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Evaluation of Broadscale Environmental Monitoring Program (BEMP) data from 2009-2012

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Title

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Contents

Non-technical summary

The Broadscale Environmental Monitoring Program (BEMP) provides a comprehensive assessment of ecological condition in the D'Entrecasteaux Channel and Huon Estuary. The program commenced in March 2009, and is currently undertaken by all marine finfish farm licence holders in the D'Entrecasteaux Channel and Huon River/Port Esperance Marine Farm Development Plan (MFDP) areas. Fifteen sites within the MFDP areas are monitored throughout the year to assess spatial and temporal patterns of water and sediment quality; this includes a broad suite of parameters capturing the physical, chemical and biological characteristics of the system. This dataset provides a significant body of information that can be used by regulators, industry and other stakeholders to assess ecological condition and to support adaptive management strategies.

This report represents a comprehensive summary of both the water and sediment quality data collected as part of the BEMP from 2009-2012. It also provides an evaluation of the data in the context of the major system drivers, previous environmental data sets and broader ecosystem performance measures. Collectively the information in this report has improved our understanding of the key processes and interactions, forms a comprehensive reference point for future assessment of the Huon and Channel system and provides an assessment of ecological functioning at the whole of ecosystem level (i.e. a "state of the system").

The water quality and sediment condition monitoring programs were undertaken at different spatial and temporal scales and as such it was easier, and appropriate, to assess these programs separately. The key findings are summarised below:

Water Column Assessment

An important component of the water column assessment was to first provide an assessment of the major external nutrient sources to the system; this provides the necessary context to interpreting the water quality data collected in the BEMP. Catchment inflows, fish farms and oceanic inputs are the major sources of nutrients, particularly nitrogen, but they vary in the form of nitrogen they input to the system. Catchments inputs are predominately organic nitrogen, fish farms are the most significant source of ammonium, and oceanic inputs are the major source of nitrate and nitrite. The BEMP water quality data demonstrates that the major oceanic influx of nitrate and nitrite occurs during winter and subsequent biological uptake from spring through autumn. Similarly, ammonium concentrations in surface waters become depleted from early spring through to mid-autumn due to biological uptake. It is also apparent that ammonium concentrations are on average higher in the Huon Estuary and northern Channel sites. This is consistent with our understanding of residual regional circulation which would facilitate the accumulation of nutrient inputs to the system in the Huon and north D'Entrecasteaux Channel.

Phytoplankton biomass was greatest between spring and autumn consistent with the aforementioned depletion of surface water concentrations of the major nutrients in these time periods. The peak biomass/blooms typically occurred in spring and late summer/autumn and were typically greater in the Huon Estuary.

The BEMP data set also provided an ideal opportunity to contrast current conditions with historical data sets collected in the D'Entrecasteaux Channel (Aquafin CRC: 2002-2005) and Huon Estuary (HES: 1996-1998 and Aquafin CRC: 2002-2005). This assessment provided further evidence of the high spatial and temporal variability in nutrient concentrations and phytoplankton biomass and composition consistent with intra and inter-annual variability in hydrodynamics and marine and river influxes. Despite the inherent natural variability and data limitations across studies, a number of system changes appear consistent with anticipated responses to increased inputs of organic matter and nutrients. This includes an increase in ammonium concentrations in bottom and surface waters and a decrease in oxygen concentrations in bottom waters in the Huon Estuary in 2009-12 compared to 1996-98. Variability in the region's hydrodynamics (e.g. far more distinct seasonal river flows in 2009-12 compared to 1996-98) and the associated effects on stratification and mixing are likely to be partly responsible for the changes in ammonium and oxygen concentrations. However, it also seems likely that the increase in ammonium concentration and decrease in bottom water oxygen concentrations in the Huon Estuary is partly due to a combination of increased organic loading to the sediments and subsequent remineralisation and increased inputs via excretion from farmed fish associated with the industry expansion. Unfortunately a lack of comparable ammonium and oxygen data pre-BEMP in the Channel obfuscates meaningful assessment in the Channel.

Despite the changes in ammonium and oxygen concentrations in the Huon Estuary there is no clear evidence of a concomitant change in water column productivity (i.e. phytoplankton biomass). There is some indication from the HPLC data that phytoplankton composition may have changed in the Huon and Channel, however, more data and further analysis (i.e. inclusion of count data) are required before concluding an unambiguous change in composition through time and/or direct links to any single source. To provide further insight to the state of the ecosystem the monitoring data was compared against recommended performance measures of the ecosystem. These performance measures incorporate 3 levels of management response associated with the relative risk to ecological function represented by increasing temporal or spatial extent of ecological conditions that are increasingly above the baseline, regardless of cause (natural/anthropogenic). It is important to note that there are a range of natural (e.g. changes in the magnitude and seasonality of catchment inputs) and anthropogenic drivers (e.g. point source discharges) that may lead to levels exceeding a trigger and as such, attribution would normally require further investigation. There were a number of instances when level 1 (low risk) trigger values were reached but very few instances of the system reaching level 2 trigger (moderate risk) for the key water quality parameters. The level 1 low risk triggers were predominately observed for bottom water ammonium and dissolved oxygen conditions, and phytoplankton biomass and bloom frequency. Overall these occurrences were more common in the Huon compared to the D'Entrecasteaux MFDP area.

Sediment Assessment:

Evaluation of sediment condition and infaunal community relationships, and comparison of this data with previous studies and indicators of benthic condition suggests no evidence of any major broadscale impacts of salmon farming at present in the Huon / D'Entrecasteaux Channel region.

Sediment biogeochemistry and infaunal community structure broadly reflect the prevailing environmental conditions, and particularly the degree of exposure and current flow regimes within the region. The sediment biogeochemistry assessment was conducted annually and most parameters showed similar response patterns over time. The redox and sulphide measurements were undertaken annually and provide a useful local scale assessment of the sediment condition. Whilst there is some variability between sites these differences appear to largely reflect the underlying sediment conditions and position in the estuary, and were within levels of expectation. The sediment grain size analysis did not suggest any major changes in sediment composition over time between regions, but provides a really valuable context for interpretation of the biological information. The isotope analysis and total organic carbon content measurements were not conducted regularly in the review period, however, the results suggest a spatial pattern very similar to that observed in previous studies. The isotope analysis does not appear to provide any more system understanding than could be obtained from the more regular biogeochemical analyses combined with biological assessments. Benthic infaunal data provides an ecological context for the observed environmental conditions; expert assessment of the significance of the species present and their functional characteristics can provide valuable information as to the source (causality) of any observed differences between sites/ times. In the BEMP dataset there was no evidence in the infaunal community composition of any significant organic enrichment or change in the community or function.

However, it is worth noting that the environmental conditions at the current control location (Recherche Bay) would appear to be quite different from the other sites sampled. The sedimentary environment at this site is inconsistent with other sites in the Huon/Channel and therefore both the natural biological community and the potential response to changes in environmental condition will be quite different. Whilst this site could provide useful information regarding temporal changes to the biogeochemistry of the system as a whole, e.g. providing some information on possible changes in major currents or broader system water conditions, the potential for comparison and translation of such changes to the Huon and Channel ecosystems would be limited.

In conclusion it is important to acknowledge the significant dataset that has been collected as part of the Broadscale Environmental Monitoring Program (BEMP). This dataset not only provides data to allow assessment of the possible system-wide effects of salmon farming in the environment, but also baseline information that improves our understanding of the Huon and Channel ecosystem as a whole. This data can be used to interpret ecosystem changes as a result of broad-scale stimuli (e.g. climate change) as well as other anthropogenic influences (e.g. regional development and urbanisation, changes in land-use and environmental flows). It also has the potential to inform and benefit a great many environmental programs and management initiatives.

KEYWORDS: aquaculture impacts, environmental assessment, monitoring requirements, benthic infaunal assessment, sediment biogeochemistry, nutrients, mineralisation, phytoplankton, water column

Acknowledgements

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We would also like to thank the staff at DPIPWE for the many useful discussions which have provided the framework for this report, and for their help in compiling the additional farm data and information from previous compliance sampling (particularly Graham Woods, Marc Santo and Eric Brain)

Finally we would like to thank our research colleagues at CSIRO who played a key role in developing the original monitoring program guidelines (Dr Peter Thompson in particular) and who have been willing to provide comment and advice along the way.

Chapter 1 General Introduction

The Broadscale Environmental Monitoring Program (BEMP) was initiated in 2009 to assess water and sediment quality in the D'Entrecasteaux Channel and Huon Estuary and is a regulatory compliance requirement, in accordance with the Tasmanian *Marine Farming Planning Act 1995*, for all licensed finfish marine farming lease holders. The BEMP requires that licensed marine finfish farming lease holders within the D'Entrecasteaux Channel Marine Farm Development Plan (MFDP) and Huon MFDP areas undertake a program of monitoring as described in Schedule 3 BEMP (Appendix 1) of their marine farming licences.

The monitoring program was based on the recommendations of research studies undertaken by Volkman et al. (2009) and Thompson et al. (2008), which investigated the cumulative effects of aquaculture operations on the local aquatic environment. The BEMP aims to assess water and sediment quality and benthic infaunal condition at a number of sites throughout the region. The program was established with the proviso that assessment and review of the resultant data be undertaken at regular intervals with a view to ensuring that both the water column and sedimentary environment remain in a satisfactory condition and that the monitoring program is relevant and effective. The BEMP sample collection for the years 2009-2012 was undertaken by Aquenal, an independent environmental consultancy employed by the industry peak body, the Tasmanian Salmonid Growers Association (TSGA), to perform this programme of work.

The aim of this report is to provide an evaluation of the observed monitoring data and to assess the outputs against ecosystem performance measures. Specifically this will include:

- Analysis and interpretation of the environmental data collected as part of the BEMP assessments between 2009 and 2012 in the context of other available information (including catchment input data and other historical environmental data available from the Huon Estuary, D'Entrecasteaux Channel and elsewhere).
- Provision of advice to DPIPWE regarding the relationship between the monitoring data, relevant CSIRO model outputs and recommended trigger levels.
- Identification of any significant gaps in the monitoring data and making recommendations regarding data collection and analysis.

The water quality and sediment condition monitoring programs were undertaken at different spatial and temporal scales and therefore it is easier, and appropriate, to assess these programs separately (Figure 1.1).

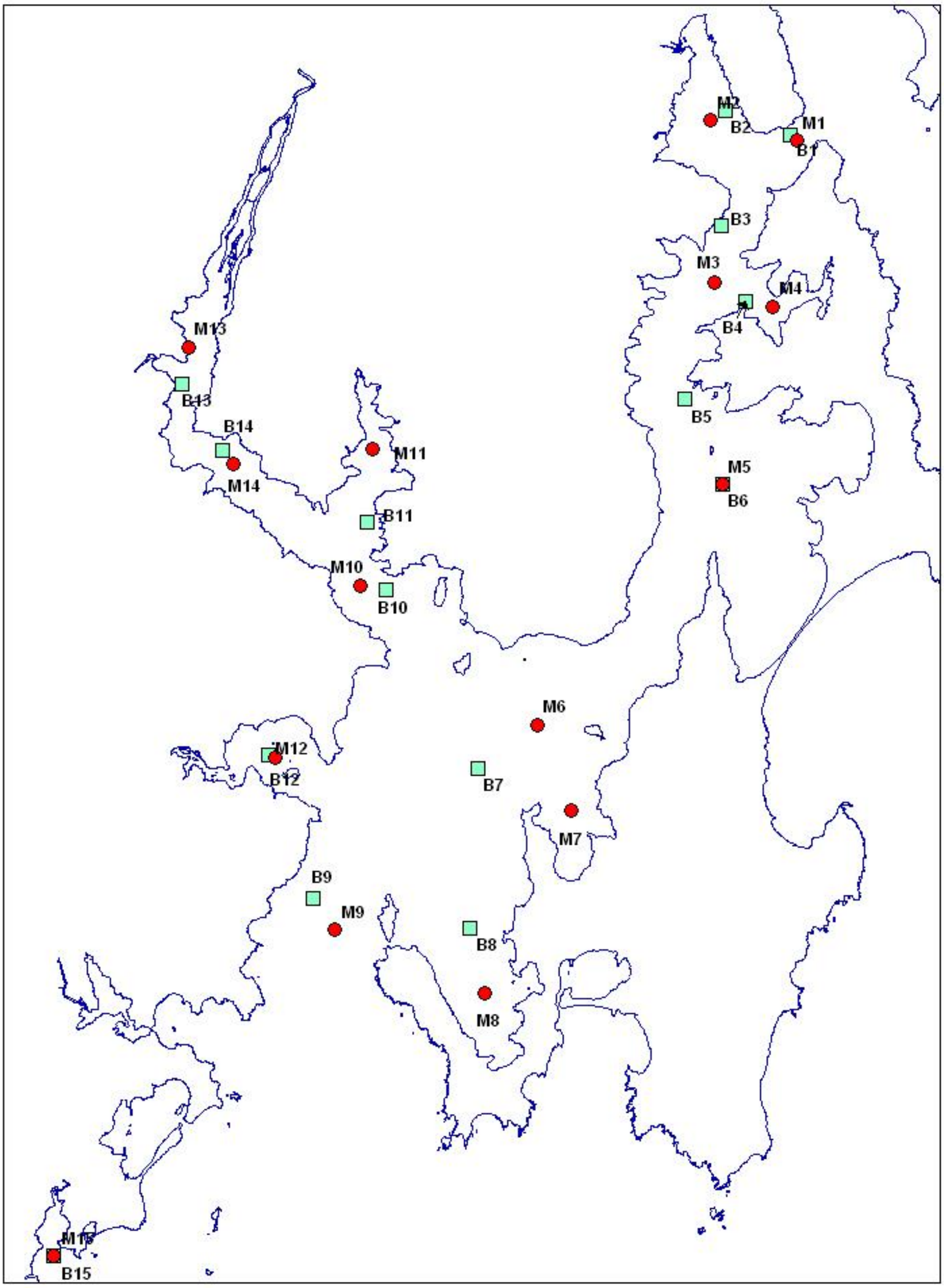


Figure 1.1: Map showing location of monitoring sites in the D'Entrecasteaux Channel and Huon Estuary. Sediment assessment sites (B1-B15) and water quality monitoring sites (M1-M15). Note that the control site at Recherche Bay is located in the bottom left corner of the map (B15/M15).

1.1 WATER COLUMN MONITORING

BEMP assessment

With three years (March 2009 – March 2012) of water column monitoring under the BEMP program now complete this report was commissioned to evaluate the data and assess the current condition of the D'Entrecasteaux Channel and Huon Estuary. In this section the spatial and temporal dynamics of the key water column parameters (dissolved nutrients, dissolved oxygen and phytoplankton biomass and community composition) are presented and discussed in the context of the major external sources of nutrients to the system; fish farms, catchment, STPs and oceanic influences.

Comparisons with the Aquafin CRC and HES

The BEMP data set also provided an ideal opportunity to contrast current conditions with historical data sets collected in the D'Entrecasteaux Channel (Aquafin CRC: 2002-2005) and Huon Estuary (HES: 1996-1998 and Aquafin CRC: 2002-2005). To provide context, the changes (or lack of) in water quality are contrasted against changes in the major external drivers over the same period. This covers a period of significant development of the Salmon Aquaculture industry in the region.

Comparison with previously modelled predictions

As part of the Aquafin CRC, a 3-D hydrodynamic, sediment and biogeochemical model of the system was used to assess the likely ecosystem response to various expansion scenarios for the salmon industry, including against projected farm inputs for 2009 (Wild-Allen 2008; Volkman et al 2009). It would be unreasonable to expect a close agreement between the modelled parameter value and 2009 BEMP observations given that the model was necessarily based on typical (2002) rather than actual 2009 physical forcing (e.g. meteorology and ocean boundary dynamics). Nonetheless, the BEMP observations provide insight into how well the model predicts seasonal and broad scale dynamics (e.g. Huon Estuary vs. northern and southern Channel) in the presence of a significant increase in salmon farming.

Baselines and trigger values

An important element in the design of the current BEMP monitoring program was the need to provide data that could be compared with baselines or trigger values proposed by Thompson et al. (2008) as being relevant for the identification of change in ecological function. These recommended baselines and triggers (Thompson et al. 2008) were based on a review of current knowledge, as well as evaluation of both data collected and the outputs of the high resolution biogeochemical modelling developed as part of the Aquafin CRC studies (Volkman et al. 2009). It is important to note that although the planning authority has not adopted these recommended trigger levels as statutory limits; they are being used to inform regulatory management of the industry. In the final part of the water column assessment the performance of key water column indicators measured in the BEMP program between March 2009 and March 2012 is assessed against these recommended baselines and trigger values. The additional data collected during the BEMP program also provides the opportunity to review the baselines and trigger levels proposed by Thompson et al. (2008), particularly in cases where data was limited at the time of development.

1.2 SEDIMENT MONITORING

The sediment monitoring program was designed to assess the environmental conditions on the seabed. The sediment sampling conditions involved collection of benthic infauna, a qualitative assessment of the condition of the sediments (appearance and smell), and a fully quantitative program measuring redox potential, particle size, sulphide concentration and stable isotope analysis (2009 only).

Sediment assessments were undertaken annually in March 2009, 2010, 2011 and 2012 at 15 sites within the Huon and Channel system (Figure 1.1, Table 1.1). This report summarises the results of the data over those 4 years and aims to provide an overall assessment of the sediment condition, relate this to the current understanding of salmon farm impacts more broadly, and provide comment on how the results relate to the proposed recommendations upon which the original sampling was based (Thompson et al. 2008).

Table 1.1: BEMP sediment study sites - showing individual site ID's and locations, Easting's and Northings, Marine Farming Development Plan (MFDP) regional categorisations and site depth (m).

Site	Description	Northing	Easting	MFDP Region	Depth
B15	Recherche Bay	492064	5178637	Control	6.8
B10	Lower Huon	507993	5210570	Huon & Port Esperance	32.4
B11	Cygnet	507095	5213795	Huon & Port Esperance	20.9
B13	Upper Huon	498168	5220383	Huon & Port Esperance	11.3
B14	Mid Huon	500172	5217258	Huon & Port Esperance	14.8
B12	Dover	502357	5202639	Huon & Port Esperance	30.4
B7	Little Taylors Bay	512422	5202010	Lower Channel	36.5
B8	Gt Taylors Bay	512028	5194350	Lower Channel	42
B9	Southern Boundary	504495	5195745	Lower Channel	45.9
B1	Northern Boundary	527388	5232358	Upper Channel	14.4
B2	Northwest Bay	524236	5233512	Upper Channel	24.2
B3	Upper Mid Channel	524089	5227962	Upper Channel	22.3
B4	Barnes Bay	525224	5224327	Upper Channel	13.7
B5	Green Island	522337	5219690	Upper Channel	24.9
B6	Central Mid Channel	524125	5215637	Upper Channel	13.4

Chapter 2 Water Column Assessment

2.1 BEMP ASSESSMENT

In this section the spatial and temporal dynamics of the key water column parameters (dissolved nutrients, dissolved oxygen and phytoplankton biomass and community composition) measured under the BEMP program between March 2009 and March 2012 are presented and discussed in the context of the major external sources of nutrients to the system; fish farms, catchment, STPs and oceanic influences. Given the potential for confusion with nutrient terminology, particularly with regard to nitrogen, the different nutrient forms and their abbreviations are summarised in Table 2.1.

Table 2.1: Nutrient forms, abbreviations and calculations. * denotes measured directly

Nutrient form	Abbreviation	Calculation
Nitrate*	NO_3	
Nitrite*	NO_2	
Nitrate + Nitrite	NOx	$NOx = NO_3 + NO_2$
Ammonium*	NH_4	
Dissolved Inorganic Nitrogen	DIN	$DIN = NO_3 + NO_2 + NH_4$
Dissolved Organic Nitrogen	DON	DON = TDN - DIN
Total Dissolved Nitrogen*	TDN	
Total Particulate Nitrogen	TPN	TPN = TN - TDN
Total Nitrogen*	TN	
Phosphate*	PO_4	
Dissolved Inorganic Phosphorus*	DIP	$DIP = PO_4$
Dissolved Organic Phosphorus	DOP	DOP = TDP -DIP
Total Dissolved Phosphorus*	TDP	
Total Particulate Phosphorus	TPP	TPP = TP-TDP
Total Phosphorus*	TP	
Silicate*	SO_4	

2.1.1 Nutrient Inputs

Marine Farming

Nitrogen inputs from fish farms are based on feed input data provided by industry to government. Following the methods of Wild-Allen et al (2005), the feed data is then converted into net loads of nitrogen released into the environment based on a conservative Food Conversion Ratio (FCR) for the Tasmanian industry of 1.35 (i.e. 1.35kg of dry feed is required to produce 1 kg of fish), a digestibility co-efficient of 90%, the nitrogen content of feed (7.2 % N) and the nitrogen content of the fish produced (3 % N). This equates to approximately 5% of total feed entering the environment as N; 85 % of which is released as dissolved N (this is the fraction used to estimate TPDNO below) and 15 % particulate N. Nitrogen released into the environment by fish farms is regulated (since 2009) via caps on total permissible dissolved nitrogen output (TPDNO). Separate caps were developed for the D'Entrecasteaux Channel Marine Farming Development Plan (MFDP) Area (1, 140.67 tonnes in any 12 month period.) and the Huon River and Port Esperance MFDP Area (1,084.63 tonnes in any 12 month period; DPIPWE 2011e)[1]. Farm inputs of dissolved nitrogen in the Huon River and Port Esperance MFDP Area have remained relatively stable at ~ 1000 tonnes p.a. (Table 2.2) across the calendar years (i.e. 2009, 2010 & 2011) that incorporate the BEMP monitoring period. In the D'Entrecasteaux Channel MFDP Area inputs have increased from 709 tonnes in 2009 to 849 tonnes in 2011 (Table 2.2). Seasonally, feed inputs are at the lowest in late summer before increasing through winter to a maximum in spring each year (Figure 2.1).

River inputs

There are 4 major rivers and more than 36 smaller rivers, creeks and streams draining into the D'Entrecasteaux Channel and Huon Estuary from 2 catchments; the Derwent Estuary – Bruny catchment (Figure 2.2) and the Huon River catchment (Figure 2.3) Loads to the Huon-Channel have previously been estimated as part of Tasmania's State of Rivers Reports (Bobbi 1998), the Huon Estuary Study (CSIRO Huon Estuary Study Team (2000) and the Aquafin CRC (Wild-Allen et al. 2005). Since then, the amount of data available to calculate loads (i.e. flow and concentration) has increased substantially through the Baseline Water Quality Monitoring program. This data is made available through the Water Information System of Tasmania (WIST) database (http://water.dpiw.tas.gov.au/wist). Although this water quality monitoring program was discontinued at a statewide level in 2011, it has been continued at 3 river sites that discharge into the Huon-Channel region, due to the importance of this information in interpreting the results of BEMP. These sites include the Huon River downstream of the Judbury River Bridge (station 635), Esperance River at the Dover water supply intake (station 7200), and the Snug Tiers Road Bridge (5202).

Table 2.2: Total dissolved nitrogen inputs from fish farms for the calendar years 2009, 2010 and 2011 in the 2 MFDP areas (Source: DPIPWE)

	Total Dissolved Nitrogen (tonnes p.a.)		
	2009	*2010*	*2011*
Total Huon	1069.6	1007.4	998.8
Total Channel	708.6	751.4	849.3
Total Farms	1778.2	1758.7	1848.1

[1] Due to improvements in diet formulation, notably the protein and nitrogen content of feed, nitrogen emissions values are now (since early 2009) calculated based on measured protein and N content in feed

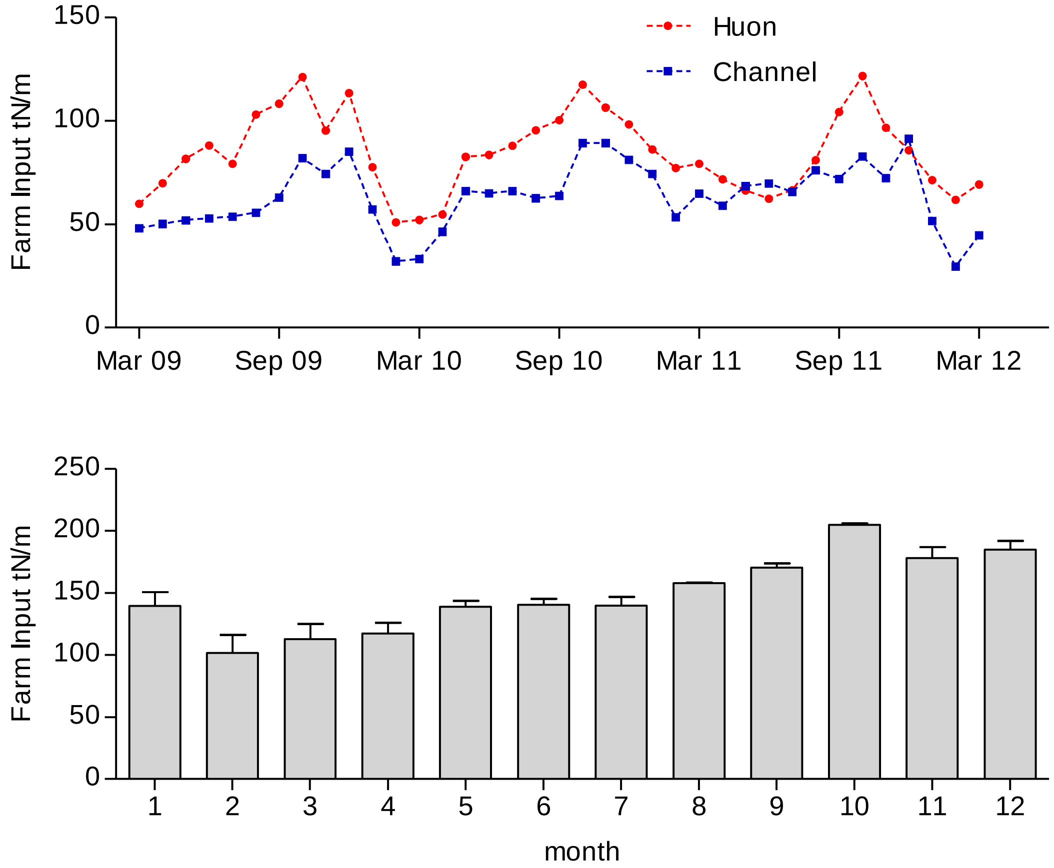


Figure 2.1: Monthly dissolved nitrogen input data by MFDP Area between March 2009 and March 2012 (top) and by calender month aggregated across years and MFDP Area.

For the purposes of the review, load estimates were also calculated for the Kermandie River (station 341) and North West Bay Rivulet (station 5201) given significant inflows and / or elevated nutrient concentrations. Although Mountain River joins the Huon upstream of Huonville and is effectively part of the Huon load to the region, it enters below the Judbury gauging station (635) where the Huon loads were estimated. Because a gauging station (station 6210) was opened in June 2008 in Mountain River 600 m upstream of the Huon, Mountain River loads were estimated separately. There have also been elevated nutrient concentrations measured in Nicholls (station 3341) and Agnes (station 3337) Rivulets (Table 2.3; Bobbi 1998) that enter the Huon at Cygnet however there is no flow gauging available to estimate loads.

Nutrient loads at each of these stations were estimated by determining the relationship between nutrient concentration and river flow, the latter being monitored continuously. In the absence of a clear relationship between flow and nutrient concentration loads were calculated by multiplying the median concentration (Table 2.3) by river flow (Figure 2.4)[2]. For North West Bay Rivulet there was gauged river flow data (station 5201 was re-opened in August 2008) but no nutrient concentration data, and as such, loads were estimated using the median nutrient concentration measured at the Snug station. Loads for the Kermandie River were estimated using water quality data collected by Bobbi (1998) between 1996-97 and river flow was estimated as 7.1 times the flow at the Riley's Creek gauging station (6202) 5km upstream of station 341 (as in Bobbi 1998). There was no flow data at Riley's Creek station during the BEMP period, and instead flow was estimated based on a scaled relationship with Huon river flow.

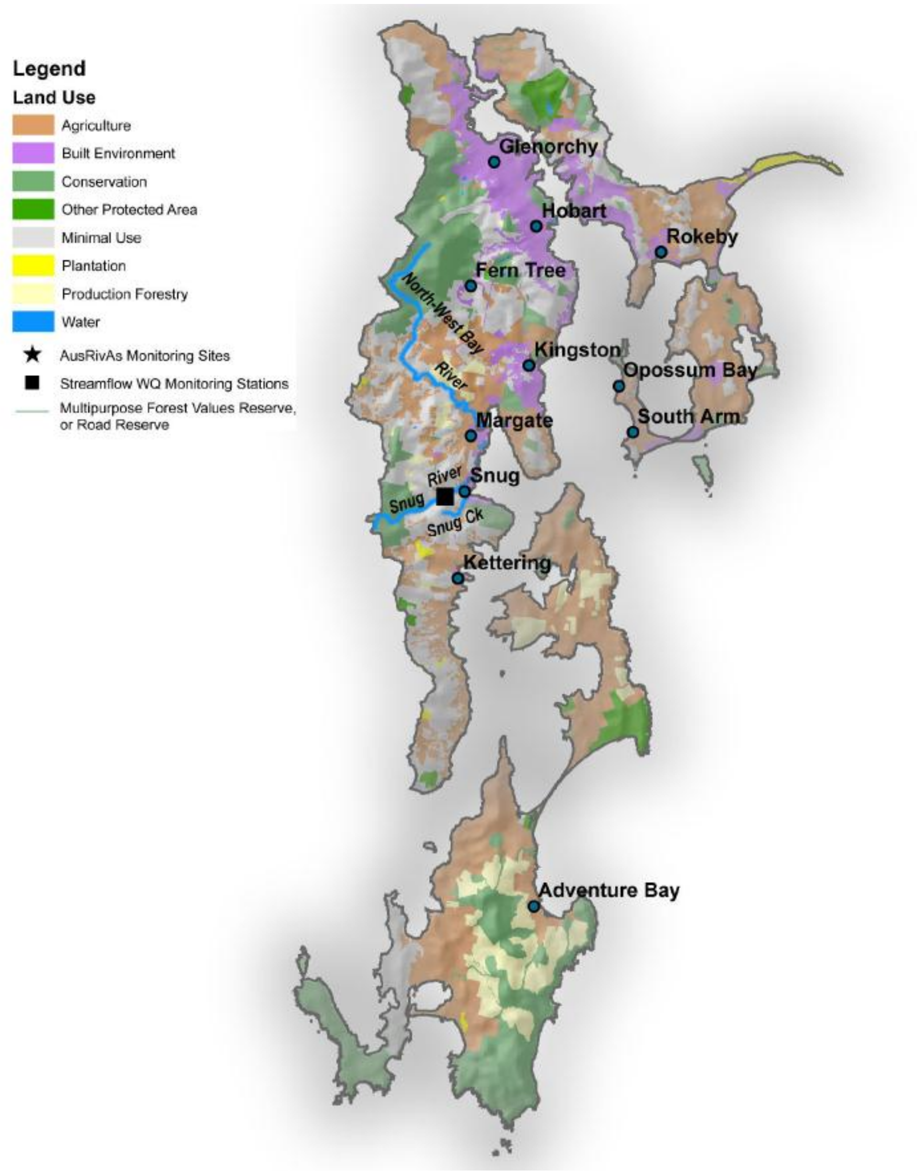


Figure 2.2: Derwent Estuary – Bruny Catchment (Source: DPIPWE 2008 Waterways Monitoring report)

[2] Please note, the estimates of load presented in this report should be treated as a first order estimate of actual loads and are provided to highlight inputs relative to other river systems and nutrient sources

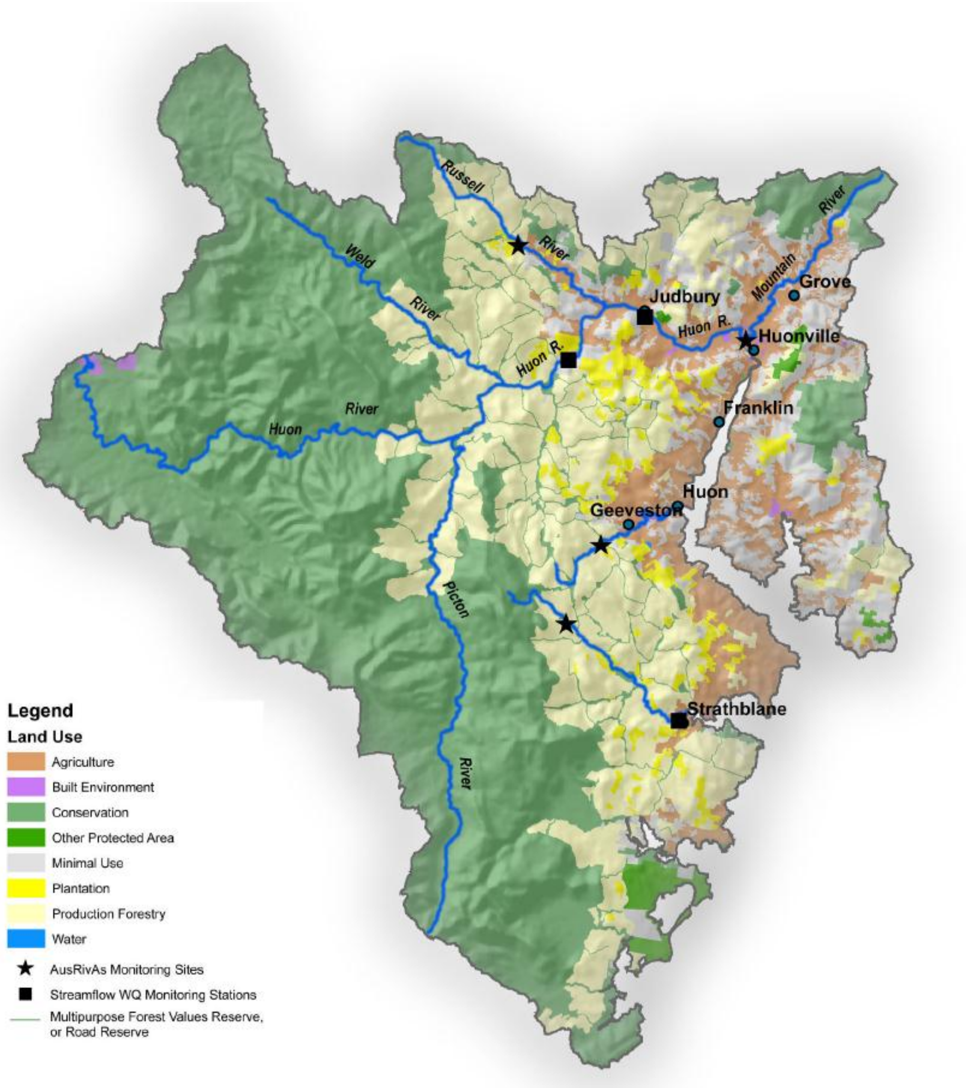


Figure 2.3: Huon River Catchment (Source: DPIPWE 2008 Waterways Monitoring report)

Table 2.3: Median concentrations of selected water quality parameter measured at DPIPWE monitoring stations

Station	Location	No. samples	NO_2 mg/L	NO_3 mg/L	NH_4 mg/L	TN mg/L	PO_4 mg/L	TP mg/L
635	HUON RIVER D/S JUDBURY RD BRIDGE	100	0.003	0.002	0.009	0.208	0.003	0.006
6210	MOUNTAIN RIVER AT RANELAGH	17	0.005	0.026	0.012	0.201		0.011
7200	ESPERANCE RIVER	96	0.002	0.002	0.009	0.206	0.003	0.008
341	KERMANDIE RIVER AT GEEVESTON	20	0.008	0.150	0.055	0.598		0.044
3341	NICHOLLS RIVULET U/S TIDAL	15	0.005	0.049	0.005	0.378		0.013
3337	AGNES RIVULET @ SLAB RD	2	0.005	0.135	0.008	0.455		0.013
5202	SNUG TIERS RD	99	0.003	0.008	0.011	0.347	0.003	0.010

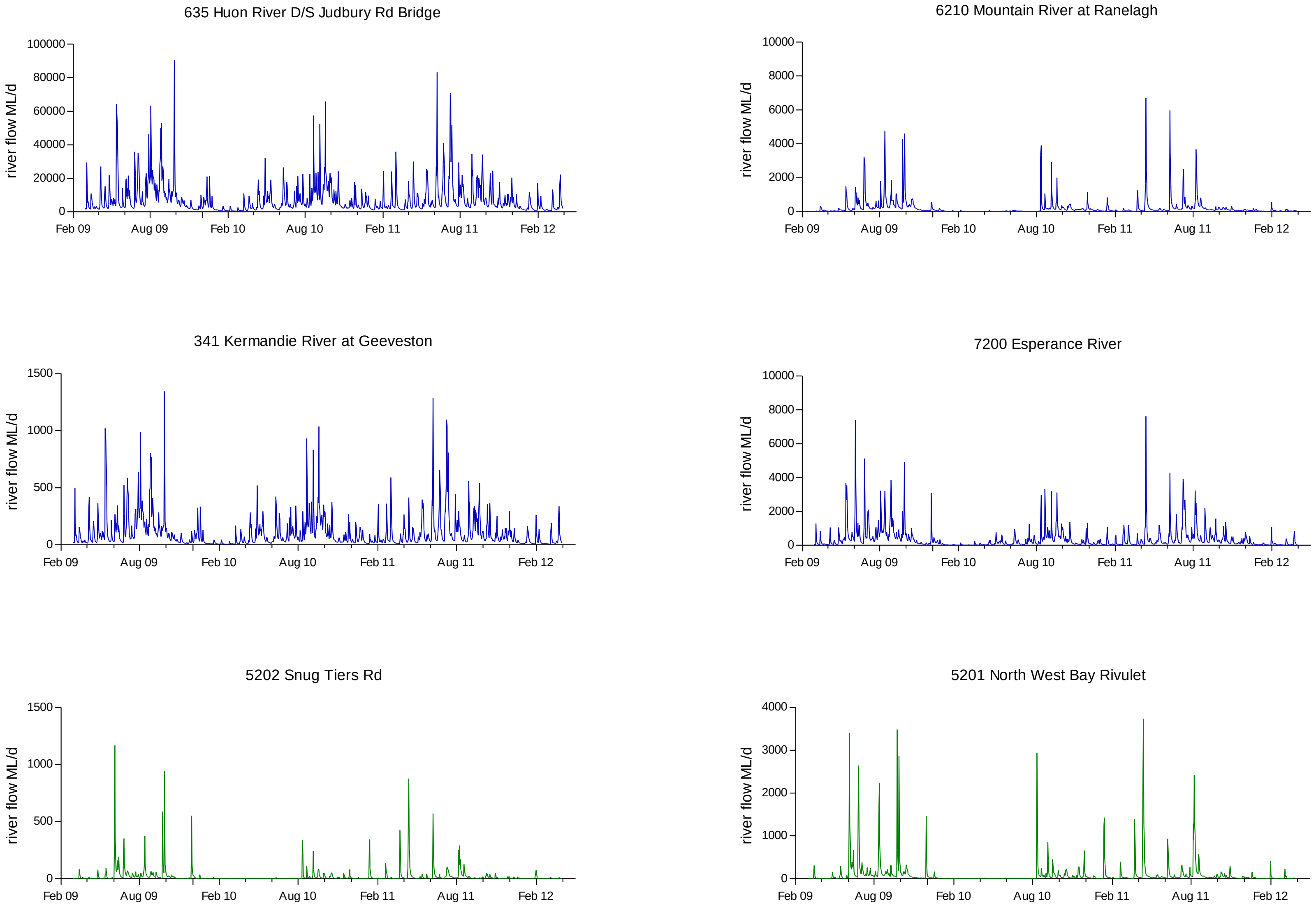


Figure 2.4: Daily river flow (ML) at 6 of the DPIPWE stations used to estimate loads to the Huon-Channel

River flow data for the 2009-11 BEMP period demonstrates that the Huon River system contributes the vast majority (90.4 %[3]) of flows to the Huon-Channel, with Mountain River that enters at the base of the Huon River contributing a further 2.4 % of total flows (Table 2.4). The Esperance River, Kermandie River, North West Bay Rivulet and Snug Rivulet contribute 4.5, 1.3, 1.2 and 0.3% of total flows to the region respectively. The strong seasonal pattern of flows is also clearly evident with flow highest during winter and early spring and lowest during summer and early autumn (Figures 2.4 & 2.5). Strong inter-annual variability is also clearly evident during 2009-11 with 2010 20-30 % drier than 2009 and 2011. Although there are differences in nutrient concentrations measured in each river system, the relative loads of total nitrogen and phosphorus largely reflect differences in flow i.e. the Huon contributing the vast majority (Table 2.4) of TN and TP loads, with loads greatest during the winter and early spring and greater in 2009 and 2011 compared to 2010 (Figure 2.5). By contrast, the loads of dissolved nutrients didn't necessarily reflect differences in flow, most notably for nitrate with Kermandie River and Mountain River representing approximately 42% and 14% of the total nitrate load respectively. The elevated loads of dissolved nitrogen from the Kermandie River most likely reflect the influence of the sewage treatment plant (see below for more detail) that operates near the mouth of the river.

