New River Estuary
Review of Water Quality Data in Relation to Eutrophication 1991-2015

Prepared for Environment Southland by
NIWA and Wriggle Coastal Management

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EXECUTIVE SUMMARY

In order to address issues of eutrophication and sedimentation identified through Environment Southland's (ES's) regular long-term estuary monitoring programme, ES have established an over-arching Estuary Health Programme (EHP). To set the initial scene and provide a foundation for more focused effort, NIWA and Wriggle Coastal Management were contracted to analyse relevant available estuary water quality data in order to assess any trends in the trophic condition.

A very comprehensive set of water column data were available for New River Estuary from monitoring undertaken by Invercargill City Council (ICC) for the period 1991-2015. Over this period ICC collected monthly data at both high and low water from seven shallow sites within the estuary and two marine dominated sites at Omaui and Oreti Beach. Data were used to:

- Assess the eutrophication status of the water column (e.g. chlorophyll *a*).
- Identify if nutrient concentrations in the water column exceed criteria that can cause algal blooms, particularly benthic macroalgal blooms in shallow intertidal dominated estuaries (SIDEs).
- Identify any trends in concentrations that can then be used in relation to trends in eutrophication/sedimentation symptoms.
- Screen for which nutrient is likely to be in shortest supply and potentially limiting to algal growth using the N/P ratio (where both N and P concentrations are available).

A primary aim for the use of these data was to establish relationships between trends in water quality from 1991 to 2015, and trends in estuarine trophic condition over the same time period to help address a known knowledge gap regarding whether nutrient concentrations are a reliable indicator of estuary trophic condition, or whether sediment nutrient indicators are also required.

Eutrophication status of the water column (chlorophyll *a*)

In overview, the chlorophyll *a* concentration data indicate that the main body of the New River Estuary had phytoplankton levels indicating slight to moderate eutrophication impacts in the water column. However, because there were regular high levels of chlorophyll *a* in the upper estuary (particularly the Waihopai Arm) during summer each year, localised high eutrophication impacts appear to be occurring. The cause of the high concentrations could not be confirmed, but was likely to be either from outside sources (i.e. upstream freshwater algae) or a result of localised poor flushing (i.e. stratification), and local retention of high nutrient loads.

Recommendation

Identifying all causes and locations of eutrophic symptoms is a priority for setting of load criteria for SIDE estuaries. Consequently, it is recommended that identifying the cause of the elevated chlorophyll *a* concentrations in the upper Waihopai Arm of the New River Estuary be undertaken in the near future. It is envisaged that the assessment would address:

- The possibility of "localised poor flushing" causing the high concentrations. It is recommended that the recently developed hydrodynamic model for the estuary is used to assess stratification and residence time of water at the Stead Street Bridge site, supported by synoptic sampling.
- The possibility of "outside sources" causing the high concentrations. It is recommended that phytoplankton identifications be included in any future monitoring at this site in order to assess the ratio of estuarine to freshwater phytoplankton, and phytoplankton and macroalgal growth.

Water Nutrient Concentrations

- **Which Nutrient To Target for Load Reductions?**

  Seawater N:P ratios, or the dissolved inorganic N:P ratio (DIN:DIP) provide, at best, a rough guide to which nutrient (N or P) might be limiting for algal growth because nutrient uptake differs between various types of plants and with various physical, chemical and biological factors. Within this caveat, the N:P ratios that indicate a transition from N limitation to combined N + P limitation (rather than single limitation by P) for phytoplankton are 16:1 (Redfield et al. 1963, Ptacnik et al. 2010, Hillebrand & Sommer, 1999), for marine angiosperms 20:1 (Duarte 1992), and for macroalgae 30:1, with ratios ranging between 10:1 and 80:1 (Atkinson and Smith, 1983). Bearing in mind the limitations noted above and that macroalgae may potentially be co-limited by N and P within the range of ratios mentioned, the simplistic approach used for assessing DIN and DRP concentrations for potential nutrient limitation in macroalgal dominated estuaries in the current report was:

- A DIN:DRP ratio <30:1 was used to indicate DRP is relatively abundant and macroalgae are likely N-limited.
- A DIN:DRP ratio >30:1 was used to indicate DIN is relatively abundant and macroalgae are likely P-limited.

Executive Summary (continued)

The only real way to know which nutrient limits growth of a given species is to add nutrients and see if the algae grows faster.

Water column results from the summer (Oct-May) period were considered to be the most ecologically important given that macroalgal growth rates were likely to be highest at this time. Water quality results from 1991-2015 from representative upper estuary sites (i.e. Stead Street and Dunns Road) showed mean summer DIN:DRP ratios were mostly in the 5-50:1 range, indicating that theoretically both P and N were generally limiting in the upper estuary. In contrast, in the mid and lower estuary, mean summer DIN:DRP ratios were mostly less than 25:1 indicating that theoretically N was generally limiting.

If water column nutrients were considered to be the major driver of eutrophic symptoms in New River Estuary, these results would support the view that reducing N concentrations was of primary importance for managing macroalgal growth in the main body of the estuary, but both nutrients should be considered important for managing macroalgal growth and water column blooms in the upper estuary.

Recommendation

Because different nutrient management strategies may be needed for N and P it is recommended that macroalgal tissue nutrient concentrations be measured over the growing season in order to provide a more robust assessment of nutrient limitation and therefore which nutrient to target to limit nuisance algal growth.

- **N Concentrations in Relation to Condition Thresholds**

  Results showed that dissolved inorganic nitrogen (DIN) concentrations in both upper estuary arms (Waihopai and Oreti) almost always greatly exceeded thresholds above which the appearance of slight to moderate eutrophic symptoms are reported (Band B-C boundary in the ETI - 0.2mg/L TN or about 0.17mg/L DIN), with winter values being generally greater than summer values. In the mid and lower estuary, mean summer values were often less than available thresholds for expression of eutrophic symptoms, but winter values were generally greater.

- **P Concentrations**

  Dissolved reactive phosphorus (DRP) concentrations were generally greatest in the upper estuary Waihopai Arm, Stead Street Bridge site (the site with the highest chlorophyll *a* concentrations in New River Estuary for 1991 to 2015), slightly less in the Oreti Arm Dunns Road Bridge site, and slightly less again at the mid estuary McCoys and lower estuary Awarua sites.

- **Trends in Chlorophyll and Nutrient Concentrations**.

  The results of the trend analysis of 7 relevant New River Estuary sites over the period 1991-2015 (including both high and low water data) showed small "ecologically important" trends at some sites (particularly upper estuary sites) for nitrate N, DIN, TP and DIN:DRP ratios and no "ecologically important" trend for chlorophyll *a*, ammoniacal-N, and DRP. Of particular significance was the dominance of winter nitrate and DIN concentrations as the main driver of the positive trends at most sites. The fact that TP concentrations showed consistent trends for winter, summer, and all year data at all estuary sites (2-5% increase per year between 1991 and 2015) was particularly significant when considered alongside the relatively stable or decreasing trends in DRP at most estuary sites over the same period. Such findings indicate that the particulate P fraction (i.e. P bound to fine sediment particles) was likely driving the increasing trend in TP, which provides support to the assumption that fine sediment loads to the estuary have likely increased over the same period and resulted in greater sedimentation rates. Unfortunately, total nitrogen (TN), which would enable some quantification of the particulate N fraction, was not measured and therefore was not available to provide greater support for this assumption.

In the absence of TN results for the estuary, a potential use of the ICC water quality data that ES may like to consider following up, is to use it within a predictive model of the estuary to derive estimates for TN loads to the estuary or to create DIN concentration/DIN load relationships for the full period of which data are available i.e. 1991-2015 (or earlier if possible). Such relationships will be useful in identifying DIN concentration versus macroalgal response relationships if any, and comparing them with TN load/ecological response relationships.

For example, if a model can be shown to accurately predict the measured ICC results, it may be possible to run the model backwards (i.e. back calculate) so that the ICC estuary water quality concentrations can be used to derive the annual input loads that produce the measured concentrations. Ideally, the model would include a derived relationship between TN and DIN (based on current state measures) and therefore be capable of predicting TN loads over the 1991-2015 period.

NEW RIVER ESTUARY WATER QUALITY

In order to address issues of eutrophication and sedimentation identified through Environment Southland's (ES's) regular long-term estuary monitoring programme, ES have established an over-arching Estuary Health Programme (EHP). To set the scene and provide a foundation for more focused effort, NIWA and Wriggle Coastal Management were contracted to analyse relevant available New River Estuary water quality data in order to assess any trends in the trophic condition.

Apart from New River Estuary, data on water quality in Southland shallow intertidal dominated estuaries (SIDEs) are very limited. This is generally because the primary symptoms of key issues in such estuaries (i.e. eutrophication, sedimentation, toxicity and habitat change) manifest in the bed of the estuary, rather than in the well-flushed water column, and as such water column monitoring has not been a monitoring priority. However where data are available, water column data can be very useful as a means of assessing the following aspects of eutrophication:

1. Confirming the eutrophication status of the water column (e.g. high chlorophyll-a levels that reflect phytoplankton blooms and high dissolved nutrient levels).
2. Identifying if nutrient concentrations in the water column exceed criteria that can cause macroalgal and phytoplankton blooms in SIDE estuaries.
3. Where an historical record is available, identifying any trends in concentrations that can then be used in relation to trends in eutrophication/sedimentation symptoms.
4. Where both N and P concentrations are available, using the N/P ratio to screen for which nutrient is likely to be in shortest supply and potentially limiting to algal growth.

Our aim was to establish relationships between trends in water quality in New River Estuary from 1991 to 2015, and trends in estuarine trophic condition over the same time period, to address a known knowledge gap in relation to whether nutrient concentrations are a reliable indicator of estuary trophic condition.

1. METHODS

Sampling
The only available water quality data for Southland SIDE estuaries are for the New River Estuary, which Invercargill City Council (ICC) Laboratory have monitored regularly since at least 1991. The 1991-2015 data were collected from 8 shallow sites within the estuary and 1 site on Oreti Beach (Figure 1). Samples were collected at monthly intervals, at both high and low water. Sites were located in the:

- upper estuary (Stead Street, Tip Outlet, Dunns Road and Ski Club),
- mid estuary (McCoys),
- lower estuary (Sandy Point, Awarua, and Omaui), and
- Oreti Beach (a high salinity coastal marine site).

Sites were sampled approx 0.5m below the water surface, either from a bridge where available or by wading from the shore. Parameters measured included; temperature (T), dissolved oxygen (DO), conductivity, nitrate-N (NO_3-N), ammoniacal-N (ammonia NH_3-N) ammonium (NH_4-N), dissolved inorganic-N (DIN), total coliforms, faecal coliforms, enterococci, total phosphorus (TP), dissolved reactive phosphorus (DRP) and chlorophyll *a* (chl-*a*). Sample handling and analytical procedures are available from the ICC laboratory.

Trend Analysis
For this report, given the focus on nutrients and sediment only, the trend analysis was undertaken on the following variables; NH_3/NH_4-N (mg/l), faecal coliforms/100ml, NO_3-N (mg/l), TP (mg/l), DRP (mg/l), chl-*a* (mg/l), DIN (mg/l) and DIN:DRP.

The trend analysis component followed the two-step procedure outlined in McBride et al. (2014, 2015) in which we ask: (a) can we confidently infer the direction of the trend? and (b) if we can, is it environmentally important? The output includes a tabulated set of summary trend analysis statistics with accompanying graphs. A simplified overview of how these statistics are to be interpreted was also provided as follows:

- Does the range between the 5% and 95% confidence intervals in the Time Trends output for the slope intersect zero? If not (i.e. for a positive trend both are above zero or for a negative trend they are both below zero) one can confidently assert the trend direction is significantly different from zero.

New River Estuary Water Quality (continued)

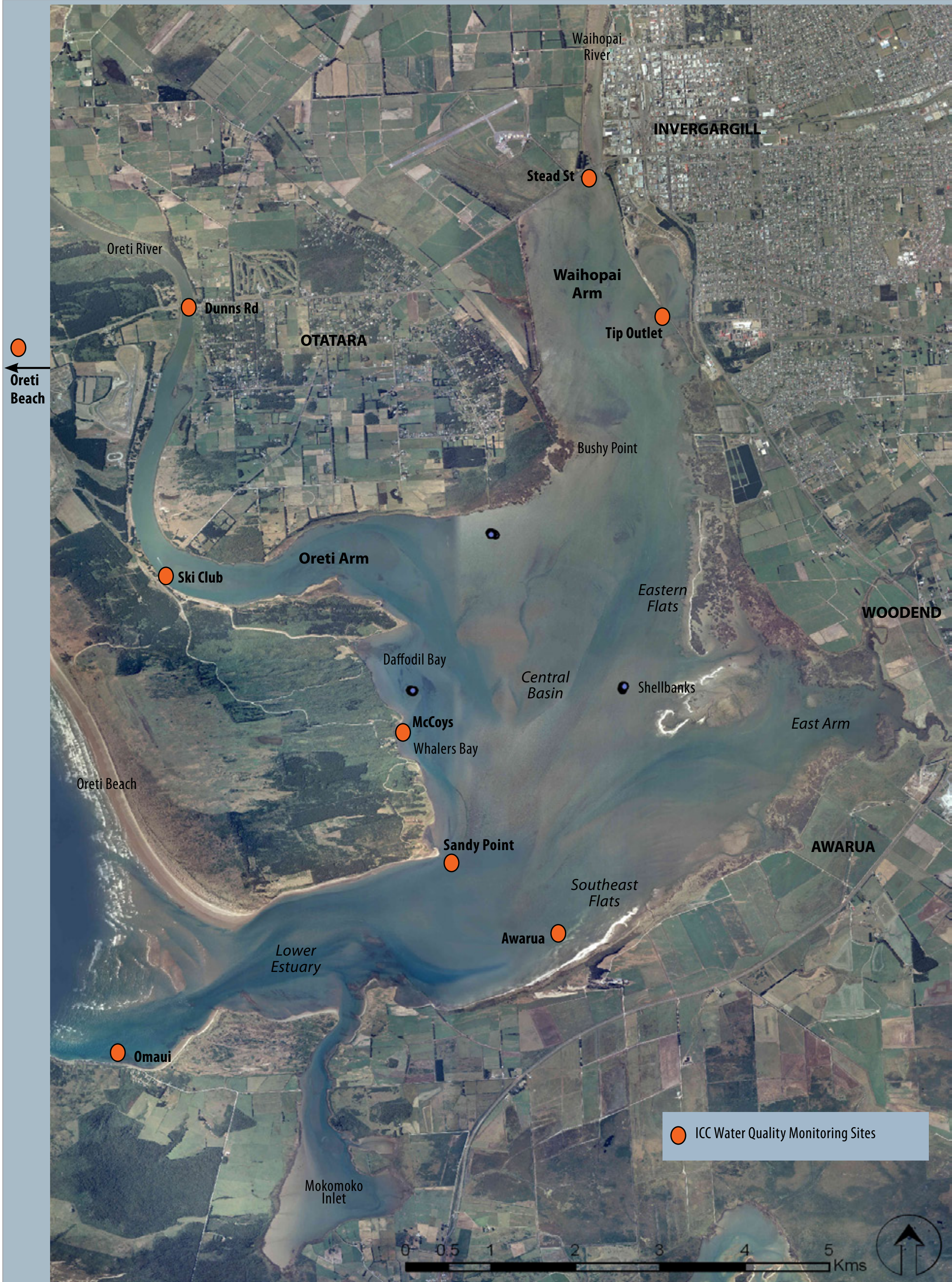


Figure 1. New River Estuary, showing location of ICC water quality monitoring sites (Photo LINZ).

- The ‘p’ value, or calculated probability is best interpreted as defining whether the data provide enough evidence for the null hypothesis (i.e. there is no trend) to be rejected. p values below 0.05 indicate that the null hypothesis is ‘rejected’ and a trend is detected with 95% confidence. p values above 0.05 do not necessarily mean that no trend exists in the data, rather that there is insufficient evidence to confidently detect a trend.
- For a given trend, the next step is to ask whether or not it is ecologically important. This should be based on expert opinion (e.g. if N was a limiting nutrient to algal growth in the New River Estuary in 1991, a small annual nitrate change after that time may be considered ecologically important). This is informed by ‘percent annual change’. In other studies of river water quality, Kendall Trend Tests (e.g. Vant and Wilson 1998, Vant 2013), trends ≥1% p.a. have been considered ‘important’, whereas trends with slopes less than that were considered ‘slight’.

2. RESULTS AND DISCUSSION

This section presents available data on water quality in New River Estuary and tests for any trends over the period it was collected. In a later section, the data are used in combination with eutrophic expression data (e.g. macroalgae) to explore the relationship between water column nutrient concentrations and eutrophic condition.

2.1. Chlorophyll *a* Concentrations

Measuring the extent to which the water column phytoplankton community is balanced (as measured by chlorophyll *a*) is a well-proven indicator of enrichment effects on estuarine biota (e.g. Bricker et al. 1999, 2003, 2007, 2008; Devlin et al. 2011), particularly for estuaries, or parts of estuaries, with residence times greater than typical phytoplankton turnover time (>2-3 days) (Ferriera et al. 2005). For SIDE estuaries typically at levels between ‘slightly impacted’ and ‘moderately impacted’, which do not retain phytoplankton for a sufficient length of time to reach high concentrations (i.e. flushing times <2-3 days), this indicator is of lesser importance (Robertson et al. 2016b).

Chlorophyll *a* Criteria

The NZ ETI (Robertson et al. 2016b) recommends that chlorophyll *a* be used as a primary symptom indicator in the calculation of the ETI Score for subtidal dominated estuaries (residence time weeks rather than days), the NZ ETI Tools (Zeldis et al. 2017) recommend that chlorophyll a be used as a primary indicator for scoring phytoplankton effects on estuary health in cases where intertidal areas are relatively small proportions of total estuary area (typically, subtidal dominated estuaries: DSDEs and riverine estuaries: SSRTREs). However chl-a can be considered a supporting indicator in the evaluation of SIDEs such as New River, with large intertidal proportions. The recommended interim rating thresholds for phytoplankton chlorophyll *a* in NZ estuaries are presented in Table 1.

