also on soft substrates where even sparse supportive elements allow settlement and beds to establish, and are tolerant of a wide range of salinities and temperatures (eg, Jeffs et al. 1999; O'Driscoll et al. 2003).

Kutai presence in the northeast of the North Island goes back millions of years, and in the Bay of Islands they have been continuously prominent throughout the record of human occupation in both ancient middens (Site Record Q05/682 on Moturua Island, dated to around 1300 AD; Robinson et al. 2019) and in more-recent middens (NZAA database; Booth 2016); they continued to be prominent in Bay of Islands ecological observations through the twentieth century (eg, Morton & Miller 1968: 395; Booth 1972; Jeffs et al. 1999; Morley & Hayward 1999). Although – in addition to the Firth of Thames – there were notable soft-sediment kutai reefs in Kaipara and Manukau harbours (McLeod 2009), only small quantities of dredged mussels have been reported from the Bay of Islands (Booth 2017). If dense beds of kutai ever did exist on soft seafloors in the Bay of Islands, it is unlikely they were extensive.

Kutai are harvested today on hard shores in open parts of the Bay of Islands, but stocks have declined markedly over the past decade or so. In the eastern part, overharvesting of the intertidal beds was followed by increasing focus on subtidal beds, only a few of which are now known to survive, most of them on the west side of Cape Brett Peninsula (Pacific Eco-logic Ltd. 2016). At the Black Rocks, the principal site in the west of the Bay for these mussels, there are various levels of depletion among intertidal and subtidal beds (Pacific Eco-logic Ltd. 2016).

Sexes are separate but co-occur, mussels in the north maturing within a year of settlement (and at about 30 mm shell length: Jeffs et al. 1999; Alfaro et al. 2006). Most northern kutai spawn from June to December, but larvae can be present in the plankton much of the time; most settlement is from late winter to early summer, but is highly variable spatially and temporally.

During the pelagic larval (veliger) stage (Figure 2), which lasts 3-4 weeks, the larvae feed mostly on phytoplankton; with their swimming confined largely to vertical movements, the larvae can potentially be transported large distances by currents.

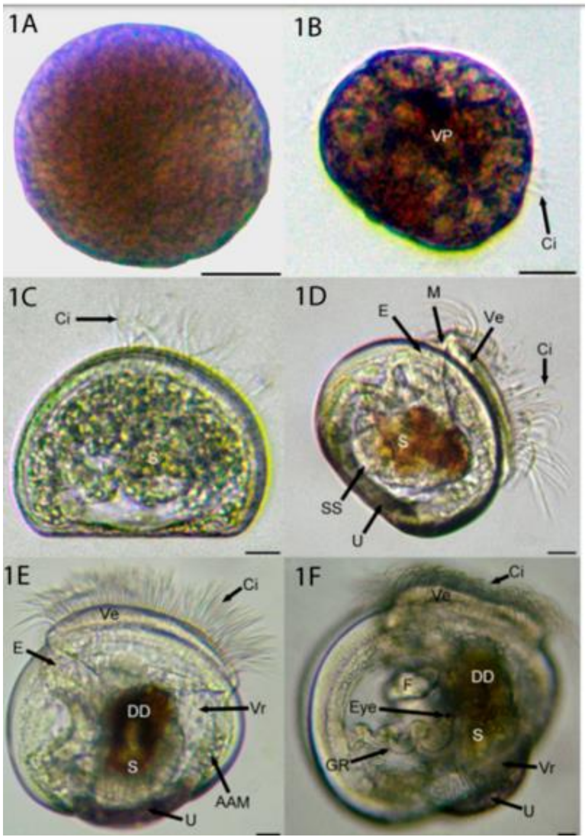


**Figure 2. (A–F) Light images of unfertilized egg to umbonate larvae of kutai. (A) Unfertilized egg. (B) Ciliated gastrula stage T0 + 18 h. (C) D-stage larva (2 days old). (D) Early umbo stage (9 days old). (E) Late umbo stage (13 days old). (F) Umbonate larva (17 days old). Abbreviations: AAM, anterior adductor muscle; Ci, cilia; DD, digestive diverticulum; E, oesophagus; F, foot; GR, gill rudiment; M, mouth; S, stomach; SS, style sac; U, umbo; Ve, velum; Vr, velar retractor muscle; VP, vegetal pole. Scale bars = 20 μm (Rusk et al. 2017).**

Primary settlement happens when kutai larvae 240−300 μm long transition to a benthic mode of life, and then metamorphose (South et al. 2017). Primary settlement onto beds of adult mussels is uncommon (Jeffs et al. 1999); larvae typically settle initially on filamentous surfaces such as hydroids, bryozoans and filamentous and turfing algae, a mechanism possibly to avoid consumption by, or competition with, adults. A variety of physical, chemical and bacterial cues have been reported to induce settlement in bivalve larvae, with marine bacterial biofilms – typically composed of a high diversity of micro-organisms (e.g., bacteria, diatoms, fungi, protozoans) – being particularly important for kutai (Alfaro et al. 2006; Ganesan et al. 2010). Settlement is completed with attachment of an excreted byssus thread and subsequent metamorphosis to the juvenile (Jeffs et al. 1999).

Secondary settlement is the process by which juvenile mussels 0.3−6 mm in length sever their byssus threads and migrate away from their initial larval settlement sites to re-settle elsewhere (eg, South et al. 2017). Most juveniles are thought to recruit onto mussel beds using either a form of byssopelagic migration (or mucus drifting; 10s to 100s m), or by pedal crawling (cm) (Jeffs et al. 1999). Juvenile kutai may move numerous times like this before finally recruiting; a potential trigger for secondary settlement is the proximity of populations of adults, possibly through waterborne chemical cues (South et al. 2017).

Kutai are filter feeders, sieving water primarily for its phytoplankton (Zeldis et al. 2004). There is a growing body of evidence to indicate that the primary reason for the absence of kutai in certain parts of the country is low food availability (eg, Helson & Gardner 2004), with certain localities in Northland with high kutai densities becoming nutrient-limited, resulting in starvation and/or significantly decreased survival (Alfaro 2006), especially at times near the peak of reproductive output (Alfaro et al. 2001; Alfaro 2006). Kutai weakened in this manner are often slow to close their valves when disturbed, and at such times mats of mussels have been observed ripped from rocks by strong wave action (creating new spaces that are quickly filled by new settlers), the compromised mussels presumably not being able to generate byssal threads sufficiently fast to maintain their hold. Alfaro (2006) was to conclude that 'massive mortality in this adult population [near Tauroa Point, on the west coast of Northland was] consistent with the hypothesis that limited food supplies during August result in death of large mussels'.

The planktonic veliger larvae are consumed by filter-feeding invertebrates; juvenile and adult kutai are preyed upon by octopus, and certain fishes (particularly snapper *Pagrus auratus*, spotty *Notolabrus celidotus* and other labrids, and leatherjackets *Meuschenia scaber*), and various predatory crabs and starfish (Jeffs et al. 1999; Rilov & Schiel 2006). Main competitors intertidally (but of little consequence) at the Black Rocks are little black mussels and other invertebrates such as barnacles. Subtidally, many rock faces are heavily colonised by invertebrates and algae, with unknown impacts on kutai recruitment and survival.

Diseases of shellfish can be classified as either non-infectious or infectious, with – in general - greater susceptibility to infection when non-infectious stressors are prevalent.

Filter feeders such as mussels are exposed to heavy metals dissolved in the water and present in seafloor deposits (eg, Naimo 1995). Shellfish can bioaccumulate certain metal to concentrations greatly exceeding those dissolved in the water – so becoming toxic to the shellfish (as well as making the shellfish useful biomarkers of heavy-metal contamination). Papers I have reviewed settle on cadmium, copper, mercury and zinc as the major metals potentially toxic to shellfish, many aquatic systems having been contaminated by these metals as a result of human activities. But species-specific data are hard to come by, the best I could locate being for *Perna viridis*. Preliminary bioassay tests revealed that the lethal ($LC_{100}$), median lethal ($LC_{50}$) and sublethal ($LC_0$) concentration of silver and chromium to *P. viridis* were 6.5, 4.0, 2.0 mg/l and 4.5, 2.5, 1.0 mg/l, respectively (Vijayavel et al. 2007). But the issue is particularly complex because early life stages can be much more sensitive to certain chemicals than the adults (eg, Wang et al. 2007).

Additionally, stressors such as high loads of fine terrigenous silt in the water make shellfish more susceptible to other water-quality issues and to disease and parasites, the silt depressing condition and the particles abrading, clogging and smothering, reducing interstitial spaces, and reducing food supply and quality through decreased light attenuation (*see* references in Booth 2020). Furthermore, excess nutrients in estuaries and coastal zones can lead to increased phytoplankton production and bursts of growth in such seaweeds as sea lettuce, potentially bringing about eutrophication, where respiration causes oxygen levels to become so low at night that organisms die and rot (Maas & Nodder 2010).

Shellfish – particularly adult bivalve – populations are known world-wide for periodic mass die-offs. These are attributable to such things as extreme weather conditions (eg, as seen in the 'cooking' of intertidal kutai near Maunganui Bluff this last summer, when high air temperatures coincided with low tides near midday – Graham-McLay [2020], a phenomenon also recently seen at Whangateau

Harbour and Pakiri and Muriwai beaches [Andrew Jeffs 30 January 2020 pers. comm.]); disease outbreaks (possibly augmented by the shellfish already being physiologically stressed); high parasite loads (sometimes leading to behaviour that makes the shellfish more prone to predation, such as 'surfacing' by cockles; Studer et al. 2013); and poor water quality (eg, Guo and Ford 2016; Jones et al. 2017).

Being fixed to the substrate means that at least intertidal kutai are highly visible - sticking out like the proverbial – and so population assessments can be relatively straight forward (typically involving multiple, randomly/haphazardously-placed quadrats from which all mussels are measured; eg, Alfaro 2006; McLeod 2009). Accordingly, the impression that kutai stocks around the country are – in the absence of harvesting pressure – relatively stable over the short to medium term, at least, is pretty secure: there certainly have been localised mortalities (eg, Alfaro 2006), but these have not impacted across whole stocks of kutai as one might expect in a severe disease event. In fact, declines in abundance of kutai reported around the country appear more consistent with overharvesting than with disease outbreak.

In Kerikeri Inlet, herpesviral disease recently brought about demise of the commercial farming of Pacific oysters (*see* Hine et al. 1992, although oyster farming continues in Te Puna Inlet); and cockles in both inlets exhibit physiological stress, no longer achieving their potential size and age despite little or no fishing pressure, possibly a result – at least in part - of parasites and/or disease (Booth 2020). In similar vein, ongoing high mortality of post-settlement kutai where an RNA virus has been implicated (Jones et al. 1996; Diggles et al. 2002) is of ongoing concern to the aquaculture industry, but as far as I can determine this virus has not been seen in wild populations. However – with aquacultured kutai earning New Zealand half a billion dollars each year, to say nothing of the value of the recreational and customary fishery – any hint of severe disease demands investigation.

| Molluscs | Diseases recorded in New Zealand |
|---|---|
| Bluff oysters (*Ostrea chilensis*) | APX, bonamiosis, herpesvirus, mudworm infestation, rickettsiosis |
| Cockles (*Austrovenus stuchburyi*) | Algal blooms, mudworm infection, perkinsosis, rickettsiosis |
| Greenshell™ mussels (*Perna canaliculus*) | Algal blooms, APX, digestive epithelial virosis, flatworm infestation, mudworm infestation |
| Pacific oysters (*Crassostrea gigas*) | Algal blooms, flatworm infestation, herpesvirus, mudworm infestation, rickettsiosis, vibriosis |
| Paua (*Haliotis* sp.) | Algal blooms, epithelial erosion, haplosporidosis, mudworm infestation, pustule disease/vibriosis, shell mycosis |
| Pipi (*Paphies australis*) | Perkinsosis |
| Rock oysters (*Saccostrea glomerulata*) | Digestive epithelial virosis, mudworm infection, rickettsiosis |
| Scallops (*Pecten novaezelandiae*) | Algal blooms, digestive epithelial virosis, flatworm infestation, mudworm infestation, mycoplasmosis, rickettsiosis |
| Toheroa (*Paphies ventricosa*) | Algal blooms, digestive epithelial virosis |
| Wedge shells (*Macomona liliana*) | Perkinsosis |

**Table 1. Mollusc diseases of importance in New Zealand in 2002 (Diggles et al 2002). This list was compiled specifically for aquaculture situations, but will take in essentially all diseases *seen* in the wild too, even though not all on the list will *occur* in the wild; 'algal blooms' as a disease are likely confined largely to cultured individuals.**

Kutai have several natural parasites (including the pea crab *Pinnotheres novaezelandiae*), but infection rates are generally low (<5% of individuals) in both the wild and in farmed situations (Hickman 1978; Trottier et al. 2012; Georgiades 2016; Castinel et al. 2019), and are non-lethal.