Wastewater treatment plants

There are nine wastewater treatment plants (WWTPs) adjacent to the Huon Estuary and D'Entrecasteaux Channel (Figure 2.6). All of these WWTPs have secondary treatment of waste and six (Margate, Electrona, Cygnet, Ranelagh, Geeveston and Dover) discharge to the waterway and are thus considered a direct input for the purposes of this review (see Parsons 2012 for a more extensive review of WWTPs in the region). Although the plant at Woodbridge discharges to a series of evaporation / transpiration beds and then to a dam, there is the potential for wastewater to reach the Channel via smaller drains (K. McLeod, Southern Water, and pers. comm.) and hence it is also characterised here as a direct input. As part of the recently completed State of the D'Entrecasteaux Channel and Lower Estuary report (Parsons 2012) inputs from the WWTPs were estimated based on monthly monitoring data (flow volume and nutrient concentration) provided by Southern Water, and this information has been provided for inclusion here. Table 2.5 provides a summary of average daily flows and nutrient concentrations for each of the WWTPs in 2011 and total annual flows and inputs for 2009-2012 on the basis of available data. Note flow data was only available from July 2009, except at Woodbridge where flow data was not available until November 2010 hence no estimates of inputs to the Huon Estuary and D'Entrecasteaux Channel could be made prior to this. Ranelagh is clearly the

[3] The percentage is based on total flows measured and estimated at the 6 gauging stations, and thus excludes the many other small streams and rivulets that enter the system

biggest contributor in terms of flow volume, however, in terms of TN and ammonia load, Margate and Electrona are also large contributors due to the higher concentrations of TN and ammonia in their effluent (Table 2.5). During 2010-11, the total load of TN and ammonia from WWTPs to the Huon Estuary and D'Entrecasteaux Channel were 22.3-27 tonnes p.a. and 14.6-19.1 tonnes p.a. respectively. The data available for 2009 (Jul – Dec) and 2012 (Jan –Jun) suggest the full year loads are likely to be similar to 2010 -11.

Table 2.4: Comparison of average daily flow and annual nutrient loads for the major catchment sources draining into the Huon-Channel region during the BEMP period 2009-2011

Station	Location	Flow ML/d	TN t/y	NH_4 t/y	NO_3 t/y	NO_2 t/y	PO_4 t/y	TP t/y
	2009							
635	HUON RIVER D/S JUDBURY RD BRIDGE	8905	928.95	29.25	6.50	9.75	9.75	19.50
6210	MOUNTAIN RIVER AT RANELAGH	277	20.33	1.21	2.63	0.51	NA	1.11
7200	ESPERANCE RIVER	515	76.49	3.11	0.38	0.38	0.56	3.11
341	KERMANDIE RIVER AT GEEVESTON	125	27.29	2.51	6.85	0.37		2.01
5202	SNUG TIERS RD	32	4.06	0.13	0.09	0.04	0.04	0.12
5201	NORTH WEST BAY RIVULET	138	17.54	0.56	0.40	0.15	0.15	0.51
		9992	**1075**	**37**	**17**	**11**	**11**	**26**
	2010							
635	HUON RIVER D/S JUDBURY RD BRIDGE	6477	640.05	21.28	4.73	7.09	7.09	14.18
6210	MOUNTAIN RIVER AT RANELAGH	115	8.43	0.50	1.09	0.21	NA	0.46
7200	ESPERANCE RIVER	245	31.84	1.34	0.18	0.18	0.27	1.28
341	KERMANDIE RIVER AT GEEVESTON	91	19.94	1.84	5.01	0.27		1.47
5202	SNUG TIERS RD	8	1.07	0.03	0.02	0.01	0.01	0.03
5201	NORTH WEST BAY RIVULET	49	6.15	0.19	0.14	0.05	0.05	0.18
		6985	**707**	**25**	**11**	**8**	**7**	**18**
	2011							
635	HUON RIVER D/S JUDBURY RD BRIDGE	8203	838.65	26.95	5.99	8.98	8.98	17.96
6210	MOUNTAIN RIVER AT RANELAGH	240	19.07	1.14	2.47	0.47	NA	1.04
7200	ESPERANCE RIVER	411	58.24	2.40	0.30	0.30	0.45	2.36
341	KERMANDIE RIVER AT GEEVESTON	114	24.89	2.29	6.25	0.33		1.83
5202	SNUG TIERS RD	27	3.41	0.11	0.08	0.03	0.03	0.10
5201	NORTH WEST BAY RIVULET	117	14.86	0.47	0.34	0.13	0.13	0.43
		9113	**959**	**33**	**15**	**10**	**10**	**24**

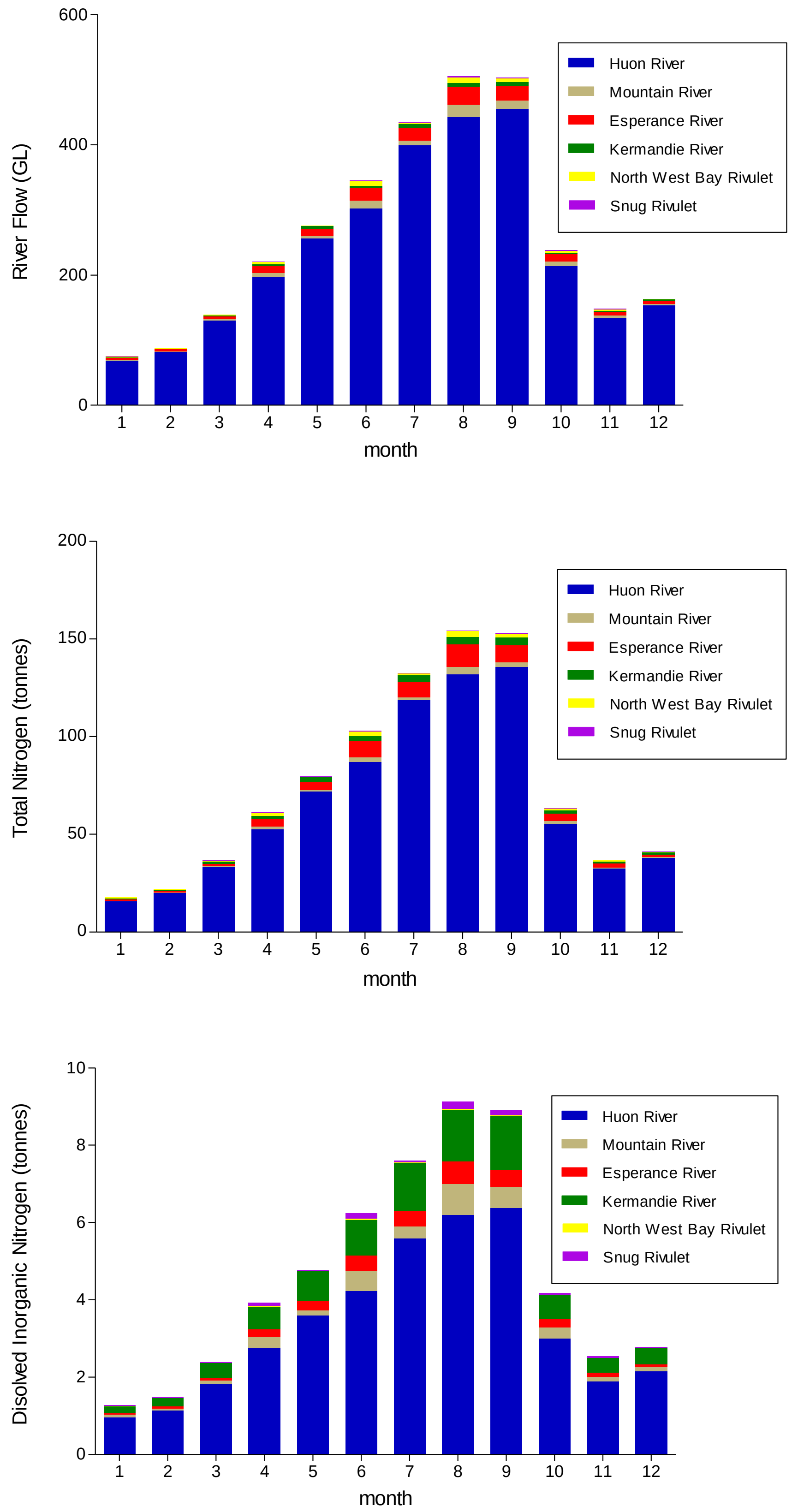


Figure 2.5: Monthly flows (top) and load estimates for total nitrogen (middle) and total dissolved nitrogen (bottom) for the 6 river systems

Figure 2.6: WWTP locations (Source: Parsons 2012).

Table 2.5: WWTP average daily flows, mean contaminant concentrations and annual inputs (Data source: Southern Water) * = Also excludes the Woodbridge WWTP - data not available. # = NOx data not available for available for Woodbridge or Margate. Loads in t/yr have been calculated using average monthly values for both the input parameter and flow, as opposed to extrapolating on the basis of the average daily flow rate for the year. Data presented for most WWTPs were derived from one effluent sample per month; annual loadings should, therefore, be viewed as 'best estimate only'

WWTP	Discharge	TSS		BOD		Ammonia		NO_x #		Total Nitrogen		Total Phosphorus	
	kL/day	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr
Woodbridge	12	35.4	0.2	22.8	0.1	1.2	0	-	-	9.3	0	5.7	0
Margate	562	51.1	10.5	45.2	9.1	27.5	5.5	-	-	33.6	6.7	6.7	1.3
Electrona	366	71.8	9.3	99.5	13.2	21.3	2.6	0.2	0	31.5	4	5	0.6
Cygnet	413	14.1	2.3	8.5	1.3	2.1	0.3	4.9	0.7	8.8	1.3	3.8	0.5
Geeveston	304	10.3	1.3	6.1	0.6	4.7	0.5	5.1	0.5	10.5	1	2	0.2
Ranelagh	1392	17.3	9.2	15.9	8.2	10.7	4.4	0.6	0.4	16.4	7.5	5.7	2.9
Dover	230	27.2	2.2	25.3	1.9	17.4	1.3	1.2	0.1	22.7	1.7	5.1	0.4

Total daily flows and inputs in tonnes per year	Discharge	TSS	BOD	Ammonia	NO_x	Total Nitrogen	Total Phosphorus
January-June							
2010*	2094	18.2	18.1	10.1	0.3	13.1	2.7
2011	3295	14.8	15.1	7	0.8	11.3	3.1
2012	2929	14.4	15.4	9.3	1.4	12.3	3.4
July-December							
2009*	3805	22.6	16.6	8.4	0.6	11.7	2.1
2010*	2852	70	14.3	9	0.5	13.6	3.1
2011	3254	20	19.2	7.6	1	11	2.8
Full Year							
2010*	2474	88.2	32.4	19.1	1	26.7	5.8
2011	3279	34.8	34.4	14.6	1.7	22.3	5.9

Industrial discharges

There are three industrial plants (two near Margate and one at Dover), all based around seafood processing, that involve direct discharge of waste water to the D'Entrecasteaux Channel and lower Huon Estuary. Outfall effluent quality is monitored on a monthly basis at all three sites, with the most recent data summarised in Table 2.6

Of the industrial discharges the Dover outfall is clearly the major source of nitrogen, mostly in the form of ammonia (5.7 tonnes in 2011). Note, an upgrade in the Dover wastewater treatment plant is scheduled for 2012/13 (Tassal 2012a).

Table 2.6: Inputs from fish processing plants (Data source: DPIPWE). TKN = the sum of organic nitrogen and ammonia

Plant	Year	Discharge (kL/day)	TKN	NO_x	NH_3	TP
Margate Tassal	2011	120	0.3		0.3	0.2
Dover Tassal	2011	252	7		5.7	0.6
Margate Tas. Seafoods	2009	0.01	0.03	0.07		0.01
TOTALS		372.0	7.3	0.07	6.0	0.8

Oceanic sources

There is considerable exchange of D'Entrecasteaux Channel and Huon Estuary waters (and its constituents) with oceanic waters across the southern and northern boundaries of the Channel (Figure 2.7). Three major oceanographic currents influence this exchange. During summer, the East Australian Current (EAC) brings warmer, nutrient-poor water down the east coast and into this region. In winter, nutrient rich-sub-Antarctic waters reach southern Tasmania via the Antarctic Circumpolar Current, while the Zeehan Current extending from the Leeuwin Current in Western Australia also influences the region. The seasonal interplay and zone of convergence between the two subtropical water masses and sub-Antarctic waters plays a major role influencing the nutrient and plankton dynamics in SE Tasmania, including the D'Entrecasteaux Channel and Huon Estuary. Estimating the timing and magnitude of nutrients supplied to the region during 2009 - 12 is difficult without a hydrodynamic model for the region. Nonetheless, the concentration and temporal patterns of nutrients measured adjacent to the boundaries (incl. sites in Storm Bay; Figure 2.8) together with previous modelled estimates of exchange provide a useful insight into the relative magnitude of oceanic sources versus those described above.

Modelling carried out as part of the Aquafin CRC (see Volkman et al. 2009) was used to calculate total nutrient budgets for the D'Entrecasteaux Channel and Huon Estuary in 2002-03 including the load crossing the ocean boundaries. Estimates of labile and refractory nitrogen inputs from ocean waters were approximately 2000 and 1000 tonnes p.a. respectively; most of which was delivered in winter. This represented approximately 60% of the nitrogen load to the system. These results were also consistent with those of the HES, which concluded that about two-thirds of the supply of nitrogen to the Huon Estuary is supplied from marine loads. The source and timing of the winter intrusion of offshore originating from depth is clearly evident from nutrient observations at sites adjacent to the ocean boundary. Figure 2.8 demonstrates the distinct winter peak in nitrate + nitrite concentrations measured in Storm Bay in 1985-89 and more recently in 2009-12. This pattern is also evident in Figure 2.9, showing bottom water nitrate + nitrite data from the HES, Aquafin CRC and BEMP programs at sites near the mouth of the Huon (M10), the northern (M1) and southern boundaries (M9) of the D'Entrecasteaux Channel and in Recherche Bay (M15) (see Figure 1.1 for site map).

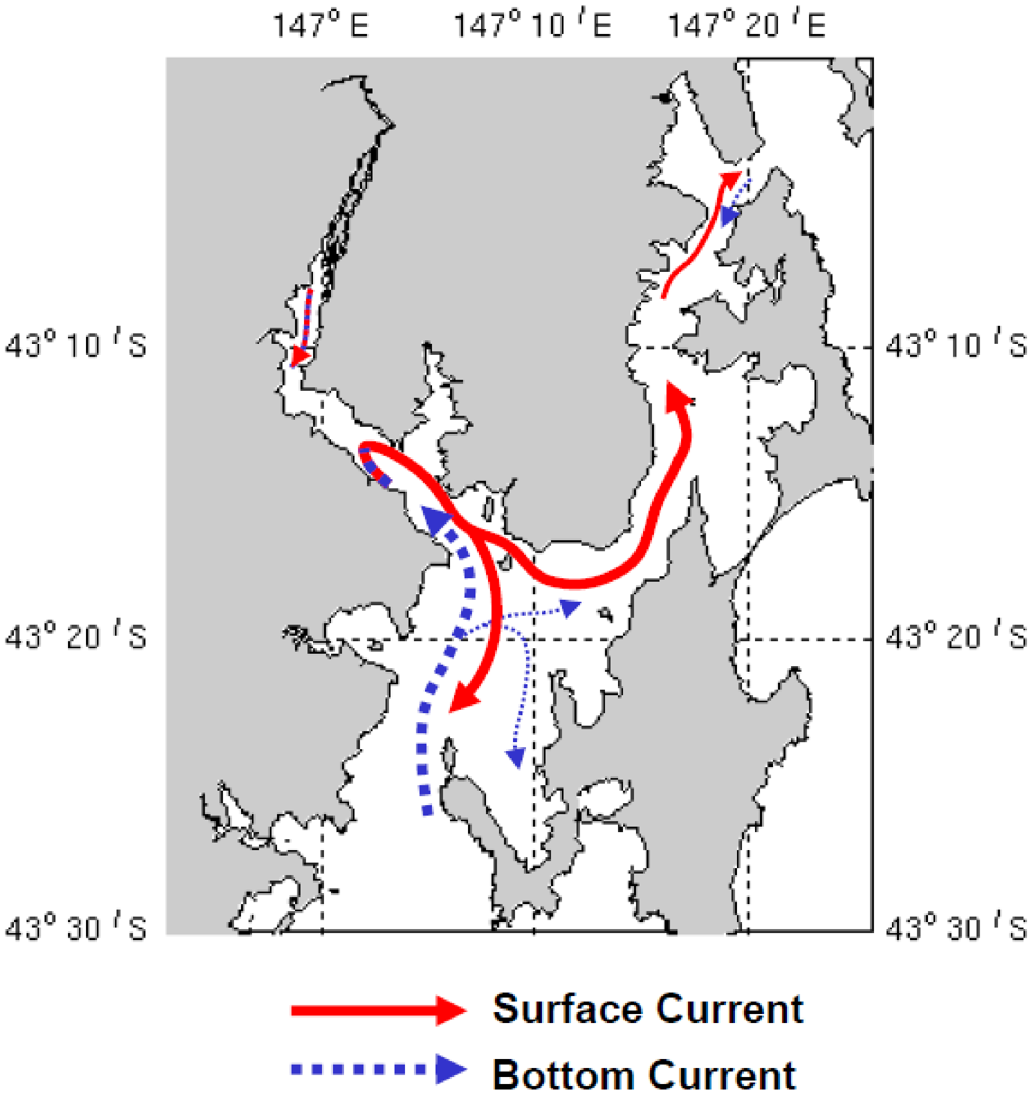


Figure 2.7: Residual circulation in the D'Entrecasteaux Channel and Huon Estuary (Source: Herzfield et al 2004)

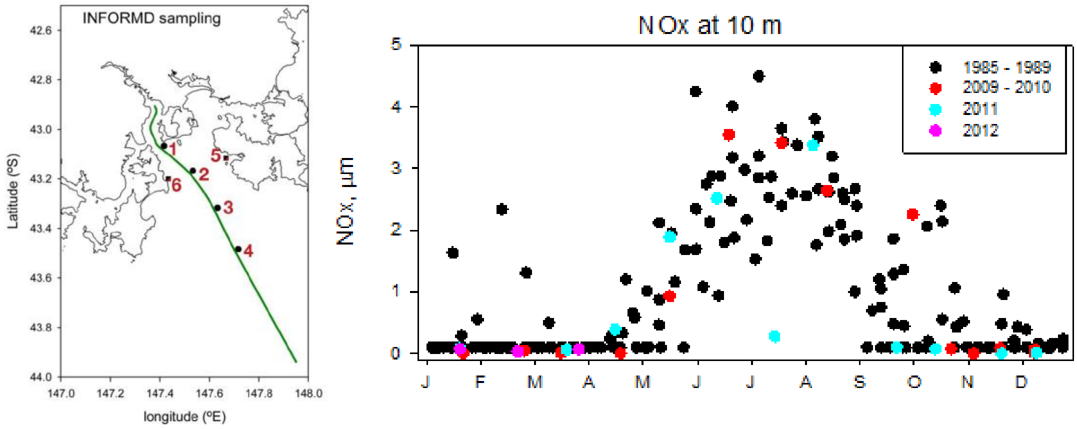


Figure 2.8: Comparison of NOx (nitrate + nitrite) data at site 2 in Storm Bay collected by CSIRO in 1985-89 and more recently in 2009-2012 (Source: K Swadling IMAS; Crawford et al. 2011)

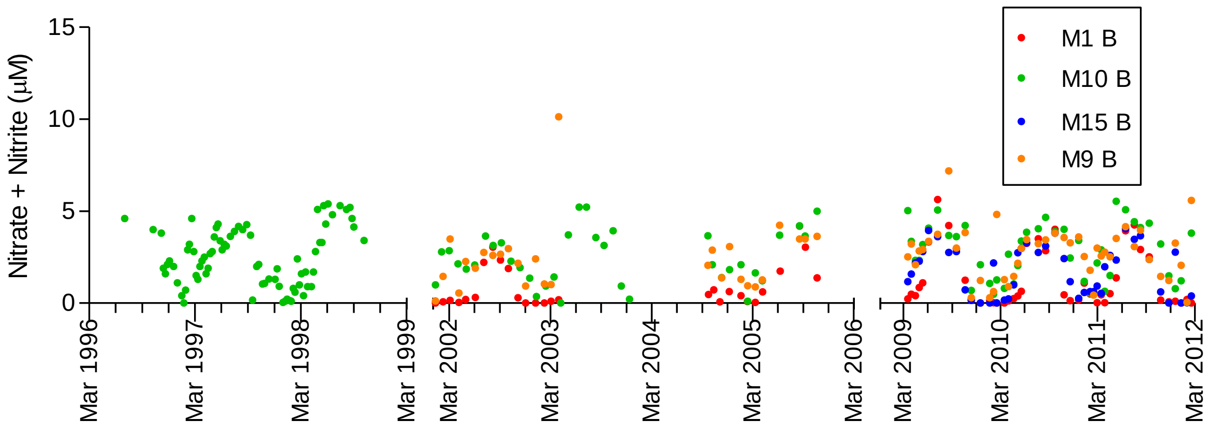


Figure 2.9: Bottom water nitrate + nitrite concentrations at sites near the mouth of the Huon (M10), the northern (M1) and southern boundaries (M9) of the D'Entrecasteaux Channel and in Recherche Bay (M15) for data collected in the HES, Aquafin CRC (1 &2) and BEMP programs (see Figure 2.1 for site map)

2.1.2 Water Quality

This section provides an overview of the spatial and temporal patterns for the key water column parameters for the 15 BEMP sites between March 2009 and March 2012. The data are presented according to depth, calendar month and MFDP area given that this largely reflects the optimal scales for detecting system wide responses.

In addition to the typical plots used to assess spatial and temporal patterns in water quality, it is important to consider the behaviour of dissolved nutrients and other solutes in relation to salinity because this provides an index of mixing, identifying potential sources and sinks in the system. If the concentration of a dissolved solute throughout an estuary is simply the dilution of one end-member (riverine or marine) with the other, the relation with salinity is a straight line joining the concentration measure in freshwater (riverine) with that measured in seawater (marine); in this case the solute is said to behave conservatively. Any departure from this linear mixing relationship can indicate that there is a source (e.g. WWTP or farm inputs) or sink (e.g. biological uptake) of the solute in the estuary between the riverine and freshwater end members[4]. For example, the schematic for nitrate shown in Figure 2.10 contrasts the biologically active summer (observations fall well below the conservative mixing line that joins the freshwater and marine end members indicating uptake) with the biologically dormant winter (observations generally falling along the conservative mixing line between freshwater and marine end members indicating little uptake). If the observations were above the conservative mixing line this would include a source of nitrate in the estuary. Given the additional insight this provides for understanding the dynamics and drivers of water quality in estuaries, mixing plots for the major nutrients and solutes in the D'Entrecasteaux Channel and Huon Estuary are presented in the following BEMP sampling period assessment.

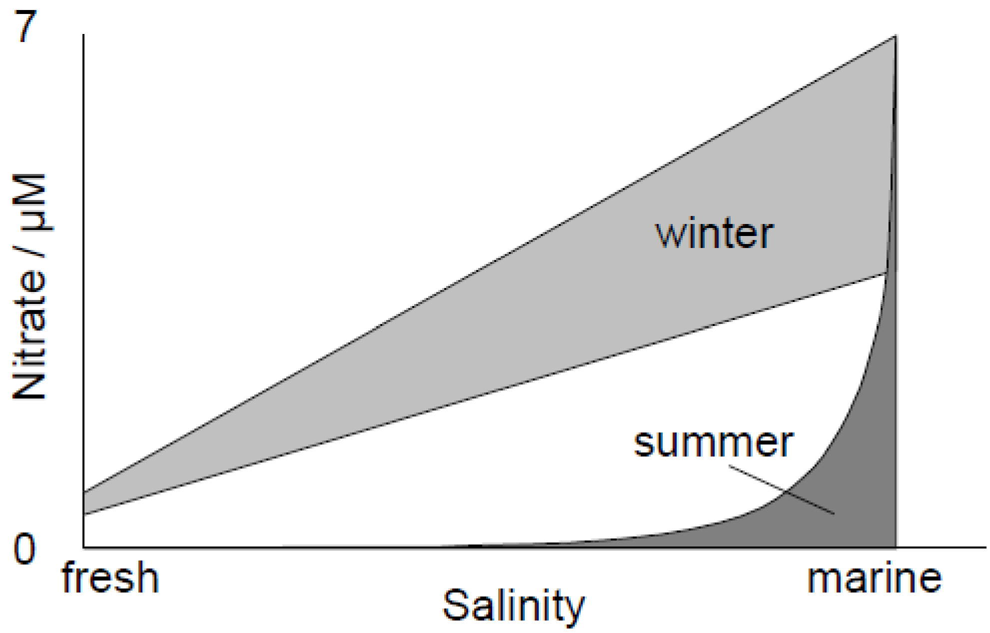


Figure 2.10 Schematic diagram of the behaviour of nitrate against salinity in winter, contrasted with that for summer; spring and autumn have distributions in between the two (Source: Butler et al. 2000)

[4] Note this simple analysis can be complicated by a range of factors (e.g. nature of field collection, short term variations in river inputs etc.) that can lead to misleading assessments of non-conservative behaviour (see Morris 1985 for further discussion).

Nitrate + nitrite (NO_x)

NO_x concentrations showed a pronounced seasonal pattern reaching a maximum of 3-5 µM in winter and a minimum, often to below detection limits (< 0.05 µM), in summer (Figure 2.10). This is consistent with the intrusion of nutrient rich ocean waters in winter and the subsequent biological uptake and depletion through spring, summer and early autumn. The greater NO_x concentration at depth is consistent with greater biological uptake in the surface photic zone and the offshore source originating from depth. Concentrations were also typically higher throughout the Huon Estuary and in the southern half of the Channel. This most likely reflects the closer proximity to both the larger intrusion of ocean waters that occurs across the southern boundary of the Channel and inputs from the Huon River.

The relationship of NO_x with salinity (Figure 2.11a) was generally consistent with the pattern reported in the HES. In winter, NO_x behaved quasi-conservatively; the general trend against salinity was linear to the marine end member concentration indicating limited biological uptake. In spring, summer and early autumn, NO_x was removed from the water column through biological activity. However, it is noteworthy that NO_x concentrations remain high at marine salinities despite the decline in marine end-member concentrations in spring through early autumn (Figure 2.8). This suggests that the winter influx of NO_x from offshore isn't exhausted and / or there is re-supply of NO_x via sediment remineralisation of organic matter deposited on the seafloor.

Ammonium

Although the seasonal pattern observed for ammonium was not as clear as seen for NO_x, concentrations of ammonium were lower during summer (Figure 2.12b), particularly in surface waters. This pattern is most evident in Figure 2.12a, with concentrations of ammonium similar in bottom and surface waters from mid-autumn through early spring before surface waters become depleted throughout summer relative to bottom water concentrations. This most likely reflects increased biological activity and uptake through summer in the photic surface waters compared with bottom waters that continue to be supplied with ammonium through sediment remineralisation of organic matter. It is also apparent that concentrations of ammonium are generally more elevated at sites in the Huon Estuary (M10,11,13 & 14) and the northern half of the Channel (M1-4) relative to sites in the southern half of the Channel (Figure 2.12c). This is consistent with model predictions that nutrients accumulate in the Huon and northern Channel due to the residual regional circulation which generally flows from the south to the north via estuarine circulation of the Huon (Figure 2.7, Wild-Allen 2008). The elevated ammonium concentrations in these areas may also reflect their proximity to river and WWTP sources of ammonium and / or a greater influx from sediment remineralisation (e.g. due to more enriched/active sediments and / or reduced water exchange).

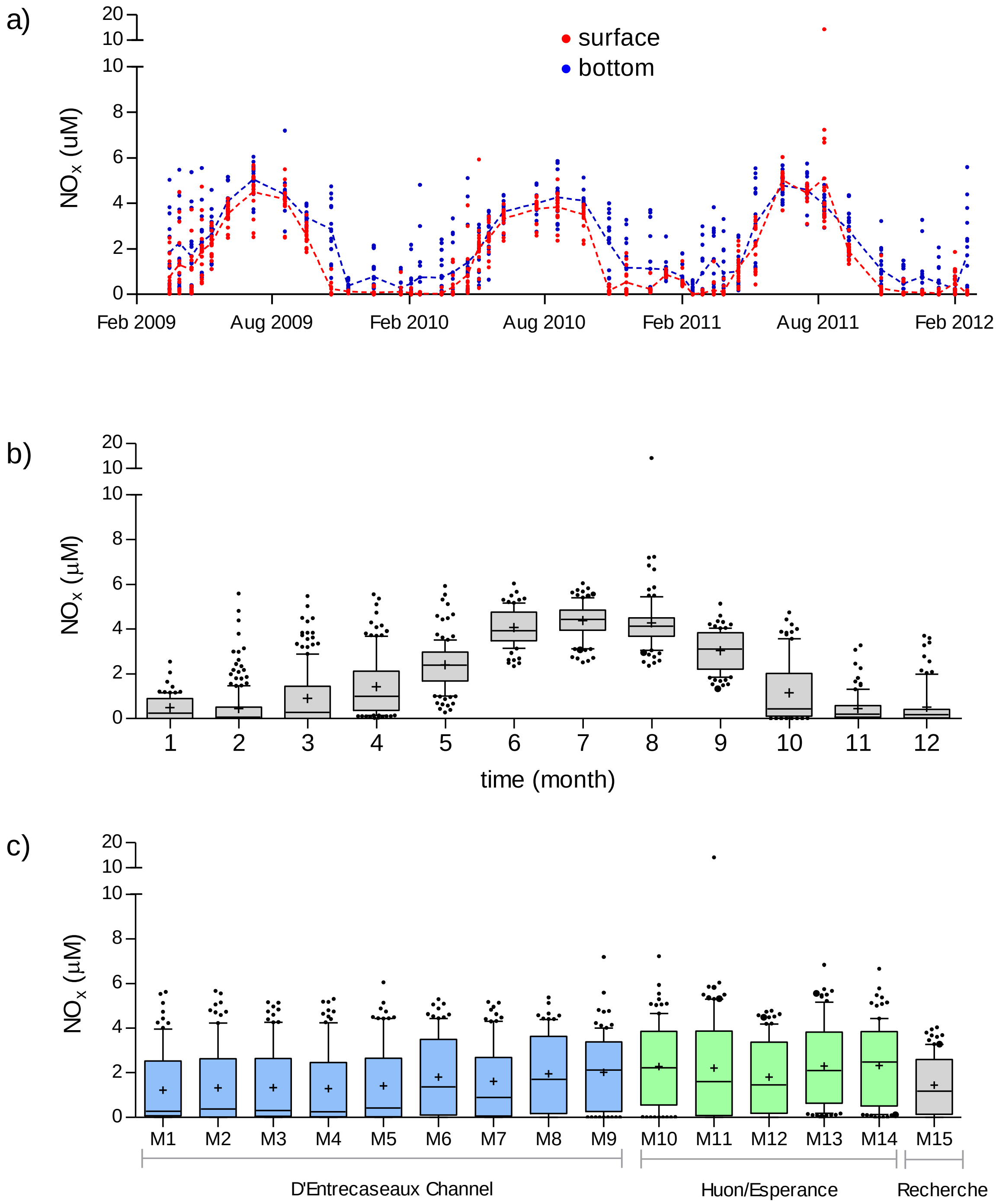
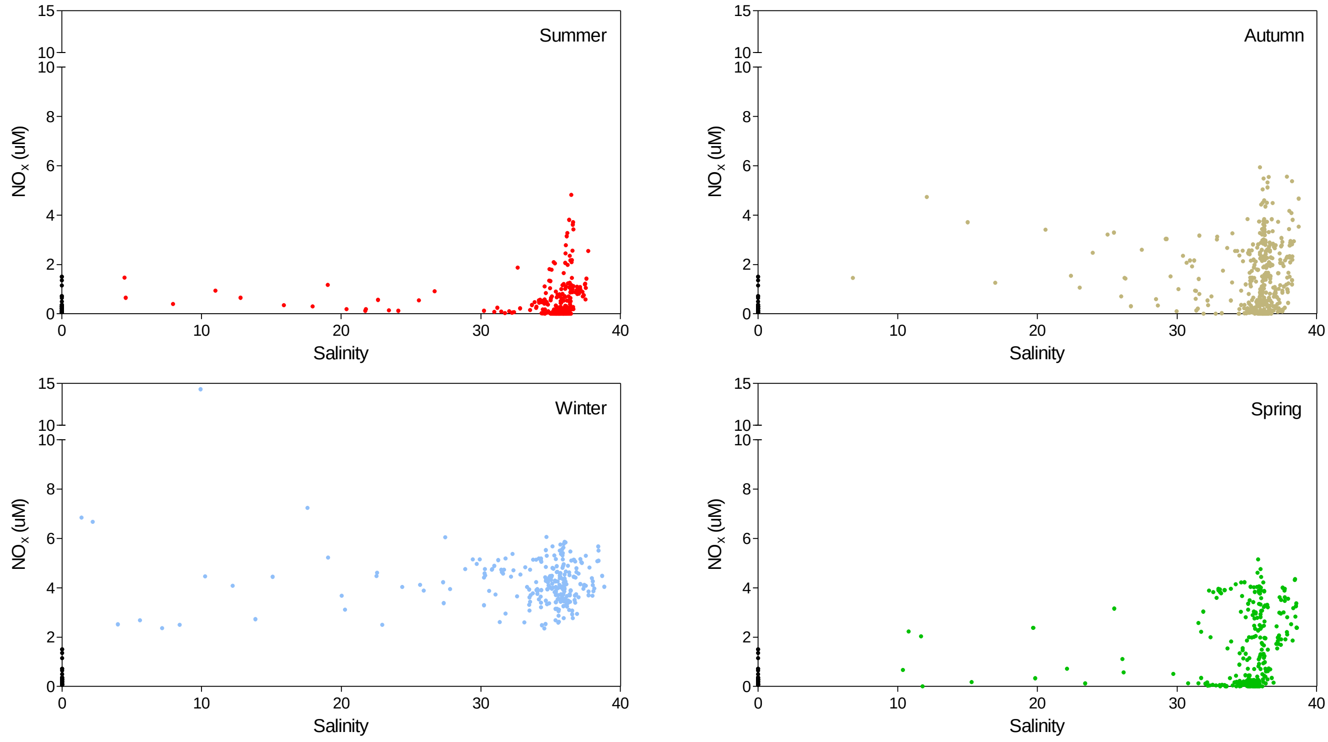


Figure 2.10: NO_x concentration in the D'Entrecasteaux and Huon Estuary from March 2009 to March 2012 in a) surface (red) and bottom (blue) waters (dashed line is the mean for each survey/depth), b) calender months and c) across sites. For box plots the edges of the boxes encompass from the 25th percentile to the 75th percentile, the horizontal line in between is the median while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. The + symbol identifies the average. The data used for the box plots includes both surface and bottom values.

a. Nitrate + Nitrite (NOx)



b. Ammonium

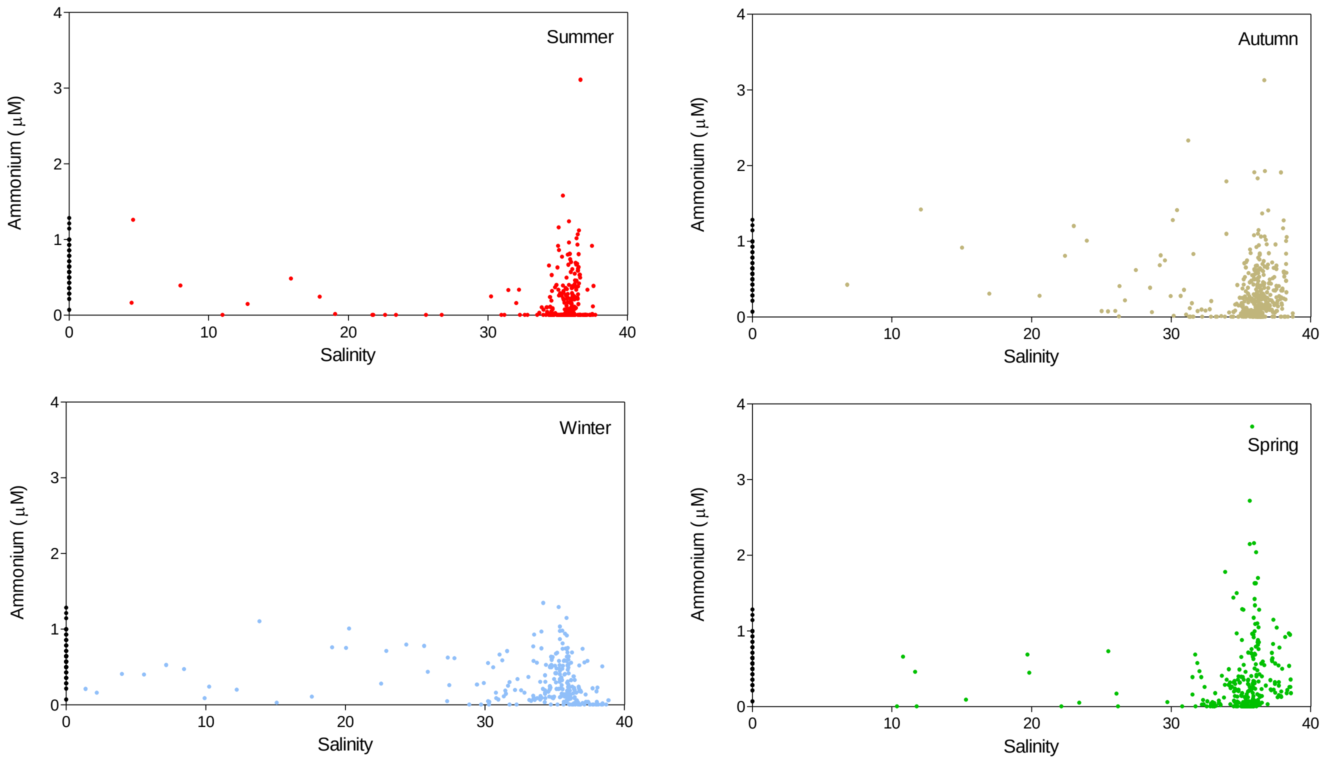


Figure 2.11: Relationship of a. NOx and b. ammonium with salinity for all BEMP surveys (all sites and depths) in summer, autumn, winter and spring.

