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New River Estuary 2018

Macroalgal Monitoring

Prepared for **Environment Southland**

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By

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EXECUTIVE SUMMARY

New River Estuary, located near Invercargill, is a large (4,600ha), shallow (mean depth ~2m) intertidal dominated, "tidal lagoon" type estuary (SIDE) that discharges to the eastern end of Oreti Beach. It drains a large 4314km^2 catchment comprising 55% intensive pasture, 14% low producing pasture, 20% native forest, and 9% exotic forest. It is a key estuary in Environment Southland's long-term coastal monitoring programme.

Broad scale monitoring in 2007 identified increased opportunistic macroalgal growth was causing nuisance conditions, and recommended monitoring of macroalgae to assess change (Robertson and Stevens 2007). Undertaken annually from 2008-2013 and in 2016, this work documented a rapid expansion in the cover and biomass of nuisance macroalgae, and gross eutrophic conditions in the estuary from 2007-2016.

The current report summarises the most recent macroalgal monitoring undertaken in Feb. 2018 using the UK-WDF (2014) Opportunistic Macroalgal Blooming Tool (OMBT) approach. Results were assessed using:

- Percent cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of potential eutrophication issues).
- Macroalgal biomass (providing a direct measure of areas of excessive growth).
- Extent of algal entrainment in sediment (highlighting where nuisance conditions have a high potential for establishing and persisting).
- Gross eutrophic zones (highlighting significant sediment degradation by measuring where there is a combined presence of high algal cover or biomass, low sediment oxygenation, and soft muds).

In addition, the recently developed NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a,b) was used to assess the overall trophic (nutrient enrichment) state of the estuary.

The 2018 results show that large sections of the well flushed lower estuary remain in good condition, however nuisance macroalgal growth is widespread and since 2016 has significantly increased in the upper estuary, with an associated decline in estuary quality.

The western Waihopai Arm was the worst impacted, with sediment conditions so degraded that nuisance macroalgae are now dying off due to the over-enriched sediment conditions present. From 2016 to 2018, macroalgal cover and biomass increased and high value seagrass habitat was displaced. The eastern Waihopai Arm also experienced a large increase in macroalgal growth and associated seagrass loss from 2016 to 2018.

Existing macroalgal beds also increased in size near Bushy Point and in the lower reaches of the Oreti River, displacing seagrass and causing significant negative changes in sediment condition through increased smothering and muddiness, and decreased sediment oxygenation.

Daffodil Bay remains heavily impacted by dense growths, and while it did not experience a large increase in macroalgal cover since 2016, the smothering high density beds are predominately associated with soft, muddy, anaerobic, and sulphide and organic rich sediments and are in poor condition.

The NZ ETI score of 0.96 indicates the estuary is eutrophic, with conditions consistently worsening since monitoring commenced in 2001. The area of the estuary with gross eutrophic conditions has now expanded from 23ha in 2001 (1% of the estuary) to 428ha in 2018 (15% of the estuary). This has caused a significant loss of dense (>50% cover) high value seagrass from the estuary (a 94% loss in the Waihopai Arm).

In short, the estuary is exhibiting significant problems associated with excessive macroalgal growth and likely represents the largest impact of this type to have occurred in a NZ SIDE estuary. Unless nutrient inputs to the estuary are reduced significantly, it is expected that there will be a continuation of these difficult to reverse adverse impacts within the estuary.

RECOMMENDED MONITORING AND MANAGEMENT

It is recommended that macroalgal cover and associated seagrass be monitored annually, with estuary wide-comprehensive broad scale habitat mapping undertaken every 5 years (next recommended in 2021).

Fine scale monitoring recommendations are presented in Robertson and Robertson (2018).

Because sedimentation is a priority issue in the estuary it is recommended that existing sediment plate depths be measured annually, and a single composite sediment sample be analysed for grain size at each site. In addition, it is recommended that the number of plates deployed in the estuary be expanded to include deposition zones in the eastern Waihopai Arm, Bushy Point and Daffodil Bay.

Previous recommendations (e.g. Stevens and Robertson 2013) are reiterated for the prioritised development of catchment nutrient and sediment guideline criteria to derive thresholds protecting against adverse sediment and nutrient impacts. Environment Southland are currently developing these criteria.

1. INTRODUCTION

Situated at the confluence of the Oreti and Waihopai Rivers near Invercargill, New River Estuary is a large (4,600ha), shallow (mean depth ~2m) intertidal dominated, "tidal lagoon" type estuary (SIDE) that discharges to the eastern end of Oreti Beach. It drains a large 4314km^2 catchment comprising 60% intensive pasture, 17% low producing pasture, 13% native forest, and 8% exotic forest.

The estuary has a wide range of habitats including extensive mud and sand flats, cockle beds, seagrass and saltmarsh areas. Historically it has also lost large areas through drainage and reclamation, with the Waihopai Arm most affected with around 1,200ha (75%) of the Arm reclaimed, greatly reducing its ability to filter, dilute, and assimilate nutrient and sediment inputs. The estuary is bordered by a mix of vegetation and land uses (urban, bush and grazed pasture). Human use and ecological values of large parts of the estuary are high, but environmental issues are present including the frequent exceedance of bathing and shellfish faecal bacterial guidelines, excessive sedimentation and muddiness, leachate, stormwater and wastewater discharges, and nuisance blooms of opportunistic macroalgae (*Ulva* and *Gracilaria*).

To gather information necessary to help make effective estuary management decisions, Environment Southland (ES) has established a long-term coastal monitoring programme that includes use of the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002). The NEMP includes broad-scale mapping of habitat types based on the dominant surface features present (e.g. substrate: mud, sand, cobble, rock; or vegetation: macrophyte, macroalgae, rushland, etc) using a combination of detailed ground-truthing and GIS-based digital mapping from aerial photography to record the features present. This work commenced in New River Estuary in February 2001, and was repeated in February 2007, and 2012 (Robertson and Stevens 2007, Stevens and Robertson 2012). Additional substrate and seagrass mapping was undertaken in 2016 (see Robertson et al. 2017). In addition, fine scale physical, chemical and biological monitoring at representative mid-estuary sites has been undertaken in 2001, 2003, 2004, 2005, 2010 and 2018 with monitoring of eutrophic arms undertaken in 2012, 2013, 2015 and 2018 (see Robertson 2018 for details, and Figure 1 for fine scale site locations).

Broad scale monitoring in 2007 highlighted an increase in localised areas where opportunistic macroalgal growth was causing nuisance conditions, and recommended annual monitoring of macroalgae to assess change (Robertson and Stevens 2007). This was undertaken annually from 2008-2013 inclusive and again in 2016. Results, summarised in Robertson et al. (2017), documented a rapid expansion in the percentage cover and biomass of nuisance macroalgae in the estuary from 2007-2016.

The presence of opportunistic macroalgae is a primary symptom of estuary eutrophication (nutrient driven enrichment). Opportunistic macroalgae are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Decaying macroalgae can also accumulate subtidally and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the macroalgal cover, biomass, persistence, and extent of entrainment within sediments, the greater the subsequent impacts.

Blooms in NZ estuaries principally contain species of green algae *Ulva* (this includes taxa formerly known as *Enteromorpha*) and *Cladophora*, red algae *Gracilaria*, and brown algae (e.g. *Ectocarpus, Pilayella, Bachelotia*). These bloom-forming species are a natural component of intertidal ecosystems (Adams 1994) and they only grow to bloom proportions when nutrient levels are elevated (Sutula et al. 2011) and where sufficient light for growth reaches macroalgal beds. As a consequence, they generally only reach nuisance conditions in shallow estuaries, or at the margins of deeper estuaries.

The macroalgal growth response to nutrient loads generally increases with water residence times (Painting et al. 2007), either of the whole estuary (as is often the case for many NZ short residence time estuaries), or part of the estuary (e.g. a poorly flushed upper estuary arm where nutrient-rich muds accumulate), or in 'backwaters' where drifting suspended macroalgae can accumulate (e.g. Avon-Heathcote Estuary: Bolton-Ritchie and Main 2005). There is some evidence this response may also be significantly attenuated by the presence of fringing saltmarsh, due to reductions in nutrient loading through processes such as denitrification (Valiela et al. 1997).

Figure 1. New River Estuary, showing location of fine scale and sediment monitoring sites (Photo LINZ).

1. INTRODUCTION (CONT...)

Other factors that can influence the expression of macroalgal growth are the presence of suitable attachment strata, and physical and hydrodynamic conditions e.g. temperature (dessication), fetch (wind driven waves), and currents (scouring) e.g. Hawes and Smith (1995).

Macroalgal blooms of *Gracilaria chilensis* commonly occur on muddy, intertidal flats in the mid to upper estuary where salinity flocculation and hydrodynamic sediment deposition is encouraged, there is little water motion, light is not limiting to growth, and exposure to elevated water column and sediment nutrient concentrations are greatest (e.g. Aldridge and Trimmer, 2009; Longphuirt et al. 2015; Robertson et al. 2017). Such locations form the major *Gracilaria* production areas of Chile, New Zealand, Malaysia, Thailand, the Philippines, Indonesia and China (Santileces and Doty 1989). The success of *Gracilaria* in these relatively harsh environmental conditions of excessive muddiness, frequent fresh-water dilutions, high nutrient regimes, very low water motion, regular exposure to air, high temperatures, burial in sediment, and often anoxic or sulphide rich sediments, is a reflection of the unique survival characteristics of *Gracilaria* spp.

