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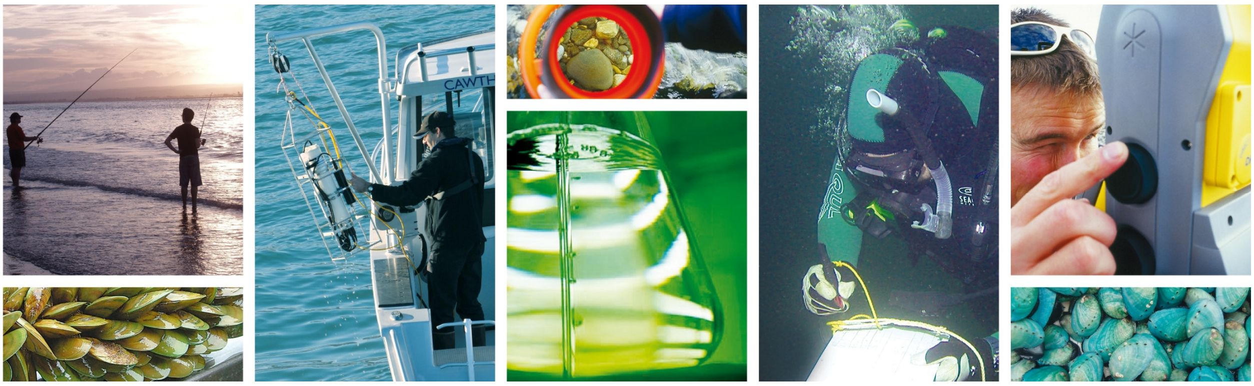
CAWTHRON

Spatial Delineation of the Motueka River Plume Influence in Tasman Bay Based on Seabed Characteristics



RESEARCH BASED SOLUTIONS

CAWTHRON

Spatial Delineation of the Motueka River Plume Influence in Tasman Bay Based on Seabed Characteristics

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Prepared for

Stakeholders of the Motueka Integrated Catchment Management (Motueka ICM) Programme

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PREFACE

An ongoing report series, covering coastal-sea components of the Motueka Integrated Catchment Management (ICM) Programme, has been initiated in order to present preliminary research findings directly to key stakeholders. The intention is that the environmental data, with brief interpretation, can be used by coastal managers, environmental groups and users of coastal marine resources to address specific questions that may require urgent attention or may fall outside the scope of ICM research objectives. We anticipate that providing access to marine environmental data will foster a collaborative problem-solving approach through the sharing of both ICM and privately collected information. Where appropriate, the information will also be presented to stakeholders through follow-up meetings designed to encourage feedback, discussion and coordination of research objectives.

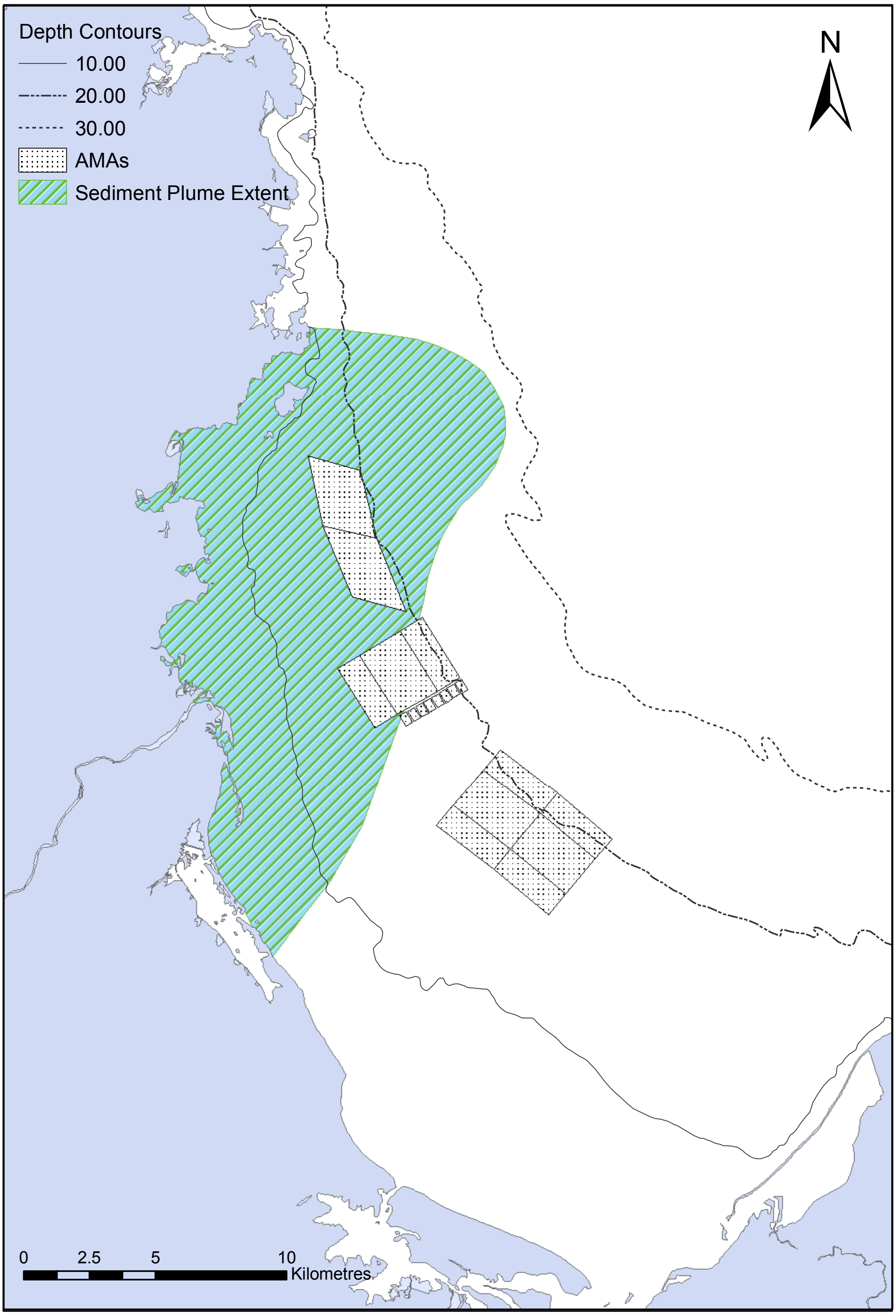
EXECUTIVE SUMMARY

The information provided in this report was collected as part of a collaborative research effort called the Motueka Integrated Catchment Management (ICM) programme. The programme was designed to assess the effects of various land use practices on terrestrial, freshwater and marine ecosystems in a "*ridge tops to the sea*" approach. One component of a Cawthron investigation into identifying the magnitude and spatial extent of freshwater influence on the coastal sea environment is presented here.

The aim of this investigation was to estimate and visually demonstrate the area of seabed strongly influenced by the river outwelling plume in order to contribute to development of a river plume ecosystem concept for management of the coastal resources of Tasman Bay. This study utilised previously collected data on a suite of seabed characteristics (physical, chemical and biological) across the Motueka River plume and western side of Tasman Bay. The present report further evaluated these data, along with other previously published and unpublished data, in order to map depositional influences of the river plume and any associated effects on the benthic biota. As a means of comparing the individual spatial patterns from a suite of benthic indicators of plume influences, the original interpolated data were reclassified into an ordinal scale between 1 and 10 thus assigning all indicators equal weight for further spatial analyses. These maps were then converted into raster datasets of equal spatial coverage that could then be combined to best represent the river plume ecosystem in terms of seabed characteristics.

This reclassification and subsequent analyses of the various raster datasets revealed distinct spatial patterns of deposition in the Motueka River plume in the form of trace metal and organic matter/lead concentrations, and their associated influence on macrofaunal community diversity. We recognise that the mechanisms controlling the distribution patterns are complex and in some cases unclear; however, we have focused on seabed characteristics that appear to be dictated primarily by the river outwelling plume. The strength of these indicators is enhanced by the unique geology of nearby mountain ranges and a good understanding of the prevailing currents. Combining these three indicators into a single composite provided a robust estimate of the spatial extent and influence of the Motueka River plume on the seabed of Tasman Bay (see figure below).