The relationship of ammonium concentrations with salinity provides further insight into the likely sources (Figure 2.11b). In contrast to NO_x, concentrations of ammonium for the marine end-member are relatively low; typically < 1 µM with no clear seasonal pattern (Crawford et al. 2011). It is also clear that concentrations recorded in the freshwater sources, typically < 1 µM are not able to explain the elevated concentrations measured at the more marine salinities. This is consistent with an internal source of ammonium most likely generated from a combination of remineralisation of organic matter deposited on the seafloor and excretion from farmed fish. During summer and to a lesser extent spring and autumn the lower ammonium concentrations at intermediate salinities are consistent with increased biological activity and uptake.

Phosphate

Phosphate concentrations also follow a seasonal pattern with concentrations elevated from autumn through to early spring, reaching a maximum in winter (Figure 2.13a, b). Concentrations in bottom waters remained higher than in surface waters throughout the year (Figure 2.13a). The decrease in phosphate concentrations in surface waters in summer is likely due to increased biological activity and uptake and sediment remineralisation of organic matter is likely to be a significant contributor to bottom water concentrations. Data collected in Storm Bay through 2009-2012 indicates that marine waters are a source of phosphate, particularly during winter (Crawford et al 2011). This is also evident in the plot of phosphate concentration versus salinity with conservative estuarine mixing evident in winter, and removal evident in the other seasons (Figure 2.14a). However, in all seasons concentrations in at least some bottom waters exceeded those observed at the marine and freshwater boundaries indicating an internal source of phosphate, and is likely sediment remineralisation. This is most evident at the Huon Estuary sites, most likely attributable to the higher sediment loading of organic matter and more frequent low bottom water dissolved oxygen concentrations observed relative to the other sites (see later discussion).

Silicate

Unlike the aforementioned nutrients silicate concentrations were generally higher in surface rather than bottom waters (Figure 2.15). This is consistent with a dominant freshwater (surface water) rather than marine (bottom water) source for silicate. Although the lower summer concentrations in surface waters are consistent with uptake by siliceous diatoms, estuarine mixing remains largely conservative indicating that reduced river flows and inputs of silicate are largely responsible for the lower surface concentrations observed in summer (Figure 2.14b). The higher concentrations recorded at sites M13 (Upper Huon), M14 (Mid Huon) and M11 (Cygnet) reflect their proximity to freshwater inputs from the Huon River and Nichols and Agnes Rivulets at Cygnet.

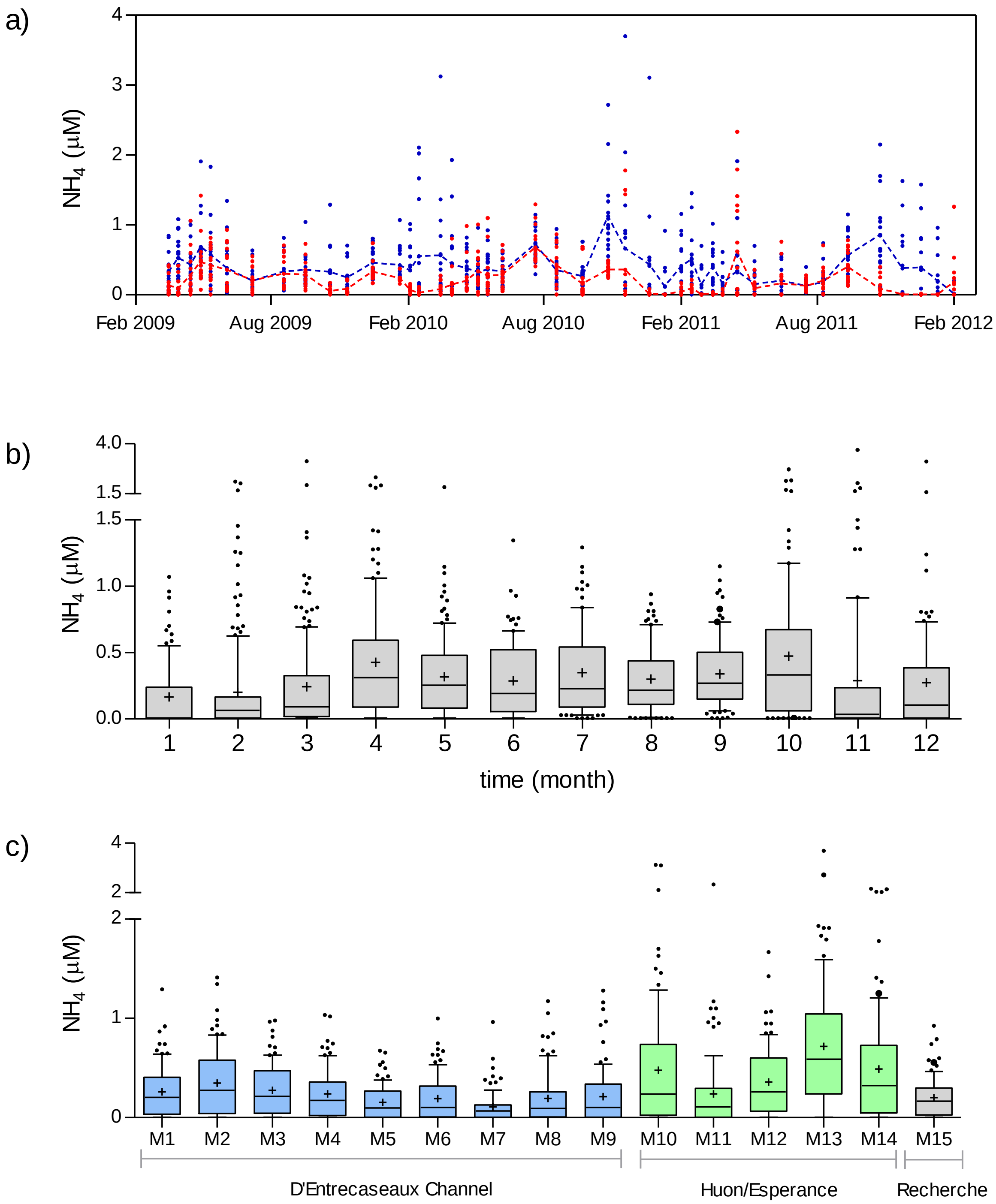


Figure 2.12: Ammonium concentration in the D'Entrecasteaux and Huon Estuary from March 2009 to March 2012 in a) surface (red) and bottom (blue) waters (dashed line is the mean for each survey/depth, b) calender months and c) across sites. For box plots the edges of the boxes encompass from the 25th percentile to the 75th percentile, the horizontal line in between is the median while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. The + symbol identifies the average. The data used for the box plots includes both surface and bottom values.

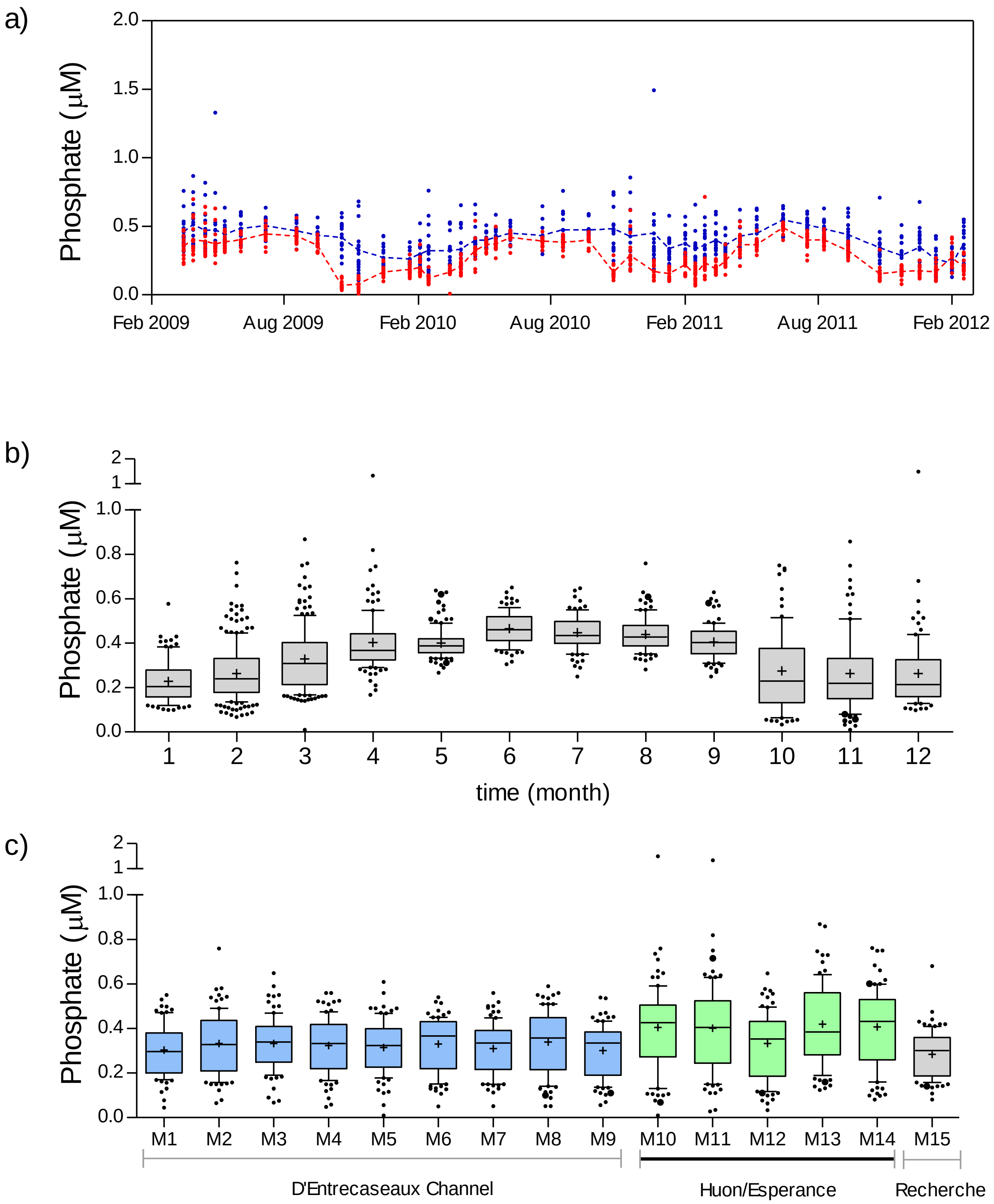
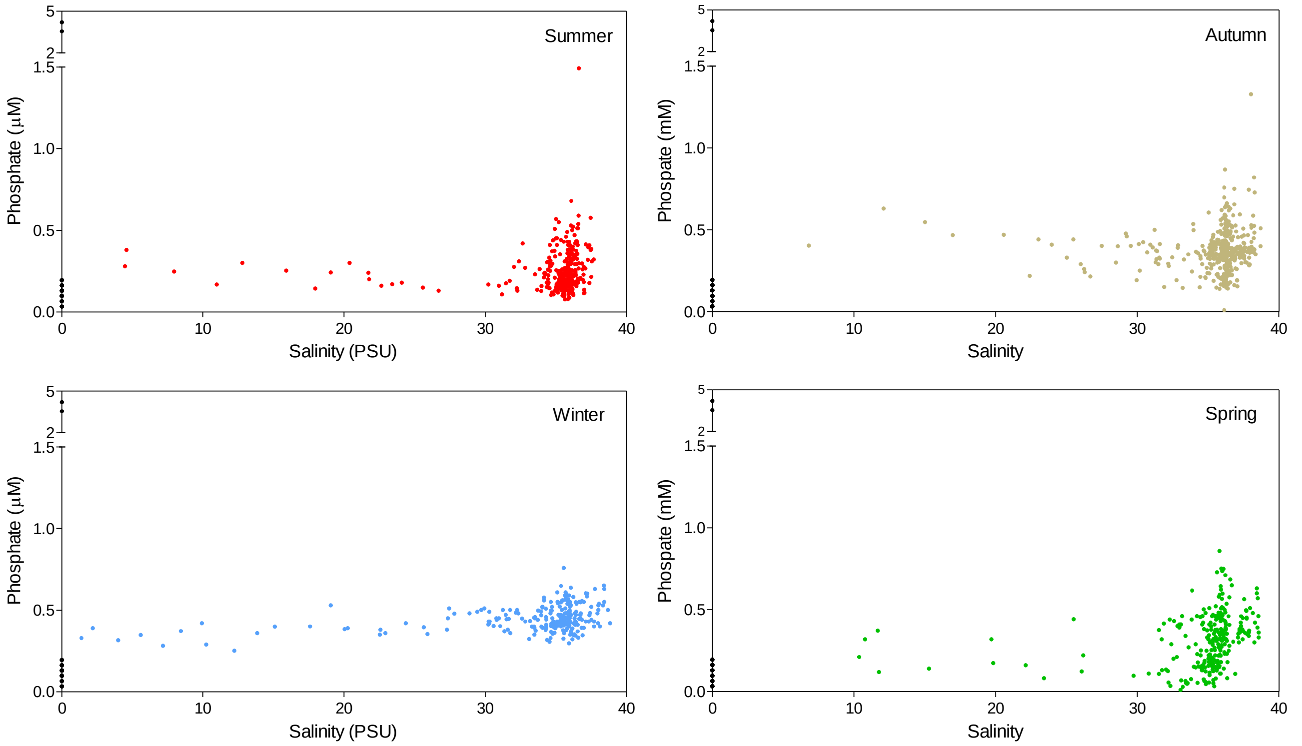


Figure 2.13: Phosphate concentration in the D'Entrecasteaux and Huon Estuary from March 2009 to March 2012 in a) surface (red) and bottom (blue) waters (dashed line is the mean for each survey/depth), b) calender months and c) across sites. For box plots the edges of the boxes encompass from the 25th percentile to the 75th percentile, the horizontal line in between is the median while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. The + symbol identifies the average. The data used for the box plots includes both surface and bottom values.

a. Phosphate



b. Silicate

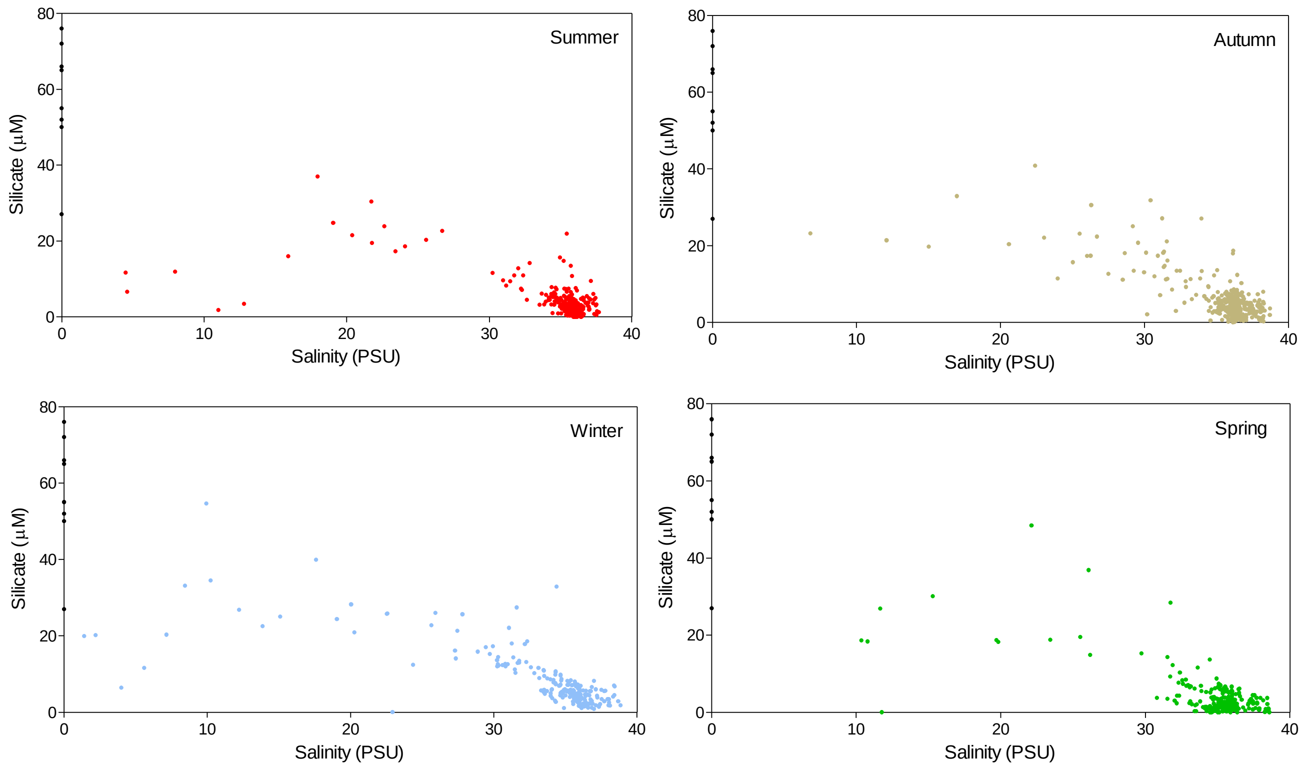


Figure 2.14: Relationship of phosphate (top) and silicate (bottom) with salinity for all BEMP surveys (all sites and depths) in summer, autumn, winter and spring

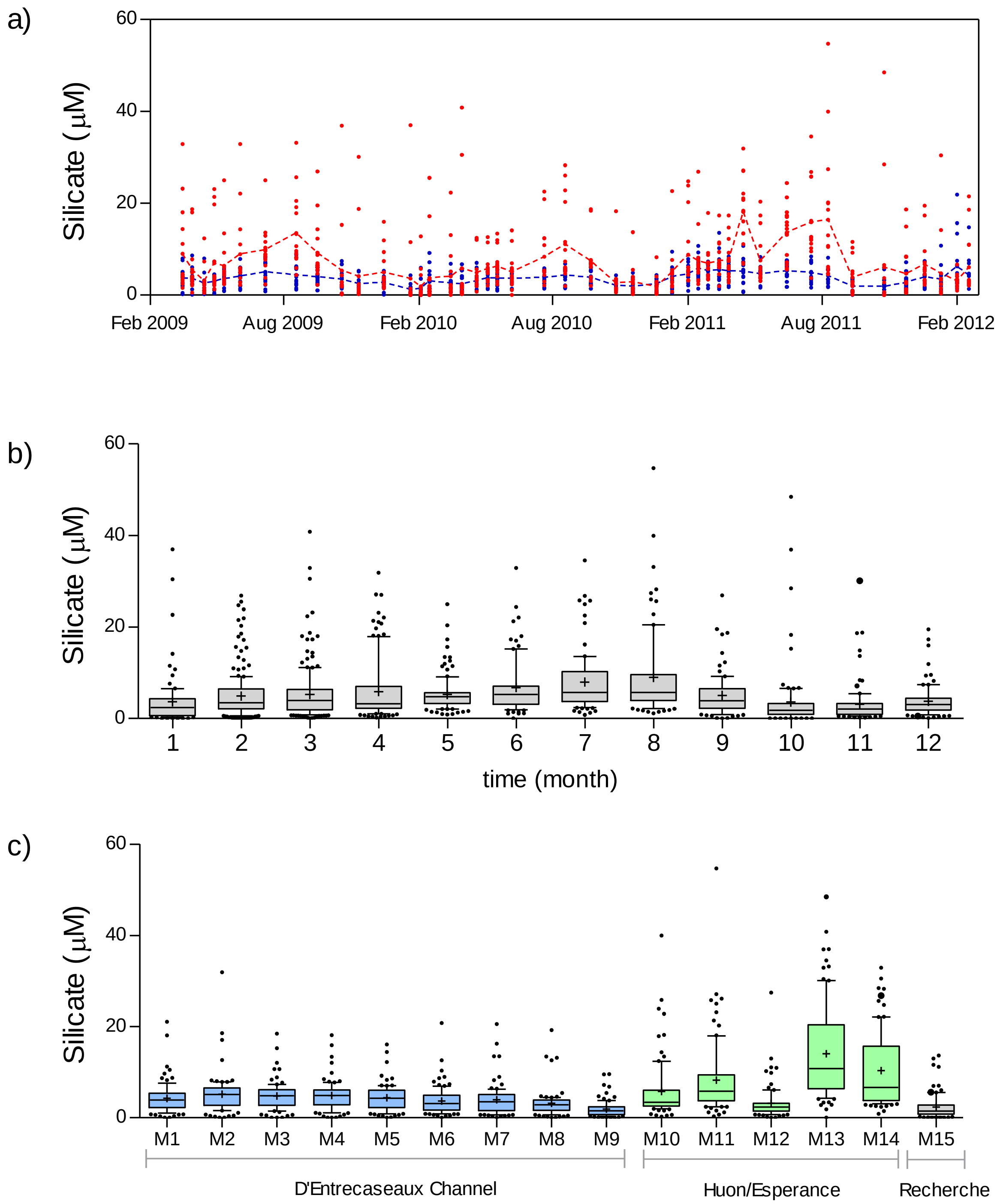


Figure 2.15: Silicate concentration in the D'Entrecasteaux and Huon Estuary from March 2009 to March 2012 in a) surface (red) and bottom (blue) waters (dashed line is the mean for each survey/depth), b) calender months and c) across sites. For box plots the edges of the boxes encompass from the 25th percentile to the 75th percentile, the horizontal line in between is the median while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. The + symbol identifies the average. The data used for the box plots includes both surface and bottom values.

Dissolved Oxygen

As expected dissolved oxygen concentrations were lower in bottom water waters throughout the sampling period (Figure 2.16a). The seasonal pattern, with lower bottom water dissolved oxygen condition in summer is consistent with higher rates of sediment remineralisation. This is most evident at sites that are in close proximity to the dominant freshwater flows that receive relatively high rates of organic loading (Figure 2.16c). The drawdown of bottom water oxygen during the warmer months is also clearly evident in the mixing plot of dissolved oxygen and salinity; the majority of low dissolved oxygen measurements are in bottom waters in spring through to autumn (Figure 2.17).

Nutrient Ratios

The N:P ratio in coastal waters can be used as indication of nitrogen or phosphorus limitation when the ratio departs markedly from the Redfield ratio of 16:1 for plankton (Redfield et al 1963). Plots of the N:P ratio demonstrates a clear seasonal signal through the BEMP sampling period. From spring though autumn when biological activity and uptake is greatest, nitrogen is depleted relative to phosphorus with ratios falling below 3 in summer in surface waters at most sites (Figure 2.18). This suggests nitrogen limitation of microalgal production. During winter the N:P ratio approaches 10 as nitrogen is replenished from freshwater and marine influxes and via sediment remineralisation.

2.1.3 Phytoplankton Biomass and Composition

Phytoplankton Biomass

Chlorophyll a (as determined by AST using UV-visible spectrophotometer) as a measure of phytoplankton biomass was higher through the warmer months with peaks in the middle of spring and autumn (Figure 2.19b). However, the timing and magnitude of the seasonal patterns varied markedly across years. Of particular note was the large bloom in autumn 2011 (mean 5.8 µg L^{-1}) compared to autumn 2010 (mean 0.9 µg L^{-1}) and 2009 (mean 1.9 µg L^{-1}). Although chlorophyll *a* concentrations of at least 3 µg L^{-1} were recorded at all of the sites in autumn 2011, large differences between sites are also clearly evident. The bloom in autumn 2011 was most apparent in the Huon Estuary at sites M10 Lower Huon (mean 16.8 µg L^{-1}), M11 Cygnet (mean 13.4 µg L^{-1}) and M14 Mid Huon (mean 11.2 µg L^{-1}) and in the Channel at site M8 in Great Taylors Bay (mean 14.9 µg L^{-1}). The timing of the peak in chlorophyll *a* also varied between sites, occurring in mid-March at M11, late-March at M10 and M14 and early April at M8. It is worth noting that these patterns are broadly consistent with the Chlorophyll a results determined using HPLC (see later discussion).

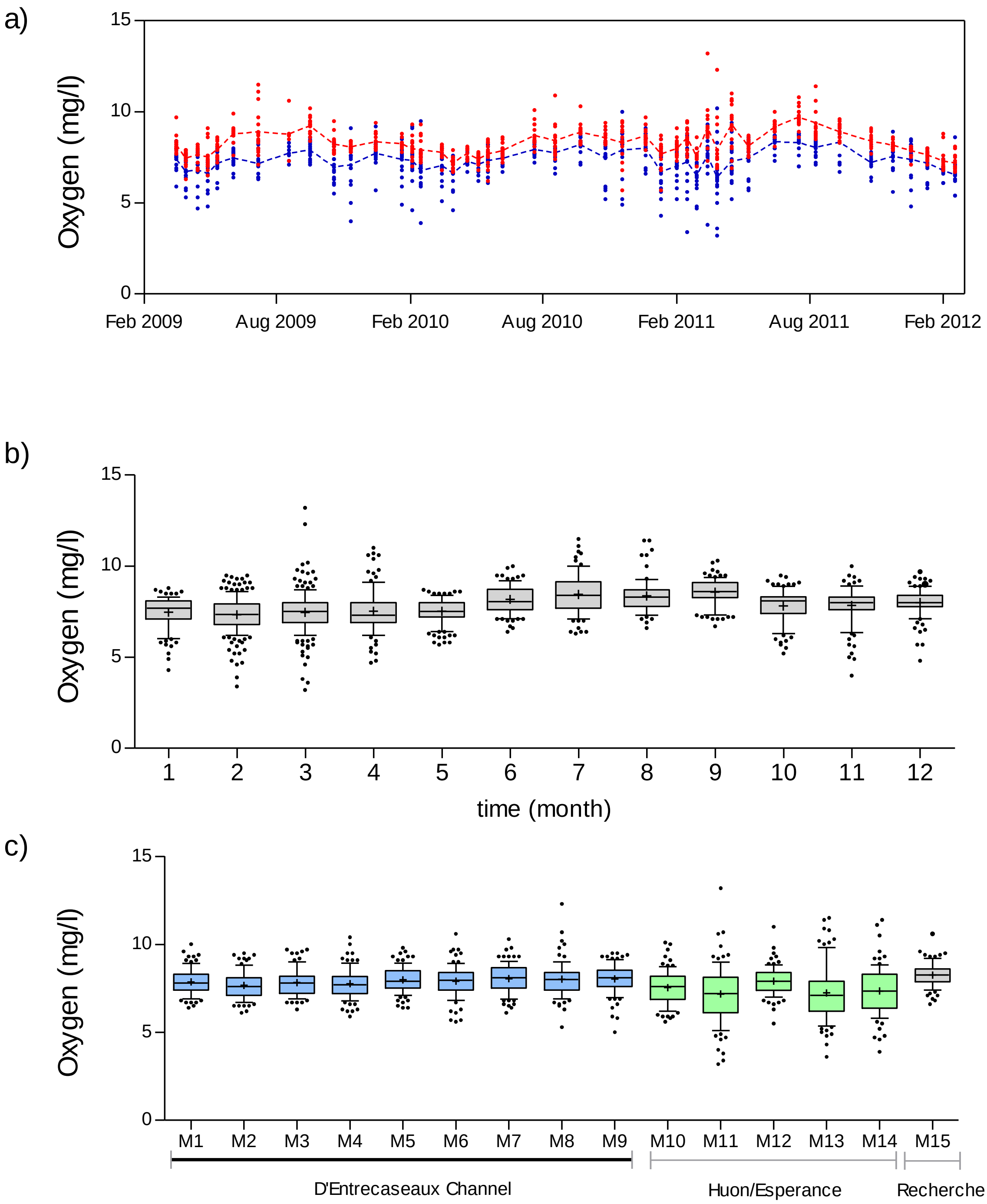


Figure 2.16: Oxygen concentration in the D'Entrecasteaux and Huon Estuary from March 2009 to March 2012 in a) surface (red) and bottom (blue) waters (dashed line is the mean for each survey/depth), b) calender months and c) across sites. For box plots the edges of the boxes encompass from the 25th percentile to the 75th percentile, the horizontal line in between is the median while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. The + symbol identifies the average. The data used for the box plots includes both surface and bottom values.

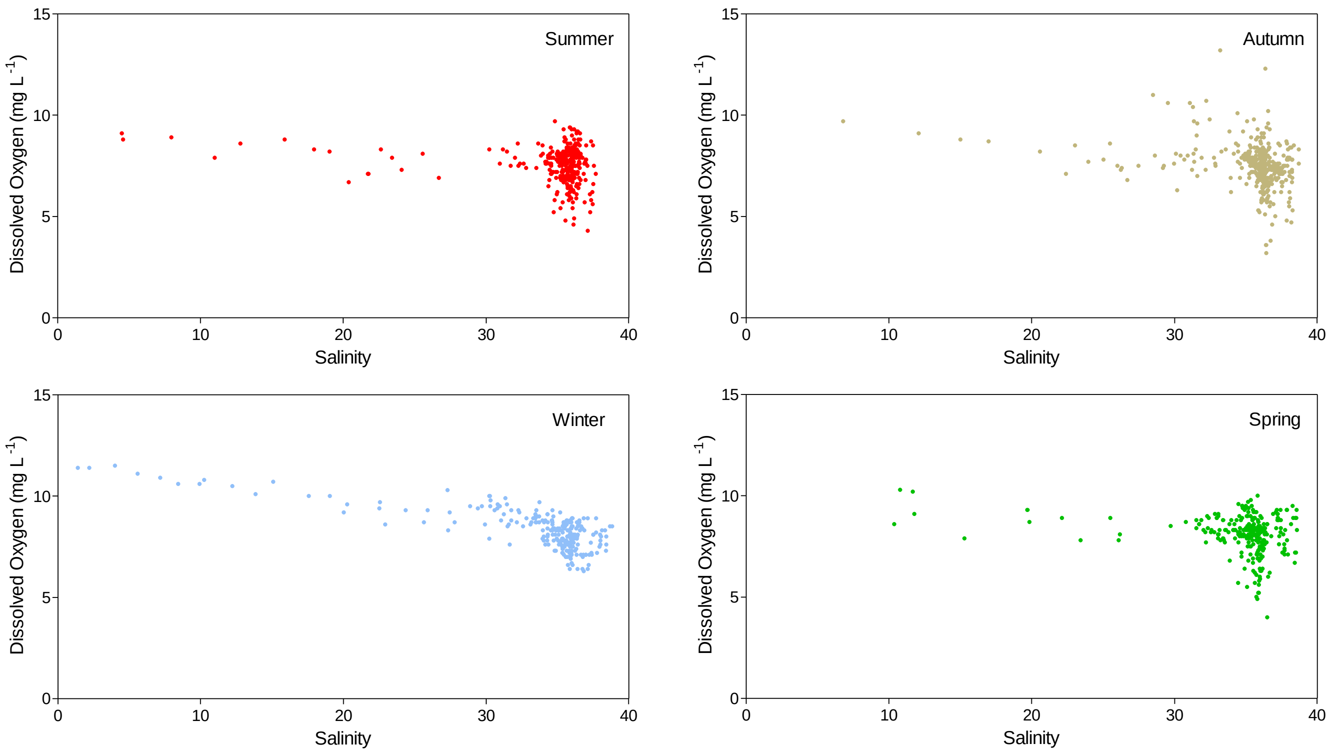


Figure 2.17: Relationship of dissolved oxygen with salinity for all BEMP surveys (all sites and depths) in summer, autumn, winter and spring

Phytoplankton Composition

HPLC

Phytoplankton community composition in the BEMP program is currently determined using two methods: HPLC pigments (CSIRO) and cell counts (AST). In the first instance, the spatial and temporal patterns in phytoplankton composition evident from the HPLC pigment analysis will be described. The cell count data will then be described and contrasted against the results of the HPLC.

HPLC pigments that relate specifically to an algal class are termed 'marker pigments' (Jeffrey and Vesk 1997). Some of these marker pigments are found exclusively in one algal class while others are the principal pigments of one class but are also found in other classes. The presence and relative contribution of these marker pigments can be used to describe the composition and biomass of phytoplankton. In this case the relative contribution of eight marker pigments (Table 2.7) is used to describe changes in the phytoplankton community composition.

To examine regional temporal variation, the data for the 8 marker pigments was averaged across all 15 sites (Figures 2.20 and 2.21). Although consistent seasonal patterns are difficult to discern across years and across the algal classes, concentration peaks did tend to occur in late summer/autumn and spring. The seasonal patterns were more evident in box plots for each marker pigment pooled across years and all 15 sites in Figure 2.22 (note the log scale for peridinin). The two major groups, dinoflagellates and diatoms peaked in autumn and spring, albeit the larger dinoflagellate occurred more in late summer/autumn. For the other major algal classes the concentration peaks occurred in late summer/autumn (Figure 2.22).