High macroalgal cover (>50% cover) or density (>500g.m^{-2}) can lead to the development of gross eutrophic zones (GEZs) in an estuary when it combines with high sediment mud contents and poor oxygenation. These areas are commonly associated with elevated nutrient and total organic carbon concentrations, and the displacement of invertebrates sensitive to organic enrichment and muds. The areas most commonly first affected are natural deposition and settlement areas, often in the upper estuary. Persistent and extensive areas of gross nuisance conditions should not be present in short residence time estuaries, and because of the highly undesirable and often rapidly escalating decline in estuary quality associated with GEZs, even relatively small changes from baseline conditions should be evaluated as a priority. Any temporal trend of increasing GEZ extent indicates changes in catchment land use management (i.e. reduced nutrient and sediment inputs) are likely to be needed.

To assess current macroalgal growth in the estuary, and any changes in condition compared to previous surveys, ES contracted Wriggle Coastal Management to undertake a broad scale macroalgal mapping assessment of New River Estuary in February 2018. This report summarises the results of the 2018 survey and incorporates the results into the recently developed NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a,b). The ETI uses many of the monitoring outputs from broad and fine scale monitoring undertaken using the NEMP and is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and related impacts from sediment muddiness.

2. METHODS

The macroalgal assessment is based on the broad scale mapping methods described in the NEMP (Robertson et al. 2002) and ETI (Robertson et al. 2016a,b). Experienced coastal scientists walked the intertidal habitat of New River Estuary (see Appendix 4) and recorded the percentage cover of macroalgae (to the nearest 10%) directly onto laminated photos in the field guided by a 6 category percent cover rating scale (Figure 2). Within these percentage cover categories, patches of comparable macroalgal growth were identified and each patch was enumerated through field measures of biomass and the degree of macroalgal entrainment within sediment. Macroalgae were defined as entrained when growing >3cm deep within muddy sediments. Biomass was measured by collecting algae growing on the surface of the sediment from within a defined area (e.g. 25x25cm quadrat) and placing it in a sieve bag. The algae was then thoroughly rinsed to remove sediment, and any non-algal material and large invertebrate fauna (e.g. crabs, shellfish) were removed. Remaining algae was then hand squeezed until water stopped running, and the wet weight of algae recorded to the nearest 10g using a 1kg Pesola light-line spring scale. Measured biomass was then used to extrapolate biomass estimates for each wider patch. In addition, the presence of soft muds and surface sediment anoxia were noted when macroalgal growth was present in order to define where nuisance conditions had developed into GEZs. Field data were entered into ArcMap 10.5 GIS software using a Wacom Cintiq21UX drawing tablet to spatially summarise results.

Results were interpreted using a multi-index approach that included:

- Percent cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of potential eutrophication issues).
- Macroalgal biomass (providing a direct measure of areas of excessive growth).
- Extent of algal entrainment in sediment (highlighting where nuisance condition have a high potential for establishing and persisting).
- Gross eutrophic zones (highlighting significant sediment degradation by measuring where there is a combined presence of high algal cover or biomass, low sediment oxygenation, and soft muds).

The key component of the interpretative approach is use of a modified Opportunistic Macroalgal Blooming Tool (OMBT). The OMBT, described in detail in Appendix 1 with data in Appendix 2, is a 5 part multimetric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which is placed within overall quality status threshold bands (i.e. bad, poor, good, moderate, high) to rate macroalgal condition (Table 1). This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution in the estuary and is supported by rating the extent of GEZs.

In order to provide a more comprehensive way to characterise broad scale changes in macroalgal biomass, a series of fixed transect based sampling locations were established in 2018 within dense macroalgal beds to enable repeat measurements to be made at the same sites over time. These are shown in Figure 3 with data in Appendix 3. The extent of ground-truthing undertaken to assess macroalgal cover in 2018, and location of field photos are shown in Appendix 4.

The georeferenced spatial habitat maps provide a robust baseline of key indicators and 2018 results have been compared to the previous broad scale survey results.

Sampling resolution and accuracy

For broad scale features like macroalgae that are spatially and temporally variable, estimates of percentage cover and biomass are considered accurate to ±10%, while boundaries between different percentage cover and density areas and overall spatial extent are considered accurate to within 10-20m where ground-truthed, and 20-50m where estimated remotely.

Table 1. Summary of macroalgal ecological condition ratings used in the present report.

MACROALGAL ECOLOGICAL QUALITY RATING (WFD_UKTAG (2014) OBMT approach - details in Appendix 1)					
ECOLOGICAL QUALITY RATING (EQR)	High	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^2) of AIH	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g.m^2) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100
Gross Eutrophic Zones (ha or %)**	<0.5ha or <1%	≥0.5 to <5ha or ≥1 to <5%	≥5 to <20ha or ≥5 to <10%	≥20 to <30ha or ≥10 to <15%	≥30ha or ≥15%

*Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation - see Appendix 1 for further detail.

** Additional rating used to support the OMBT EQR.

Figure 2. Visual rating scale for percentage cover estimates of macroalgae.

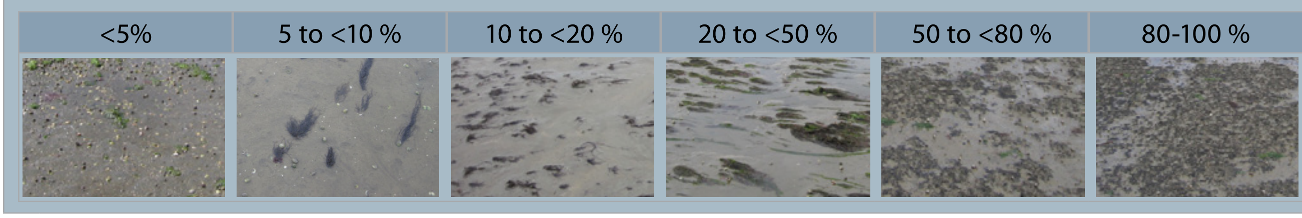


Figure 3. Fixed sampling locations established in 2018 for biomass measurements.

3. RESULTS AND DISCUSSION

Opportunistic macroalgal growth was assessed by mapping the spatial spread and density of macroalgae in the Available Intertidal Habitat (AIH) (Figure 4), and calculating an "Ecological Quality Rating" (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT) described in Appendix 1.

The overall opportunistic macroalgal EQR for New River Estuary in February 2018 was 0.284 (Table 2), a quality status of "POOR" and indicates that the estuary overall is expressing significant symptoms of eutrophication. The individual metrics that are used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area), are also scored and have quality status threshold bands to guide key drivers of change. These range from MODERATE to BAD, the moderate score reflecting the large well flushed lower estuary having few issues. The macroalgae present was dominated by red alga *Gracilaria chilensis* and the green alga *Ulva* spp. *Ulva* tended to have a relatively low biomass (<200g.m^{2}) and was most common on sands, the decaying roots of old *Spartina* beds, and rocks in the lower estuary. In many areas *Ulva* was growing as a sparse cover on top of *Gracilaria* beds.

Gracilaria was present throughout the estuary, but was most obvious in very extensive and very high biomass (>5000g.m^{2}) beds in the soft mud deposition zones in Waihopai Arm and Daffodil Bay, and near the Oreti River mouth and at Bushy Point. Localised depositional areas near the Oreti River mouth had wet weight biomass of 30,000-40,000g.m^{2}. The threshold at which significant adverse impacts from excessive macroalgal growth become apparent has been determined from multiple studies in NZ and internationally to be >1450g.m^{2} biomass wet weight. It is clear from Figure 4 that high biomass areas are now very extensive throughout the upper reaches of New River Estuary. Compared to previous years, the average biomass of the affected area has increased significantly (from 2005g.m^{2} in 2016 to 3160g.m^{2} in 2018). There has also been a significant increase in macroalgal growth in the previously sparsely vegetated eastern Waihopai Arm.

EQR scores, including those retrospectively determined from broad scale data in 2001, 2007, 2012, are presented in Figure 5 along with a synoptic narrative of changes in Table 3. Conservative values have been used for retrospective estimates of growth so that any bias will tend to underestimate possible adverse impacts rather than over-state problems. To this end, macroalgal cover in the Pleasure Bay embayment adjacent to the landfill has been excluded from all estimates as this area may be confounded by local point source impacts and restricted water flows.

It is also noted that, as in 2016, the 2018 EQR (Table 5 below) does not take into account the significant reduction in macroalgal biomass evident in the Waihopai Arm since 2013 that is likely driven by extreme sediment anoxia and high sulphide levels being so bad that macroalgae can no longer survive in these areas. As such the 2018 EQR is considered a conservative estimate of the extent of macroalgal related degradation evident in the estuary.

