coastalmanagement

Catlins Estuary

Fine Scale Monitoring 2016/17

Prepared
for

**Otago
Regional
Council**

**May
2017**

Cover Photo: Catlins Estuary near mouth

Catlins Estuary upper arm

Catlins Estuary

Fine Scale Monitoring 2016/17

Prepared for
Otago Regional Council

by

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RECOMMENDED CITATION:

Robertson, B.M., Robertson, B.P., and Stevens, L.M. 2017. Catlins Estuary: Fine Scale Monitoring 2016/17. Report prepared by Wriggle Coastal Management for Otago Regional Council. 32p.

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CATLINS ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the first year of fine scale baseline monitoring (2016) of two benthic intertidal sites, and three water column sites, within Catlins Estuary, a large, shallow, intertidal dominated (SIDE) estuary on the Otago coast. It is one of the key estuaries in Otago Regional Council's (ORC's) long-term coastal monitoring programme. The following table summarises the fine scale monitoring results, risk indicator ratings, overall estuary condition, and monitoring recommendations.

FINE SCALE BENTHIC MONITORING RESULTS

Benthic Intertidal Results

- There was no seagrass and <5% cover of opportunistic macroalgae at both sites.
- Sediment mud content was low (5.5% mud) at lower basin Site A, and moderate-high (25% mud) at upper basin Site. B.
- Sediment oxygenation was good at Site A but poor at Site B (redox potential <-150mV below 0.5cm depth).
- The indicators of organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were at low concentrations.
- The estuary macroinvertebrate community index (NZ HybAMBI) indicated a normal healthy community at Site A but a poor, unbalanced community affected by high mud concentrations and poor oxygenation at Site B.

Water Column Results

- Salinity and temperature data showed no evidence of bottom water stratification in the estuary.
- Total nitrogen (TN) concentrations exceeded the eutrophication threshold of 0.4mgl^{-1} in the upper estuary, but not at the other sites.
- Chlorophyll *a* concentrations, the primary indicator of water column eutrophication, were all relatively low (<10ugl^{-1}).

BENTHIC RISK INDICATOR RATINGS

(INDICATE RISK OF ADVERSE ECOLOGICAL IMPACTS)

🟦	Low	🟨	Moderate
⬜	Very Low	🟧	High

Catlins Estuary	Site Cat A (lower basin)				Site Cat B (upper basin)			
	2016	Yr 2	Yr 3	Yr 4	2016	Yr 2	Yr 3	Yr 4
Sediment Mud Content	⬜				🟨			
Redox Potential (Oxygenation)	🟦				🟧			
TOC (Total Organic Carbon)	⬜				⬜			
Total Nitrogen	🟦				🟦			
Invertebrate Mud/Org Enrichment	⬜				🟧			
Metals (Cd, Cu, Cr, Hg, Ni, Pb, Zn As)	⬜				⬜			

ESTUARY CONDITION AND ISSUES

Benthic Habitat

The fine scale monitoring of representative intertidal sediments showed that in 2016, Site A (lower basin) sediments were sandy, well oxygenated, with a balanced macroinvertebrate community, and had low organic content, nutrient concentrations and macroalgal cover. Site B (upper basin) sediments also had low organic content, nutrient concentrations and macroalgal cover, but were relatively muddy, poorly oxygenated and supported a poor macroinvertebrate community. Such findings are typical of NZ SIDE estuaries with developed catchments, where excessive levels of fine sediment have entered the estuary over time and accumulate in upper estuary deposition basins more than in well flushed lower estuary areas.

Catlins Estuary - Executive Summary (continued)

Water Column Habitat

In relation to the water column habitat, the December 2016 data indicate that despite N concentrations in the upper estuary exceeding the eutrophication threshold, susceptibility to water column phytoplankton blooms in the Catlins Estuary appears low due to an absence of stratification. However, given only one comprehensive sampling event and the possibility of stratification occurring later in the growing season, there is a possibility that stratified bottom water eutrophication could occur in parts of the estuary later in summer (e.g. upper estuary channels of both the Owaka and Catlins Rivers).

Overall, the findings indicate that muddiness in the upper estuary, and to a lesser extent, potential bottom-water phytoplankton blooms are issues that require further attention.

RECOMMENDED MONITORING

Catlins Estuary has been identified by ORC as a priority for monitoring because it is a large estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

Broad scale habitat mapping and fine scale sampling has now been undertaken for 1 baseline year (December 2016). To complete the fine scale baseline in Catlins Estuary, it is recommended that 3 consecutive years of annual summer (i.e. Dec-Feb) fine scale monitoring of intertidal sites (including sedimentation rate measures), and water column monitoring, be undertaken in 2017, 2018 and 2019.

Dense red macroalgal blooms in soft muddy, anoxic sediments of Owaka River arm of estuary.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. The Otago Regional Council's "Regional Policy Statement and Regional Plan: Water" demonstrates the Council's determination to maintain estuaries in good condition. In the period 2005-2008 Otago Regional Council (ORC) undertook preliminary (one-off) monitoring of the condition of seven Otago estuaries in its region. In 2016, ORC began a more comprehensive long-term estuary monitoring programme designed to particularly address the key NZ estuary issues of eutrophication and sedimentation within their estuaries, as well as identifying any toxicity and habitat change issues. The estuaries currently included in the programme are; Shag Estuary, Waikouaiti Estuary and Catlins Estuary.

Monitoring of the Catlins Estuary began with preliminary broad and fine scale monitoring undertaken in November 2008 and October 2012 with the first year of comprehensive baseline monitoring undertaken in December 2016.

Within NZ, the approach for monitoring estuary condition follows the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) and the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a and b). It consists of three components as follows:

1. **Ecological Vulnerability Assessment (EVA**) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has not yet been undertaken on a regional scale for Otago and hence relative vulnerabilities of their estuaries to the key issues have not been formally identified.
2. **Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) maps the key habitats within the estuary, determines their condition, and assesses changes to these habitats over time. Preliminary broad scale intertidal mapping of Catlins Estuary was first undertaken in 2008 (Stewart and Bywater 2009) and the Owaka arm in 2012 (Stewart 2012), with the first comprehensive mapping undertaken in December 2016 (Stevens and Robertson 2017).
3. **Fine Scale Monitoring (NEMP approach).** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of Catlins Estuary, was undertaken in a partial form in November 2008 (Stewart and Bywater 2009) and extended to include the Owaka arm in November 2012 (Stewart 2012), with the first year of baseline monitoring of the whole estuary undertaken on 17 December 2016. This latter monitoring is the subject of this report.

To help evaluate overall estuary condition and decide on appropriate monitoring and management actions, a series of risk indicator ratings is presented and described in Section 2. The current report describes the 2016 fine scale results and compares them to the previous findings.

CATLINS ESTUARY

Catlins Estuary is a large-sized (~830ha and ~12km long), shallow, intertidal dominated, estuary (SIDE) that discharges via one permanent open tidal mouth to the Pacific Ocean via a broad embayment at Pounawea, Otago (Figure 1). The estuary is fed by two rivers, the Catlins (mean flow ~3.7$m^3.s^{-1}$) and the slightly smaller Owaka River (mean flow 3.1$m^3.s^{-1}$) [source NIWA CLUES 10.3, 2016]. The Catlins River catchment is ~415km^2 with land cover dominated by high producing grassland (61%), indigenous forest (23%), and exotic forest (5%). On high producing exotic grassland, sheep and beef grazing represents the majority of recorded land use, with dairy, deer and forestry being less common.

The majority of the estuary is bordered by farmland, mainly sheep and beef, with a large barrier spit to the north of the estuary entrance near the village of New Haven. A small area of virgin podocarp forest (rimu, totara, matai, kahikatea and miro) borders the estuary at Pounawea, a remnant and reminder that the main industry of the Catlins from 1870 to 1970 was sawmilling these giant podocarp trees.

A large wetland is located at the western head of the estuary (Catlins River) which is an important habitat for waterfowl and fish breeding. The estuary itself is also an important habitat for marine and freshwater fish and as a coastal recreation area with boating, swimming, fishing and walking, and is listed as a coastal protection area with Kai Tahu cultural and spiritual values. The estuary falls into two main areas, the eastern basin around Pounawea near the estuary entrance which has strong tidal flushing and is dominated by sands, and the muddier upper reaches to the west of the Hinahina Road bridge, termed Catlins Lake, which is relatively shallow with more restricted flushing.

Overall the estuary has moderate to high ecological habitat diversity with variable substrate types including sand, rock shell, gravel and mud, extensive shellfish beds, but relatively small areas of saltmarsh (1.5% of the estuary), and seagrass (3.5% of the estuary). Historically there has been a significant loss (>300ha) of saltmarsh since c.1850 as a consequence of drainage and reclamation with much of the natural vegetated margin now developed for grazing.

Table 1. Summary of the major environmental issues affecting most New Zealand estuaries.

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007, 2010, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include:

- habitat loss such as the infilling of saltmarsh and tidal flats,
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows,
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients,
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders; and
- making the water unappealing to swimmers.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sedimentation	Soft Mud Area	GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time.
	Seagrass Area/Biomass	GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Saltmarsh Area	GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Mud Content	Grain size - estimates the % mud content of sediment.
	Water Clarity/Turbidity	Secchi disc water clarity or turbidity.
	Sediment Toxicants	Sediment heavy metal concentrations (see toxicity section).
	Sedimentation Rate	Fine scale measurement of sediment infilling rate (e.g. using sediment plates).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

2. Eutrophication

Eutrophication is a process that adversely affects the high value biological components of an estuary, in particular through the increased growth, primary production and biomass of phytoplankton, macroalgae (or both); loss of seagrass, changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services (Ferriera et al. 2011). Susceptibility of an estuary to eutrophication is controlled by factors related to hydrodynamics, physical conditions and biological processes (National Research Council, 2000) and hence is generally estuary-type specific. However, the general consensus is that, subject to available light, excessive nutrient input causes growth and accumulation of opportunistic fast growing primary producers (i.e. phytoplankton and opportunistic red or green macroalgae and/or epiphytes - Painting et al. 2007). In nutrient-rich estuaries, the relative abundance of each of these primary producer groups is largely dependent on flushing, proximity to the nutrient source, and light availability. Notably, phytoplankton blooms are generally not a major problem in well flushed estuaries (Valiela et al. 1997), and hence are not common in the majority of NZ estuaries. Of greater concern are the mass blooms of green and red macroalgae, mainly of the genera *Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose, both within the estuary and adjacent coastal areas. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there (Anderson et al. 2002, Valiela et al. 1997).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
	Phytoplankton (water column)	Chlorophyll *a* concentration (water column).
	Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
	Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
	Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

Table 1. Summary of major environmental issues affecting New Zealand estuaries (continued).

3. Disease Risk

Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time (e.g. Stewart et al. 2008). Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003). Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Disease Risk	Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring (Council or industry driven).

4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural stormwater runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

5. Habitat Loss

Estuaries have many different types of high value habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), tidal flats, forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of such habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges (IPCC 2007 and 2013, Kennish 2002).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.
	Shellfish Area	Broad scale mapping - estimates the area and change in shellfish habitat over time.
	Unvegetated Habitat Area	Broad scale mapping - estimates the area and change in unvegetated habitat over time, broken down into the different substrate types.
	Sea level	Measure sea level change.
	Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

2. ESTUARY RISK INDICATOR RATINGS

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity, and habitat change; Table 1), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality.