## 1.2 Physical setting

Waters in the region of the Black Rocks have their origins within the main basin of the Bay of Islands - in turn influenced by the characteristics of oceanic waters entering the mouth of the Bay – but, particularly, they are shaped by attributes of the waters flowing down the two estuaries that feed into this region.

Bay of Islands is a series of drowned river valleys; with about 180 km$^2$ in surface area at high-water, many of its numerous islands mark summits of what were once hills. The underlying geology is predominantly greywacke, resultant soils and clays being prone to erosion and aquatic leaching, although there are also extensive basaltic zones in the west, including the Black Rocks. Catchment land-use is mainly agricultural, the low levels of industry (including quarrying) around the Bay meaning generally low chemical contamination of aquatic systems (Griffiths 2011). Waters are reasonably well mixed, with a residence time of ~19 tidal periods (MacDiarmid et al. 2009).

The main oceanic influence on the waters of the Bay of Islands is the East Auckland Current, this coastal current generating a weak countercurrent across the mouth of the Bay, which in turn ensures a constant supply of clear, fresh oceanic water into the Bay (Booth 1974; Mitchell et al. 2009), including into the area of Te Puna (Figure 3). This oceanic influence is seen in the abundance of tropical and subtropical species, particularly in the southeast of the Bay of Islands including Maunganui Bay (Brook & Carlin 1992; Francis & Evans 1992; Francis et al. 1999).

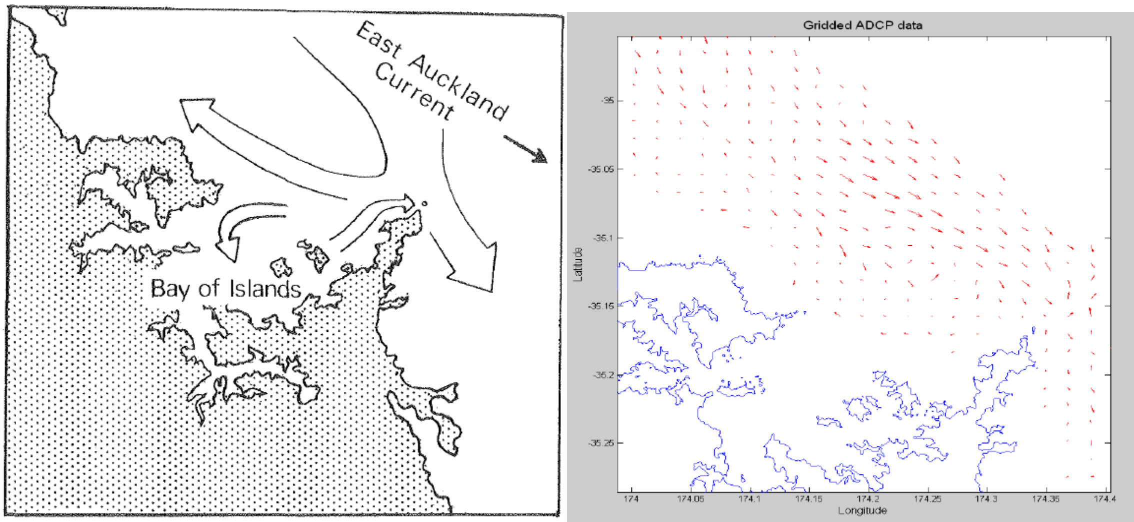


**Figure 3. Probable surface water circulation pattern for Bay of Islands (Booth 1974) (left). Net direction of flow in the water column near the mouth of the Bay of Islands in spring 2008; the length of the arrow is proportional to the velocity (Mitchell et al. 2009) (right).**

The strongest currents within the Bay of Islands are, however, brought about by the tide (Chiswell et al. 2010). Tides are semi-diurnal (two highs each day), with amplitudes of 2.0 m and 1.4 m for high water spring and high water neap tides respectively. On the east coast of Northland, the tidal stream floods north, turning west into the Bay at Motukokako, the sequence reversing on the outgoing tide (Figure 4) (MacDiarmid et al. 2009, precisely as James Cook had reported in his journal in December 1769). This pattern possibly leads to somewhat less turn-over of waters in the west of the Bay of Islands than in the east, but there is no evidence that turn-over there is not fulsome.

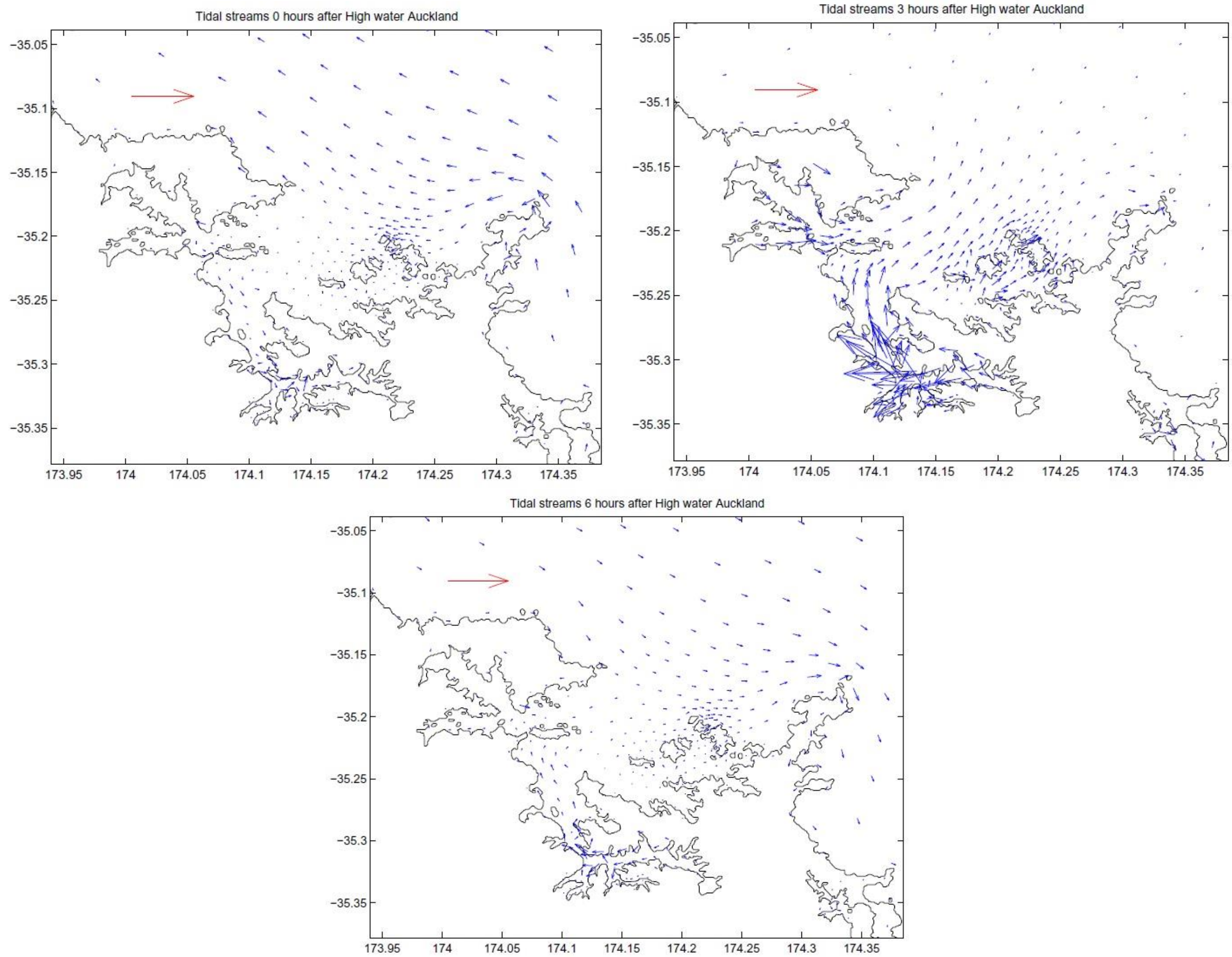


**Figure 4. Tidal streams computed from NIWA's tidal model for three phases of the tide – at high tide, 3 h after high tide and at low tide at Auckland (*read* Opua) (MacDiarmid et al. 2009).**

The river inflows into the bay provide flow force and a tendency for freshwater to be present at the surface, with salty water moving upstream lower in the water column to reciprocate (Chiswell et al. 2010). We can also expect strong winds to influence currents in the bay – setting up wind-driven currents and mixing waters vertically, thereby disrupting this estuarine circulation.

With these gross flow patterns in mind, the physical, chemical and biological properties of the waters within the region of the Black Rocks are now considered. With both oceanic- and tidal-flow patterns apparently leading to abundant renewed marine waters seaward of the Black Rocks, and with no evidence for the waters around the Black Rocks themselves being particularly influenced by stream or land discharge emerging from the shore in the north (Poraenui Point to Cape Wiwiki) or in the south (north shore of Moturoa Island), where catchments are small and comprised mainly of low-intensity pastoral farming and rehabilitating bush cover, the characteristics of the waters of Kerikeri and Te Puna inlets are pivotal in any water quality issues near the Black Rocks.

Kerikeri Inlet is an 8-km-long shallow drowned-valley that narrows near Scudders Beach into two tidal-rivers, the Kerikeri (upstream catchment-area 99 $km^2$) and Waipapa (34 $km^2$), tidal mudflats occupying around half the surface. Current catchment land-use is mainly agricultural (Griffiths 2011), the Kerikeri catchment dominated by pasture (52%), orchards (18.3%, primarily citrus), native forest (6.4%), manuka/kanuka scrub (4.5%) and pine forest (9.5%); and Te Puna catchment by pasture (73%), manuka/kanuka scrub (12%), native forest (5%) and pine forest (4%) (Swales et al. 2012).

More is known of the water characteristics of the Kerikeri than Te Puna Inlet, but most relevant here is the nature of the waters discharged from the mouth of each and flowing towards the Black Rocks. Booth (1974) showed that waters over the tidal cycle at the confluence of these two inlets is essentially fully oceanic. Even though kutai are mainly an open-shore species, thriving where salinities are high, they are nevertheless tolerant of waters of varying salinity (Jeffs et al. 1999). Northland Regional Council's (NRC) 2010-14 Bay of Islands water monitoring programme shows lowest salinities at the Waipapa River and Kerikeri River stations - both close to freshwater inputs – but high salinities at other stations closer to the Black Rocks (Doves Bay and Windsor Landing in the lower Kerikeri) (Griffiths 2015:9) (Figures 5 and 6). Together, these show that low salinity is unlikely to be an issue for Black Rocks kutai.

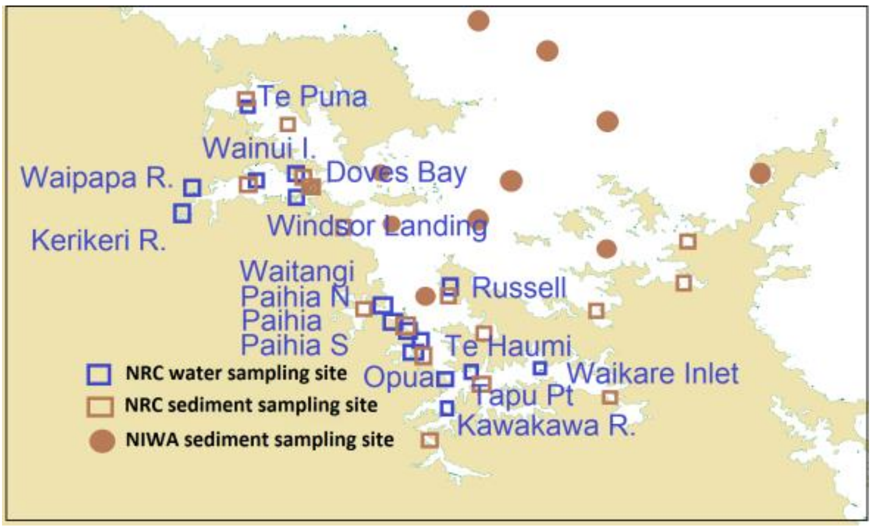


**Figure 5. Location of Northland Regional Council's fortnightly water sampling sites (blue boxes and labels) and annual sediment sampling sites (brown boxes) for the Bay of Islands.**

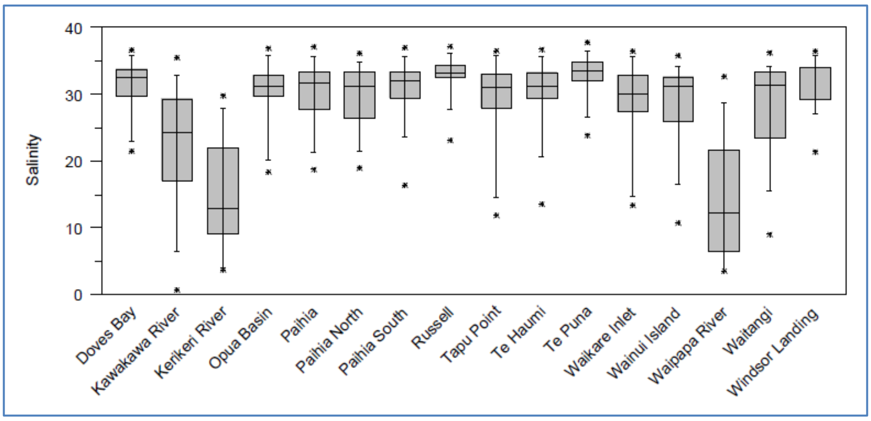


**Figure 6. Northland Regional Council salinity data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

Terrigenous sediment is a well-known stressor of bivalves, as previously discussed. The average annual sediment loads over the past ~150 y of the Kerikeri and Waipapa rivers are 12,100 t and 4,300 t respectively (there are no significant rivers flowing into Te Puna Inlet), from a total for the Bay of ~509,000 t (95% CIs 299,000–719,000) (Swales et al. 2012). Most terrestrial material enters the sea after heavy rainfall on steep and erosion-prone terrain, resulting in increasing suspended sediments in the water column and fine sediments deposited within channels and on their margins, some subsequently being resuspended and transported seaward.