Table 2. Summary of intertidal opportunistic macroalgal cover, New River Estuary, Feb. 2018.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	2944		
Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	17.9	0.543	Moderate
Biomass of AIH (g.m^{-2}) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	1205	0.252	Poor
Biomass of Affected Area (g.m^{-2}) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	3160	0.191	Bad
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	35.3	0.298	Poor
Affected Area (use the lowest of the following two metrics)		0.137	Bad
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	1123	0.137	Bad
Size of AA in relation to AIH (%) = (AA / AIH) x 100	38.1	0.468	Moderate
OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.284**	**POOR**

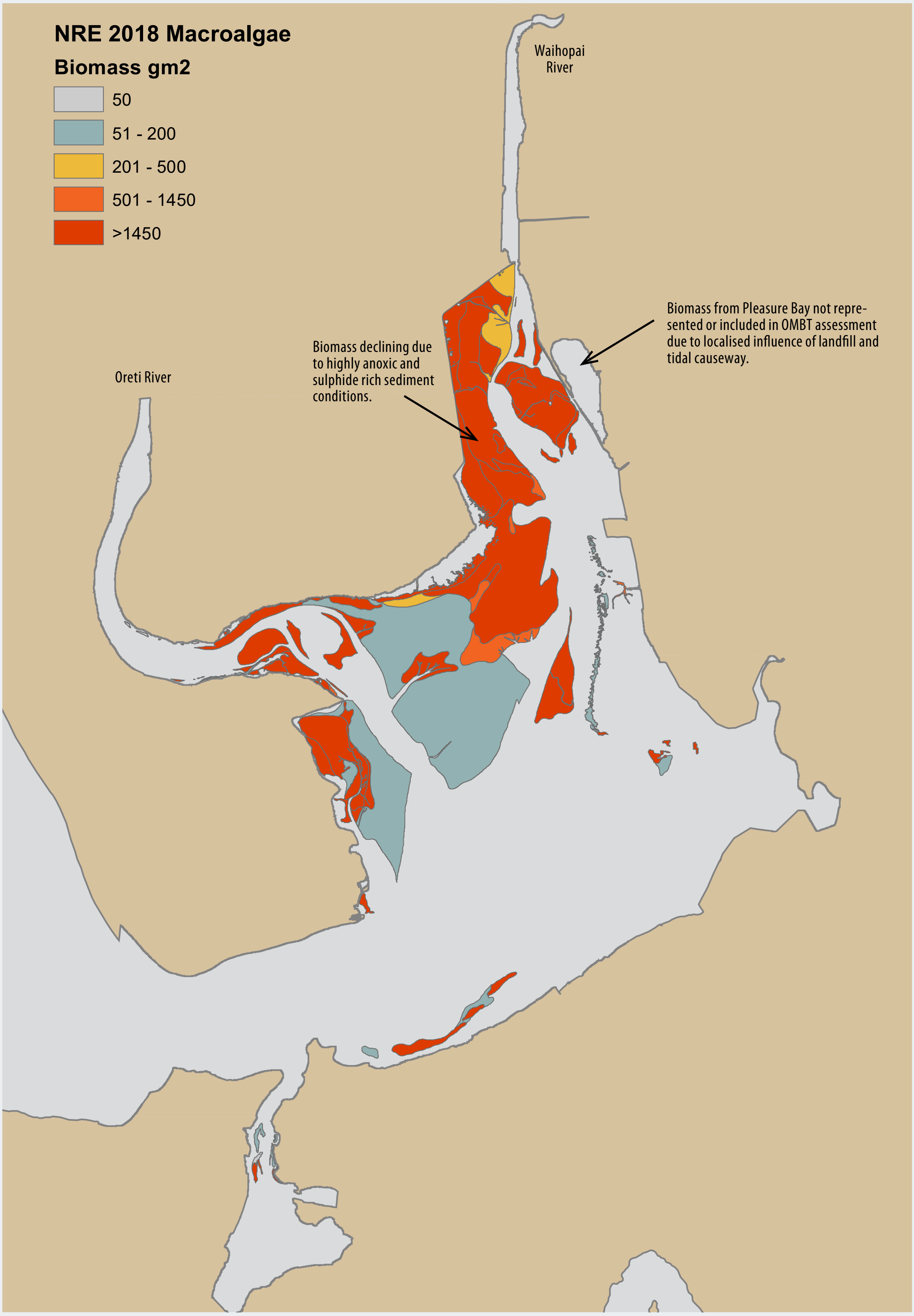


Figure 4. Map of Macroalgal Biomass (g.m[2]) - New River Estuary, Feb. 2018.

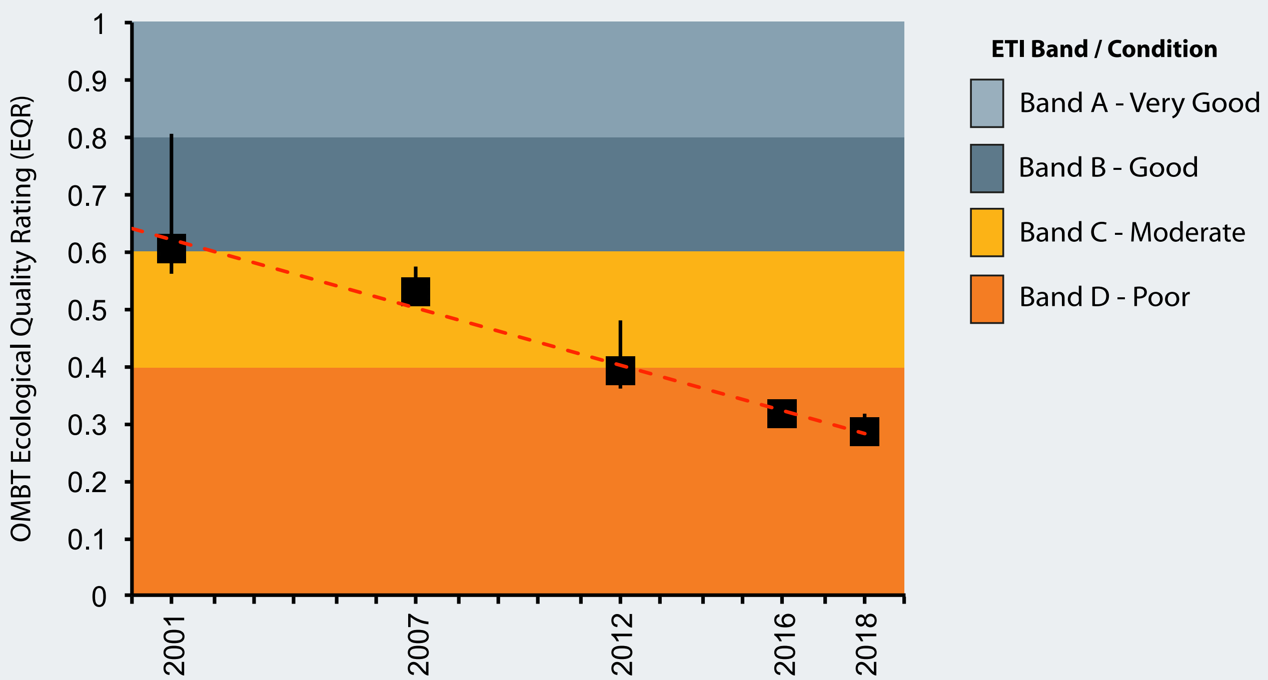


Figure 5. OMBT EQR (90% upper and lower Confidence Interval, and trend line) - New River Estuary, Feb. 2001-2018.

Table 3. Summary of intertidal opportunistic macroalgal cover, New River Estuary, 2001-2018.

Year	Result
2001	<1% of the estuary with high (>50%) macroalgal cover (based on personal observation and initial broad scale mapping (e.g. Robertson et al. 2002).
2007	Low cover across most of estuary. Patches of high cover near the Oreti River mouth and west of the Waihopai channel by Bushy Point.
2008	Large increase in cover and nuisance conditions on the west side of the northern arm from 2007. Low cover across most of the central and lower estuary.
2009	Large increase in cover and nuisance conditions in the west Waihopai Arm and Bushy Point since 2008. Low cover across central and lower estuary.
2010	Rapid deterioration of sediment quality in the west Waihopai Arm. Extensive growths at Bushy Point and Daffodil Bay. Low cover across central/lower estuary.
2011	Extensive areas of poor sediment quality in the Waihopai Arm. Heavy growths at Bushy Point and Daffodil Bay. Low cover across central/lower estuary.
2012	Extensive areas of poor sediment quality in the Waihopai Arm. Heavy growths at Bushy Point and Daffodil Bay. Low cover across central/lower estuary.
2013	Increased growth in Waihopai arm, Daffodil Bay, and Oreti River mouth. Sediment degradation at Bushy Point. Low cover in central/lower estuary.
2016	Significant die off of macroalgae in Waihopai Arm and very poor sediment quality. Large increase in growth at Bushy Point and Oreti River mouth. Increased growths in Mokomoko Inlet and parts of central/lower estuary.
2018	Very poor sediment quality and extensive macroalgal growth in western Waihopai Arm. Large increase in macroalgal growth in eastern Waihopai Arm. Large increase in growth, and decline in sediment condition at Bushy Point and Oreti River mouth.

CHANGES IN MACROALGAL RATINGS 2001-2018

Figure 5 shows a consistent and significant decline in the macroalgal EQR over the 2001-2018 period from a GOOD state to a POOR state, reflecting a large expansion in the area affected by macroalgae, increasing macroalgal biomass and entrainment in sediment when present, and rapidly deteriorating sediment quality - all indicators of significant eutrophication impacts. In particular, there has been ongoing expansion of problem growths at Bushy Point (Figure 6), near the Oreti River mouth (Figure 7), and a large increase in macroalgal cover on the previously unaffected eastern side of the Waihopai Arm (Figure 8). Photographic examples of the representative transition from good conditions with low macroalgal growth to degraded conditions and high growth between 2007 to 2018 are shown in Figure 9 (Bushy Point), and Figure 10 (western Waihopai Arm).

Figure 11 presents a time series of maps of macroalgae percentage cover in the estuary from 2001 to 2018. There has been a progressive and consistent expansion of macroalgal cover over this 17 year period. Most significant have been the very large increases in macroalgal cover in Daffodil Bay, Waihopai Arm, Bushy Point and near the Oreti River mouth, which appear ongoing (see below).

Figure 6. Field photo illustrating dense macroalgal cover at Bushy Point in 2018.

Figure 7. Field photo illustrating dense macroalgal cover in the lower Oreti River in 2018.

Figure 8. Field photos illustrating widespread macroalgal cover in the eastern Waihopai Arm in 2018.

Mobile sands, 10% macroalgal cover, aRPD >5cm. | Muddy sands, 20-50% macroalgal cover, aRPD 3-5cm. | Soft muds, 80-100% macroalgal cover, aRPD 1-3cm. | Soft muds, 80-100% macroalgal cover, aRPD 0-1cm.