In order to facilitate this assessment process, "risk indicator ratings" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (see Table 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of considering other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ and overseas data and presented in the NZ Estuary Trophic Index (NZ ETI; Robertson et al. 2016a and 2016b). However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
    - * Statistical measures be used to refine indicator ratings where information is lacking.
    - * Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    - * The outputs stimulate discussion regarding what the acceptable level of risk is, and managing it.
    - * The indicators and condition ratings used for the Catlins monitoring programme are summarised in Table 2, with detailed background notes explaining the use and justifications for each indicator presented in the NZ ETI (Robertson et al. 2016a and 2016b). The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of NZ estuaries. Work to refine and document these relationships is ongoing.

Table 2. Summary of relevant estuary condition risk indicator ratings used in the present report.

RISK INDICATOR RATINGS / ETI BANDS (indicate risk of adverse ecological impacts)				
INDICATOR	Very Low - Band A	Low - Band B	Moderate - Band C	High - Band D
Apparent Redox Potential Discontinuity (aRPD)**	Unreliable	Unreliable	0.5-2cm	<0.5cm
Redox Potential (mV) upper 3cm***	>+100	-50 to +100	-50 to -150	<-150
Sediment Mud Content (%mud)*	<5%	5-10%	>10-25%	>25%
Macroinvertebrate Enrichment Index (NZ AMBI) ****	0-1.0 None to minor stress on benthic fauna	>1.0-2.5 Minor to moderate stress on fauna	>2.5-4.0 Moderate to high stress on fauna	>4.0 Persistent, high stress on benthic fauna
Total Organic Carbon (TOC)*	<0.5%	0.5-<1%	1-<2%	>2%
Total Nitrogen (TN)*	<250mg/kg	250-1000 mg/kg	>1000-2000 mg/kg	>2000 mg/kg
Metals	<0.2 x ISQG Low	0.2 - 0.5 x ISQG Low	0.5 x to ISQG Low	>ISQG Low

* NZ ETI (Robertson et al. 2016b), ** and *** Hargrave et al. (2008), ***Robertson (in prep.), Keeley et al. (2012), **** Robertson et al. (2016).

3. METHODS

FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002), and subsequent extensions (e.g. Robertson et al. 2016b) and provides detailed information on indicators of chemical and biological condition of the dominant habitat type in the estuary. This is most commonly unvegetated intertidal mudflats at low-mid water (avoiding areas of significant vegetation and channels). In addition, because some SIDE estuaries also include subtidal habitat that is at risk from eutrophication and sedimentation (e.g. deep stratified areas or main channel sections in estuaries where the mouth is restricted), synoptic water quality samples from surface and bottom waters, and subtidal sediment are commonly collected to support intertidal assessments.

Using the outputs of the broad scale habitat mapping, representative intertidal sampling sites (usually two per estuary, but varies with estuary size) are selected and samples collected and analysed for the following variables.

- Salinity, Oxygenation (Redox Potential Discontinuity depth - aRPD or RPmV), Grain size (% mud, sand, gravel).
- Organic Matter and Nutrients: Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorus (TP).
- Heavy metals and metalloids: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), and Zinc (Zn) plus mercury (Hg) and arsenic (As). Analyses are based on non normalised whole sample fractions to allow direct comparison with ANZECC (2000) Guidelines.
- Macroinvertebrate abundance and diversity (infauna and epifauna).
- Other potentially toxic contaminants: these are measured in certain estuaries where a risk has been identified.

For the Catlins Estuary, two 30m x 15m fine scale sampling sites were selected in unvegetated, mid-low water habitat (Figure 1). Site A was located in the lower arm at a location considered more representative of the dominant habitat than the two preliminary monitoring sites used in 2008. Site B was located in the main deposition zone or the upper estuary basin. Each site was marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each, and sampling undertaken as described in the following sections: plots were selected, a random position defined within each, and sampling undertaken as described in the following sections:

Physical and chemical analyses

- At each site, average apparent Redox Potential Discontinuity (aRPD) depth was recorded within three representative plots, and in one plot, redox potential (RP mV) was directly measured with an oxidation-reduction potential (ORP) meter at 0, 1, 3, 6 and 10cm depths below the surface.
- At each site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core for chemical analysis. All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1):
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

Infauna (animals within sediments) and epiflora/fauna (surface dwelling plants and animals)

From each of 10 plots, 1 randomly placed sediment core (130mm diameter (area = 0.0133m^2) tube) was taken.

- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled 0.5mm nylon mesh bag. Once all replicates had been collected at a site, the bags were transported to a nearby source of seawater and fine sediments were washed from the core. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.

Figure 1. Location of water quality (orange) and fine scale monitoring (yellow) sites in Catlins Estuary (Photo: Google).

- The samples were sorted by experienced Wriggle staff before being sent to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).
- Where present, macroalgae and seagrass vegetation (including roots), was collected within each of three representative 0.0625m^2 quadrats, squeezed (to remove free water), and weighed in the field. In addition, the % cover of each plant type was measured.
- Conspicuous epifauna visible on the sediment surface within the 15m x 30m sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna species are identified and allocated a SACFOR abundance category based on percentage cover (Table A, Appendix 1), or by counting individual organisms >5mm in size within quadrats placed in representative areas (Table B, Appendix 1). Species size determines both the quadrat size and SACFOR density rating applied, while photographs are taken and archived for future reference. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal and microalgal cover.

Water quality and subtidal sediment

Three representative sites were selected in deep main channel sections in the lower, mid and upper estuary where there was a potential for estuary water to become stratified (Sites X, Y and Z respectively, see Figure 1).

At each site at high tide, a YSI-Sonde (6000 series) hand held field meter was deployed from a kayak to directly measure and log depth, chlorophyll *a*, salinity, temperature, pH, and dissolved oxygen in upper and lower 0.5m of the water column. At the same locations water samples were also collected with a van dorn water sampler for laboratory nutrient analyses (total N, nitrate-N, ammonia-N, dissolved reactive P and total P concentrations).

3. Methods (continued)

In addition, at each site secchi disc clarity was measured and one benthic sediment sample was collected using either a remotely triggered van veen grab sampler or a custom built sediment sampling hoe with telescopic handle). Once at the surface the sediment aRPD depth measured, and a sub-sample collected for subsequent chemical analysis for TOC, grain size, TN and TP.

- All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1):
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.

Water sampling Site X, lower estuary.

Sediment accumulation

To determine the future sedimentation rate, a simple method of measuring how much sediment builds up over a buried plate over time is used. Once a plate has been buried and levelled, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance. These are then measured over time (commonly annually) to assess sediment accrual.

Two sites, each with four plates (20cm square concrete paving stones) were established in December 2016 in Catlins Estuary at fine scale Sites A and B (Figure 1), with Site A representing the main estuary basin and Site B the main deposition zone. Plates were buried deeply in the sediments where stable substrate was located and positioned 2m apart in a linear configuration along the baseline of each fine scale site. Steel reinforcing rod was also placed horizontally next to each buried plate to enable relocation with a metal detector.

The GPS positions of each plate were logged, and the depth from the undisturbed mud surface to the top of the sediment plate recorded (Appendix 2). In the future, these depths will be measured annually and, over the long term, will provide a measure of the rate of sedimentation in the estuary.

4. RESULTS AND DISCUSSION

A summary of the results of the December 2016 fine scale sediment and water quality monitoring of the Catlins Estuary is presented in Tables 3 and 4, with detailed results in Appendices 2 and 3. Also included are the summary results of the preliminary fine scale sediment monitoring undertaken in the lower basin in 2008 (Stewart and Bywater (2009), and the Owaka arm in 2012 (Stewart 2012).

Table 3. Mean fine scale sediment physical, chemical, plant growth (n=3) and macrofauna (n=10) results, Catlins Estuary, November 2008 and 7 December 2016.

Year Site	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2016 A	3	34	<0.05	5.5	93.9	0.5	0.013	6.0	2.3	4.1	1.3	11.1	5.3	<0.01	<500	217
2016 B	2	25	0.27	24.7	75.2	0.1	0.019	8.6	4.5	5.7	2.2	24.3	2.9	0.0130	600	263
2008 D/S	5	NA	NA	5.6	94.4	0.1	0.017	5.6	3.7	4.9	1.7	16	NA	NA	760	220
2008 U/S	3	NA	NA	7.2	88.5	4.4	0.015	6.1	4.0	4.7	2.5	18	NA	NA	940	260
2012 D/S	7	NA	NA	26.0	71.2	2.8	<0.1	11.0	8.0	6.0	4.8	40	4.9	NA	1000	380
2012 U/S	3	NA	NA	20.9	78.4	0.7	<0.1	12.0	10.0	8.0	8.5	64	5.0	NA	900	480

Year Site	Seagrass Biomass and Cover	Macroalgal Biomass and Cover	Macrofauna Abundance	Macrofauna Richness
	$g.m^{-2}$ wet weight (%)	$g.m^{-2}$ wet weight (%)	Individuals/m^2	Species/core
2016 A	0 (0%)	5 (3%)	1296	5
2016 B	0 (0%)	5 (1%)	20625	8
2008 D/S	0 (0%)	- (2%)	9050	10
2008 U/S	0 (0%)	- (0%)	2175	9
2012 D/S	0 (0%)	- (<5%)	6225	6
2012 U/S	0 (0%)	- (0%)	3725	7

NA = Not Assessed

Table 4. Summary of fine scale water quality results (upper water column, bottom water column and bottom sediment, Catlins Estuary, 16 December 2016.

Parameter	Units	Catlins Lower Site X (surface)	Catlins Lower Site X (bottom)	Catlins Mid Site Y (surface)	Catlins Mid Site Y (bottom)	Catlins Upstream Site Z (surface)	Catlins Upstream Site Z (bottom)
Depth	m	0.1	2.3	0.1	2.0	0.1	1.2
Temperature	degrees C	13.8	13.8	14.0	14.0	15.2	14.8
Salinity	ppt	34.4	34.4	29.8	29.8	7.22	7.12
Dissolved Oxygen	mg/l	9.52	9.52	9.28	9.28	11.61	11.92
pH		8.3	8.3	8.4	8.4	8.0	8.1
Chlorophyll *a*	mg/m^3	0.1	0.1	4.9	4.9	9.7	9.9
Total Nitrogen	g/m^3	<0.3	<0.3	0.2	0.3	0.6	1.16
Total Ammoniacal-N	g/m^3	<0.010	<0.010	0.046	0.032	0.039	0.039
Nitrate-N	g/m^3	0.012	0.012	0.009	0.009	0.13	0.129
Dissolved Reactive Phosphorus	g/m^3	0.01	0.01	0.012	0.014	0.014	0.016
Total Phosphorus	g/m^3	0.013	0.014	0.069	0.069	0.11	0.125

Site	aRPD (cm)	TOC (%)	Mud (%)	Sand (%)	Gravel (%)	TP (mg/kg)	TN (mg/kg)
Catlins Bottom Sediment Site X	>10	0.12	4.8	95.2	<0.1	182	<500
Catlins Bottom Sediment Site Y	>5	0.15	7.2	86.5	6.4	230	<500
Catlins Bottom Sediment Site Z	0	4.4	47.1	52.8	<0.1	580	3100

4. Results and Discussion (continued)

Analysis and discussion of the 2016 results are presented as two main steps; firstly, the intertidal benthic habitat condition and secondly, the water column condition. The assessment is undertaken with a focus on the key SIDE estuary issues of muddiness (or sedimentation), eutrophication, and toxicity.