Since the plume-affected seabed covers a significant area (at least 180 km^2) in western Tasman Bay, it is critical that catchment effects on coastal resources and ecosystem services are evaluated and managed in consultation with coastal stakeholders. Consideration of the previously reported gradients in water column characteristics under contrasting river flows and the spatial patterns of seabed influences demonstrated in this report add to the developing understanding of the "River Plume Ecosystem".



Spatial representation of the Motueka River plume benthic ecosystem in Tasman Bay based on a composite of multiple seabed indicators.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Background

The coastal marine component of the collaborative "ridge tops to the sea" integrated catchment management (ICM) research programme (http://icm.landcareresearch.co.nz) focuses on the influences of the Motueka River outwelling plume on the ecosystem of western Tasman Bay.

Tasman Bay, located at the northern end of the South Island of New Zealand, is a large (~1500 m^2), relatively shallow (mainly within the 30 m depth contour) embayment covering a primarily soft-sediment seabed habitat (Figure 1). Its catchment or watershed is relatively extensive (~3876 km^2), receiving water from several significant rivers. The largest river is the Motueka River with a catchment of 2180 km^2 (Basher 2003). This river contributes about 62% of the total freshwater inflow to Tasman Bay with a mean flow of ~68 m^3/s and a measured flow range from <6 to >2100 m^3/s (Basher 2003; Bowden *et al.* 2004). The land from which the Motueka River and its tributaries drain are comprised of approximately 35% native bush, 25% planted forest, 19% pasture and 12% scrub by area (Basher 2003). Within this flow, the Motueka River transports an estimated average of 291 tonnes per year of suspended sediment eroded from the catchment through the lower river (L Basher, LCR, pers com).

With limited retention habitats (*e.g.* peripheral mudflats, vegetated wetlands or eelgrass beds) present at the Motueka River mouth, fine suspended materials are efficiently flushed through the intertidal delta, and further seaward as a "river plume" into Tasman Bay. Thompson *et al.* (2005) found that a fan-shaped subtidal delta off the Motueka River mouth was composed mainly of mobile sand that quickly graded into finer, mud-dominated substrata in waters greater than five metres depth (*i.e.* within approximately 1.5 km off the mouth). Forrest (2007) reported increasing proportions of fine (mud-sized) particles in sediments with increasing distance from shore. These studies indicate that a large portion of the Bay is dominated by muddy, potentially river-derived sediments (Figure 1).

Tasman Bay is recognised as an important regional and national resource with a variety of amenity and economic values (MacKenzie *et al.* 2003). Currently, the Bay supports a number of commercially and recreationally important fin- and shellfish species. Along with Golden Bay to the northwest and the Marlborough Sounds to the east, Tasman Bay comprises the area of New Zealand's major scallop (*Pecten novaezelandiae*) fishery although, due to depleted stocks, Tasman Bay has not contributed to commercial scallop harvests since 2005. Three aquaculture management areas (AMAs) have been designated in western Tasman Bay (Figure 1). The AMAs, covering a total of 4190 ha, consist of three separate zones for the longline culture of Greenshell™ mussel (*Perna canaliculus*) and/or the collection of both mussel and scallop spat for commercial use. The central zone, located between five and eight kilometres offshore from the mouth of the Motueka River, is presently being used for the staged development of mussel farming. All of these resources and associated activities are dependent on the maintenance of a high standard of habitat and water quality within Tasman Bay.

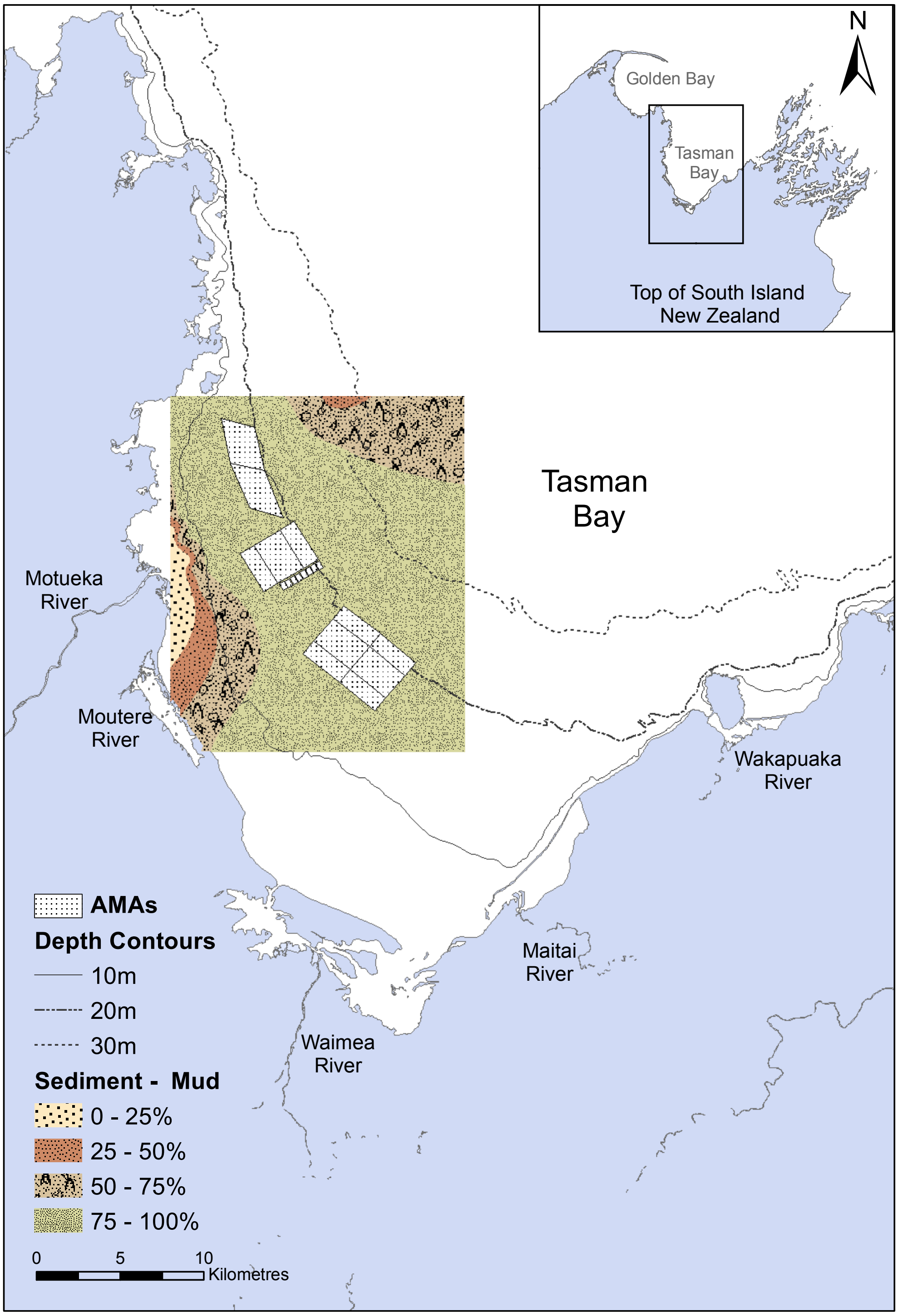


Figure 1. Tasman Bay study location and the location of associated aquaculture management areas (AMAs) with spatial patterns of sediment texture in the region of the Motueka River plume (interpolated from Thompson *et al.* (2005) and Forrest (2007).

1.2. Scope

As part of the ICM initiative, Forrest (2007) examined the spatial patterns of a suite of benthic characteristics along a series of transects bisecting the Motueka River plume. The present report further evaluates the data of Forrest (2007) in order to map depositional indicators of the river plume, and their potential influence on benthic biota. The primary objective was to estimate and visually demonstrate the area of seabed strongly influenced by the river outwelling plume in order to contribute to development of a river plume ecosystem concept for management of the coastal resources of Tasman Bay.