Figure 9. Field photos illustrating representative changes in macroalgal cover at Bushy Point in 2007, 2012, 2016 and 2018.

Very soft muds, 10% macroalgal cover, aRPD 1cm. | Very soft muds, 80-100% macroalgal cover, aRPD 0cm. | Very soft muds, 80-100% macroalgal cover, aRPD 0cm, high sediment organic and sulphur content. | Very soft muds, 80-100% macroalgal cover, aRPD 0cm, high sediment organic and sulphur content.

Figure 10. Field photos illustrating representative changes in macroalgal cover at the southern Waihopai Arm in 2007, 2012, 2016 and 2018.

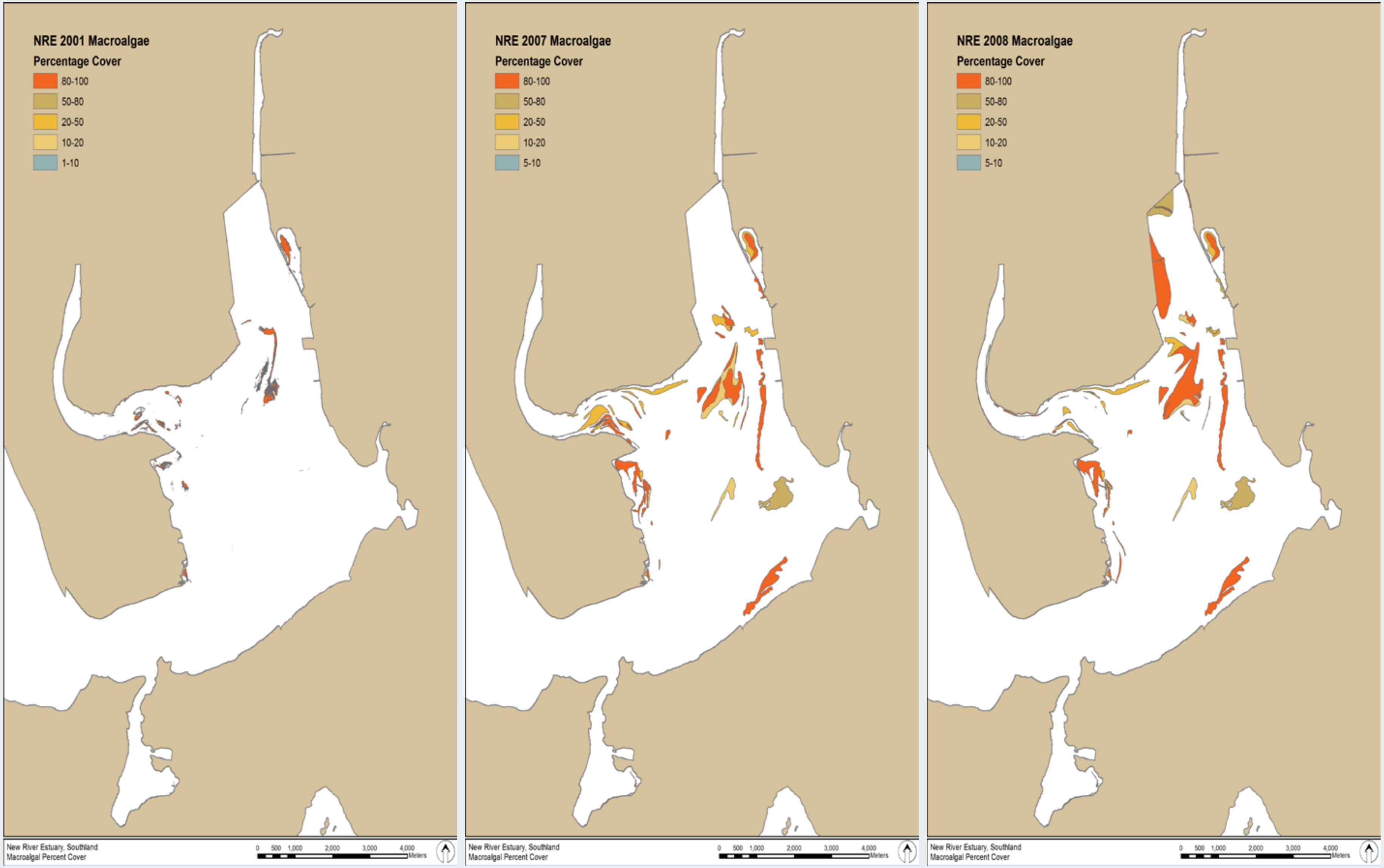


Figure 11a. Map of Macroalgal Percentage Cover - New River Estuary, Feb. 2001, 2007, 2008.

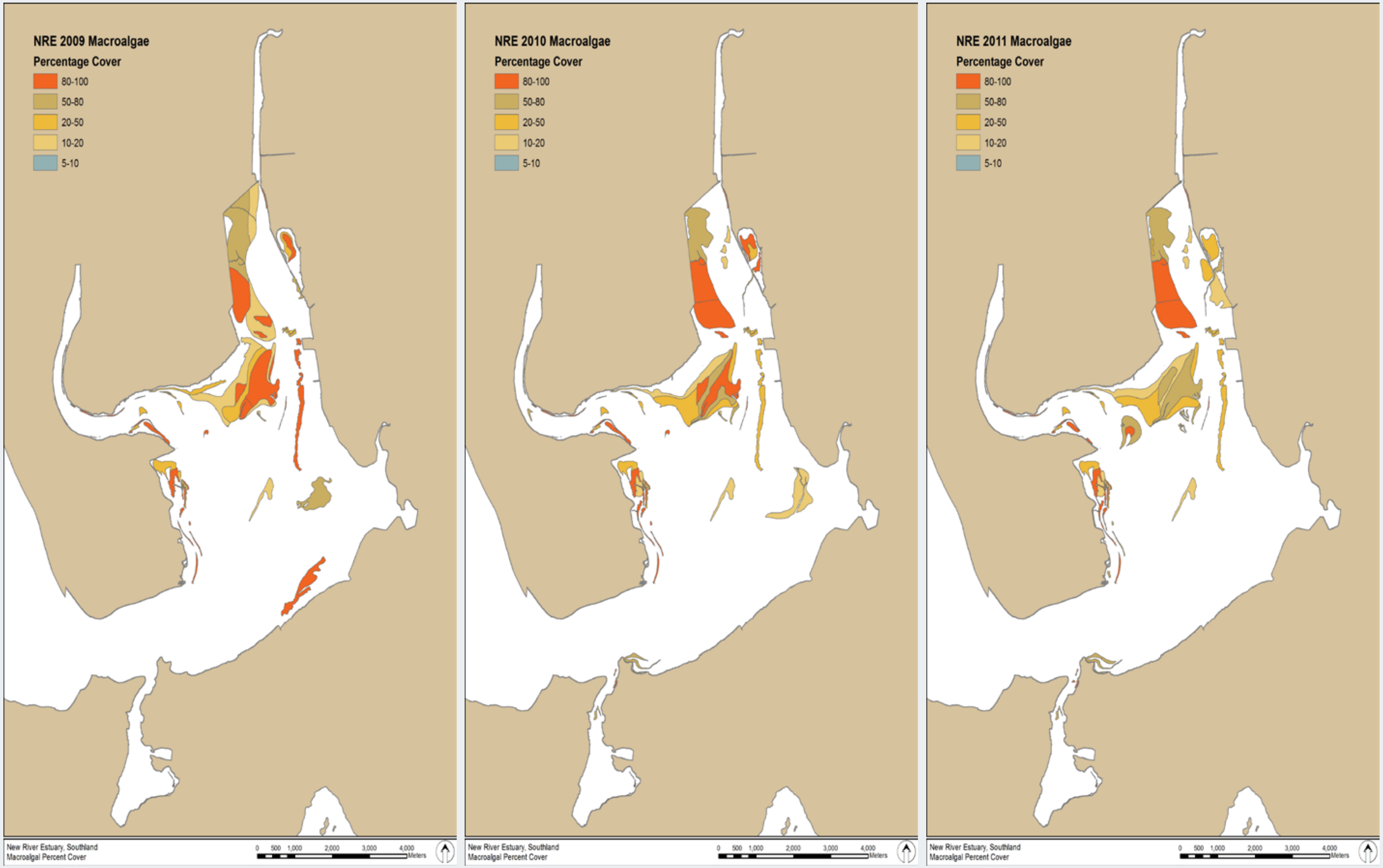


Figure 11b. Map of Macroalgal Percentage Cover - New River Estuary, Feb. 2009, 2010, 2011.