Table 1. Recommended interim rating thresholds for phytoplankton chlorophyll *a* concentrations in NZ estuaries (as 90th percentile based on monthly measurements) sourced from NZ ETI (Robertson et al. 2016b).

Band	A	B	C	D
Ecological Quality	Ecological communities are healthy and resilient.	Ecological communities are slightly impacted by additional phytoplankton growth arising from nutrient levels that are elevated.	Ecological communities are moderately impacted by phytoplankton biomass elevated well above natural conditions. Reduced water clarity likely to affect habitat available for native macrophytes.	Excessive algal growth making ecological communities at high risk of undergoing a regime shift to a persistent, degraded state without macrophyte/seagrass cover.
Euhaline Estuaries[1]	<3 ug/l	3-8 ug/l	>8-12 ug/l	>12 ug/l
Oligo/Meso/Polyhaline Estuaries[2]	<5 ug/l	5-10 ug/l	>10-16 ug/l	>16 ug/l

[1] 90th percentile based on monthly measurements.

[2] Oligohaline 0.5-5ppt salinity, Mesohaline >5-18ppt, Polyhaline >18-30ppt, Euhaline>30ppt

Chlorophyll *a* New River Estuary

Figure 2 shows that 90th percentile chlorophyll *a* concentrations in the upper estuary (Waihopai Arm) at Stead St Bridge (the site with the highest chlorophyll *a* concentrations in New River Estuary for 1991 to 2015) regularly exceeded the Band C threshold, indicating that phytoplankton concentrations exceeded levels that were likely to cause eutrophication symptoms in the upper estuary with excessive phytoplankton growth likely to cause a persistently degraded state. On three occasions, elevated chlorophyll *a* (Band D) concentrations also occurred in the upper estuary of the Oreti Arm at Dunns Road Bridge (Figure 3).

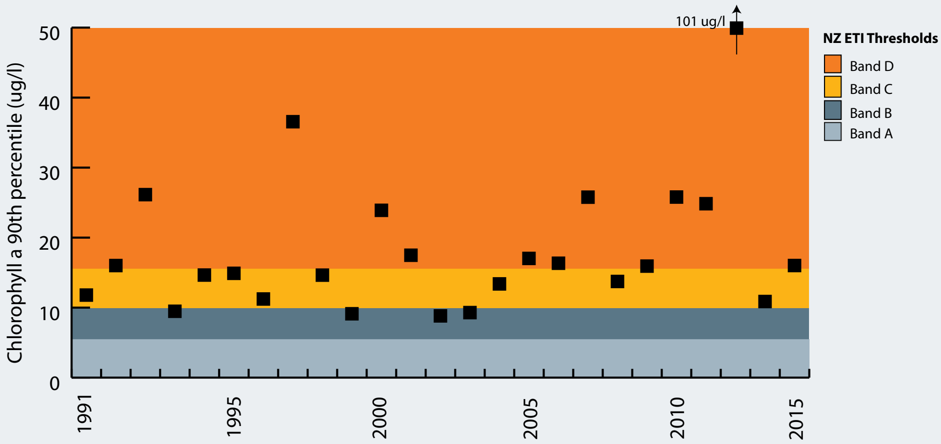


Figure 2. Upper estuary Stead St Bridge chlorophyll *a* concentrations (90th percentile, monthly values).

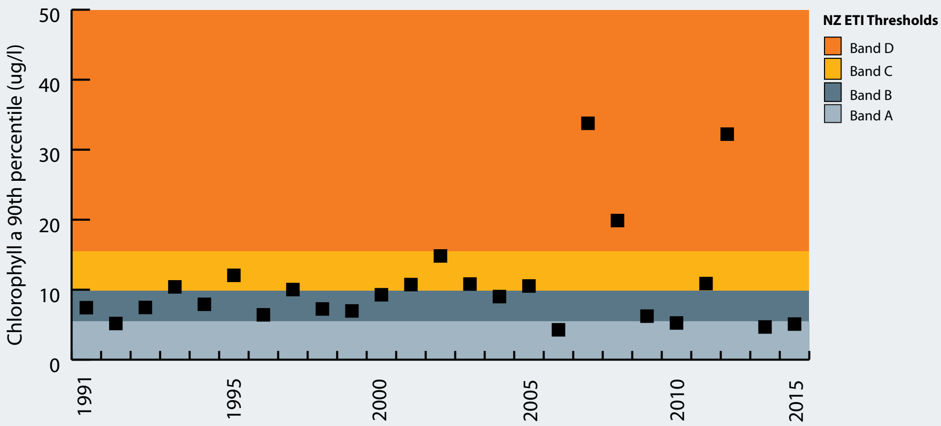


Figure 3. Upper estuary Dunns Road Bridge chlorophyll *a* concentrations (90th percentile of monthly values).

However, in the mid estuary at McCoys, and lower estuary at Awarua, the 90th percentiles fitted within the A-C thresholds, indicating that phytoplankton concentrations were typically at levels between 'slightly impacted' and 'moderately impacted' in the main body of the estuary (Figures 4 and 5).

The cause of the elevated chlorophyll *a* concentrations in the upper estuary could be explained as follows:

1. Residence times for phytoplankton in the upper estuary may be much longer than in the mid estuary, and consequently phytoplankton can take advantage of the very high nutrient levels at these sites and grow to bloom proportions.
2. The upstream river feeding into the estuary may have elevated chlorophyll *a* concentrations in the summer period, particularly at low water when such elevated concentrations were measured.
3. There is a possibility that high chlorophyll *a* concentrations in ICC oxidation pond wastewater discharged to the lower Waihopai arm may be carried into the upper estuary at times although this has not been assessed.

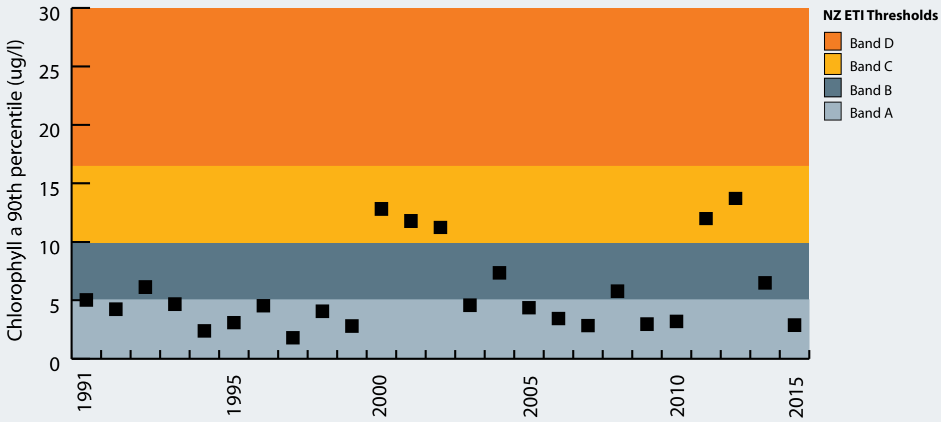


Figure 4. Mid estuary McCoys chlorophyll *a* concentrations (90th percentile of monthly values).

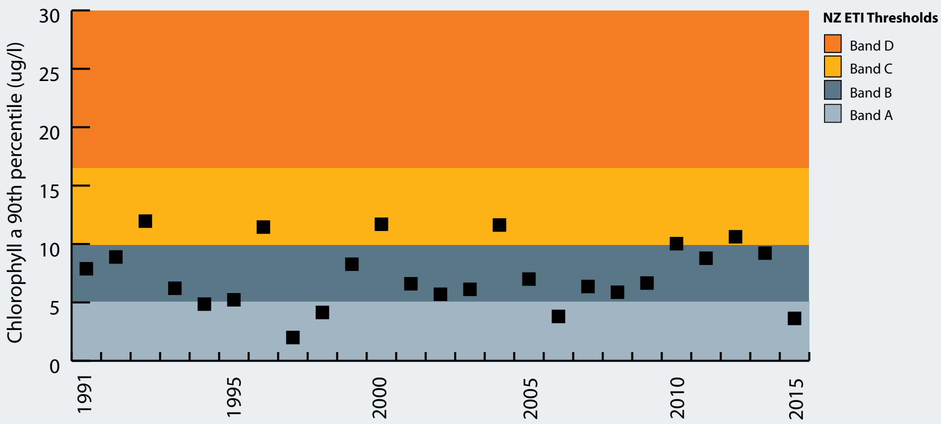


Figure 5. Lower estuary Awarua chlorophyll *a* concentrations (90th percentile of monthly values).

In overview, the chlorophyll a concentration data indicate that the main body of the New River Estuary had phytoplankton levels indicating slight to moderate eutrophication impacts in the water column. However, because there were regular high levels of chlorophyll *a* in the upper estuary (particularly the Waihopai Arm) during summer each year, localised high eutrophication impacts appear to be occurring. The cause of the high concentrations could not be confirmed, but was likely to be either from outside sources (i.e. upstream freshwater algae) or a result of localised poor flushing and high nutrient loads. The absence of any trend in chlorophyll a concentrations at any sites (see trend analysis section) may provide some support for the "outside source" possibility (i.e. given there was a trend of increasing nutrient concentrations at the upper estuary site, see next section).

Recommendations

Identifying all causes and locations of eutrophic symptoms is a priority for setting of load criteria for SIDE estuaries. Consequently, it is recommended that identifying the cause of the elevated chlorophyll *a* concentrations in the upper Waihopai Arm of the New River Estuary be undertaken in the near future. It is envisaged that the assessment would address:

- The possibility of "localised poor flushing" causing the high concentrations. It is recommended that the recently developed hydrodynamic model for the estuary is used to assess stratification and residence time of water at the Stead Street Bridge site.
- The possibility of "outside sources" causing the high concentrations. It is recommended that phytoplankton identifications be included in any future monitoring at this site in order to assess the ratio of estuarine to freshwater phytoplankton.

New River Estuary Water Quality (continued)

New River Estuary: Photographs taken January 2012

New River Estuary Stead St Bridge showing green coloration to water (photo taken at low water 17 Jan. 2012 during broad scale mapping survey by Wriggle). ICC sampling at this site at low tide on 30 Jan and 13 Feb. 2012 measured chlorophyll *a* 205 and 324ug/l respectively.

2.2. Water Column N and P Concentrations

Concentration Condition Thresholds

Water column dissolved N and P concentrations are expected to be a partial predictor of eutrophication symptoms, particularly for phytoplankton blooms and intertidal macroalgal blooms, in SIDE estuaries (Robertson et al. 2016a). However, it is useful to examine estuary water column nutrient concentrations in relation to concentration criteria that have been found to encourage high algal growth in other estuaries. If nutrient concentrations in the estuary were found to exceed such criteria, then it could be concluded that both macroalgal and phytoplankton blooms were possible given the right conditions. In particular, for phytoplankton, the residence time would need to be greater than 2-3 days to allow sufficient time for them to bloom and, for macroalgae to bloom, they would need immersion in water with sufficient nutrients to sustain high growth rates. The presence of stable attachment points for the plants is also important, although in areas of poor flushing plants may be entrained in soft sediments.

A survey of tissue-δ^{15}N and tissue-N values in the green macroalga, *Ulva*, from around the NZ coast found tissue-δ^{15}N from 'natural' exposed coastal sites to be in the range 6.6 ± 0.1 to 8.8 ± 0.1‰ in both summer and winter (Barr et al. 2014). Departures in *Ulva* tissue-δ^{15}N ratios outside this range, particularly when coupled with high (>3.1%) tissue-N values, were identified as having significant contributions of terrestrially-derived nitrogen to coastal seawater. This was based on the fact that in the national survey, *Ulva* collected from enriched sheltered sites in summer which had tissue-N values greater than about 3% tended to be associated with >140 ugN.l^{-1} water column DIN concentrations (which Barr et al. (2014) categorised as "very high"). Based on those findings, Plew and Barr (2015) proposed draft target ranges for both *Ulva* tissue-N content and potential water DIN concentrations for controlling potential growth as follows.

Potential Growth Rate	Low	Low-Moderate	Moderate-High	High
Ulva tissue-N (%)	<1	1-2	2-3	>3
DIN (ug.l^{-1})	<28	28-70	70-210	>210

It should be realised that these DIN levels were derived using observed DIN concentrations in the surveyed estuaries (Barr et al. 2014). This means they were likely to be underestimates (Plew et al. 2018), because they would have included effects of algal uptake and denitrification which draw down observed DIN values. The preferred approach is to derive limits using 'potential' nutrient levels as used in the ETI, which are based on nutrient loads and degrees of estuary mixing with the ocean. These provide estimates of the nutrient concentrations available to the algae and so represent the pressure on the estuary due to nutrient loading (Plew et al. 2018).

New River Estuary Water Quality (continued)

Recent work in the Estuarine Trophic Index project (Robertson et al. 2016) has compared potential TN concentrations with a database of *Ulva* biomass (measured as Ecological Quality Rating (EQR: Ibid) across 17 SIDE estuaries in New Zealand (Zeldis et al. 2017). Potential TN was predicted using the CLUES-Estuaries tool (Plew et al. 2018). This resulted in the following bandings of EQR relative to potential TN concentration:

	Band A	**Band B**	**Band C**	**Band D**
EQR Potential	0.8	0.6	0.4	0.2
TN (ug/l, upper)	<80	≥80 to <200	≥200 to <320	≥320
macroalgae ww (g/m^2, upper)	100	200	500	2000
macroalgae dw (g/m^2, upper)	13	26	65	260

These TN values are somewhat higher than the DIN values described by Plew and Barr (2014) which could reflect the analyte difference (TN vs DIN) and the aforementioned use of observed N values instead of 'potential' N values as used in the ETI (Plew et al. 2018). Preliminary information from the Avon-Heathcote estuary (J.Zeldis, N. Barr NIWA pers. comms. 2017) from 2007-2014 shows that *Ulva* percent cover has fallen strongly (by 77%), as have isotopic and biochemical signatures of enrichment in *Ulva* tissues, following the diversion of Christchurch City wastewater from the estuary in 2010. Post-diversion potential TN concentration is ~200 ugTN l^{-1}, (calculated from the CLUES Estuary component of the ETI Tool). This shows that TN reductions to such levels can be expected to favour strong reductions in *Ulva* biomass.

The current European estuary guidelines (OSPAR 2008) for DIN concentrations are:

- High <280ug/l, Good 280-420ug/l, Moderate 420-630 ug/l, Poor >630 ug/l.

These values are higher than those derived for NZ conditions described above.

Currently, there are no concentration condition thresholds for phosphorus.

In overview, it appears that although additional work is needed to determine thresholds of macroalgal eutrophication relative to nutrient loading, usable values are accruing within the New Zealand context. A value of approximately 200ug/l TN (or 0.20mg/l TN) appears near a boundary between slight-to-moderate eutrophication effects (the B-C boundary of the ETI banding). Using ETI Tool 1, it can be expected that about 85% of this TN will be in DIN, meaning that the ETI B/C threshold is about 170ug/l DIN.

In the following section we describe time series of water quality in New River Estuary using the ICC dataset. These are presented as DIN levels and are compared with the thresholds given above from NZ information, for potential TN. Two factors should be taken into account in their interpretation. First, the water quality N data are in-estuary values, and not potential N values. As such they are subject to aliasing due to effects of algal uptake and denitrification (which do not affect predictions from CLUES Estuaries). These effects are likely seen in the water quality data: summer values (when both uptake and denitrification can be expected to be highest) are uniformly lower than winter values, noting that winter may also contribute to greater runoff to the estuary. Secondly, the thresholds given are for TN, not DIN, and as such could be expected to be overestimates of thresholds based on DIN.

DIN Concentrations in New River Estuary Compared with Condition Thresholds

Figures 6 and 7 show that summer and winter, high water DIN concentrations (often 1000-2000ug/l) in both the upper estuary Waihopai Arm, Stead Street Bridge site (the site with the highest chlorophyll *a* concentrations in New River Estuary for 1991 to 2015) and Oreti Arm Dunns Rd Bridge site, almost always greatly exceeded available thresholds for expression of eutrophic symptoms described in the previous section. In general, winter values were greater than summer values.

Figures 8 and 9 show that mean summer high water DIN concentrations in both the mid estuary McCoys site and the lower estuary Awarua site were much lower than in the upper estuary but were nevertheless often near or exceeding the 170ug/l DIN threshold. Winter values were generally greater than the threshold.

DRP Concentrations in New River Estuary

Figures 10-13 show that summer and winter, high water dissolved reactive phosphorus (DRP) concentrations were generally greatest in the upper estuary Waihopai Arm, Stead Street Bridge site (the site with the highest chlorophyll *a* concentrations in New River Estuary for 1991 to 2015), slightly less in the Oreti Arm Dunns Road Bridge site, and slightly less again at the mid estuary McCoys and lower estuary Awarua sites.