4.1 Benthic Habitat Condition

4.1.1 Muddiness (or Sedimentation)

The primary environmental variables that are most likely to be driving the ecological response in relation to estuary muddiness are sediment mud content (often the primary controlling factor) and sedimentation rate. Sediment mud content data are presented and assessed below, however, preliminary sedimentation rate data will not be available until December 2017.

Sediment Mud Content

Sediment mud content (i.e. % grain size <63µm) provides a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments are generally sand dominated (i.e. grain size 63µm to 2mm) with very little mud (e.g. ~1% mud at Freshwater Estuary, Stewart Island), unless naturally erosion-prone with few wetland filters (e.g. Whareama Estuary, Wairarapa). In contrast, estuaries draining developed catchments typically have high sediment mud contents (e.g. >25% mud) in the primary sediment settlement areas e.g. where salinity driven flocculation occurs, or in areas that experience low energy tidal currents and waves (i.e. upper estuary intertidal margins and deeper subtidal basins). Well flushed channels or intertidal flats exposed to regular wind-wave disturbance generally have sandy sediments with a relatively low mud content (e.g. 2-10% mud).

Results showed the Catlins Estuary had a mix of sediment mud contents (2-26% mud) (Table 3, Figure 2) with muddier sediments in the upper arm and sandy sediments in the lower.

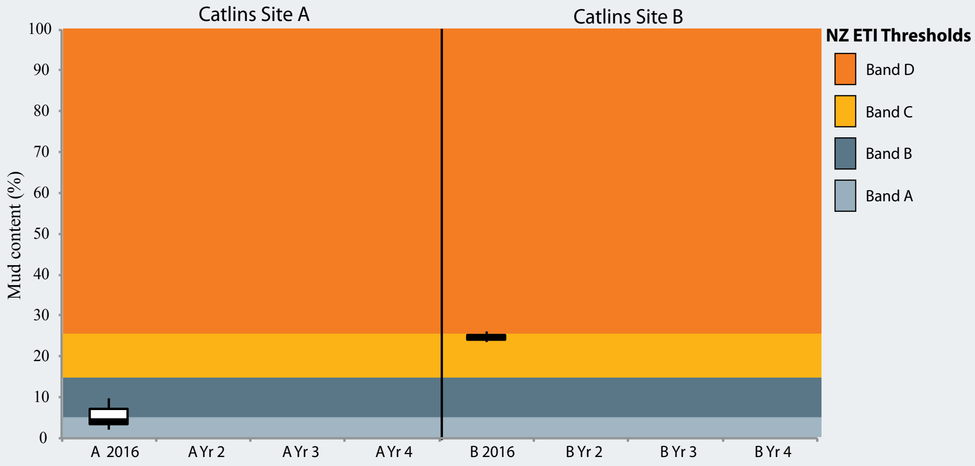

Figure 2. Mean mud content (median, interquartile range, total range, n=3), Catlins Estuary, December 2016.

Site A (lower estuary basin) had a low mud content (mean 5.5% mud) and also showed the largest variation, primarily because marine sands intermittently mix with catchment derived muds at this site. The low mud content for Site A fits the Band A rating, and indicates the following ecological conditions are likely (Robertson et al. 2016b):

- *No, or minor, stress caused by the indicator on any aquatic organisms.*

Site B, which was located in the depositional zone of the estuary (i.e. top end of the upper arm and closest to the main river input) had a moderate mud content (mean 24.7% mud) which fits the Band C rating, and indicates the following ecological conditions are likely (Robertson et al. 2016b):

- *Moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost, especially if nutrient loads elevated.*

4. Results and Discussion (continued)

Catlins Estuary: Photographs taken December 2016

Upper estuary

Mid-estuary main channel

Lower estuary intertidal flats near main channel

Nuisance opportunistic macroalgal beds (*Gracilaria* sp.) beds in the very soft muds of the upper estuary (Catlins River arm)

Seagrass beds in the lower estuary

Dominant sand habitat in the lower estuary

4.1.2 Eutrophication

The primary variables indicating eutrophication impacts are sediment mud content, aRPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and macroalgal and seagrass cover.

Macroalgae and Seagrass

The presence of opportunistic macroalgae on the sediment surface or entrained in the sediment, can provide organic matter and nutrients to the sediment which can lead to a degraded sediment ecosystem (Robertson et al. 2016b). In addition, seagrass (*Zostera muelleri*) cover and biomass on the sediment surface is also measured when present because seagrass can mitigate or offset the negative symptoms of eutrophication and muddiness. When seagrass losses occur it provides a clear indication of a shift towards a more degraded estuary state.

Results showed no seagrass and <5% cover of opportunistic macroalgae was present at Sites A and B (Figure 3). Such findings indicate low levels of eutrophication at the sites and that conditions are unsuitable for high value seagrass habitat. However, as the broad scale survey showed, seagrass was relatively common in the lower arm of the estuary in other areas (Stevens and Robertson 2017).

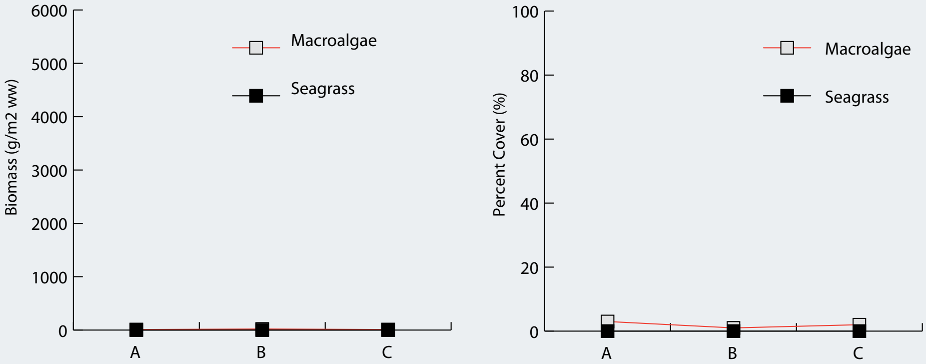

Figure 3. Biomass and percent cover of opportunistic macroalgae and seagrass, Catlins Estuary, December 2016.

Sediment Mud Content

This indicator has been discussed in the previous sediment section and is not repeated here. However, in relation to eutrophication, the low mud content at Site A indicates sediment oxygenation is likely to be relatively good, and the moderate-high mud content at Site B indicates sediment oxygenation is likely to be relatively poor.

Redox Potential Discontinuity (RPD)

The depth of the RPD boundary indicates the extent of oxygenation within sediments. Currently, the condition rating for redox potential is under development (Robertson et al. 2016b) pending the results of a PhD study in which aRPD and redox potential (RP) measured with an ORP electrode and meter, are being assessed for a gradient of eutrophication symptoms. Initial findings indicate that the recommended NZ estuary aRPD and redox potential thresholds are likely to reflect those put forward by Hargrave et al. (2008) (see Table 2 and Figure 3).

Figure 4 shows the aRPD depths from the surface, and redox potentials (5 depths at each site, mean of triplicate measures plotted) for the two Catlins Estuary sampling sites for December 2016.

The results show that the aRPD depth was 3cm at Site A and 2cm at Site B. The redox potential for the sites (Figure 4) identified good oxygenation conditions throughout the sediment profile at Site A (i.e. >-50mV) but poor oxygenation conditions (i.e. low redox <-150mV, Band D) beginning at approximately 0.5cm depth at Site B. These results indicate that conditions at Site A are sufficiently well oxygenated to support a range of sensitive taxa. However, the very low redox levels throughout the sediment profile at Site B (Band D) indicate sediment oxygenation is likely to support predominantly tolerant opportunistic species. Such findings are likely to be reflected as a change in the abundance of mud and organic enrichment sensitive taxa between the sites (see Section 4.1.4).

4. Results and Discussion (continued)

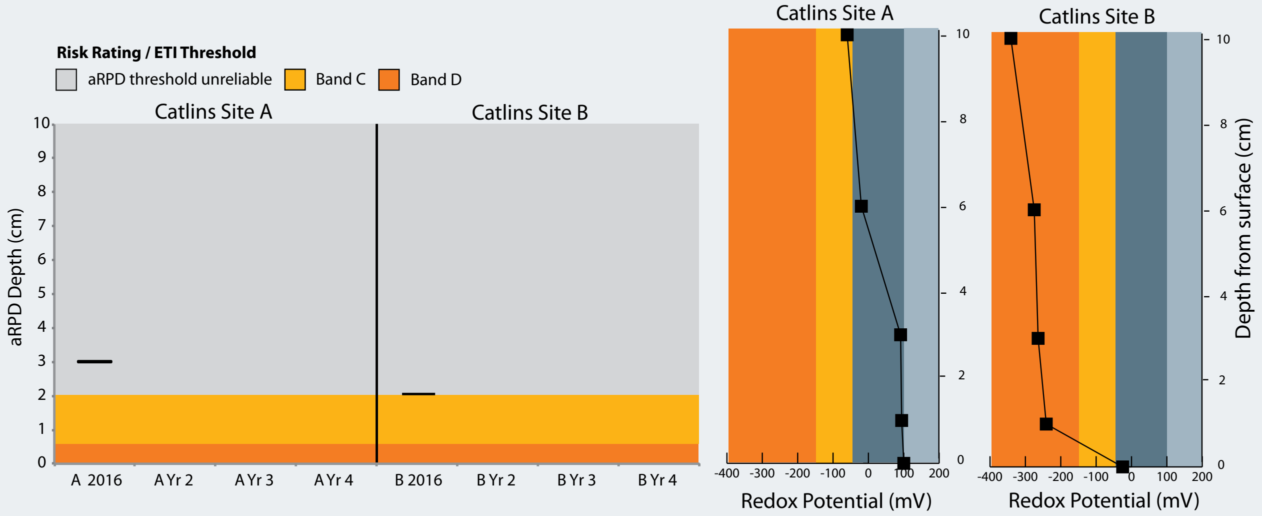

Figure 4. Mean apparent Redox Potential Discontinuity (aRPD) depth, (median, interquartile range, total range, n=3), and redox potential (mV) at 5 depths, Catlins Estuary Sites A and B, December 2016.

Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (TOC) and nutrients (TN and TP) provide valuable trophic state information. In particular, if concentrations are elevated and eutrophication symptoms are present [i.e. shallow aRPD, excessive algal growth, high NZ AMBI biotic coefficient (see the following macroinvertebrate condition section)], then elevated TN, TP and TOC concentrations provide strong supporting information to indicate that loadings are exceeding the assimilative capacity of the estuary.

Results for the two sites showed TOC (<0.5%) and TN (<600mg/kg) were in the “very low” or “low” risk indicator ratings, while TP (rating not yet developed) was relatively low at 217-263mg/kg (Figures 5, 6 and 7).