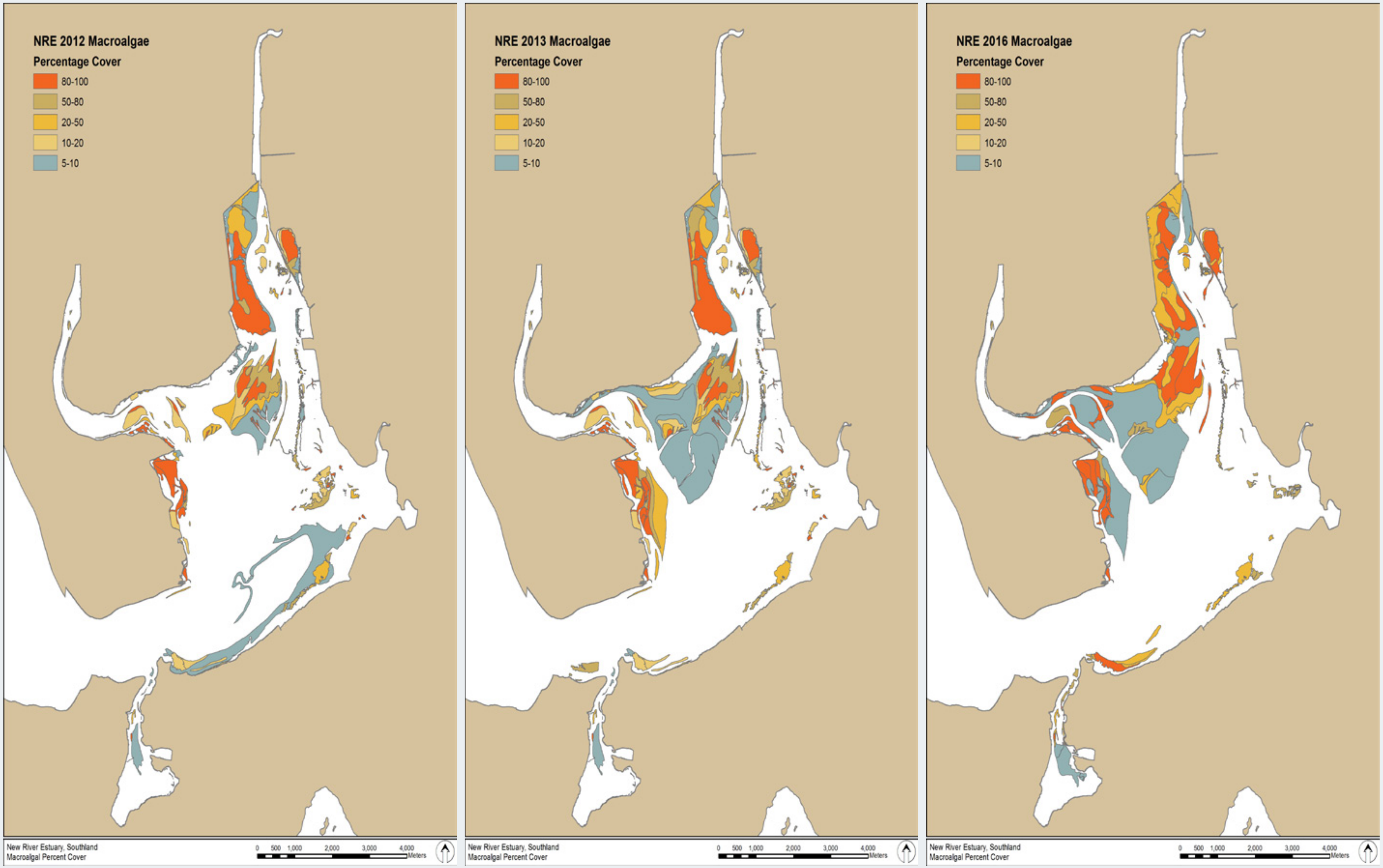


Figure 11c. Map of Macroalgal Percentage Cover - New River Estuary, Feb. 2012, 2013, 2016.

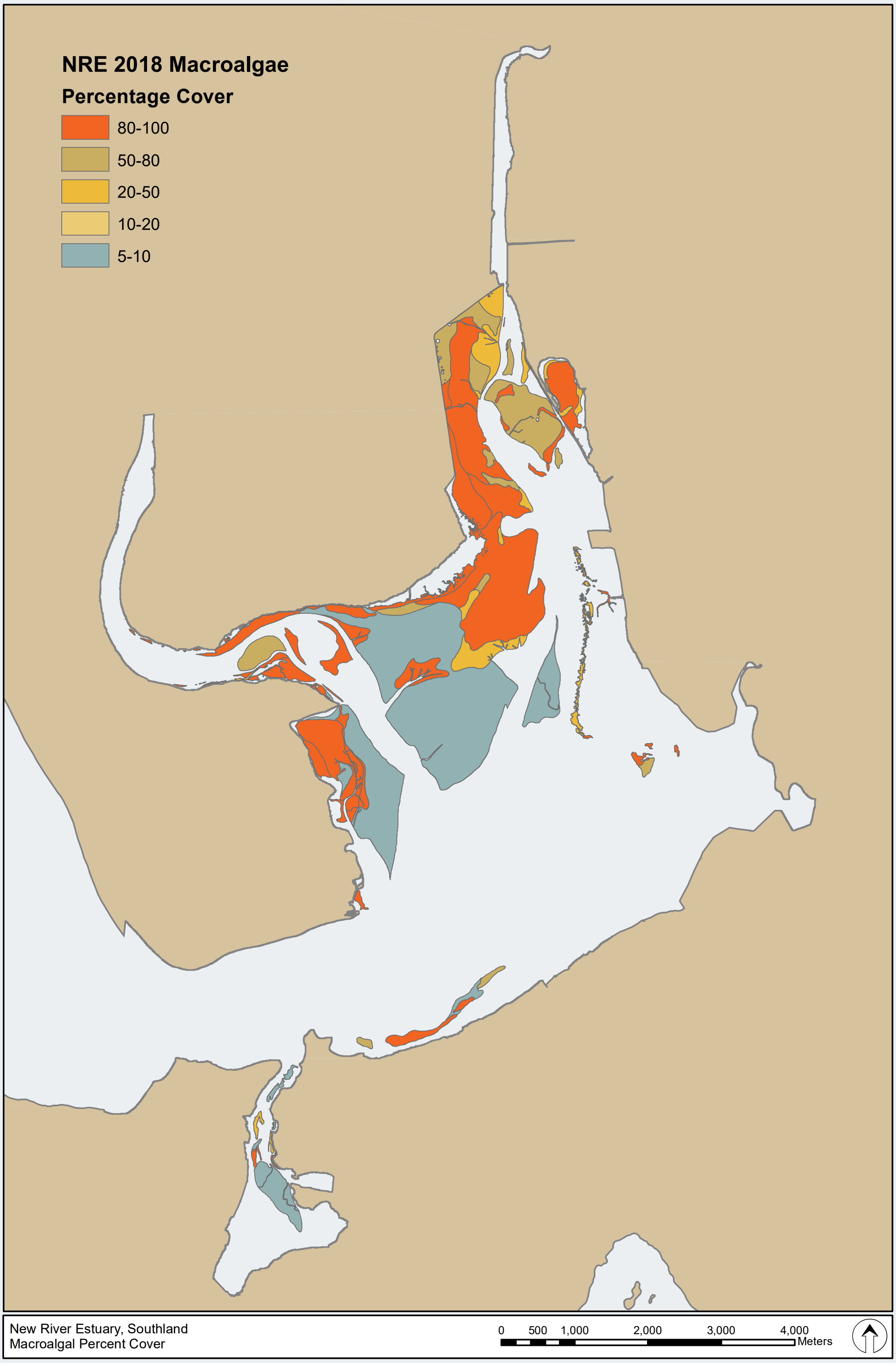


Figure 11d. Map of Macroalgal Percentage Cover - New River Estuary, Feb. 2018.

GROSS EUTROPHIC CONDITIONS

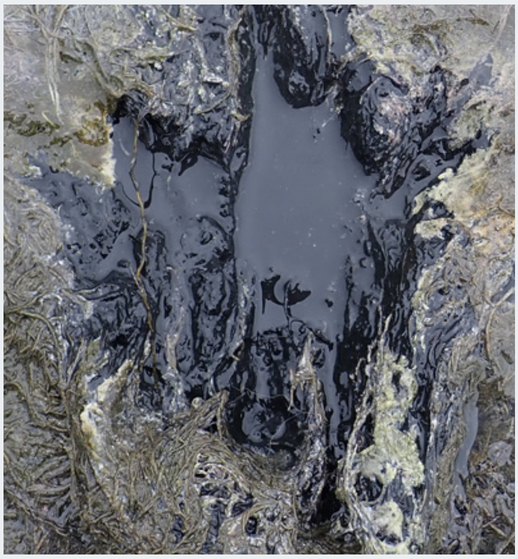
When sediments exhibit combined symptoms of a high mud content, a shallow RPD, elevated nutrient and organic concentrations, and high macroalgal growth (>50% cover), they represent gross eutrophic conditions. These conditions will kill or displace most estuarine animals and shellfish, and also release nutrients previously bound in the sediments. In extreme cases sediment condition deteriorates to such an extent that macroalgae can no longer survive. Released nutrients will predominantly be in the form of ammonia, which is much more readily available to fuel macroalgal growth, supporting a cycle of increasing habitat deterioration that is likely to be difficult to reverse. In New River Estuary, these conditions are most common on sheltered tidal flats which are also those most favourable for the growth of high value seagrass habitat.

Gross eutrophic conditions should not be present in short residence time tidal lagoon estuaries (like New River), with their presence providing a clear signal that the assimilative capacity of the estuary is being exceeded. In 2018, 428ha (15%) of the estuary was classified as being in a significantly ecologically degraded state (Figure 12). The GEZ extent is very large and has expanded greatly since 2001 (Table 4), clearly illustrating consistently worsening conditions over the last 17 years. The most recent expansion in GEZs has been concentrated along the lower reaches of the Oreti River, at Bushy Point, and in the eastern Waihopai Arm. In the western Waihopai Arm where widespread GEZ conditions first established, the high level of hydrogen sulphide and extent of rotting macroalgae is such that there may be human health risks from any prolonged exposure in this part of the estuary.

Figure 12. Location and extent of GEZs in New River Estuary, Feb. 2018.

Table 4. Gross eutrophic intertidal zones, New River Estuary, 2001-2018.

Year	Area (ha)	Percent
2001	23	1%
2007	49	2%
2012	240	8%
2016	351	12%
2018	428	15%



Anoxic sulphide-rich muds in the western Waihopai Arm

SEAGRASS COVER

Mapping of seagrass in conjunction with macroalgae in the Waihopai Arm indicated there has been a further reduction of high value seagrass habitat. Since 2016, dense (>50% cover) seagrass on the western side of Waihopai Arm has been completely displaced by macroalgal growths and muds, while there has been a significant reduction in beds on the eastern side of the Waihopai Arm, with beds buried by soft muds or over grown with macroalgae (see upper photos in Figure 13). Small low density patches remain, but are clearly under significant stress.