**Figure 7. Surface flood water flowing eastward out of Kerikeri Inlet at right (Te Puna Inlet is to the left; Moturoa Island and the Black Rocks are in the upper middle distance) will affect waters at least as far east as the Black Rocks. (Dean Wright Photography)**

It appears however that, although sediment accumulation rates (SARs) in Kerikeri and Te Puna inlets have *averaged* 1.8-2.4 mm.yr$^{-1}$ since ~1880/1900, and mud predominates surface sediments in much of Kerikeri Inlet today (Swales et al. 2012), the situation is complicated, there having been recent (post-1970) increases in SARs in certain parts – particularly at the margins – of at least the upper Kerikeri and Te Puna (Booth 2020, although confirmatory cores are not available). Accordingly, waters of the mid- and upper-Kerikeri Inlet are described by locals as perpetually murky: transparency tube [Secchi disk] readings the length of the Inlet in summer 2019 after little rain were low in mid- and upper-parts (<0.6 m [~1.0 m]; Booth 2020), and over longer periods, mid-Inlet turbidities have typically been 4–5 NTU [mainly 1.3–1.6 m Secchi depth] (Griffiths 2015).

## 1.3 The Black Rocks

The Black Rocks (within the Black Rocks Scenic Reserve, gazetted in 1987) lie to the east and northeast of Moturoa Island, 2.5 km east of the confluence of Kerikeri and Te Puna inlets (Figure 1, with Chart NZ 5125 showing 'Battleship Rock' – and presumably the associated islets and reefs to its south – being distinct from the 'Black Rocks', and – in turn – the Black Rocks *not* including islets and reefs further west). I was unable to track down names for any of the islets of the Black Rocks, so I have provisionally referred to the elliptical one to the northeast, which is an important focus in this korero, as 'Motukutai'; and the one to its south that from above takes on a circular appearance, 'Motuwiro'.

In places reaching around 10-m or more in height above the sea surface, the Black Rocks are remarkable for the manner in which they protrude almost vertically 20-30-m above a somewhat featureless, flat seafloor that is interrupted only by large, broken-off boulders (as illustrated for Motukutai in Figure 9). The faces of these columnar basaltic lava-flow remnants are interspersed with caves, tunnels and shafts (Brook & Carlin 1992). To Governor Robert Fitzroy, in 1840, they resembled the remains of some giant mole (Keynes 2001). But his was a temperament prone to depression (culminating in 1865 when 'he rose from his bed, bolted the door to his dressing room and slit his throat with a razor'), so his account concerning the origins of these impressive castle-rocks might be taken with a pinch of salt. In fact, it was physical and chemical processes contriving over the millennia to break up the great slabs of stone that have left us today with these vestiges (Brook & Carlin 1992: 49). And the great mole's remains are for now celebrated in the flagship wine of Kerikeri's Marsden Estate: 'Black Rocks' Chardonnay, 'a mouth-filling body yet smooth.'

Charles Dickens - although of course primarily a novelist – is surely more dependable in his accounts around the Black Rocks. '*From the Black Rocks, on Friday*' is an apparently truthful record of an English clergyman, who, in August 1859, was blown clear away from the Black Rocks to end up at Sunday (= Raoul) Island in the Kermadec group (Reed 1950). This little-acknowledged 'Dickens' account (which historian Marie King says had been submitted by a clergyman to Charles Dickens in London, 'The story [being] accepted and published in one of the magazines or annals') is also not without its snags, for it seems that the clergyman's Black Rocks lay six miles east of Cape Brett and were always visible above the sea surface. No such rocks exist there today, nor did they within five years of the ecclesiastic's misadventure, according to 1864's *The New Zealand Pilot*.

> 'Off the northern and eastern ends of Motu-Roa lie the Black Rocks, so called from their colour; they are a remarkable group of smooth, flat-topped rocks, about 15 feet high, steep, and with no dangers about them'.

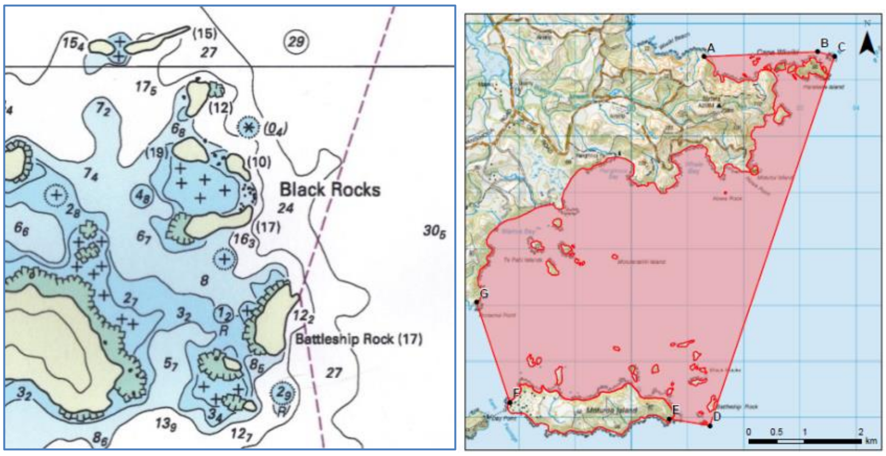


**Figure 8. Chart (left, with depths in metres) of the confluence of Kerikeri and Te Puna Inlets and the Black Rocks; and the area of Te Puna Mātaitai (right).**

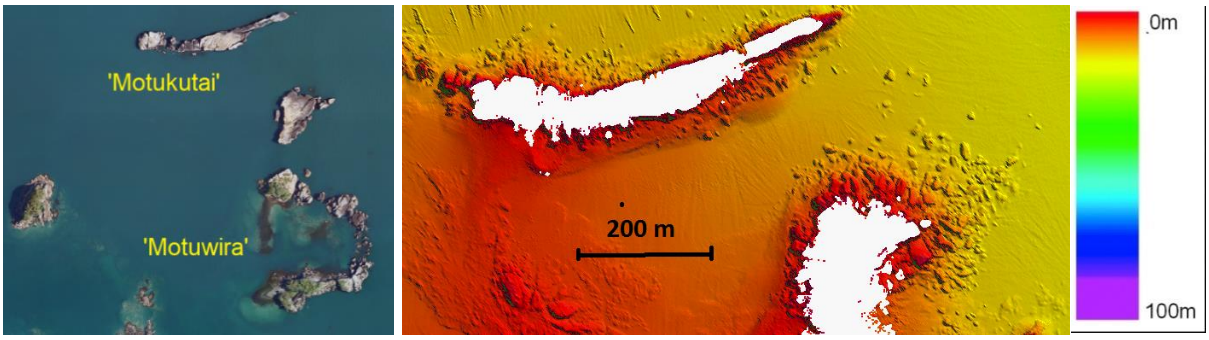


**Figure 9. 'Motukutai' emerges from depths of around 30 m. ('Motukutai' and 'Motuwira' are no more than interim, concocted names.)**

A relatively recent (2016) characterisation of the flora and fauna of the upper ~5 m of the subtidal faces of the Black Rocks (Figure 10 shows sites sampled) by Froude (2016a: 44, 71) is as follows.

> Mostly walls on all sides, often 70-90 degree slopes. Visibility 7 m. Variable bottom depth depending on location. In the north the intertidal contained scattered mussels, limpets and abundant barnacles. The first 2 m of subtidal wall had a cover of *Carpophyllum* (mostly *C. mashalocarpum*) with *Cystophora*, occasional *Ecklonia*, abundant *Pterocladia*, some mussels, and some tall coralline turfs. Where mussels had been removed there were more low turfs and algal felts. For the subtidal walls from 2-7 m deep *Ecklonia* formed 10-30% of the cover with *Pterocladia*, tall coralline turfs, and encrusting fauna (sponges, anemones, bryozoans). Occasional mussels were present. Very few kina were seen. The kina that were seen were usually associated with areas of mussel removal. The northern most rock is a special site [*see* Froude 2016b). Abundant blue maomao and sweep.
>
> The southern Black Rocks group is similar to the northern Rock but with slightly reduced visibility and less diverse encrusting fauna. The intertidal area was similar to the northern rocks plus the occasional *Lessonia*. There were fewer tall brown in the 2.5 m-7.5 m depth range. There was also a higher cover of encrusting fauna (especially in some locations), as well as more low turfs and algal felts.

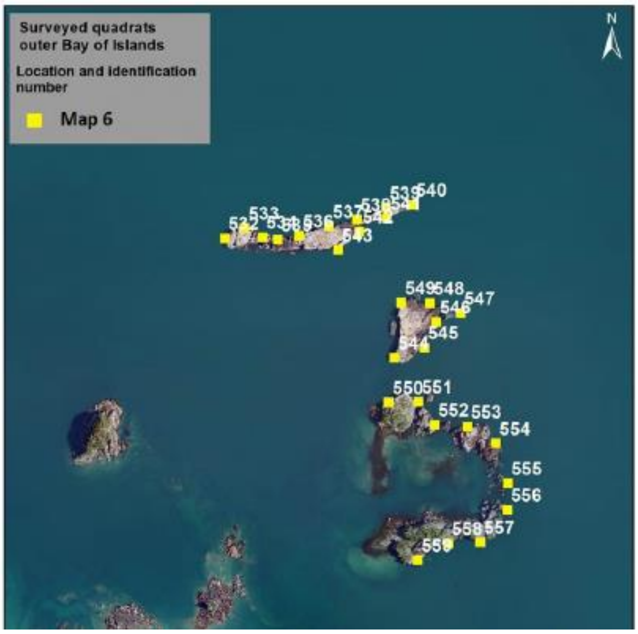


**Figure 10. Location at the Black Rocks of the 27 quadrats (5 m x 5 m) examined in 2016 for algal cover by Froude (2016a).**

## 2. Black Rocks kutai

In this section I document what I have been able to glean concerning recent (past decade or so) availability of kutai at the Black Rocks, and a harvesting history; by no means is this account complete, to be added to as further reports surface and are formally recorded. It seems kutai have been abundant around certain – but by no means all – of the Black Rocks for many years, even though any periodicity in their abundance over the longer term is unclear. All kutai measurements are mm length (the greatest dimension).

### 2.1 Harvester/observer evidence

The memories of people around the availability of kutai, and the extent of their harvestings, over the years are important to our understanding of changes in the state of mussel stocks at the Black Rocks. Such accounts achieve full potential when recorded in a systematic manner (eg, Parsons et al. 2009). I have not interviewed extensively, but the following are what I believe to be some key recollections.

*Interviewee 1* (XX pers. comm. 2019, mainly concerning subtidal kutai): This diver has dived the Black Rocks for the past 20 years – for rock lobsters *Jasus edwardsii* and also for kutai. Motukutai has been the main target area, together with the islet northeast of Motuwira. On Motukutai's north face, kutai up to 80 mm occupied the intertidal; at depths of 6-18 m, large (up to 150 mm) kutai were present in patches and beds; on its more-gently sloping south side, large mussels were until recently abundant at ~9 m depth. All these localities now have far fewer kutai.

*Interviewees 2 and 3* (XX, XX pers. comm. 2019, concerning intertidal kutai): Kutai have until recently been moderately common on the north side of Motuwira, and on islet 400 m to the west, but are now confined to very sparse and small patches.

