CAWTHRON

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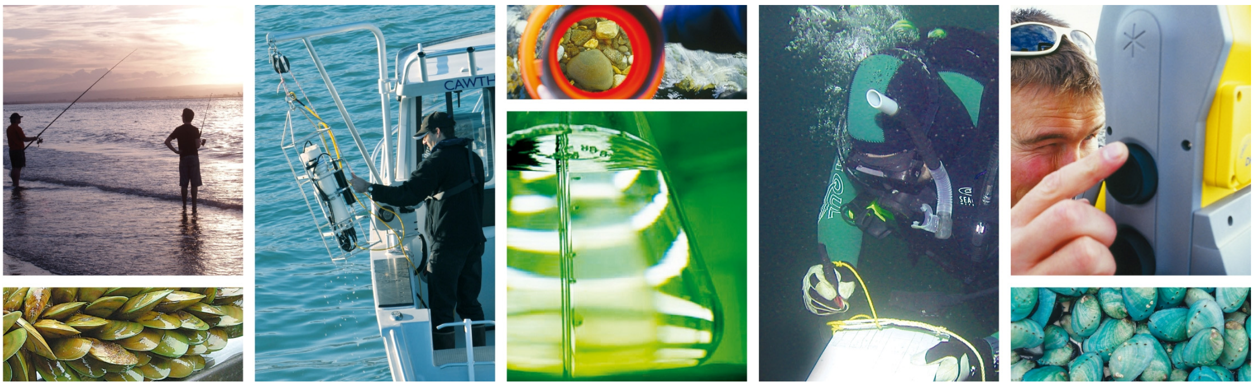
# Assessment of the East Cape Marine Water Quality and Implications for Aquaculture



RESEARCH BASED SOLUTIONS

# Assessment of the East Cape Marine Water Quality and Implications for Aquaculture

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# EXECUTIVE SUMMARY

Cawthron was commissioned by the Gisborne District Council (GDC) to investigate aspects of the water quality of the Gisborne coast in relation to aquaculture feasibility. The coastline of the East Cape of the North Island of New Zealand is characterised by large areas of unpolluted productive waters due to energetic East Cape currents and relatively low levels of terrestrial development. This may prove favourable for future aquaculture developments in the region.

This study is intended to provide a relatively broad overview of the water quality conditions of the East Cape region to assist Council and future aquaculture ventures with assessing aquaculture feasibility. The results of this work, while useful in the preliminary stages of site evaluation should not be used to replace a site-specific review. The work involved desktop analyses of existing data and information to assess water quality conditions in relation to the feasibility of aquaculture developments. This included review of Council and National Institute of Water & Atmospheric Research (NIWA) data for river flow volumes and water quality parameters of greatest relevance to aquaculture, including nutrients, faecal bacteria concentrations, and total suspended solids. Satellite imagery was used to assess the extent of sediment plumes using estimates of light extinction at 490 nm (a proxy for turbidity). Satellite imagery of chlorophyll *a* concentration was also used as a proxy for phytoplankton biomass in surface waters to assess whether levels would support aquaculture development.

A summary of the main findings are as follows:

- Rivers along the coast can lead to high levels of nutrient loading and potentially enhance productivity within the area influenced by river plumes; however, the benefits of any enhanced production may not outweigh the potential risks associated with high levels of sedimentation and/or faecal contaminants that likely co-occur with nutrient loading.
- Levels of suspended solids in outwelling coastal river plumes did not appear to be high enough to inhibit farming of shellfish such as Greenshell™ mussels. The exception would be farming of scallops close to shore.
- Farming of finfish close to shore is not recommended due to the potential sub-lethal effects of high sedimentation on fish gill function and condition. Waters further offshore (perhaps >6 km) are likely suitable for some finfish species such as kingfish.
- Rivers in the region were moderately high in faecal bacteria; periods of high contamination likely coincide with rain events and catchment runoff.
- Coastal marine waters can exhibit high faecal bacteria concentrations at times that likely coincide with rain events and flooding into coastal waters.
- Based on the available water quality data, much of Poverty Bay is presently unsuitable for aquaculture due to high faecal bacterial loading from rivers and wastewater. Faecal contamination in nearshore waters close to rivers during periods of rainfall also potentially restricts aquaculture areas to outside an approximate 6 km radius of rivers. Targeted water quality survey(s) in areas proposed for aquaculture would assist in minimising uncertainty around the potential for contamination.

- Based on an analysis of a select number of satellite images, extensive sediment plumes associated with large rain events can extend >10 km offshore. Further delineation of plume extent is recommended to refine aquaculture site selection. This could be achieved by more targeted analysis of satellite imagery, examining true-colour satellite images (not available for this project), or through further modelling (which would require site-specific current data).
- There was a decrease in chlorophyll *a* levels with distance from shore, and shellfish productivity would be best at sites within approximately 10 km from shore. Concentrations of chlorophyll *a* within this range appeared suitable for shellfish culture.

# TABLE OF CONTENTS



# LIST OF FIGURES

# LIST OF TABLES



# LIST OF APPENDICES

# 1. INTRODUCTION

The Gisborne region has not designated Aquaculture Management Areas (AMAs) as part of a regional coastal plan, however there has been growing interest from stakeholders in initiating aquaculture developments. Through an Envirolink small advice grant (698-GSDC55), Gisborne District Council (GDC), the Cawthron Institute (Cawthron) and interested stakeholders met and identified further research that would be required in order to progress with determining aquaculture feasibility within the region. A gap in information on the water quality of the Gisborne coastal waters was identified, and subsequently Cawthron was commissioned by GDC, through Envirolink 879-GSDC78, to investigate aspects of Gisborne's coastal water quality in relation to aquaculture feasibility.

This study is intended to provide a relatively broad overview of the water quality conditions of the East Cape region to assist council and future aquaculture ventures with assessing aquaculture feasibility. The results of this work, while useful in the preliminary stages of site evaluation should not be used to replace a site-specific review. This work involved desktop analyses of existing data and information to assess water quality conditions. This included:

- A review of Council and National Institute of Water & Atmospheric Research (NIWA) data for river flow volumes and water quality parameters of greatest relevance to aquaculture, including nutrients, faecal bacteria concentrations, and total suspended solids.
- Analysis of selected satellite images to assess the extent of river plumes using estimates of light extinction at 490 nm (a proxy for turbidity).
- Analysis of satellite imagery of chlorophyll *a* concentrations in order to obtain relative estimates of phytoplankton biomass in surface waters and assess whether these would support shellfish aquaculture development.

During flood events, catchment-sourced sediments and contaminants (*e.g.* nutrients, faecal microbes, metals) can be carried >10 kilometres off shore and transported along the coast (Gillespie *et al.* in prep.). Water quality can significantly affect aquaculture, and poor water quality (due to high sediment loads, bacteria or nutrients) can preclude some areas from aquaculture development, particularly for shellfish farming. Hence an important step in designating AMA space is assessing feasibility with regard to water quality conditions, that can vary considerably depending on surrounding land uses and coastal physical processes.

# 2. METHODS

## 2.1. Council water quality data

Cawthron was provided with water quality monitoring datasets from Gisborne District Council that included data from over 3600 sampling locations in rivers, coastal waters and various other water sources. Data used in the analyses were limited to the past 10 years and to data collected at water quality monitoring sites located furthest downstream in the rivers and sites in coastal waters. For the purpose of this report, we focused primarily on two types of data that were of most relevance to describing coastal water quality in relation to aquaculture potential; including, total suspended solids (relevant to feeding effectiveness of bivalves), and faecal contaminants (relevant to shellfish quality and harvest restrictions). In our assessment, we also consider river flows of the major coastal rivers, since they ultimately determine the extent to which coastal waters may be affected by sediment and contaminant loading. Nutrient loading from rivers is an important consideration since it influences primary productivity in the water column. However, in the absence of offshore nutrient data we focused more on satellite imagery of chlorophyll *a* concentrations (a proxy for phytoplankton biomass) to provide an indication of the feasibility of East Cape waters for supporting productive shellfish aquaculture.

Total suspended solids (TSS) in river and coastal water were used as a proxy for the amount of sediment in the water. Faecal indicator bacteria (FIB) concentrations (faecal coliforms) from river and coastal water sampling sites were used to assess the potential for contamination in coastal waters. There are a number of FIB used in water quality monitoring; however, we focus on faecal coliforms since these are commonly used for managing shellfish growing waters. Box and whisker plots were generated for each of the water quality parameters for both river and coastal sites ordered from north to south in order to visually assess any patterns in water quality.

In order to assess potential levels of nutrient, sediment and contaminant loading to coastal waters, we utilised both the data provided by the council and the NIWA Water Resources Explorer on-line tool (http://Wrenz.niwa.co.nz). Using Council data we multiplied average concentrations of faecal coliforms by average flows for rivers distributed along the coast to provide an indication of sediment and faecal contaminant loading, respectively. The NIWA Water Resources Explorer was also used to approximate sediment loading (expressed as sediment yield) as well as nitrogen loading from the rivers. Regional maps were then generated in GIS to show visually the levels of nutrient, sediment and faecal loading to coastal waters.