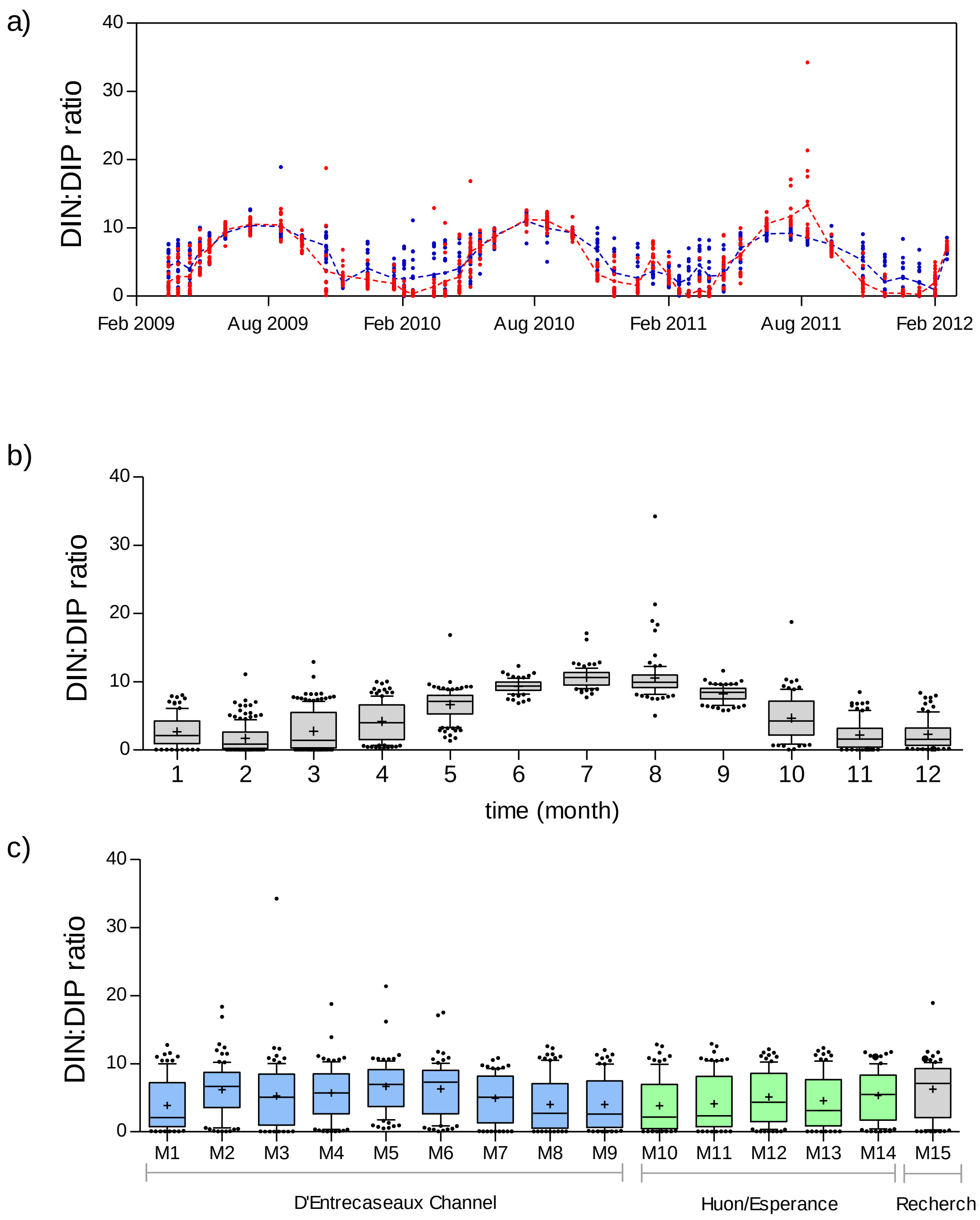


Figure 2.18: DIN:DIP ratio in the D'Entrecasteaux and Huon Estuary from March 2009 to March 2012 in a) surface (red) and bottom (blue) waters (dashed line is the mean for each survey/depth), b) calender months and c) across sites. For box plots the edges of the boxes encompass from the 25th percentile to the 75th percentile, the horizontal line in between is the median while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. The + symbol identifies the average. The data used for the box plots includes both surface and bottom values.

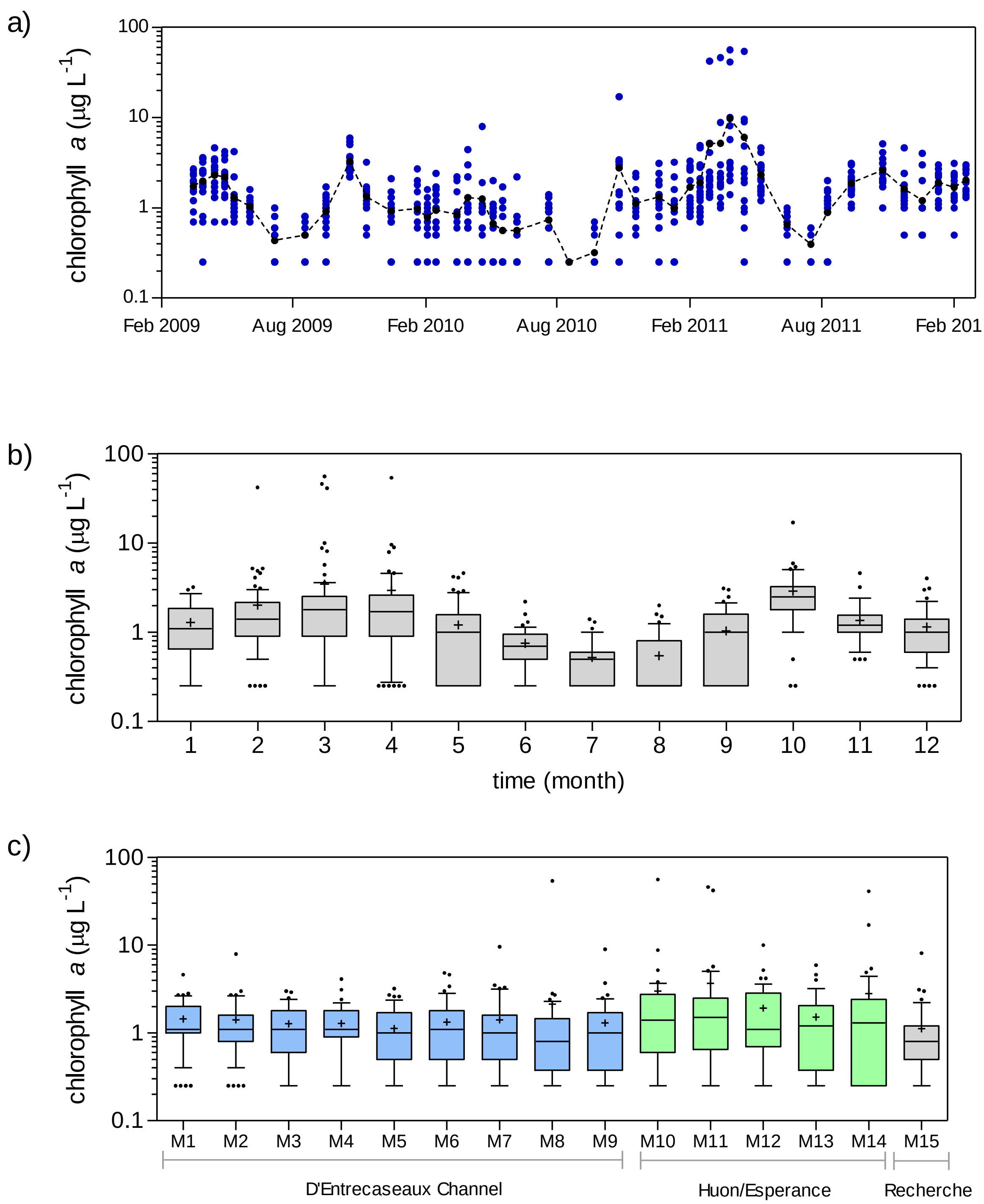


Figure 2.19: Chlorophyll *a* concentration (µg L^{-1}) in the D'Entrecasteaux and Huon Estuary from March 2009 to March 2012 in depth integrated samples (dashed line is the mean for each survey), b) calender months and c) across sites. For box plots the edges of the boxes encompass from the 25^{th} percentile to the 75^{th} percentile, the horizontal line in between is the median while the capped bars enclose the 10^{th} and 90^{th} percentiles and the outliers are shown as symbols. The + symbol identifies the average. The data used for the box plots includes both surface and bottom values.

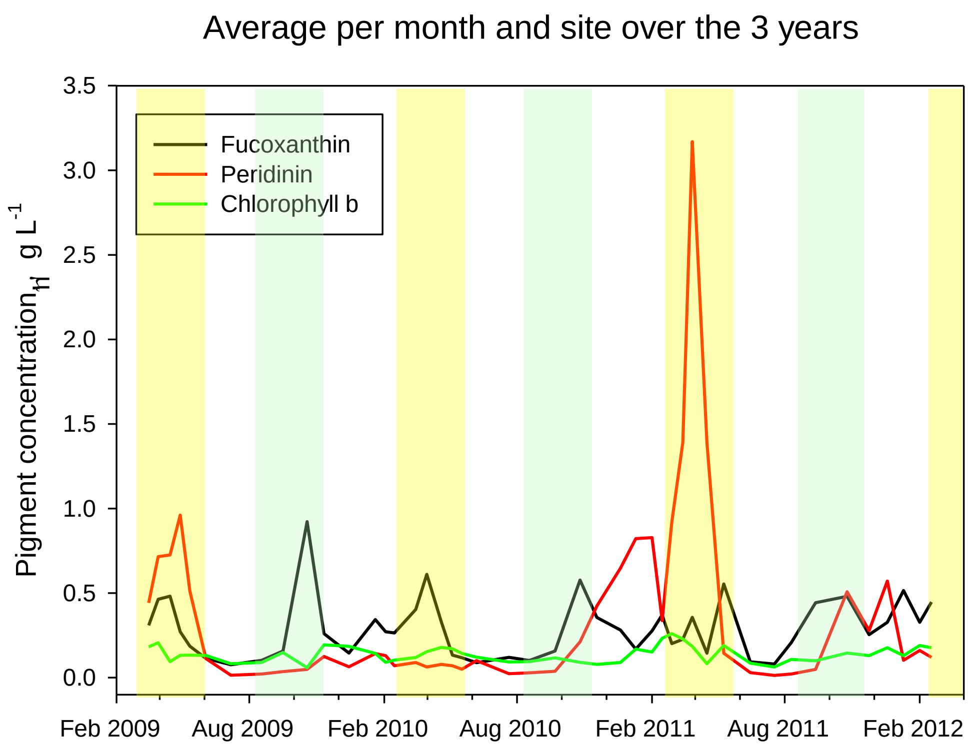
Table 2.7: Marker pigments and the algal classes they represent

Pigment	Algal class
Peridinin	Dinoflagellates
Fucoxanthin	Diatoms
19'-hexanoyloxyfucoxanthin	Haptophytes
Alloxanthin	Cryptophytes
19'-butanoyloxyfucoxanthin	Chrysophytes
Prasinoxanthin	Prasinophytes
Zeaxanthin	Cyanobacteria
Chlorophyll b	Green algal groups

Comparisons across sites showed very little spatial pattern (Figure 2.23; note the log scale for peridinin). However, sites in the Huon Estuary tended to have a greater range of concentrations measured, including higher maximum values compared to sites in the D'Entrecasteaux. The concentrations of peridinin (= dinoflagellates) also tended to be higher in the Huon (M10, 11, 13 and 14) Port Esperance (M12) and north D'Entrecasteaux Channel (M1-4). This may be explained by our understanding of residual regional circulation which would facilitate the accumulation of nutrient inputs to the system in the Huon and north D'Entrecasteaux Channel (Thompson et al 2008).

Count data

The regional temporal pattern from count data was also consistent with blooms tending to occur in late summer/autumn and spring (Figure 2.24). Most notable was the contribution of Prymnesiophyta (haptophytes) and Dinophyta (dinoflagellates) to the autumn 2009 and 2011 blooms respectively. Furthermore, the comparison across sites shows that the dinoflagellate blooms tend to occur in the Huon Estuary, but also at site M8 in Great Taylors bay and at M15, the control site in Recherche bay. By contrast, the bloom of haptophytes in autumn 2009 occurred in the north D'Entrecasteaux Channel, largely at sites M4 in Barnes Bay and the adjacent site M3, to the northwest in the main channel. Differences in the results of the 2 techniques (HPLC and count data) are perhaps best exemplified for dinoflagellates. In terms of pigments, peridinin (= dinoflagellates) is a major component of the phytoplankton community throughout, whereas from the count data, with the exception of the autumn 2011 bloom, cell densities Dinophyta (= dinoflagellates) are a relatively small component of the phytoplankton community (Figures 2.24 and 2.25).Importantly though, it is the magnitude of the bloom relative to the other classes rather than detecting the presence of the bloom that differs between the techniques. For example, the spring 2011 bloom of dinoflagellates evident from the pigment data in both Figure 2.20 and Figure 2.21 is also clear from the cell count data in Figure 2.25a compared with Figure 2.24. These differences are to be expected given that variability in cell sizes, pigment content etc. across taxa and groups will have varying influences over each technique.



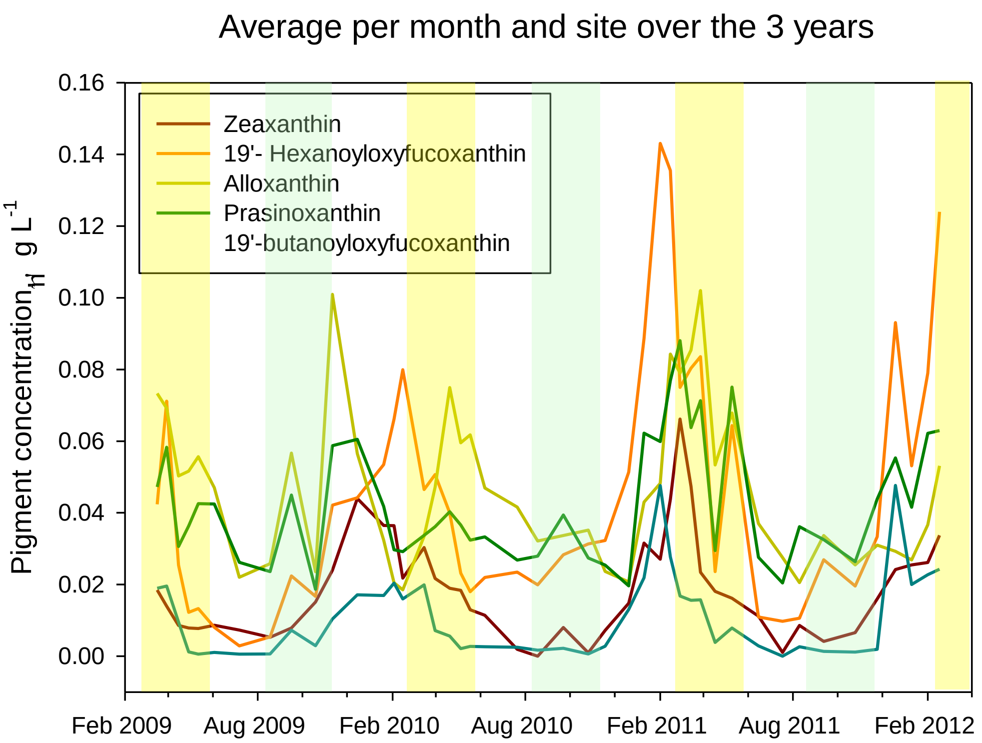
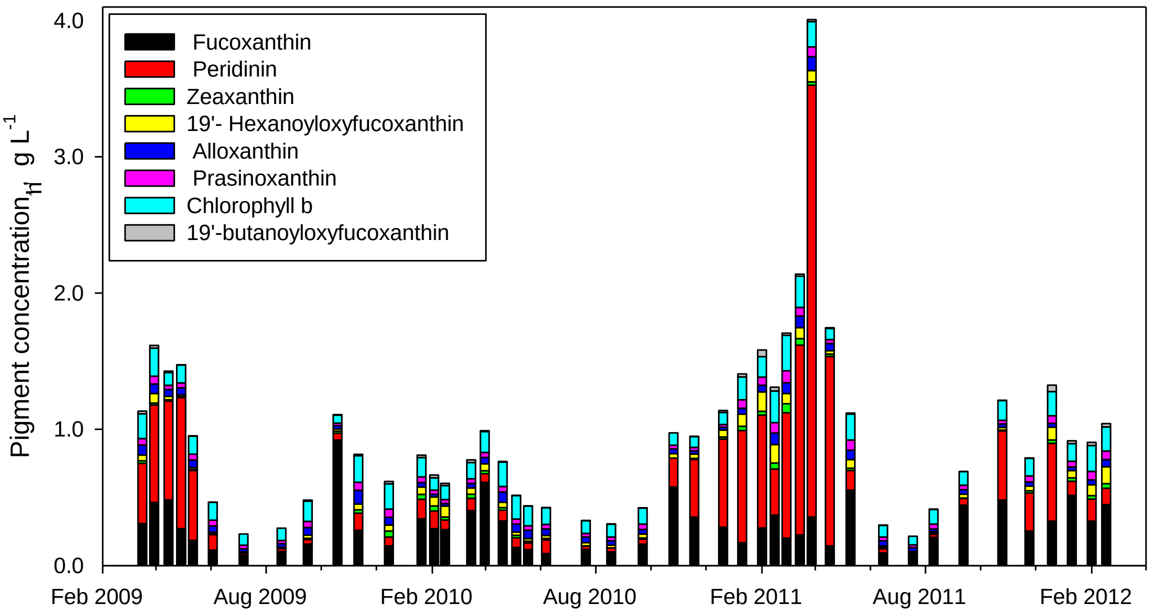


Figure 2.20: Concentrations of the 8 major marker pigments (see Table 2.7) from 0-12 m depth integrated samples and averaged per month and across 15 sites collected between March 2009 and March 2012. Yellow and green shading identifies autumn and spring respectively.



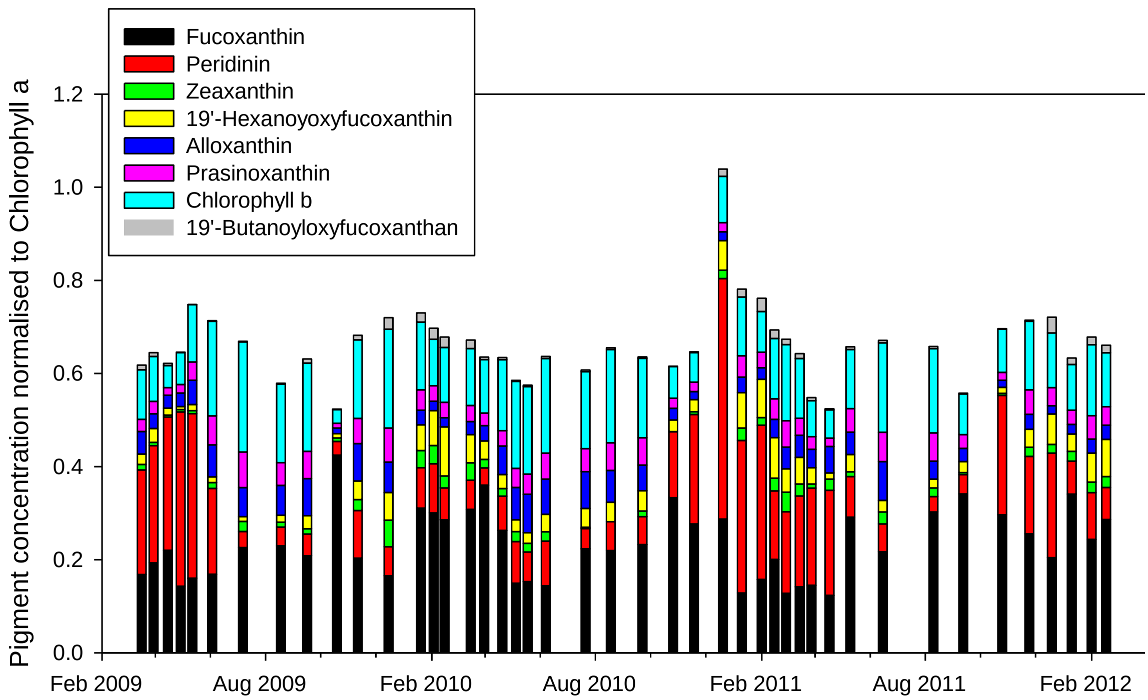


Figure 2.21: Composition of major marker pigments (see Table 2.7) from 0-12 m depth integrated samples averaged across 15 sites collected between March 2009 and March 2012. Pigment data normalised to total chlorophyll *a* is shown in the bottom panel.

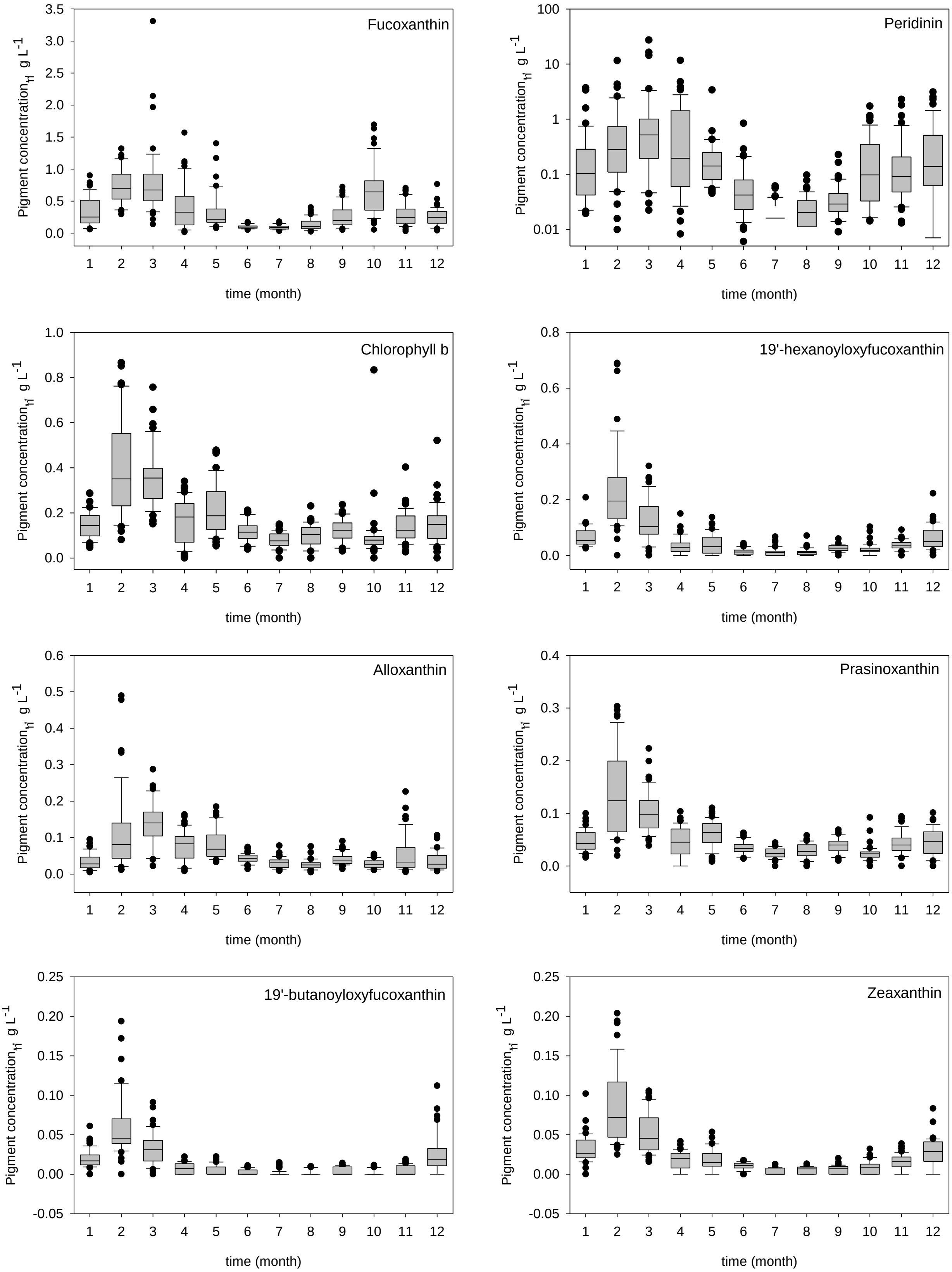


Figure 2.22: Concentrations of the major marker pigments averaged across years and sites and plotted by month. The edges of the boxes encompass from the 25th percentile to the 75th percentile while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols

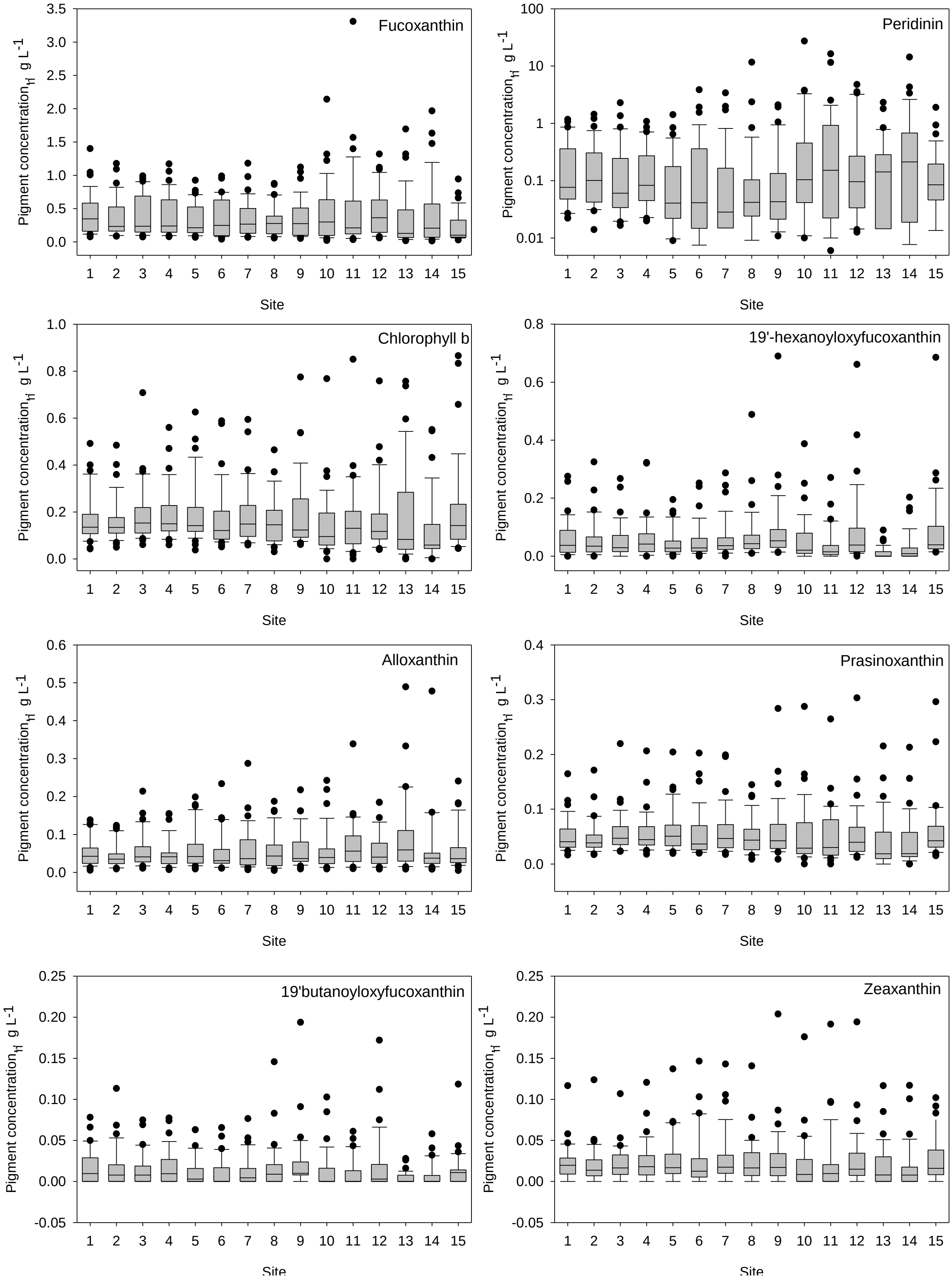


Figure 2.23: Concentrations of the major marker pigments averaged through time and plotted by site. The edges of the boxes encompass from the 25th percentile to the 75th percentile while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols

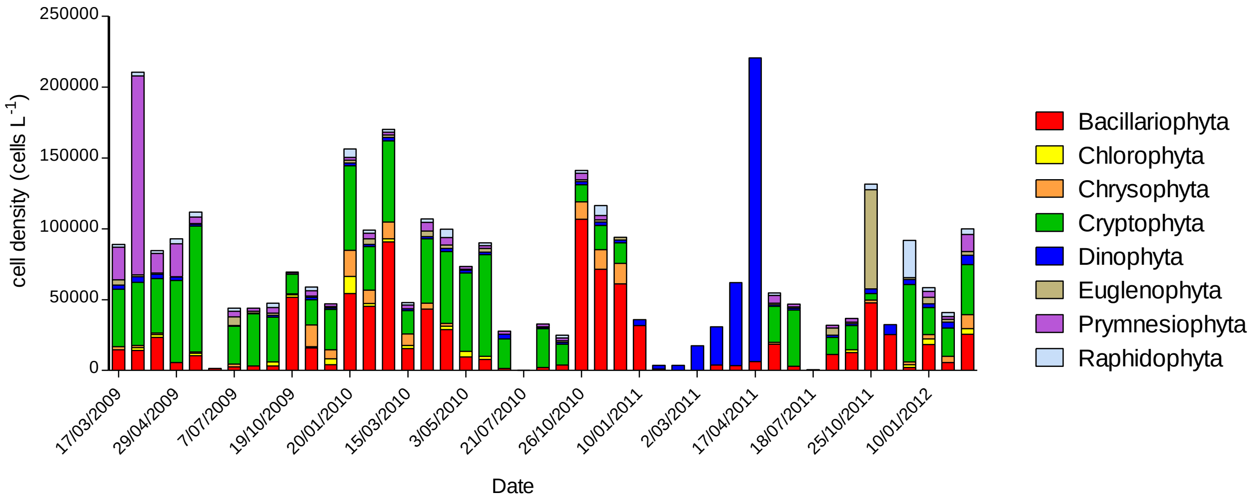


Figure 2.24: Composition of major algal class from cell counts for each survey between March 2009 and March 2012, data is averaged across the 15 sites. Note, the x-axis is currently not scaled with respect to date at this stage but rather according to surveys (1-46).

2.1.4 Synthesis of BEMP period

Over the BEMP sampling period (March 2009-March 2012) the major external sources of nutrients to the system were catchment inflows, fish farming and oceanic inputs. These sources differ in their composition, timing and magnitude. Catchment inflows (total mean flow 3174 GL p.a.) delivered on average 914 tonnes p.a. of nitrogen of which approximately 6% (56 tonnes p.a.) is in dissolved inorganic form (ammonium, nitrate and nitrite). The majority of this load is delivered via the Huon River (90.4 % of flow and ~83.7% of TN load) with significant inputs also coming from the Esperance River (6.1%), Kermandie River (2.6%), Mountain River (1.7%), North West Bay Rivulet (1.4%) and Snug Rivulet (0.3%). It also appears that locally significant loads enter via Agnes and Nicholls rivulets at Cygnet; however there is no flow gauging to estimate actual loads. Not surprisingly, the timing and magnitude of catchment inflows follow typical seasonal rainfall patterns, with peak flows/loads increasing through winter before peaking in spring. Inter-annual variability was also clearly evident with drier conditions in 2010 resulting in 25-30% lower catchment loads compared to 2009 and 2011. Although the temporal pattern for fish farm loads to the system were not as distinct, loads are also lowest in late summer before increasing through winter to a maximum in spring each year. Annual loads in the Huon River and Port Esperance MFDP Area remained relatively stable at ~1000 tonnes p.a. of dissolved nitrogen while loads in the D'Entrecasteaux Channel Marine Farming Development Plan (MFDP) Area increased from 708 to 850 tonnes p.a. of dissolved nitrogen between 2009 and 2011 respectively. In terms of the forms of nitrogen that enter the system, fish farming is the most significant source of ammonium (i.e. via. fish excretion and bacterial mineralisation of faeces and feed). However by contrast, the majority of nitrate and nitrite enters the system from oceanic sources and mostly in winter. Previous estimates have indicated that in the

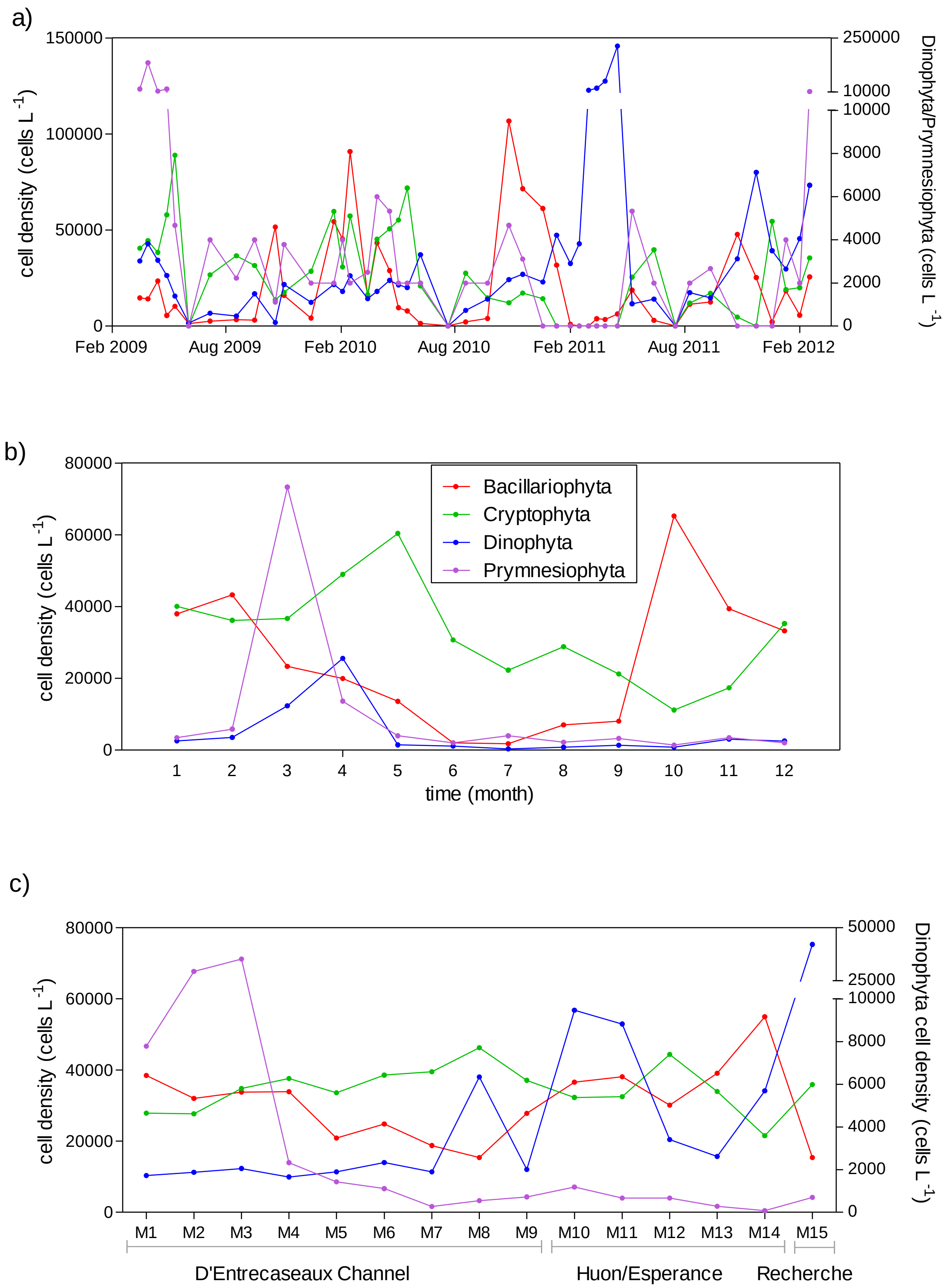


Figure 2.25: Cell densities of the 4 major algal classes for a) each survey between March 2009 and March 2012 (averaged sites) b) calendar month (averaged across years and sites) and c) across sites (averaged through time).

order of 3000 tonnes p.a. of nitrogen (~65% estimated to be labile) enters the system from the ocean.

In comparison to catchment, fish farm and ocean sources, WWTP and industrial discharge are relatively small at the whole of system level, yet their loads are likely to be significant with respect to the local receiving environment. Of the WWTPs that discharge into the system, Ranelagh (7.5 tonnes TN p.a.), Margate (6.7 tonnes TN p.a.) and Electrona (4.0 tonnes TN p.a.) represent the largest sources; 65-70 % of which is in the form of ammonia. The other major point source of nitrogen, particularly ammonia (5.7 tonnes p.a.), is the Dover outfall from the Tassal seafood processing plant. Note, a major upgrade to the Dover wastewater plant is scheduled for 2012/13 (Tassal 2012a).

The review of key water quality data collected over the 3 year BEMP period provided further insight into the ecosystem dynamics of the D'Entrecasteaux Channel and Huon Estuary and the role of external drivers, both natural and anthropogenic. The review also highlights the challenges given the inherent spatial and temporal variability typical of coastal systems and the resultant data sets. Consistent with previous studies the influence of oceanic influences to the system was evident, particularly for nitrate + nitrite. The influx of nitrate + nitrite occurred during the winter months and biological uptake was evident from spring through autumn. Although not as pronounced an ocean influx in winter and biological uptake in the warmer months a similar pattern was also evident for phosphate. There is also evidence that water column pools for nitrate + nitrate and phosphate receive inputs via sediment mineralisation. By contrast, the major source of silicate to the system is through catchment inflows and the mixing plots indicate uptake during summer. The major source of ammonium is internal; most likely via a combination of the remineralisation of organic matter deposited on the seafloor and excretion by farmed fish. From early spring through to mid-autumn surface water concentrations of ammonia become depleted due to biological uptake. It is also apparent that ammonium concentrations are on average higher at the Huon Estuary and northern Channel sites. This may reflect closer proximity to river and WWTP sources of ammonium and/or a greater influx from sediment remineralisation (e.g. due to more enriched/active sediments). This is consistent with our understanding of residual regional circulation that would facilitate the accumulation of nutrient inputs to the system in the Huon and north D'Entrecasteaux Channel (Thompson et al 2008). Interestingly nitrate + nitrite concentrations are on average higher at the Huon Estuary and southern Channel sites. The higher concentrations measured at the southern rather than northern Channel sites most likely reflects greater oceanic exchange and inflows at southern boundary of the Channel.