2. METHODS

2.1. Data collection

Forrest (2007) analysed physical, chemical and biological attributes of sediment samples collected along four transects set perpendicular to the coastline; two transects within the expected plume area directly off the Motueka River mouth and two control transects to the north and south. Sample stations along each transect were spaced at 5 m depth intervals, starting at approximately 5 m depth and extending out to the 25 m contour. At each of these 20 sample stations, five random replicate grab samples of sediment were collected within a 50 m x 50 m square area. The resulting data were averaged for each sampling station and interpolated into two-dimensional, graduated-colour contour maps using the kriging interpolation (with default settings) technique in SURFER v.7 surface mapping software to determine the spatial extent of several sediment characteristics.

2.2. Spatial analyses

For the present study, Forrest's (2007) SURFER maps were exported as polygon shapefiles in order to spatially analyse sediment results within a geographic information system (ArcGIS v.9.2). Once individual map files were rectified into a NZ map grid (1949) coordinate system, they were converted into raster datasets (*e.g.* grids) based on 50 m x 50 m cells to match the same spatial scale at which the original replicate sediment samples were collected at each sampling station.

In order to compare the spatial patterns of sediment characteristics, each raster dataset was reclassified into ten equal interval categories. The different ranges of data were converted into an ordinal scale between 1 and 10, representing the smallest and largest concentration or diversity, in order to give all datasets equal weight in further spatial analyses. An example is shown in Table 1 and the other dataset ranges are listed in the Appendix.

Simple summary calculations were carried out between the reclassified raster datasets using the 'Raster Calculator' in ArcGIS' extension, Spatial Analyst. The raster calculator allows the user to apply a range of algebraic functions between each cell or grid within one dataset with the spatially equivalent cell or grid in other datasets, and deriving a new raster output. In this study, composites of any reclassified datasets were simply averaged by the number of raster datasets used.

Table 1. An example of how the original data range of nickel concentrations from sample sites was converted into ten equal and ordinal categories.

Original Data Range	Ordinal Categories
20 - 48	1
48.00001 - 76	2
76.00001 - 104	3
104.00001 - 132	4
132.00001 - 160	5
160.00001 - 188	6
188.00001 - 216	7
216.00001 - 244	8
244.00001 - 272	9
272.00001 - 300	10

3. RESULTS

The reclassification and subsequent analyses of the various raster datasets revealed distinct spatial patterns in sediment trace metals and organic matter concentrations consistent with depositional influences of the Motueka River plume. Patterns in macrofaunal diversity were also assessed to explore potential links with river plume effects according to the distribution of trace metals and organic matter.

3.1. Trace metals

Metals, due to distinctive catchment characteristics, provide a means of effectively delineating the depositional footprint of the Motueka River plume. Some of the highest concentrations of trace metals, such as nickel and chromium, were reported in Forrest (2007) in muddier substrates adjacent to sandy, inshore habitats. Based on the metals composition of Tasman Bay sediments, it appears that sediments washed down from the Motueka catchment radiate out from the river mouth, through the sandier subtidal regions, and are concentrated in muddy sediments found directly seaward with gradually declining concentrations towards offshore regions.

Converting all the different metals concentrations into the same ordinal scale allowed for equal representation of all data in the mean spatial composite; including those metals present at very low concentrations (see Appendix TableA1). The resulting spatial composite of the eight trace metals considered, highlighted two specific regions of above-ambient concentrations (Figure 2). The largest region paralleled the western coastline of Tasman Bay. The highest concentration was centred directly off the river mouth extending approximately 6.5-7.5 km offshore and at least 6 km to the north and south.

A secondary region of above-ambient sediment metals concentrations was highlighted near the most northern and offshore sampling sites. Concentrations in this area were slightly less elevated and pinpointed the possibility of the long-term accumulation of some trace metals occurring just beyond the sampling area. In order to better understand the mechanisms involved, further evaluation of the relationships observed amongst the individual metals was required.

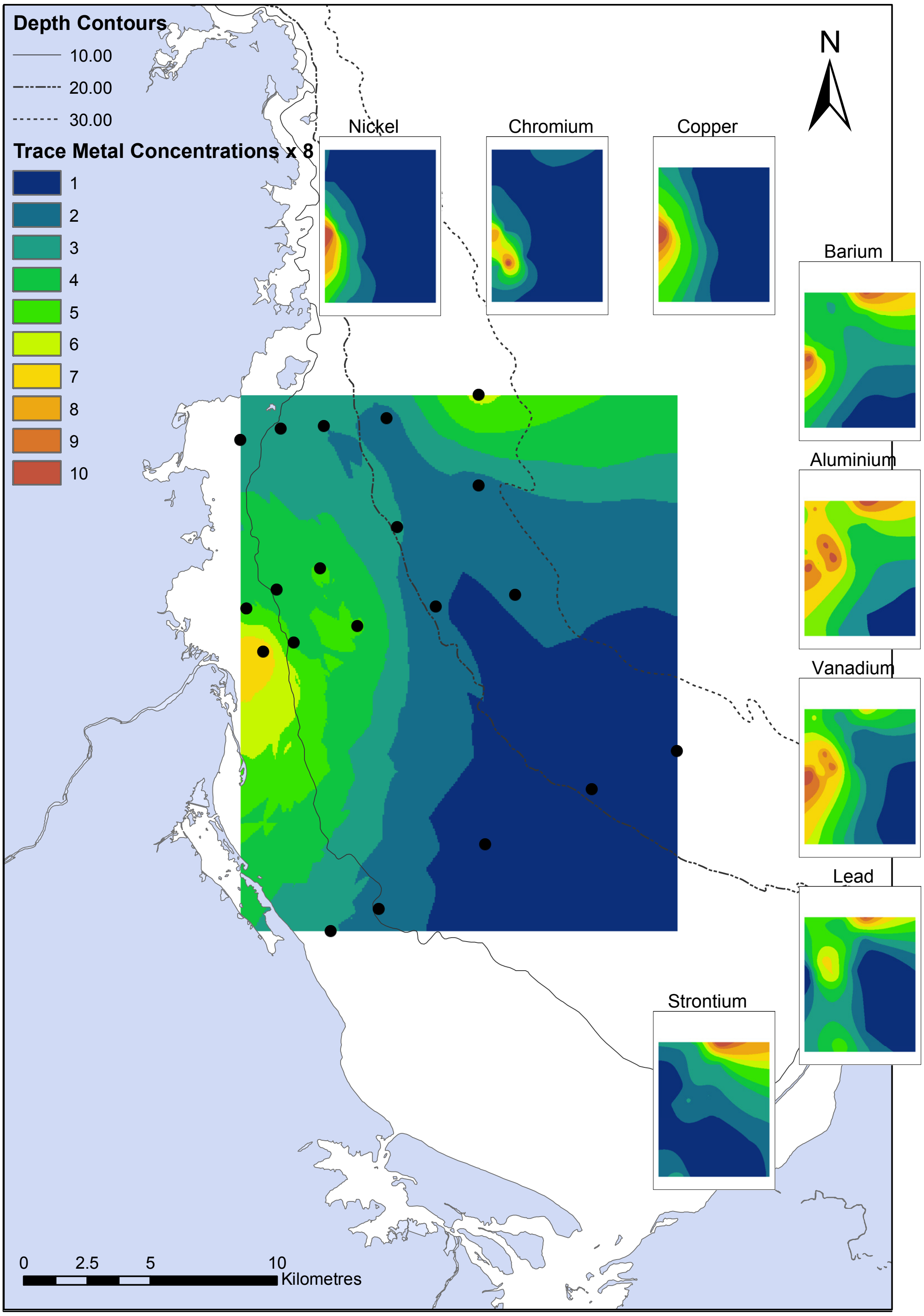


Figure 2. The mean spatial distribution of eight sediment trace metals in the vicinity of the Motueka River plume. Inset smaller images represent the individual results of the eight different trace metals used to create the spatial composite (larger image). The black dots represent the original sediment sampling sites.