Water quality conditions can be extremely variable in time and space and using monitoring data collected at a coarse scale does not allow for accurate predictions of the spatial extent of areas that may or may not be suitable for aquaculture. However, the intentions of the water quality component of this report were to provide broadscale information on the feasibility of aquaculture in the region. Where possible we identify those areas that would be best suited for aquaculture, based on water quality conditions, and those that may present the greatest risk with regard to poor water quality. For gauging potential effects of nutrient, sediment and contaminant loading from rivers on coastal waters, we draw comparisons to data and research outputs from the Motueka River Integrated Catchment Management (ICM) programme in Tasman Bay. Although oceanographic conditions are different in Tasman Bay compared to the exposed Gisborne coastline, our available knowledge on the interaction of river flows and management of AMAs enabled us to place likely conditions in the study region within the context of a well-studied area. In addition, outputs from the satellite imagery provide some indication of the potential "footprint" of the river plumes, and subsequently the areas that may be most prone to effects from land-derived nutrients, sediments and/or faecal contaminants.

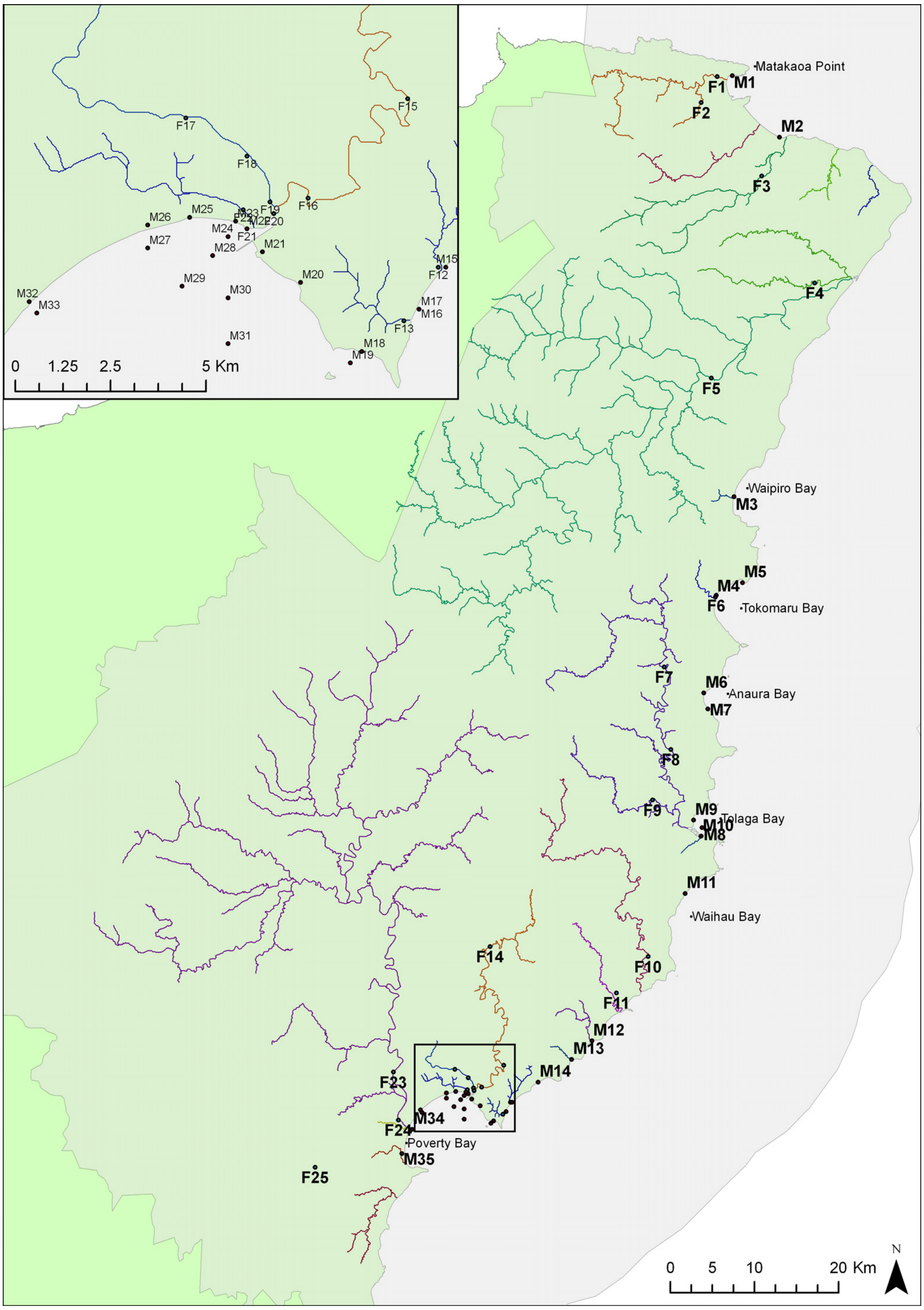


**Figure 1.** Region map showing major rivers, and freshwater and marine monitoring sites where data were collected and provided by GDC for the purpose of this report. Rivers illustrated were main flows and were generated from data from FWENZ (Freshwater Environments of New Zealand, Leathwick *et al.* 2008). Refer to Appendix 1 for total catchments and river names.

## 2.2. Satellite-derived water clarity

Given the scope of the project and the large area of the region examined, this study used satellite-derived data rather than direct measurements to quantify water clarity for the region. In order to aid an understanding of the large amount of data reviewed in this study, several reference sites along the coast were selected to provide detailed data (Figure 2). These sites were initially chosen for a project examining the physical oceanography of the Gisborne District in relation to aquaculture (Envirolink 878-GSDC77, Knight *et al.* 2010). The sites were chosen in consultation with GDC and reflected suitable depths (over 30 m generally considered suitable for shellfish and finfish farming), contrasting coastal aspects, representative sections of the coastline, proximity to areas with suitable access, and protection from land features (such as the Mahia Peninsula and offshore islands). Some potential constraints were also taken into account when positioning the sites (*e.g.* shipping lanes and conservation areas). The sites did not necessarily represent potential aquaculture sites; rather they were indicative of conditions in the general areas. An offshore site (10) was chosen in order to compare characteristics with coastal sites along the shelf and to understand the influence of depth on wave action.

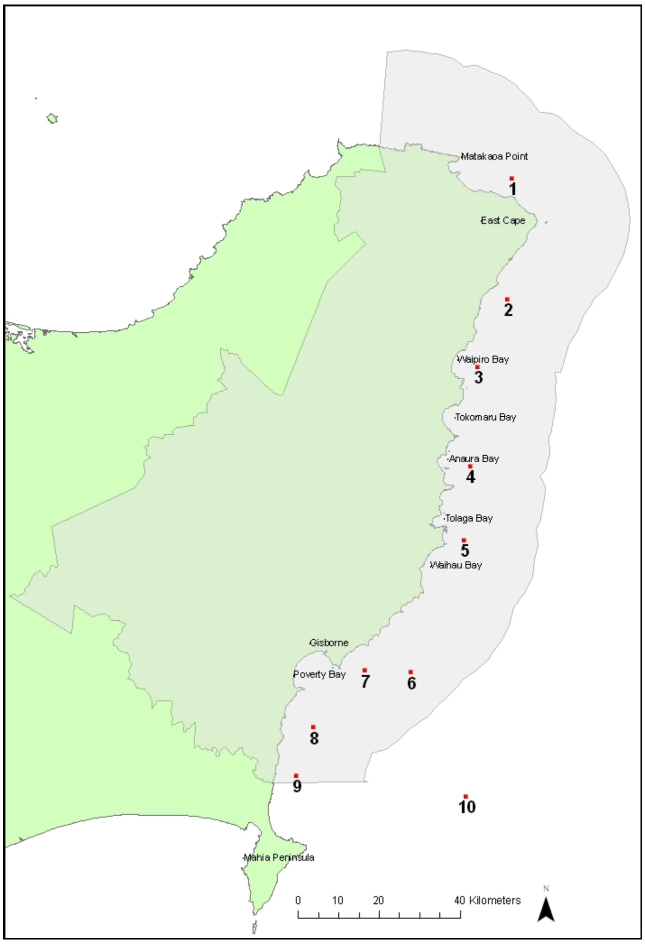


**Figure 2.** Map of the Gisborne District, showing the regional boundary and the 10 selected satellite imagery evaluation sites.

The satellite imagery data were provided for a period of four years from 2003 to 2007 from the MODIS Aqua satellite sensor 490 nm attenuation ($k_{490}$) data. The specific methods used to generate 490 nm attenuation coefficients are derived from spectral reflectance data that has been matched to empirically derived relationships from *in situ* measurements.

These coefficients relate the relative intensity of 490 nm ($R_{490}$) light at depth $z$ to the surface intensity ($I_0$) through the expression:

$$R_{490}(z) = \frac{I_z}{I_0} = e^{-k_{490}.z} \tag{1}$$

These data are used to construct a more meaningful extinction metric ($Z_{1\%}$) which is the depth to which 1% of the surface light penetrates to. The metric is calculated using the following formula:

$$Z_{1\%} = \frac{\ln(0.01)}{-k_{490}} \tag{2}$$

This metric is similar to (but not directly comparable to) secchi disc depth which is measured by lowering a black and white disc into the water and recording the distance at which it can no longer be seen. Therefore a high value of $Z_{1\%}$ indicates clear water, and a low value indicates turbid water. By collating the lowest values of $Z_{1\%}$ at all locations along the East Cape, we can see areas of water that had high turbidity and therefore provide an indication of the likely extent of elevated coastal sediments along the coast.