Synoptic fine scale monitoring results collected from two sites in November 2008 (Stewart and Bywater 2009) are presented alongside the current results in Table 3 and show the 2008 results were similar to those from similar habitat at Sites A and B in 2016. However, the 2008 and 2012 synoptic surveys have not been comprehensively assessed in the current report as it did not meet the requirements of a full baseline survey (e.g. involved one-off sampling outside of the recommended December-March summer period, used limited replication (a single composite chemistry sample and 3 macroinvertebrate replicates instead of the recommended 10), did not assess the high susceptibility upper estuary basin deposition zone, and did not monitor for water column eutrophication).

Site A, located on the dominant mobile sands, lower estuary

Site B, located on the soft mud sands, upper estuary

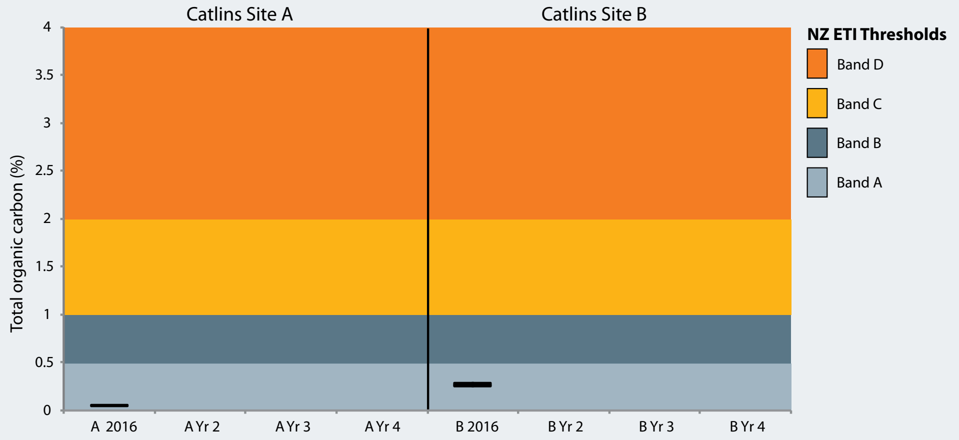

Figure 5. Mean total organic carbon (median, interquartile range, total range, n=3), December 2016.

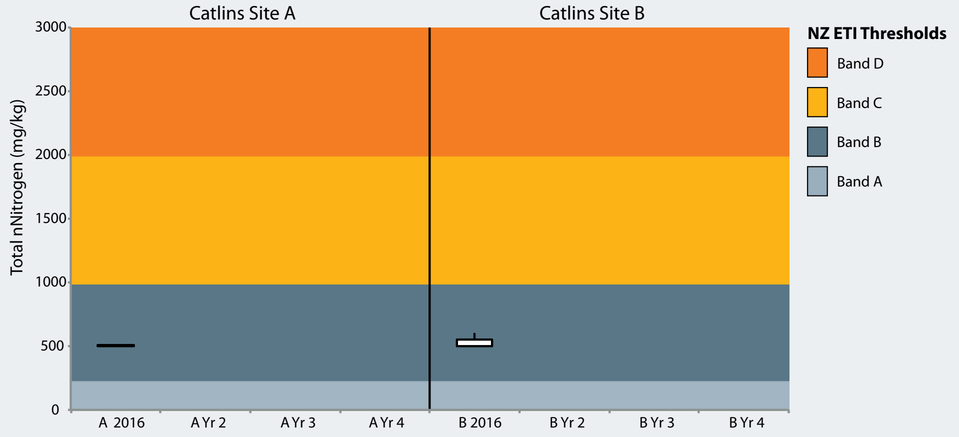

Figure 6. Mean total nitrogen (median, interquartile range, total range, n=3), December 2016.

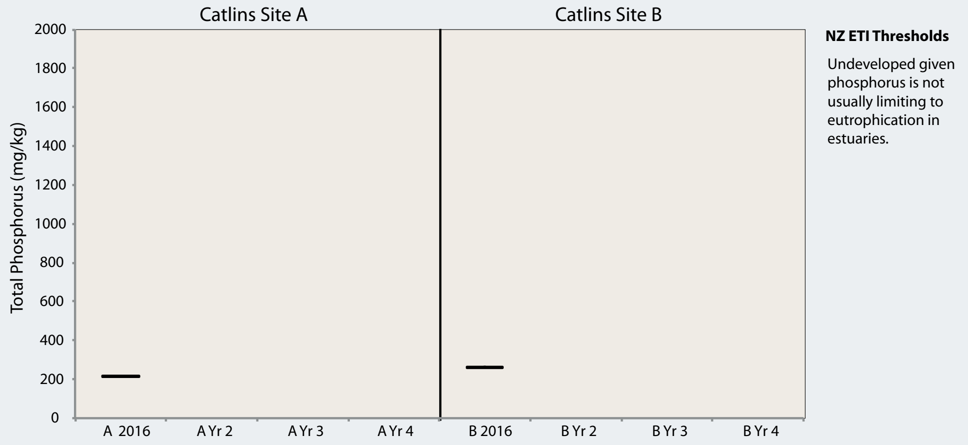

Figure 7. Mean total phosphorus (median, interquartile range, total range, n=3), December 2016.

4.1.3 Toxicity

The influence of non-eutrophication related toxicity is primarily indicated by concentrations of heavy metals, with pesticides, PAHs, and SVOCs generally only assessed where inputs are likely, or metal concentrations are found to be elevated.

Results for heavy metals Cd, Cr, Cu, Hg, Pb, Ni, Zn and arsenic, used as indicators of potential toxicants, were present at "very low" to "low" concentrations at both sites, with all non-normalised values below the ANZECC (2000) ISQG-Low trigger values (Table 5), and therefore indicate the toxicant indicators monitored posed no threat to aquatic life.

Table 5. Indicator toxicant results for Catlins Estuary (Sites A and B), December 2016.

Year/Site/Rep	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
	mg/kg							
2016 A 1-4 [b]	0.015	6.1	2.2	4.2	1.27	12	5.1	<0.010
2016 A-4-8 [b]	0.013	5.9	2.1	3.9	1.15	10.4	5.1	<0.010
2016 A-9-10 [b]	0.011	6	2.5	4.1	1.34	10.9	5.6	<0.010
2016 B-1-4 [b]	0.019	8.5	4.3	5.5	2.1	23	2.9	<0.010
2016 B-4-8 [b]	0.018	8.2	4.2	5.5	2.1	24	2.8	0.013
2016 B-9-10 [b]	0.02	9.2	4.9	6.2	2.3	26	3.1	<0.010
Condition Thresholds (ANZECC 2000 criteria, Very Low, <0.2 x ISQG Low; Low, 0.2 - 0.5 x ISQG Low; Moderate, 0.5 x to ISQG Low; High, >ISQG Low)								
[a] Band A Very Low Risk	<0.3	<16	<13	<4.2	<10	<40	<4	<0.03
[a] Band B Low Risk	0.3 - 0.75	16 - 40	13 - 32.5	4.2 - 10.5	10 - 25	40 - 100	4 - 10	0.03 - 0.075
[a] Band C Moderate Risk	0.75 - 1.5	40 - 80	32.5 - 65	10.5 - 21	25 - 50	100 - 200	10 - 20	0.075 - 0.15
[a] Band D High Risk	>1.5	>80	>65	>21	>50	>200	>20	>0.15
[a] ISQG-Low	1.5	80	65	21	50	200	20	0.15
[a] ISQG-High	10	370	270	52	220	410	70	1

[a] ANZECC 2000, * composite samples

4.1.4 Benthic Macroinvertebrate Community

Benthic macroinvertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong primary linkage to sediments and secondary linkage to the water column (Dauer et al. 2000, Thrush et al. 2003, Warwick and Pearson 1987, Robertson et al. 2016). Because they integrate recent disturbance history in the sediment, macroinvertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors.

The response of macroinvertebrates to stressors in Catlins Estuary will be analysed in detail once sufficient baseline monitoring data is available. This analysis will include four steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among each fine scale site over time.
2. The BIO-ENV program in the PRIMER (v.6) package will be used to evaluate and compare the relative importance of different environmental factors and their influence on the identified macrobenthic communities.
3. Assessment of species richness, abundance, diversity and major infauna groups.
4. Assessment of the response of the macroinvertebrate community to increasing mud and organic matter among fine scale sites over time, based on identified tolerance thresholds for NZ taxa (NZ AMBI, Robertson et al. 2015, Robertson et al. 2016).

At this stage, with only one year of monitoring data, this section of the report will present and interpret data in relation to steps 3 and 4 only.

Species Richness, Abundance, Diversity and Infauna Groups

In this step, simple univariate whole community indices, i.e. species richness, abundance and diversity are presented for each site (Figure 8), and in the future when more data is available, will be used to help explain any differences between years indicated by other analyses.

4. Results and Discussion (continued)

The data showed species richness at both Sites A and B was relatively low (i.e. 2-9 per core at Site A and 6-9 per core at Site B), whereas abundance was relatively high at Site B (211-342 per core) and low at Site A (9-29 per core). Shannon diversity (0.5-1.3 per core at Site A and 0.5-0.7 per core at Site B) was relatively low. In comparison, examples of these indices from other typical NZ SIDE estuaries are as follows: Waimea Inlet [species richness (6-13 per core), abundance (8-83 per core) and Shannon diversity (1.4-2.4 per core] - Robertson and Stevens 2014; Porirua Harbour [species richness (10-25 per core), abundance (50-220 per core) and Shannon diversity (1.1-1.6 per core)] - Robertson and Stevens 2015.