Forrest (2007) found a large amount of spatial collinearity between the different trace metal concentrations, as demonstrated by the individual spatial plots included in Figure 2 (see smaller images). As a result, any correlated spatial patterns found between multiple datasets would have a larger influence on the mean spatial composite. To remove the spatial effect of this redundancy on the mean composite, correlation coefficients were calculated for all possible metal combinations (Table 2) resulting in several metals (vanadium , chromium, copper, aluminium, strontium and lead) being dropped from the spatial analysis as discussed further below.

Table 2. The correlation coefficients for all pair-wise comparisons between trace metal data. Data were $\log_{10}$ transformed prior to comparisons (Forrest 2007).

Variable	Variable	Correlation Coefficient	Significant Correlations
Al	V	0.921	**
Al	Cr	0.663	*
Al	Ni	0.536	
Al	Cu	0.694	*
Al	Sr	0.097	
Al	Ba	0.862	**
Al	Pb	0.462	
V	Cr	0.825	**
V	Ni	0.778	**
V	Cu	0.894	**
V	Sr	-0.199	
V	Ba	0.790	**
V	Pb	0.298	
Cr	Ni	0.956	**
Cr	Cu	0.886	**
Cr	Sr	-0.435	
Cr	Ba	0.746	*
Cr	Pb	-0.209	
Ni	Cu	0.943	**
Ni	Sr	-0.593	
Ni	Ba	0.606	
Ni	Pb	-0.275	
Cu	Sr	-0.474	
Cu	Ba	0.668	*
Cu	Pb	-0.015	
Sr	Ba	0.164	
Sr	Pb	0.496	
Ba	Pb	0.162	

** = correlation coefficients between 0.99 and 0.75 resulted in a metal being removed
* = correlation coefficients between 0.749 and 0.65 did not result in any further metals being removed

Vanadium was removed because its concentrations were strongly correlated with every other metal except strontium and lead (Table 2). Nickel was chosen as the metal to represent similar spatial patterns with chromium and copper due to its relatively higher concentrations in plume-affected sediments with levels approximately six times higher than the ANZECC (2000)

Interim Sediment Quality Guidelines (ISQG) trigger values for nickel that indicate "probable biological effects" (Forrest *et al.* 2007). Barium was chosen over aluminium as it had fewer and/or weaker correlations with the remaining metals (Table 2). In addition, aluminium is often used as a proxy for variation of clay content within sediments (Loring & Rantala 1992). We note that clay particles are generally a small (5-10%) but significant component of the muddy sediments in the plume region. As such, spatial patterns of this metal may be more indicative of clay particle distribution than the distributions of other metals within the riverine sediments.

Strontium was also removed from the metal composite as Forrest (2007) found extremely large variation in concentrations amongst all sampling sites. He noted that some marine organisms are able to substitute strontium for calcium in their tests or skeletons under certain chemical conditions (*e.g.* Dodd 1965; Amiel *et al.* 1973). Variations in strontium could therefore have been tied to the varying amounts of carbonate material in the sediments. Forrest (2007) also notes that, due to strontium possibly having a stronger adsorption to sediment particles than other metals, the weak-acid leaching analytical technique may be insufficient to desorb this particular metal effectively making test results for strontium inconclusive in this case.

The last metal removed from the spatial analysis was lead, which is known to be associated with organic matter in sediments (Gupta & Chen 1975). Forrest (2007) found the highest concentrations of lead were associated with higher percentages of organic matter and, as such, spatial patterns were potentially more indicative of organic matter distribution than metal levels within the river sediments.

The mean spatial extent of the remaining two trace metals, nickel and barium (Figure 3), was similar in its general pattern to the previous composite of all eight trace metals, differing only in its northerly extent and category of effect (refer Table 1). The influence of the river plume, as predicted by nickel and barium concentrations, appears to have its greatest effect directly off the river mouth and out to 5.5 km offshore with lesser but still noticeable effects out to 7 km offshore. This influence also extends to the north by at least 4.5 km and up to 8.5 km, and to the south by up to 10.5 km.

The secondary region of elevated trace metals concentrations, also highlighted in Figure 2, was still present in this composite and, can be attributed solely to the barium data (Figure 3). Varying concentrations of trace metals in this area may be due to significantly more gravel-sized particulates in the samples, which consisted almost entirely of broken shell and bryozoan material (Forrest 2007). The resulting spatial patterns within this region were therefore assumed not to be associated with the Motueka River plume as nickel concentrations, a signature metal of this particular catchment, were extremely low.

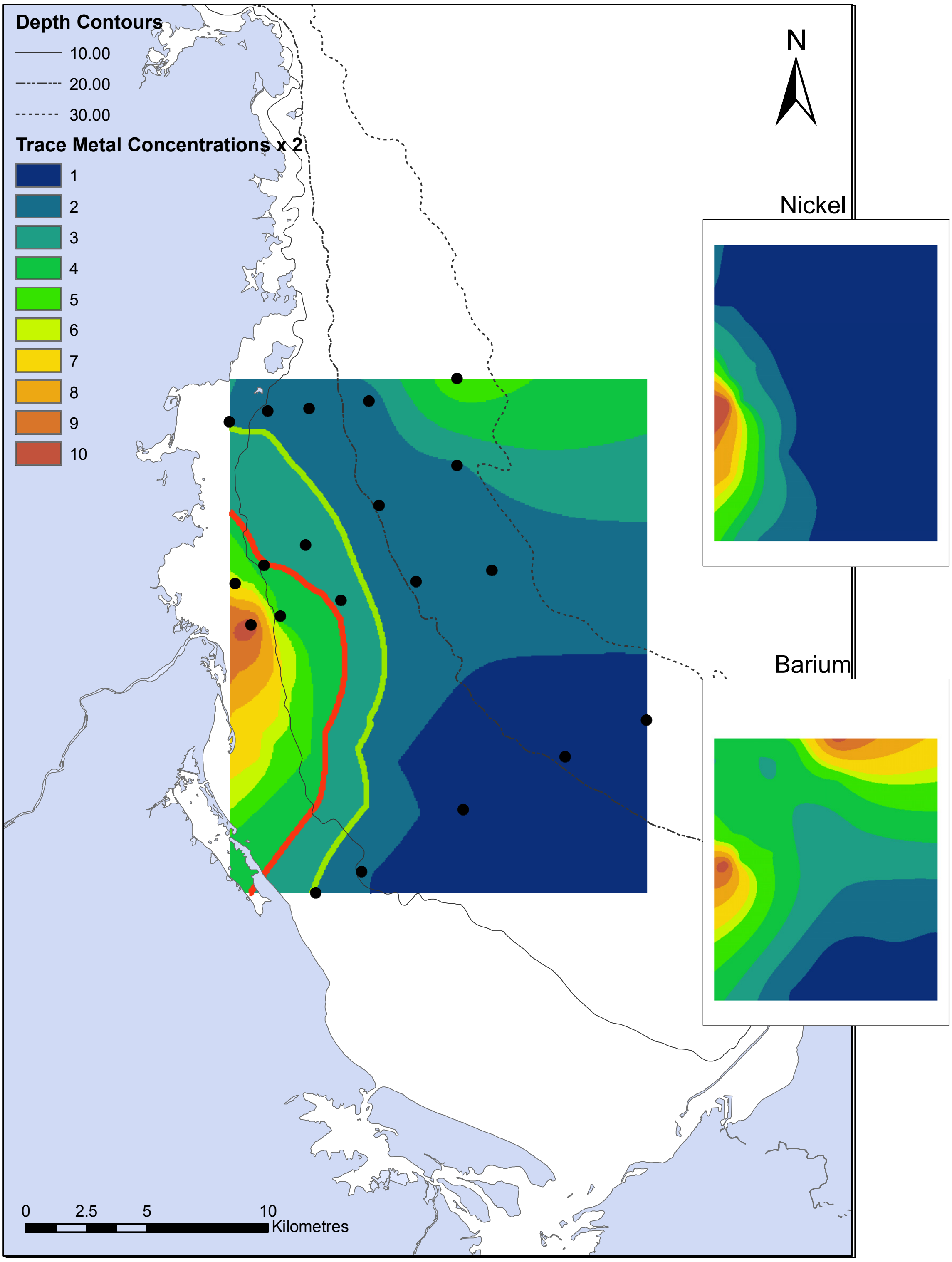


Figure 3. The spatial distribution of representative sediment trace metals in the vicinity of the Motueka River plume. The red and green contour lines highlight major and minor catchment influences. Insets represent the individual results of the two trace metals used to create the spatial composite (larger image). Black dots represent the original sediment sampling sites.