## 2.3. Satellite-derived phytoplankton concentrations

As with the determination of water clarity, given the large area of the region, we made use of satellite-derived data to estimate chlorophyll *a* (chl *a*) concentration in the region. These data were provided for a period of four years from 2003 to 2007 from the MODIS Aqua satellite sensor using derived chl *a* data. Chlorophyll *a* is typically used to estimate phytoplankton abundance as it is a common pigment in marine phytoplankton and increases in concentration are generally associated with increased phytoplanktonic carbon (typically a carbon to chlorophyll ratio of 50:1 is used however this can vary over a large range).

# 3. RESULTS AND DISCUSSION

## 3.1. Analyses based on water quality data

Environmental issues of greatest potential threat to the region's coastal marine area relate to water quality, which in turn is critically important to sustaining the life supporting capacity of coastal waters. Key stressors include sedimentation and reduced water clarity associated with sediment loading, increased nutrient concentrations and subsequent increases in primary production with potential for generating harmful algal blooms, and influx of a range of contaminants including faecal microorganisms that impact coastal resources.

Gisborne coastal waters are affected by a number of river plumes that can achieve significant proportions during floods. The spatial footprint and extent to which freshwater extends alongshore and/or offshore within buoyant plumes will be dependent on the amount of rainfall, winds and oceanographic conditions (waves, tides). Rivers often flow into estuaries, which can effectively filter and "clean" water before it reaches the sea. However, along the East Cape the rivers primarily flow into coastal waters without first passing through estuaries and therefore have the potential to deliver significant amounts of nutrients, sediments and faecal contaminants more directly into the marine environment. Nutrients are generally considered to be favourable to shellfish aquaculture. Aquaculture Management Areas placed near river mouths can benefit from the added nutrients that enhance water column productivity (Figure 3). There are tradeoffs, however, since rivers tend to also carry high levels of suspended sediments and faecal contaminants that can impact on shellfish quality.

Data from GDC river monitoring sites indicate relatively high and consistent levels of suspended solids and faecal contaminants in most rivers along the coast (Figure 4). Levels of suspended solids are particularly high for the region in comparison to other locations around New Zealand. The Waipaoa River, for instance, has the lowest water clarity out of a total of 76 rivers ranked by the Ministry for the Environment's 2007 water quality league assessment. As indicated in Figure 4, this river has the highest median TSS concentration of approximately 100 g/m$^3$. The Waiapu median TSS concentration is lower at approximately 50 g/m$^3$, however this measurement was from relatively high in the catchment and sediment yield into the coastal environment is the highest in the region, with over 35 million tonnes of sediment discharged per year (Figure 3). In all the rivers there are times that faecal contaminants are very high (above 10,000 cfu/100 ml) and well in excess of red alert bathing guidelines. The sources that lead to these high values would depend on surrounding land uses and are likely to be dominated by ruminant animals (cows, sheep) and wildlife in more rural catchments.

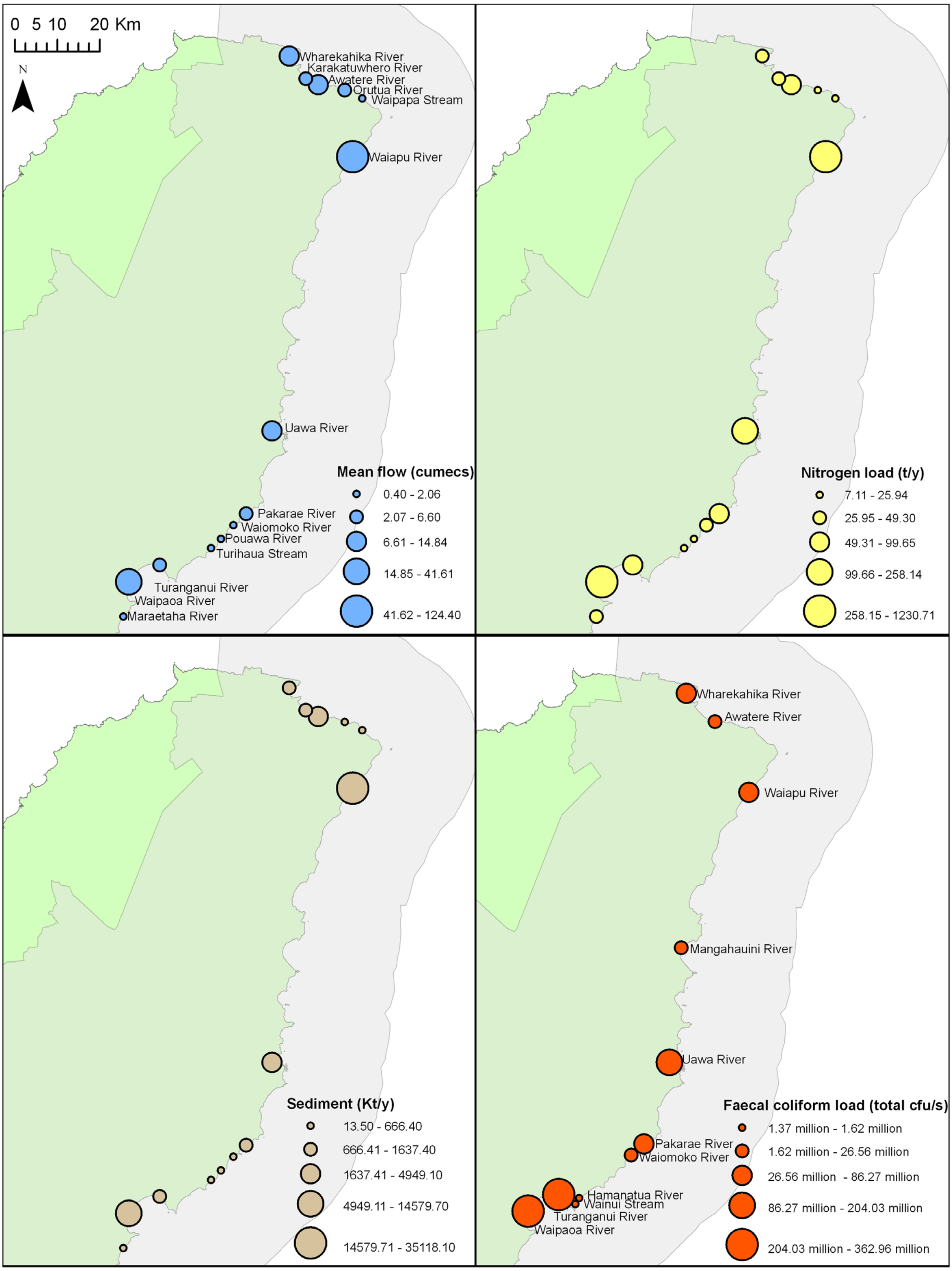


**Figure 3.** Regional maps showing average river discharge, total yearly nitrogen and sediment yield for main rivers (order 4 and above), as estimated by the NIWA Water Resources website, and the estimated faecal bacteria loading based on the average faecal coliform concentration and river flows. Note that these are based on averages, and that river flows and faecal contaminants are both highest during floods, and it is during floods that the greatest risk of contamination will occur. Nonetheless, the average loads provide an indication of those areas that may be most prone to contamination.