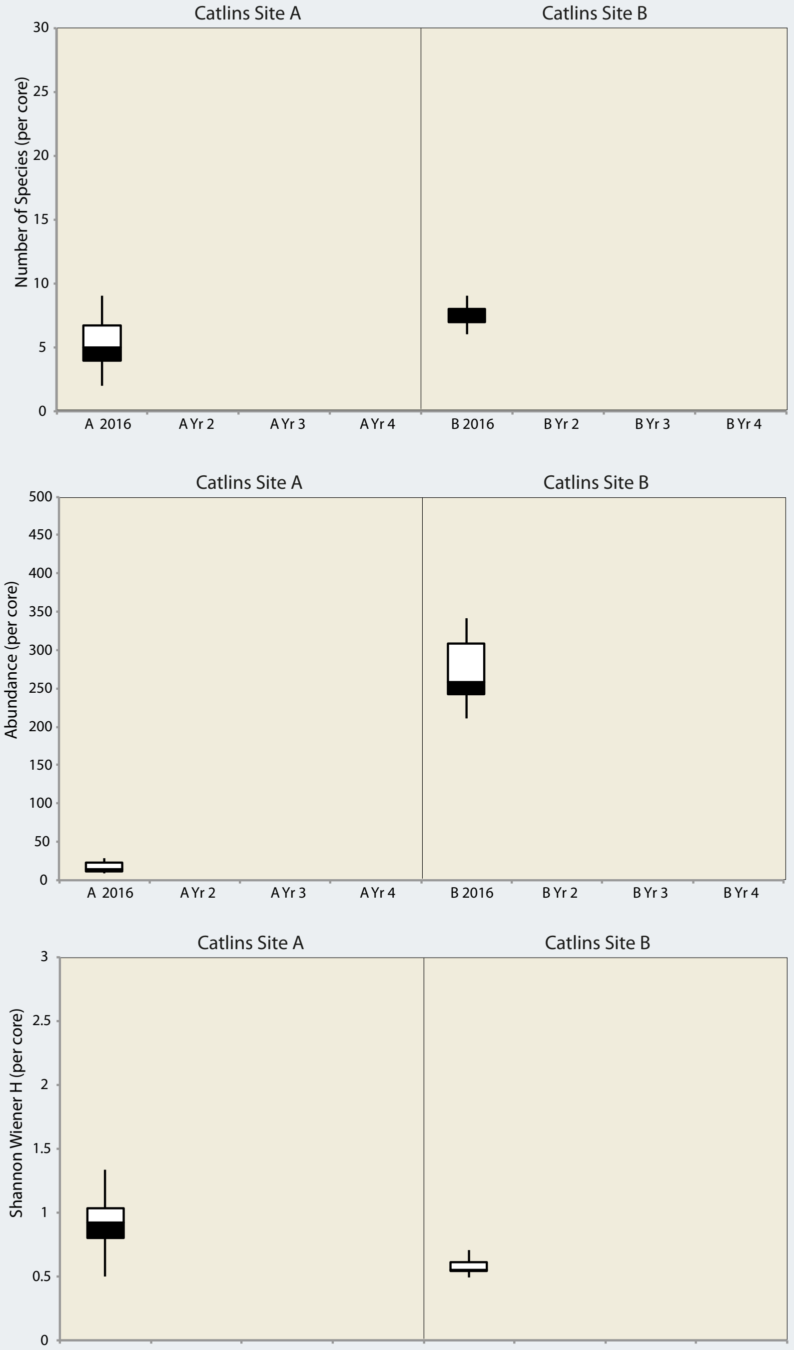

Figure 8. Mean number of species, abundance per core, and Shannon Diversity index (±SE, n=10), Catlins Estuary, December 2016.

Figure 9 shows that, although the macroinvertebrate community at each site was dominated by crustacea, polychaetes and bivalves, there was an obviously much larger abundance of crustacea at Site B. The plot also shows that gastropods were only present at Site A. These differences are discussed in more detail in the following sections.

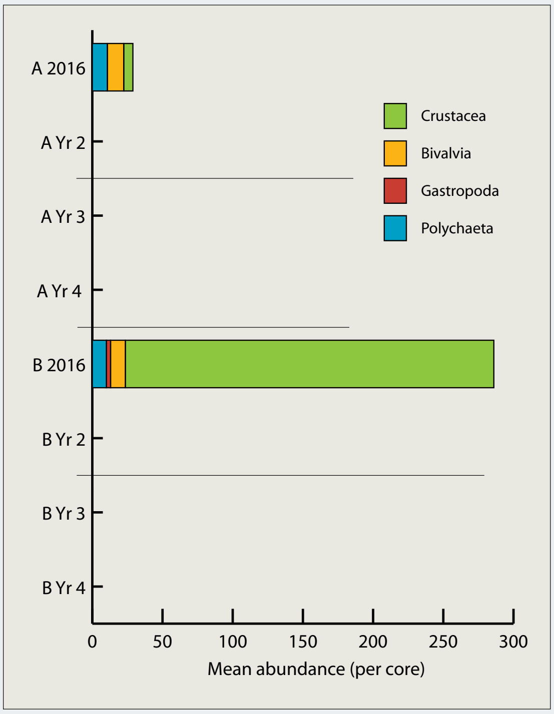

Figure 9. Mean abundance of major infauna groups (n=10), Catlins Estuary, December 2016.

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

1. Mud and Organic Enrichment Index (NZ AMBI)

This step is undertaken by using the NZ AMBI (Robertson et al. 2016), a benthic macroinvertebrate index based on the international AMBI approach (Borja et al. 2000) which includes several modifications to strengthen its response to anthropogenic stressors, particularly mud and organic enrichment as follows:

- integration of previously established, quantitative ecological group classifications (Robertson et al. 2015),
- addition of a meaningful macrofaunal component (taxa richness), and
- derivation of classification-based and breakpoint-based thresholds that delineated benthic condition along primary estuarine stressor gradients (in this case, sediment mud and total organic carbon contents). The latter was used to evaluate the applicability of existing AMBI condition bands, which were shown to accurately reflect benthic condition for the >100 intertidal NZ estuarine sites surveyed: 2% to ~30% mud reflected a “normal” to “impoverished” macrofauna community, or “high” to “good” status; ~30% mud to 95% mud and TOC ~1.2% to 3% reflected an “unbalanced” to “transitional to pollution” macrofauna community, or “good” to “moderate” status; and >3% to 4% TOC reflected a “transitional to pollution” to “polluted” macrofauna community, or “moderate” to “poor” status.

In addition, the AMBI was successfully validated (R^2 values >0.5 for mud, and >0.4 for total organic carbon) for use in shallow, intertidal dominated estuaries New Zealand-wide.

For the two fine scale sites in the Catlins Estuary, the NZ Hybrid AMBI biotic coefficients were very different, with medians of 0.7 at Site A, and 4.4 at Site B (Figure 10). The coefficients indicate that Site A was in the "high" category, indicating a normal healthy community, whereas Site B was in the "poor" category indicating an "impoverished" type community indicative of high mud concentrations, possibly accompanied by organic enrichment.

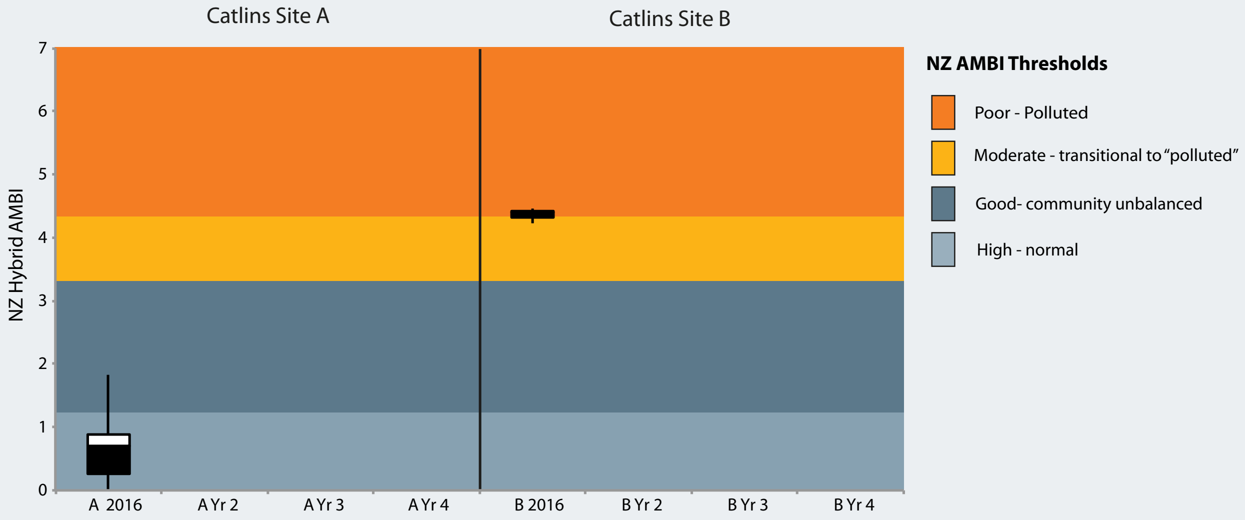

Figure 10. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=10), Catlins Estuary, December 2016.

2. Individual Species

To further explore the macroinvertebrate community in relation to taxa sensitivities to mud and organic enrichment, a comparison was made of the mean abundances of individual taxa within the 5 major mud/enrichment tolerance groupings (i.e. *1 = highly sensitive to (intolerant of) mud and organic enrichment; 2 = sensitive to mud and organic enrichment; 3 = widely tolerant of mud and organic enrichment; 4 = prefers muddy, organic enriched sediments; 5 = very strong preference for muddy, organic enriched sediments*) (Figure 11).

The key findings were as follows:

- Both sites included low numbers of some highly sensitive Group 1 organisms but they were more prevalent at Site A (5 taxa) than Site B (2 taxa). Of particular note, was the higher incidence of the small, highly sensitive bivalve *Perrierina turneri* at Site A.
- Group 2 organisms were present in low numbers at each site, including the suspension-feeding cockle, *Austrovenus stutchburyi*.
- Group 3 organisms were only represented by one taxa at each site.
- Group 4 and Group 5 mud preference taxa were only present at Site B (except for one Group 4 taxa at Site A). The dominant taxa responsible for the strong presence of these two groups at Site B were:
    * the tube-dwelling crustacean amphipod *Paracorophium excavatum*, which is the dominant corophioid amphipod in the South Island. *Paracorophium* is well-known as a major primary coloniser (and hence indicator) of disturbed estuarine intertidal flats (Ford et al. 1999). Examples of common disturbances are, macroalgal mats settling on the tidal flats as a result of coastal eutrophication and mud deposition after mobilisation of fine sediments from exposed soil surfaces in the catchment. In these situations, *Paracorophium* can become very abundant and, through its burrowing activities, increases oxygen exchange which in turn mitigates the effect of the disturbance.
    * the surface deposit feeding spionid polychaete *Scolecolepides benhami* and, the deposit-feeding nut clam, *Arthritica* sp.

Figure 11. Mud and organic enrichment sensitivity of macroinvertebrates, Catlins Estuary Sites A and B, December 2016 (see Appendix 3 for sensitivity details).

4. Results and Discussion (continued)

4.2 Water Column Condition

Background

In NZ SIDEs the rapid flushing time (<3 days for these estuaries) means water column phytoplankton cannot reach high concentrations before they are flushed to the sea. As a consequence, water column eutrophication is minimal, except for some estuaries where parts of the upper estuary water column can be more poorly flushed. This occurs in low flow-baseflow periods when inflowing freshwater flows over more saline tidal water and results in a dense isolated layer of saline bottom water that neither freshwater or tidal inflow currents are strong enough to flush out. Such isolated (or stratified) bottom water (often situated in the 1-2m depth range) is susceptible to phytoplankton blooms, low dissolved oxygen, elevated nutrient concentrations and accumulation of fine sediment.

In estuaries where stratification occurs, the preferred target for eutrophication management is nitrogen which has been identified as the element most limiting to algal production in most estuaries in the temperate zone (Howarth and Marino 2006). Since nitrogen is continually cycling between all of the major nitrogen forms, an assessment of total nitrogen (TN) is needed in order to gauge the level of nitrogen within an embayment and therefore its potential nutrient related health. Reliance on a nitrogen fraction, e.g. inorganic nitrogen, results in inaccurate assessments, since even in a large algal bloom inorganic concentrations may be low due to the uptake by the plants (Howes et al. 2003). Based on the following literature, a TN threshold concentration of approximately 0.4mgTN.l-^{1} (0.4mgNl^{-1}) for the appearance of eutrophic conditions in poorly flushed sections of SIDE estuaries can be identified (see inset).