3.2. Organic matter and lead

Catchment-derived fine-grained particulate organic matter, consisting primarily of non-living plant and animal remains or detritus, is expected to remain suspended longer than coarser-grained or heavier sediment materials. As such, organic matter carried within the river plume was expected to have a different spatial distribution pattern than heavier trace metals-associated particles and thus was evaluated separately. We recognise, however, that organic materials of marine origin can also contribute to spatial gradients as a result of enhanced sedimentation of phytoplankton in nutrient enriched plume waters (MacKenzie 2004).

The interpolated map of organic matter composition indicated that those sediments with higher percentages were found mainly north of the Motueka River mouth (~4 km) and along the western coastline (Figure 4). Slightly lower percentages were observed spreading directly offshore (out to ~15 km) from the river mouth. Consistent with model predictions of plume behaviour (Tuckey *et al.* 2006), synoptic surveys of water column characteristics (MacKenzie *et al.* 2003) indicated a clockwise tidal circulation pattern within Tasman Bay in which waters from the Motueka River are directed northward, with additional wind forcing, along the western shoreline. This predominant current pattern would explain how organic matter adsorbed to finer clay or silt particles could be carried in buoyant plume waters 4 km or more to the north before settling out.

As discussed in the previous section, lead is known to strongly adsorb to suspended humic particles. Therefore any resulting spatial patterns in sediment lead concentrations will likely reflect finer particle distribution within the river plume rather than those of other trace metals. As both lead and organic matter concentrations are considered to be plume-related and associated with finer sediment particles, they were combined into a mean spatial composite (Figure 5). This composite has a similar spatial pattern to that observed for organic matter alone with a slightly lower overall categorical effect and a wider spread to offshore waters in the northern region of the study area.

In addition, ANZECC (2000) noted that an inverse relationship exists between the toxicity of some metals and dissolved organic carbon concentration. More specifically this is due to the ability of organic chelators (*e.g.* humic acids) to bind with, and therefore neutralise, the toxicity of free ionic metal ions. This mechanism is particularly evident with respect to the expression of copper toxicity (Gillespie & Vacarro 1978). Thus the spatial pattern of higher organic matter levels observed in this study may result in reduced impacts of elevated metals concentrations.

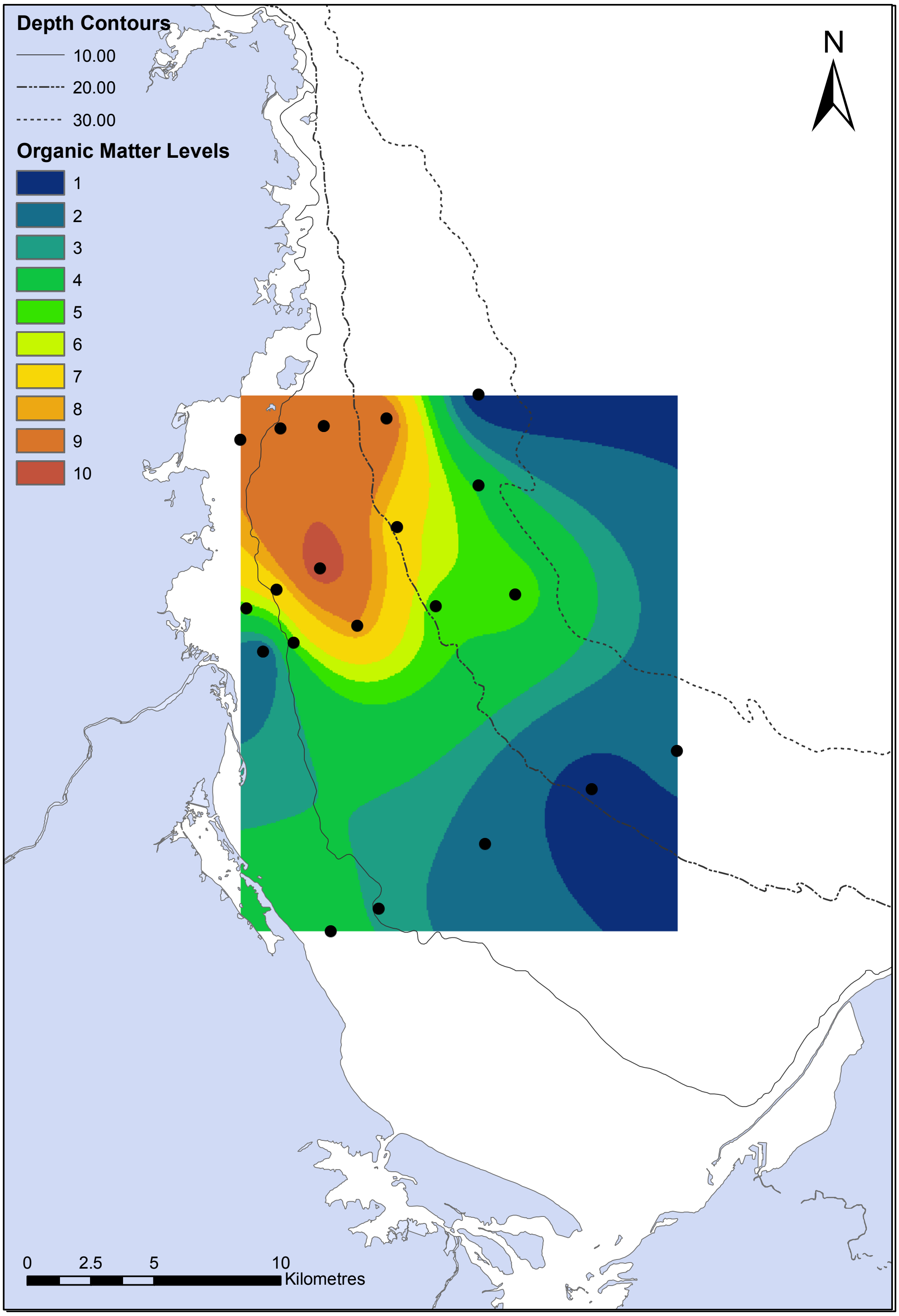


Figure 4. The spatial distribution of sediment organic matter in the vicinity of the Motueka River plume. Black dots represent the original sediment sampling sites.