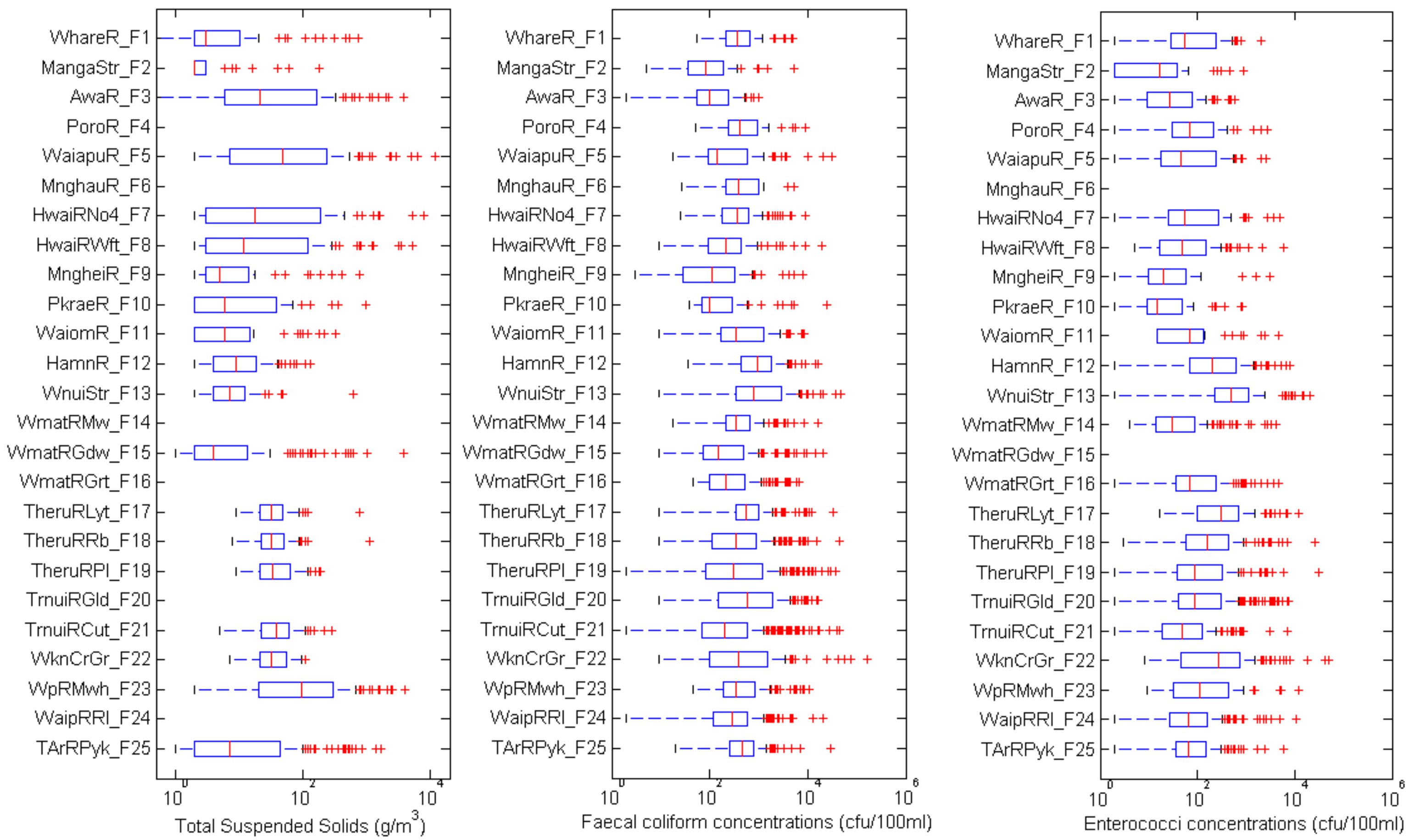


**Figure 4.** Total suspended solids (g/m$^3$), and faecal coliform concentration (cfu/100ml) for rivers; ordered from north (top) to south (bottom).

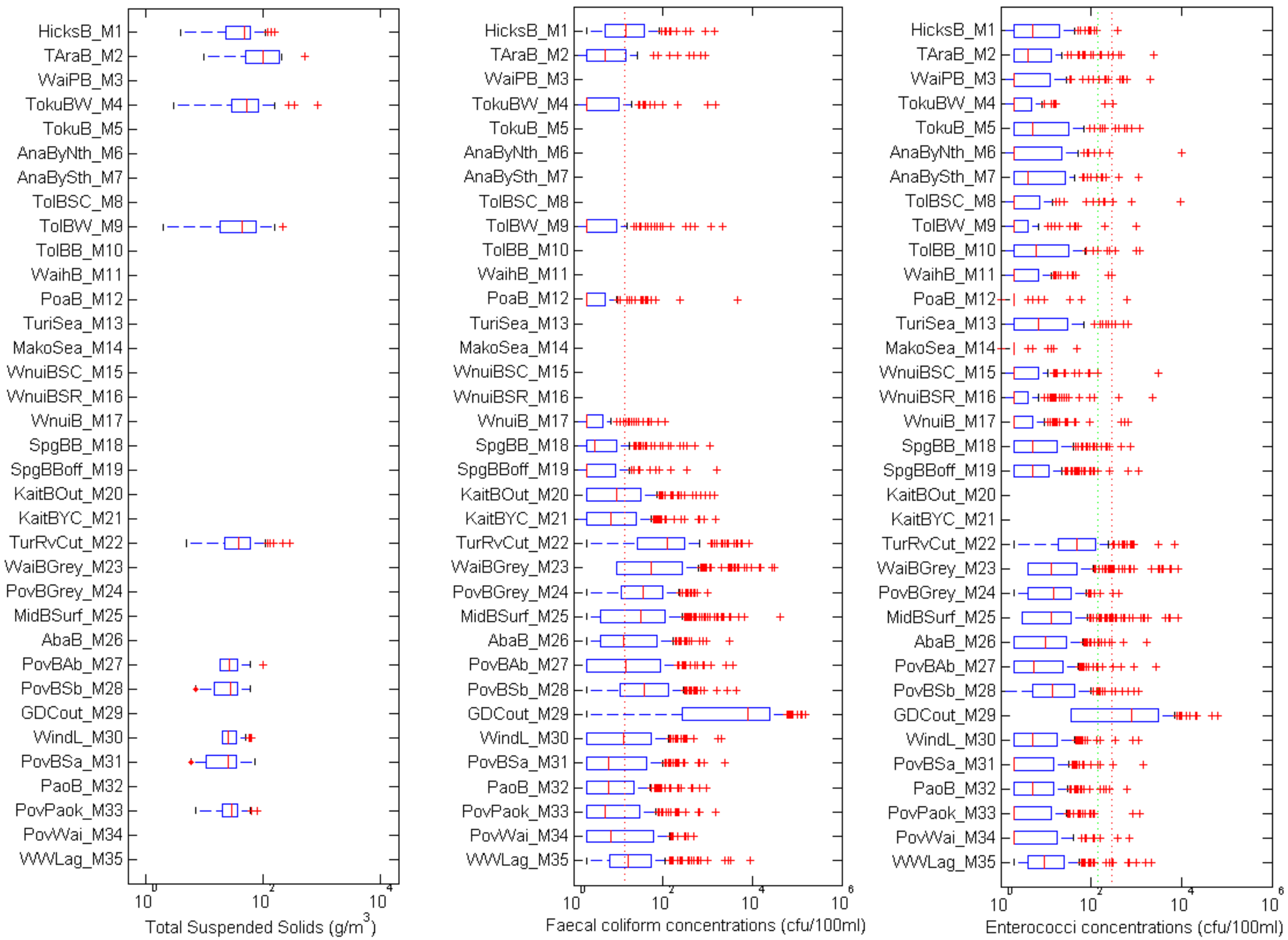


**Figure 5.** Total suspended solids (g/m$^3$), and faecal coliform and enterococci concentrations (cfu/100ml) in coastal waters for monitoring sites located in the north (top) to those in the south (bottom). Vertical lines on the faecal coliform plot indicate the threshold for shellfish harvest (median of 14 cfu/100ml over a season) and the lines on the enterococci plot refer to the amber and red alert concentrations for bathing water quality.

Outliers in TSS and faecal bacteria toward the high end in Figure 4 and Figure 5 most likely coincide with rainfall events. There is also a seasonal component to the frequency of rainfall events; hence levels of nutrients, sediments and faecal contaminants entering coastal waters will be greatest during floods and also during the wetter winter season. The extent to which river nutrients, suspended solids and faecal contaminants will affect coastal waters will depend on river flows (volume of water entering coastal waters) and land uses in the catchment. Nearshore hydrodynamics that are influenced by tides and winds will in turn influence the level of mixing and dilution in coastal waters and the extent to which river plumes form and extend offshore into potential aquaculture management areas.

Levels of TSS at coastal monitoring sites are relatively constant along the coast and on average are as high (or even higher) than levels observed in the rivers (Figure 4). The median concentration of suspended solids is above 10 g/m$^3$ at all sites and as high as 100 g/m$^3$ at Te Araroa Beach (M2). Typically more turbid river waters tend to mix and dilute with clearer marine waters. The high levels likely reflect the close proximity of sampling sites to the coastline (see Figure 1) and the added contribution of resuspended sediments in shallow nearshore waters.

So what are the implications of these turbid waters for aquaculture development? Filter feeding bivalves such as mussels, oysters and cockles naturally occur in nearshore benthic environments that are frequently exposed to resuspended sediments and high turbidity. As a result, they are highly tolerant of periods of high sedimentation that would occur during wave-driven resuspension events and/or flood events. They would, however, be less tolerant of prolonged exposure to high sedimentation in the water column, particularly if the majority of the total suspended solids were comprised of inorganic sediments.

The composition of the suspended solids near the river mouths is likely to be dominated by inorganic sediments; for instance ~97% of suspended solids in the Waipaoa River are comprised of muds and fine sands (Foster & Carter 1997). Shellfish can tolerate a wide range of suspended solid concentrations although tolerance tends to vary among species. The commonly farmed Greenshell™ mussel (*Perna canaliculus*) can effectively feed at levels of suspended matter approximately 10-fold higher than those observed along the East Cape (Hawkins *et al.* 1999). The pacific oyster (*Crassostrea gigas*) appears to be less tolerant of high sedimentation, with filtration declining at levels above 100 g/m$^3$ (Hawkins *et al.* 1999), which is slightly higher than the median TSS measured at coastal monitoring sites. Scallops in Tasman Bay have been observed to stop feeding at suspended sediment concentrations above 11 g/m$^3$ (P. Gillespie, unpub. data); hence this species may not be suitable for aquaculture unless farmed offshore in clearer water. This information suggests that coastal waters along the East Cape are likely suitable for growing bivalve species other than scallops with regard to suspended sediments. This is particularly true if aquaculture areas are established away from the shoreline (*e.g.* ~2 km offshore) and the main influence of river plumes.