Literature Supporting TN Threshold

- In Horsen's Estuary, Denmark, research indicates a mean growing season threshold value of 0.398mgTN l^{-1} to meet good ecological status (Hinsby et al. 2012). This research also identified a threshold for inorganic nutrients as 0.021mgDIN l^{-1} and 0.007mgDIP l^{-1}.
- Similarly, ECan Avon-Heathcote Estuary data from 2010-2014 suggests the appearance of eutrophic conditions may be unlikely below a TN concentration around 0.4mgTN/l (John Zeldis pers. comm. 2016).
- In the US, EPA Region 1 has considered total N threshold concentrations for estuaries and coastal waters of 0.45mgTN l^{-1} as protective of DO standards and 0.34mgTN l^{-1} as protective for eelgrass (Latimer and Rego 2010, State of New Hampshire 2009, Benson et al. 2009).
- As concentrations at inner Massachusetts estuaries rose to levels above 0.40gTN l^{-1}, with the entry of a wastewater nitrogen plume, eelgrass beds began declining and localized macro-algal accumulations were reported (Howes et al. 2003).

Results

The water quality results for the surface and bottom waters at three sites in the Catlins Estuary (lower, mid and upper estuary sites, Sites X, Y and Z respectively) are presented in Table 4. The main findings were as follows:

Stratification

There was minimal difference between surface and bottom water temperature, salinity (Figure 12), chlorophyll *a* or dissolved oxygen (Figure 14) indicating stratification was not occurring in the estuary when sampled on 17 December 2016. However, given only one comprehensive sampling event and the possibility of stratification occurring later in the growing season, there is a possibility that stratified bottom water eutrophication could occur in parts of the estuary later in summer (e.g. upper estuary channels of both the Owaka and Catlins Rivers).

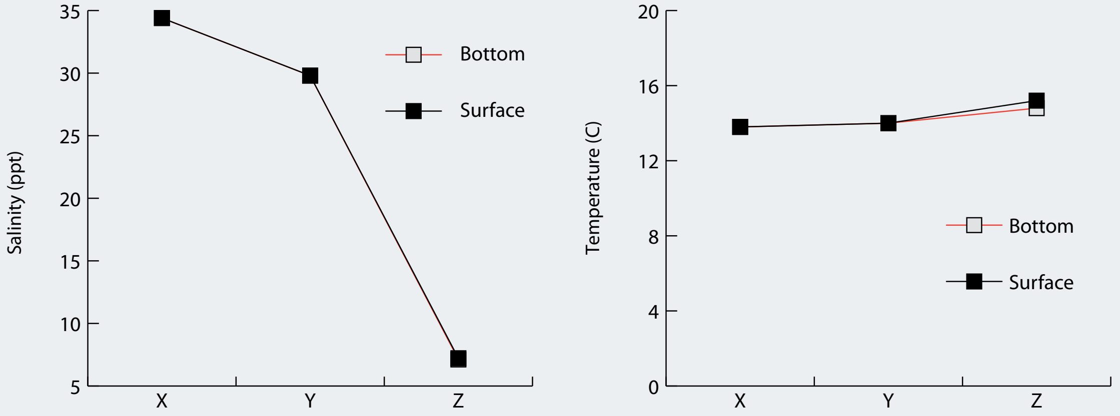

Figure 12. Salinity and temperature in surface and bottom water, Catlins Estuary, 17 December 2016.

Susceptibility To Eutrophication Based on TN Concentrations

Total nitrogen concentrations in the water column at the upper estuary Site Z (0.6 and 1.1mgNl^{-1} in the surface and bottom water respectively), exceeded the eutrophication threshold level of mean 0.4mgNl^{-1} identified above, whereas in the mid and lower estuary sites X and Y, TN concentrations were all less than the threshold (Figure 13). As a consequence, susceptibility to water column eutrophication, based on TN concentrations alone (i.e. not considering flushing), was relatively high in the upper estuary, but low in the lower estuary. However, in this case, where data for only one discrete event were collected, the results can only be used as an early indicator of likely growing season susceptibility. To assess the susceptibility to eutrophication over the whole growing season (November-April), monthly TN concentrations should be used.

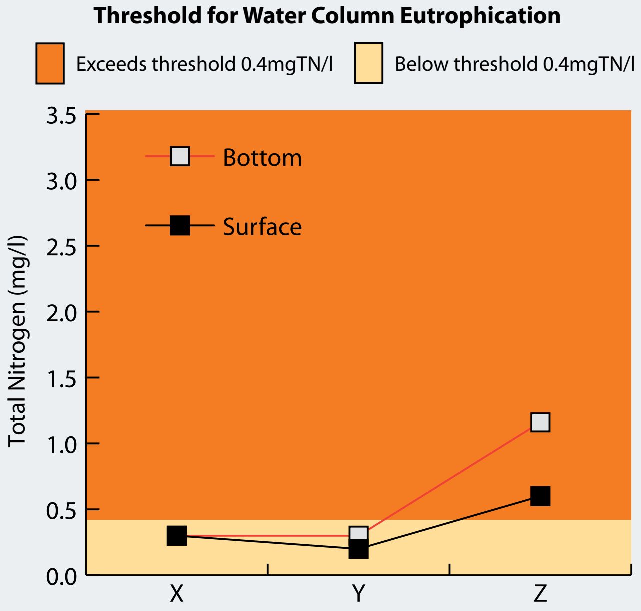

Figure 13. Total nitrogen concentration in surface and bottom water, Catlins Estuary, 17 December 2016.

Other measurements of plant nutrients showed relatively low levels in the lower estuary waters, but higher concentrations of ammoniacal N, and TP at the middle and upper estuary sites, and high nitrate N at the upper estuary site (Table 4, Figure 14).

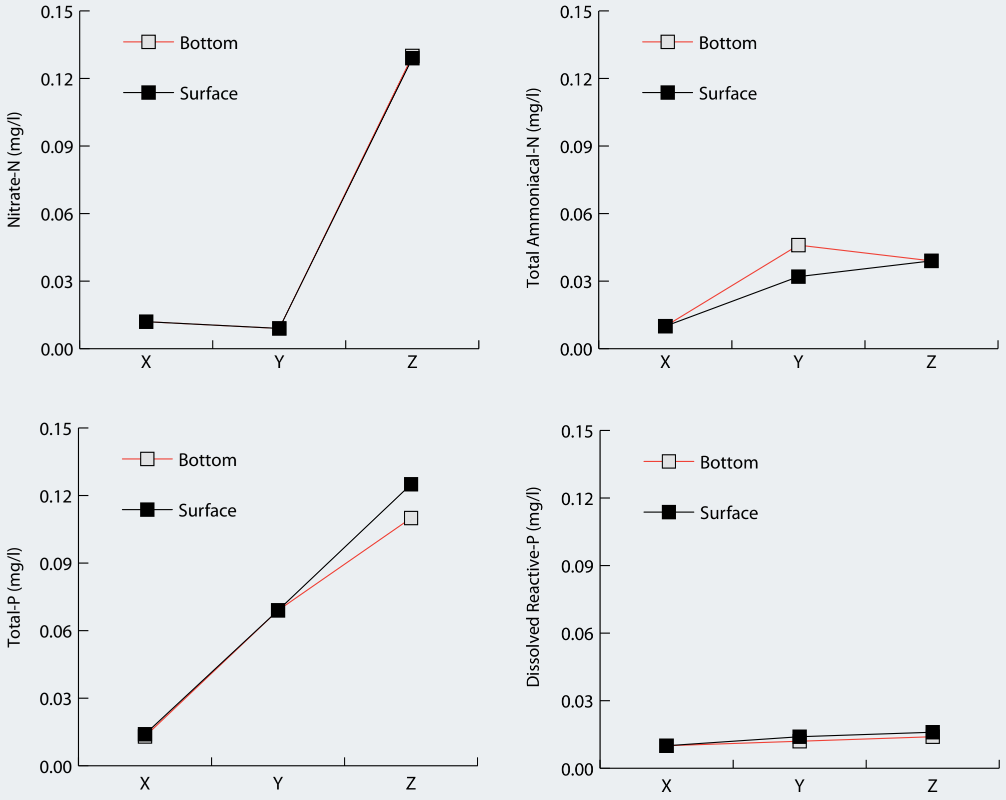

Figure 14. TP, DRP, Ammoniacal N and Nitrate N concentrations in surface and bottom water, Catlins Estuary, 17 December 2016.

Eutrophic Status Based on Chlorophyll *a* and Dissolved Oxygen

The NZ ETI threshold for chlorophyll *a* (the primary indicator of water column eutrophication) is expressed as the 90th percentile of monthly measures collected during the growing season, and for dissolved oxygen (the main eutrophication supporting indicator), a 7 day mean. Consequently the one-off measures collected on 17 December 2016 can only be used as an indication of current condition.

Chlorophyll *a* concentrations were all less than 10ugl^{-1} (Figure 15), low-moderate concentrations compared to the NZ ETI eutrophication Band D ("Poor") threshold level of 16ugl^{-1} (Robertson et al. 2016b). Dissolved oxygen, was >9mgl^{-1}, well above the NZ ETI eutrophication Band D ("Poor") threshold of 6mgl^{-1} (Figure 15).

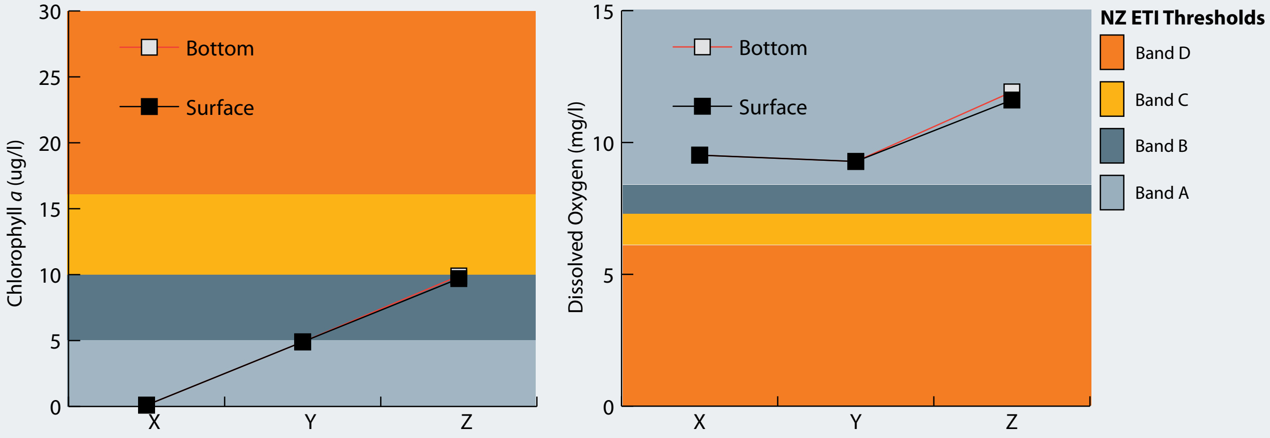

Figure 15. Chlorophyll *a* and dissolved oxygen concentrations in surface and bottom water, Catlins Estuary, 17 December 2016.