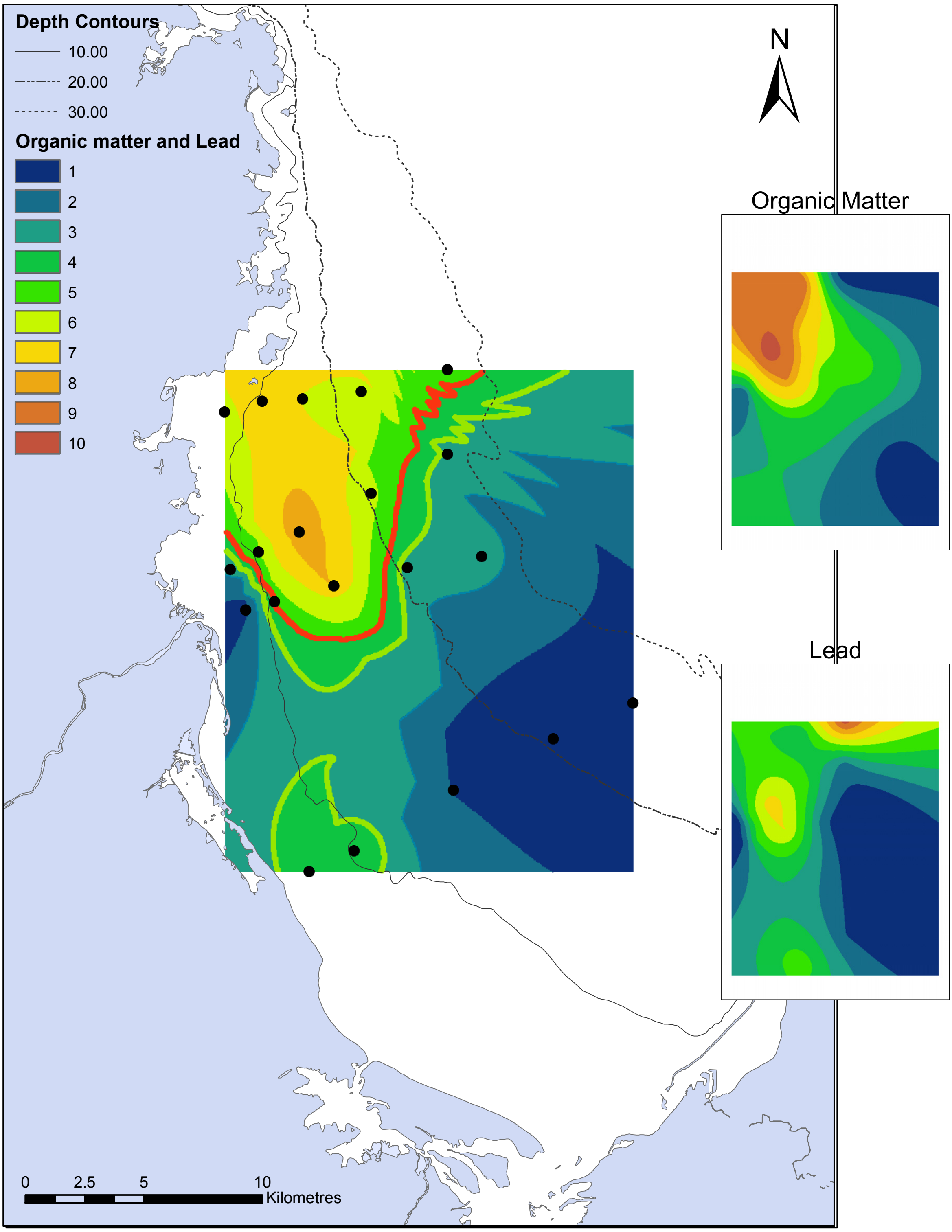


Figure 5. The spatial distribution of organic matter and lead in the vicinity of the Motueka River plume. The red and green contour lines highlight major and minor catchment influences. Insets represent the individual results of organic matter and lead concentrations used to create the spatial composite (larger image). Black dots represent the original sediment sampling sites.

3.3. Macrofauna

Forrest (2007) evaluated two components of sediment macrofaunal community structure; abundance (total number of individuals present) and species richness (total number of different taxa present). However, because these characteristics were highly correlated (R^2=0.80) the Shannon-Weiner (SW) diversity index (Shannon 1948), which incorporates both richness and abundance, was instead used to represent the macrofaunal community diversity of sediment samples (see Appendix Table A2).

Diversity data were reclassified in order to view the extent to which the diversity of communities might reflect the spatial patterns of metal concentrations associated with the Motueka River plume (Figure 6). This spatial composite of macrofauna data highlighted two main regions where both species abundance and richness were relatively high as indicated by a higher SW diversity index. The largest region was observed within mid to offshore sampling sites along the northern transect; *i.e*. at the northern edge of the study area. This region is most likely related to biogenic factors rather than plume effects as the sediments there contained higher proportions of gravel-sized shell hash.

A relatively diverse region was also observed directly off the Motueka River mouth and extending to the south but not to the north. This is contrary to what might be expected if elevated nickel and chromium concentrations were restricting macrofaunal communities, however it is not unexpected that the spatial patterns found within physico-chemical aspects of the river plume do not fully explain the spatial patterns found in macrofaunal diversity. Although the mechanisms of plume influence on macrofauna communities are complex and unclear, it may be that the positive effects of the plume on these communities simply outweigh the negative.

Forrest *et al.* (2007) and Forrest (2007) also reported elevated abundances of the non-indigenous bivalve, *Theora lubrica*, and the capitellid polychaete worm, *Heteromastus filiformis* within regions of elevated nickel and chromium concentrations. Since both of these animals are known to be disturbance tolerant (Borja *et al.* 2000; Forrest *et al.* 2007), the use of particular indicator species for defining plume-affected regions may warrant further investigation.

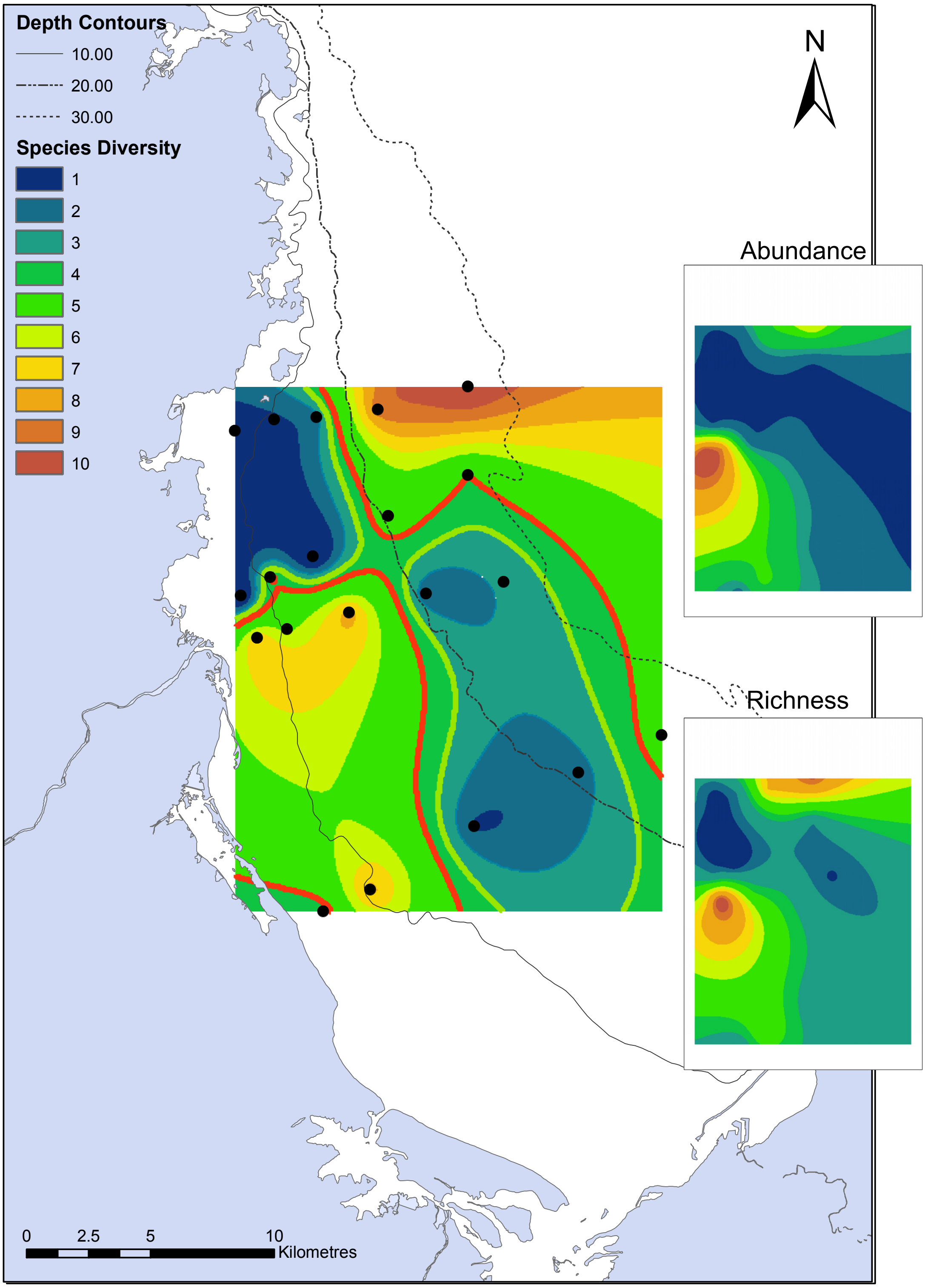


Figure 6. The spatial distribution of benthic macrofauna diversity based on the Shannon Weiner index (data range 1.8 – 2.4) in the vicinity of the Motueka River plume. The red and green contour lines highlight major and minor catchment influences. Black dots represent the original sediment sampling sites. Insets represent the individual results of species abundance and species richness used to originally calculate the Shannon-Weiner diversity index that has been reclassified on an ordinal scale to make the larger image.