*Interviewee 4* (XX pers. comm. 2020, concerning subtidal kutai only): Once abundant around Motukutai, including carpet-beds to the southwest; it was this part of the population that was for several years the basis of harvests for the Tall Ships hangi. Also at 'Danger Rock', and at an unnamed island close to the shore of Moturoa. This diver believes there used not to be any clear distinction between the intertidal and subtidal kutai – there was more or less a continuum to 18 m or so depth.

*Interviewee 5* (XX pers. comm. 2020, concerning intertidal kutai only): On the northern face of Motukutai, in late winter 2019, kutai became poorly adhered (easily removed off rocks), and after a period of heavy swells, a significant portion was gone. (This fits with Alfaro [2006: 313]; Andrew Jeffs email 28 January 2020: I am aware of detaching from farm lines two years ago during summer heatwave in Hauraki Gulf, surface water temperatures were up over 24 degrees and adult mussels of the same size range were just dropping off the lines – heat stress I suspect.)

*Interviewee 6* (XX pers. comm. 2020, concerning mainly subtidal kutai): Large numbers ('a metre deep') of dead kutai shells on the seafloor at several parts of the Black Rocks (and elsewhere in the Bay of Islands too?).

Dr Vicky Froude, an experienced ecologist who has dived many parts of the Bay of Islands over the past decade, recently reported as follows (Froude 2019):

> I have observed the steady decline in mussels from the Blacks Rocks area since about 2010. In the last few years the abundance of green lipped mussels has dramatically declined and today there are only a few intertidal and shallow subtidal mussels in the very outer-most exposed sites in the Blacks Rocks area. …... These [sparse, patchy subtidal] beds are clearly being harvested by divers using scuba and so the mussels are present in discontinuous patches.
>
> Intertidal mussels are smaller (and likely younger) than mussels found at depth…. Shore-based collectors [in the eastern Bay of Islands] often used knives or machetes removing all mussels – large and small.
>
> Given the decline and then loss of green lipped mussels at one site after another [in the outer Bay of Islands], and the harvesting practices I have observed, I consider that the major reason for the dramatic decline in green-lipped mussels in the Bay of Islands (and Black Rocks area in particular) is excessive recreational harvesting, facilitated by the use of scuba equipment.
>
> Different members of a local Bay of Islands family that has snorkelled for mussels at Black Rocks for thirty-forty years, reported abundant green-lipped mussels in the earlier years. The sons thought there had been some reduction in mussel abundance about twenty years ago but then they increased again. From about five or more years ago green-lipped mussel abundance at Black Rocks declined significantly. Today green-lipped mussels at Black Rocks

Are very patchy having been depleted throughout with almost all of the larger mussels having been harvested. No mussels remain on the silt seabed at 18 m. Green-lipped mussel numbers had held on longer at Black Rocks than other areas in the Bay of Islands. They thought that harvesting using scuba equipment had been a key reason for the decline of green-lipped mussels at Black Rocks.

## 2.2 Systematic/published observations of kutai populations

There is a dearth of systematically-collected data concerning the distribution, abundance and size characteristics of the kutai useful in providing a benchmark from which to gauge change over time at the Black Rocks. The historic (2010 and earlier) systematic/quantitative ecological surveys of the Bay of Islands (Trenery et al. 1987; Brook & Carlin 1992; Morley & Hayward 1999; Parsons et al. 2010; Nelson & D'Archino 2010; Jones et al. 2010) do not provide useful material concerning kutai at the Black Rocks.

Since those earlier surveys, some of Froude's (2016a) 27 immediately-subtidal snorkel-quadrats (each 5 m x 5 m, separated by ~50 m) at the Black Rocks (Figure 10), part of a comprehensive survey and reporting of shallow-water algal cover (and, its reciprocal, 'urchin barren') across outer shores of much of the main basin of the Bay of Islands, contained mussels. The area was dominated by steep walls, with 'mussels' (confirmed to be kutai) occupying 3.89% (± 2.5 95% CI) of the surfaces. Notably, this region had the second highest proportion of urchin barrens in the entire study (an average of only 21.2% kelp cover remaining, mainly *Ecklonia*), although – with low abundance of kina in the quadrats – Froude thought it likely that some of the 'urchin barrens' were actually the residual cover after the harvesting of mussels, rather than the result of kina browsing (Froude 2016a: 44).

Booth et al. (2019) undertook a photographic survey of intertidal kutai within Te Puna Mātaitai during a particularly low tide in September 2019, mussels being present at several locations, including one sites within the Black Rocks (Figure 11). The intertidal mussels were mainly 60-80 mm, and there was evidence of kutai of similar size just subtidally at a number of places – but these need further investigation. (The full imagery is available from Chris Booth: chris@chrisbooth.co.nz.)

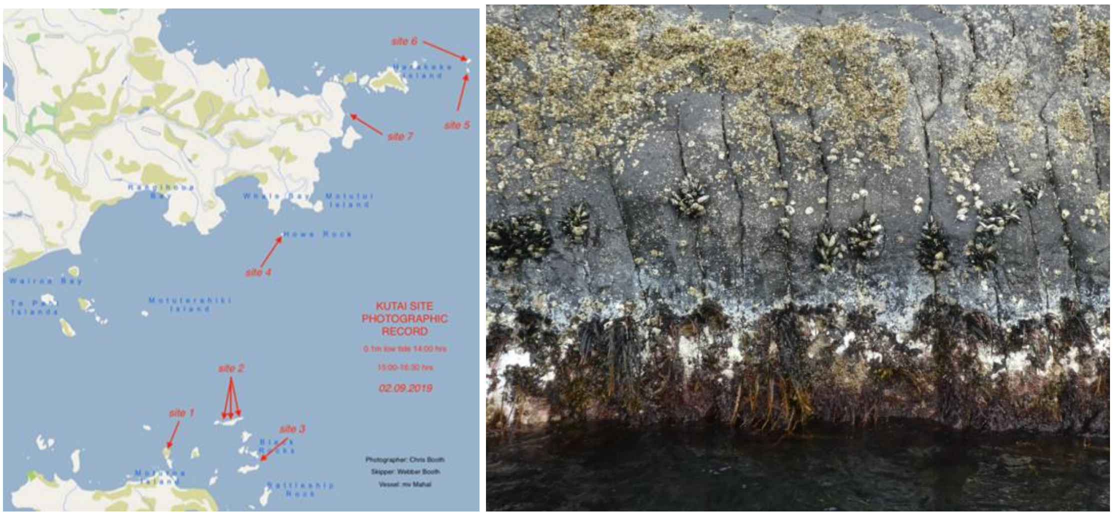


**Figure 11. Location of photographed intertidal faces, September 2019 (Booth et al. 2019, with images available from the author) (left). The only face at the Black Rocks found to bear kutai in any quantity was on the north side of Motukutai, with small clumps of mainly ~70-mm long mussels (right).**

Finally, in October 2019 David Heller (DOC) video-ed subtidal kutai on the north face of Motukutai – near to where the intertidal images above were taken - and from which some size and abundance characteristics of the mussels can be discerned. The subtidal mussels were mainly at 14-16 m depth, where there were small patches of 150-180 mm individuals; standout was the level of invertebrate fouling – particularly anemones – typical of subtidal kutai (Figure 12). (The video clips are available from the author, courtesy of David.)

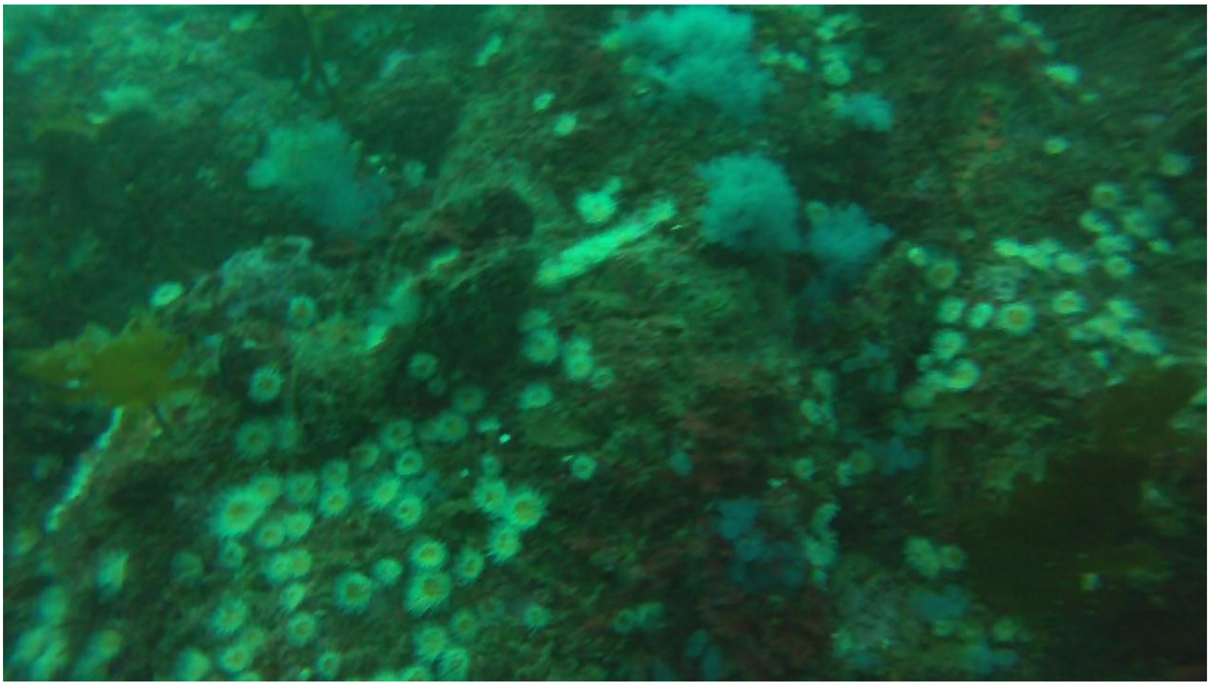

**Figure 12. Groups of 150-180 mm long kutai at 14-16 m depth on the north face of Motukutai, October 2019 (D. Heller).**

## 2.3 Synthesis

Around the Black Rocks today, kutai appear to be largely of two more-or-less distinct components, apparently confined to just a few localities. The intertidal population is the most obvious, forming a band from about mid-tide level to about ELWS of smallish (up to ~80 mm) individuals (Figure 11). The only one of the three rock faces at the Black Rocks examined (because they were the only faces known to the authors to have recently supported intertidal kutai), and which contained significant numbers of mussels, was a small section of the north face of Motukutai. It is not clear if all intertidal patches necessarily also once had subtidal beds associated with them.

Below this, among the kelp (mainly *Ecklonia*), and extending to at least 20 m depth, have been individuals and clumps (possibly even beds) of much larger individual kutai. We have the photographic evidence from David Heller, with confirmed depths (Figure 12). Here we have apparently-healthy remnants of what was possibly once an extensive carpet of kutai.

This, it seems, is the situation that prevails now – and has prevailed - for the past year or so – at the Black Rocks. Although there have been no definitive surveys that allow insight into earlier populations of this mussel, there are sufficient credible anecdotal accounts to conclude that there has been gross reduction in kutai abundance. Whether the apparent distinction of the intertidal kutai and subtidal kutai has always been clear-cut is not certain. The reasons why kutai have flourished on some rocks and not on others is largely unknown, but both interseasonal and spatial dynamism is not uncommon in kutai elsewhere (eg. Alfaro 2006).

# 3. Water quality in northwest Bay of Islands, and evidence for disease and parasites among kutai

In this section I address the quality of the waters in the Black Rocks area, and korero around the possibility of disease or parasites bringing about kutai mortality – among either the juveniles or the adults. Water transparency, oxygen content, nutrient status and heavy metal contamination are reported. Not considered here are 1) faecal coliforms, a diverse group of bacteria found mainly in the intestinal tract of warm-blooded animals and which don't affect shellfish survival – but are bacterial barometers of water quality hazardous to humans; and 2) paralytic shellfish poisoning (PSP, and associated conditions; Rhodes et al 2001) – caused by human toxins produced by natural algal blooms (*see* Figure 15). Heavy-metal concentrations in the substrate and in shellfish flesh are addressed, most being related to natural leaching within the catchment. And finally, diseases and parasites known to afflict kutai are tackled.

I conclude that chronic or intolerably high levels of organic or inorganic contaminants are unlikely to be the primary reason for any kutai mortality: at least since 2008, enrichment in the water column and surficial sediments have been, at most, low to moderate in much of the Bay of Islands including the lower Kerikeri and Te Puna Inlets, with no lethal levels of bivalve toxins. Further, nutrients being present in the water in levels too low to sustain shellfish like kutai is also unlikely. But the possibility of disease having contributed to kutai mortality cannot be discounted.