Consistent with the depletion of surface water concentrations of the major nutrients between spring and autumn, phytoplankton biomass was greatest between spring and autumn. The peak biomass/blooms typically occurred in spring and late summer/autumn and were typically greater in the Huon Estuary. Interestingly, concentrations of peridinin

(=dinoflagellates) tended to be higher in the Huon and north D'Entrecasteaux, potentially explained by the regional circulation and accumulation of ammonium in these areas. The phytoplankton composition data, whether measured via HPLC or cell counts highlighted significant variability in both the timing and location of phytoplankton blooms. For example, in autumn 2009 there was a bloom of haptophytes at sites in the north D'Entrecasteaux Channel, whereas dinoflagellate blooms typically occur at the Huon sites.

2.2 COMPARISON WITH HES AND AQUAFIN CRC

In this section conditions measured during the BEMP period (March 2009 – March 2012) are contrasted with historical data sets collected in the D'Entrecasteaux Channel (Aquafin CRC: 2002-2005) and Huon Estuary (HES: 1996-1998 and Aquafin CRC: 2002-2005). To provide context, the changes (or lack of) in water quality are contrasted against changes in the major external drivers over the same period. This covers a period of significant development of the Salmon Aquaculture industry in the region.

Marine Farming

The expansion of salmon farming in the D'Entrecasteaux Channel and Huon Estuary has seen a concomitant increase in total dissolved nitrogen (TDN) inputs to the system since the mid 1990's. Farm input data provided by DPIPWE for 2000-2012[5] shown in Figure 2.26 illustrates the major increase in farming between the Aquafin CRC (2002-05) and BEMP sampling periods (2009-12), from an average of 760 to 1795 tonnes TDN p.a., respectively. During the HES sampling period (1996-1998), a TDN input of 123 tonnes was reported for salmon farms in the Huon Estuary in 1997 (CSIRO Huon Estuary Study Team 2000). Despite the limited data set for the HES sampling period (e.g. no data available for the Channel) it is clear that TDN inputs associated with salmon farming in the D'Entrecasteaux Channel and Huon Estuary had increased ~ 4 fold between the HES and Aquafin CRC sampling periods.

[5] Since 2005 licence holder reporting requirements include total dissolved nutrient input data, and such the data could be broken down by MFDP area.

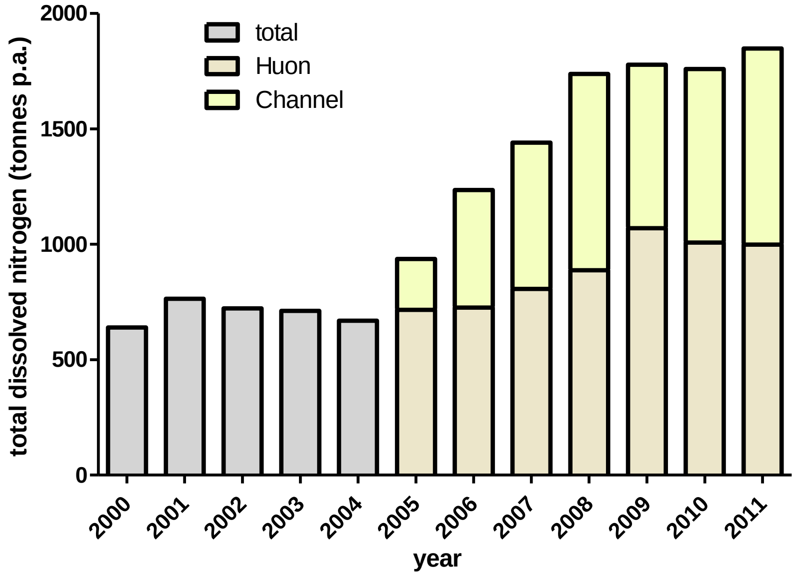


Figure 2.26: Annual dissolved nitrogen inputs (tonnes) by year. Licence holder reporting from 2005 allowed input data to be displayed by MFDP Area.

River Inputs

Rather than estimate loads for each of the major rivers and streams that enter the D'Entrecasteaux Channel and Huon Estuary for the past 16 years, which is problematic given gaps in long term flow records (e.g. Figure 2.28), loads were estimated for the Huon River because it contributes the vast majority of flows and loads to the Huon-Channel. Loads for the Huon River were calculated as described above based on the relationship between nutrient concentration and river flow. Note, the same nutrient flow relationship was assumed across the 16 year period because there isn't sufficient river concentration data to test whether this has changed. River flow data for the Huon at Judbury (station 635) wasn't available between 1996 and 2000, and instead flow was estimated based on a scaled relationship with flow measured upstream of Frying Pan Creek (station 119).

Not surprisingly, river flow and loads from the Huon River were highly variable at inter- and intra-annual time scales (Figure 2.27, Table 2.8). This was also reflected when contrasting the 3 study periods with large variation in flows and loads between years within each study period. However, over the course of each study the average annual flows and loads were similar; average annual river flow ranging from ~2800 -2900 GL and load from 770 – 830 tonnes TN p.a. Although the seasonality of flows appeared similar across studies, albeit less pronounced in the HES[6], there was significant inter-annual variability in the timing and magnitude of flood events (Figure 2.28).

[6] This comparison should be treated with caution given the flow data for station 635 wasn't available between 1996-2000, and the data depicted is based on a scaling relationship with upstream station 119

Table 2.8 Annual river flow and total nitrogen (TN) loads for 1996-2012. The shaded values indicate the HES, Aquafin CRC and BEMP sample periods.

Year	River flow (GL/yr)	TN (tonnes/yr)
1996	3472.880475	986
1997	2652.361563	731
1998	2219.307251	580
1999	2080.071661	539
2000	3066.046594	874
2001	2559.046933	698
2002	3404.46313	987
2003	2619.528365	752
2004	3074.27481	874
2005	2527.421011	696
2006	2664.840807	728
2007	2517.092775	726
2008	2360.568476	648
2009	3250.189012	929
2010	2363.980605	640
2011	2994.110602	839

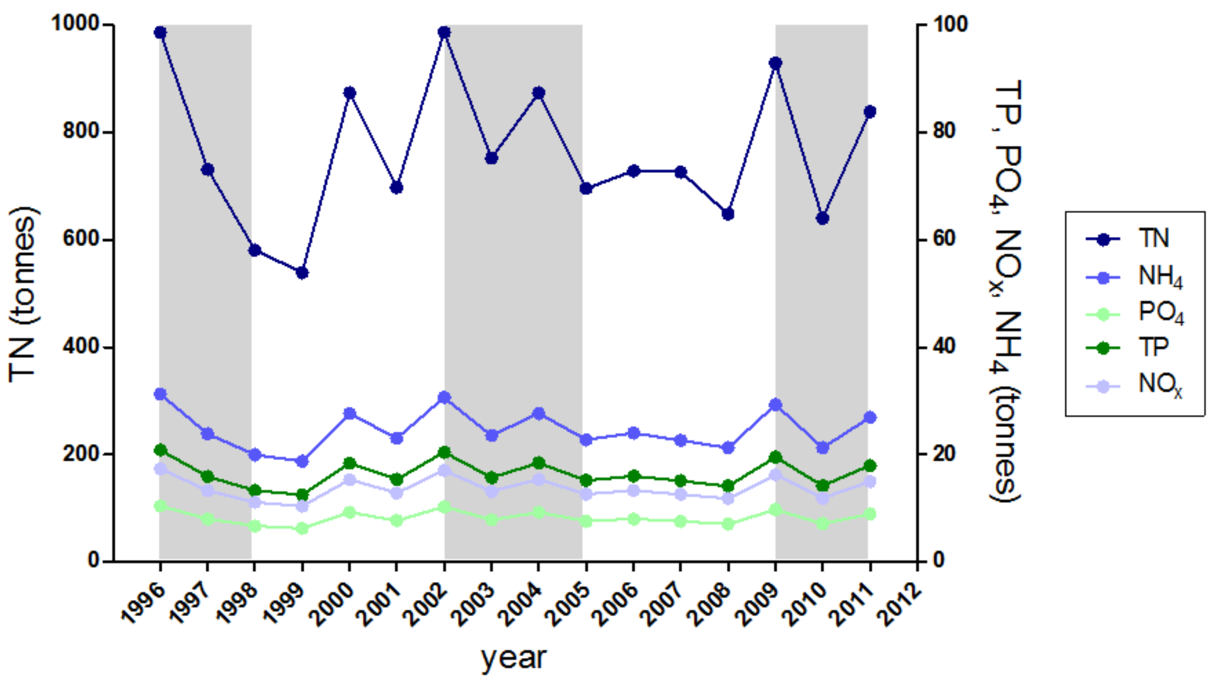


Figure 2.27: Estimated annual loads from the Huon River of total nitrogen (TN), ammonium (NH4), nitrate + nitrite (NOx), total phosphorus (TN) and phosphate (PO4) for 1996-2012. The shaded areas indicate the HES, Aquafin CRC and BEMP sample periods.

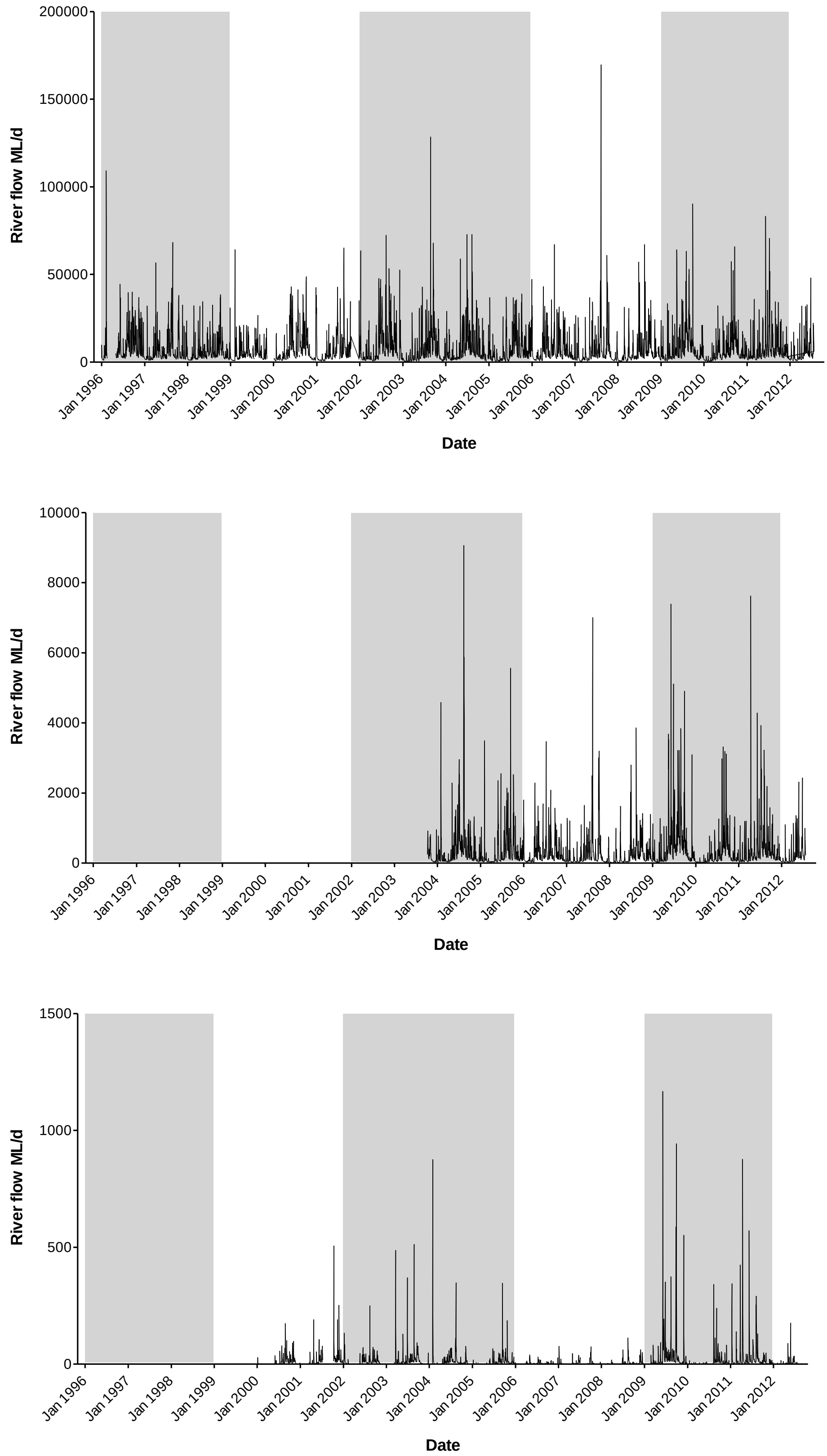


Figure 2.28: Daily flow records for the Huon (station 635) and Esperance (station 7202) Rivers and Snug Rivulet (station 5202) between 1996 and 2012. The shaded areas indicate the HES, Aquafin CRC and BEMP sample periods. Note flow data for station 635 wasn't available for 1996-2000, and the data depicted is based on a scaling relationship with upstream station 119

Annual Wastewater treatment and industrial plants

As discussed by Parsons (2012) long term trends in WWTP loads cannot be assessed due to the absence of effluent flow volume data prior to July 2009. Although WWTP loads were estimated as part of the HES and Aquafin CRC studies, the estimates were based on population statistics and predicted inputs/household and didn't include analysis based on outfall flow and concentration data. Earlier data available on effluent concentrations (Figure 2.29) indicated in increase in TN and ammonia concentrations, most notably at the Margate and Electrona plants, but unfortunately with no flow volume information this can't be converted into load. Despite these data limitations it seems unlikely that the capacity of WWTPs inputs to elicit system wide ecosystem responses has changed significantly over the past 16 years relative to changes in other external sources of nitrogen to the system.

Similarly for the fish processing plants that discharge into the system, a lack of historical flow volume and concentration data mean that longer term trends in loads cannot be estimated. However, it might be reasonable to expect that the loads have tracked increases in fish farm production in the region over the last 16 years described above.

Oceanic influences

Understanding the dynamics (e.g. timing and magnitude) of nutrient influxes from offshore across the 3 study periods is not possible without a hydrodynamic model. Nonetheless, insight into the intra and inter – annual variation in the transport of nutrients, particularly nitrate, into the D'Entrecasteaux Channel is provided through the results of a 4-year model simulation of the region covering the period 2002-05 (Herzfeld 2008; Figure 2.30). Whilst it is highly likely that oceanic exchange is the dominant source of nitrate to the system across each of the studies, the simulations by Herzfeld clearly demonstrate that the timing and magnitude of nitrate transport into the region is likely to vary markedly from year to year within and between studies.

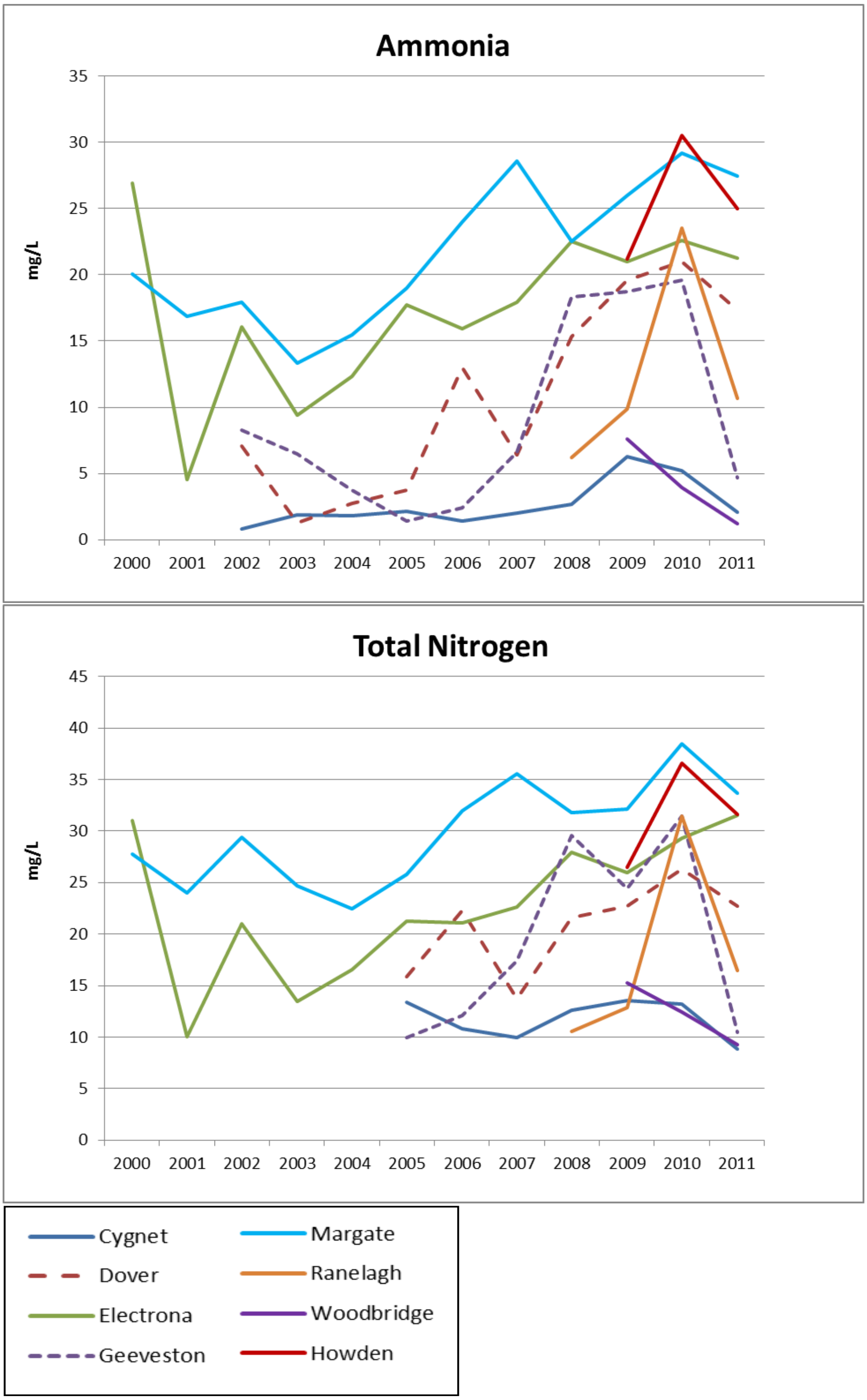


Figure 2.29: Average annual effluent concentrations at WWTPs (Data source: Southern Water).

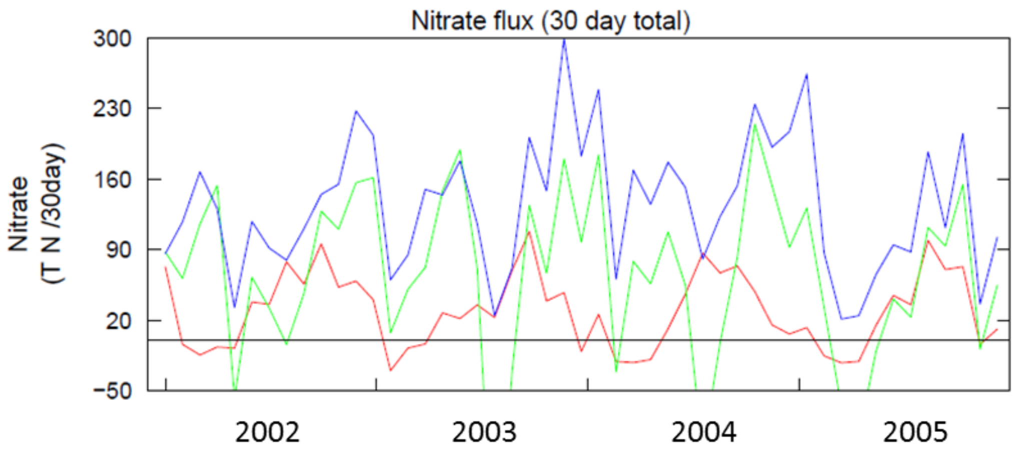


Figure 2.30: Comparison of modelled nitrate flux through the southern D'Entrecasteaux Channel. The different colour lines represent different model configurations (see Herzfeld et al. 2008 for further details).

2.2.1 Changes in water quality

Nitrate + Nitrite (NO_x)

Concentrations of NO_x in the D'Entrecasteaux Channel in bottom and surface waters were markedly higher in autumn and winter but similar in spring and summer in 2009-12 compared to 2002-05 (Figure 2.31). Similar differences between 2009-12 and 2002-05 NO_x concentrations were recorded for the Huon Estuary (Figure 2.31). By contrast, concentrations measured in the Huon Estuary during 1996-98 were higher in autumn and winter compared with 2002-05. While variability in other external (e.g. river and WWTP inputs) and internal (e.g. sediment mineralisation) inputs may help explain these patterns, inter-annual variability (e.g. as demonstrated by Herzfeld 2008) in the influx of nitrate from oceanic waters is likely to be the major factor driving these differences based on the magnitude and timing (seasonal) of the observed differences.

Ammonium

For the purposes of this review the ammonium data was restricted to that analysed at CSIRO. Thus, ammonium data collected during the Aquafin CRC in the Huon Estuary and analysed at AST was not included[7]. Concentrations of ammonium in bottom and surface waters in the D'Entrecasteaux Channel were similar in 2009-12 compared with 2002-03[8] (Figure 2.32). However, the highly variable nature of the ammonium data makes detecting

[7] Inter-laboratory comparisons between AST and CSIRO indicate the potential for post analysis correction to the ammonium data that will facilitate meaningful comparison and inclusion in data reviews such as this.
[8] Ammonium was only measured during phase 1 (2002-03) of the Aquafin CRC

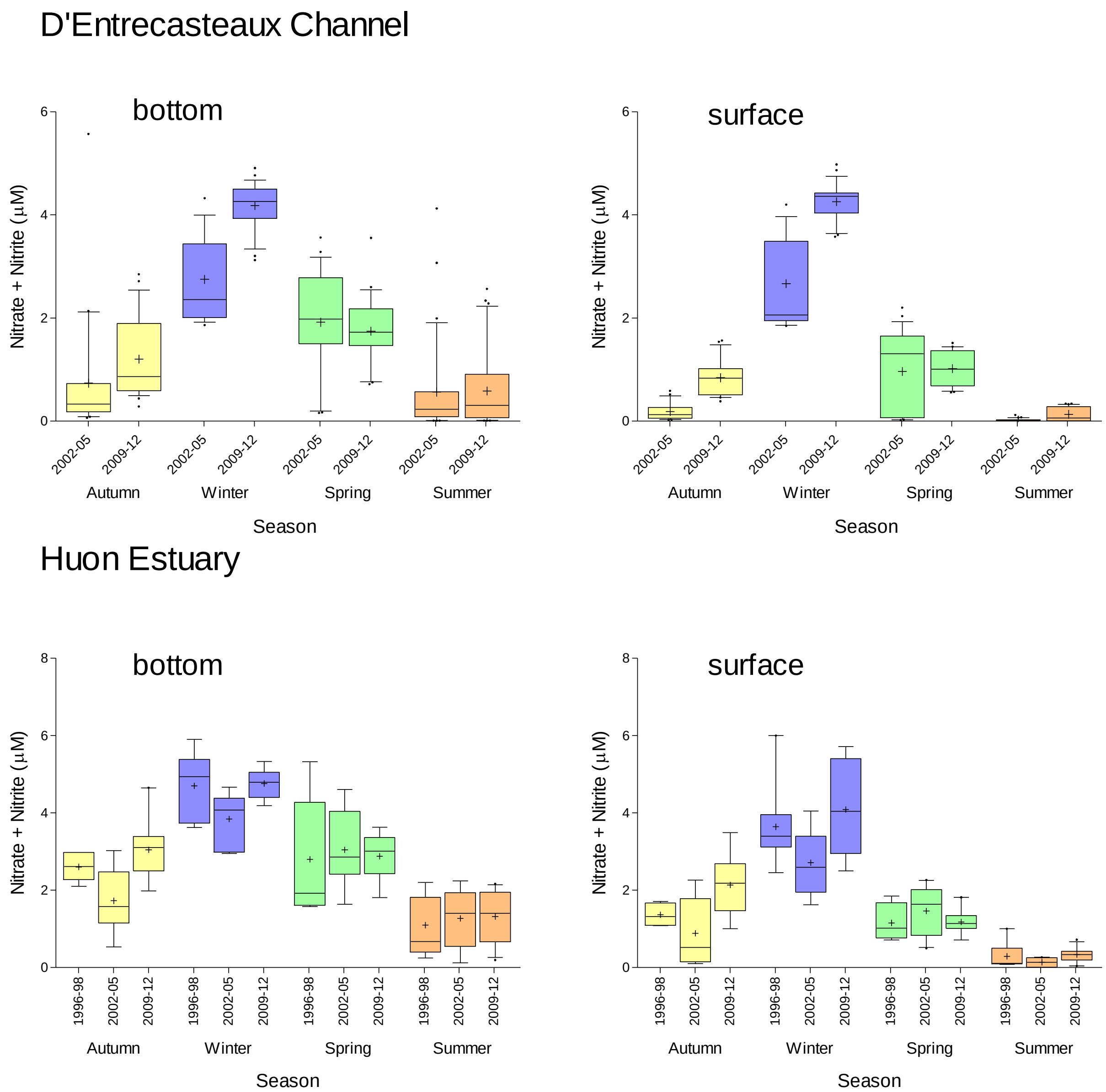


Figure 2.31: Seasonal nitrate + nitrite concentrations in bottom and surface waters in the D'Entrecasteaux and Huon Estuary during the HES (1996-98), Aquafin CRC (2002-05) and BEMP (2009-2012) study periods. Boxes encompass the 25-75 percentiles while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. Medians are the horizontal lines across the box and means the "+" symbol.

change difficult. Despite similar variation, there appears to have been an increase in bottom and surface water concentrations across all seasons, with the exception of surface water concentrations in summer, in the Huon Estuary in 2009-12 compared with 1996-98 (Figure 2.32). The change in ammonium concentrations is more evident in the full time series plot for each of the three Huon Estuary monitoring stations (Figure 2.33). Variability in the region's hydrodynamics (e.g. far more distinct seasonal river flows in 2009-12 compared to 1996-98) and the associated effects on stratification and mixing are likely to be partly responsible for the elevated ammonium concentrations. However, it also seems likely that the increase in ammonium concentration is partly due to a combination of increased organic loading to the sediments and subsequent remineralisation and increased inputs via excretion from farmed fish associated with the industry expansion. The lower bottom water dissolved oxygen concentrations recorded in 2009-12 compared to 1996-98 (see discussion below; Figure 2.35) are consistent with increased organic loading and mineralisation on the seafloor. Again, it is also likely that variability in the systems hydrodynamics and the associated effects on water retention and mixing will have contributed to the variability with and between the study periods.

Despite these changes in ammonium and oxygen concentrations in the Huon Estuary there is no clear evidence of a concomitant change in water column productivity (i.e. phytoplankton biomass; section 2.2.2). See section 2.4 below for further assessment of these levels against recommended trigger levels for the ecosystem.

Phosphate

Phosphate concentration showed a pattern similar to NO_x (Figure 2.34). Concentrations in bottom and surface waters during autumn and winter were higher in 2009-12 compared to 2002-05, while concentrations in 1996-98 were generally higher compared to 2002-05 in the Huon. As per NO_x, inter-annual variability in the influence of oceanic waters that import phosphate to the system is likely have played a role in driving these differences. It is also likely that changes in organic loading and remineralisation and the influence of dissolved oxygen on phosphate release from sediments will have played a role. For example the lower bottom water dissolved oxygen conditions measured during 2009-12 compared with 1996-98 may be responsible for increased release of sediment bound phosphate.

Oxygen

Unfortunately, oxygen data was not easily available from the Aquafin CRC[9] in a comparable format to the HES and BEMP limiting the ability to assess long term changes in oxygen conditions. Given the key role of dissolved oxygen as an indicator of ecosystem performance, extracting the data from the CRC data set should be a future priority in assessing long term changes in ecosystem condition. The data available from the Huon Estuary sites shows that bottom water dissolved oxygen conditions are lower in 2009-12 compared to 1996-98 (Figure 2.35, 2.36). This could reflect variability in the regions hydrodynamics e.g. increased stratification and reduced vertical and horizontal exchange in 2009-12 due to more pronounced seasonal flows. The lower bottom water dissolved oxygen conditions in 2009-12 may also reflect increased organic loading and sediment mineralisation due to greater faecal loads to the sediments from salmon and greater water column productivity.

[9] i.e. it is stored in continuous depth profiles and would need to be extracted for the depths corresponding to the surface and bottom water nutrient sampling. This also applies to temperature and salinity

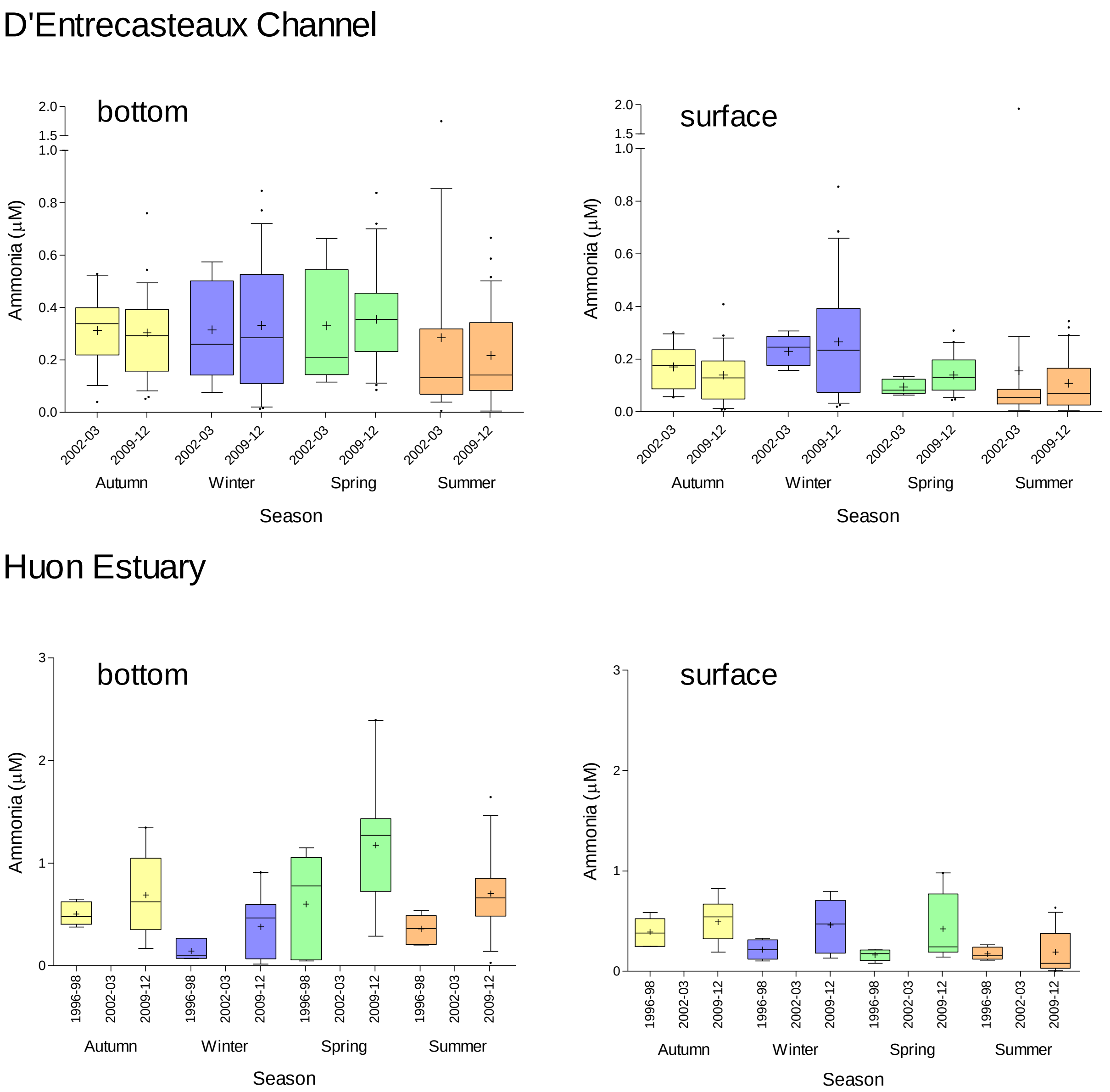


Figure 2.32: Seasonal ammonium concentrations in bottom and surface waters in the D'Entrecasteaux and Huon Estuary during the HES (1996-98), Aquafin CRC (2002-05) and BEMP (2009-2012) study periods. Boxes encompass the 25-75 percentiles while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. Medians are the horizontal lines across the box and means the "+" symbol.

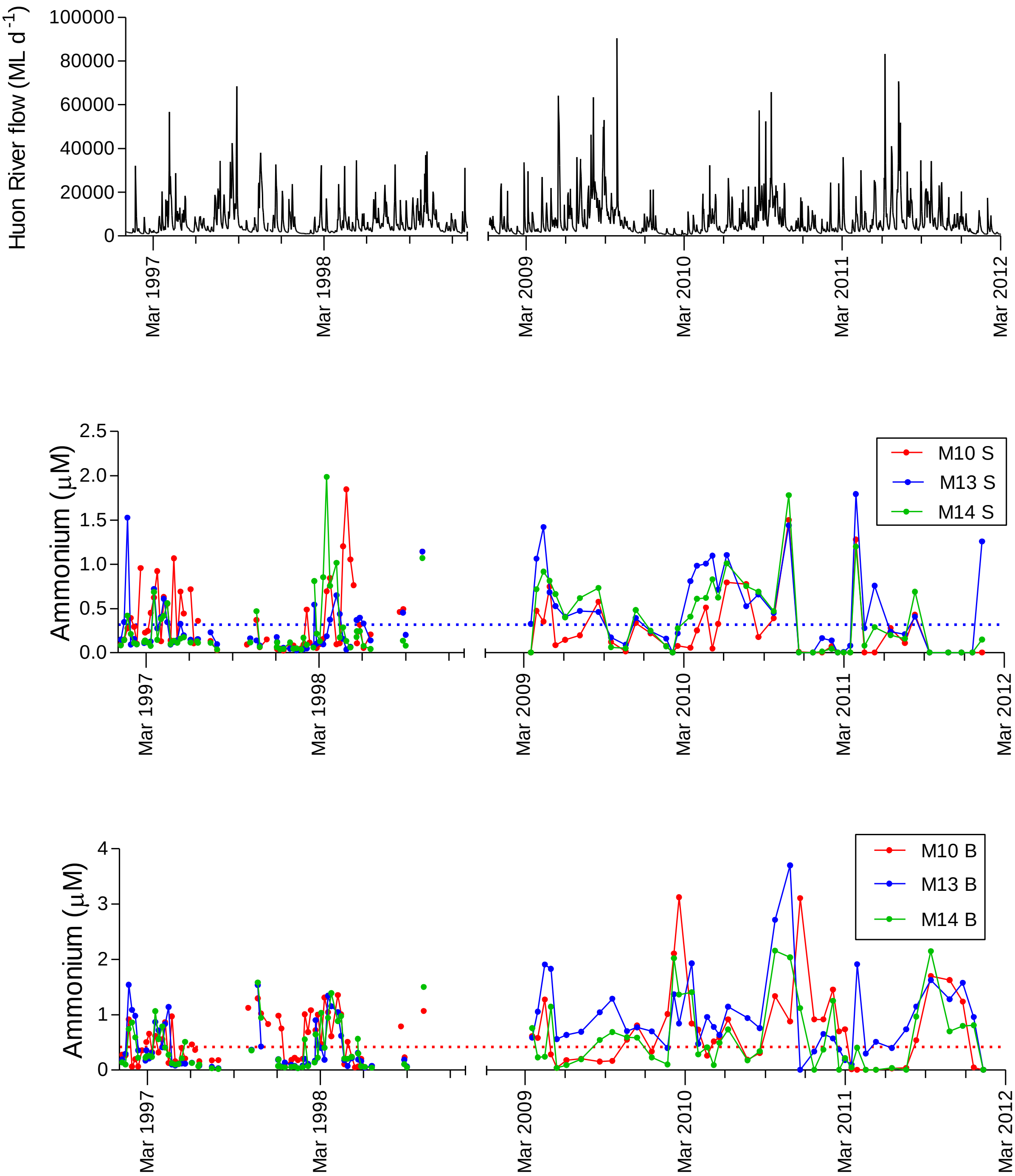


Figure 2.33: Huon River flow (ML d^{-1}; top panel) and ammonium concentrations from weekly (HES 1996-98) and monthly (BEMP 2009-12) observations at 3 Huon Estuary sites in surface (middle panel) and bottom (bottom panel) waters. The dotted line represents the baseline value (see section 2.4) proposed by Thompson et al (2008).