Suspended sediments can impact finfish behaviour and their condition (see Morrison *et al.* 2008 for review). While fish can tolerate short periods of high turbidity, it is likely that farmed species such as salmon and kingfish would be affected by prolonged exposure to suspended sediments due to sub-lethal effects on gill structures and respiration. The levels of suspended sediments known to affect finfish are based on experimental studies and are higher than those observed at coastal monitoring sites (see Morrison *et al.* 2008 and references therein); nonetheless, finfish aquaculture would be best suited offshore in clearer water as a conservative measure due to a lack of information on the effects of suspended sediments on New Zealand farmed species. Farming away from the main influence of the river plume would also reduce risks of fish mortality that could result from extensive sediment loading during extreme flood events (*e.g.* Cyclone Bola in 1988).

Contrary to suspended solids, the concentrations for faecal indicator bacteria at coastal water sites are considerably lower than those observed in the rivers (*cf.* Figure 4 and Figure 5). This is due to mixing and dilution as well as die-off of faecal bacteria in marine waters. As expected, the concentration of faecal coliforms is higher than enterococci in river samples, and approximately equivalent to each other in marine waters. This reflects the higher survivorship of enterococci in marine waters.

Low risk of faecal contamination is critical to producing high quality, safe shellfish products and managing harvests. Harvest closures are primarily based on routine sanitation surveys, where a median faecal coliform concentration in growing waters must not exceed 14 cfu/100 ml and the *E. coli* concentrations within the shellfish themselves must not exceed 230 cfu/100 ml. In addition, no more than 10% of water quality samples can exceed a faecal coliform concentration of 43 cfu/100 ml. Based on these standards and results from coastal water quality monitoring over the past 10 years (Figure 5 and Table 1), the conditions for shellfish harvesting close to the shoreline are relatively poor. This is particularly true for Poverty Bay near Gisborne City, where there is significant faecal contaminant loading associated with the Waipaoa River, the Taruheru and Waimata Rivers and the Gisborne outfall (see Figure 5 and Figure 3). Matakaroa Point (M1) was also reasonably high for faecal coliforms as was the site downstream of the Wherowhero Stream in southern Poverty Bay. Faecal indicator bacteria drop off in concentration for sites such as M30 and M31 in Poverty Bay, which are 2 to 4 km from land and the outfall. However, these waters may still be unsuitable for shellfish harvest since the percentage of samples over 43 cfu/100 ml exceeds 10% (Table 1).

It is possible that shellfish farming in Poverty Bay may be suitable at distances further than 4 km from the outfall, and in fact such farming could benefit water quality in the bay. Water quality is expected to improve with upgrades to the Gisborne wastewater treatment facility in late 2010. A more in-depth study on the sources and potential fate of faecal contaminants is warranted prior to initiating any aquaculture development within the bay since large catchments with multiple land uses drain into the system. For example, the Waipaoa and the Turanganui rivers flowing into the bay represent the largest amount of faecal contamination loading into Gisborne coastal waters (see Figure 3).

A recent study on the Motueka River plume in Tasman Bay demonstrated that significant faecal contamination of shellfish can occur within AMAs located more than 6 km offshore during moderate flood events with a river flow of 400 $m^3/s$ (see Figure 6; Cornelisen *et al.* in prep). The primary source of this contamination was determined to be ruminant animals in the catchment. There are a number of rivers with similar or greater flows during floods along the East Cape, including the Wharekahika, Awatere, Waiapu, Hikuwai and Waipaoa Rivers. Depending on coastal ocean conditions these rivers would be expected to create river plumes high in sediments and faecal contaminants during flood events that would span distances similar to or greater than the Motueka River. Indeed, satellite images of water clarity reveal that plumes associated with the rivers flowing into Poverty Bay and the Waiapu River form very large plumes that would on occasion extend considerably more than 10 km offshore (see Section 3.2, Figure 8 – Figure 11).

**Table 1.** Median faecal coliform concentrations and percentage of marine site samples containing concentrations greater than 43 cfu/100 ml.

| Site code | Sampling Site | Median (cfu/100mL) | % Samples > 43 cfu/100mL |
|---|---|---|---|
| M1 | Hicks Bay Wharf | 15 | 22% |
| M2 | Te Araroa Beach | 5 | 16% |
| M4 | Tokumaru Bay Wharf | 2 | 7% |
| M9 | Tolaga Bay Wharf | 2 | 12% |
| M12 | Pouawa Beach | 2 | 5% |
| M17 | Wainui Beach | 2 | 3% |
| M18 | Sponge Bay Beach | 3 | 6% |
| M19 | Sponge Bay (400m offshore) | 2 | 8% |
| M20 | Kaiti Beach Outfall | 9 | 17% |
| M21 | Kaiti Beach Yacht Club | 7 | 17% |
| M22 | Turanganui River (The Cut) | 125 | 73% |
| M23 | Waikanae Beach Grey St. | 56 | 53% |
| M24 | Poverty Bay Grey St | 37 | 44% |
| M25 | Midway Beach (Surf Club) | 32 | 44% |
| M26 | Abattoirs Beach | 13 | 31% |
| M27 | Poverty Bay Abattoir | 15 | 35% |
| M28 | Poverty Bay (Sb zone) | 38 | 48% |
| M29 | GDC outfall | 81 | 86% |
| M30 | Windsurfing Lane | 13 | 30% |
| M31 | Poverty Bay (Sa zone) | 6 | 25% |
| M32 | Paokahu Beach | 6 | 18% |
| M33 | Poverty at Paokahu | 5 | 23% |
| M34 | Poverty at Waipaoa | 7 | 29% |
| M35 | Wherowhero Lagoon | 17 | 27% |

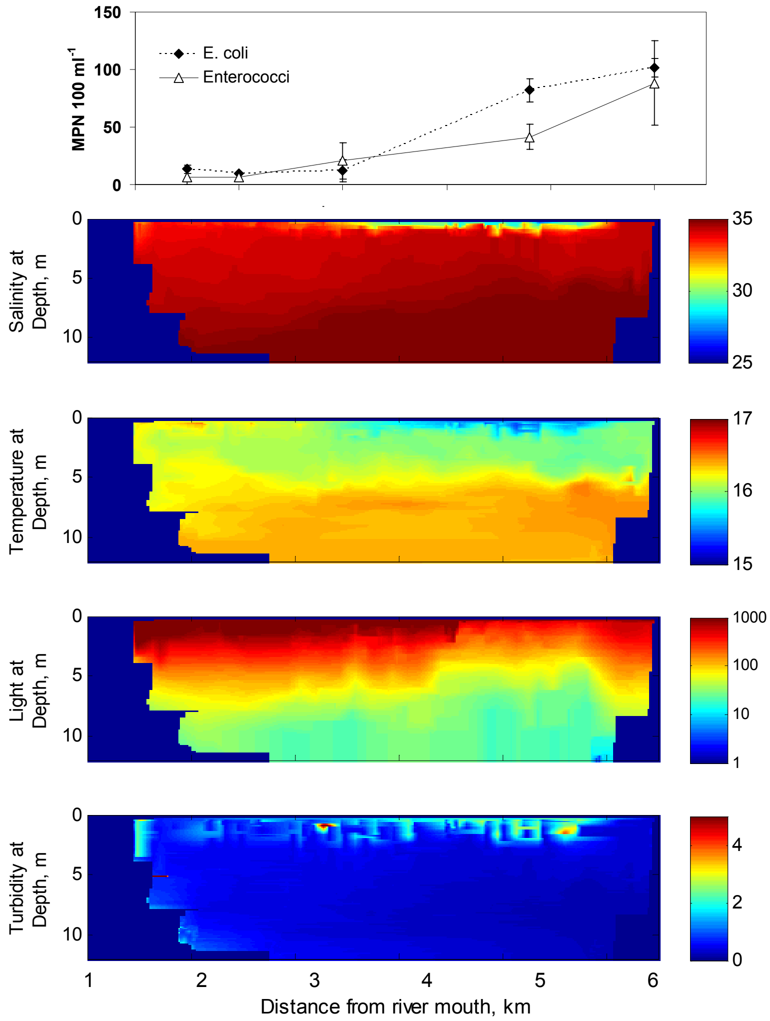


**Figure 6.** Faecal indicator bacteria (*E. coli* and enterococci) concentrations in Tasman Bay surface water (1 m depth) as a function of distance from the Motueka River mouth (top panel) followed by vertical (0 to 12 m depth) cross sections of interpolated salinity, temperature, light and turbidity between the river mouth and the AMAs located 6 km offshore. This plume was the result of a 400 $m^3$/s flood, and resulted in contamination of mussels in the AMAs that was linked to ruminant sources in the catchment.

Knowledge of faecal bacteria loading in rivers as a function of flows has been used for managing harvests around contamination risk. For example, closures in the AMA located between 6 and 10 km from the Motueka River in Tasman Bay are managed around average river flows over a 24 hr period, with less than 150 $m^3s^{-1}$ leading to no closure, and flows greater than 150 $m^3s^{-1}$, 200 $m^3s^{-1}$, 310 $m^3s^{-1}$ and 730 $m^3s^{-1}$ leading to closures of 1, 2, 4 and 7 days, respectively. Based on river flow statistics, these AMAs would be closed for approximately 10% of the year. Although a relatively small percentage, the timing of closures could have a large impact on the farms if rainfall events occur when mussels are reaching peak condition. The ability to time harvesting with peak mussel condition is critical to maximising product value. If the farm is closed for a period of time that included a spawning event, the mussels could rapidly lose condition before harvesting was allowed. In order to minimise this risk, shellfish farms should be established in areas that are the least frequently exposed to faecal contamination. Such areas would include the central stretch of coastline and the bays removed from the direct influence of major rivers (see Figure 1). It is noted, however, that even these areas periodically experience high levels of faecal indicator organisms that are likely associated with small streams and runoff (Figure 4 and Figure 5). Faecal bacteria can also persist in sediments, beach sands, and algae (Boehm 2009; Ishii & Sadowsky 2008; Ksoll *et al.* 2007; Yamahara *et al.* 2007). Fine-grained sediments can resuspend during wind/wave events causing spikes in FIB in the absence of any rainfall and subsequent increase in river flows. Hence it is best to minimise risk of closure by farming in areas some distance from the shoreline. Targeted water quality survey(s) in areas proposed for aquaculture would assist in minimising uncertainty around the potential for contamination.