Similar losses are occurring to the seagrass beds in the lower Oreti River (see lower photos in Figure 13). Figure 14 highlights the most recent changes in the Waihopai Arm and demonstrate that the estuary is losing important habitat at an alarming rate with a 94% reduction in dense seagrass in the Waihopai Arm from 2001-2018, attributed primarily to smothering by fine sediments and nuisance macroalgal growths that initially established in 2007.

Seagrass beds being smothered by muds and overgrown by *Gracilaria* in the eastern Waihopai Arm.

Seagrass beds being smothered by muds and overgrown by *Gracilaria* in the lower Oreti River.

Figure 13. Seagrass beds impacted by muds and macroalgal growths in the eastern Waihopai Arm and lower Oreti River, Feb. 2018.

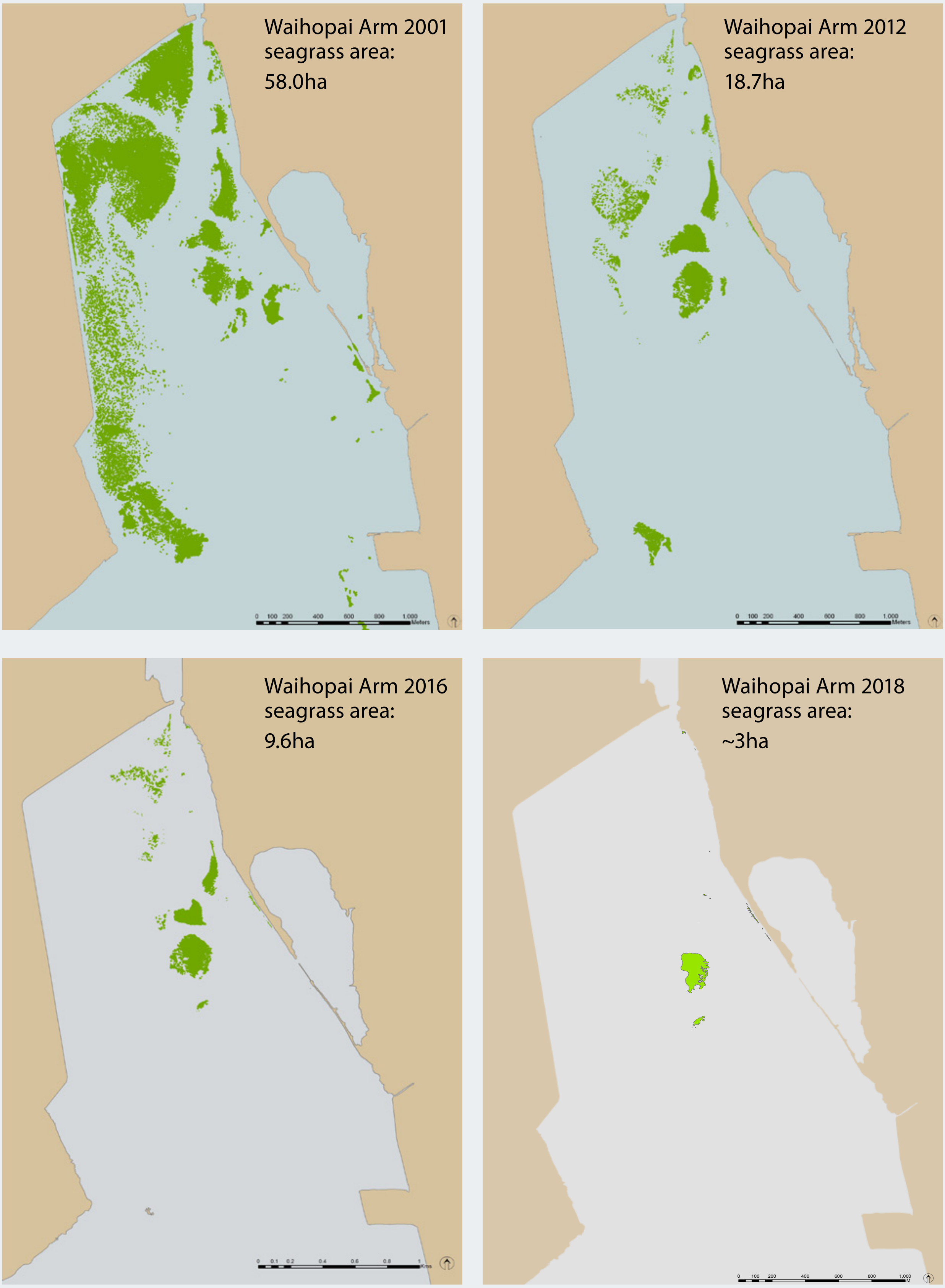


Figure 14. Changes in dense (>50%) seagrass cover in the Waihopai Arm, 2001, 2012, 2016 and 2018.

3. RESULTS AND DISCUSSION (CONT...)

NZ ESTUARY TROPHIC INDEX

The NZ ETI (Robertson et al. 2016a,b) is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness. An integrated online calculator is available [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/] to calculate estuary physical and nutrient load susceptibility (primarily based on catchment nutrient loads combined with mixing and dilution in the estuary), as well as trophic expression based on key estuary indicators [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/]. The more indicators included, the more robust the ETI score becomes. Where established ratings are not yet incorporated into the NIWA ETI online calculator they can be included via spreadsheet calculator.

The indicators used to derive an ETI scores for New River Estuary are presented below using the broad scale monitoring results presented in this report, and Robertson et al. (2017), and raw data collected by ES from Site F in the eutrophic Waihopai Arm in February 2018 (see Figure 1 for site location).

ETI Tool 1 rates the nutrient load susceptibility as HIGH.

ETI Tool 2 rates eutrophic symptom scores as POOR.

The ETI score places New River Estuary at the very extreme end of possible scoring and highlights the widespread eutrophication symptoms in the estuary.

Table 5. Primary and supporting indicator values used to calculate an ETI score for New River Estuary, 2018.

ETI scoring summary for New River Estuary, February 2018.

				Primary Symptom	
PRIMARY SYMPTOM INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)				**Value**	**Score**
Required	Opportunistic Macroalgae	OMBT EQR	shallow intertidal	0.284	13
Required	Macroalgal GEZ %	% Gross Eutrophic Zone (GEZ)/Estuary Area	shallow intertidal	15	13
Required	Macroalgal GEZ Ha	Ha Gross Eutrophic Zone (GEZ)	shallow intertidal	428	16
Optional	Phytoplankton biomass	Chl- a (summer 90 pctl, mg/m^3)	water column	-	
Optional	Cyanobacteria (if issue identified) NOTE ETI rating not yet developed		water column	-	
SUPPORTING INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES (MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)				**Supporting Indicator Value**	**Score**
Required Indicators	Sediment Oxygenation	Mean Redox Potential (mV) at 1cm depth in most impacted sediments and representing at least 10% of estuary area	shallow intertidal	-402	15
Required Indicators	Sediment Oxygenation	% of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow intertidal	15	13
Required Indicators	Sediment Oxygenation	Ha of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow intertidal	423	16
Required Indicators	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area	shallow intertidal	3.5	14
Required Indicators	Sediment Total Nitrogen	Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area	shallow intertidal	4400	16
Required Indicators	Macroinvertebrates	Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area	shallow intertidal	4.3	13
Optional Indicators	Muddy sediment	Proportion of estuary area with >25% mud content	shallow intertidal	0.27	16
Optional Indicators	Sedimentation Rate	Ratio of mean annual Current State Sediment Load (CSSL) relative to mean annual Natural State (NSSL)	shallow intertidal	-	
Optional Indicators	Dissolved oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case conditions) ($mg.m^3$)	water column	-	
NZ ETI Score		**Final Primary Indicator Score**			16
		Final Supporting Indicator Score			14.7
			ETI SCORE	**0.96**	
			ETI BAND	**POOR**	

4. SUMMARY AND CONCLUSIONS

The 2018 broad scale macroalgal mapping results show that while large sections of the well flushed lower estuary remain in good condition, since 2016 there has been a significant increase in macroalgal growth, and an associated decline in estuary quality, in the upper estuary. Overall, the red alga *Gracilaria* was the dominant species present, with the green alga *Ulva 'intestinalis'* common along channel margins and on the root systems of sprayed *Spartina* beds (which remain largely intact), and *Ulva 'lactuca'* (sea lettuce) most common on sandy flats near Bushy Point and Omaui.

The NZ ETI score of 0.96 indicates the estuary is significantly impacted by eutrophic conditions. Ecological condition has consistently declined since monitoring commenced in 2001, and particularly since 2007. The area of the estuary with gross eutrophic conditions has expanded significantly from 23ha in 2001, to 428ha in 2018. This has caused a very significant loss of dense (>50% cover) seagrass from the estuary (94% loss in the Waihopai Arm), while the macroinvertebrate community in these GEZ areas is severely degraded (little animal life is able to establish in the anoxic sediments, and surface feeding species are few in number and limited to those tolerant of poor conditions). Such conditions limit the food availability for fish and birdlife, and show the capacity of the estuary to assimilate nutrient and sediment loads from the catchment is currently exceeded.

The western Waihopai Arm is the worst impacted, with sediment conditions so degraded that nuisance macroalgae are now dying off due to the over-enriched sediment conditions present. Macroalgal cover and biomass has increased and high value seagrass habitat has been displaced. The eastern Waihopai Arm has also experienced a large increase in macroalgal growth and associated seagrass losses from 2016 to 2018.