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for two long term intertidal monitoring sites within Catlins Estuary in December 2016 showed the following findings in relation to the key estuary issues of eutrophication, muddiness and toxicity:

BENTHIC HABITAT

Muddiness

The intertidal sites, chosen to represent the main benthic habitats in the estuary, showed muddier sediments in the estuary's main deposition zone (upper estuary Site B - mean 24.7% mud) and sandier sediments in the lower estuary (Site A - mean 5.5% mud). In terms of potential for ecological effects, the moderate-high mud content at Site B indicates a *moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost, especially if nutrient loads elevated.* Site A should have a balanced community with *no, or minor, stress caused by the indicator on any aquatic organisms* (Robertson et al. 2016b).

Eutrophication

The macroalgal results show that in December 2016 there was no seagrass cover and less than 5% cover of opportunistic macroalgae at both Sites A and B. In addition, both sites had low organic carbon and nutrient contents in the underlying sediments. However, the upper estuary Site B, in addition to being muddy, showed poor oxygenation conditions (i.e. low redox <-150mV, Band D) beginning at approximately 0.5cm depth. These results indicate that the macroinvertebrate community would likely to be dominated by mud tolerant species. Such a biological response was reflected in the NZ estuary macroinvertebrate community index (the NZ Hybrid AMBI) results, median 4.4 at Site B, compared with 0.7 for the sandy Site A. These coefficients indicate a "poor "ecological condition category for Site B (i.e. an "impoverished" type community indicative of elevated mud concentrations, possibly accompanied by organic enrichment), and a normal, balanced community for Site A.

Toxicity

Indicators of sediment toxicants [heavy metals (Cd, Cr, Cu, Pb, Hg, Ni, Zn and As)] were at concentrations that were not expected to pose toxicity threats to aquatic life.

WATER COLUMN HABITAT

Eutrophication

Taken as a whole, the available stratification data indicates that susceptibility to water column phytoplankton blooms in the Catlins Estuary in December 2016 to be low, despite N concentrations in the upper estuary exceeding the eutrophication threshold. However, given only one comprehensive sampling event and the possibility of stratification occurring later in the growing season, there is a possibility that stratified bottom water eutrophication could occur in parts of the estuary later in summer (e.g. upper estuary channels of both the Owaka and Catlins Rivers).

Based on expert opinion, such events would likely manifest as cycles of bottom water stratification and accompanying eutrophication, that gradually increase towards the end of the cycle, with the cycles being broken by intermittent high flow events that disrupt the stratification and flushes phytoplankton and nutrients into the main body of the estuary and out to sea. The magnitude of the blooms would likely depend on the duration between flood events, with nuisance conditions increasing as time between floods increases.

Although upper estuary bottom water stratification is a natural event in many shallow NZ estuaries, it can be exacerbated by reductions in natural river inflows (e.g. from upstream water abstraction and damming). Once established, the extent of eutrophication in the bottom layer is likely to be primarily driven by catchment nutrients, particularly nitrogen. Preliminary indications suggest that river total nitrogen inputs would need to be much less than $0.4 mgNl^{-1}$ in order to minimise eutrophication symptoms in this sensitive zone of an estuary.

In terms of risk to estuarine ecology from cyclical degradation of the upper-mid estuary bottom water layer if it were to occur, the likely main threats would be to benthic macroinvertebrates and fish through loss of important habitat.

5. Summary and Conclusions (continued)

Overview

In overview, the benthic habitat results at the sites indicate the estuary expresses symptoms of muddiness and poor oxygenation in the upper estuary, but only low levels of eutrophication (low macroalgal cover). The combination of these symptoms in the upper estuary have resulted in an impoverished type macroinvertebrate community.

The water column results indicate no stratification at the time of sampling and a low risk of eutrophication under such conditions. However, should the estuary stratify, current nutrient concentrations appear sufficiently high to result in eutrophication conditions establishing in localised areas.

The "Overview Report" which accompanies the current fine and broad scale reports identifies appropriate nutrient load versus estuary eutrophication response thresholds that can be used to manage these issues, as well as providing more details on the issues.

6. MONITORING

Monitoring

Catlins Estuary has been identified by ORC as a priority for monitoring because it is a large estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of ORC's coastal monitoring programme being undertaken throughout the Otago region. Broad scale habitat mapping and fine scale sampling has now been undertaken for 1 baseline year (December 2016).

In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

The present report addresses the fine scale component of the long term programme. The recommendation for ongoing monitoring to meet this requirement for the Catlins Estuary is as follows:

Fine Scale Monitoring

To complete the fine scale baseline in Catlins Estuary it is recommended that the remaining 3 consecutive years of annual summer (i.e. December-February) fine scale monitoring of intertidal sites (including sedimentation rate measures), be undertaken in 2017, 2018 and 2019 (preferably during a summer low flow period).

To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column monitoring of the upper to mid estuary be undertaken during a prolonged summer, low flow period in 2018. It is envisaged that this should include sampling of surface and bottom water at 5-6 sites in the main channels of the estuary (i.e. Catlins and Owaka Rivers).

To characterise the potential for excessive sedimentation, it is recommended that sedimentation rate be assessed annually, using appropriately placed sediment plates, and the areal extent of muddy sediments be assessed at 5-10 yearly intervals (the latter assessed in broad scale monitoring).

Broad Scale Habitat Mapping

It is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2026).

7. ACKNOWLEDGEMENTS

Many thanks to Rachel Ozanne (Otago Regional Council) for her support, feedback and review of this report.

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson) *	N/A
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference).	0.1 g/100g dry wgt
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g/100g dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg/kg dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg/kg dry wgt
Total recoverable mercury	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<0.27 mg/kg dry wgt
Total recoverable arsenic	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<10 mg/kg dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg/kg dry wgt
Dry Matter (Env)	R.J. Hill	Dried at 103°C (removes 3-5% more water than air dry)	

* Coastal Marine Ecology Consultants (established in 1990) specialises in coastal soft-shore and inner continental shelf soft-bottom benthic ecology. Principal, Gary Stephenson (BSc Zoology) has worked as a marine biologist for more than 25 years, including 13 years with the former New Zealand Oceanographic Institute, DSIR. Coastal Marine Ecology Consultants holds an extensive reference collection of macroinvertebrates from estuaries and soft-shores throughout New Zealand. New material is compared with these to maintain consistency in identifications, and where necessary specimens are referred to taxonomists in organisations such as NIWA and Te Papa Tongarewa Museum of New Zealand for identification or cross-checking.

Water Quality Indicator	Laboratory	Method	Detection Limit
Filtration, Unpreserved	R.J Hill	Sample filtration through 0.45μm membrane filter.	-
Total Kjeldahl Digestion	R.J Hill	Sulphuric acid digestion with copper sulphate catalyst.	-
Total Phosphorus Digestion	R.J Hill	Acid persulphate digestion.	-
Total Nitrogen	R.J Hill	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: Default Detection Limit of 0.05 g/m3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m3.	0.05 g/m^3
Total Ammoniacal-N	R.J Hill	Saline, filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500- NH3 F (modified from manual analysis) 22nd ed. 2012.	0.010 g/m^3
Nitrite-N	R.J Hill	Saline sample. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g/m^3
Nitrate-N	R.J Hill	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m^3
Nitrate-N + Nitrite-N	R.J Hill	Saline sample. Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g/m^3
Total Kjeldahl Nitrogen (TKN)	R.J Hill	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-Norg D. (modified) 4500 NH3 F (modified) 22nd ed. 2012.	0.10 g/m^3
Dissolved Reactive Phosphorus	R.J Hill	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22nd ed. 2012.	0.004 g/m^3
Total Phosphorus	R.J Hill	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012. Also modified to include the use of a reductant to eliminate interference from arsenic present in the sample. NWASCA, Water & soil Miscellaneous Publication No. 38, 1982.	0.004 g/m^3

Appendix 1. Details on Analytical Methods (continued)

Epifauna (surface-dwelling animals).
SACFOR Percentage Cover and Density Scales (after Marine Nature Conservation Review - MNCR).

A. PERCENTAGE COVER	Growth Form	
	i. Crust/Meadow	ii. Massive/Turf
>80	S	-
40-79	A	S
20-39	C	A
10-19	F	C
5-9	O	F
1-4	R	O
<1	-	R

SACFOR Category
S = Super Abundant
A = Abundant
C = Common
F = Frequent
O = Occasional
R = Rare

- Whenever percentage cover can be estimated for an attached species, it should be used in preference to the density scale.
- The massive/turf percentage cover scale should be used for all species except those classified under crust/meadow.
- Where two or more layers exist, for instance foliose algae overgrowing crustose algae, total percentage cover can be over 100%.

B. DENSITY SCALES

SACFOR size class				Density				
i	ii	iii	iv	0.25m^2	1.0m^2	10m^2	100m^2	1,000m^2
<1cm	1-3cm	3-15cm	>15cm	(50x50cm)	(100x100cm)	(3.16x3.16m)	(10x10m)	(31.6x31.6m)
S	-	-	-	>2500	>10,000			
A	S	-	-	250-2500	1000-9999	>10,000		
C	A	S	-	25-249	100-999	1000-9999	>10,000	
F	C	A	S	3-24	10-99	100-999	1000-9999	>10,000
O	F	C	A	1-2	1-9	10-99	100-999	1000-9999
R	O	F	C			1-9	10-99	100-999
-	R	O	F				1-9	10-99
-	-	R	O					1-9
-	-	-	R					<1

APPENDIX 2. 2016/17 DETAILED RESULTS

Catlins Estuary fine scale site boundaries

Catlins Site A	1	2	3	4	**Catlins Site B**	1	2	3	4
NZTM EAST	1346650	1346665	1346652	1346637	NZTM EAST	1341986	1341960	1341968	1341994
NZTM NORTH	4847651	4847677	4847684	4847658	NZTM NORTH	4847999	4847982	4847970	4847986

Fine scale station locations, Catlins Estuary, 17 December 2016

Catlins Site A	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1346649	1346654	1346656	1346661	1346657	1346654	1346651	1346647	1346642	1346645
NZTM NORTH	4847655	4847663	4847668	4847674	4847678	4847672	4847667	4847660	4847661	4847668
Catlins Site B	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1341985	1341978	1341970	1341966	1341970	1341976	1341983	1341987	1341991	1341986
NZTM NORTH	4847996	4847990	4847987	4847980	4847978	4847982	4847986	4847991	4847987	4847984

Catlins Estuary sediment plate and peg locations and depth of plate (mm) below surface

Site A Sed Plates (Firm Muddy Sand)	NZTM East	NZTM North	Height/Depth (mm) 17 Dec 2016	**Site B Sed Plates** (Soft Mud)	NZTM East	NZTM North	Height/Depth (mm) 17 Dec 2016
Peg 1 (0m)	1346650	4847651		Peg 1 (0m)	1341986	4847999	
Plate 1 (2m)	1346648	4847652	-132	Plate 1 (2m)	1341987	4847997	-92
Plate 2 (4m)	1346647	4847653	-129	Plate 2 (4m)	1341988	4847995	-117
Peg 2 (5m)				Peg 2 (5m)			
Plate 3 (6m)	1346645	4847654	-114	Plate 3 (6m)	1341989	4847994	-93
Plate 4 (8m)	1346643	4847655	-112	Plate 4 (8m)	1341990	4847992	-94
Peg 3 (10m)				Peg 3 (10m)			