## 3.1 Water quality

Water quality in northwest Bay of Islands – physical, chemical and biological attributes (including contaminants taken up by shellfish, which may in turn impact shellfish health) – was the subject of 1) early surveys (Booth 1972 – turbidity; Nielsen & Nathan 1975 – heavy metals in shellfish flesh); 2) synoptic Oceans 20/20 surveys (MacDiarmid 2009, Maas & Nodder 2010 – heavy metals in the water column, in sediments and in shellfish flesh); 3) NRC's ongoing surveys of water quality (clarity, and nutrients and trophic state – Cornelisen et al. 2011; Griffiths 2011, 2014, 2015; and heavy metals in sediments – Bamford 2016); and 4) serendipitous other post-2000 surveys (Whyte et al. 2009 –

heavy metals in kutai flesh). I am not aware of any surveys concerning shellfish condition or contagion for Bay of Islands kutai.

Booth (1974) showed that waters over the tidal cycle at the confluence of Kerikeri and Te Puna Inlets are – during normal water flows – essentially fully oceanic, saturated with oxygen, and reasonably transparent.

NRC carries out long-term, state of the environment water-quality monitoring at 16 sites that capture the main freshwater inputs into the Bay of Islands (bi-monthly sampling of water clarity, and [at 0.5-m depth] nutrients and trophic state, beginning in May 2008, including five stations in Kerikeri Inlet and one in Te Puna Inlet; Figure 5), with Griffiths (2015) presenting the results for January 2010 to December 2014. (Readings have not yet been publicly updated, but there has not been notable deterioration in water quality since 2014; Richard Griffiths, NRC, pers. comm., April 2020). (The Oceans 20/20 water quality surveys [Maas & Nodder 2010] were essentially one-offs, with results generally in line with the NRC data; the only indicators of interest *not* covered by the NRC sampling concern the levels of *dissolved* heavy metals, given later.)

The NRC report compared the results for the Bay of Islands with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC) (Australian New Zealand Environment Conservation Council, 2000) and the Ministry for Environment Microbiological Water Quality Guidelines (Griffiths 2015). The data were presented in box plots, displaying the interquartile range (middle 50% of the data), with the middle line indicating the median. The upper whiskers extend to the maximum data points within 1.5 box heights from the top of the box and the lower whiskers extend to the minimum data points within 1.5 box heights from the bottom of the box. Outliers are depicted by an asterisk (*). Median values for each parameter at each site were assessed against the relevant water quality guideline. The ANZECC guideline document states 'The guideline trigger values are the concentrations of the key performance indicators, below which there is a low risk that adverse biological effects will occur. The physical and chemical trigger values are not designed to be used as 'magic numbers' or threshold values at which an environmental problem is inferred if they are exceeded. Rather they are designed to be used in conjunction with professional judgement, to provide an initial assessment of the state of a water body regarding the issue in question' (Australian and New Zealand Environment Conservation Council, 2000) (Griffiths (2015).

**Water clarity** is important for the healthy functioning of marine ecosystems. Increased suspended solid loads that reduce water clarity can affect the amount of photosynthesis (primary production) of aquatic plants (Griffiths 2015). Reduced water clarity can also affect the feeding efficiency of visual predators like fish and sea birds and sediment particles can clog the feeding structures and gills of fish and suspension feeding animals like cockles and pipi. Secchi depth is a measure of the transparency of the water body. High secchi depth readings indicate high levels of transparency or good water clarity, while low secchi depth readings indicate low transparency or poor water clarity. Turbidity, measured using a nephelometer, is a measure of the degree to which light is scattered in water by particles, such as sediment and algae. None of the sites had a median turbidity which exceeded the ANZECC guideline value of 10 NTU for estuarine and marine waters (Figures 13 and 14).

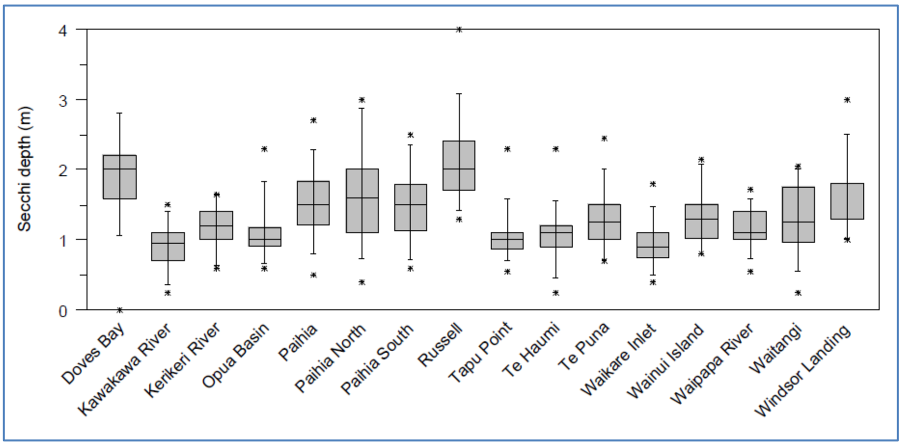


**Figure 13. Northland Regional Council secchi depth data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

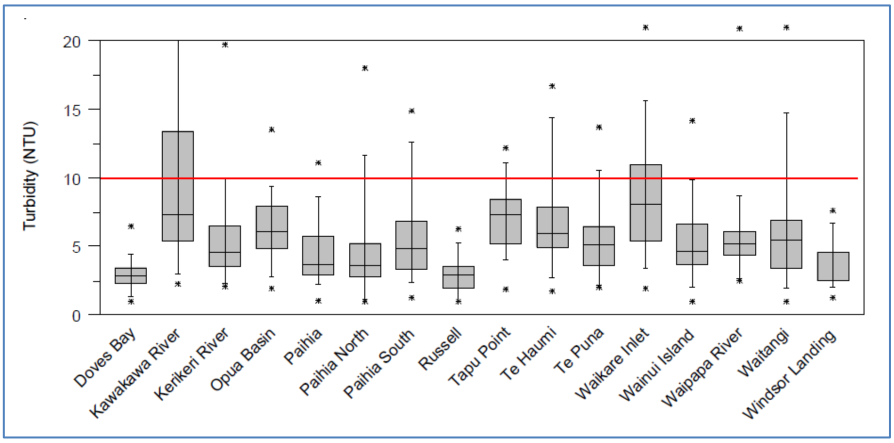


**Figure 14. Northland Regional Council turbidity data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

Note that not all discoloured water in the Bay of Islands, however, is fouled: 1) red tides – typical of spring and early summer – are natural (although there may be PSP potential) (Figure 15); 2) during the spring bloom, in particular, waters often appear green because of high concentrations of phytoplankton; and 3) tannin-coloured waters flowing into the Bay can be found in parts of the Bay, including Kerikeri Inlet (Figure 15).

**Figure 15. Patch of red tide in the Bay of Islands in December 1996 (left). A tannin-laden plume flowing out onto an oyster farm in Kerikeri Inlet in 2009, emanating from extensive wetlands nearby (right).**

**Dissolved oxygen** is a measure of the quantity of oxygen in the water column. Oxygen is required by marine organisms for efficient functioning, and reduced oxygen levels have been shown to cause lethal and sub-lethal effects (physiological and behavioural) in a variety of organisms (Griffiths (2015). Significant decreases in dissolved oxygen levels can occur when there is an excess of organic material in the system, for example, sewage effluent or dead plant material.

In the Bay of Islands the lowest median values were recorded at Windsor Landing and Te Haumi (both 7.2 mg/l) (Figure 16). The ANZECC 2002 guidelines do not include a default trigger value for dissolved oxygen concentration (mg/l) although the 1992 ANZECC guidelines recommended that dissolved oxygen should not normally be permitted to fall below 6 mg/l, determined over at least one diurnal cycle; all sites had median values above 6.0 mg/l. Dissolved oxygen saturation is a ratio (expressed as a percentage) of the concentration of dissolved oxygen in the water to the maximum amount of oxygen that will dissolve in water at that temperature, salinity and pressure under stable equilibrium Griffiths (2015). The lowest concentrations were generally found at more exposed outer estuarine locations (Figure 17).

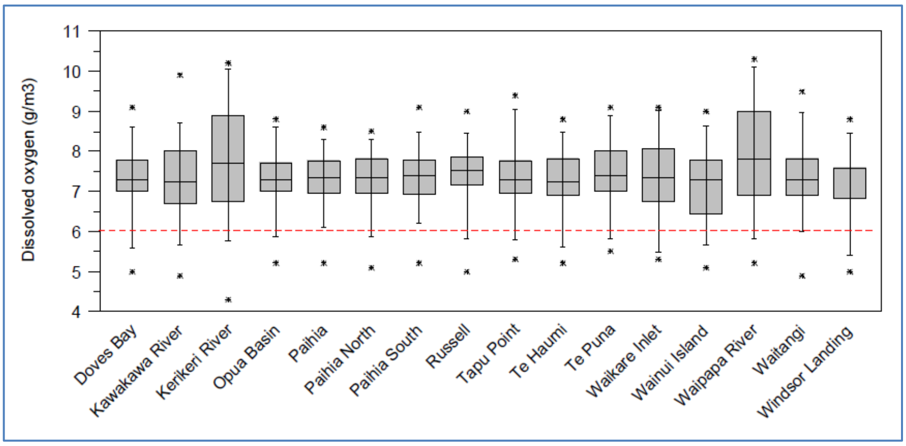


**Figure 16. Northland Regional Council dissolved oxygen data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

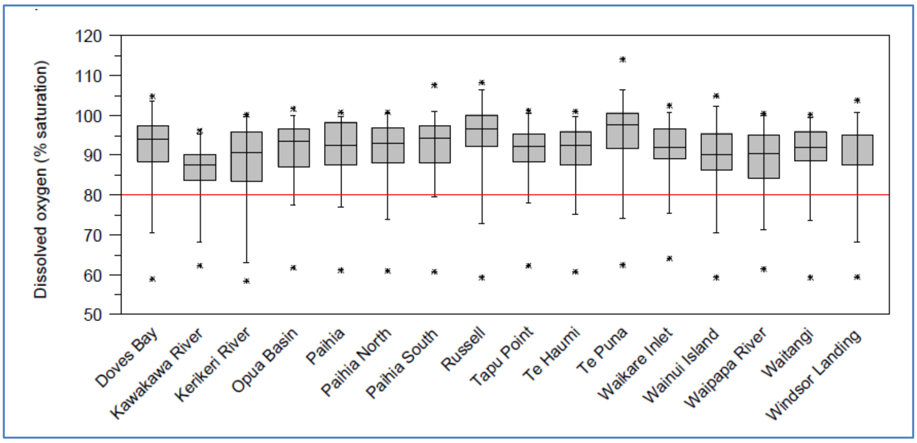


**Figure 17. Northland Regional Council oxygen saturation data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

**Chlorophyll a** is a green pigment found in plants that is used to absorb sunlight during photosynthesis; concentrations are therefore an indicator of phytoplankton abundance and biomass in coastal waters, which is in turn an indicator of trophic status (Griffiths 2015). The highest median chlorophyll *a* concentrations were found at Kerikeri River, Waipapa River, lower Waikare Inlet and lower Kawakawa River (Figure 18), all being inner estuarine sites close to freshwater inputs. The lowest concentrations were generally found at more exposed outer estuarine locations. The ANZECC default trigger value for chlorophyll a is 0.004 mg/l for estuarine waters and 0.001 mg/l for marine waters. All estuarine sites had a median concentration below 0.004 mg/l (Griffiths 2015).

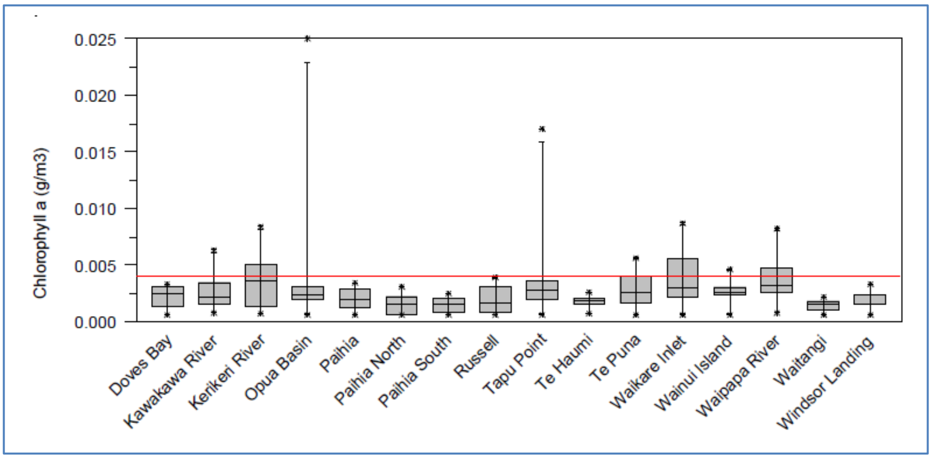


**Figure 18. Northland Regional Council chlorophyll *a* data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

While **nutrients** are essential for all forms of life, nutrients that enter the environment from anthropogenic sources, such as fertiliser, stormwater, treated wastewater, sewage overflows and failing septic systems, may exceed overload ecosystems (Griffiths 2015). Elevated nutrients in the water can cause excessive plant growth leading to algal blooms, which in turn can cause lowered levels of dissolved oxygen and water clarity. Concentrations of ammonium ($NH_4$), nitrate-nitrite nitrogen (NNN), total phosphorus (TP), and dissolved reactive phosphorus (DRP) are direct measures of nutrient concentrations which may be responsible for over-enrichment.