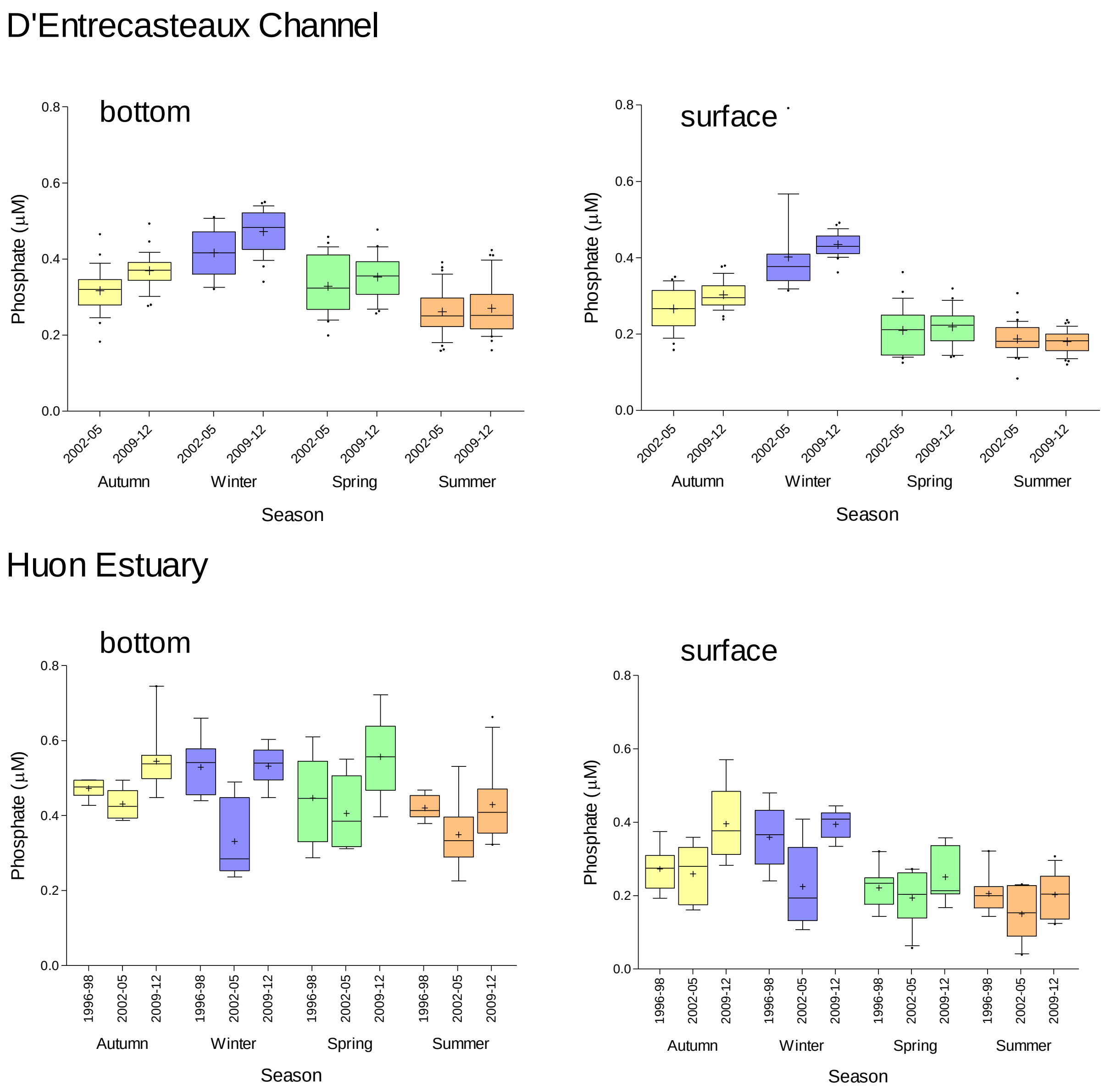


Figure 2.34: Seasonal phosphate concentrations in bottom and surface waters in the D'Entrecasteaux and Huon Estuary during the HES (1996-98), Aquafin CRC (2002-05) and BEMP (2009-2012) study periods. Boxes encompass the 25-75 percentiles while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. Medians are the horizontal lines across the box and means the "+" symbol.

Huon Estuary

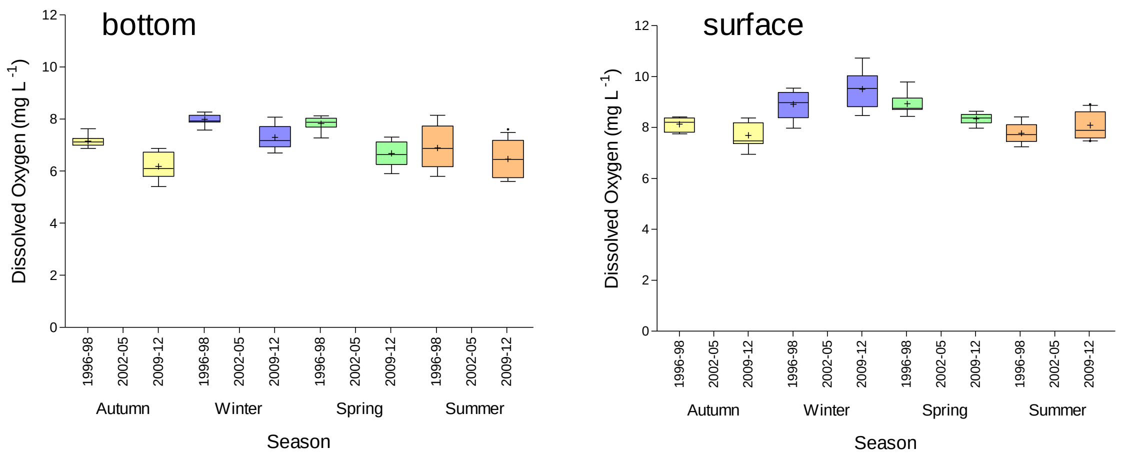


Figure 2.35: Seasonal dissolved oxygen concentrations in bottom and surface waters in the Huon Estuary during the HES (1996-98) and BEMP (2009-2012) study periods. Boxes encompass the 25-75 percentiles while the capped bars enclose the 10^{th} and 90^{th} percentiles and the outliers are shown as symbols. Medians are the horizontal lines across the box and means the "+" symbol.

2.2.2 Changes in phytoplankton composition and biomass

Biomass

Chlorophyll *a* measured by spectrophotometry and HPLC gave broadly similar patterns in space and time (Figure 2.37). In the D'Entrecasteaux Channel, chlorophyll *a* concentrations were similar in 2009-12 compared to 2002-05 for winter, spring and summer. However, concentrations were higher and more variable in autumn in 2009-12 compared to 2002-05; largely attributable to phytoplankton blooms in autumn 2009 and 2011 (Figure 2.38b). In the Huon Estuary, the chlorophyll *a* data is clearly more variable which is not surprising given the more dynamic nature of the Huon compared to the Channel (Figure 2.37, 2.38a). At this stage there are no clearly discernable changes in Huon Estuary chlorophyll a concentrations when contrasting data across the three studies.

It is also important to note that the HPLC data was far more limited in the CRC study, with 12 samples collected monthly over a year (Oct 2004 - Oct 2005) compared with ~75 samples collected weekly/fortnightly in the HES over 2 years (Oct 1996 - Oct 1998) and 45 samples collected monthly/fortnightly in the BEMP over 3 years (Mar2009 – Mar 2012). This was similar for chlorophyll *a* determined using spectrophotometry for the Huon sites (e.g. only 1 year of samples in the CRC); however in the Channel samples were collected for a full year in 2002/03 and 2004/5. This provides further confidence in the observed increase in autumn chlorophyll *a* concentrations in the Channel.

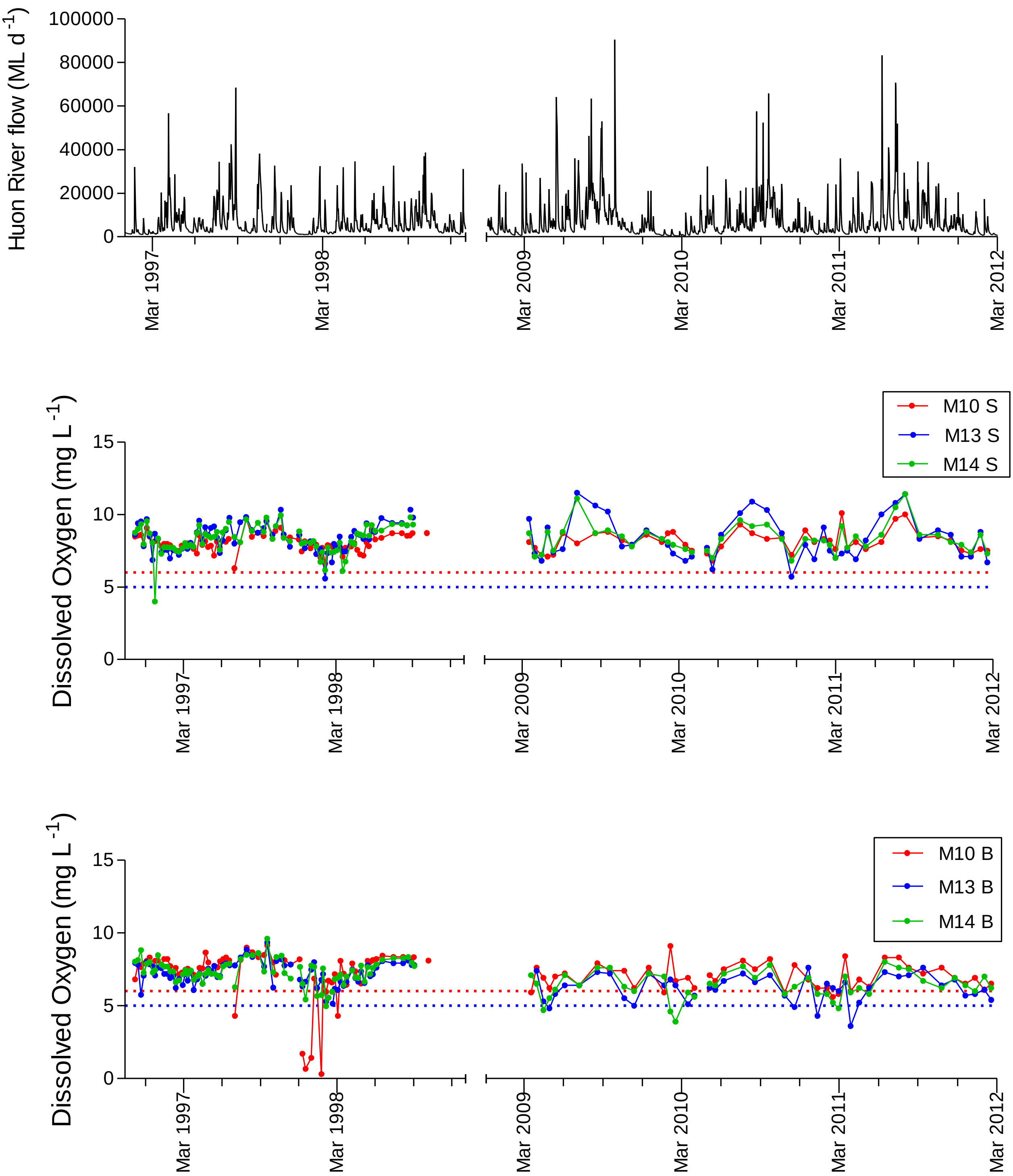


Figure 2.36: Huon River flow (ML d^{-1}; top panel) and oxygen concentrations from weekly (HES 1996-98) and monthly (BEMP 2009-12) observations at 3 Huon Estuary sites in surface (middle panel) and bottom (bottom panel) waters. The dotted line represents the baseline values proposed by Thompson et al (2008) for bay (blue line) and channel (red line) sites.

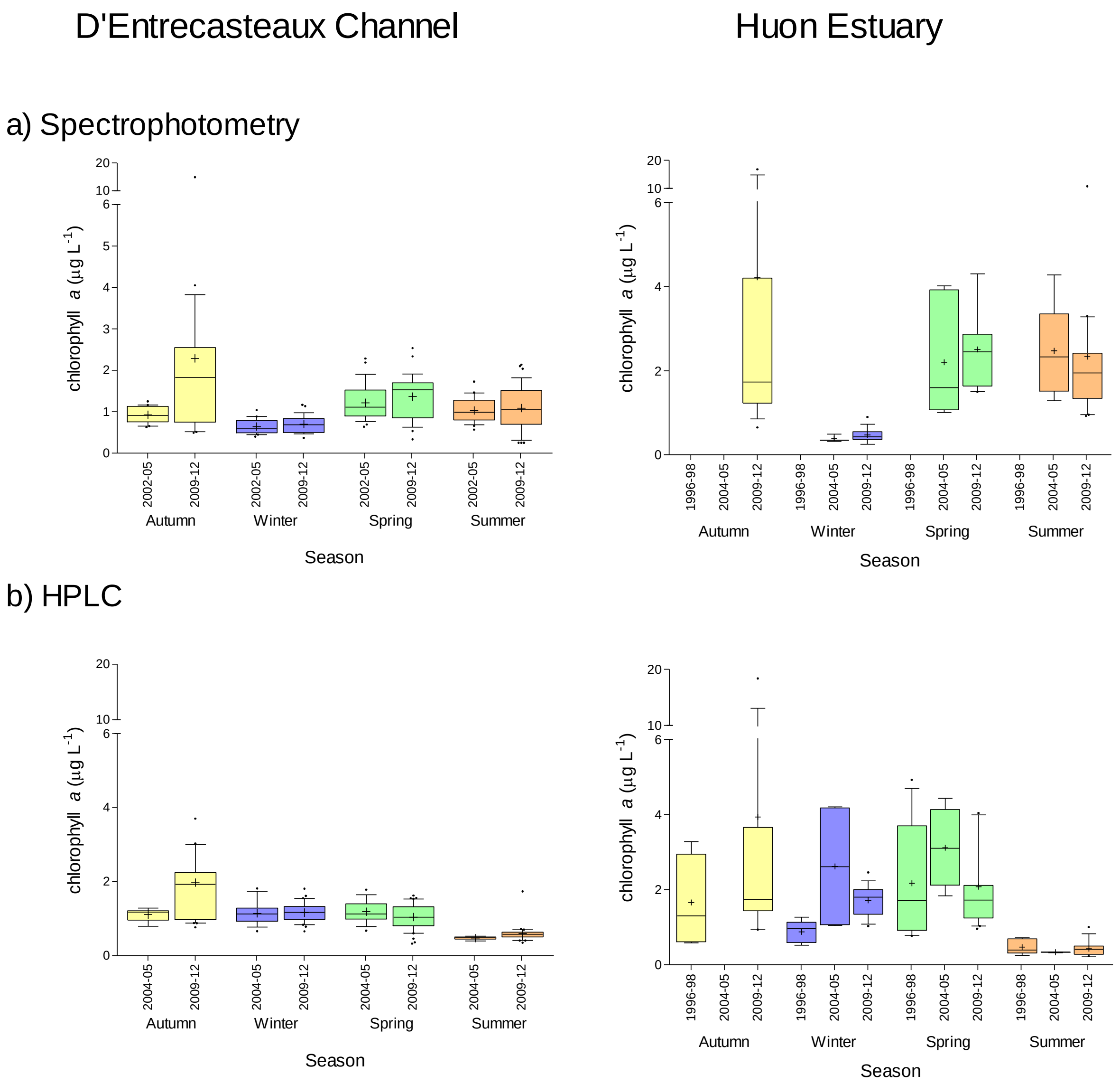
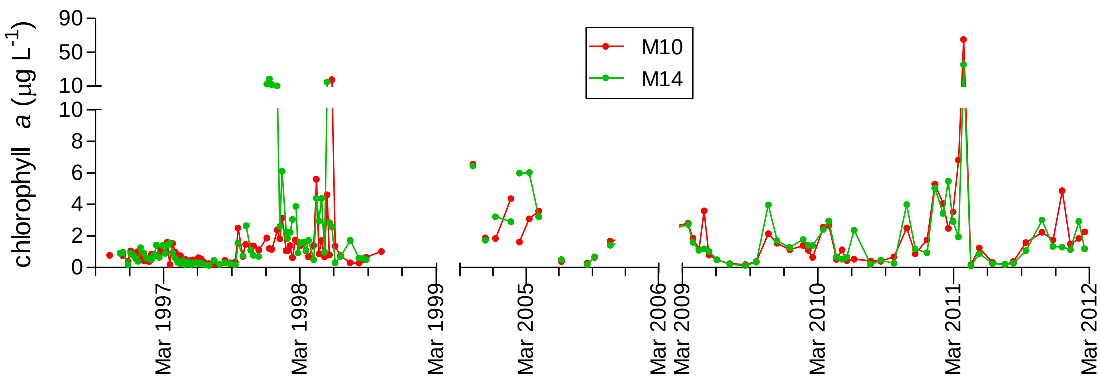


Figure 2.37: Seasonal chlorophyll *a* concentrations determined using a) spectrophotometry and b) HPLC from 0-12 m depth integrated samples in the D'Entrecasteaux and Huon Estuary during the HES (1996-98), Aquafin CRC (2002-05) and BEMP (2009-2012) study periods. Boxes encompass the 25-75 percentiles while the capped bars enclose the 10th and 90th percentiles and the outliers are shown as symbols. Medians are the horizontal lines across the box and means the "+" symbol.

Phytoplankton Composition

This comparison was restricted to the HPLC data given the time required to extract and reformat phytoplankton count data from the earlier studies. The results suggest an increase in the dominance and magnitude of dinoflagellate (Peridinin) and diatom (Fucoxanthin) blooms in 2009-12 compared to 2004-05 (Figure 2.39) in the Channel. A similar pattern is also apparent in the Huon when comparing 2009-12 with 2004-05 and 1996-98, but perhaps more so for diatoms than dinoflagellates (Figure 2.40). Representation of the of the pigments that identify Chyrsophytes and Prasinophytes are also now a more dominant representatives of the phytoplankton community in the Huon Estuary based on the pigment data in 2004-05 and 2009-12 compared with 1996-98. Nonetheless, the results for both the Huon and Channel should be treated with caution, particularly in the Channel given the limited data set collected during the Aquafin CRC, with more data and further analysis (i.e. inclusion of count data) required before concluding an unambiguous change in composition through time and/or direct links to any single source.

a. Huon Estuary



b. D'Entrecasteaux Channel

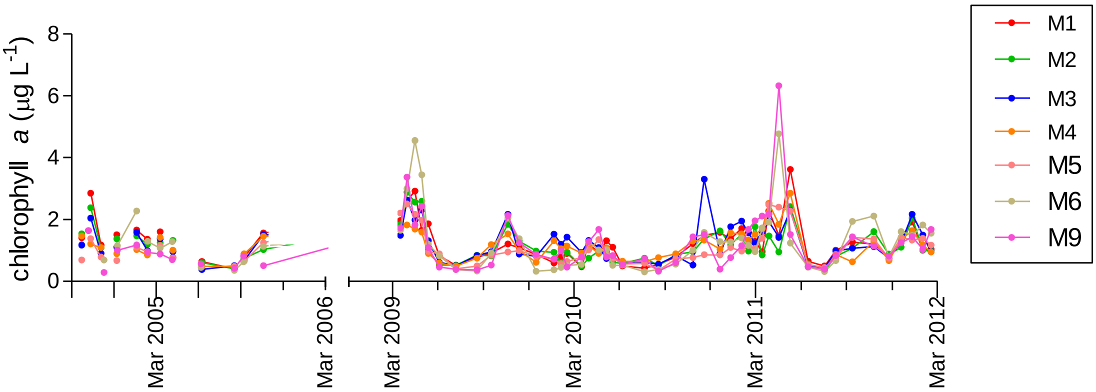


Figure 2.38 Chlorophyll *a* concentrations determined using HPLC from 0-12 m depth integrated samples in the a) Huon Estuary and b) D'Entrecasteaux at sites mesured during the HES (1996-98), Aquafin CRC (2002-05) and BEMP (2009-2012) study periods.

2.2.3 Synthesis of comparison across studies

The four year model simulation (2002-05) of the region conducted as part of the Aquafin CRC (Volkman et al. 2009) demonstrated that spatial and temporal variability in hydrodynamics, and marine and river influxes, dominate the regional dynamics of nutrients and plankton in the D'Entrecasteaux Channel and Huon Estuary. The authors also concluded that the likelihood of detecting impacts of farming activity exceeding natural system variability throughout much of the system appeared small based on model analysis. The availability of the three comprehensive data sets covering the period of major development of the salmon industry in the region provided a unique opportunity to assess the longer term dynamics of the system and the potential effects of salmon farming based on field observations.

This comparison across studies provided further evidence of the high spatial and temporal variability in nutrient concentrations and phytoplankton biomass and composition consistent with intra and inter-annual variability in hydrodynamics and marine and river influxes. For example, variation in autumn and winter NO_x, and to a lesser extent phosphate concentrations, between studies is likely due to inter-annual variability in the influx of oceanic nutrients as described by Herzfeld (2005).

Nonetheless, despite the inherent natural variability and data limitations across studies, a number of system changes appear consistent with anticipated responses to increased inputs of organic matter and nutrients. This includes an increase in ammonium concentrations in bottom and surface waters (Figure 2.33) and a decrease in oxygen concentrations in bottom waters (Figure 2.35) in the Huon estuary in 2009-12 compared to 1996-98. . Variability in the region's hydrodynamics (e.g. far more distinct seasonal river flows in 2009-12 compared to 1996-98) and the associated effects of stratification and mixing are likely to be partly responsible for the changes in ammonium and oxygen concentrations. However, it also seems likely that the increase in ammonium concentration and decrease in bottom water oxygen concentrations in the Huon Estuary is partly due to a combination of increased organic loading to the sediments and subsequent remineralisation and increased inputs via excretion from farmed fish associated with the industry expansion. Unfortunately a lack of comparable ammonium and available oxygen data pre-BEMP in the Channel obfuscates meaningful assessment in the Channel. Despite the changes in ammonium and oxygen concentrations in the Huon Estuary there is no clear evidence of a concomitant change in water column productivity (i.e. phytoplankton biomass; section 2.2.2). There is some indication from the HPLC data that phytoplankton composition may have changed in the Huon and Channel, however, with more data and further analysis (i.e. inclusion of count data) required before concluding an unambiguous change in composition through time and/or direct links to any single source.

2.3 COMPARISON WITH MODEL PREDICTIONS

A 3-D hydrodynamic, sediment and biogeochemical model of the inshore waters of southern Tasmania was used to evaluate the environmental impact of salmon farming in the Huon Estuary and D'Entrecasteaux Channel (Wild-Allen 2008). The model was calibrated against 2002 observations and simulations included with and without fish farms in 2002, and with

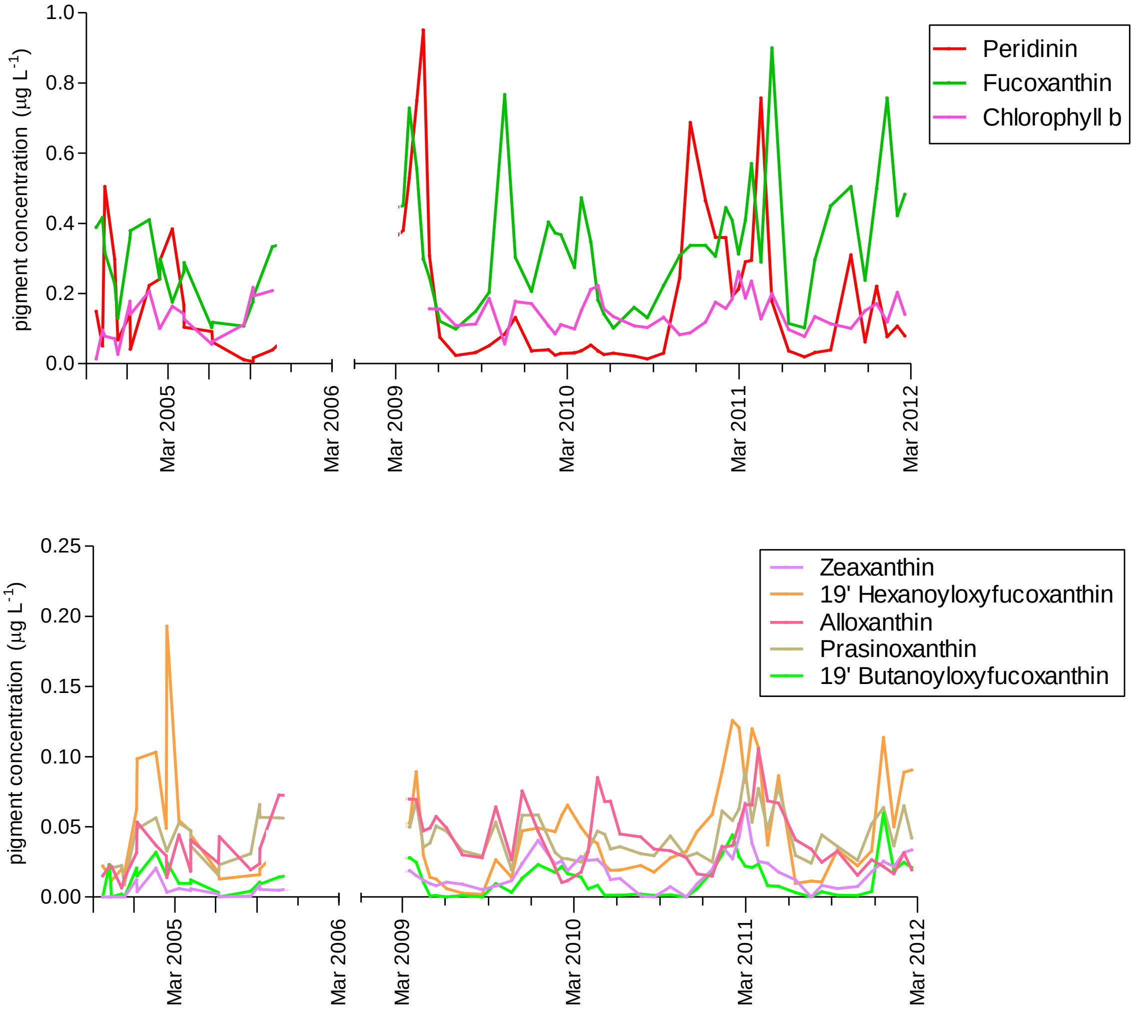


Figure 2.39: Time series plots of the concentrations of the 8 major marker pigments (see Table 2.7) from 0-12 m depth integrated samples (pooled across 7 sites : M1-6,M9) collected in the D'Entrecasteaux Channel during the Aquafin CRC and BEMP.

projected inputs for 2009 to assess the system-wide spatial and temporal environmental footprint of the industry. It is important to point out that it would be unreasonable to expect close agreement between the modelled parameter values and 2009 BEMP observations given that the model was necessarily based on typical (2002) rather than actual 2009 physical forcing (e.g. meteorology and ocean boundary dynamics). Furthermore, the projected total TDN input for the system was 2202 tonnes compared to actual inputs of 1779 tonnes. The spatial and temporal distribution of farm inputs used in the model was also different to actual inputs in 2009. Nonetheless, the BEMP observations provide insight into how well the model predicts seasonal and broad scale dynamics in the presence of a significant increase in salmon farming.

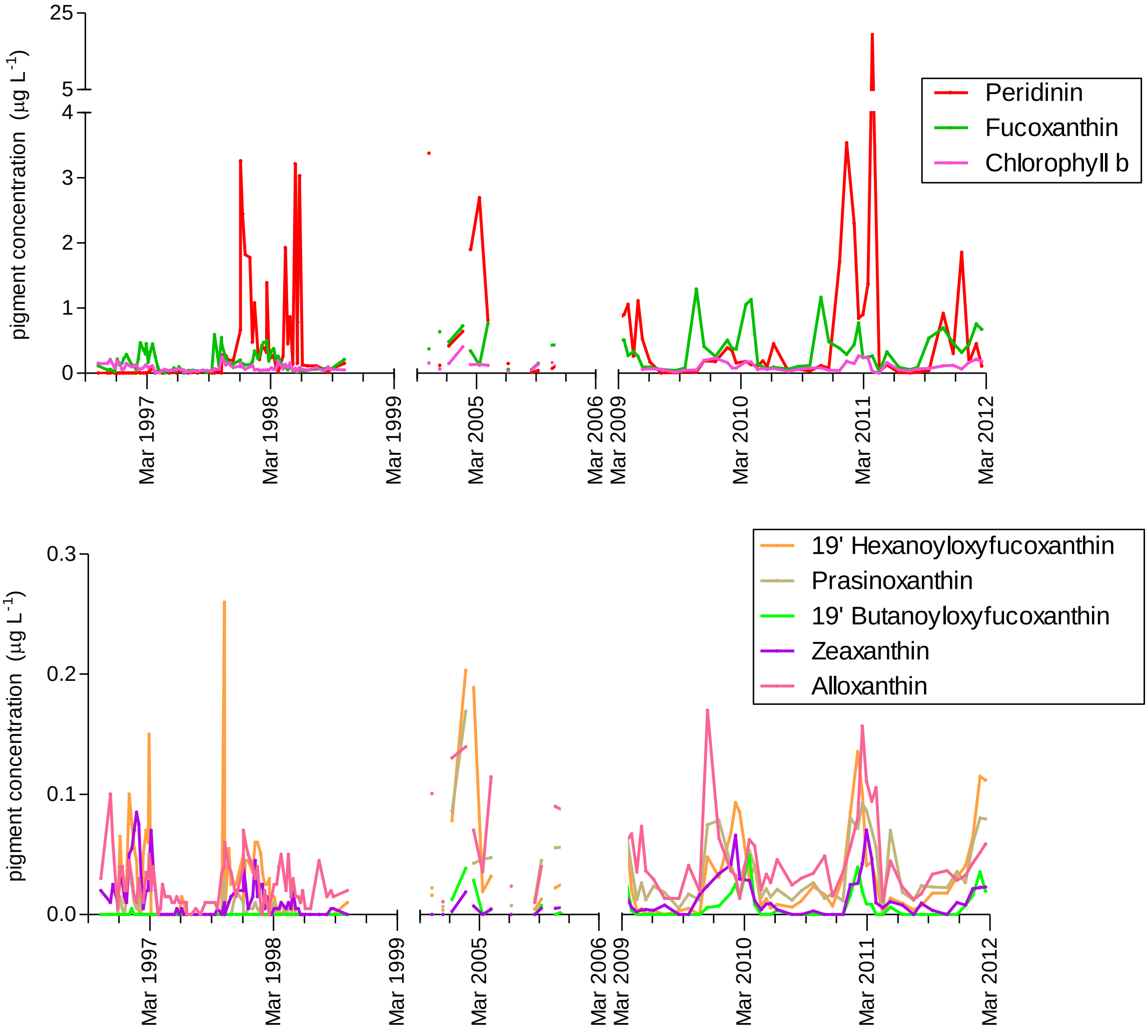


Figure 2.40: Time series plots of the concentrations of the 8 major marker pigments (see Table 2.7) from 0-12 m depth integrated samples (pooled across 2 sites : M10,M14) collected in the Huon Estuary during the HES, Aquafin CRC and BEMP.

A key finding of these simulations and earlier model runs of the system (Wild-Allen et al 2005) model is that nutrients (from any source), and thus impacts are likely to accumulate in the Huon and north D'Entrecasteaux Channel due to the residual regional circulation that generally flows from south to north via the estuarine circulation of the Huon (Figure 2.7). The spatial pattern of ammonium concentrations during the BEMP were broadly consistent with these predictions, with higher concentrations generally recorded at the Huon (M10, 11, 13 & 14) and northern Channel sites (M1-4; see Figure 2.12). Although the pattern is not as clear for chlorophyll *a*, concentrations also appeared higher in the Huon and northern Channel sites (Figure 2.19) consistent with the expected phytoplankton response to higher nutrient concentrations. More evident though was the apparent shift in phytoplankton community composition and bloom dynamics e.g. concentrations of peridinin (= dinoflagellates) tended to be higher in the Huon (M10, 11, 13 and 14) Port Esperance (M12) and north D'Entrecasteaux Channel (M1-4).

2.4 COMPARISON WITH RECOMMENDED WATER COLUMN TRIGGER LEVELS

An important element in the design of the current BEMP monitoring program was the need to provide data that could be compared with the baselines or trigger values proposed by Thompson et al. (2008) as being relevant for the identification of change in ecological function. These recommended baselines and triggers (Thompson et al. 2008; Table 2.9) were based on a review of current knowledge, as well as evaluation of both data collected and the outputs of the high resolution biogeochemical modelling developed as part of the Aquafin CRC studies (Volkman et al. 2009). The trigger values are designed to incorporate 3 levels of management response associated with the relative risk to ecological function represented by increasing temporal or spatial extent of ecological conditions that are increasingly above the baseline, regardless of cause (natural/anthropogenic). It is important to note that there are a range of natural (e.g. changes in the magnitude and seasonality of catchment inputs) and anthropogenic drivers (e.g. point source discharges) that may lead to levels exceeding a trigger and as such, attribution would normally require further investigation. This report provides a review of system performance against the recommended baselines and triggers and does not imply causation. In the following section we discuss the 2009-2012 BEMP water column assessment data in relation to the recommended trigger levels (Thompson et al. 2008).[10]

Nutrients

The concentration of ammonium (NH_4) was selected as an important indicator of environmental condition because it generally indicates a failure of the ecosystem to either assimilate or export the total nitrogen pool.

Bottom waters

The low risk level 1 trigger level (summer mean up 25% or 3 successive annual means >baseline, or mean for any one site + 50%) for the D'Entrecasteaux were not exceeded during the BEMP (Figure 2.41). In contrast, NH_4 concentrations in the Huon Estuary exceeded the level 2 and level 1 trigger in summer 2010 and 2011 respectively. The 3 annual means reached the level 1 trigger values. At the site level summer mean concentrations at M10 (lower Huon) and M13 (upper Huon) increased by 50% in 2011 and 2012 respectively.

Surface waters

In most cases the low risk level 1 trigger level (summer mean up 25% or 3 successive annual means >baseline, or mean for any one site + 50%) was not exceeded in the D'Entrecasteaux

[10] It is important to note that the trigger level calculations in this report are based on MFDP areas i.e. the Huon Estuary and Port Esperance MFDP area and the D'Entrecasteaux Channel MFDP area. In contrast, Thompson et al. (2008) calculations were based on geographic boundaries in which Port Esperance is included as part of the D'Entrecasteaux Channel

Table 2.9. Proposed trigger levels for various parameters with 3 levels of trigger values.

Parameter	Standard or Baseline value[1]		Level 1	Level 2	Level 3
	Huon Estuary	D'Entrecasteaux Channel	(low risk)	(moderate risk)	(high risk)
Sediment biota (infauna)	To be determined TBD	To be determined TBD	Significant change over time since start of assessments at one or more sites + other indicators TBD	Significant change in multivariate community structure at 1 site since last assessment + other indicators TBD	Significant change in multivariate community structure at ⩾ 2 or more locations since last assessment + other indicators TBD
Seagrass and other macrophytes	TBD	TBD	Significant change over time or relative to control site.	As level 1 + TBD	As level 1 +TBD
Sediment chemistry	ANZECC guidelines for metals and TBD	ANZECC guidelines for metals and TBD	Significant change over time at one site.TBD	Significant change at 2 sites in ⩾ 2 indicators. Exceeds ANZECC guidelines for low metal concentrations. TBD	Significant change at ⩾ 3 sites in ⩾ 2 indicators. Exceeds ANZECC guidelines for high metal concentrations. TBD
Nutrients	Summer NH_4^+ surface = 0.32 µM. Bottom = 0.42 µM	Summer NH_4^+ surface = 0.12 µM. Bottom = 0.27 µM	summer mean up 25%, or 3 successive annual means > baseline, or mean for any one site +50%	summer mean up 50%, or 8/10 annual means > baseline for any site, or mean for any single site up 200%	Summer mean +100%, or summer mean > 1 µM (~ ANZECC)
chlorophyll *a*	sites 10 to 14 annual = 1.4 µg/L.Summer = 1.7 µg/L	Sites 1 to 9 summer mean = 0.66 µg/L. Annual mean = 0.80 µg/L	Any site[5]: annual mean +100%; or average summer mean +50%	Any site[5]: annual mean +200%; or average summer mean +100%; or average annual mean +50%	Any site[5]: annual mean +400%; or average summer mean +200%; or average annual mean +100%
Phytoplankton blooms	7% obs. > 3x median chla	3.6% obs. > 3x median chla	% obs. > 3x median rise 50%	% obs. > 3x median rise 100%	% obs. > 3x median rise 200%
Harmful Phytoplankton *G. catenatum*[4]	TSQAP data from 7 areas 1997-2007	TSQAP data from 7 areas 1997-2007	# of days 7 areas are closed to shellfish harvest due to HAB >226 days	# of days 7 areas are closed to shellfish harvest due to HAB >336 days	Not defined
Absolute DO[3]	Channel mean > 6 ppm. Bay mean > 5 ppm	Channel mean > 6 ppm. Bay mean > 5 ppm	Any 2 channel observations ⩽ 6 ppm. Any 2 bay observations ⩽ 5 ppm	50% of channel observations ⩽ 6 ppm. 50% of bay observations ⩽ 5 ppm. Any 2 observations < 2 ppm	Channel mean ⩽ 6 ppm. Bay mean ⩽ 5 ppm. Any 2 measurements < 1 ppm
Relative DO (percent saturation)	Set at 20th percentile from 1st year of observations	Set at 20th percentile from 1st year of observations	[2]Number of observations below baseline increases 50%	[2]Number of observations below baseline increases 100%	Mean falls 10% from baseline (~ ANZECC)

and Huon surface waters during the BEMP (Figure 2.42). The only instance when concentration means reached the level 1 trigger values was in summer 2010 in the D'Entrecasteaux Channel; mean summer concentrations at M6 (Central Mid Channel) and M8 (Great Taylors Bay) were 50% greater than the baseline value and the summer mean for the D'Entrecasteaux Channel was 25% greater than the baseline value.