Further towards the Oreti River, extensive macroalgal beds have increased in size around Bushy Point trapping fine sediment and making the previously sandy and relatively well oxygenated sediments muddier and less oxygenated. The nearly complete blanketing of the sediment surface with thick macroalgal growths is having significant adverse impacts to underlying macrofauna including shellfish.

Within the lower reaches of the Oreti River, previously well flushed substrate along the channel edge that supported many seagrass beds is now dominated by dense beds of sediment entrained *Gracilaria*. This is displacing seagrass and, as above, is leading to significant negative changes in sediment condition through increased smothering and muddiness, and decreased oxygenation.

Daffodil Bay remains heavily impacted by dense growths, and while it has not experienced large increases in the extent of macroalgal cover since 2016, beds are predominately associated with soft, muddy, anaerobic, and sulphide and organic rich sediments and are in poor condition.

In short, the estuary is exhibiting significant problems associated with excessive nutrient fuelled nuisance macroalgal growth and likely represents the largest impact of this type to have occurred in a NZ SIDE estuary. Unless nutrient inputs to the estuary are reduced significantly, it is expected that there will be a continuation of these very difficult to reverse adverse impacts in the estuary.

5. MONITORING

New River Estuary has been identified by Environment Southland as a high priority for monitoring, and is a key part of their coastal monitoring programme being undertaken in a staged manner throughout the Southland region. Monitoring recommendations for the estuary are as follows:

Macroalgal and Seagrass Monitoring

Continue with the programme of annual broad scale mapping of macroalgae. Next monitoring recommended for February 2019. It is noted that monitoring has shifted from that of problem detection to documenting the extent of the issue. In addition, to assess changes in seagrass cover (particularly in the Waihopai Arm), it is recommended that seagrass cover be monitored annually in priority areas in tandem with the macroalgal monitoring.

Broad Scale Habitat Mapping

Continue with the programme of 5 yearly broad scale habitat mapping. In light of targeted monitoring undertaken in 2016 and 2018, full monitoring is next recommended in February/March 2021.

5. MONITORING (CONT...)

Sedimentation Rate Monitoring

Because sedimentation is a priority issue in the estuary it is recommended that existing sediment plate depths be measured annually, and a single composite sediment sample be analysed for grain size at each site. In addition, it is recommended that the number of plates deployed in the estuary be expanded to include deposition zones in the eastern Waihopai Arm, Bushy Point and Daffodil Bay.

Fine Scale Monitoring

Fine scale monitoring recommendations are provided in Robertson and Robertson (2018).

6. MANAGEMENT

Eutrophication and sedimentation have been identified as major issues in New River Estuary since at least 1973 (Blakely 1973), with worsening conditions reported since 2007-2008 (Robertson and Stevens 2007, 2008), as has been the case for several other Southland estuaries (e.g. Jacobs River, Waimatuku and Waituna Lagoon).

Previous recommendations (e.g. Robertson and Stevens 2011, 2012, 2013, Stevens and Robertson 2011, 2012, 2013) are reiterated for the prioritised development of catchment nutrient and sediment guideline criteria for each estuary type in Southland, to derive thresholds protecting against adverse sediment and nutrient impacts. New River Estuary was identified as the first priority for this work because of its current extent and rate of degradation. The 2018 results emphasise the importance and priority of this work which ES has commenced (Robertson et al. 2017).

7. ACKNOWLEDGEMENTS

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Bushy Point Feb. 2018

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APPENDIX 1. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5 part multimetric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5 part multimetric OMBT, modified for NZ estuary types, is fully described below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of ***mud, muddy sand, sandy mud, sand, stony mud and mussel beds***. Areas which are judged unsuitable for algal blooms e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:.

1. Percentage cover of the available intertidal habitat (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH where macroalgal cover >5% are mapped spatially.

2. Total extent of area covered by algal mats (affected area (AA)) or affected area as a percentage of the AIH (AA/AIH, %).

In large water bodies with proportionately small patches of macroalgal coverage, the rating for total area covered by macroalgae (Affected Area - AA) might indicate high or good status, while the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities. In order to account for this, an additional metric established is the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the waterbody. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse case scenario.

3. Biomass of AIH ($g.m^{-2}$).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded.

For quality assurance of the percentage cover estimates, two independent readings should be within +/- 5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. Measures of biomass should be calculated to 1 decimal place of wet weight of sample. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

4. Biomass of AA ($g.m^{-2}$).

Mean biomass of the Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.

5. Presence of Entrained Algae (percentage of quadrats).

Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool.

All the metrics are equally weighted and combined within the multimetric, in order to best describe the changes in the nature and degree of opportunist macroalgae growth on sedimentary shores due to nutrient pressure.

Timing: The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in summer (Dec-March), although peak timing may vary among water bodies, so local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification; e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

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Suitable Locations: The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing ICOLLs due to the particular challenges in setting suitable reference conditions for these water bodies.

Derivation of Threshold Values.

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A1).

- **Reference Thresholds.** A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this adverse effects were not seen, so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of the natural community functioning.

  The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g m^{-2} wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed.

  An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.
- **Class Thresholds for Percent Cover:**

  High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.

  Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).

  Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).
- **Class Thresholds for Biomass.** Class boundaries for biomass values were derived from DETR (2001) recommendations that <500 $g.m^{-2}$ wet weight was an acceptable level above the reference level of <100 $g.m^{-2}$ wet weight. In Good status only slight deviation from High status is permitted so 500 $g.m^{-2}$ represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500 $g.m^{-2}$ but less than 1,000 $g.m^{-2}$ would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1$kg.m^{-2}$ wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).
- **Thresholds for Entrained Algae.** Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

Each metric in the OMBT has equal weighting and is combined to produce the ecological quality ratio score (EQR).

Table A1. The final face value thresholds and metrics for levels of the ecological quality status

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) of >5% macroalgae (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass ($g.m^2$) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass ($g.m^2$) of AA	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation.

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EQR calculation

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Ratio** score (EQR).
The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the following categories:

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2

The EQR calculation process is as follows:

1. Calculation of the face value (e.g. percentage cover of AIH) for each metric. To calculate the individual metric face values:

- Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 - *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*
- Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%).
- Biomass of AIH ($g.m^{-2}$) = Total biomass / AIH - *where Total biomass = Sum of (patch size x average biomass for the patch)*
- Biomass of Affected Area ($g.m^{-2}$) = Total biomass / AA - *where Total biomass = Sum of (patch size x average biomass for the patch)*
- Presence of Entrained Algae = (No. quadrats with entrained algae / total no. of quadrats) x 100
- Size of AA in relation to AIH (%) = (AA/AIH) x 100

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A2).

The face values are converted to an equidistant EQR scale to allow combination of the metrics. These steps have been mathematically combined in the following equation:

Final Equidistant Index score = Upper Equidistant range value – ({Face Value - Upper Face value range} * (Equidistant class range / Face Value Class Range)).

Table A2 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range.
Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.
The final EQR score is calculated as the average of equidistant metric scores.
Table A3 presents the modified face value thresholds reflecting monitoring results for NZ estuaries used in the current study.
A spreadsheet calculator is available to download from the UK WFD website to undertake the calculation of EQR scores.

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APPENDIX 1. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

Table A2. Values for the normalisation and re-scaling of face values to EQR metric.

METRIC	QUALITY STATUS	FACE VALUE RANGES			EQUIDISTANT CLASS RANGE VALUES		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH (g m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) (g m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

Table A3. The final face value thresholds and metrics for levels of the ecological quality status used to rate opportunistic macroalgae in the current study (modified from UK-WDF 2014).

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) of >5% macroalgae (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^2) of AIH	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g.m^2) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation.

APPENDIX 2. MACROALGAL DATA USED IN THE OMBT

Figure A1. Location of macroalgal patches >5% cover used in assessing New River Estuary, Feb. 2018.

APPENDIX 2. MACROALGAL DATA USED IN THE OMBT (CONT...)