The highest **ammonium** medians were found at the Waipapa River (0.0245 mg/l) and Kerikeri River (0.0195 mg/l) (Figure 19). The ANZECC default trigger value for $NH_4$ is 0.015 mg/l for both estuarine and marine waters (Griffiths 2015). All of the sites with a median above the ANZECC trigger values were inner estuarine or tidal creek sites.

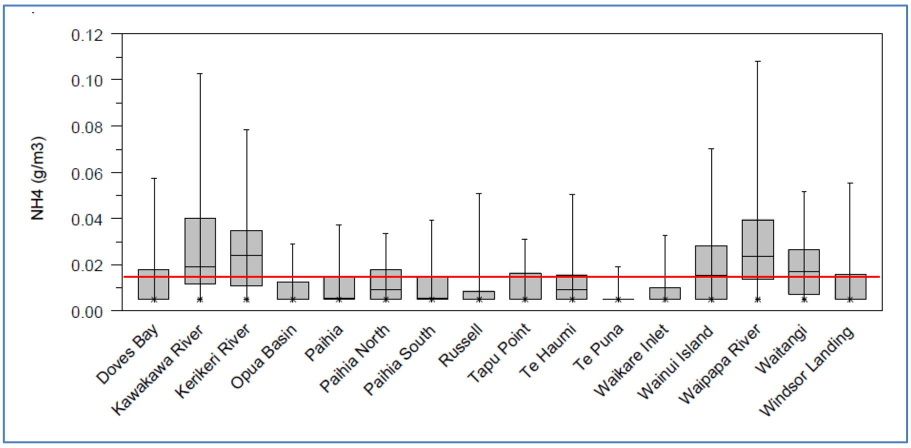


**Figure 19. Northland Regional Council ammonium data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

**Nitrate-nitrite nitrogen** is a common contaminant in rural and urban areas and originates from waste water discharges, septic systems, fertilisers and animal effluent (Griffiths 2015). Nitrate may also occur naturally due to the dissolution of nitrate-bearing rock within the aquifer. In the Bay of Islands the highest median concentration was found at Kerikeri River (0.145 mg/l), double the next highest site (Figure 20). The ANZECC default trigger value for NNN is 0.015 mg/l for estuarine waters and 0.005 mg/l for marine waters. Most of the sites with a median above the ANZECC default trigger values were inner estuarine or tidal creek sites (Griffiths 2015).

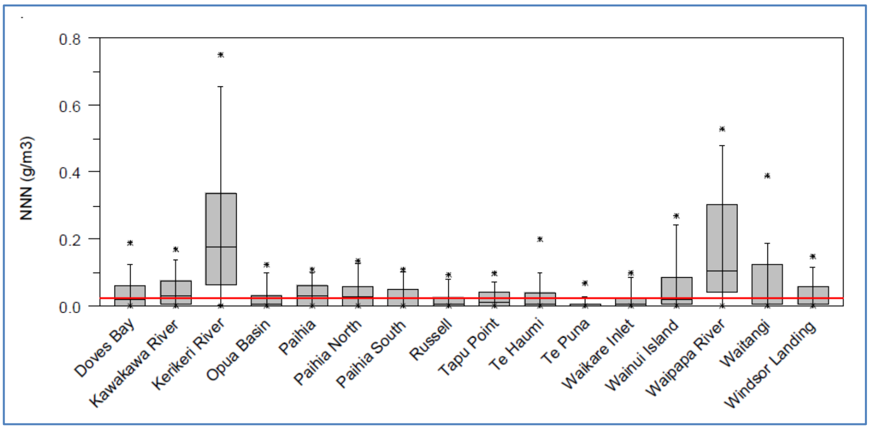


**Figure 20. Northland Regional Council nitrate-nitrite nitrogen data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

The measurement of **total phosphorus** includes the total of all filterable and particulate forms of phosphorus. Phosphorus occurs naturally in water as a result of the weathering of rocks and soils, and the decomposition of organic material. Human sources of phosphorus include human sewage, cleaning products and detergents, fertilisers and animal effluent. Human activities such as urban development and forestry that can cause soil erosion will also release phosphorus, which may reach waterways (Griffiths 2015). The drainage of wetlands for development may also expose phosphorus that was buried. All sites in the Bay of Islands had relatively low median TP concentrations, with the highest median recorded at the Kawakawa River site (0.0255 mg/l) (Figure 21).

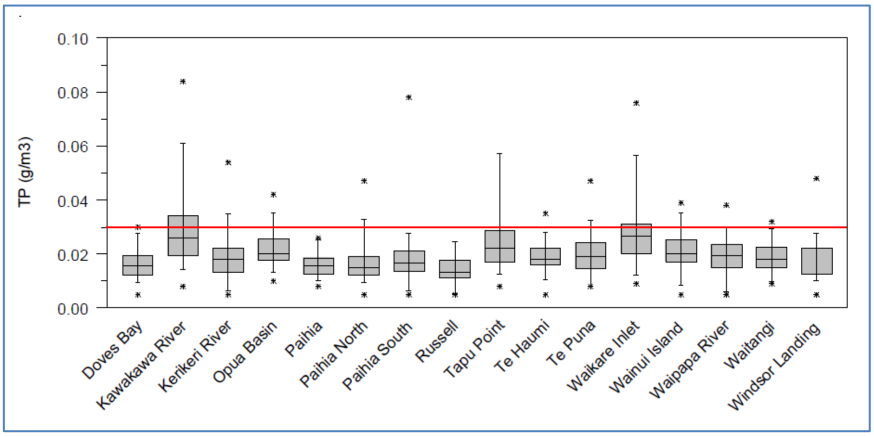


**Figure 21. Northland Regional Council total phosphorus data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

**Dissolved reactive phosphorus** is the fraction of phosphorus that consists largely of the inorganic orthophosphate ($PO_4$) form of phosphorus. The inorganic orthophosphate fraction is the form of phosphorus that is directly taken up by algae (Griffiths 2015). The amount of dissolved reactive phosphorus therefore indicates the amount of phosphorus that is immediately available for algal growth. The highest median concentration was recorded at the Kawakawa River, which is one of the main fresh water inputs to the Bay of Islands system. The lowest median concentrations of dissolved reactive phosphorus were recorded at Kerikeri River (0.005 mg/l) and Waipapa River (0.006 mg/l), both being tidal creek sites in the upper Kerikeri Inlet (Figure 22). The ANZECC default trigger value is 0.005 mg/l for estuarine waters and 0.010 for coastal waters. Most of the sites had median concentrations that exceeded the default ANZECC trigger value of 0.005 mg/l for estuarine water. One site (Kerikeri River) had a median value of exactly 0.005 mg/l (Griffiths 2015).

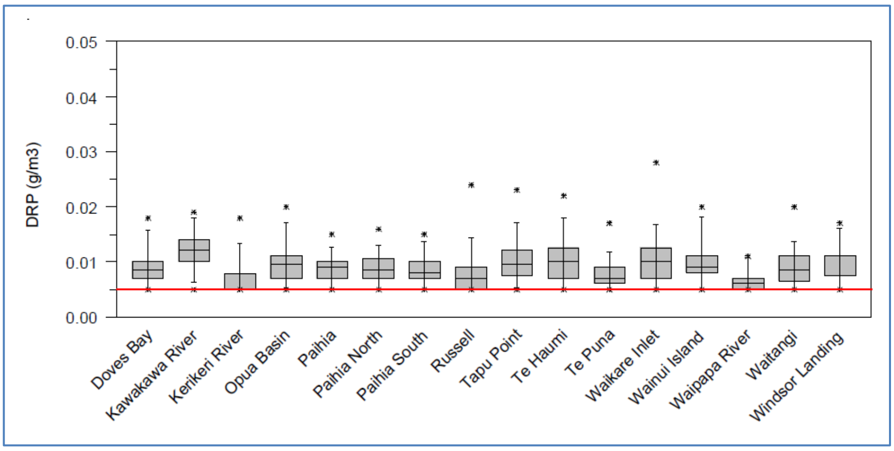


**Figure 22. Northland Regional Council dissolved reactive phosphorus data collected in Bay of Islands from January 2010 to December 2014, with stations being shown in Figure 5.**

**Trends over time** in the above parameters and variables: the only local sites showing significant changes between 2010 and 2014 were Doves Bay and Winsor Landing, with NNN reductions of 22.3% and 19.5% respectively, and a 2.6% increase in dissolved oxygen at Waipapa River (Griffiths 2015: 52).

**Dissolved heavy metals** have not been part of NRC's sampling, but were reported in the Oceans 20/20 survey results for August 2009 (Figure 23). Concentrations were typically below detectable limits at most sites and water depths, except for As for which concentrations ranged 5-14 mg/m$^3$. The low Interim Sediment Quality ANZECC Guidelines threshold (ISQG_Low) was exceeded at only three sites (Maas & Nodder 2010: 57), only one (Te Puna mouth) being within our area of interest.

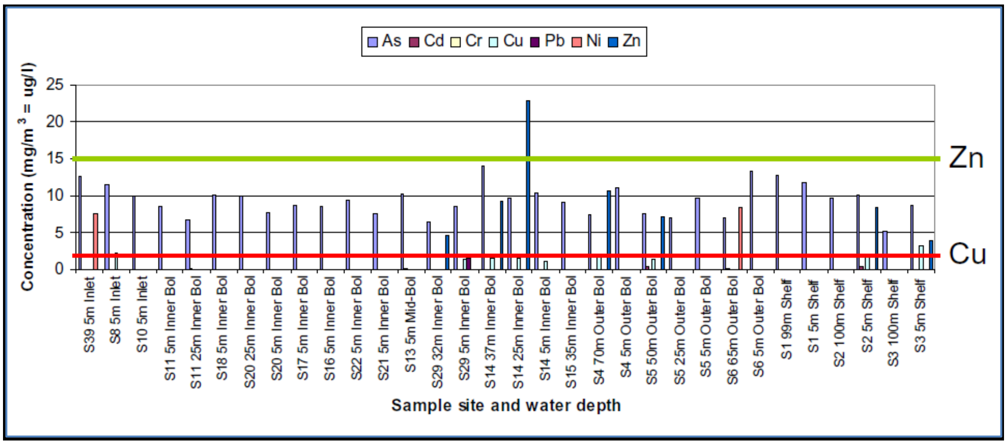


**Figure 23. Dissolved heavy metal concentrations (arsenic As, cadmium Cd, chromium Cr, copper Cu, lead Pb, nickel Ni and zinc Zn) in the Bay of Islands water column, collected in August 2009. The ANZECC ISQG_Low thresholds are also shown for copper (1.3 ug/l, red line) and zinc (15 ug/l, green line) (Maas & Nodder 2010: 58). (For location of stations, refer to source paper).**

## 3.2 Sediment contamination

**Metal contaminants** can have lethal and sub lethal effects on marine organisms and in a contaminated environment the species diversity and species richness may decrease (Bamford 2016). Metal contaminants are generally not subject to bacterial attack or other breakdown so are permanent additions to the marine environment. Although plants and animals can usually regulate metal contaminants within a certain range, metals that cannot be excreted remain within the organisms and accumulate over time. As metals accumulate in an organism they can interfere with biological processes. The contaminants can also move progressively up the food chain as organisms are consumed by other animals including humans and this may ultimately pose a risk to human health (Bamford 2016).

NRC monitored sediment metal and nutrient concentrations in surficial sediments at 16 sites in the Bay of Islands in 2016 (Bamford 2016; the same sites sampled in 2010, 2012 and 2014). Sites were located in order to capture the main freshwater inputs to the bay and to ensure a good geographical spread throughout the outer bay (Figure 24). The sediment metal concentrations were assessed against ANZECC ISQG-Low Trigger values and threshold effect levels (TEL) developed by MacDonald et al. (1996, in Bamford 2016). ANZECC guidelines do not include trigger values for nutrients or TOC in sediments and there are currently no nationally accepted guideline values. Instead, sediment nutrient concentrations and TOC were assessed against a classification developed by Robertson & Stevens (2007, in Bamford 2016).