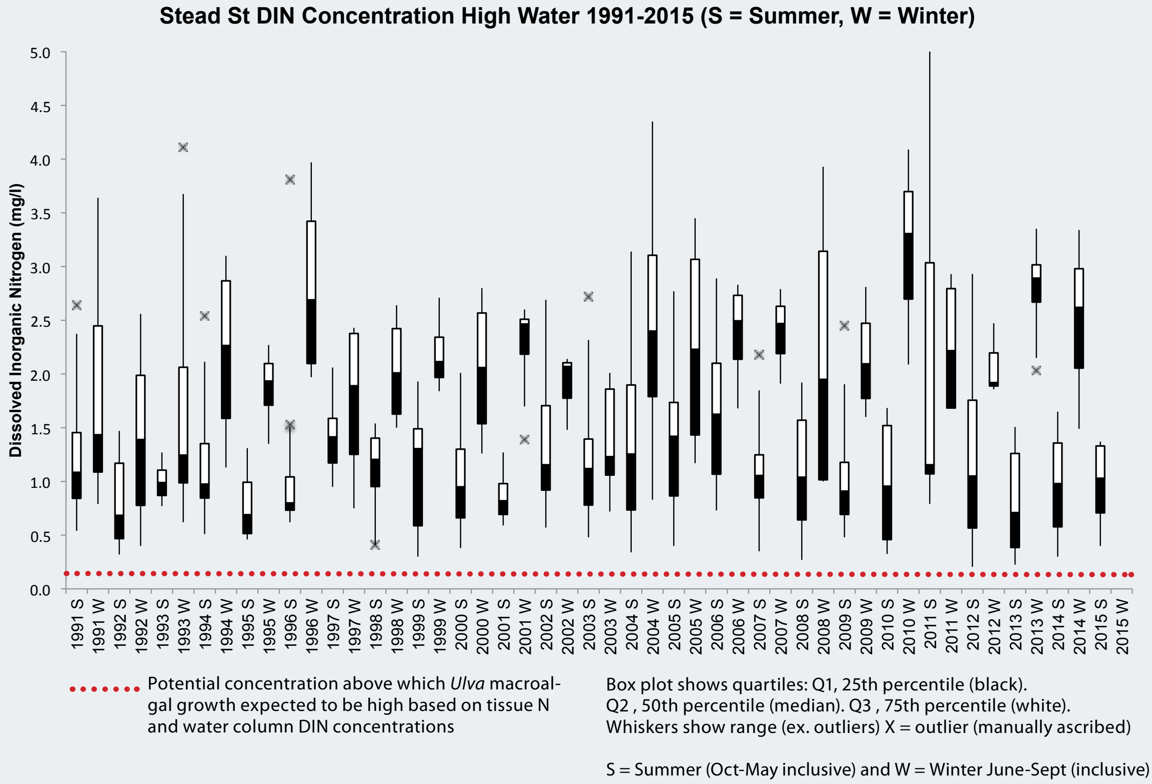


Figure 6. Stead Street Bridge (upper estuary) mean monthly high water DIN concentrations 1991-2015.

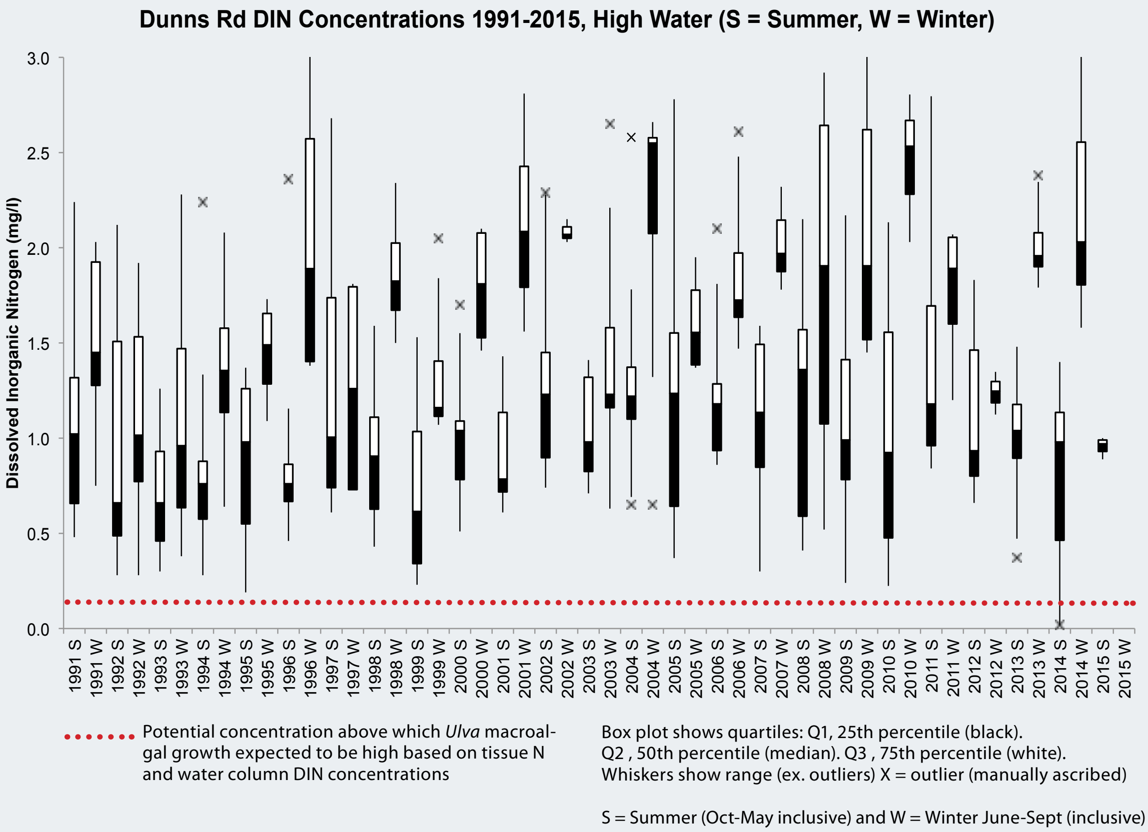


Figure 7. Dunns Road Bridge (upper estuary) mean monthly high water DIN concentrations 1991-2015.

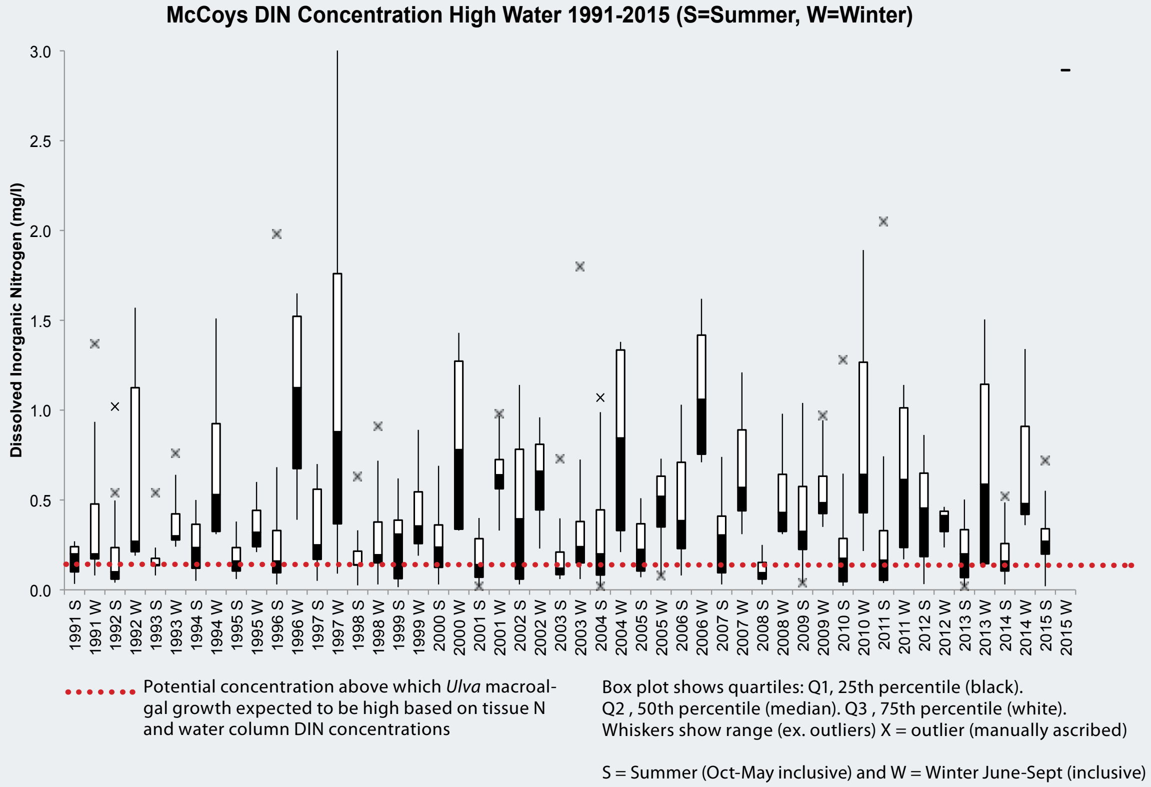


Figure 8. McCoys (middle estuary) mean monthly high water DIN concentrations 1991-2015.

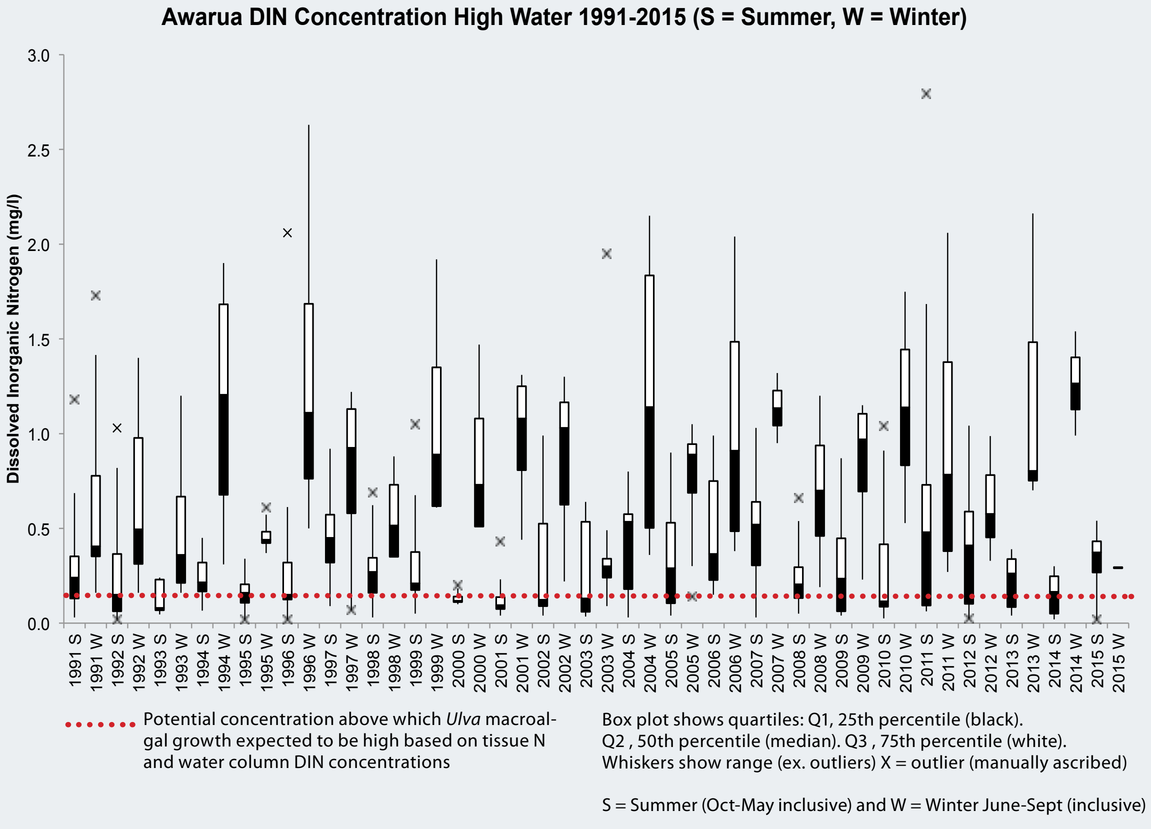
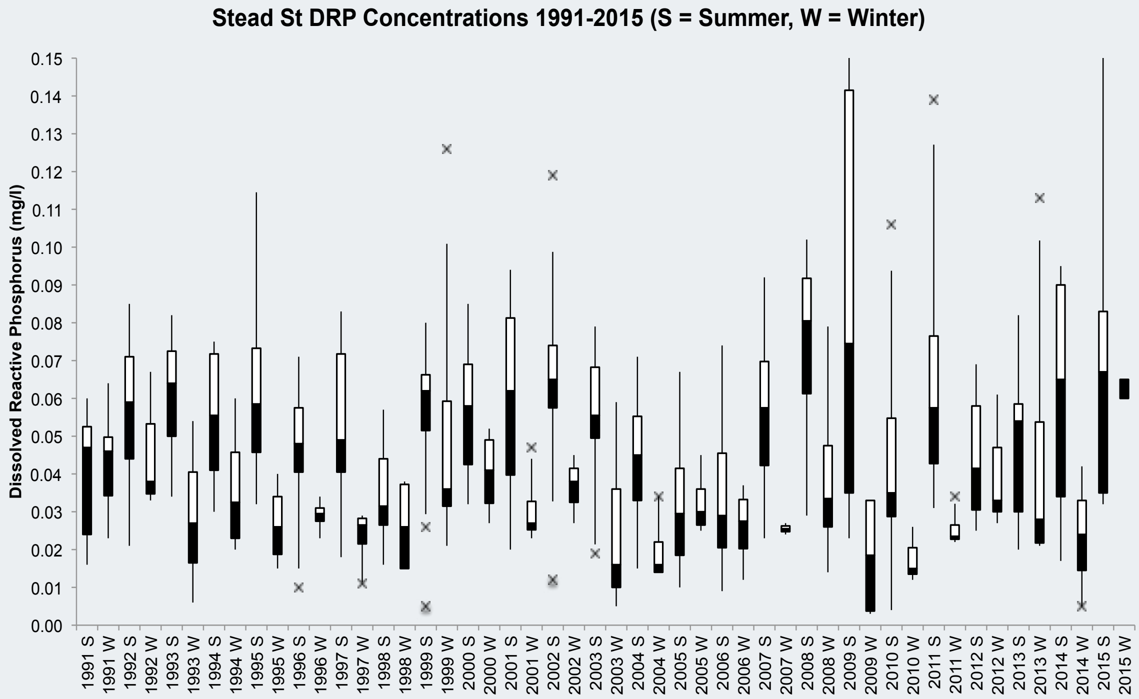


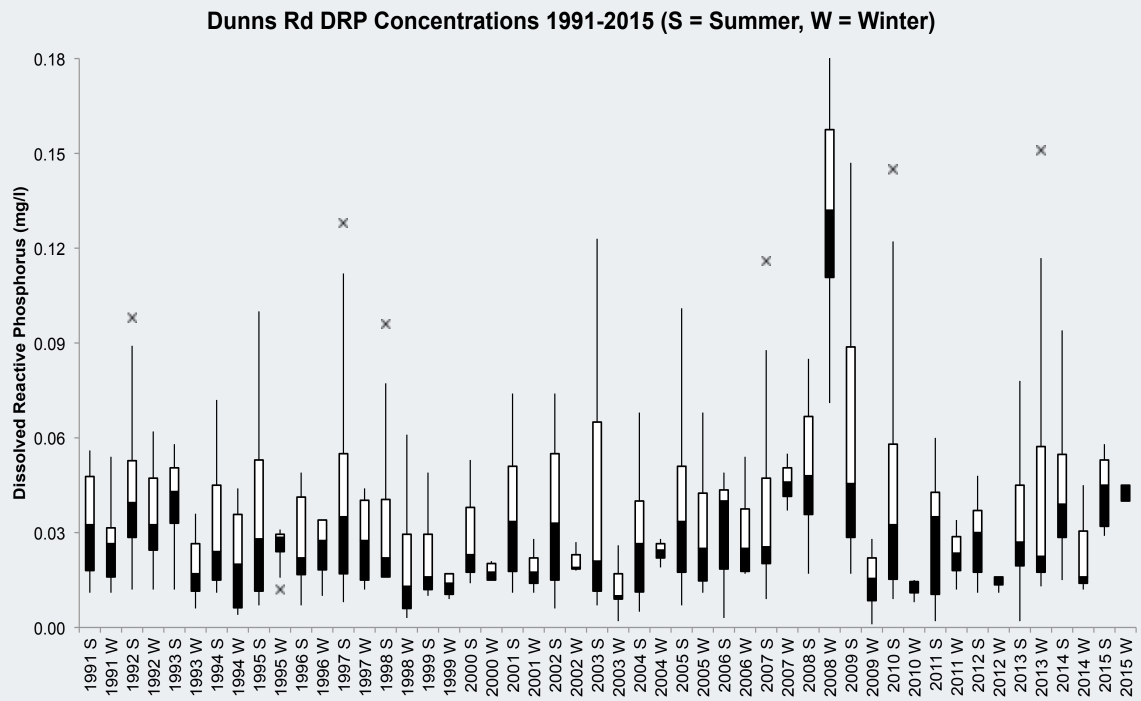
Figure 9. Awarua (lower estuary) mean monthly high water DIN concentrations 1991-2015.