**Interaction of sediment and faecal loading**

There are potential interactive effects associated with combined sediment and faecal contaminant loading. An increase in suspended sediments enhances the transport and survivorship of faecal microbes into the coastal environment. High turbidity in discharged river water can effectively block incoming irradiation, which is the primary factor driving mortality of faecal bacteria and viruses in the environment. Bacteria and viruses also bind to particulate matter and sediment particles, which provide microhabitats and shade from ultraviolet radiation (Maille-Lyons *et al.* 2007). In the previously discussed study on the Motueka River plume, contamination of mussels occurred at depths below the primary influence of the low salinity plume. Hence mussels were likely feeding on contaminated particles that were settling out from the overlying low salinity plume (Cornelisen *et al.* in prep). These findings highlight the complexity of contamination events and the need to more fully understand the interactive and cumulative effects of land use on coastal ecosystems and resources.

## 3.2. Surface water clarity

The study used light attenuation data to estimate the effect of coastal run-off on areas that may be used for future aquaculture. Unfortunately, due to bias problems with the satellite images that tended to provide data only during periods of fine/dry weather with low cloud cover, it was difficult to detect any differences between coastal sites (Figure 7) or see any increased turbidity signature from the coast in spatial data (Appendix 2).

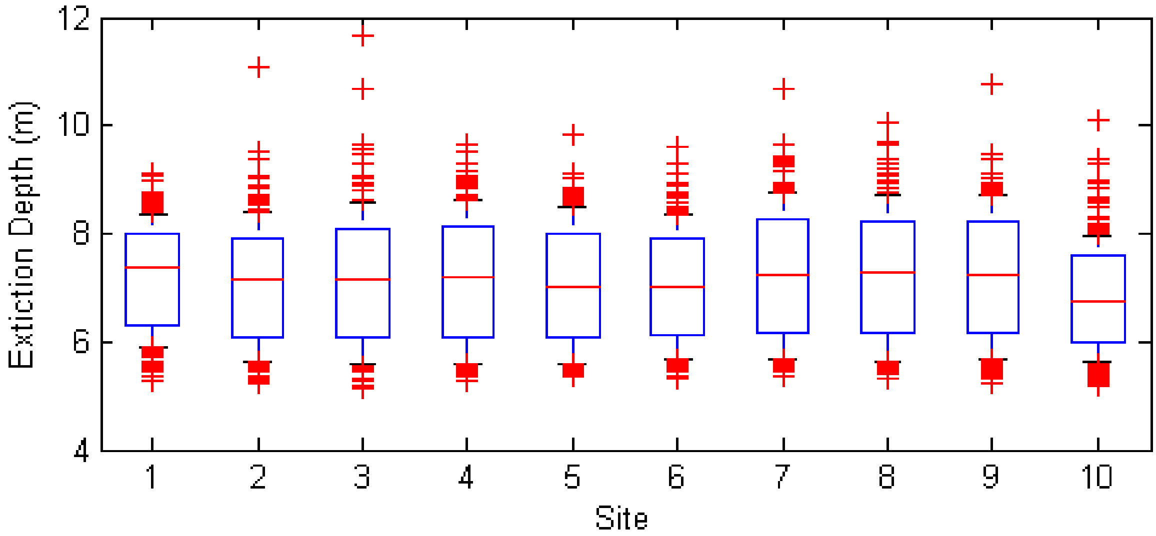


**Figure 7.** Distribution of water clarity expressed as extinction depth for 10 sites along the coast. Refer to Figure 2 for site locations.

In order to see if any images may have captured coastal sediment plumes, we inspected many of the images. As shown in Appendix 2, the nearshore waters appear to be clearer than the offshore water for the majority of the time. It is difficult to state conclusively why this may have been the case, but it is probable that this region undergoes upwelling during periods of northerly winds which may drag cool, clear nutrient rich water to the surface. As this process can occur during fine (cloud-free) weather the satellite images are able to detect this. Unfortunately determining river plume extent requires firstly a period of high rainfall, followed by a period of fine weather so the satellite can record the extent of the plume.

By visual inspection we discovered several instances where there appeared to be areas of high turbidity close to the coast. Figure 8 shows data from 25 December 2002 which followed a period of reasonably high rainfall, based on observations from Gisborne airport (Figure 9). According to these data it appears that the coastal water close to Gisborne and further up the coast was slightly more turbid than surrounding waters. Nevertheless, even with this observation it seems unlikely that aquaculture located more than ~2 km from the coast would have much interaction with coastal suspended sediment run-off.

A major rainfall event occurred on 22 October 2005, and Figure 10 shows clear water prior to the event, and high turbidity inside and north of Poverty Bay (out to approximately 10 km offshore) five days afterwards. This plume had appeared to shift further offshore by seven days after the event, and clearer waters were evident nine days afterwards. Figure 11 shows a plume seven days after a rain event, at Waipiro Bay which extended approximately 20 km offshore. This plume may have originated from the Waiapu River, and drifted south.

Further delineation of plume extent would be necessary prior to aquaculture structure placement. This could be achieved by more targeted analysis of satellite imagery, examining true-colour satellite images (not available for this project), or through further modelling (which would require site-specific current data).

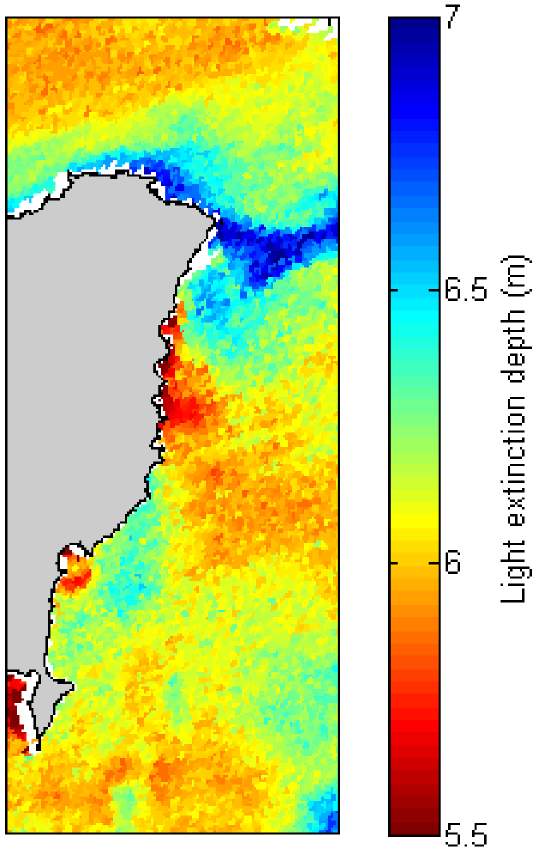


**Figure 8.** Extinction depth on 25 December 2002 after a moderate rain event. Some indication of high turbidity water (orange and red colours) in Gisborne Harbour and at some locations on the coast.