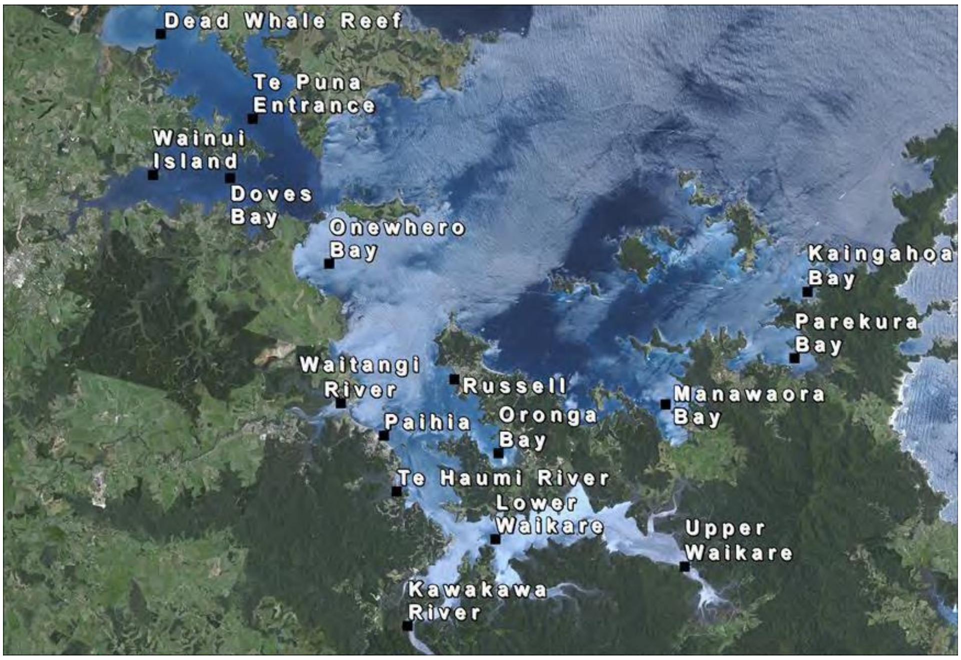


**Figure 24. Location of Northland Regional Council's sediment sampling sites in the Bay of Islands.**

Concentrations of metals have remained relatively stable throughout the Bay of Islands, with all metals below ANZECC ISQG-Low and TEL at all sites over the course of all four sampling years (Bamford 2016) (Table 2). Concentrations of copper, lead and zinc in sediments were generally less than those measured in the Kerikeri River and Waipapa Stream previously, although similar to those from the Pickmere Channel in Kerikeri Inlet proper (unpublished 2008-09 data, R. Griffiths, NRC).

| 2016 | Cadmium | Chromium | Copper | Lead | Nickel | Zinc |
|---|---|---|---|---|---|---|
| Wainui Island | 0.09 | 48 | 12 | 7.9 | 14 | 82 |
| Doves Bay | 0.088 | 38 | 12 | 11 | 15 | 56 |
| Te Puna Entrance | 0.091 | 35 | 12 | 12 | 15 | 56 |
| Dead Whale Reef | 0.091 | 28 | 10 | 15 | 10 | 49 |
| Kawakawa River | 0.09 | 9.9 | 8 | 8.4 | 7.3 | 55 |
| Lower Waikare | 0.09 | 19 | 15 | 14 | 8.6 | 69 |
| Upper Waikare | 0.091 | 14 | 9.9 | 13 | 7.9 | 66 |
| Te Haumi River | 0.089 | 7.2 | 5 | 7.8 | 4.5 | 46 |
| Paihia | 0.088 | 13 | 8.7 | 7.8 | 6 | 48 |
| Waitangi River | 0.089 | 9.9 | 10 | 6.9 | 6.7 | 45 |
| Oronga Bay | 0.088 | 16 | 6.6 | 8.1 | 4.3 | 48 |
| Russell | 0.091 | 16 | 13 | 15 | 6.7 | 59 |
| Manawaora Bay | 0.091 | 16 | 4.1 | 7.1 | 4.3 | 33 |
| Parekura Bay | 0.091 | 14 | 5.3 | 8.6 | 4.7 | 55 |
| Kaingahoa Bay | 0.092 | 12 | 3.2 | 3.9 | 3.4 | 25 |
| Onewhero Bay | 0.09 | 15 | 1.7 | 5.7 | 5.3 | 23 |

**Table 2. Metal concentrations (mg/kg) of sediment in NRC's Bay of Islands sampling (Bamford 2016). Green = below TEL, Orange = exceeded TEL, Red = exceeded ANZECC ISQG-Low effect trigger values, N.S. = not sampled.**

NIWA's Ocean Survey 20/20 results were similar for these metals (and for arsenic too; Maas & Nodder 2010). Even when normalised to 100% mud content, Bay of Islands sediments were still below ANZECC ISQG_Low (2000) guidelines.

For **nutrient status**, 13 sites were classified as 'enriched' for phosphorus and seven sites for TOC Bamford (2016) (Table 3). Concentrations of TOC and nutrients were more variable over the three years of sampling (2012, 2014 and 2016) than the concentrations of metals, but none was of particular concern (Bamford 2016).

| 2016 | TOC (%w/w) | Nitrogen(mg/kg) | Phosphorus (mg/kg) |
|---|---|---|---|
| Wainui Island | 3.23 | 1000 | 980 |
| Doves Bay | 4.39 | 1700 | 760 |
| Te Puna Entrance | 3.89 | 1700 | 730 |
| Dead Whale Reef | 2.84 | 1500 | 640 |
| Kawakawa River | 0.85 | 320 | 510 |
| Lower Waikare | 2.84 | 1600 | 590 |
| Upper Waikare | 1.64 | 670 | 450 |
| Te Haumi River | 1.06 | 330 | 610 |
| Paihia | 2.02 | 520 | 700 |
| Waitangi River | 1.72 | 1000 | 520 |
| Oronga Bay | 1.39 | 580 | 380 |
| Russell | 2.49 | 870 | 550 |
| Manawaora Bay | 1.98 | 760 | 560 |
| Parekura Bay | 1.43 | 540 | 580 |
| Kaingahoa Bay | 2.71 | 1100 | 390 |
| Onewhero Bay | 1.14 | 280 | 700 |

**Table 3. Nutrient concentrations of sediment in the Bay of Islands (Bamford 2016). Green = 'very good', Yellow = 'low to moderate enrichment', Orange = 'enriched', Red = 'very enriched'**

From the Oceans 20/20 sampling, DRP and nitrate values measured in winter 2009 and summer 2010 were within the expected ranges, while ammonium values were typically at the lower end of the concentration range indicated by NRC, but were well above ANZECC water quality trigger levels at certain locations (Maas & Nodder 2010). Winter nitrate concentrations in the Bay of Islands (including the inlets) were significantly higher than those observed in summer. In contrast, dissolved reactive phosphate (DRP) and ammonium levels were similar across all shallow water sites (less than 10 m water depth) and across both seasons, Of some concern is that ammonium and nitrate levels from the Bay of Islands were substantially higher than in the Firth of Thames and the northeast coast North Island - but international standards were not being breached.

## 3.3 Shellfish-flesh contamination

Shellfish tend to accumulate heavy metals in their flesh, mercury, lead and cadmium in particular being of interest because of their high toxicity to humans. With a relatively small human population, little heavy-metal pollution in New Zealand comes from industrial sources. Rather – as a young country geologically and relatively rich in minerals – such elements can leach out of soils into the sea, often with large local variations in levels (Nielsen & Nathan 1975). There was considerable variability in the uptake of heavy metals among the Bay of Islands shellfish analysed, dredge oysters (*Tiostrea chilensis*) and scallops (*Pecten novaezelandiae*) tending to accumulate cadmium; kutai, and possibly cockles appearing to accumulate lead and the native rock oyster *Saccostrea glomerata* zinc, and – to lesser extent – copper – but these do not point to concentrations that are toxic to the shellfish themselves.

In an analysis of heavy metals in Bay of Islands kutai in 2005, none was present in sufficient concentration to be of known threat to kutai survival. Whyte et al. (2009) found that cadmium, mercury, arsenic, lead and tin concentrations were well below the Food Standards Australia and New Zealand maximum limits and were comparable to, or less than, concentrations observed in previous New Zealand studies.

For Oceans 20/20, concentrations of copper, lead and zinc in shellfish flesh were similar to those recorded from other northern New Zealand coastal environments (Maas & Nodder 2010). The highest copper concentrations across all of these studies were found in oyster flesh from the Doves Bay Marina, with a mean of 167 ± 23 mg/kg, in line with the high numbers of boats with copper-based antifouling (Maas & Nodder 2010: 69). Nevertheless, concentrations of arsenic, cadmium, chromium, copper, lead, nickel and zinc in shellfish flesh were generally well below trigger values (Maas & Nodder 2010), and are unlikely to be a threat to kutai.

## 3.4 Disease and parasites

There is a considerable list of kutai pathogens and parasites implicated in mussel disease in New Zealand (Castinel et al. 2019) (Table 4), but when the extent of their impacts are considered, there is nothing of real concern for kutai at the Black Rocks. The one group of possible concern (virus, highlighted) seems not been an issue in the wild since the early-1990s. So, whereas you might have expected prolonged dialogue in this section of my report, there is actually little more that I can add.

**Table 4. Main pathogens and parasites recorded in New Zealand mussel species and other susceptible shellfish hosts (Castinel et al. 2019). This does not include pathogens that can be vectored by mussels.**

| **Main group** | **Name** | **Occurrence in *P. canaliculus and/or M. galloprovincialis*** | **Occurrence in other NZ hosts** | **Impact in NZ shellfish** |
|---|---|---|---|---|
| Virus, clone or mutagen | Disseminated Hemic Neoplasia | *M. galloprovincialis* only | Flat oyster (*Ostrea chilensis*) | No clinical impact observed. |
| Virus (putative aetiology) | Digestive Epithelial Virosis (DEV) | Both species | Scallop (*Pecten novaezelandiae*), rock oyster (*Saccostrea glomerata*) | Ubiquitous with high intensity in scallops. High mortality reported in *P. canaliculus* early 1990s. |
| Bacteria | *Rickettsia* and *Chlamydia* | Both species | Numerous shellfish species | Common. Potential threat in high density culture. |
| Bacteria | *Vibrio* spp. | Both species | Numerous shellfish species | Opportunistic pathogenic role for *Vibrio splendidus.* |
| Fungus | *Microsporidium rapuae* | Both species | Flat oyster (*O. chilensis*) | No clinical impact observed. |
| Protozoa | Apicomplexan Parasite X (APX) | Both species | Pacific oyster (*Crassostrea gigas**), flat oyster (*O. chilensis*) | No clinical impact observed in mussels but predisposition for bonamiasis in flat oysters. |
| Protozoa | Other apicomplexans, e.g. *Nematopsis* sp. | Both species | Pacific oyster (*C. gigas*), flat oyster (*O. chilensis*) | No clinical impact observed. |
| Protozoa | Invasive ciliates | Both species | Pacific oyster (*C.* | No clinical impact |

| | | | | |
|---|---|---|---|---|
| | | | *gigas*), flat oyster (*O. chilensis*) | observed. |
| Protozoa | Ciliates (other) | Both species | Pacific oyster (*C. gigas*), flat oyster (*O. chilensis*) | No clinical impact observed. |
| Protozoa | *Perkinsus olseni* | *P. canaliculus* only | Abalone (*Haliotis iris*) and other shellfish species | Possible clinical impact obscured by copepod infection in digestive gland. |
| Platyhelminthes (Turbellaria) | *Paravortex* sp. | Both species | Scallop (*P.novaezelandiae*) and other shellfish species | Ubiquitous. No clinical impact observed. |
| Platyhelminthes (Turbellaria) | Other flatworms (*Enterogonia orbicularis*, and putative planocerid) | Both species | Numerous shellfish species | Opportunistic pathogen, only significant with heavy infestation. |
| Platyhelminthes (Digenea) | *Bucephalus* sp. | *P. canaliculus* only | Flat oyster (*O. chilensis*) | Impact unclear. |
| Platyhelminthes (Digenea) | *Tergestia agnostomi* | Both species | Unknown | Impact unclear. |
| Crustacea (Decapoda) | *Pinnotheres* sp., parasitic crab | Both species | Numerous shellfish species | No clinical impact observed but *Pinnotheres* may transfer *Nematopsis*. |
| Crustacea (Copepoda) | *Lichomolgus uncus* | Both species | Numerous shellfish species | No clinical impact observed. |
| Crustacea (Copepoda) | *Pseudomyicola spinosus* | Both species | Numerous shellfish species | No clinical impact observed. |
| Annelida (Polychaeta) | *Boccardia* spp. and *Polydora* spp. | Both species | Numerous shellfish species. | Borer worms causing shell damage and unmarketable shellfish. Potential intermediate hosts for *Marteilia* spp. |

Nevertheless, any large quantity of dead mussel shells on the seafloor below the kutai beds of the Black Rocks cannot be ignored. Although no material is yet available for examination, I understand that most are large kutai. In any natural population, there is ongoing mortality, so some of these may be mussels that have died of old age. It has been argued that shells at depths of 20 m or so will tend to accumulate, not being as readily dispersed as, for example, those in shallower waters where the effects of sea turbulence and tidal movement will be more manifest – so, are most of the shells fresh or are they mainly old and eroded. If there has indeed been mass mortality among the kutai, was it a single major event, which would be typical of disease outbreak; or has it being taking place in more-measured manner over the years and therefore perhaps more indicative of chronic stress leading to mortalities (or simply natural mortality). Are all sizes affected similarly? And, perhaps most importantly - are all the mussels *actually dead*, or are there ones that have been dislodged and fallen alive to the seafloor?