New River Estuary Water Quality (continued)



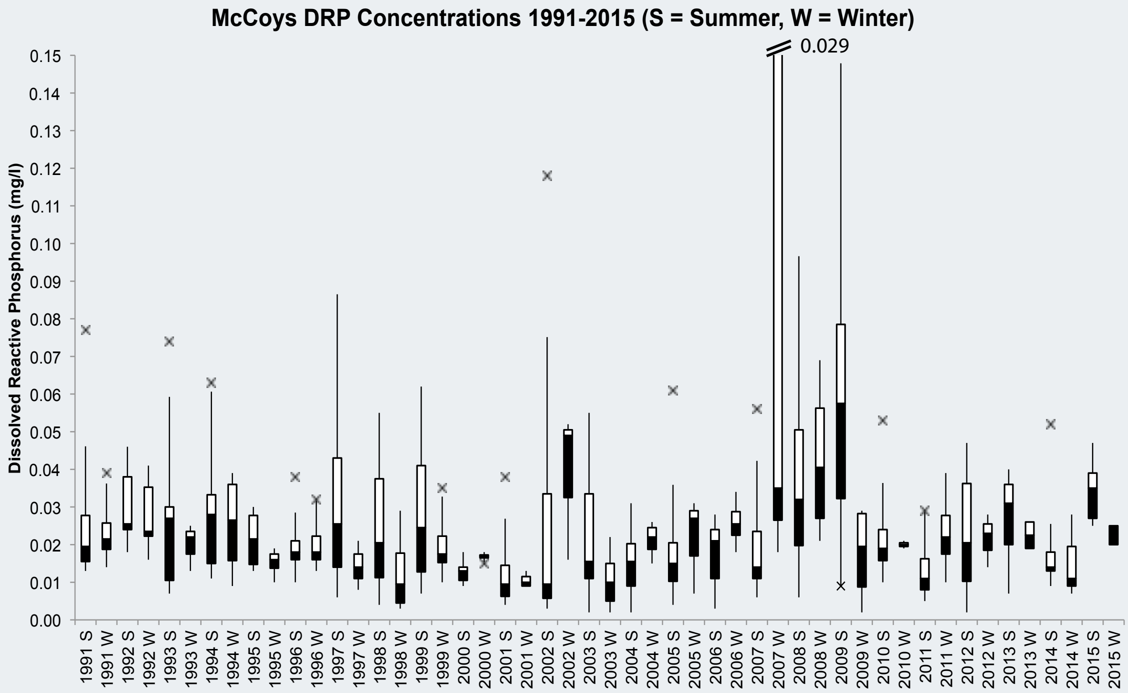
Box plot shows quartiles: Q1, 25th percentile (black). Q2, 50th percentile (median) Q3, 75th percentile (white).
Whiskers show range (ex. outliers) X = outlier (manually ascribed)
S = Summer (Oct-May inclusive) and W = Winter June-Sept (inclusive)

Figure 10. Stead Street Bridge (upper estuary) mean monthly high water DRP concentrations 1991-2015.



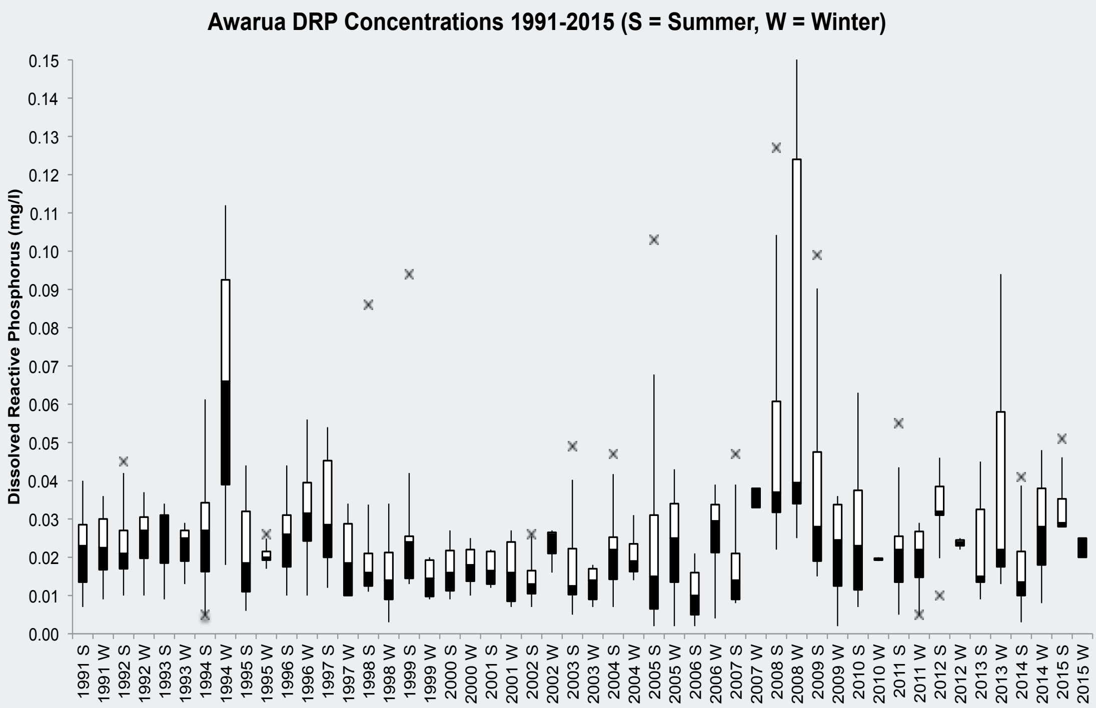
Box plot shows quartiles: Q1, 25th percentile (black). Q2, 50th percentile (median) Q3, 75th percentile (white).
Whiskers show range (ex. outliers) X = outlier (manually ascribed)
S = Summer (Oct-May inclusive) and W = Winter June-Sept (inclusive)

Figure 11. Dunns Road Bridge (upper estuary) mean monthly high water DRP concentrations 1991-2015.



Box plot shows quartiles: Q1, 25th percentile (black). Q2, 50th percentile (median) Q3, 75th percentile (white).
Whiskers show range (ex. outliers) X = outlier (manually ascribed)
S = Summer (Oct-May inclusive) and W = Winter June-Sept (inclusive)

Figure 12. McCoys (middle estuary) mean monthly high water DRP concentrations 1991-2015.



Box plot shows quartiles: Q1, 25th percentile (black). Q2, 50th percentile (median) Q3, 75th percentile (white).
Whiskers show range (ex. outliers) X = outlier (manually ascribed)
S = Summer (Oct-May inclusive) and W = Winter June-Sept (inclusive)

Figure 13. Awarua (lower estuary) mean monthly high water DRP concentrations 1991-2015.

New River Estuary Water Quality (continued)

Which Nutrient to Manage, N or P?

Another important question to ask is which nutrient to control, or are they both important? Since N and P are the most common limiting nutrients for algae, it is useful to assess or predict nutrient-limitation using the relative abundance of both nutrients. The relative abundance of N and P can be expressed as concentration ratios, abbreviated as N:P ratio. If dissolved inorganic forms are of particular concern, the dissolved inorganic N:P ratio (DIN:DIP) is relevant. The most common forms of DIN are nitrate and ammonium, and the most common forms of DIP are ortho-phosphates, which are often referred to collectively as dissolved reactive phosphorus, or DRP. DIN/DRP ratios are expressed as molar units (i.e. atomic weights) which are calculated by dividing the mass (mg/L) by the molecular weight (N=mw14, P=mw31). That is, millimolar DIN/DRP ratio expressed as molar units = (DIN (mg/L)/14)/(DRP (mg/L)/31).

> Seawater N:P ratios provide, at best, a rough guide to which nutrient (N or P) might be limiting for algal growth. This is because nutrient uptake rates vary considerably with various physical (light, temperature, water mixing effects), chemical (nitrogen sources i.e. NH_3^-, NH_4^+) and biological factors (e.g. nutritional history, plant and tissue type, life stage/age, surface area:volume ratio) (Harrison and Hurd 2001). Surge uptake rates can also be particularly important for some seaweed species e.g. *Ulva* and *Gracilaria* that are able to optimise the uptake of pulsed nutrient inputs and store nutrients intracellularly to maintain growth rates during periods of nutrient limitation (Chapman and Craigie (1977) cited in Harrison and Hurd 2001).
>
> Because nutrient uptake differs between various types of plants, optimum N:P ratios will also differ. The Redfield ratio (e.g. Redfield et al. 1963) is most suited to assessing nutrient limitation in phytoplankton and indicates a transition from N limitation to combined N + P limitation (rather than single limitation by P) above ratios of 16:1 (Ptacnik et al. 2010). For other plants, various N:P ratios indicating nutrient limitation are reported e.g. 17:1 for benthic microalgae (Hillebrand & Sommer, 1999), 20:1 for marine angiosperms (Duarte 1992), and an average of 30:1 (range 10:1 to 80:1) for macroalgae (Atkinson and Smith, 1983). Further, much higher ratios have been found to be ideal for some species (e.g. 87:1 for freshwater macroalgae (Townsend et al. 2007).

If the ratios in a representative range of samples was significantly greater than <u>16:1 for phytoplankton and >30:1 for macroalgae</u> then it is likely it would require less effort to reduce P to levels that limit growth than to reduce N. If significantly less than <u>16:1 for phytoplankton and <30:1 for macroalgae</u> then it is likely it would require less effort to reduce N to levels that limit growth than to reduce P. If N:P ratios were between 10:1 and 50:1 then it is possible that the potential limiting nutrient could be either N or P.

Based on the above, the approach used for assessing DIN and DRP concentrations for nutrient limitation in macroalgal dominated estuaries was as follows:

- A DIN:DRP ratio <30:1 was used to indicate DRP is relatively abundant and macroalgae are likely N-limited.
- A DIN:DRP ratio >30:1 was used to indicate DIN is relatively abundant and macroalgae are likely P-limited.
- When both DIN and DRP concentrations are very high (e.g. DIN above 1.0 mg/L, DRP above 0.03 mg/L), then the risk of algal proliferations is high because there is little or no N and P limitation.
- When both DIN and DRP concentrations are very low (e.g. DIN below 0.005 mg/L, DRP below 0.001 mg/L), then the risk of algal proliferations is low regardless of their relative proportions.

It should be noted that these are not absolute numbers, but rather a guide to how water quality could be managed to mitigate unwanted macroalgal growth in estuaries (e.g. a more conservative benchmark for P-limitation might be a DIN:DRP ratio of at least 70:1). The only real way to know which nutrient limits growth of a given species would be to add nutrients and see if the algae grows faster.

It is also common practice to augment such water column studies with macroalgal intracellular N:P ratios by measuring the intracellular C:N:P ratio in the dominant benthic macroalgal species in the target estuary (e.g. *Gracilaria* spp. and *Ulva* spp.) and comparing this with the typical ratio for benthic macroalgae of <u>C:N:P of 215:14:1 and a C:N ratio of 15</u> (Atkinson and Smith 1983). The intracellular concentrations that limit growth for *Ulva* spp. are >2% for N and >0.12% for P, and are currently unknown for *Gracilaria* spp. If concentrations exceed these levels then it could be concluded that the macroalgae were replete in N and P and growth was not limited by these nutrients.

New River Estuary Water Quality (continued)

Water Column DIN:DRP Ratios

Figures 14 -17 show water column DIN:DRP ratios (molar units) for the 1991-2015 period for representative New River upper estuary sites (i.e. Stead Street and Dunns Road), and mid estuary and lower estuary sites (i.e. McCoys and Awarua). Mean monthly DIN:DRP ratios for all years by season (summer or winter) are presented in the following table. Because macroalgal growth rates are likely to be highest during summer (Oct-May) this period is considered to be the most ecologically important to consider.

Site		Summer			Winter		
		Q1 (25th percentile)	Q2 (median)	Q3 (75th percentile)	Q1 (25th percentile)	Q2 (median)	Q3 (75th percentile)
Upper estuary	Stead Street	29:1	**50**:1	85:1	136:1	**200**:1	313:1
	Dunns Road	77:1	**49**:1	115:1	211:1	**162**:1	322:1
Middle estuary	McCoys	13:1	**23**:1	43:1	73:1	**54**:1	105:1
Lower estuary	Awarua	15:1	**24**:1	45:1	62:1	**91**:1	140:1

Figures 14 and 15 show DIN:DRP ratios at Stead Street and Dunns Road were >30:1 for the majority of the 1991-2015 period, with DIN:DRP ratios dipping below 30:1 during summer (Oct-May) on a few occasions, but remaining predominantly high. Winter values were significantly higher - see table above. This indicates that N is present in excess and that P would theoretically be the primary nutrient limiting macroalgal growth. However, this would only be the case if DIN:DRP ratios >30:1 were present along with low P concentrations i.e. <0.03mg/L. This is not the case. Figures 10 & 11 show high P concentrations are consistently present, and in combination with high DIN (Figures 6 & 7), indicate these upper estuary sites appear to be nutrient saturated.

Figures 16 and 17 show that DIN:DRP ratios at McCoys and Awarua were lower and indicate that theoretically both P and N were generally limiting (i.e. mean summer DIN:DRP ratios were frequently <30:1, with 75% of the summer results having ratios between 15:1 to 45:1). Winter ratios were higher, indicating that there is surplus N available. Figures 12 & 13 suggest that there may be more P limitation in the middle and lower estuary than in the upper estuary, but both DIN and DRP concentrations, and sources of sediment bound nutrients, remain sufficiently elevated that there is likely to be little or no nutrient limitation. The results currently indicate that both nutrients should be considered important for managing water column blooms in the estuary, with a reduction in N concentrations of primary importance in the upper estuary. In order to provide a more robust assessment of which nutrient to target to limit nuisance algal growth, it is recommended that macroalgal tissue nutrient concentrations also be measured over the growing season.

Because macroalgal growth can also be driven by the release and cycling of sediment bound nutrients, particularly at times when the estuary is not bathed in nutrient rich waters, there may be multiple drivers of eutrophic symptoms in New River Estuary that contribute to bloom conditions and need to be factored in to management decisions.

Recent work underway in NIWA is deriving experimentally-determined growth responses of New River Estuary Gracilaria (B. Dudley, NIWA, pers comm. September 2018). The parameters investigated include nitrate, ammonium, DRP and salinity.

Other work is investigating the likelihood of N/P co-limitation of algal production in New River Estuary using CLUES-Estuary tools (D. Plew, NIWA, pers comm. September 2018).

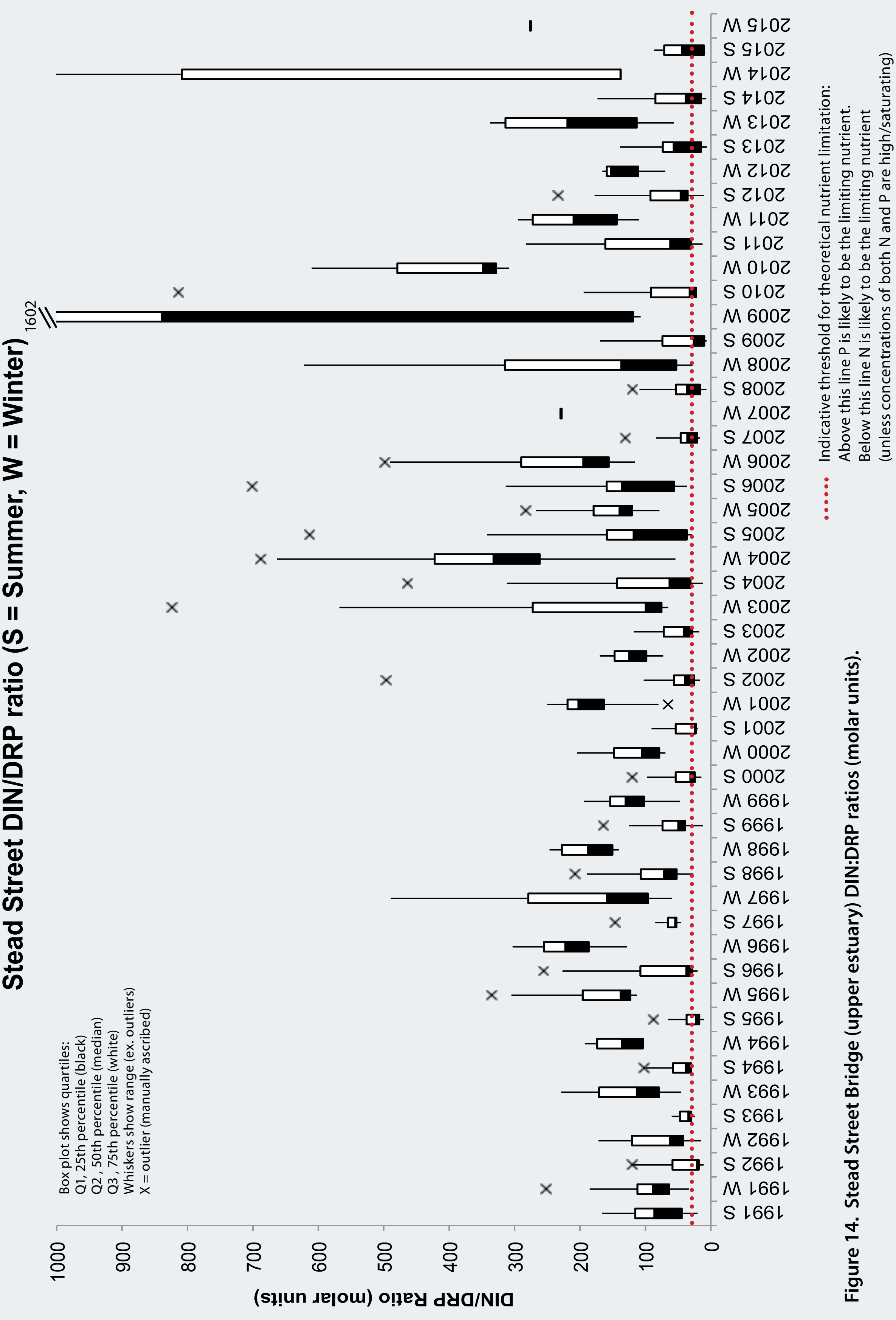


Figure 14. Stead Street Bridge (upper estuary) DIN:DRP ratios (molar units).