3.4. Possible contributions from other rivers

Moderately elevated levels of trace metals and organic matter/lead were observed in sediments to the south of the Motueka River. Previous studies have noted that while the Motueka River catchment delivers more than 62% of the total freshwater flow into Tasman Bay (Basher 2003), smaller rivers to the south also contribute. The headwaters of the Waimea River catchment, located to the south-east of the Motueka River catchment (refer Figure 1), drains from the Dun Mountain mineral belt (the Dun Mountain Ophiolites). Suspended sediments sourced from this region result in elevated concentrations of nickel and chromium in Waimea Estuary sediments (Gillespie *et al.* 2009) and may also result in elevated metal concentrations in the southern head of the Bay. Hence similar trace metal signatures may also be carried into Tasman Bay by adjacent river plumes. Their overall input to the Bay may be less pronounced due to their semi-enclosed estuaries naturally filtering out finer sediments, yet those particles ultimately discharged into Tasman Bay would be entrained in the same clockwise current, and over time deposited in areas to the northwest and potentially within the southern section of the current study's sampling area. Nonetheless, the observed gradients indicate the Motueka catchment as the dominant source of sediment metals as defined in this study.

4. SUMMARY OF RIVER PLUME BENTHIC EFFECTS

The composite gradients shown in Figure 7 (trace metals, lead associated with organic matter and macrofaunal diversity) represent three effective indicators for the spatial extent and influence of the Motueka River plume. Summarising the spatial extent of the Motueka River plume's depositional footprint requires careful consideration of the distribution patterns observed for these seabed indicators. We recognise that the mechanisms controlling the distribution patterns are complex and in some cases unclear, however the strength of these indicators for delineating the Motueka River plume's influence on the benthos is enhanced by the unique geology of nearby mountain ranges and a good understanding of the prevailing currents.

Adding previously mapped river-affected intertidal and shallow subtidal habitats as described by Thompson *et al.* (2005), and combining the three indicator composites shown in Figure 7 into a single overall representation, results in a more complete picture of the area of seabed that is strongly influenced by the river plume. However, because the intensity of expression varied considerably amongst the three indicator composites, (*i.e.* the lower levels of trace metals and macrofauna results tended to negate the northern fine particle spread associated with high organic and lead levels), the composites could not be simply averaged together. Instead, a summary diagram was constructed manually (Figure 8) in order to capture the dominant features of all three indicator components.

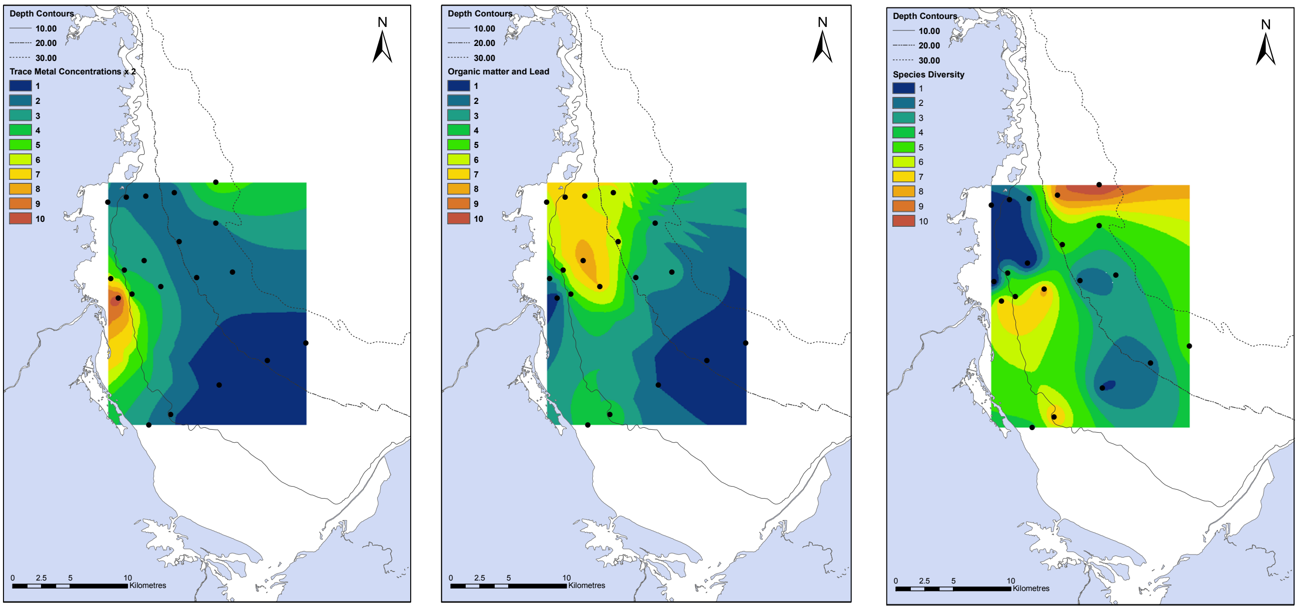


Figure 7. The spatial distribution of a) mean sediment trace metals concentrations, b) mean organic matter and lead concentrations, and c) benthic macrofauna diversity in the vicinity of the Motueka River plume. Red-orange coloured grids represent high values while dark blue grids indicate low values. The black lines represent the depth contours of Tasman Bay.

There are some caveats associated with construction of this diagram. Because the shoreward and the northern boundaries of the organic matter/lead composite are uncertain due to the limited extent of the sampling area, they were extended to provide a more realistic representation of the entire plume. The observed macrofaunal gradients suggest that they are at least partly plume-related, and as such only the immediately affected region off the Motueka River mouth is included in the manual composite. The high macrofauna diversity zone at the northern edge of the study area was assumed to be not directly related to the plume and was therefore omitted from the summary diagram.

The resulting area of seabed strongly influenced by the river outwelling plume (from Figure 8) was ~180 km^2. Thus the plume is expected to encompass the entire northern block and one half of the central block of the AMA. Although the southern block would be less affected by the plume, it may receive some influence from the Waimea and Maitai catchments at the head of the Bay. Overlapping plume effects (*e.g.* from the Waimea catchment) have not yet been assessed.