## 4. Discussion

There seems little doubt that kutai populations at the Black Rocks – both intertidal and subtidal - have declined significantly in density and extent over the past decade. These beds had been associated, apparently, with only a few of the many rock faces, islets and reefs within the archipelago, so all significant intertidal populations, and most subtidal ones, can be expected to have become pretty well known, given the long harvesting history (at least the past 40 years, and probably essentially since the times of Kupe). Accordingly, anecdotal though the reports may be, harvesters' histories, taken in their entirety, confirm significant decline, with few if any fishers – as far as I can determine – believing that kutai numbers have remained the same, although there is debate around the reasons for the decline.

There are many competing and/or compounding potential explanations for significant and enduring reduction in the abundance of kutai at the Black Rocks.

1) 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;
2) Chronic food-limitation brought about by low productivity: *however*, conditions are not unproductive, kutai having been in good condition, no other filter feeders are reported to have been in poor condition, and tidal flushing is fulsome;
3) Greater numbers of predators or competitors: *however*, there is no evidence for noteworthy changes in the abundance of these;
4) Chronically insufficient larvae: *however*, breeding-sized kutai are not uncommon in the broader Kerikeri Inlet and elsewhere in the Bay of Islands;
5) Chronic stress, possibly brought about by persistent, and at times catastrophic, deposition of terrigenous silt, has left kutai less-resistant to parasites and disease: *however*, divers have not expressed concern over heavy levels of siltation at the Black Rocks;
6) Periodic and damaging environmental episodes (eg, eutrophication, harmful algal-blooms) have led to mass mortalities of kutai: *however*, even though the passage between Te Pahi Islands and the Black Rocks is heavily used by recreational fishers, there have been no boatee or fisher reports – that I'm aware of – of such events;
7) Greater prevalence of disease-causing organisms: this is a possibility;
8) Failure among new recruits to establish: this is very likely;
9) Harvesting pressure has risen to such an extent that recruitment cannot keep up it: this is also very likely.

Generally lower densities of kutai at the Black Rocks today probably result from multiple causes but underpinned by poor juvenile recruitment, overharvesting, and possibly disease outbreak. Each is discussed in more detail below.

With both primary and secondary settlement being integral, recruitment in kutai is one helluva complex process, with several potential weak points/bottlenecks. Indeed, failure in recruitment has been invoked in other major kutai grounds suffering declines, such as the Firth of Thames (McLeod et al, 2011, possibly together with lack of suitable settlement substrate [Wilcox et al. 2019]). Photographs (as well as harvester reports) show that the intertidal population at Motukutai, the only remaining intertidal population of significance at the Black Rocks, is dominated by a narrow size-range of individuals (mainly 60-80 mm), with little evidence of significant new recruitment. This may be an issue of 1) too few larvae in the plankton; 2) failure of primary settlement through loss of suitable surfaces such as calcareous red algae, or through contagion among the settlers; 3) mortality among the secondary settlers, through disease, starvation, degraded settlement surfaces, or unsuitable hydrological conditions; or 4) the thousand other reasons you are dreaming up, as we speak.

Andrew Jeffs offers the following (pers. comm. 2019):

> We have no idea what is going on with these [Firth of Thames] populations, but if they are anything like our restored beds, the recruitment component seems to be absent and we don't why. You would think that in the Hauraki Gulf with all the mussel farms pouring larvae into the water that there would be a super abundance of settlers, but doesn't seem to be that way. One possibility is the absence of filamentous red algae which is the primary settlement habitat of *Perna* larvae I suspect it is smothered by sediment or shaded by increasingly turbid water – but no hard evidence for this.

In the face of apparently poor juvenile recruitment at the Black Rocks, harvesting pressure takes on greater moment. The intertidal populations have – from the harvester reports – almost certainly been hammered, with apparently little or no natural replacement taking place to keep things sweet. This situation is exacerbated where harvesters use bulk and indiscriminate removal methods – such as spades/blades that remove everything – as reported by some observers. Added to this is the possibility of mussels being in relatively poor condition in late winter to spring, when the shellfish are putting resources into gonad development, losing grip and falling to the seafloor. (Note that a good proportion of these dislodged kutai should survive, providing they have not fallen into choking mud. This needs checking.)

The possibility of widespread disease outbreaks in recent times cannot be discounted – but more information is needed. I have been unable to locate a single report from anywhere in the country where there has been mass die-off of kutai – apart from the heat-caused deaths mentioned earlier. Nowhere could I find reports of large quantities of dead mussels on the seafloor next door to mussel beds. University of Auckland's Professor Andrew Jeffs, specialist in *Perna* biology and behaviour, considers it unlikely that disease has played any catastrophic role in the decline of kutai at the Black Rocks (pers. comms. January-April 2020), essentially all declines observed in the wild having been because of summer-heat events, or overharvesting. Specialists in *P. canaliculus* disease, Dr Aurelie Castinel (MPI) and Dr Steve Webb (Cawthron Institute), explained (tentatively) that, given the known scarcity of disease among kutai in the wild, dead shells at the Black Rocks are unlikely to be mortality ascribable to disease (pers. comms. April 2020). Furthermore, for the Black Rocks, I'm not aware of significant proportions of dead mussels *among* the living ones, as one might expect in a disease-ravaged stock (nor among the blue mussels in the region, this mussel having similar disease profiles to kutai; Table 4), nor of low flesh condition or mussels being slow to close when disturbed (as reported by Alfaro [2006: 313] for compromised kutai further north). And – perhaps most importantly: 1) nearby populations of kutai seem to be largely intact: Booth et al. (2019) reported several significant beds of kutai 2-4 km east of the Black Rocks, at least one with dense cover (Figure 25); and 2) harvesters and divers report no shortage of newly recruited and also larger kutai on man-made objects such as mooring buoys and derelict/fouled boats around the Bay of Islands, including in the lower Kerikeri Inlet in particular (Simon Taylor; Cam Low, pers. comms. 2020).

Sampling of kutai for pathology must be of *moribund* individuals (weak, and slow to close when disturbed) – not either dead nor apparently healthy ones. Samples need to be fixed in formalin while alive, and then transferred to 70% ethanol after 48 hours (I have both chemicals in stock, particularly the ethanol!); as Chris Richmond points out, ideally we will obtain samples not just from the Black Rocks, but also from anywhere else in the Bay of Islands where die-offs have possibly taken place.

Whatever the cause, there may be ecological ramifications around the loss of significant proportions of the Black Rocks kutai stock. It has been suggested that with the decline in this adult population, Bay of Islands may have lost its main source of kutai larvae. Constrained sources of larval recruitment have been identified as a likely contributor to lowered settlement, but – as in the Firth of Thames, with its many mussel farms – large sources of larvae nearby have not necessarily led to good settlement. Undoubtedly breeding-sized kutai (>30 mm) are far less common around the Bay than a decade ago, but it is drawing a long bow to directly link their demise to too-few larvae being present to maintain recruitment. Kutai are highly fecund (millions of gametes at each individual's spawning, with evidence of some trickle spawning through the year too; Alfaro et al. 2001), and – with no established direct stock-recruit relationship – environmental and ecological vagaries are more likely to be having most impact on larval delivery and successful settlement.

**Figure 25. Dense population of kutai on a reef a little east of the Black Rocks in September 2019 (Booth et al. 2019).**

Harvestable green-lipped mussel have not been confined to the northwest Bay of Islands: they are harvested on hard shores in open parts of much of the Bay of Islands (Simon Taylor, pers. comm. 2020), but stocks have declined markedly over the past 10-15 years as well. In eastern parts, overharvesting of the intertidal beds was followed by increasing focus on subtidal beds, only a few of which are now known to survive, most of them on the west side of Cape Brett Peninsula (Pacific Eco-logic Ltd. 2016). Dr Froude (Froude 2019) has the following to add.

> When we arrived in 2006 green-lipped mussels were relatively widespread in the outer eastern Bay of Islands. They were generally present in the intertidal and shallow subtidal on exposed rock shores in the outer Bay of Islands. From about 2009 I observed the initially-gradual decline and then complete loss of one green-lipped mussel site after another. If required I can provide information from my dive log-books that records the timing and pattern of decline and then complete loss of one eastern Bay of Islands site after another [*author's addition: it is important this is done, so that any temporal consistency, and any size-dependent effects, are revealed*.] I have observed the serial decline from the Waewaetorea Passage and nearby islets and rocks, Moturua Island and associated islands and rocks, Motukiekie Island and associated islets and rocks, the reef between Moturua

Island and Motuarohia (Te Miko Reef), and Moturahurahu (Oke Bay). In my 2016 assessment [Froude 2016a] I found only a couple a couple of relatively remote locations in the eastern Bay of Islands where any green lipped mussels were still present. Green lipped mussels on reefs at Tapeka and Long Beach on the Russell Peninsula have also disappeared. Given the decline and then loss of green lipped mussels at one site after another, and the harvesting practices I have observed, I consider that the major reason for the dramatic decline in green-lipped mussels in the Bay of Islands (and Black Rocks area in particular) is excessive recreational harvesting, facilitated by the use of scuba equipment.

The remaining pockets of subtidal (below 10 m) kutai at the Black Rocks may be the final vestiges of a now rare and rapidly-disappearing biome, one that is characterised by the large size of its kutai and, in turn, the exceptional cover and settlement space available to other taxa – particularly invertebrates – to colonise. Beds of large (150-180 mm) kutai in the Firth of Thames have essentially disappeared, and patches of them in Hauraki Gulf are apparently restricted to just a few places; Andrew Jeffs, pers. comm. 2019). It is yet to be confirmed if there are deepwater patches remaining anywhere else in the Bay of Islands, but divers I have spoken to have not seen them. Kaitiaki of the Black Rocks (and the entire Mātaitai) might consider banning use of scuba for harvesting kutai in order to maintain this population: the rarity of this biome beholdens (is that the right word?) us to try to maintain at least its vestiges – not just to feel good, or for altruistic reasons, but because every form of biological diversity on the planet not only has its place, but also any one of them may eventually turn out to host life-forms (eg, particular sponges with cancer-fighting potency) essential to human wellbeing. And finally, the residual populations of subtidal kutai at the Black Rocks *could* now be the primary source of larvae for circulation and settlement throughout the Bay of Islands.

There is little in the way of long-term population data for shellfish anywhere in New Zealand (the longest and most useful being for species highly sought/threatened – the Foveaux Strait dredge oyster *Tiostrea lutaria* and the toheroa *Paphies ventricosum*). We tend to take what we know right now, and what we know of the immediately-recent past (say, 10 years), as the long-term norm of a biological stock for a certain locality. But shellfish populations are likely to be highly variable over time – even in situations without direct and consequential anthropogenic influence. We have come to see this in some of the few population studies that have extended over decades – for instance in the changing fortunes among certain invertebrate populations in the Hauraki Gulf (Hayward et al. 1997). And, 50 years ago, Booth (1972) was aghast at how blue mussels in the Bay of Islands had undergone such dramatic reduction in abundance. A systematic collection of kutai size- and density-data for the Black Rocks – even if they had been taken only every few years – would have allowed valuable insight into the reasons behind the present predicament. It is reassuring to realise that it is never too late to start a time series – which these days can simply be standardised, georeferenced photo images, with a scale.

I recommend further baseline photography/sampling of population characteristics (shellfish numbers, sizes, distribution) immediately, and again at the end of the 3-year rahui, with ongoing ~3-yearly monitoring thereafter. Formal recording of further oral accounts of past harvesting are necessary – particularly from among older fishers, in order to establish a more definitive recent-harvest history. Data sources need to be categorised (even prioritised) according to origin, photographic evidence probably having highest currency, closely followed by systematically-collected data specific with regard to such things as species (kutai or a mix of mussels), densities (numbers per square metre) and abundance (taking into account patchiness), shell sizes (mean, variability, and whether shell length or height), and depth in the water column (preferably relative to high tide level, so as to take into account the intertidal ones) being among the parameters to record.

Consideration should be given to banning the use of scuba at the Black Rocks in order to reduce pressure on the remaining subtidal populations and to allow persistence of a refuge population of breeding adults.

## Acknowledgments

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***I have almost all of these digitally, so sing out if you would like any***

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