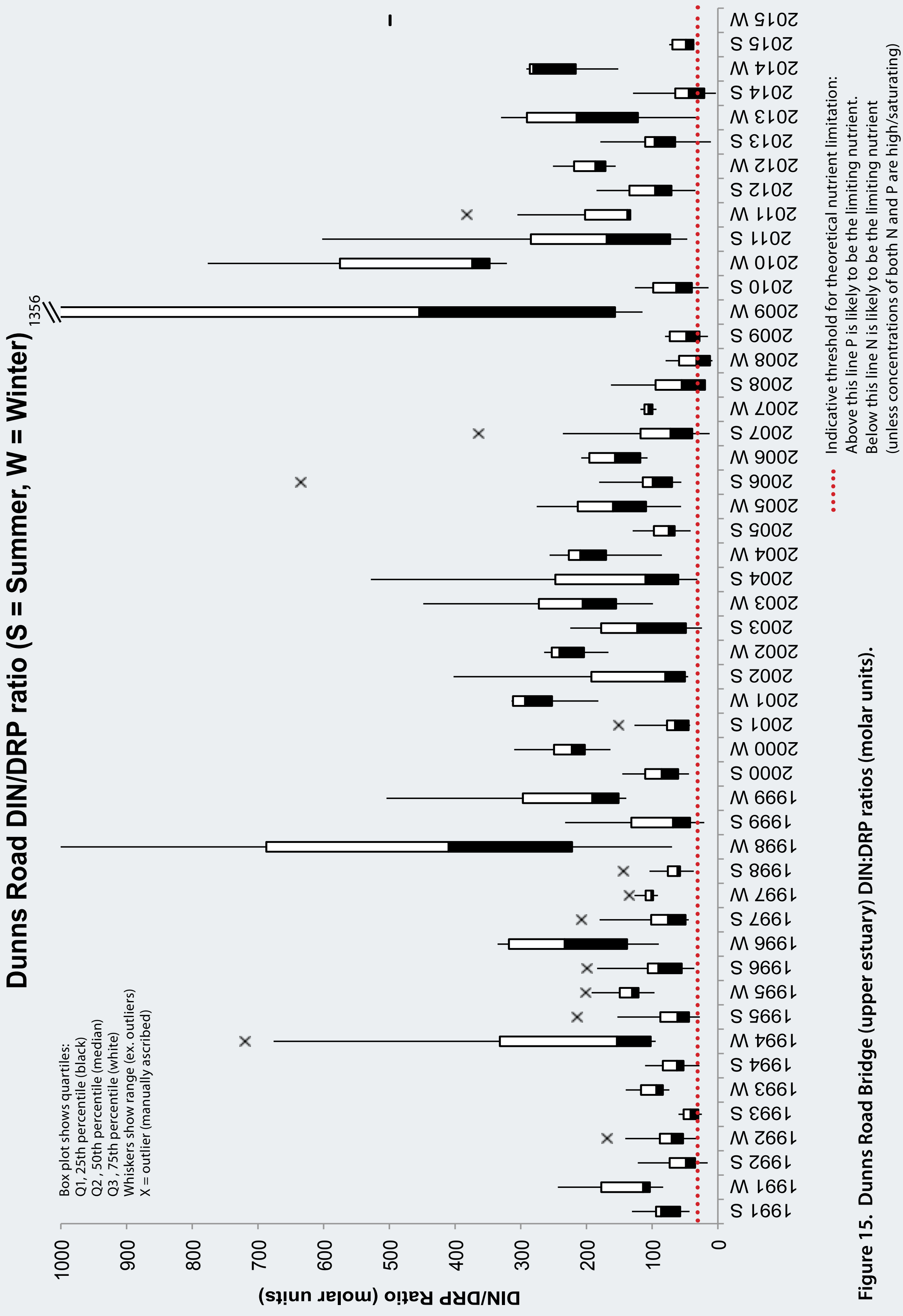


Figure 15. Dunns Road Bridge (upper estuary) DIN:DRP ratios (molar units).

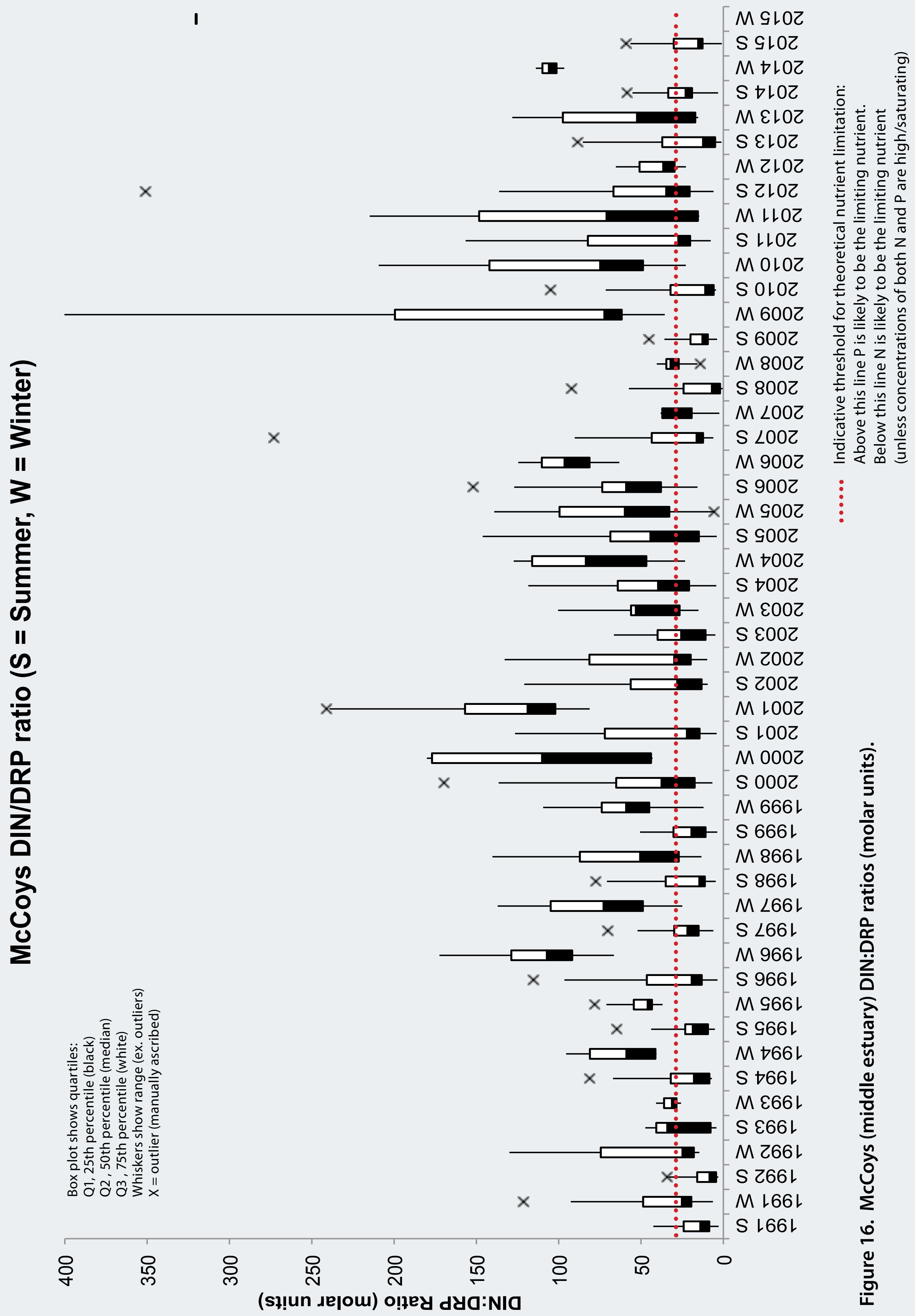


Figure 16. McCoys (middle estuary) DIN:DRP ratios (molar units).

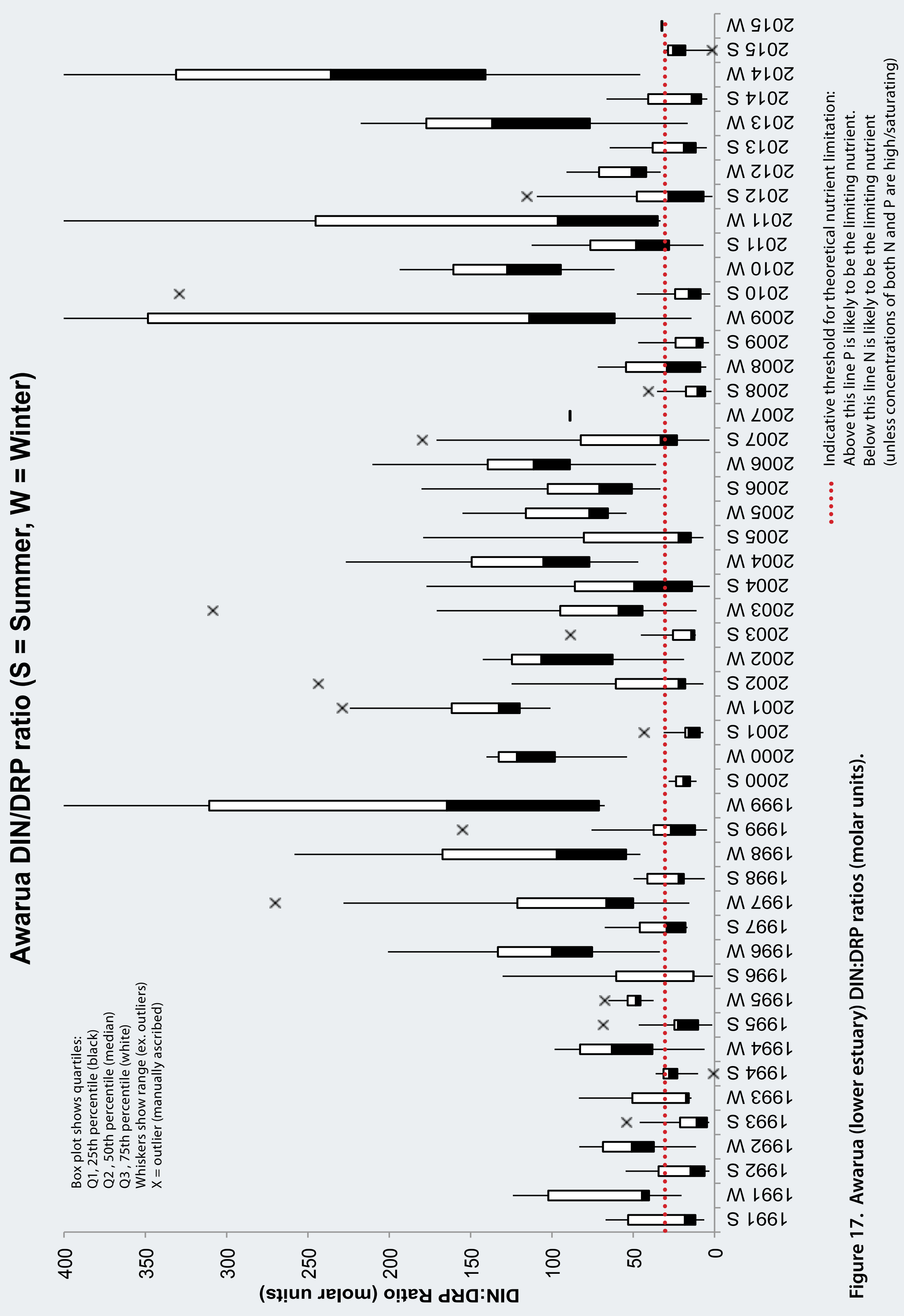


Figure 17. Awarua (lower estuary) DIN:DRP ratios (molar units).

2.3. Water Column N and P Trends

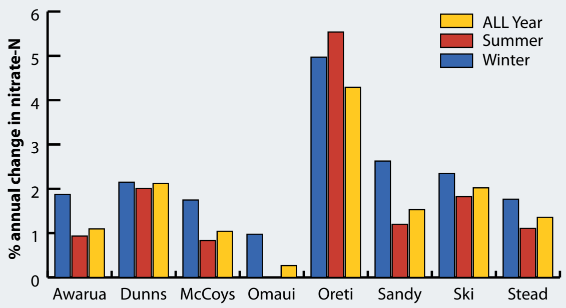
The results of the trend analysis (1991-2015) for each of the eight New River Estuary and one ocean water quality monitoring sites (including both high and low water data) are shown in Table 2 (includes all year data), Table 3 (includes summer data only) and Figures 22-30 (with detailed data in Appendix 1). Note Figures 22-30 label DRP as SRP. The key indicators that are directly relevant to the issues of eutrophication and sedimentation are listed as ammoniacal-N (NH_3/NH_4-N), nitrate-N (NO_3-N), TP, DRP, chl-*a*, DIN and DIN:DRP (faecal coliforms are also included for their role as an indicator of animal, including human, influences). In summary, the relevant results are:

Chlorophyll *a*

- "All Year" chlorophyll *a* concentrations at all sites showed no significant trend between 1991 and 2015, as did the "Summer Only" data, except for the Tip Outlet site which showed a small positive, "ecologically important" trend over that period. The Tip Outlet site was considered an outlier in that it was likely influenced by localized discharges from the landfill area.

Nitrogen and Phosphorus

- "All Year" nitrate-N concentrations at all estuary sites, except the Tip Outlet and Omaui, showed a small "ecologically important" increasing trend of between 1-2.5% per year between 1991 and 2015. However, for the "Summer Only" data, only Stead St, Dunns Rd, Ski Club and Sandy Pt sites showed small "ecologically important" increasing trends (1-2% per year) between 1991 and 2015. The higher rates of winter nitrate-N concentrations as the main driver of the positive trends at most sites is demonstrated in Figure 18.
- "All Year" and "Summer Only" ammoniacal N concentrations at all sites showed no significant trend between 1991 and 2015, except for "Summer Only" data from Tip Outlet which showed a small "ecologically important" decreasing trend of -2.9% per year between 1991 and 2015. This latter trend was likely to be a result of the decommissioning of the landfill during this period, and perhaps to treatment improvements in the nearby ICC wastewater discharge.
- Dissolved inorganic N (sum of nitrate-N and ammoniacal N) concentrations at all estuary sites, except the Tip Outlet, Omaui, Awarua and McCoys) showed a small "ecologically important" increasing trend of between 1-2.5% per year between 1991 and 2015. However, for the "Summer Only" data, only Dunns Rd, Ski Club and Sandy Pt sites showed small "ecologically important" increasing trends (1-2% per year) between 1991 and 2015. The dominance of winter DIN concentrations as the main driver of the positive trends at most sites is demonstrated in Figure 18.



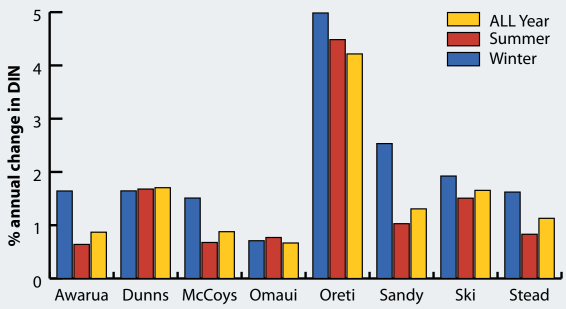


Figure 18. Percent annual change in nitrate-N (left) and DIN (right) for all year, summer and winter periods between 1991 and 2015; estimated from seasonal Kendall test with multiple values per season including both high and low water.

- "All Year" DIN:DRP ratios at Stead St, Ski Club and Sandy Pt showed a small "ecologically important" increasing trend of between 1-1.5% per year between 1991 and 2015, whereas other estuary sites showed no significant trend (Figure 19). However, for "Winter Only" data, DIN:DRP ratios at all sites showed "ecologically important" increasing trends of 2-3.5% per year between 1991-2015. Combined with the DIN trend analysis above, this latter trend indicates a pattern of increasing winter DIN concentrations and decreasing winter DRP concentrations (Figure 20) in the estuary over the 1991-2015 period. No "ecologically important" increasing trends were recorded using the "Summer Only" data.

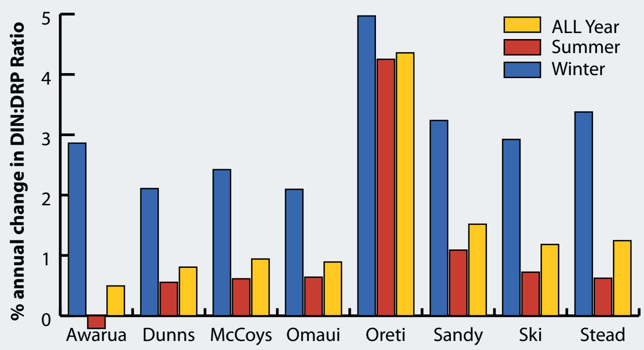


Figure 19. Percent annual change in DIN:DRP ratio for all year, summer and winter periods 1991-2015; estimated from seasonal Kendall test with multiple values/season including both high and low water.

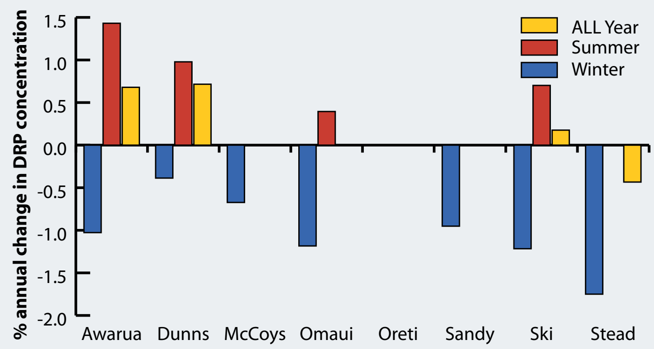


Figure 20. Percent annual change in DRP concentration for all year, summer and winter periods 1991-2015; estimated from seasonal Kendall test with multiple values/season including both high and low water.

- "All Year", "Winter Only" and "Summer Only" trends for TP concentrations at all estuary sites showed small "ecologically important" increasing trends (2-5%) between 1991 and 2015 (Figure 21). This latter consistent trend throughout the estuary is particularly significant when considered alongside the relatively stable or decreasing trends in dissolved reactive phosphorus at most estuary sites over the same period. Such findings indicate that the particulate P fraction (i.e. P bound to fine sediment particles) was likely driving the increasing trend in TP, which provides support to the assumption that fine sediment loads to the estuary have likely increased over the same period and resulted in greater sedimentation rates. Unfortunately, total nitrogen (TN), which would enable some quantification of the particulate N fraction, was not measured and therefore was not available to provide greater support for this assumption.