Patch ID	Dominant species	Patch area (ha)	Percent cover of macroalgae	Presence (1) or absence (0) of entrained algae	Mean Biomass (g.m-2 wet weight)	Total Patch Biomass (kg wet weight)	aRPD depth (cm)	Presence (1) or absence (0) of soft mud
1	grch ulla	25.0	2	0	15	3754	5	0
2	grch	1.6	80	1	9010	143648	1	1
3	grch	0.7	5	1	50	366	0	1
4	grch ulla	0.4	100	0	2000	7640	0	0
5	grch ulla	0.8	20	0	120	948	2	0
6	grch	0.1	100	1	1500	1207	0	1
7	grch ulin	0.3	10	0	110	308	2	0
8	ulla grch	3.1	5	0	20	627	3	0
9	ulla grch	2.0	20	0	200	3963	2	1
10	grch	2.1	50	0	80	1658	2	0
11	grch	11.1	80	1	3000	334437	5	0
12	grch	5.0	10	0	60	3009	5	0
13	grch	3.0	50	1	3520	106998	5	0
14	grch	3.1	100	1	8730	271327	1	1
15	grch	3.0	50	1	170	5119	2	0
16	grch ulla	0.4	100	0	3500	14721	2	0
17	grch ulla	30.9	10	0	1500	464123	0	0
18	ulla	10.1	20	0	80	8102	1	1
19	grch	1.2	80	1	1200	14299	1	0
20	grch	5.5	80	1	10000	548046	0	1
21	grch	1.9	50	1	2000	37553	1	1
22	grch	1.4	100	1	8000	108552	1	1
23	grch	4.5	100	1	10000	449376	1	1
24	grch	55.8	50	1	5000	2787936	1	1
25	grch	0.3	80	1	6500	22546	1	1
26	grch	2.9	25	1	2200	64553	1	1
27	grch	3.7	50	1	1800	67435	1	1
28	grch	28.5	20	1	500	142545	1	1
29	grch	35.0	50	1	2350	821811	1	1
30	grch	77.9	90	0	9500	7397056	0	0
31	grch	2.8	100	1	4480	127145	1	1
32	grch	23.5	80	1	30000	7039781	1	1
33	grch	27.9	80	1	8800	2457463	1	1
34	grch	2.5	40	1	1000	25218	1	1
35	grch	1.3	20	1	1200	15044	1	0
36	grch	10.4	80	1	6500	674206	1	1
37	grch	2.3	50	1	3000	67922	2	0
38	grch	4.0	20	1	900	36158	3	0
39	grch	21.6	25	1	950	205665	3	0
40	grch	35.7	80	1	7500	2676785	1	1
41	grch	15.1	90	1	6500	983010	1	1
42	grch	6.7	50	0	500	33397	3	0
43	grch	6.7	80	1	2500	166307	1	1
44	grch ulla	300.8	5	0	80	240648	3	0
45	grch	0.8	80	1	50	419	1	1
46	grch	0.3	80	1	4000	10768	1	1
47	ulla	0.4	10	0	80	287	5	0
48	ulla grch	0.7	20	0	150	1083	5	1
49	grch	4.1	80	1	6000	245469	0	1
50	grch	7.7	100	1	40000	3068629	0	1
51	grch	3.1	100	1	6500	198599	0	0
52	grch	16.6	50	1	3500	580049	3	0
53	grch ulla	1.5	100	1	30400	454719	0	1
54	grch	0.5	10	1	650	3470	1	0
55	grch	0.6	80	1	8000	44498	1	0
56	grch	44.3	100	1	5150	2279309	0	1
57	grch	7.3	80	1	4000	293938	0	0
58	grch	8.9	80	1	2010	179386	1	1
59	grch	1.9	80	1	1520	28309	1	1
60	grch	89.0	5	0	120	106793	3	0
61	grch	1.8	100	1	3800	67034	0	1
62	grch	6.7	50	1	3040	204024	1	1
63	grch	143.8	100	1	6500	9346957	1	1

grch= *Gracilaria chilensis*, ulla= *Ulva lactuca*, ulin=*Ulva intestinalis*

APPENDIX 3. MACROALGAL DATA FROM DEFINED LOCATIONS

Fixed point macroalgal sampling details, New River Estuary, Feb. 2018.

ID	Estuary	Transect	Site	%cover	w.w(g)	x	bag(g)	g/m2	Sp	NZTM_E	NZTM_N	Sed	aRPD(cm)	Note	Date	Label
0	NRE	T1	0	50	210	16	70	2240	Grch	1240915	4847610	vsm	0.5	Stead Street end of Waihopai - near road	18-24/2/2018	T10
1	NRE	T1	1	90	1040	16	150	14240	Grch	1240976	4847622	vsm	0.5	Stead Street end of Waihopai - near sed pla	18-24/2/2018	T11
2	NRE	T1	2	90	750	16	80	10720	Grch	1241162	4847660	vsm	0.5	Stead Street end of Waihopai - halfway to ch	18-24/2/2018	T12
3	NRE	T1	3	50	220	16	70	2400	Grch	1241298	4847683	vsm	0.5	Stead Street end of Waihopai - near channe	18-24/2/2018	T13
4	NRE	T2	0	100	380	16	100	4480	Grch	1240847	4847429	vsm	0.5	Nth sed plate site - near accessroad	18-24/2/2018	T20
5	NRE	T2	1	90	600	16	100	8000	Grch	1240975	4847462	vsm	0.5	Nth sed plate site RR1	18-24/2/2018	T21
6	NRE	T2	2	50	210	16	100	1760	Grch	1241199	4847438	vsm	1	Nth sed plate site - halfway to channel	18-24/2/2018	T22
7	NRE	T2	3	50	280	16	100	2880	Grch	1241333	4847468	sm	1	Nth sed plate site - near channel	18-24/2/2018	T23
8	NRE	T3	0	50	605	16	80	8400	Grch	1240989	4846355	vsm	0.5	RR2 sed plate site - near access road	18-24/2/2018	T30
9	NRE	T3	1	90	630	16	80	8800	Grch Ulin	1241151	4846412	vsm	0.5	RR2 sed plate site RR2	18-24/2/2018	T31
10	NRE	T3	2	100	450	16	80	5920	Grch	1241301	4846425	vsm	0.5	RR2 sed plate site - halfway to channel	18-24/2/2018	T32
11	NRE	T3	3	70	270	16	80	3040	Grch	1241455	4846440	vsm	0.5	RR2 sed plate site - near channel	18-24/2/2018	T33
12	NRE	T4	1	10	580	16	0	9280	Grch	1241304	4845576	vsm	0.5	Sth sed plate site - near access road	18-24/2/2018	T41
13	NRE	T4	2	75	410	16	0	6560	Grch	1241473	4845722	vsm	1	Sth sed plate site RR2	18-24/2/2018	T42
14	NRE	T4	3	100	2100	16	0	33600	Grch	1241641	4845815	vsm	0	Sth sed plate site - halfway to channel	18-24/2/2018	T43
15	NRE	T4	4	25	60	16	0	960	Grch	1241660	4845843	vsm	1	Sth sed plate site - near channel	18-24/2/2018	T44
16	NRE	Bu	1	90	410	16	100	4960	Grch	1241765	4845090	sm	0.5	Nth end of Bushy Point Bed	18-24/2/2018	Bu6
17	NRE	Bu	2	100	480	16	0	7680	Grch	1241297	4844534	sm	0.5	Centre of Bushy Point Bed	18-24/2/2018	Bu5
18	NRE	Bu	3	100	1450	4	0	5800	Grch	1241209	4844204	fms	2	Sth end of Bushy Point Bed	18-24/2/2018	Bu4
19	NRE	OTL	1	90	1660	4	120	6160	Grch	1238360	4844251	fsm	0.5	Upstream at lower end of confined channel	18-24/2/2018	Bu3
20	NRE	OTL	2	75	650	4	40	2440	Grch	1239615	4844340	fms	1	Downstream of Oreti channel widening	18-24/2/2018	Bu2
21	NRE	OTL	3	50	190	4	55	540	Grch	1239948	4844408	fms	3	North of fine scale site	18-24/2/2018	Bu1
22	NRE	OTR	1	100	375	16	0	6000	Grch	1238610	4843544	vsm	0	Upstream at lower end of confined channel	18-24/2/2018	Oreti1
23	NRE	OTR	2	100	1250	32	0	40000	Grch	1238896	4843516	fms	0	Downstream of Oreti channel widening	18-24/2/2018	Oreti2
24	NRE	OTR	3	100	950	32	0	30400	Grch	1239161	4843323	vsm	0	Highly sulphitic drift algal accumulation	18-24/2/2018	Oreti3
25	NRE	D1	1	100	400	16	65	5360	Grch	1239095	4842843	vsm	0	Daffodil Bay north	18-24/2/2018	D11
26	NRE	D1	2	100	230	16	60	2720	Grch	1239106	4842773	vsm	0	Daffodil Bay	18-24/2/2018	D12
27	NRE	D1	3	100	180	16	45	2160	Grch	1239144	4842598	vsm	0	Daffodil Bay	18-24/2/2018	D13
28	NRE	D1	4	100	530	16	60	7520	Grch Ulla	1239191	4842447	vsm	0	Daffodil Bay	18-24/2/2018	D14
29	NRE	D1	5	90	190	16	55	2160	Grch	1239235	4842318	vsm	0	Daffodil Bay	18-24/2/2018	D15
30	NRE	D1	6	100	880	16	60	13120	Grch	1239265	4842221	vsm	0	Daffodil Bay	18-24/2/2018	D16
31	NRE	D1	7	100	265	16	75	3040	Grch	1239351	4842130	vsm	0	Daffodil Bay south	18-24/2/2018	D17
32	NRE	D1	8	80	125	16	0	2000	Grch	1239400	4841827	vsm	0	Whalers Bay north	18-24/2/2018	D18
33	NRE	D1	9	80	95	16	0	1520	Grch	1239456	4841569	vsm	0	Whalers Bay south	18-24/2/2018	D19
34	NRE	SP	1	80	250	16	0	4000	Grch	1239665	4840557	vsm	1	Sandy Point	18-24/2/2018	SP1
35	NRE	SP	2	80	260	16	0	4160	Grch	1239672	4840467	vsm	0	Sandy Point	18-24/2/2018	SP2
36	NRE	SP	3	80	200	16	0	3200	Grch	1239773	4840360	vsm	0.5	Sandy Point	18-24/2/2018	SP3
37	NRE	Sb	1	80	550	16	70	7680	Grch Ulla	1243498	4842375	sm	1	east of shellbanks	18-24/2/2018	Sb1
38	NRE	Sb	2	80	220	16	0	3520	Grch	1241427	4839417	ms	5	opposite deer farm	18-24/2/2018	Sb2
39	NRE	Mok	1	90	570	16	110	7360	Grch	1238248	4836955	vsm	0.5	dense bed near Mokomoko carpark	18-24/2/2018	Mok1

grch= *Gracilaria chilensis*, ulla= *Ulva lactuca*, ulin=*Ulva intestinalis*
fms=firm muddy sand, fsm=firm sandy mud, ms=mobile sand, sm=soft mud, vsm=very soft mud,

APPENDIX 4. NEW RIVER ESTUARY
GROUND TRUTHING AND LOCATION OF FIELD PHOTOS

Figure A2. Ground truthing extent and location of field photos New River Estuary, Feb. 2018.