Water quality and subtidal sediment site locations, Catlins Estuary, 17 December 2016

Catlins	**Site X (lower)**	**Site Y (mid)**	**Site Z (upper)**
NZTM EAST	1347197	1343869	1339381
NZTM NORTH	4848356	4848390	4846486

Sediment quality results for Sites X, Y and Z, Catlins Estuary, 17 December 2016

Year/Site	**TOC**	**Mud**	**Sand**	**Gravel**	**TN**	**TP**
	%				**mg/kg**	
Catlins SED X 2016	0.12	4.8	95.2	<0.1	<500	182
Catlins SED Y 2016	0.15	7.2	86.5	6.4	<500	230
Catlins SED Z 2016	4.4	47.1	52.8	<0.1	3100	580

Redox Potential (mV) at fine scale sites, Catlins Estuary, 17 December, 2016

Year/Site	**Redox Potential (mV)**				
	0cm	**1 cm**	**3cm**	**6cm**	**10cm**
2016 A	100	94	91	-20	-60
2016 B	-25	-241	-264	-275	-341

Appendix 2. 2016/17 Detailed Results (continued)

Physical and chemical results for fine scale Sites A and B, Catlins Estuary, 17 December 2016

Year/Site/Rep	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2016 A 1-4 [b]	3	34	<0.05	2.1	97.3	0.6	0.015	6.1	2.2	4.2	1.27	12	5.1	<0.010	<500	220
2016 A-4-8 [b]	3	34	<0.05	9.8	89.6	0.6	0.013	5.9	2.1	3.9	1.15	10.4	5.1	<0.010	<500	210
2016 A-9-10 [b]	3	34	<0.05	4.7	94.8	0.4	0.011	6.0	2.5	4.1	1.34	10.9	5.6	<0.010	<500	220
2016 B-1-4 [b]	2	25	0.24	23.5	76.5	<0.1	0.019	8.5	4.3	5.5	2.1	23	2.9	<0.010	600	270
2016 B-4-8 [b]	2	25	0.27	26.0	73.8	<0.1	0.018	8.2	4.2	5.5	2.1	24	2.8	0.013	<500	260
2016 B-9-10 [b]	2	25	0.3	24.7	75.3	<0.1	0.02	9.2	4.9	6.2	2.3	26	3.1	<0.010	<500	260
ISQG-Low [a]	-	-	-	-	-	-	1.5	80	65	21	50	200	20	0.15	-	-
ISQG-High [a]	-	-	-	-	-	-	10	370	270	52	220	410	70	1	-	-

[a] ANZECC 2000. [b] composite samples.

Water quality results for Sites X, Y and Z, Catlins Estuary, 17 December 2016

Site	Units	Catlins Lower Site X (surface)	Catlins Lower Site X (bottom)	Catlins Mid Site Y (surface)	Catlins Mid Site Y (bottom)	Catlins Upstream Site Z (surface)	Catlins Upstream Site Z (bottom)
Depth	m	0.1	2.3	0.1	2.0	0.1	1.2
Temperature	degrees C	13.8	13.8	14.0	14.0	15.2	14.8
Salinity	ppt	34.4	34.4	29.8	29.8	7.22	7.12
Dissolved Oxygen	mg/l	9.52	9.52	9.28	9.28	11.61	11.92
pH		8.3	8.3	8.4	8.4	8.0	8.1
Chlorophyll a	mg/m^3	0.1	0.1	4.9	4.9	9.7	9.9
Total Nitrogen	g/m^3	<0.3	<0.3	0.2	0.3	0.6	1.16
Total Ammoniacal-N	g/m^3	<0.010	<0.010	0.046	0.032	0.039	0.039
Nitrate-N	g/m^3	0.012	0.012	0.009	0.009	0.13	0.129
Dissolved Reactive Phosphorus	g/m^3	0.01	0.01	0.012	0.014	0.014	0.016
Total Phosphorus	g/m^3	0.013	0.014	0.069	0.069	0.11	0.125

Epifauna abundance and macroalgal cover at fine scale sites, Catlins Estuary ,17 December 2016

Group	Family	Species	Common name	Scale	Class	A	B
Topshell	Amphibolidae	*Amphibola crenata*	Estuary mud snail	#	ii	R	A
Red algae	Gracilariaceae	*Gracilaria* sp.	*Gracilaria* weed	%	ii	R	-
Green algae	Ulvaceae	*Ulva lactuca*	Sea lettuce	%	ii	R	-

Seagrass (*Zostera muelleri*) and macroalgal cover and biomass at fine scale sites, Catlins Estuary, 17 December 2016

Year/Site	Seagrass Biomass and Cover (g.m^{-2}wet weight (%)	Macroalgal Biomass and Cover g.m^{-2} wet weight (%)
2016 A	0 (0%)	5 (3%)
2016 B	0 (0%)	5 (1%)

Appendix 2. 2016/17 Detailed Results (continued)

Infauna results for fine scale Sites A and B, Catlins Estuary, 17 December 2016

Infauna (numbers per 0.01327m² core) (Note NA = Not Assigned)

Group	Species	NZ Hyb AMBI	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
POLYCHAETA	*Boccardia syrtis*	3	2						1	1												
	Capitella sp.#1	4										1	5	1	5	1	1					
	Maldanidae sp.#1	1					1		1													
	Microspio maori	1			1	1	1		1			1	6	2	1		2	1	1	1	1	
	Nereididae (unid. juveniles)	3	4	7	3		4		1	3	2											
	Orbiniidae sp.#1	1					1															1
	Perinereis vallata	2			1																	
	Scolecolepides benhami	4										2	5	4	5	7	5	12	3	9	7	
OLIGOCHAETA	Oligochaeta sp.#1	3												3	6	2	2	1		3	4	1
BIVALVIA	*Arthritica* sp.#1	4										1			8	1	2	4	50	7	3	
	Austrovenus stutchburyi	2				1						1				1						
	Perrierina turneri	1	16	3	2	5	9	10	21	8	7											
	Hiatula sp.#1	NA	1																			
CRUSTACEA	Amphipoda sp.#1	5										2	2			1		1	2	1	1	
	Colurostylis lemurum	2		1	2			1		1		1		4	3	5	1			2	1	2
	Copepoda sp.#1	2											3	5								
	Gastrosaccus australis	NA	1																			4
	Hemiplax hirtipes	5															2					
	Paracorophium excavatum	4	1		1				1			200	301	240	223	323	261	212	241	235	219	7
	Phoxocephalidae sp.#1	NA							1	2												3
	Stomatopoda sp.#1	1			1				1													219
	Tenagomysis sp.#1	2										2	20		3		6	2	21	1	2	1
	Waitangi sp.#1	NA	1	1	1	2	2		1	8	1											
Total individuals in sample			**22**	**26**	**12**	**12**	**9**	**18**	**11**	**29**	**23**	**10**	**211**	**342**	**259**	**254**	**341**	**282**	**233**	**318**	**259**	**238**
Total number of species in sample			**4**	**7**	**4**	**7**	**4**	**6**	**2**	**9**	**6**	**3**	**9**	**7**	**7**	**8**	**8**	**9**	**7**	**6**	**8**	**8**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		NZ Hyb AMBI Gp*	Details
Polychaeta	*Boccardia syrtis*	2	A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions.
	Capitella sp. 1	4	A blood red capitellid polychaete which is very pollution tolerant. Common in suphide rich anoxic sediments. Commonly *Capitella capitata.*
	Maldanidae sp. 1	1	Bamboo worms are large, blunt-ended, cylindrical worms and feed as bulk consumers of sediment using a balloon-like proboscis. Most bamboo worms live below the surface in flimsy sediment tubes. They process copious amounts of sediment and deposit it in earthworm-like surface casts.
	Microspio maori	1	A small, common, intertidal spionid. Can handle moderately enriched situations. Prey items for fish and birds.
	Nereididae	3	Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete Nereis diversicolor is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of elevated sulphide concentrations.
	Orbiniidae sp. 1	1	Long, slender, sand-dwelling unselective deposit feeders which are without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant.
	Perinereis vallata	2	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers mud/sand sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.
	Phoxocephalidae sp. 1	2	A family of gammarid amphipods. Common example is Waitangi sp. which is a strong sand preference organism.
	Scolecolepides benhami	4	A spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. A close relative, the larger Scolecolepides freemani occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai Arm, New River Estuary.
Oligochaeta	Oligochaeta sp. 1	3	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
Bivalvia	Arthritica sp. 1	4	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
	Austrovenus stutchburyi	2	Family Veneridae bivalves are very sensitive to organic enrichment. Cockles are suspension feeders with a short siphon - live a few cm deep at mid-low water situations. Responds positively to relatively high levels of SS for short period; long term exposure has adverse effects. Small cockles are an important in diet of wading bird species; including SI and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, they struggle. Cockles improve sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006).
	Hiatula sp. 1	NA	A saltwater clam, marine bivalve molluscs in the family Myidae.

Appendix 3. Infauna Characteristics (continued)

Group and Species		NZ Hyb AMBI Gp*	Details
Bivalvia	*Perrierina turneri*	1	A small bivalve - relatively uncommon.
Crustacea	*Amphipoda* sp. 1	5	An unidentified amphipod species.
	Colurostylis lemurum	1	A cumacean and a semi-pelagic detritus feeder. Cumacea is an order of small marine crustaceans, occasionally called hooded shrimps. Some species can survive in water with a lower salinity rate, like in brackish water (e.g. estuaries). Most species live only one year or less, and reproduce twice in their lifetime. Cumaceans feed mainly on microorganisms and organic material from the sediment. Species that live in the mud filter their food, while species that live in sand browse individual grains of sand.
	Copepoda sp. 1	2	Copepods are a group of small crustaceans found in the sea and nearly every freshwater habitat and they constitute the biggest source of protein in the oceans. Usually having six pairs of limbs on the thorax. The benthic group of copepods (Harpactacoida) have worm-shaped bodies.
	Gastrosaccus australis	NA	A pelagic littoral shrimp belonging to the Family Mysidae
	Hemiplax hirtipes	5	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud. Previously *Macrophthalmus hirtipes.*
	Paracorophium excavatum	4	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference.
	Stomatopoda sp. 1	NA	Mantis shrimp or stomatopods are marine crustaceans. They are neither shrimp nor mantids, but receive their name purely from the physical resemblance to both the terrestrial praying mantis and the shrimp. Considered to have the most complex eyes in the animal kingdom.
	Tenagomysis sp. 1	2	Tenagomysis is a genus of mysid shrimps in the family Mysidae. At least nine of the fifteen species known are from New Zealand.
	Waitangi sp. 1	NA	An amphipod of the Phoxocephalidae Family with a strong sand preference.

* NZ AMBI Biotic Index sensitivity groupings sourced from Robertson et al. (2015).
1 = highly sensitive to (intolerant of) mud and organic enrichment;
2 = sensitive to mud and organic enrichment;
3 = widely tolerant of mud and organic enrichment;
4 = prefers muddy, organic enriched sediments;
5 = very strong preference for muddy, organic enriched sediments.

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