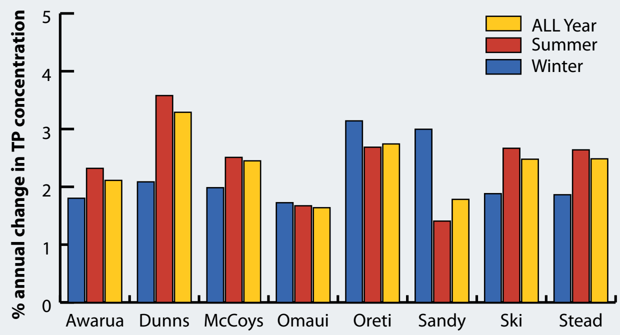


Figure 21. Percent annual change in TP concentration for all year, summer and winter periods 1991-2015; estimated from seasonal Kendall test with multiple values/season including both high and low water.

New River Estuary Water Quality (continued)

Table 2. All Year, Seasonal Kendall test with multiple values/season (both high and low water, summer and winter)

Seasons used in analysis are: Dec - Feb, Mar - May, Jun - Aug, Sep - Nov. If the sample size is less than 10 small sample size probabilities are used otherwise a normal approximation is used to determine P value.

Variable/Site	Trend direction	Confidence in trend direction	Percent annual change	Ecologically important	Trend direction	Confidence in trend direction	Percent annual change	Ecologically important
	Awarua				**Sandy Pt**			
NH3/NH4-N (mg/L)			0				0	
Faecal coliforms/100ml	Negative	High	-1.7704	Yes	Negative	High	-2.9854	Yes
NO3--N (mg/L)	Positive	High	1.0959	Yes	Positive	High	1.5291	Yes
Total P (mg/L)	Positive	High	2.1114	Yes	Positive	High	1.7828	Yes
Soluble reactive P (mg/L)			0.6789				0	
Chlorophyll a (mg/L)			-0.1815				-0.5617	
Dissolved inorganic N (mg/L)	Positive	High	0.8692	No	Positive	High	1.307	Yes
DIN:SRP			0.4947		Positive	High	1.5173	Yes
	Dunns				**Ski Club**			
NH3/NH4-N (mg/L)			0				-0.5364	
Faecal coliforms/100ml			-0.4511		Negative	High	-1.9872	Yes
NO3--N (mg/L)	Positive	High	2.1196	Yes	Positive	High	2.0219	Yes
Total P (mg/L)	Positive	High	3.2897	Yes	Positive	High	2.478	Yes
Soluble reactive P (mg/L)	Positive	High	0.7154	No			0.1763	
Chlorophyll a (mg/L)			-0.6544		Negative	High	-0.6446	No
Dissolved inorganic N (mg/L)	Positive	High	1.7042	Yes	Positive	High	1.6546	Yes
DIN:SRP	Positive	High	0.806	No	Positive	High	1.1818	Yes
	McCoys				**Stead St Bridge**			
NH3/NH4-N (mg/L)			0				-0.4163	
Faecal coliforms/100ml	Negative	High	-2.2126	Yes	Negative	High	-5.116	Yes
NO3--N (mg/L)	Positive	High	1.0398	Yes	Positive	High	1.3554	Yes
Total P (mg/L)	Positive	High	2.4495	Yes	Positive	High	2.4842	Yes
Soluble reactive P (mg/L)			0				-0.4335	
Chlorophyll a (mg/L)	Negative	Low	-0.2103	No			-0.0734	
Dissolved inorganic N (mg/L)	Positive	High	0.8786	No	Positive	High	1.1296	Yes
DIN:SRP	Positive	High	0.9407	No	Positive	High	1.2445	Yes
	Omaui				**Tip Outlet**			
NH3/NH4-N (mg/L)			0		Negative	High	-2.5874	Yes
Faecal coliforms/100ml	Negative	High	-1.7544	Yes	Negative	High	-11.7929	Yes
NO3--N (mg/L)	Positive	High	0.2668	No			0.1809	
Total P (mg/L)	Positive	High	1.6386	Yes	Positive	High	2.0825	Yes
Soluble reactive P (mg/L)			0				0.1873	
Chlorophyll a (mg/L)	Negative	High	-0.9515	No			0.5575	
Dissolved inorganic N (mg/L)	Positive	Low	0.6664	No	Negative	Low	-0.2922	No
DIN:SRP	Positive	High	0.8912	No	Negative	Low	-0.3305	No
	Oreti							
NH3/NH4-N (mg/L)			0					
Faecal coliforms/100ml	Negative	Low	0	No				
NO3--N (mg/L)	Positive	High	4.2903	Yes				
Total P (mg/L)	Positive	High	2.7417	Yes				
Soluble reactive P (mg/L)			0					
Chlorophyll a (mg/L)	Negative	High	-0.673	No				
Dissolved inorganic N (mg/L)	Positive	High	4.2157	Yes				
DIN:SRP	Positive	High	4.358	Yes				

New River Estuary Water Quality (continued)

Table 3. Summer Only, Seasonal Kendall test with multiple values/season (both high and low water, summer)

Seasons used in analysis are: Dec - Feb, Mar - May, Jun - Aug, Sep - Nov. If the sample size is less than 10 small sample size probabilities are used otherwise a normal approximation is used to determine P value.

Variable/Site	Trend direction	Confidence in trend direction	Percent annual change	Ecologically important	Trend direction	Confidence in trend direction	Percent annual change	Ecologically important
	Awarua				**Sandy Pt**			
NH3/NH4-N (mg/L)			0	No			0	
Faecal coliforms/100ml			0.165	No	Negative	High	-2.7829	Yes
NO3--N (mg/L)	Positive	Low	0.935	No	Positive	High	1.1974	Yes
Total P (mg/L)	Positive	High	2.319	Yes	Positive	High	1.4072	Yes
Soluble reactive P (mg/L)	Positive	High	1.431	Yes			0	
Chlorophyll a (mg/L)			0.31	No			0.157	
Dissolved inorganic N (mg/L)	Positive	Low	0.639	No	Positive	High	1.029	Yes
DIN:SRP			-0.21	No	Positive	Low	1.0884	Yes
	Dunns				**Ski Club**			
NH3/NH4-N (mg/L)			0				0	
Faecal coliforms/100ml			-0.49		Negative	High	-1.7736	Yes
NO3--N (mg/L)	Positive	High	2.0074	Yes	Positive	High	1.8223	Yes
Total P (mg/L)	Positive	High	3.5789	Yes	Positive	High	2.6672	Yes
Soluble reactive P (mg/L)	Positive	High	0.9781	No			0.7012	
Chlorophyll a (mg/L)			-0.0252				0.1832	
Dissolved inorganic N (mg/L)	Positive	High	1.6792	Yes	Positive	High	1.5079	Yes
DIN:SRP	Positive	High	0.5543	No	Positive	Low	0.7223	No
	McCoys				**Stead St Bridge**			
NH3/NH4-N (mg/L)			0				-0.6371	
Faecal coliforms/100ml	Negative	High	-2.2075	Yes	Negative	High	-5.116	Yes
NO3--N (mg/L)	Positive	Low	0.8313	No	Positive	Low	1.1065	Yes
Total P (mg/L)	Positive	High	2.5094	Yes	Positive	High	2.6393	Yes
Soluble reactive P (mg/L)			0				0	
Chlorophyll a (mg/L)	Negative	Low	0.4461	No			0	
Dissolved inorganic N (mg/L)	Positive	High	0.6763	No	Positive	High	0.8305	No
DIN:SRP			0.6126				0.6222	
	Omaui				**Tip Outlet**			
NH3/NH4-N (mg/L)			0		Negative	High	-2.8762	Yes
Faecal coliforms/100ml			-1.1743	Yes	Negative	High	-12.1235	Yes
NO3--N (mg/L)			0				-0.4269	
Total P (mg/L)	Positive	High	1.672	Yes	Positive	High	2.5074	Yes
Soluble reactive P (mg/L)	Positive	High	0.3949	No	Positive	High	0.7835	No
Chlorophyll a (mg/L)			-0.4005		Positive	High	1.1188	Yes
Dissolved inorganic N (mg/L)	Positive	Low	0.7697	No	Negative	High	-0.8524	No
DIN:SRP			0.6395		Negative	High	-1.4199	Yes
	Oreti							
NH3/NH4-N (mg/L)			0					
Faecal coliforms/100ml			0					
NO3--N (mg/L)	Positive	High	5.5366	Yes				
Total P (mg/L)	Positive	High	2.6857	Yes				
Soluble reactive P (mg/L)			0					
Chlorophyll a (mg/L)			-0.3806					
Dissolved inorganic N (mg/L)	Positive	High	4.4843	Yes				
DIN:SRP	Positive	High	4.2514	Yes				

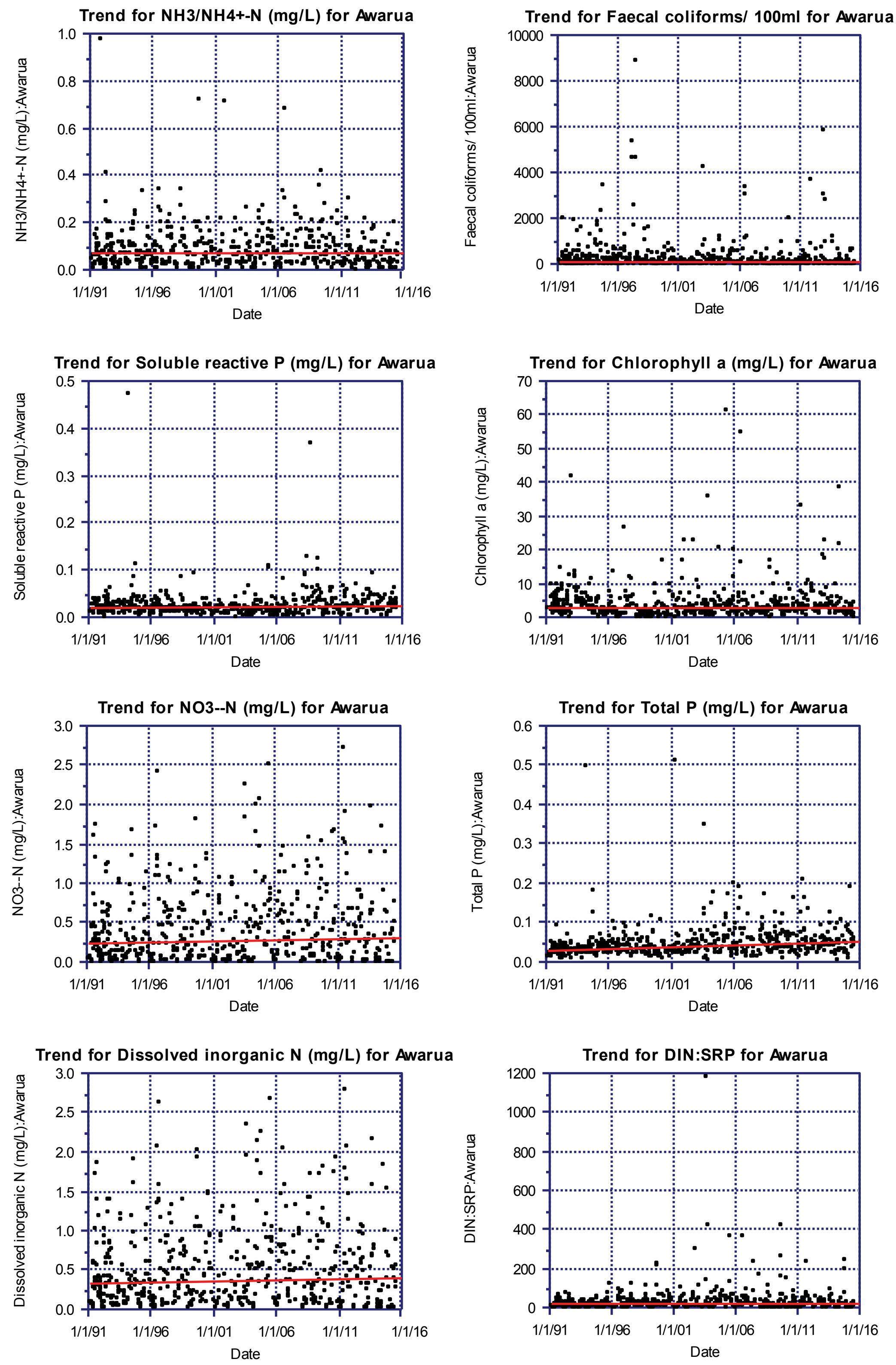


Figure 22. Awarua water quality for 1991-2015 (Ammonical-N, DRP, Nitrate-N, DIN, FC, Chl-a, TP, DIN:DRP). Seasonal Kendall test with multiple values per season including all data (both high and low water).

New River Estuary Water Quality (continued)

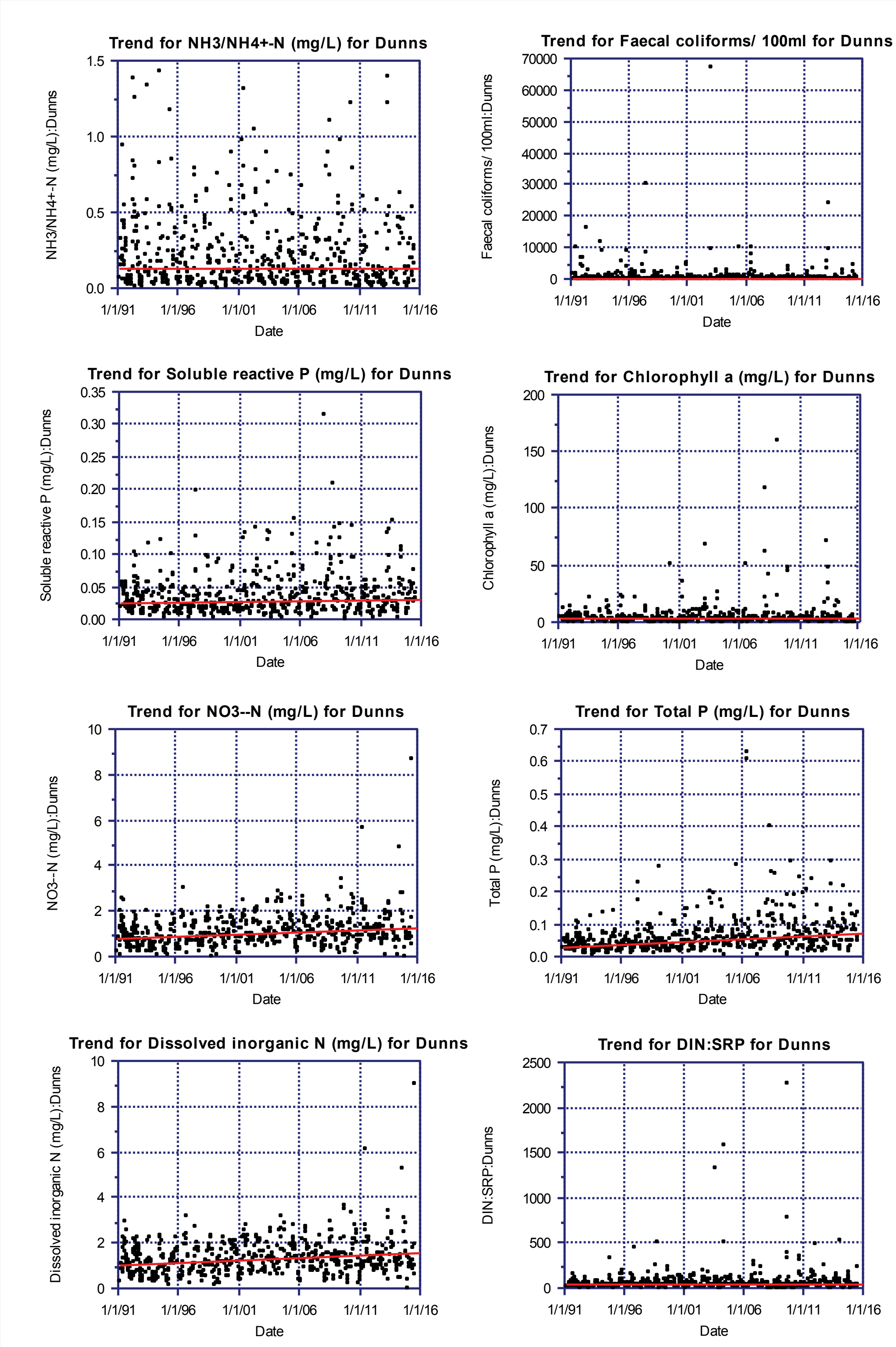


Figure 23. Dunns Road Bridge water quality for1991-2015 (Ammonical-N, DRP, Nitrate-N, DIN, FC, Chl-a, TP, DIN:DRP).
Seasonal Kendall test with multiple values per season including all data (both high and low water).