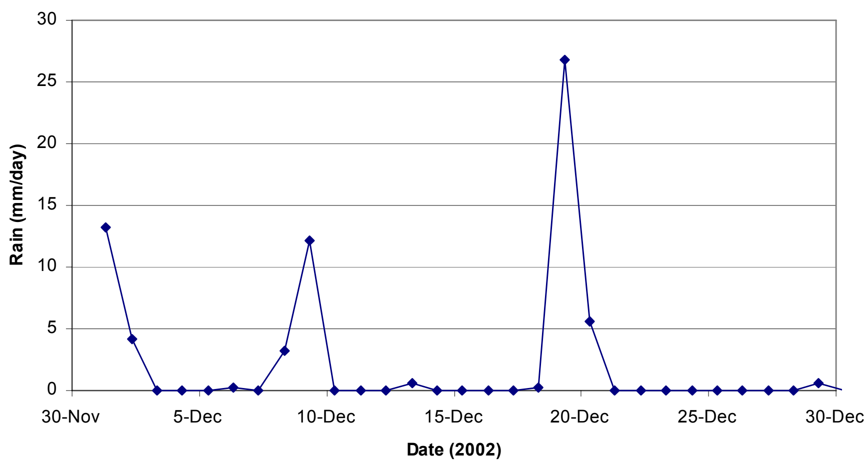


**Figure 9.** Gisborne rainfall for the month of December, 2002.

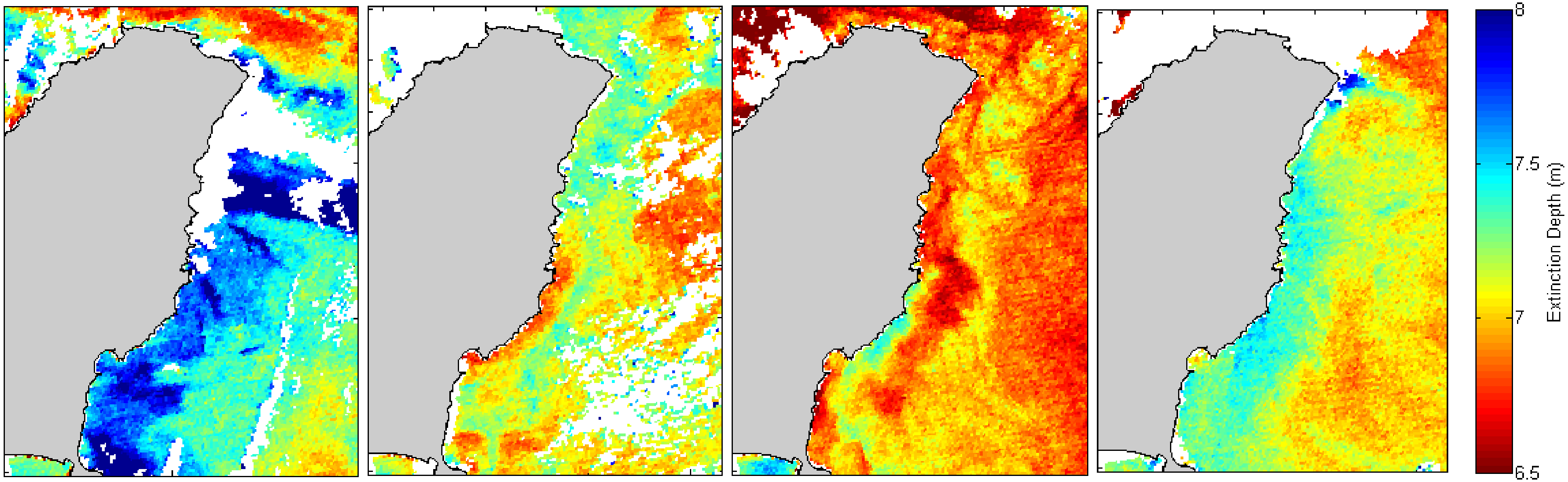


**Figure 10.** Extinction depth on 20, 27, 29 and 31October 2005 before and after a major rain event on 22 October 2005 (146 mm/day).

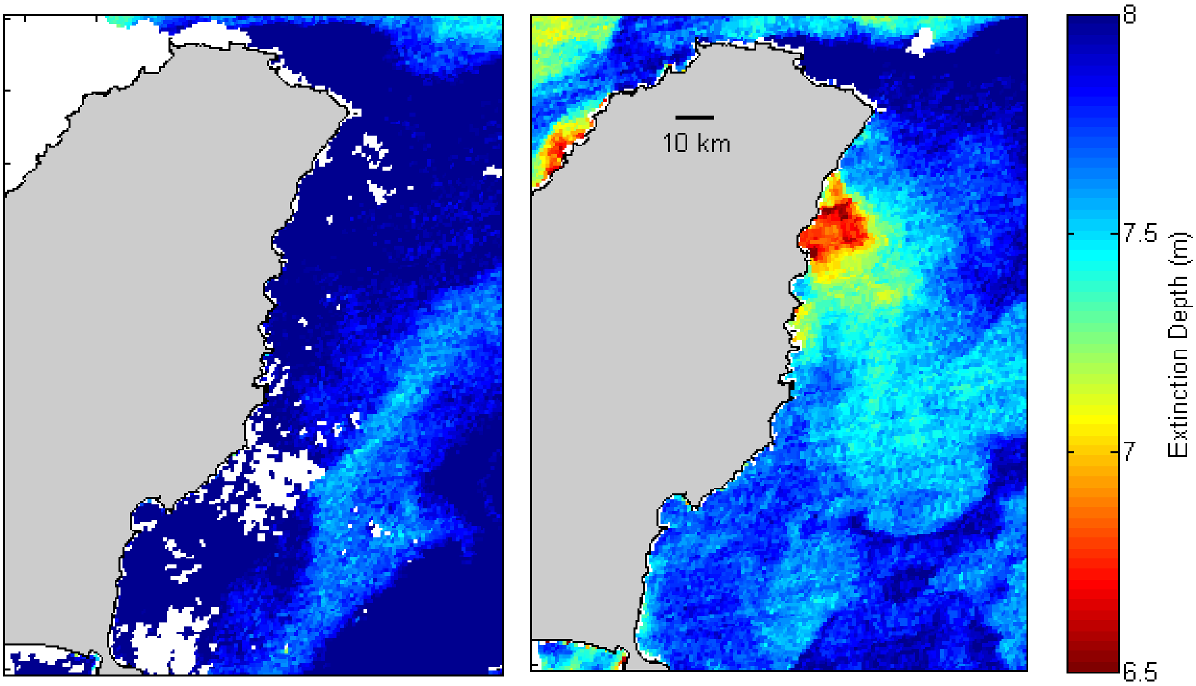


**Figure 11.** Extinction depth on 19 and 27 October 2007 before and after a moderate rain event on 19 October 2007 (53mm/day).

## 3.3. Phytoplankton concentrations

As with the water clarity data, chlorophyll data were also limited due to cloud cover and the images were biased towards fine weather conditions. Despite this issue, analysis of offshore coastal sites shows some differences between sites with moderate (~1 mg/m$^3$ or higher) chl *a* concentrations at most sites (Figure 12). Sites 6 and 10 were the furthest offshore and showed the lowest values. Typically chl *a* concentrations of greater than 1 mg/m$^3$ are considered suitable for shellfish culture (Inglis *et al.* 2000).

Analysis of the wider region (Figure 13) shows a clear decreasing gradient of phytoplankton abundance between nearshore and offshore waters, with offshore waters showing relatively low median chl *a* concentrations. Generally a higher concentration of chl *a* is considered to be beneficial for shellfish aquaculture and therefore it appears that the best areas for shellfish aquaculture (where chl *a* is greater than 1 for over 50% of the time) are relatively close to shore (about 5-10 km).

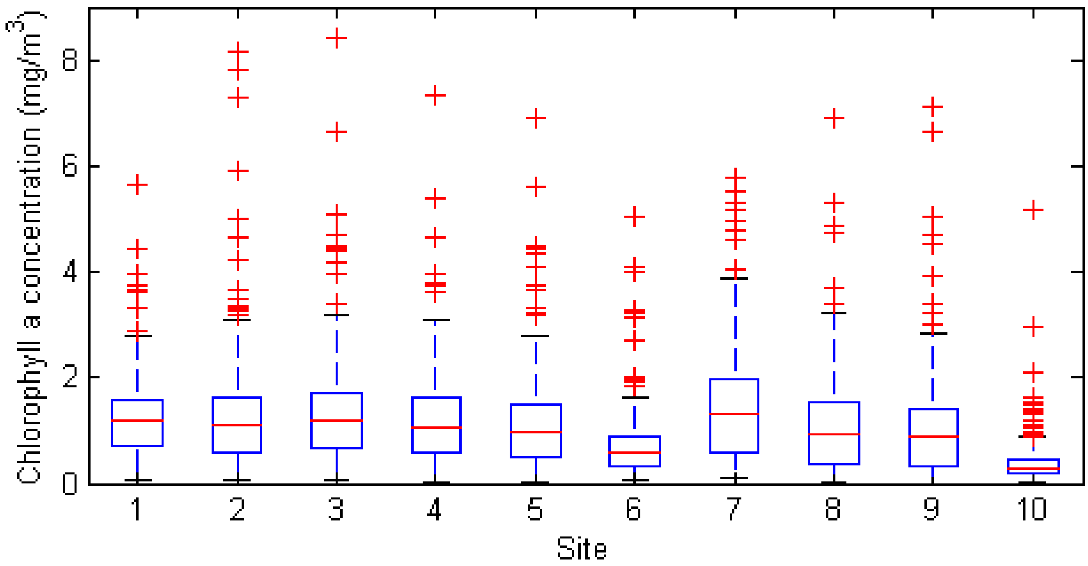


**Figure 12.** Chlorophyll *a* concentration distributions from 10 sites located along the East Cape coastline. The number of samples was approximately 300 out of the 1,277 satellite images analysed. Refer to Figure 2 for site locations