Chlorophyll *a*

The low risk level 1 trigger level for chlorophyll a (any site: annual mean + 100% or average summer mean + 100%) for the D'Entrecasteaux was reached in 2011 for the annual mean, and the average summer mean over the BEMP period reached level l (low risk) but not level 2 (moderate risk) trigger level. A number of the site means reached level l (low risk) but not level 2 (moderate risk) trigger levels from 2010 to 2011 and 2011 to 2012 summer means. For the Huon estuary the low risk level 1 annual mean value was also exceeded in 2011. Similarly, the average summer mean over the BEMP period reached the level l (low risk) but not level 2 (moderate risk) trigger level. A number of the site means reached level l (low risk) trigger levels in 2011, with the Cygnet site exceeding the level 2 value in 2011. The 2011 trigger in both the Huon and Channel reflect the large bloom that occurred from spring 2010 to winter 2011.

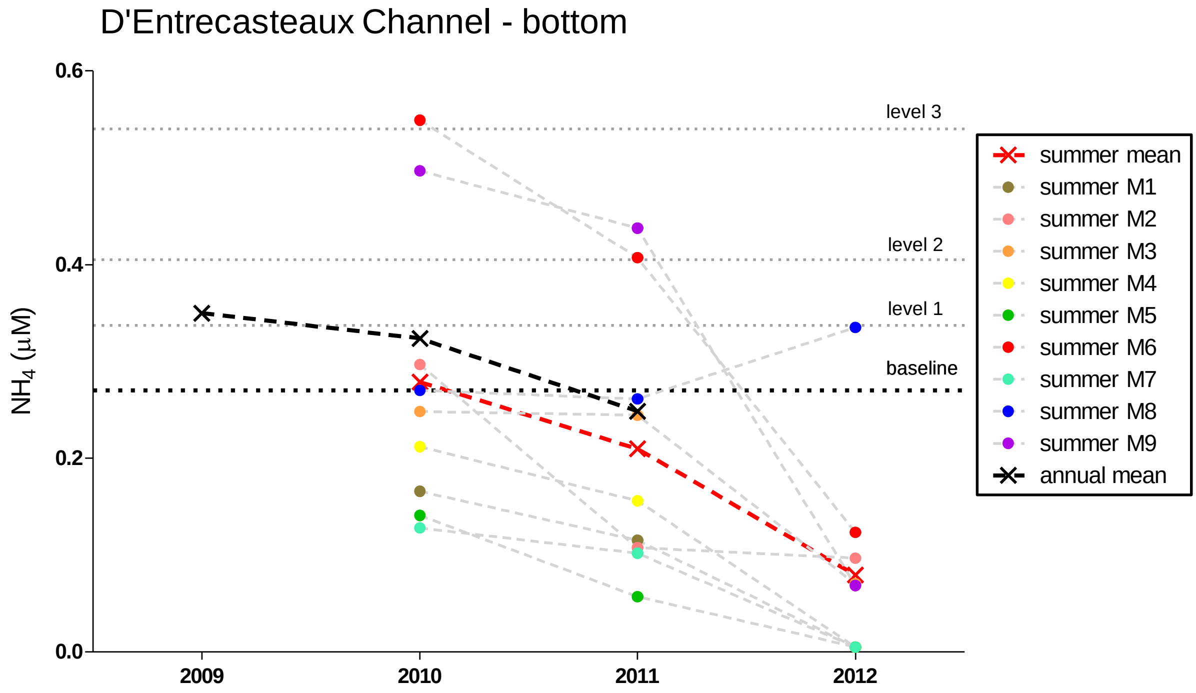
Phytoplankton blooms

Thompson et al. (2008) defined blooms as the number of observations of chlorophyll *a* concentration that exceeded three times the median concentration. The proposed baseline for bloom frequency in the Huon and Channel was set at 7 and 3.6 % of observations exceeding three times the median concentration for each region respectively. The level 1 trigger for each region is reached when the percentage of observation greater than 3 times the median rose by 50% i.e. when 10.5 % and 5.4 % of observations exceeded three times the median concentration for the Huon and Channel respectively. In the first 2 years[11] the frequency of phytoplankton blooms did not reach the low risk level 1 trigger in either MFDP area, however in the 3rd year the level 1 trigger was reached in both regions (Figure 2.43, Table 2.10).

Dissolved oxygen

Thompson et al. (2008) proposed that both absolute and relative values be used as performance measures for dissolved oxygen conditions in the Huon Estuary and D'Entrecasteaux Channel. For absolute measures a mean value of > 6 ppm is proposed for all mid channel locations and a mean value of > 5 ppm is proposed for all bays. For relative measures it was proposed that a baseline be set at the 20th percentile of % saturation measurements from the first year of sampling.

[11] Because the program began in March 2009, the annual statistics for phytoplankton bloom frequency and dissolved oxygen were based on rolling 12 month periods starting in March 2009.



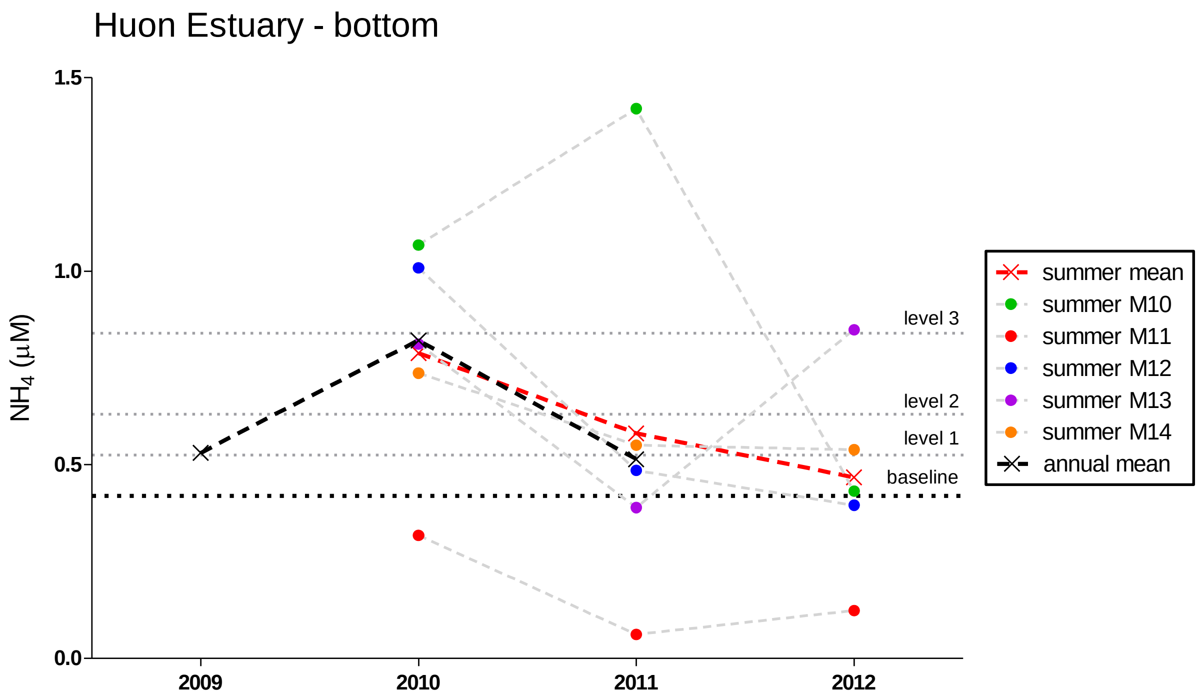
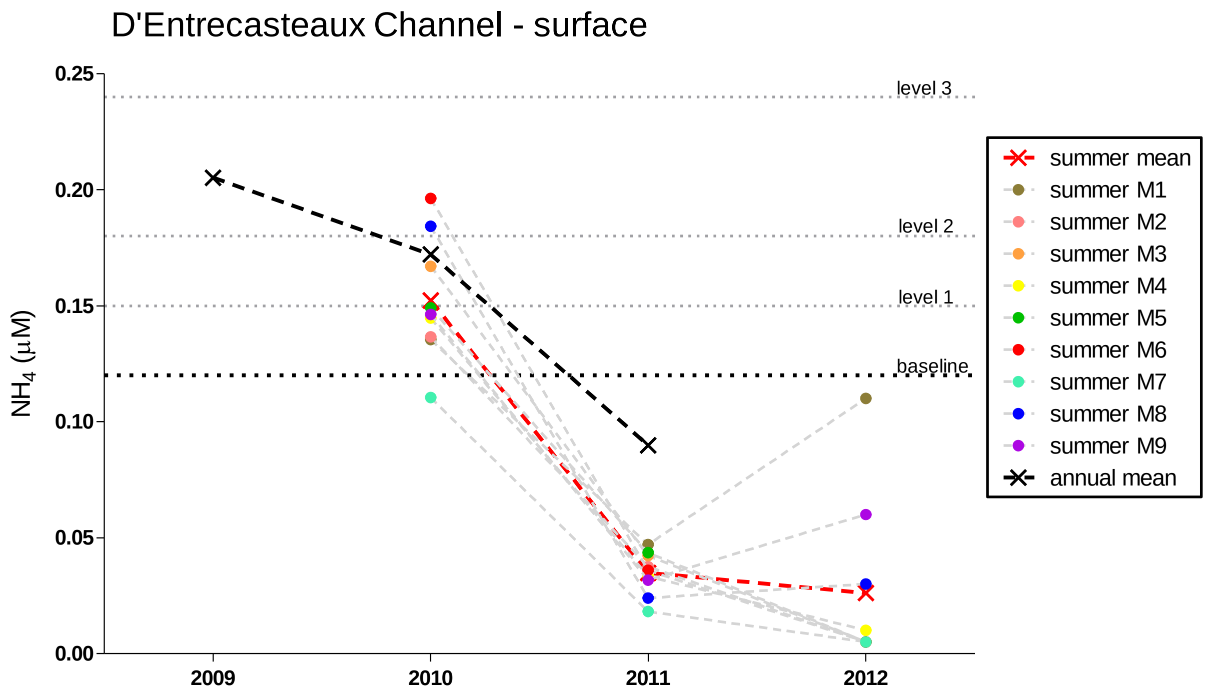


Figure 2.41: Bottom water summer and annual average ammonium concentrations measured during the BEMP program against the proposed baseline and 3 trigger levels

(dashed horizontal lines) in the D'Entrecasteaux Channel (top panel) and Huon Estuary (bottom panel). Individual site averages are provided for summer.



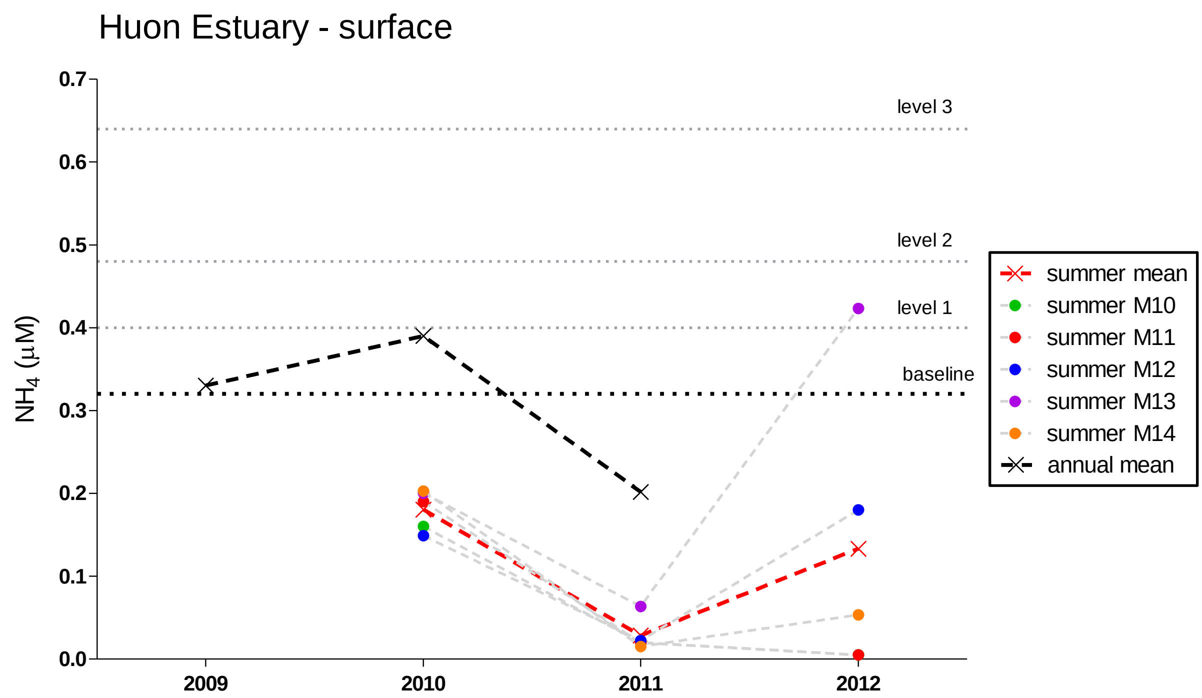
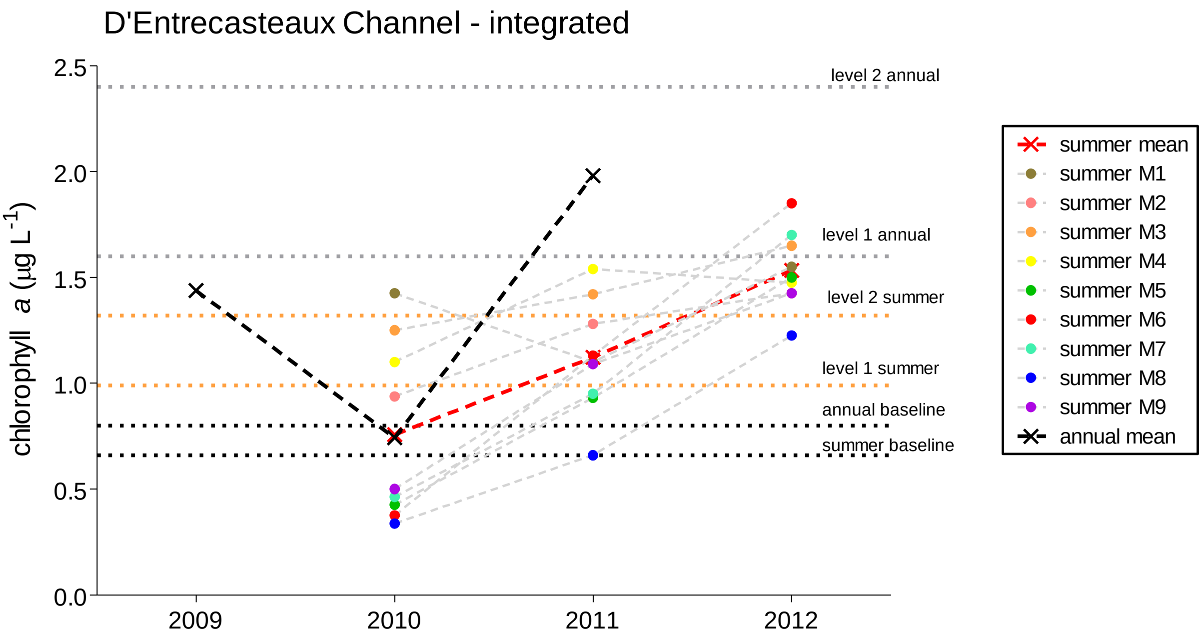


Figure 2.42 Surface water summer and annual average ammonium concentrations measured during the BEMP program against the proposed baseline and 3 trigger levels (dashed horizontal lines) in the D'Entrecasteaux Channel (top panel) and Huon Estuary (bottom panel). Individual site averages are provided for summer.



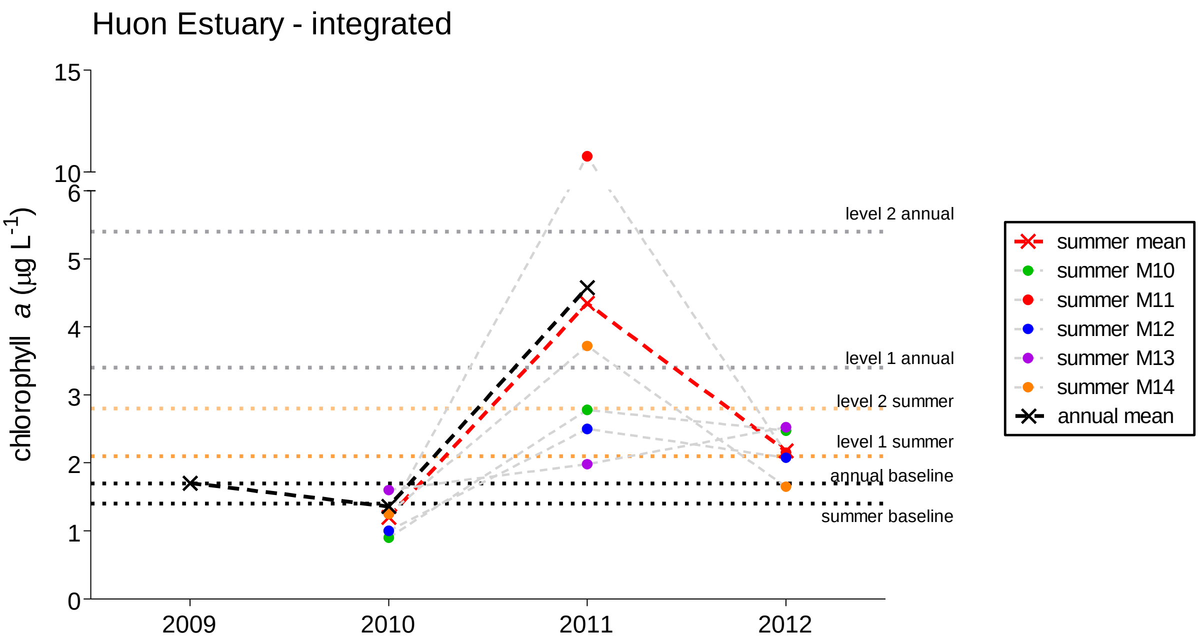


Figure 2.43: Summer and annual average chlorophyll *a* concentrations measured during the BEMP program against the proposed baseline and 3 trigger levels (dashed horizontal lines) in the D'Entrecasteaux Channel (top) and Huon Estuary (bottom). Individual site averages are provided for summer

Table 2.10 Calculation of summary statistics and bloom frequency from integrated chlorophyll-*a* samples collected during the BEMP period, March 2009 - 2012 in the Huon and Channel MFDP areas.

	Channel	**Huon**
Median chlorophyll-a (ug l^{-1})	1	1.4
3 x median (ug l^{-1})	3	4.2
total no. observations per year	135	75
1st year (% > 3xmedian)	3.7%	4.0%
2nd year (% > 3xmedian)	0.7%	9.3%
3rd year (% > 3xmedian)	8.1%	10.7%

There were very few instances of observations of absolute dissolved oxygen below the D'Entrecasteaux Channel baseline and no observations below the bay baseline (Figure 2.44, Table 2.11). In the Huon there were a few observations below the bay baseline each year whereas there were markedly more observations below the baseline for channel sites in the Huon. However, the number of observations below the baseline for channel sites in the Huon reached the level l (low risk) but not level 2 (moderate risk) trigger level in each year. In the first full year of sampling during the BEMP (March 2009 –2012) the 20th percentiles were 82.5 and 85.6 % saturation for D'Entrecasteaux Channel and bay sites respectively. In the Huon the 20th percentiles were 70.9 and 70.7 % saturation for channel and bay sites respectively (Figure 2.45, Table 2.12). There were 11 and 15 observations below the baseline for bay and channel sites respectively in the D'Entrecasteaux Channel and 6 and 8 observations below the baseline for bay and channel sites respectively in the Huon. The level 1 (low risk) trigger (number of observations below baseline increases 50%) was not reached during the BEMP in the channel or bay sites in either the D'Entrecasteaux Channel or Huon.

Table 2.11 Total number of observations and number of observations below the proposed baseline values of absolute concentrations of dissolved oxygen (mg l^{-1}) in the first 3 years

	Channel		Huon	
	Bay	Channel	Bay	Channel
	≤ 5 mg l^{-1}	≤ 6 mg l^{-1}	≤ 5 mg l^{-1}	≤ 6 mg l^{-1}
total no. observations per year	56	70	30	44
1st year no. observations ≤	0	3	2	12
2nd year no. observations ≤	0	1	3	16
3rd year no. observations ≤	0	1	3	9

Table 2.12 20th percentile of dissolved oxygen (% saturation) from 1st year of observations and number of observations below the proposed baseline in each year

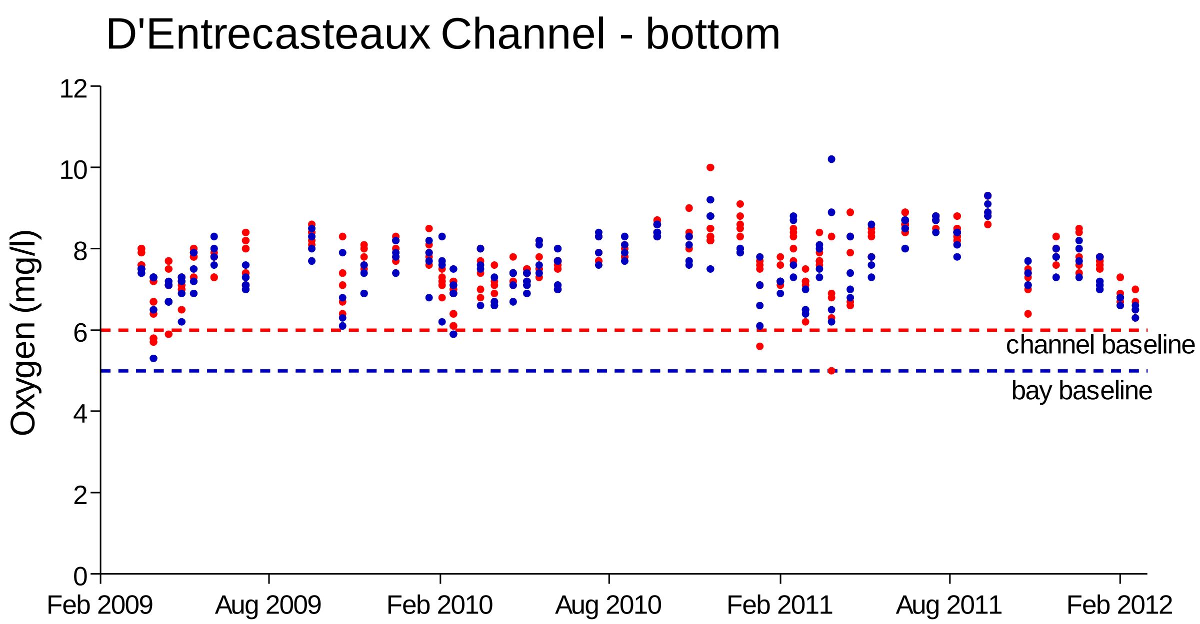
	Channel		Huon	
	Bay	Channel	Bay	Channel
1st year 20th percentile	82.5	85.6	70.9	70.7
1st year no. observations	60	60	30	45
1st year no. less than 20th percentile	11	15	6	8
2nd year no. less than 20th percentile	3	3	7	9
3rd year no. less than 20th percentile	1	7	7	`5

2.4.1 Synthesis of trigger level assessment

As Thompson et al. (2008) noted there are many different options for setting trigger levels, including those prescribed in the ANZECC (2000) guidelines. The approach proposed by Thompson et al. (2008) offers many advantages over the ANZECC approach. Most notably, it considers the high seasonal and spatial variability that occurs in Tasmania, and rather than require action based upon a single high value, the proposed trigger values are based upon multiple measurements spanning the region (e.g. MFDP area) and time scale (e.g. season) of interest. This provides a more statistically robust method for detecting whether a real change has occurred.

The comparison of BEMP data against the proposed baselines and trigger levels of Thompson et al. (2008) found there were very few instances of the system reaching level 2 trigger (moderate risk) for the key water quality parameters. However, there were a number of instances when level 1 (low risk) trigger values were reached, particularly for bottom water ammonium and dissolved oxygen conditions and phytoplankton biomass and bloom frequency. These occurrences were in general more common in the Huon compared to the D'Entrecasteaux MFDP area.

The development of proposed baseline and trigger values for the region provided by Thompson et al. (2008) is comprehensive, however moving forward it will be important to clarify the degree of pooling of data (or lack of) across spatial and temporal scales used to develop the baselines and trigger values to ensure comparable calculations and statistics are used when assessing performance. There also appears to be some modifications that could be made. For example, Thompson et al. (2008) recommended that the sampling regime and subsequent trigger level statistics for dissolved oxygen should be stratified by bays and channel sites given that bays may have characteristically lower dissolved oxygen levels. However, there appeared to be very little difference between bay and channel sites from the BEMP data set, and thus, it seems reasonable to remove the bay and channel stratification for each MFDP area.



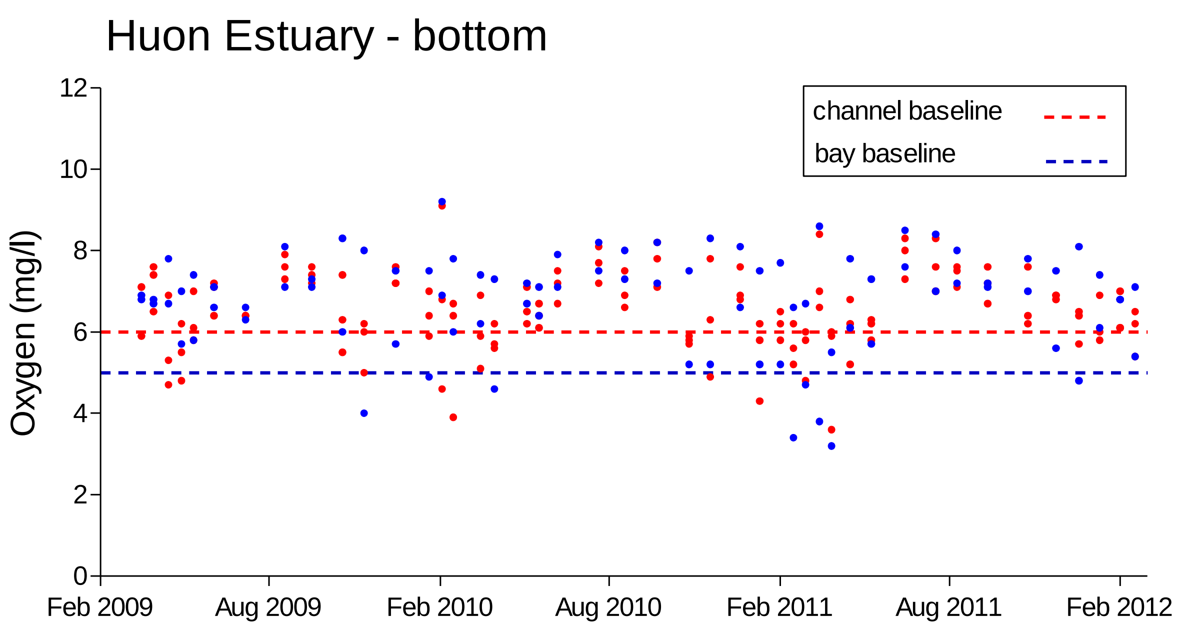


Figure 2.44 Bottom water dissolved oxygen concentrations (mg/L) measured during the BEMP program against the proposed baselines for bay and channel sites (dashed horizontal lines) in the D'Entrecasteaux Channel (top panel) and Huon Estuary (bottom panel).

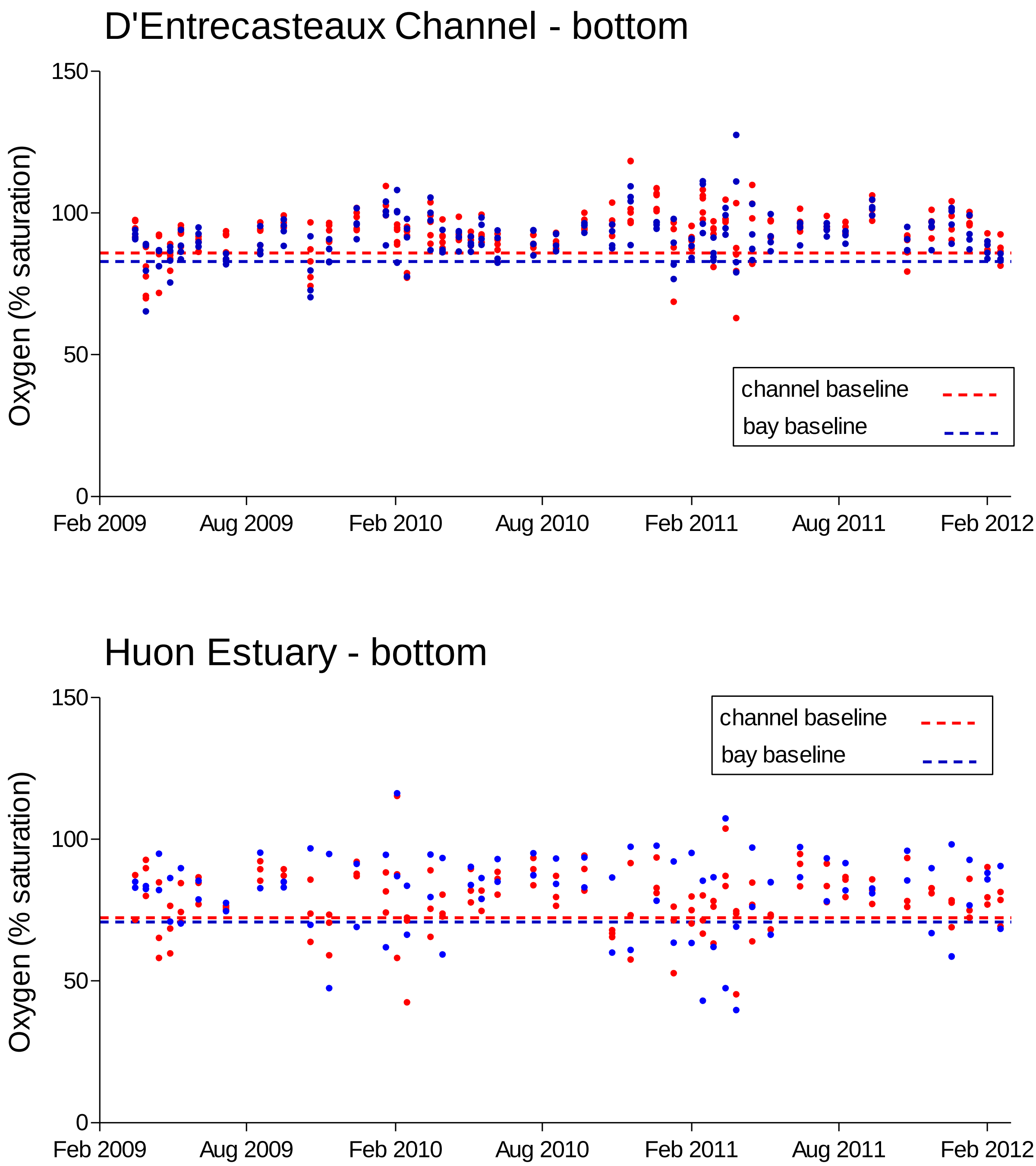


Figure 2.45 Bottom water dissolved oxygen (precent saturation) measured during the BEMP program against the proposed baselines for bay and channel sites (dashed horizontal lines) in the D'Entrecasteaux Channel (top panel) and Huon Estuary (bottom panel).

Chapter 3 Sediment Assessments

The general sampling requirements are outlined in the Broadscale monitoring requirements provided by DPIPWE (Appendix 1), with detailed accounts of the methods for each sampling event outlined in the commercial in confidence annual reports provided to industry by Aquenal. We have summarised these methods and the specific data collected in each survey below, along with an explanation of any changes in analytical approach.

3.1 SEDIMENT CHEMISTRY

Analysis of sediment cores collected in March 2009, 2010, 2011 and 2012 included: a visual assessment; measurement of redox potential and sulphide concentration; stable isotope analysis (2009 only); evaluation of organic content via loss on ignition (LOI), and determination of particle size. Triplicate sediment cores were collected, using a Perspex corer with a 50 mm diameter, at each sample site.

Redox potential was measured in each core on return to the laboratory at the end of each field day. Redox potentials were measured, at a depth of 3 cm from the top of the cores, using a WTW pH 320/set-1 meter with Mettler Toledo P14805-DXK-S8/225 combination redox probe. The probe was calibrated prior to analysis using the method described in Macleod *et al.* 2004. The probe was allowed to stabilise before taking measurements and was re-calibrated between each measurement.

A visual assessment of each core was conducted at the Aquenal laboratory and sub-samples extracted for determining sulphide concentration, particle size analysis and loss on ignition / stable isotope analysis as appropriate. The visual assessment included measuring the length of the core, noting the sediment colour using a Munsell soil chart, noting animal and plant life and checking for gas vesicles and smell (indicating presence/absence of hydrogen sulphide).

The sulphide probe was conditioned and calibrated according to Macleod *et al.* 2004 before analysis of sediment from the cores. A sediment sub-sample of 2 mL was extracted from a port in the side of each core tube using a 5 mL syringe, and placed in a glass vial, 2 ml SAOB was added to each jar (refer to Macleod *et al.* 2004) and sulphide concentration measured (mV) by placing the probe into the jar, and slowly stirring the sediment / buffer mix until the reading stabilised. The mV readings were converted to sulphide concentration using the calibration curve prepared prior to the analysis being undertaken.

For particle size analysis the top 100 mm of each core (less the 12 ml sample taken for stable isotope analysis) was homogenised and placed in a 70 mL jar (filled to the top). Each sample was wet sieved through a sieve stack comprising 4, 2, 1 mm, 500 µm, 250 µm, 125 µm and 63 µm sieves. The material retained on each sieve was carefully removed and placed in a graduated cylinder to which a known volume of water was added; the volume of sediment from this fraction was calculated from the displaced water volume.

Although samples were collected for stable isotope assessment in each year, analysis was undertaken in 2009 only with samples from 2010 and 2011 being archived. Sub samples of sediment from 2010 and 2011 cores (12 ml) were dried and frozen for long term storage according to Environmental Isotopes Pty Ltd protocols for isotope analysis.

As with stable isotope analysis, assessment of total organic carbon (TOC) content was only required in 2009. Measurements were obtained using the LOI approach outlined in the BPS (Appendix 1). However, analysis was also undertaken in 2011 by Analytical Services Tasmania and the results are provided here for comparison.

Infaunal samples were collected by triplicate Van Veen grabs at each site in March 2009 2010 and 2011. The full infaunal assessment was undertaken only in 2009 samples with the intention that other samples be archived and processed only if the 2009 or previous years sample data analysis indicated it was warranted.

The BPS (Appendix 1) requires that samples be assessed to family level and counted, with some defined exceptions i.e. the Family Capitellidae, Family Turitellidae and all introduced marine species. Although the data were reported at family level according to the BEMP schedule requirements, it was available at species level. Species level assessment may allow the identification of subtler changes in community ecology and function. Given that the previous datasets collected from this region have for the most part also been gathered at species level, and that we wanted to be able to identify the lowest level impact possible, we felt it would be more valuable to analyse the data at this level. Aquenal agreed to provide access to the species level data for this assessment, and we are very grateful for this as it has enabled us to provide a more detailed interpretation of the ecological status and change.

Grab samples were washed through an aluminium funnel into polypropylene bags with a mesh size of 0.8 mm. The bagged samples were labelled and placed into a 20 L drum of 10% buffered formalin for a minimum of three days to ensure full fixation of the biological material. In the laboratory, the samples were washed through a 1 mm sieve and the retained material sorted under a dissecting microscope to separate out the animals.

All specimens were placed in labelled vials and preserved in 70% alcohol for longer term storage. Storage jars were labelled according to the BPS provided by DPIPWE.

3.1.1 Results and Discussion

The data have been presented in this section according to both Marine Farming Development Plan regions and according to groupings that more broadly represent the ecological changes / categorisation in the system. The latter categorisation sees both the Huon and Port Esperance and upper and lower Channel sites separated.

Visual assessment

The Aquenal 2009-2011 Annual Report (Aquenal 2012) indicates that sediments were on the whole fine to very fine, which suggests depositional environments in most areas (Eleftheriou and McIntyre, 2005). However, in the upper channel there was a greater proportion of shell grit and coarser sediments potentially signifying a more dynamic current regime. Aquenal's interpretation of the results suggests that there has been no significant change in sediment colour over the monitoring period, with very little evidence of sediment anoxia / sulphide accumulation (black streaking). Visual evidence can be a good indicator of the presence of sulphide in sediments (Gibson et al. 2011, Birchenough et al. 2012). Visual evaluation forms the basis of the sediment profile imaging (SPI) approach (Rhoads and Germano, 1982, Solan et al. 2003), which is commonly used to determine sediment condition in monitoring programs associated with oil exploration/ drilling (Diaz and Trefry, 2006) and aquaculture operations (Wildish et al. 2003, Labrune et al. 2012) overseas.

The fishy odour noted in individual cores is likely to be transient anoxia or localised sediment degradation, since it was only evident intermittently and in individual replicates. The smell was also generally associated with very fine sediments where oxygen penetration may be more limited, thus contributing to localised areas of anoxia. The fact that all cores showed evidence of faunal colonisation and active bioturbation, and there was no concurrent sediment sulphide traces, would suggest that the anoxia associated with this fishy odour is most likely episodic change and that there have been no major change in the benthic sediment biogeochemistry.

Redox Potential

Redox potential was positive at all sites throughout the three years of sampling, with redox levels consistently above 100mV (Figure 3.1). As identified in the Aquenal report (2012) the between site differences in redox appear to reflect the underlying environmental differences in the sites and their respective sedimentary conditions (geochemistry) and position in the estuary systems. The upper channel sites in the coarser/ sandier areas generally having higher redox levels than those from siltier regions such as the Huon.

The redox results do not appear to have changed markedly over time and do not suggest any specific farming related or broadscale deterioration in sediment condition.