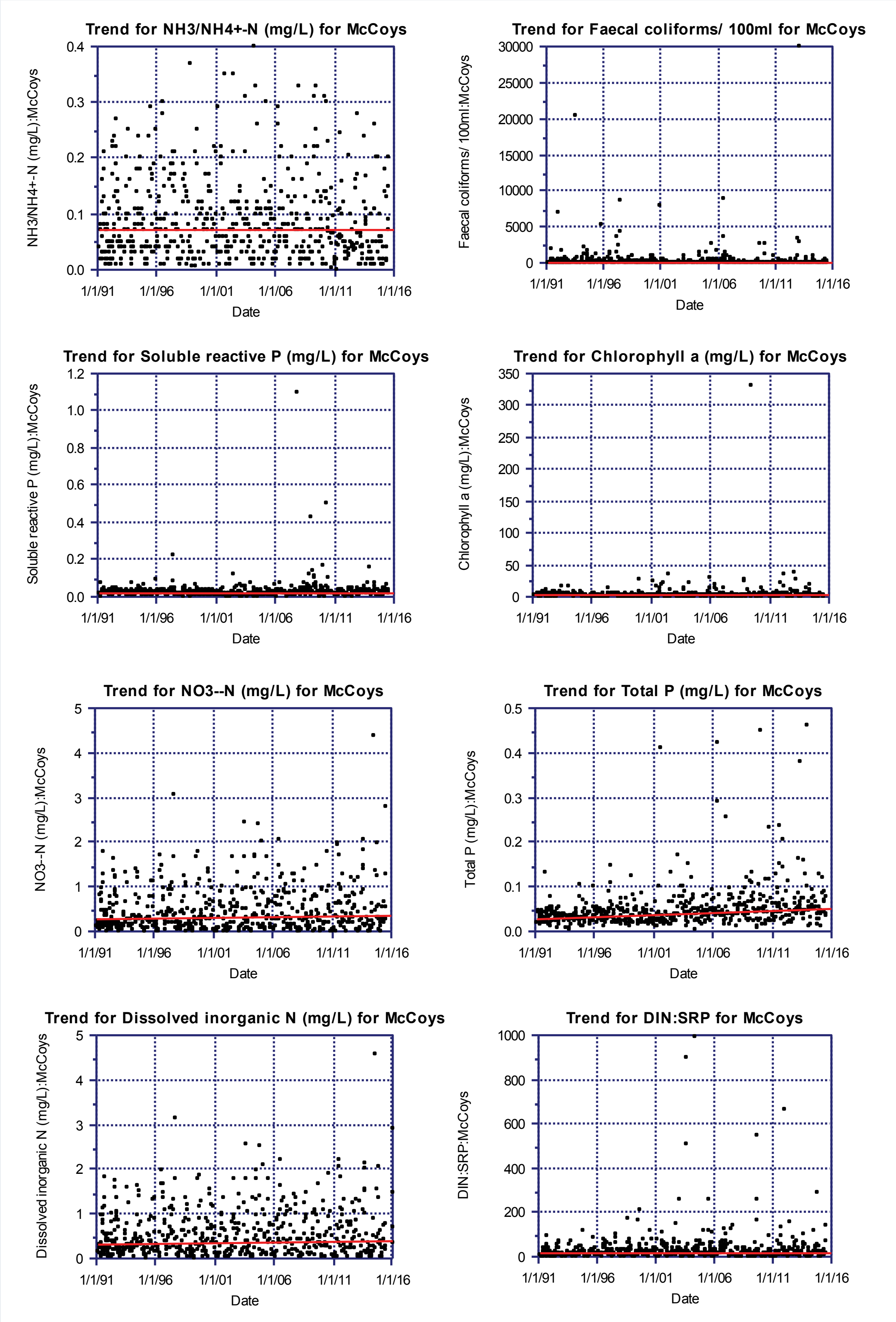


Figure 24. McCoys water quality for 1991-2015 (Ammonical-N, DRP, Nitrate-N, DIN, FC, Chl-a, TP, DIN:DRP). Seasonal Kendall test with multiple values per season including all data (both high and low water).

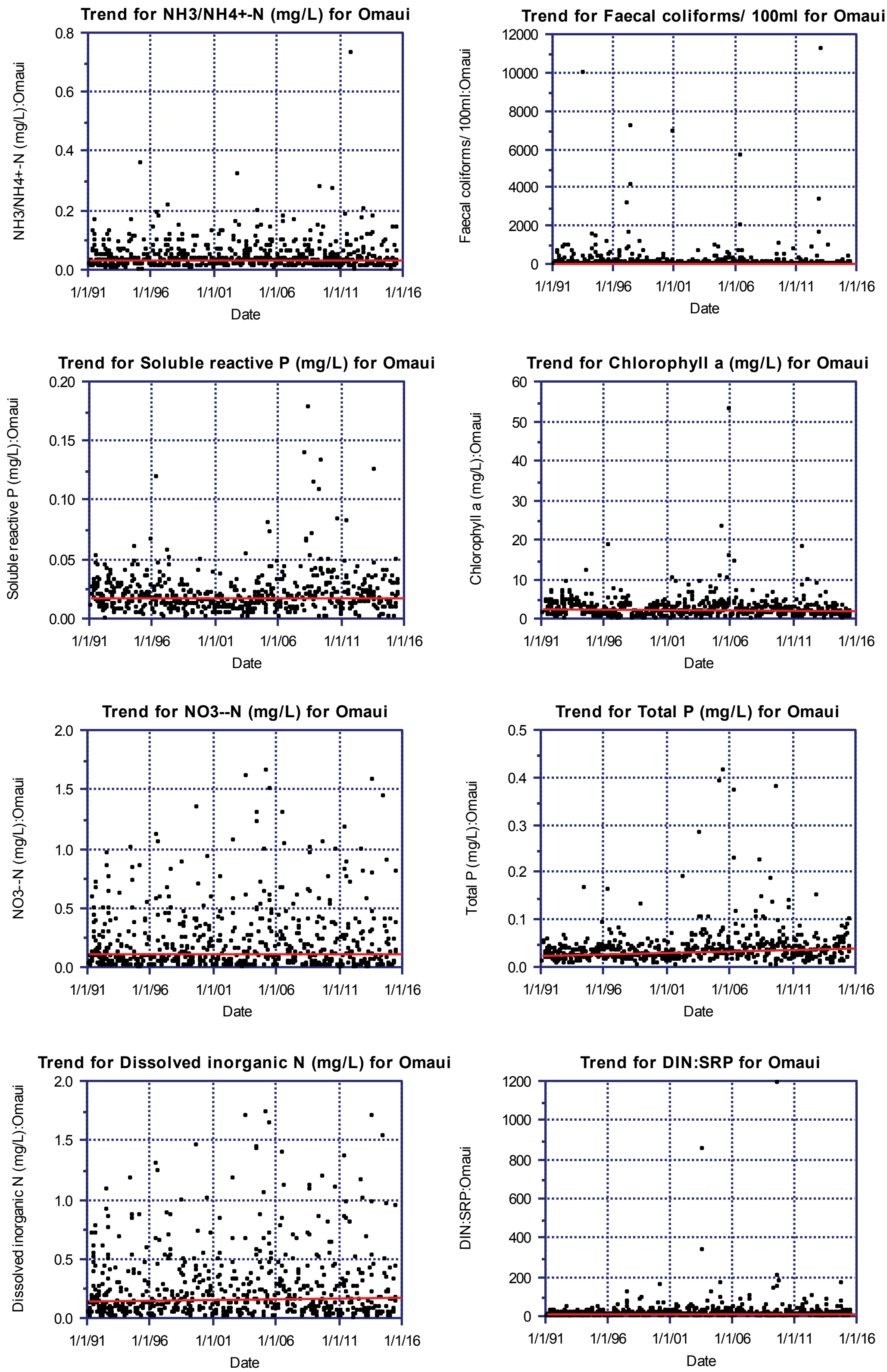


Figure 25. Omaui water quality for 1991-2015(Ammonical-N, DRP, Nitrate-N, DIN, FC, Chl-a, TP, DIN:DRP).
Seasonal Kendall test with multiple values per season including all data (both high and low water).

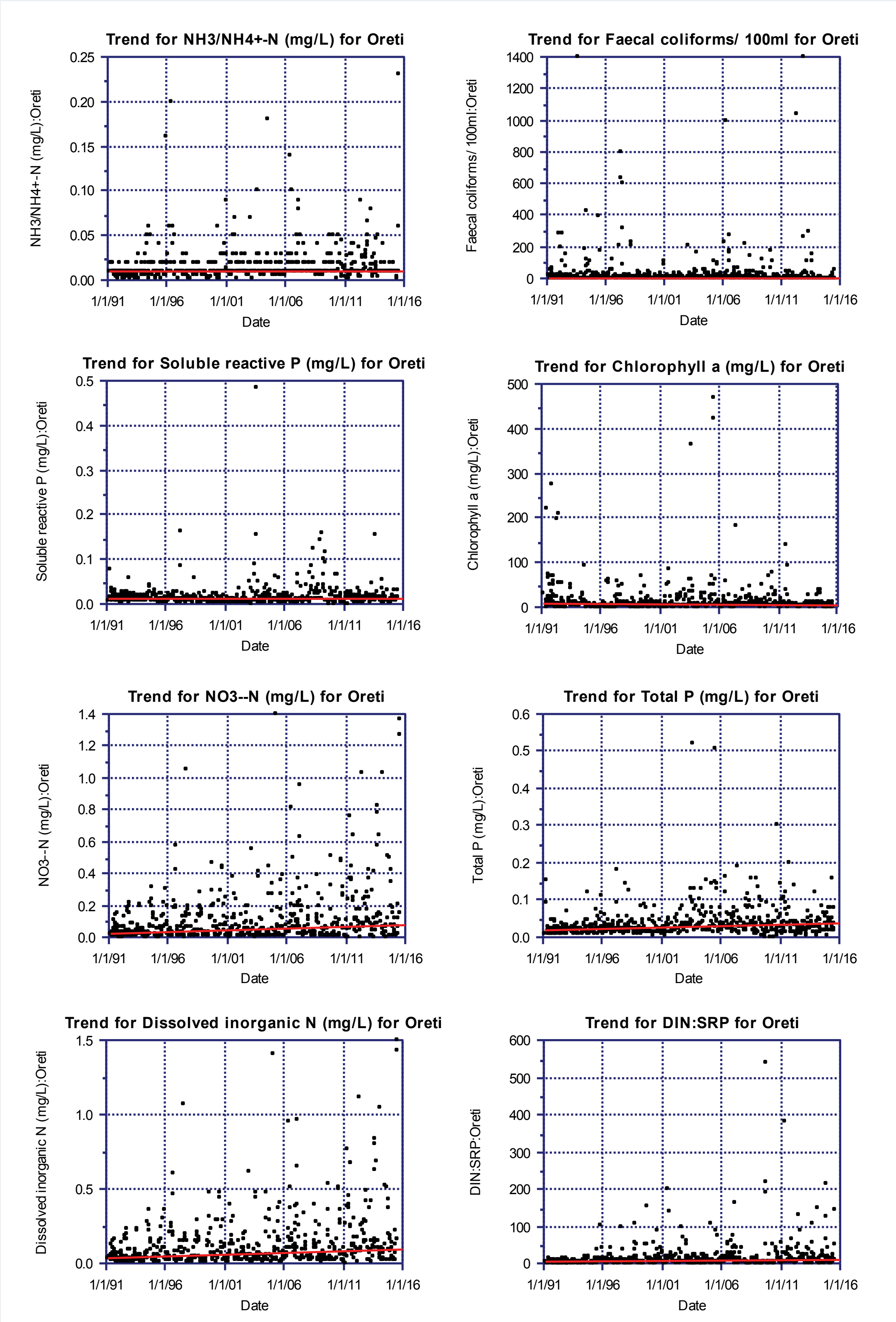


Figure 26. Oreti water quality for 1991-2015 (Ammonical-N, DRP, Nitrate-N, DIN, FC, Chl-a, TP, DIN:DRP). Seasonal Kendall test with multiple values per season including all data (both high and low water).

New River Estuary Water Quality (continued)

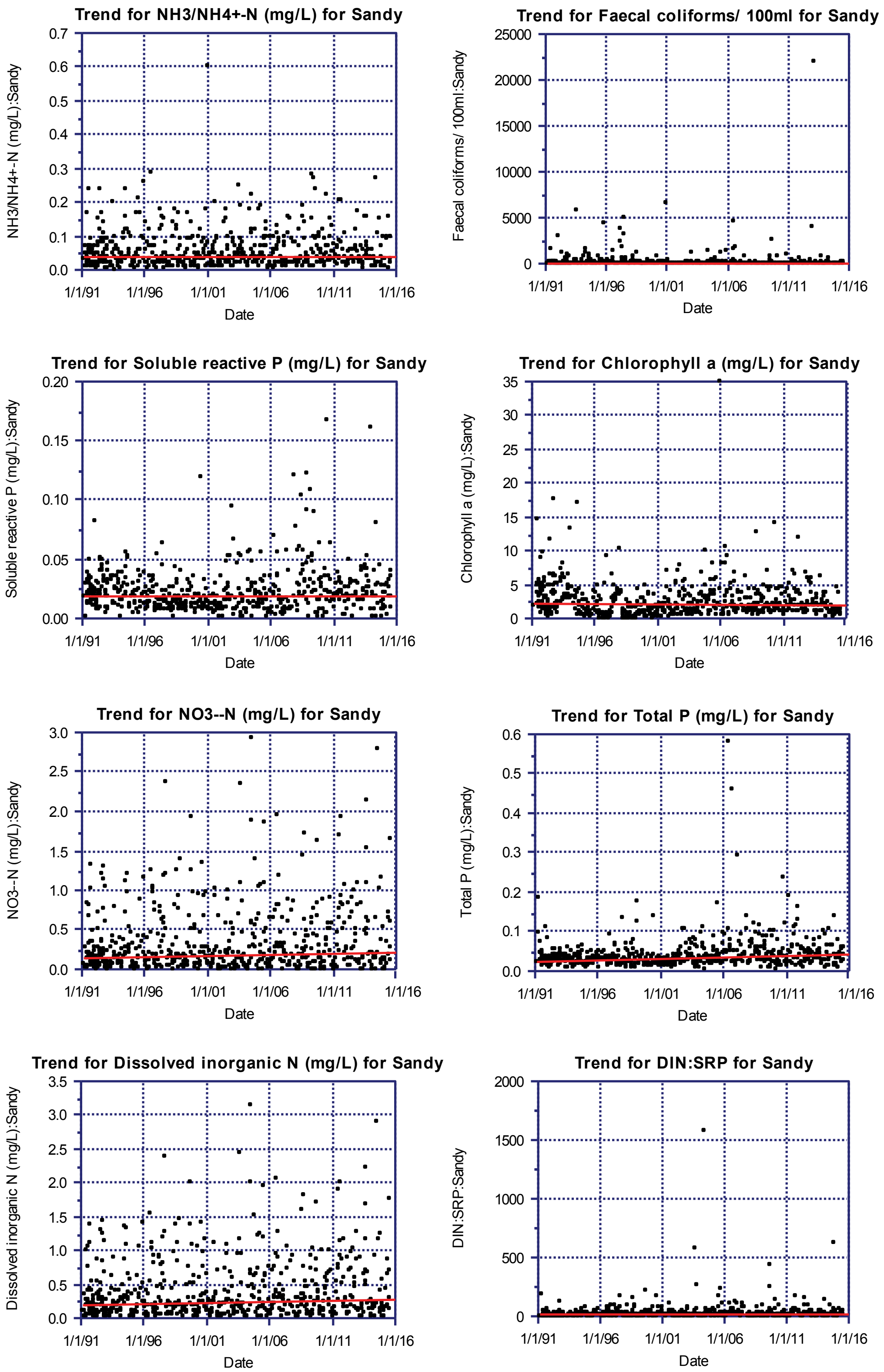


Figure 27. Sandy Point water quality for 1991-2015 (Ammonical-N, DRP, Nitrate-N, DIN, FC, Chl-a, TP, DIN:DRP). Seasonal Kendall test with multiple values per season including all data (both high and low water).

New River Estuary Water Quality (continued)

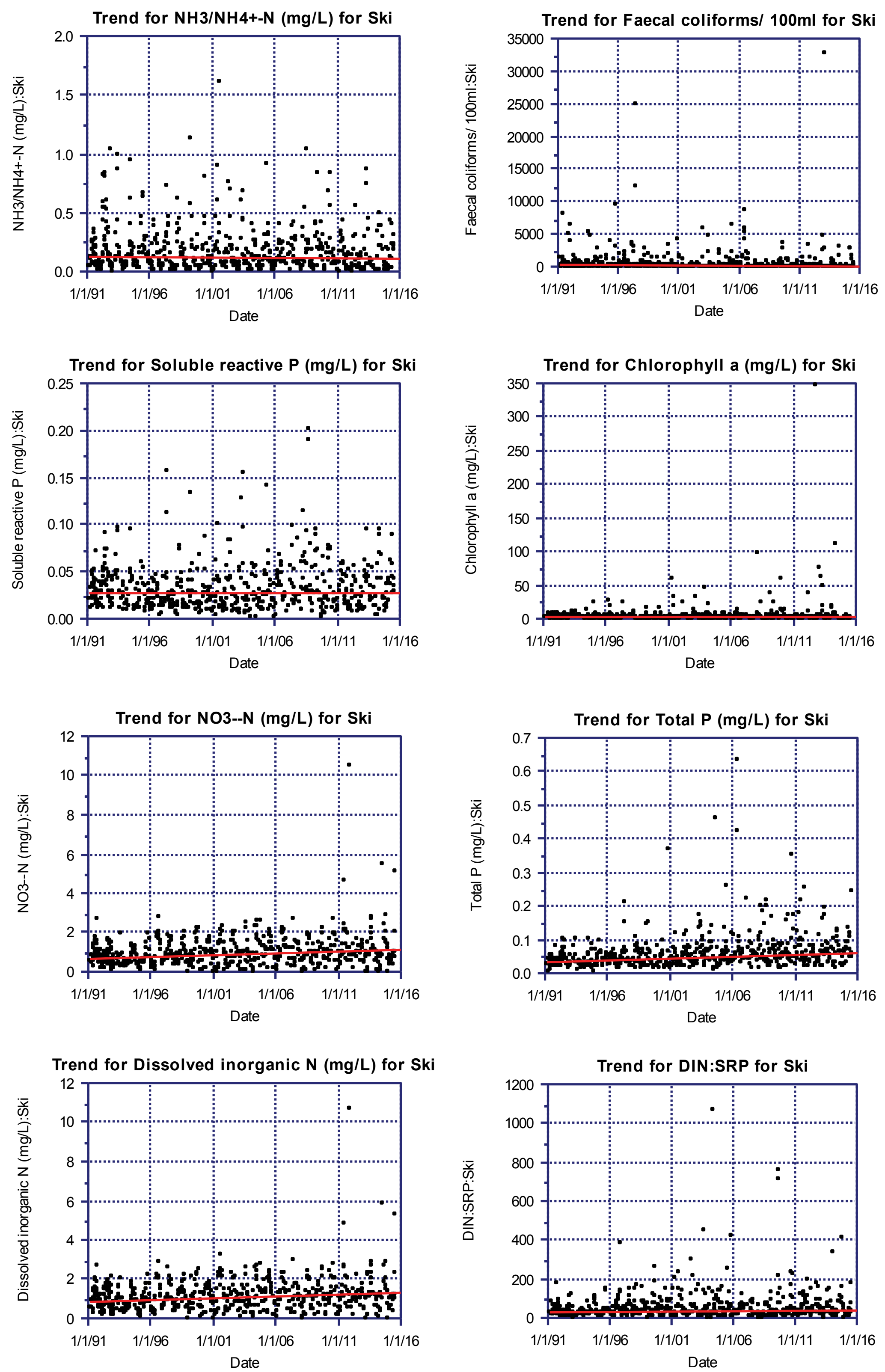


Figure 28. Ski Club water quality for 1991-2015 (Ammonical-N, DRP, Nitrate-N, DIN, FC, Chl-a, TP, DIN:DRP). Seasonal Kendall test with multiple values per season including all data (both high and low water).