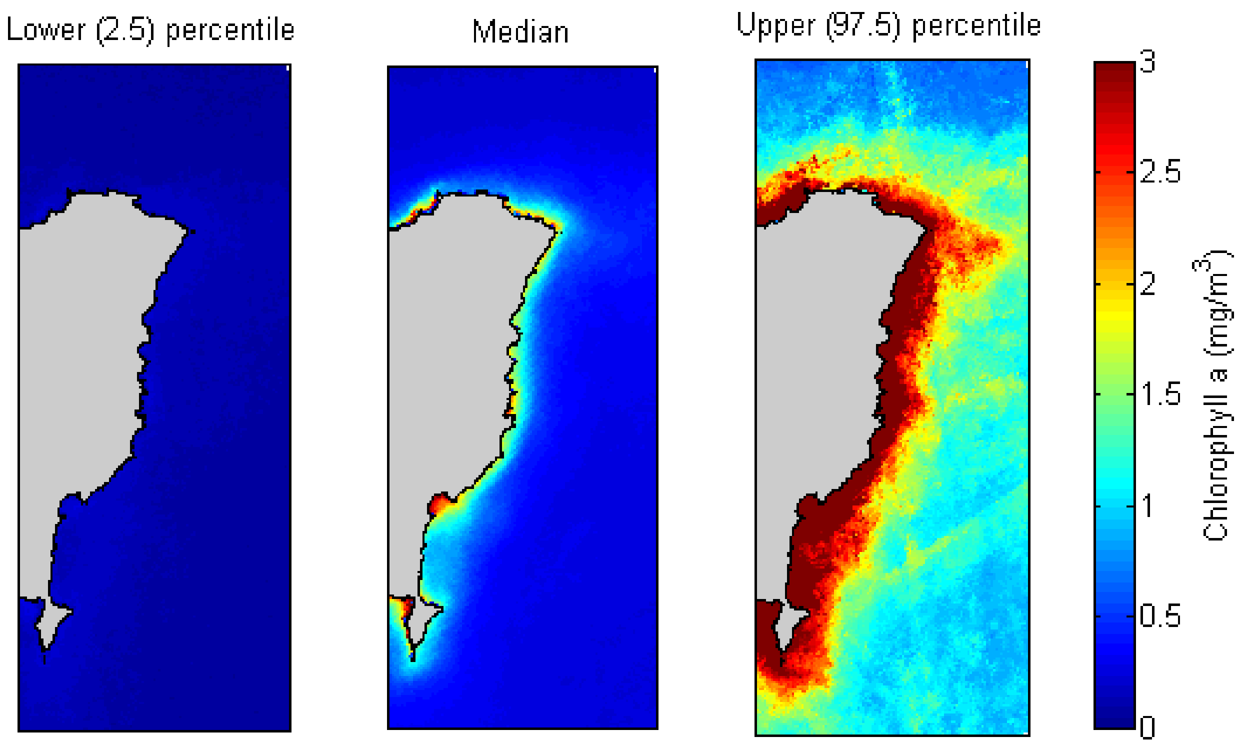


**Figure 13.** Lower (left), median and upper (right) percentile chlorophyll *a* concentrations derived from satellite data.

Although chl *a* concentrations are a useful guide for determining shellfish site suitability, there are still a lot of unknown elements that may effect shellfish growth. For instance, shellfish also have the ability to feed on other particulate organic matter, such as detritus, bacteria or zooplankton that may not have the pigment and are therefore not shown in the satellite data. Satellite data shows near-surface concentrations, so it is also likely that phytoplankton concentrations may differ below the surface. Sometimes the peak phytoplankton biomass may be some depth below the water surface if more nutrients are available and the water is sufficiently clear to allow penetration of the light (5 to 10 m). Below this peak biomass depth, phytoplankton concentrations will decrease and hence the vertical positioning in the water column of shellfish aquaculture becomes important. Physical constraints may require the structures to be submerged, but if they are submerged too deep the shellfish may not have access to a sufficient quantity of suspended organic material.

Even if suitable chl *a* concentrations are observed, the size of the phytoplankton in the region must also be appropriate to be consumed by shellfish, hence in order to fully assess site suitability for shellfish aquaculture, investigation of the quantity and quality of suspended particulate material in the water column would be recommended.

# 4. CONCLUSIONS

Analysis of water quality data revealed that nearshore areas close to major rivers would be periodically exposed to high nutrient, suspended sediment and faecal bacterial loadings. High nutrient loading can potentially enhance productivity within the area influenced by river plumes; however, the benefits of any enhanced production might not outweigh the potential risks associated with high levels of sedimentation and faecal contaminants that likely co-occur with nutrient loading.

While nearshore sediment loads do not appear to be high enough to significantly inhibit farming of shellfish such as Greenshell™ mussels, scallop and fish culture may be precluded due to potential lethal and sub lethal effects. Based on the available water quality data, much of Poverty Bay is presently unsuitable for aquaculture due to high faecal bacterial loading from rivers and wastewater. Faecal contamination in nearshore waters close to rivers during periods of rainfall potentially restricts aquaculture areas to outside an approximate 6 km radius of rivers. This is based on experiences in Tasman Bay; the extent of river plumes along the East Cape likely vary from that of the Motueka River plume due to differences in catchment characteristics, river flows and the exposed nature of the coast. Targeted water quality survey(s) in areas proposed for aquaculture would assist in minimising uncertainty around the potential for contamination.

Based on a coarse analysis of a select number of satellite images, extensive sediment plumes associated with large rain events can extend considerably more than 10 km offshore. Further delineation of plume extent (in terms of both suspended sediments and faecal contaminants) is recommended to refine aquaculture site selection. This could be achieved by more targeted analysis of satellite imagery, examining true-colour satellite images (not available for this project), or through further modelling (which would require site-specific current data).

There was a decrease in chl *a* levels with distance from shore, and shellfish productivity would likely be best at sites within approximately 10 km from shore. Concentrations of chl *a* within this range appeared suitable for shellfish culture (*cf.* Inglis *et al.*2000).

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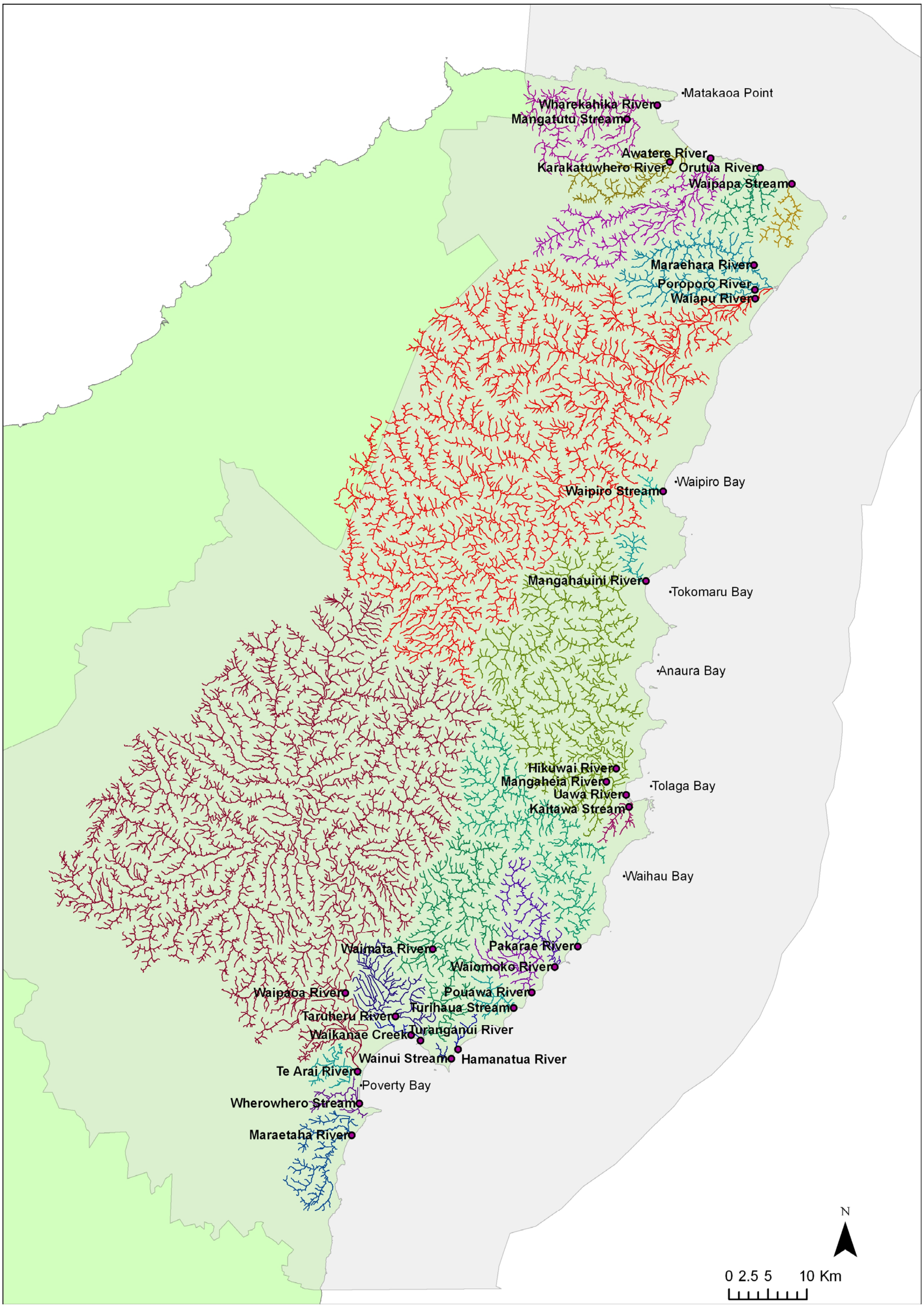
# 6. APPENDICES

**Appendix 1.** Region map showing major rivers and their catchments. River extents were generated using data from FWENZ (Freshwater Environments of New Zealand, Leathwick *et al.* 2008)



**Appendix 2.** Spatial distribution of lower (left), median and upper (right) satellite derived 490 nm light extinction data. Note that the nearshore water generally appears to be clearer than offshore water, however, part of the reason for this is because satellite images are not possible when cloud cover is present and hence these graphs tend to have a sampling bias towards clear, low rainfall weather periods.