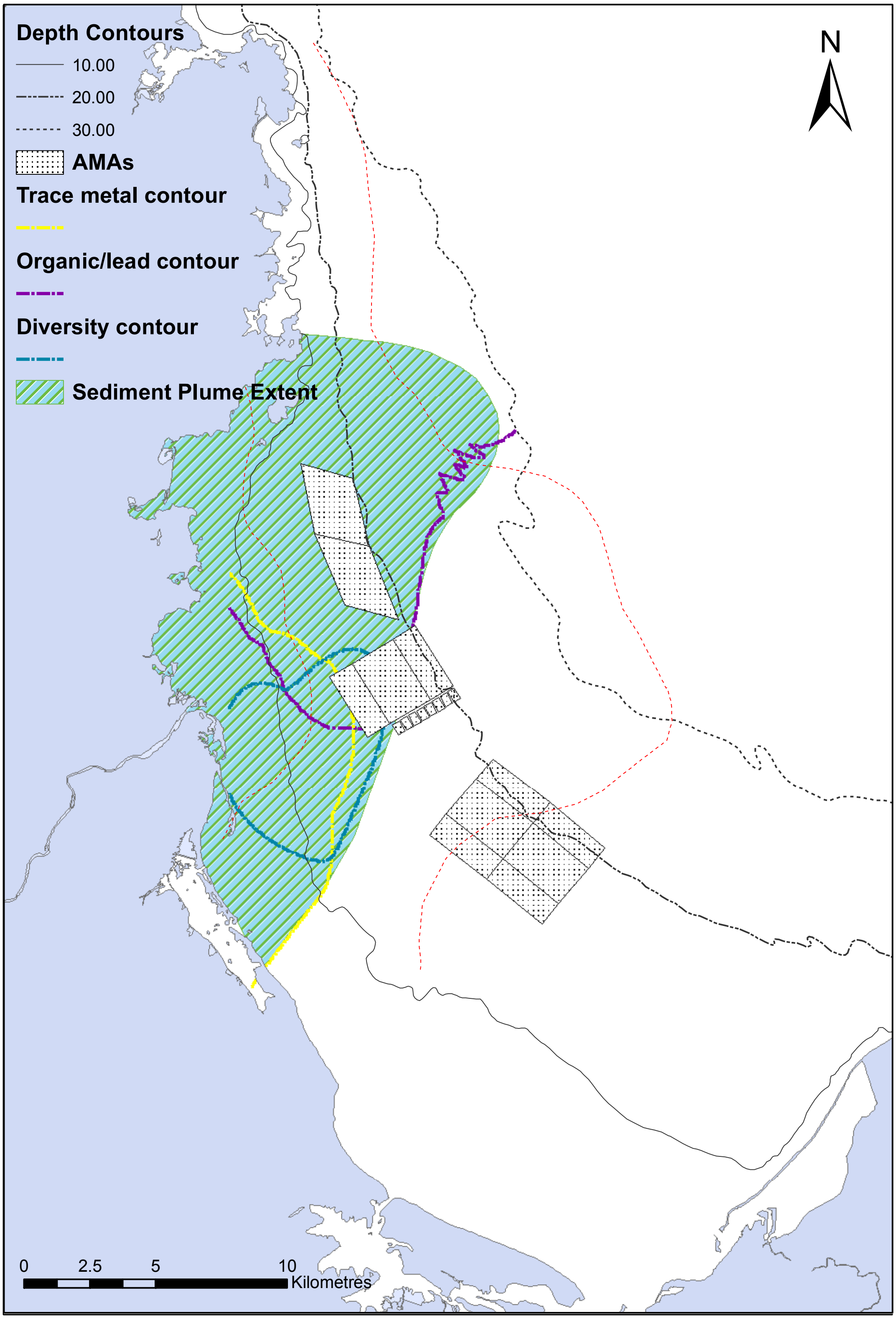


Figure 8. Summarised spatial representation of the Motueka River plume ecosystem in Tasman Bay based on a composite of the three seabed indicators. Red dotted lines refer to river plume 35 psu isohalines during low flows (<18 m^3/s) and moderate flood flows (210 m^3/s), respectively, in the Motueka River (from Tuckey *et al.* 2006).

Modelled predictions of the spatial extent and behaviour of the Motueka River plume (Tuckey *et al.* 2006) are complemented with buoy-mounted *in situ* data collection (Gillespie unpublished) and synoptic surveys of plume water column and sediment physical, chemical and biological gradients (Gillespie 2003; Mackenzie 2004; Mackenzie & Adamson 2004; Thompson *et al.* 2005; Gillespie & Rhodes 2006; Forrest *et al.* 2007). Consideration of the previously reported gradients in water column characteristics under contrasting river flows and the spatial patterns of seabed influences demonstrated in this report add to the understanding of the "River Plume Ecosystem". This information can be used to provide context for integrating catchment and coastal management. Since the plume-affected seabed covers a significant area (at least 180 km^2) in western Tasman Bay, it is critical that catchment effects on coastal resources and ecosystem services are evaluated and managed in consultation with coastal stakeholders. This is particularly relevant where activities such as finfish and scallop harvesting and aquaculture overlap with the plume-affected seabed area.

5. ACKNOWLEDGEMENTS

The original physical, chemical and biological data on seabed sediments off the Motueka River and Tasman Bay were collected by Reid Forrest (Cawthron Institute), partly through a MSc project with supervision from Drs Barrie Peake and Keith Probert (University of Otago) and Paul Gillespie (Cawthron Institute). Additional data on sediments within the Motueka delta subtidal zone were collected by Stephanie Thompson, Grant Hopkins and Murray Clarke (Cawthron Institute) and processed with the help of Paul Barter (Cawthron Institute).

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7. APPENDIX

Table A1. The original data ranges of trace metal concentrations from sample sites (Forrest 2007) and the equivalent ordinal categories used in spatial analyses.

Ordinal Categories	Nickel	Chromium	Copper	Barium	Aluminium*	Vanadium	Lead
1	20 - 48	45 - 52.5	8 - 10.4	13 - 14.8	13 - 13.6	31 - 32.6	10.5 - 11.0
2	48.00001 - 76	52.50001 - 60.0	10.40001 - 12.8	14.80001 - 16.6	13.60001 - 14.2	32.60001 -34.2	11.00001 - 11.5
3	76.00001 - 104	60.00001 - 67.5	12.80001 - 15.2	16.60001 - 18.4	14.20001 - 14.8	34.20001 - 35.8	11.50001 - 12.0
4	104.00001 - 132	67.50001 - 75.0	15.20001 - 17.6	18.40001 - 20.2	14.80001 - 15.4	35.80001 - 37.4	12.00001 - 12.5
5	132.00001 - 160	75.00001 - 82.5	17.60001 - 20.0	20.20001 - 22.0	15.40001 - 16.0	37.40001 - 39.0	12.50001 - 13.0
6	160.00001 - 188	82.50001 - 90.0	20.00001 - 22.4	22.00001 - 23.8	16.00001 - 16.6	39.00001 - 40.6	13.00001 - 13.5
7	188.00001 - 216	90.00001 - 97.5	22.40001 - 24.8	23.80001 - 25.6	16.60001 - 17.2	40.60001 - 42.2	13.50001 - 14.0
8	216.00001 - 244	97.50001 - 105.0	24.80001 - 27.2	25.60001 - 27.4	17.20001 - 17.8	42.20001 - 43.8	14.00001 - 14.5
9	244.00001 - 272	105.00001 - 112.5	27.20001 - 29.6	27.40001 - 29.2	17.80001 - 18.4	43.80001 - 45.4	14.50001 - 15.0
10	272.00001 - 300	112.50001 - 120.0	29.60001 – 32.0	29.20001 - 31.0	18.40001 - 19.0	45.40001 - 47.0	15.00001 - 15.5
Concentration Ranges	20 - 300 mg/kg	45 - 120 mg/kg	8 - 32 mg/kg	13 - 31 mg/kg	13 - 19 g/kg*	31 - 47 mg/kg	10.5 - 15.5 mg/kg

* Note that aluminium concentrations were recorded as grams per kilogram rather than milligrams per kilograms.

Table A2. The original data ranges of organic matter composition and macrofauna diversity from sample sites (Forrest 2007) and the equivalent ordinal categories used in spatial analyses.

Ordinal Categories	Organic Matter	Total Number of Species (Richness)	Total Species Abundance	Shannon-Weiner Diversity Index
1	3.8 - 4.12	7 - 8.4	10 - 25	1.8 - 1.86
2	4.120001 - 4.44	8.40001 - 9.8	25.00001 - 40	1.86001 - 1.92
3	4.440001 - 4.76	9.80001 - 11.2	40.00001 - 55	1.92001 - 1.98
4	4.760001 - 5.08	11.20001 - 12.6	55.00001 - 70	1.98001 - 2.04
5	5.080001 - 5.40	12.60001 - 14.0	70.00001 - 85	2.04001 - 2.10
6	5.400001 - 5.72	14.00001 - 15.4	85.00001 - 100	2.10001 - 2.16
7	5.720001 - 6.04	15.40001 - 16.8	100.00001 - 115	2.16001 - 2.22
8	6.040001 - 6.36	16.80001 - 18.2	115.00001 - 130	2.22001 - 2.28
9	6.360001 - 6.68	18.20001 - 19.6	130.00001 - 145	2.28001 - 2.34
10	6.680001 - 7.00	19.60001 - 21.0	145.00001 – 160	2.34001 - 2.40
Data Ranges	3.8 - 7 % organic matter by weight	7 - 21 different species	10 - 160 animals	1.8 - 2.4 (on 0-4.6 index scale)