New River Estuary Water Quality (continued)

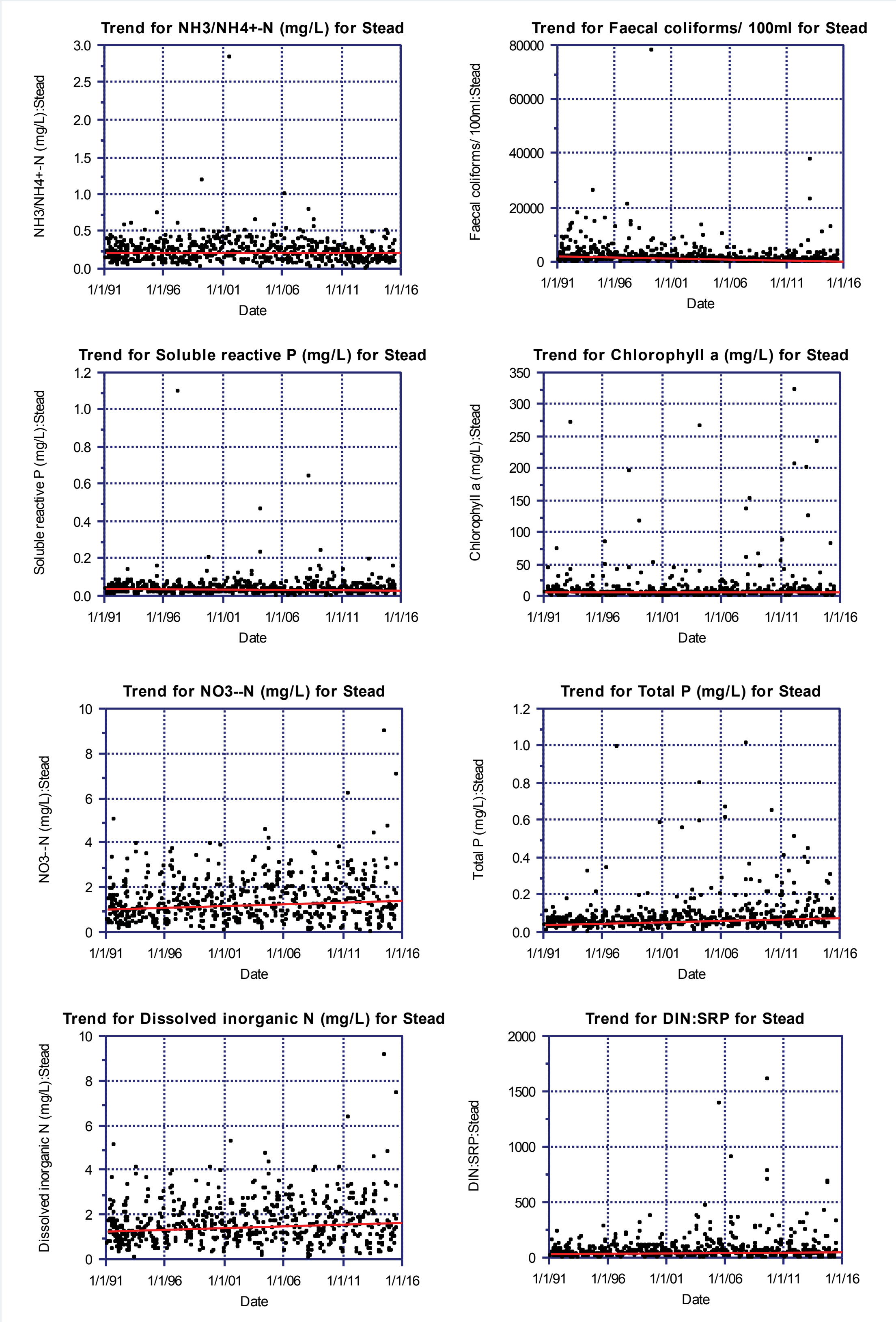


Figure 29. Stead Street Bridge water quality for 1991-2015 (Ammonical-N, DRP, Nitrate-N, DIN, FC, Chl-a, TP, DIN:DRP).
Seasonal Kendall test with multiple values per season including all data (both high and low water).

New River Estuary Water Quality (continued)

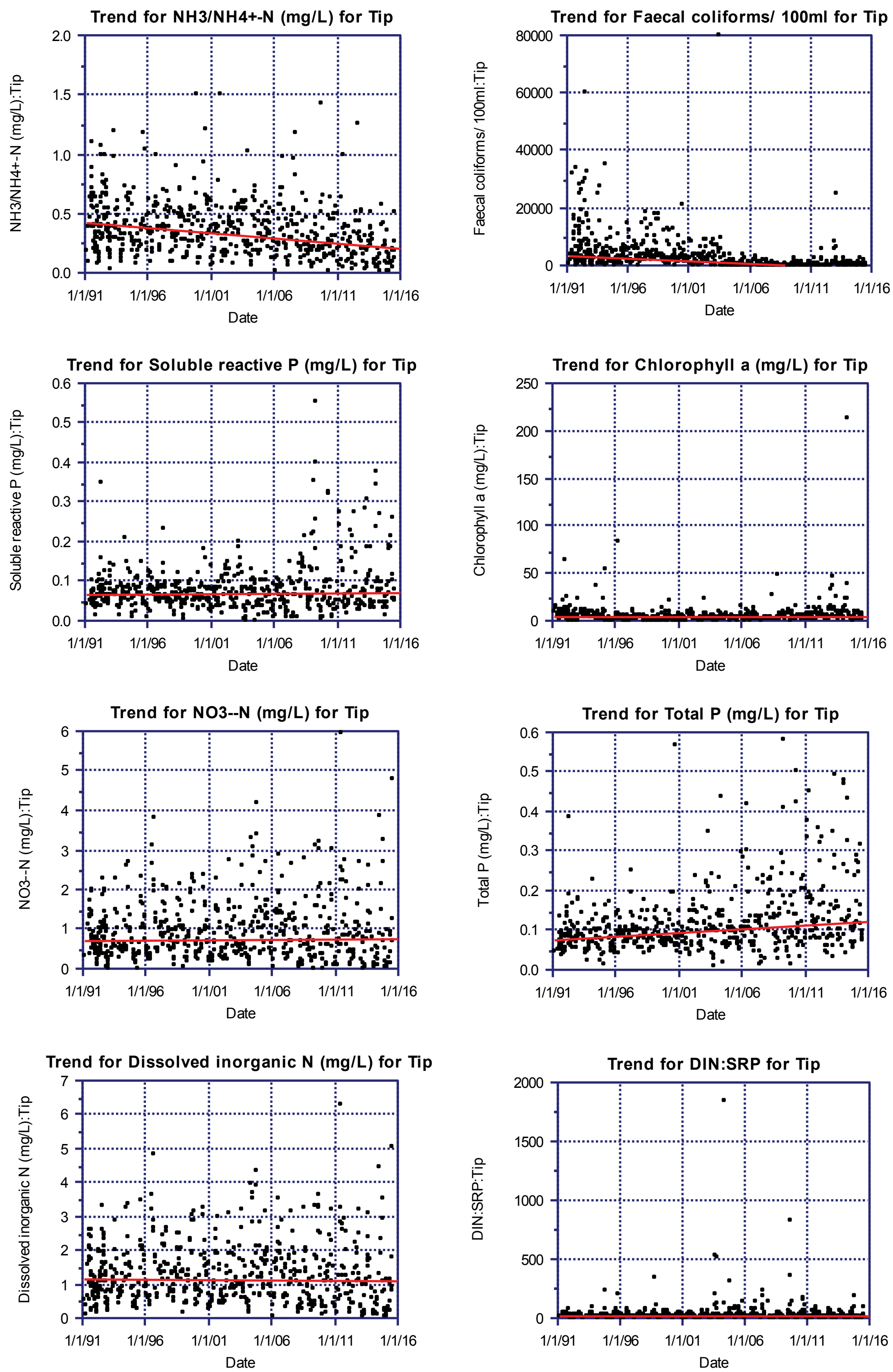


Figure 30. Tip Outlet water quality for 1991-2015 (Ammonical-N, DRP, Nitrate-N, DIN, FC, Chl-a, TP, DIN:DRP).
Seasonal Kendall test with multiple values per season including all data (both high and low water).

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APPENDIX 1. NEW RIVER ESTUARY ICC WATER QUALITY DATA

Seasonal Kendall test with multiple values per season. Seasons used in analysis are: Dec-Feb, Mar-May, Jun-Aug, Sep-Nov. If the sample size is less than 10 small sample size probabilities are used otherwise a normal approximation is used to determine P value.

Variable/Site	Samples used	Z	P	Sen slope (annual)	5% confidence limit for slope	95% confidence limit for slope	Percent annual change
Awarua							
NH3/NH4-N (mg/L)	561	-0.177	0.8595	0	0	0	0
Faecal coliforms/100ml	572	-3.2643	0.0011	-1.434	-2.4351	-0.6646	-1.7704
NO3--N (mg/L)	561	2.9296	0.0034	0.0028	0.0009	0.005	1.0959
Total P (mg/L)	538	7.3718	0	0.0008	0.0006	0.001	2.1114
Soluble reactive P (mg/L)	543	1.8785	0.0603	0.0001	0	0.0003	0.6789
Chlorophyll a (mg/L)	552	-0.3669	0.7137	-0.005	-0.028	0.0161	-0.1815
Dissolved inorganic N (mg/L)	561	2.2746	0.0229	0.003	0.0007	0.0057	0.8692
DIN:SRP	542	1.2599	0.2077	0.0814	-0.0223	0.2102	0.4947
Dunns							
NH3/NH4-N (mg/L)	614	-0.8459	0.3976	0	-0.0009	0	0
Faecal coliforms/100ml	628	-0.9816	0.3263	-0.6315	-1.7563	0.4267	-0.4511
NO3--N (mg/L)	613	8.5729	0	0.0206	0.0167	0.0244	2.1196
Total P (mg/L)	589	10.5806	0	0.0015	0.0013	0.0018	3.2897
Soluble reactive P (mg/L)	593	2.5577	0.0105	0.0002	0.0001	0.0003	0.7154
Chlorophyll a (mg/L)	602	-1.6679	0.0953	-0.0181	-0.038	0	-0.6544
Dissolved inorganic N (mg/L)	613	7.1614	0	0.021	0.0164	0.0252	1.7042
DIN:SRP	592	2.6134	0.009	0.314	0.1152	0.5314	0.806
McCoys							
NH3/NH4-N (mg/L)	615	-1.44	0.1499	0	-0.0006	0	0
Faecal coliforms/100ml	629	-4.4234	0	-0.6638	-0.9999	-0.3875	-2.2126
NO3--N (mg/L)	615	2.6262	0.0086	0.003	0.0009	0.0053	1.0398
Total P (mg/L)	591	8.4699	0	0.001	0.0008	0.0011	2.4495
Soluble reactive P (mg/L)	596	-0.1305	0.8961	0	-0.0001	0.0001	0
Chlorophyll a (mg/L)	607	-0.4736	0.6358	-0.0049	-0.0224	0.012	-0.2103
Dissolved inorganic N (mg/L)	615	2.2235	0.0262	0.0032	0.0006	0.0061	0.8786
DIN:SRP	594	2.1844	0.0289	0.1536	0.0378	0.2877	0.9407
Omaui							
NH3/NH4-N (mg/L)	615	1.3884	0.165	0	0	0	0
Faecal coliforms/100ml	630	-3.5125	0.0004	-0.2982	-0.4976	-0.1418	-1.7544
NO3--N (mg/L)	614	1.7642	0.0777	0.0003	0	0.0014	0.2668
Total P (mg/L)	590	5.2669	0	0.0005	0.0003	0.0007	1.6386
Soluble reactive P (mg/L)	595	0.2066	0.8363	0	-0.0001	0.0001	0
Chlorophyll a (mg/L)	604	-2.2511	0.0244	-0.0183	-0.0319	-0.005	-0.9515
Dissolved inorganic N (mg/L)	615	1.9194	0.0549	0.001	0	0.002	0.6664
DIN:SRP	594	2.2582	0.0239	0.0891	0.0206	0.1681	0.8912
Oreti							
NH3/NH4-N (mg/L)	619	5.7551	0	0	0	0	0
Faecal coliforms/100ml	633	-1.2785	0.2011	0	-0.0663	0	0
NO3--N (mg/L)	619	8.4992	0	0.0021	0.0016	0.0027	4.2903
Total P (mg/L)	597	7.6414	0	0.0007	0.0005	0.0009	2.7417
Soluble reactive P (mg/L)	600	-0.5123	0.6084	0	-0.0001	0	0
Chlorophyll a (mg/L)	608	-1.4173	0.1564	-0.0383	-0.0899	0.0067	-0.673
Dissolved inorganic N (mg/L)	619	8.9448	0	0.0025	0.002	0.0032	4.2157
DIN:SRP	599	7.3532	0	0.2421	0.1768	0.3115	4.358
Sandy Pt							
NH3/NH4-N (mg/L)	601	1.3005	0.1934	0	0	0.0002	0
Faecal coliforms/100ml	614	-5.3886	0	-0.6269	-0.9343	-0.3842	-2.9854
NO3--N (mg/L)	601	3.1212	0.0018	0.0028	0.0012	0.0044	1.5291
Total P (mg/L)	582	5.4012	0	0.0006	0.0004	0.0007	1.7828
Soluble reactive P (mg/L)	583	-0.2465	0.8053	0	-0.0001	0.0001	0
Chlorophyll a (mg/L)	592	-1.2163	0.2239	-0.011	-0.0269	0.0033	-0.5617
Dissolved inorganic N (mg/L)	601	3.1867	0.0014	0.003	0.0014	0.0049	1.307
DIN:SRP	583	3.3141	0.0009	0.2023	0.0957	0.3203	1.5173

Appendix A2. New River Estuary ICC Water Quality Data (continued)

Seasonal Kendall test with multiple values per season. Seasons used in analysis are: Dec-Feb, Mar-May, Jun-Aug, Sep-Nov. If the sample size is less than 10 small sample size probabilities are used otherwise a normal approximation is used to determine P value.

Variable/Site	Samples used	Z	P	Sen slope (annual)	5% confidence limit for slope	95% confidence limit for slope	Percent annual change
Ski Club							
NH3/NH4-N (mg/L)	611	-1.8741	0.0609	-0.0006	-0.0013	0	-0.5364
Faecal coliforms/100ml	625	-3.8202	0.0001	-2.3847	-3.54	-1.2915	-1.9872
NO3--N (mg/L)	611	6.7363	0	0.0172	0.0131	0.0212	2.0219
Total P (mg/L)	588	8.5883	0	0.0011	0.0009	0.0013	2.478
Soluble reactive P (mg/L)	592	0.7514	0.4524	0	-0.0001	0.0002	0.1763
Chlorophyll a (mg/L)	602	-1.4716	0.1411	-0.0145	-0.0313	0.0016	-0.6446
Dissolved inorganic N (mg/L)	611	5.8405	0	0.0175	0.0126	0.0225	1.6546
DIN:SRP	592	3.3194	0.0009	0.4074	0.1962	0.6243	1.1818
Stead St Bridge							
NH3/NH4-N (mg/L)	614	-1.5336	0.1251	-0.0009	-0.002	0	-0.4163
Faecal coliforms/100ml	627	-9.2188	0	-56.2761	-67.3364	-46.1457	-5.116
NO3--N (mg/L)	613	4.4051	0	0.0161	0.0101	0.0224	1.3554
Total P (mg/L)	588	7.9055	0	0.0014	0.0011	0.0018	2.4842
Soluble reactive P (mg/L)	593	-1.2874	0.198	-0.0001	-0.0003	0	-0.4335
Chlorophyll a (mg/L)	604	-0.1818	0.8558	-0.0033	-0.0378	0.0289	-0.0734
Dissolved inorganic N (mg/L)	614	4.2302	0	0.0163	0.01	0.0224	1.1296
DIN:SRP	593	3.0186	0.0025	0.56	0.2395	0.8847	1.2445
Tip Outlet							
NH3/NH4-N (mg/L)	615	-8.8874	0	-0.0084	-0.01	-0.0068	-2.5874
Faecal coliforms/100ml	627	-17.406	0	-176.8939	-198.66	-156.723	-11.7929
NO3--N (mg/L)	604	0.5065	0.6125	0.0013	-0.0029	0.0056	0.1809
Total P (mg/L)	582	8.036	0	0.002	0.0016	0.0024	2.0825
Soluble reactive P (mg/L)	587	0.7017	0.4829	0.0001	-0.0001	0.0004	0.1873
Chlorophyll a (mg/L)	609	1.2033	0.2289	0.02	-0.008	0.0483	0.5575
Dissolved inorganic N (mg/L)	615	-1.0073	0.3138	-0.0032	-0.0084	0.0022	-0.2922
DIN:SRP	587	-0.8965	0.37	-0.0548	-0.146	0.0512	-0.3305