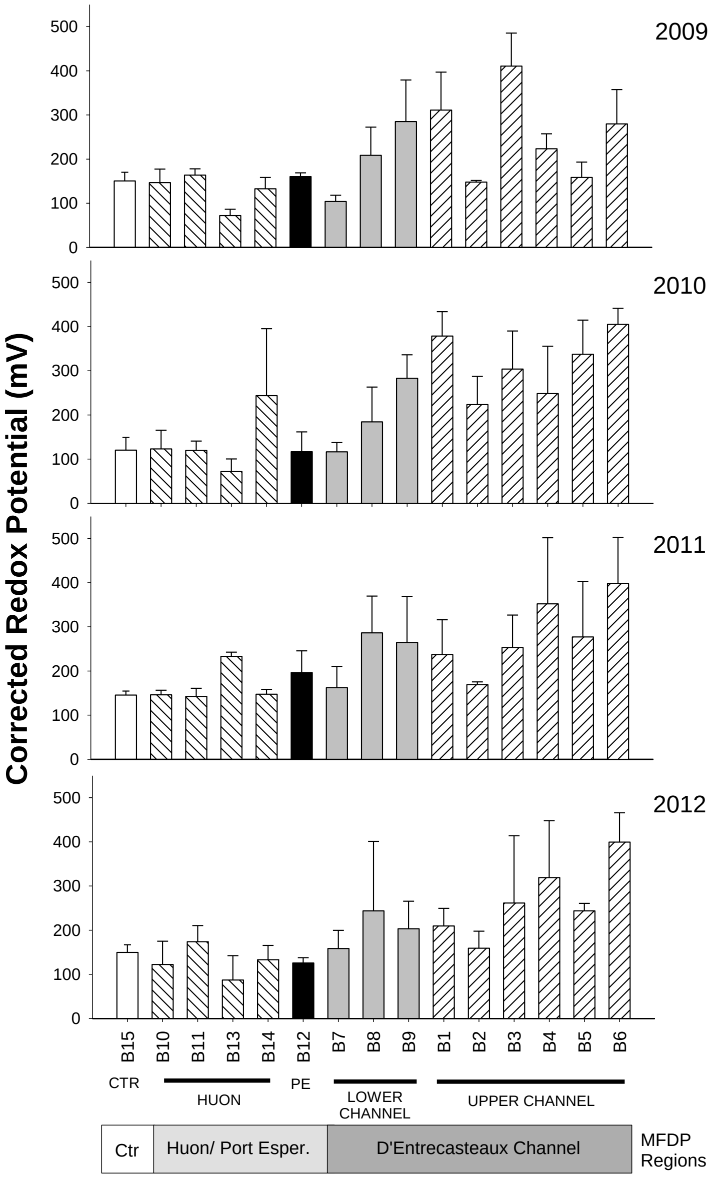


Figure 3.1: Average corrected redox potential (+/- standard deviation) at each site in each year.

Sulphide Concentration

Sulphide concentrations were very low at most sites and sampling times, with the singular exception of site B1 (northern boundary site) in 2012, where one replicate had a much higher than expected sulphide concentration (Figure 3.2). Given that the other replicate samples at this time were markedly lower it is likely that this result reflects an anomalous sampling event, and may simply be the result of a localised patch of organic material breaking down (e.g. sampling over a patch of driftweed). As noted in the Aquenal report (2012), with the single exception of site B1, the sulphide concentration in all samples was well below the value of 50 µM suggested as indicative of moderate impact under active farming conditions (Macleod & Forbes, 2004) and well within the sulphide range described as normal (0-300um) for soft sediments by Wildish et al. (2001).

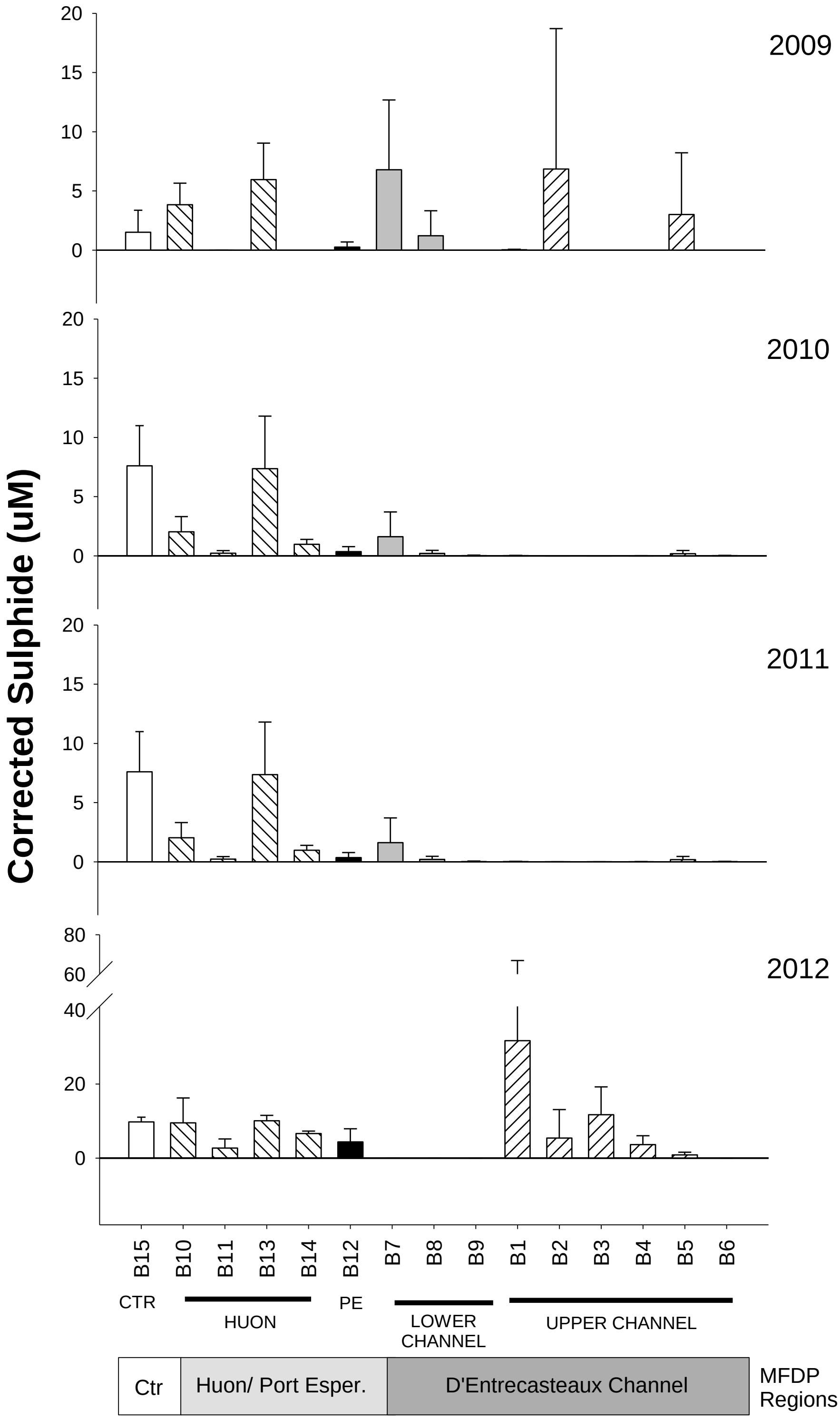


Figure 3.2: Average corrected sulphide concentration (uM) (+/- standard deviation) at each site in each year.

Organic content (TOC)

TOC was measured in 2009 and 2011, although it is important to note that it was not a formal reporting requirement in 2011. The levels are substantially different between years

(Figure 3.3). However, this does not necessarily signify a temporal change as the analytical approaches used in each year differed. Unfortunately, as pointed out by Aquenal (2012), TOC measurements are highly susceptible to differences in laboratory practices; in 2009 the samples were analysed by Aquenal using a “loss on ignition” approach and in 2011 by AST using “total organic carbon” analysis. The loss on ignition approach can result in over-estimation or inconsistencies in evaluation of the carbon content where the acidification process is insufficient or where ignition temperatures differ (Heiri et al. 2001). Consequently the observed inter annual variability may simply be a sampling artefact.

Within each year the control site showed the lowest total organic carbon (TOC) content. The Huon sites had high TOC levels (approx. 20%) in both 2009 and 2011, and the levels were broadly consistent throughout all sites. Port Esperance was similar to the Huon results. The channel was more variable, although TOC levels in many of the channel sites were amongst the lowest observed.

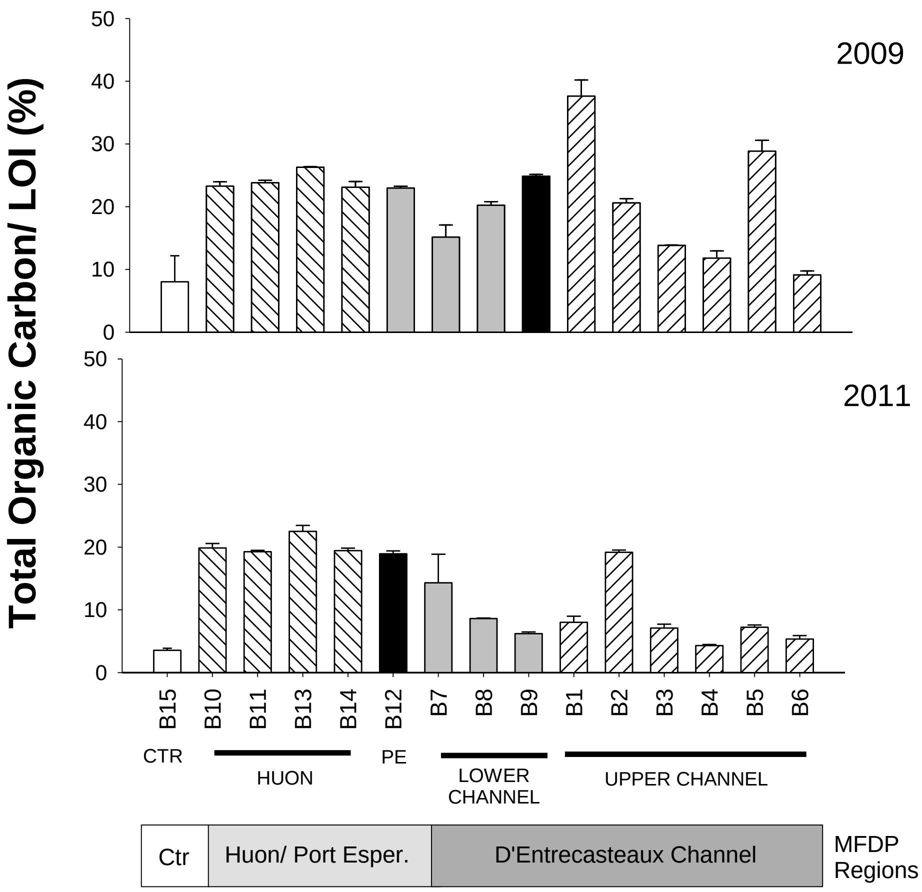


Figure 3.3: Average organic carbon content (+/- standard deviation) in 2009 and 2011.

Generally % organic matter has been shown to have a strong relationship with particle size, and in particular with % silt-clay (Snelgrove and Butman, 1994, Eleftheriou and McIntyre, 2005). However, this was not the case with the 2009 data where the overall correlation was poor (R^2 = 0.32). The Huon samples were more strongly related to sediment particle size (R^2

= 0.81), which is not surprising as previous studies have shown these sites to be depositional and to have a high degree of organic matter as a result of the inputs from the Huon River (Butler et al. 2000, Volkman et al. 2009). Interestingly the overall correlation between particle size (% silt-clay) and % organic matter in 2011 was more consistent (R^2 = 0.93). In this case the relationship between silt-clay and TOC was more uniform in the Channel with 0.94 in the Lower Channel and 0.95 in the Upper Channel, and it was the Huon system that was less reliable (R^2 = -0.59).

The levels reported in the current assessments are consistent with those previously reported from the Huon and Channel systems (Butler et al. 2000, Volkman et al. 2009). It is possible to get significant interannual variation in sediment TOC, particularly in systems subject to seasonal flooding and or increased riverine inputs (Butler et al. 2000, Volkman et al. 2009). However, as noted above, the analysis in each year was conducted within two different laboratories consequently it is not possible to be sure to what extent this may have influenced the results and therefore they can only be reliably used to assess spatial variability within year classes.

Stable isotopes

Stable isotope analysis was only undertaken in 2009.

The C/N ratio was highest in the Huon samples, with a gradual decline from the upper Huon sites (B13), mid-Huon (B14), Cygnet (B11) to the lower Huon (B10) (Figure 3.4). Levels were very consistent in all other samples, with a ratio of approximately 11.0, which is comparable with the findings of previous studies in the region (Butler et al. 2000, Thomson 2008, Volkman et al. 2009).

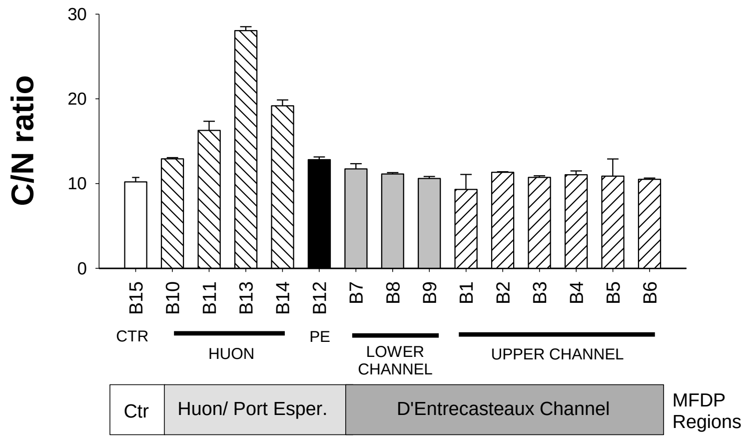


Figure 3.4: C/N ratio (+/- standard deviation) at each site in 2009.

The Huon Estuary study suggested that a 13C value of -28.5 % and a 15N value of 1.5 % was indicative of material derived from terrestrial sources whilst a 13C value of -22 % and a 15N value of 7.5% indicated a marine origin (Butler et al, 2000). Applying this model in the current study suggests that the Huon sites have more C and N of terrestrial origin than the sites in the Channel, with sites B13 and B14 in the upper Huon having particularly high 13C values (Figure 3.5). The bulk of the samples collected from the Channel fall in the marine domain with relatively subtle gradation between samples, probably reflecting small scale changes in the depositional environment and distance from the Huon. The results for the control and Port Esperance sites sit between that of the Huon and the Channel. The overall signal for each site is consistent with that previously reported for sites in the area, i.e. in the Huon study (Butler et al, 2000) and in the Aquafin CRC study (Thomson et al. 2004, 2008). The results indicate no specific impact as a result of fish farming in the region.

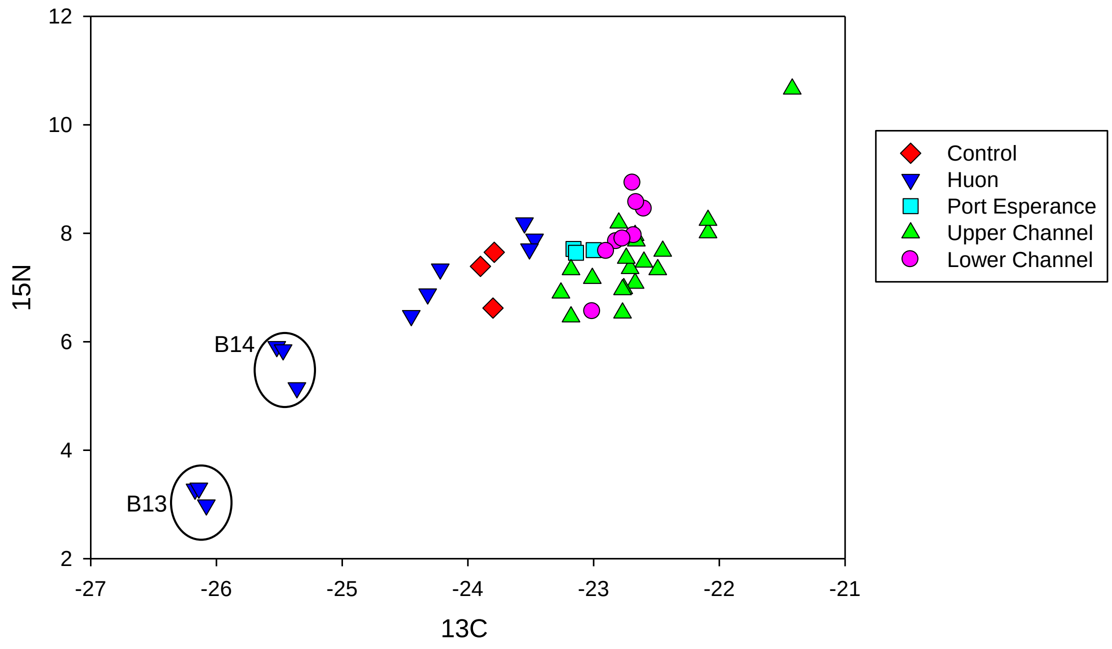


Figure 3.5: Δ13C versus Δ15N values for samples collected in 2009.

Particle size

The sediment composition has remained broadly consistent over time for all sites, with overall sediment classifications as outlined in the Aquenal report 2012 remaining similar throughout the study. The inter-annual changes that were observed are small and consistent with the levels of natural variability observed at the control site. Such changes are unlikely to have any major effects on the local ecology or overall biodiversity. However, in 2011 several sites appeared to show an increase in the proportion of fine sediments (Figure 3.6, 3.7), in particular the Huon sites (B10, 11, 13 and 14), site B7 in the Channel just out from the mouth of the Huon, site B12 at Port Esperance and site B2 in NW Bay. This change was not continued in 2012, and the sediment structure appears to have returned to one more consistent with that of previous years. This may be an anomaly of the data collection (i.e. a result of the relatively small number of samples collected at each time and the potential for spatial patchiness within the system). However, these sites had been relatively consistent in their sediment composition over the previous two years, and from the nutrient input and flow data it is apparent that these sites are all in areas which may have been subject to increased riverine inputs in 2011. Consequently the observed sediment changes are likely to be a direct result of increased sediment transport associated with higher rainfall and river flows in 2011 (See Chapter 2). These changes appear to have been largely absorbed by the system with sediments returning in 2012 to a proportional grain size composition more similar to that observed in previous years. This suggests there is a degree of resilience within the system in so much that such inter-annual anomalies can be accommodated.

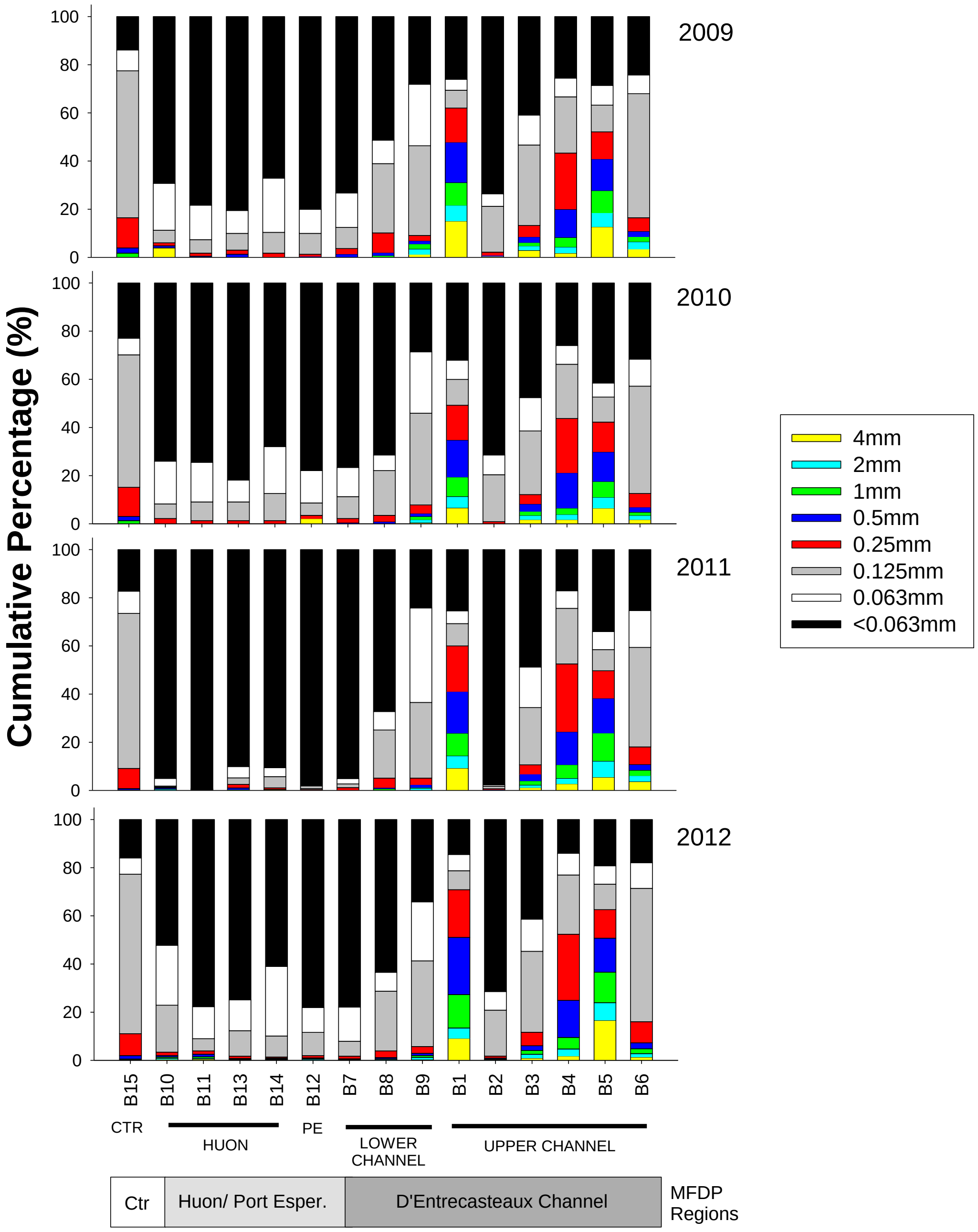


Figure 3.6: Mean Cumulative Particle Size for each year of sampling

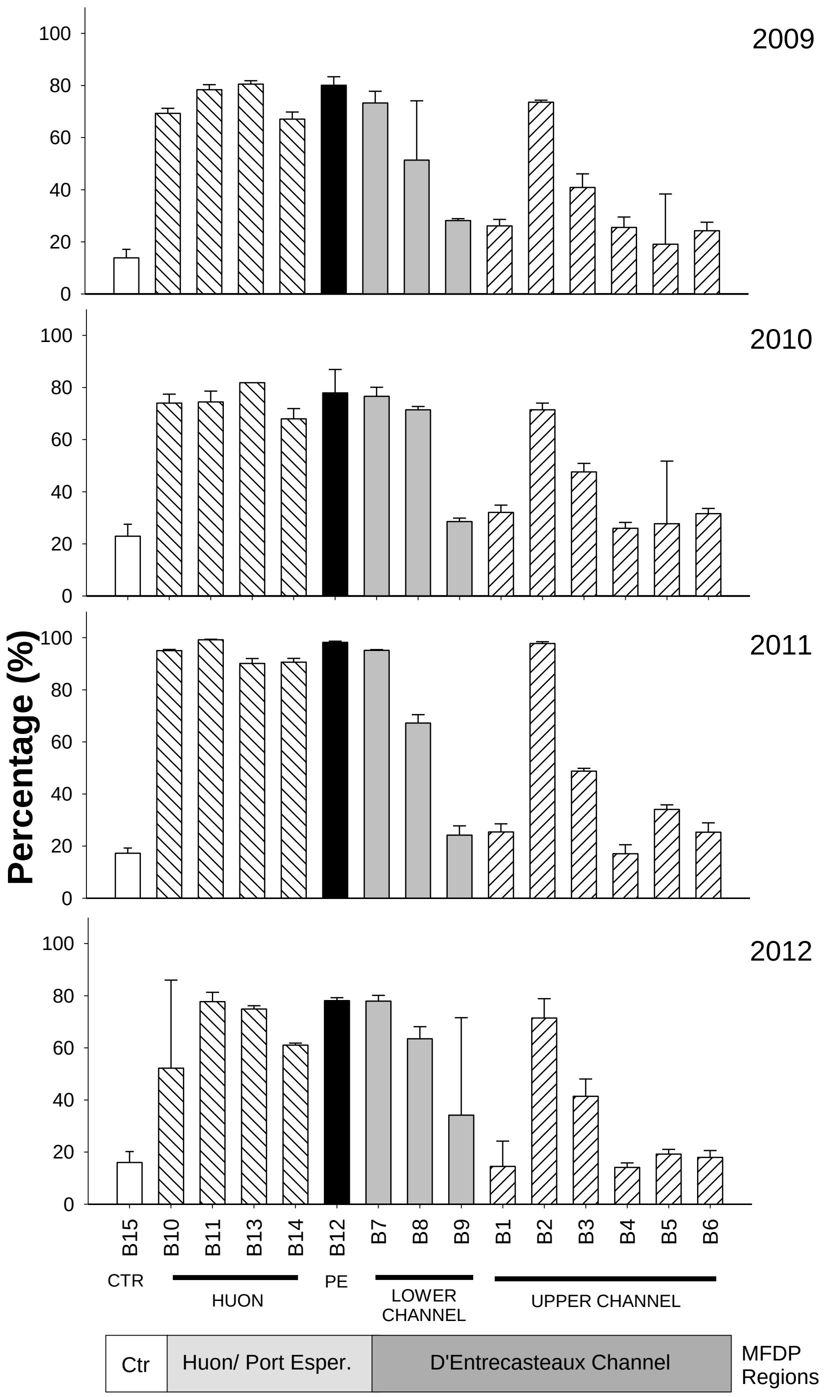


Figure 3.7: Average percentage silt-clay (+/- standard deviation) at each site in each year

3.1.2 Summary of sediment results

The combined results of the sediment biogeochemical evaluations do not present any obvious cause for concern. None of the assessments indicate any significant inter-annual change in the sediment chemistry, nor is there any indication of any declining trend at this point in the conditions at any site or region.

3.2 BENTHIC INFAUNA

3.2.1 BEMP Assessment

Number of species and abundance was significantly lower in the Huon than in the Upper Channel or Port Esperance (Figure 3.8). However, this was not markedly different from the control conditions and is consistent with the numbers reported at un-impacted sites in previous studies within the same localities (e.g. Macleod and Helidoniotis, 2005, Edgar et al. 2005, Macleod et al.2008a) and in other cool temperate regions where salmonid farming occurs (e.g. Hansen et al. 2001, Schanning and Hansen, 2005, Hargrave et al. 2008, Keeley et al. 2012). Abundance was moderate to low with the Upper Channel sites having the greatest numbers of individuals. The Shannon diversity index was relatively high at all sites; no sites fell below 1.0, the level identified in previous studies as being indicative of organic enrichment (Macleod et al. 2007), and in fact H' values were generally above 2.0.

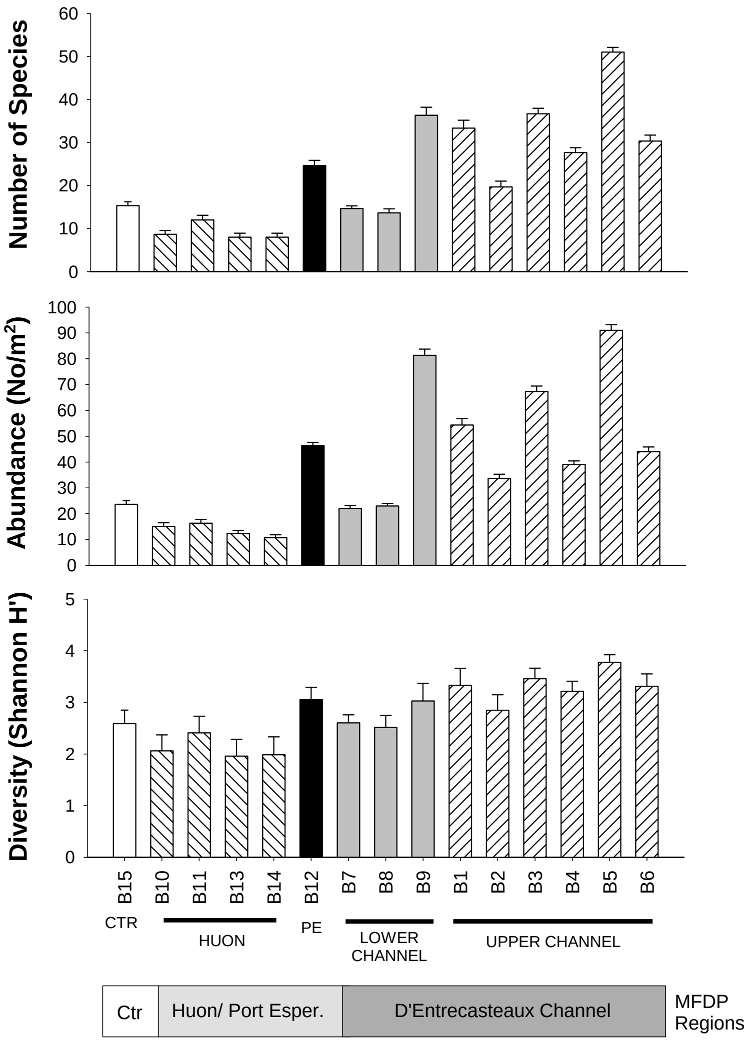


Figure 3.8: Average number of species, abundance and diversity (Shannon index) at each site in 2009

The k-dominance curves suggest that overall the species distributions in the Channel and Huon were very similar and do not indicate any particular species dominance (Figure 3.9). There was a lot of similarity in the curve profiles for the Upper Channel sites, and those from Port Esperance and sites B7 and B8 in the lower Channel. Only 2 sites differed markedly from this typical profile; site B9 (Lower Channel boundary), and site B13 in the upper Huon. The community structure underpinning these differences is discussed in detail in the multivariate analysis section. Site B15 (the Control site in Recherche Bay) showed a broadly similar profile but had the highest observed initial dominance.

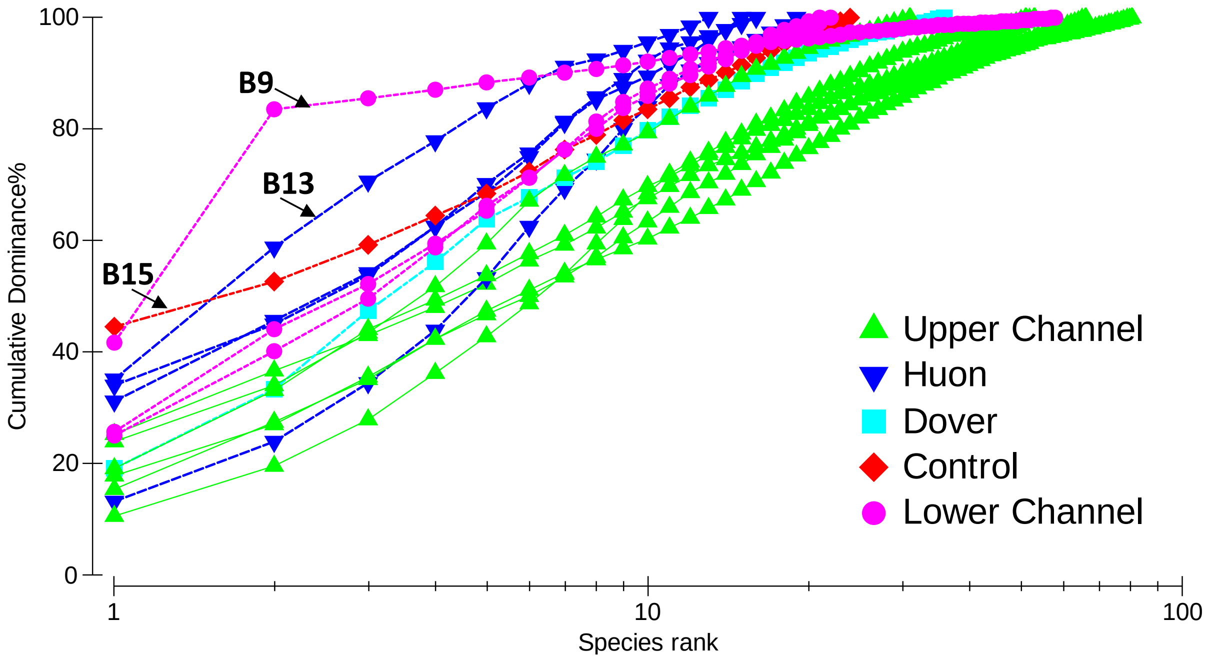


Figure 3.9: K-dominance curves for all sites (replicates averaged)

There are species which are considered indicative of organic enrichment and can be used as "biomonitors". These opportunistic species tend to be highly tolerant of hypoxic conditions and proliferate under organically enriched conditions. One such example, commonly used as an indicator of fish farm impacts, is the polychaete *Capitella capitata* (Macleod et al. 2004b, Hargrave, 2010). This species has long been shown to be indicative of moderately to highly enriched conditions (Pearson and Rosenberg, 1978). Such responses have been documented in association with marine farming operations in the Huon estuary, Port Esperance and the D'Entrecasteaux Channel, but have generally been constrained to the areas immediately adjacent to the cages (Macleod et al. 2004b, Edgar et al. 2005, 2010). There were no *Capitella capitata* identified in the BEMP samples, in fact there was no evidence of any opportunistic species that might indicate organic enrichment or eutrophication.

The distribution of the individual samples as a result of multivariate analysis shows both the high similarity between the individual replicates and the considerable overlap in the samples from sites in the Channel region (Figure 3.10). Aquenal (2012), grouped these sites in accordance with the cluster analysis outputs from the analysis of all replicates, identifying

4 key groups:
Group 1 (at only 9% overall similarity) – Site B15, the control location
Group 2 (at 12% similarity) – Sites B9, at the southern boundary of the D'Entrecasteaux Channel
Group 3 (at approximately 16% similarity) – Sites B1 and B5, in the upper Channel
Group 4 - contained the remaining sites, which drop out sequentially at similarities above 22 %.

It is quite clear that there are strong similarities between the replicates. Consequently, for ease of interpretation we have used the average site values for interpretation of the overall community patterns. The main grouping (Group 4) contains a combination of Huon and Channel sites; in order to evaluate the relevance of the differences at these locations, as suggested by the sediment biogeochemistry, the sites are shown in subsequent analyses classified by region.

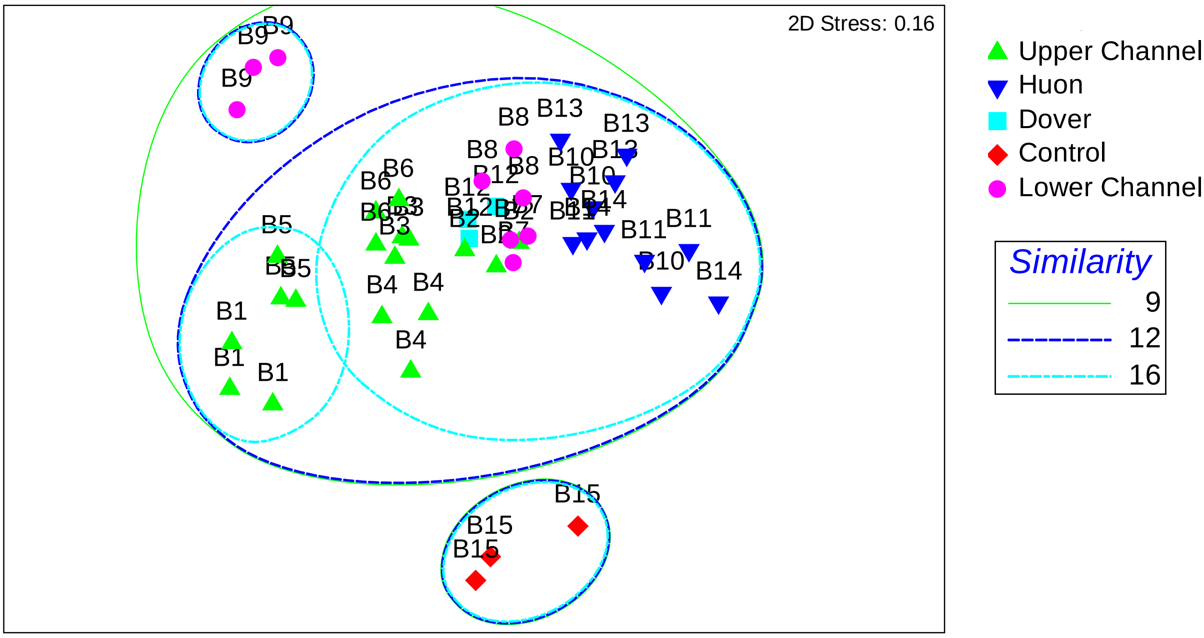


Figure 3.10: Multidimensional scaling ordination, calculated using Bray-Curtis similarities based on full species complement, showing the relationship between individual replicates collected as part of the BEMP study 2009 and the similarity levels at which the first three cluster analysis groupings occur.

Cluster analysis shows that the sites separated fully at a similarity level of 69%, which suggests a relatively high degree of endemism at each of the sites (Figure 3.11). At 50% similarity some community overlap was evident, with the Huon sites B10, 11 and 14 (Lower Huon, Cygnet and Mid-Huon) grouping together, and the lower Channel sites B7 and B8 (Little Taylors Bay and Great Taylors Bay) forming another cluster with site B12 (Port Esperance). At 38% similarity, groups are formed that broadly differentiate the Huon/ Lower Channel from the Upper Channel.

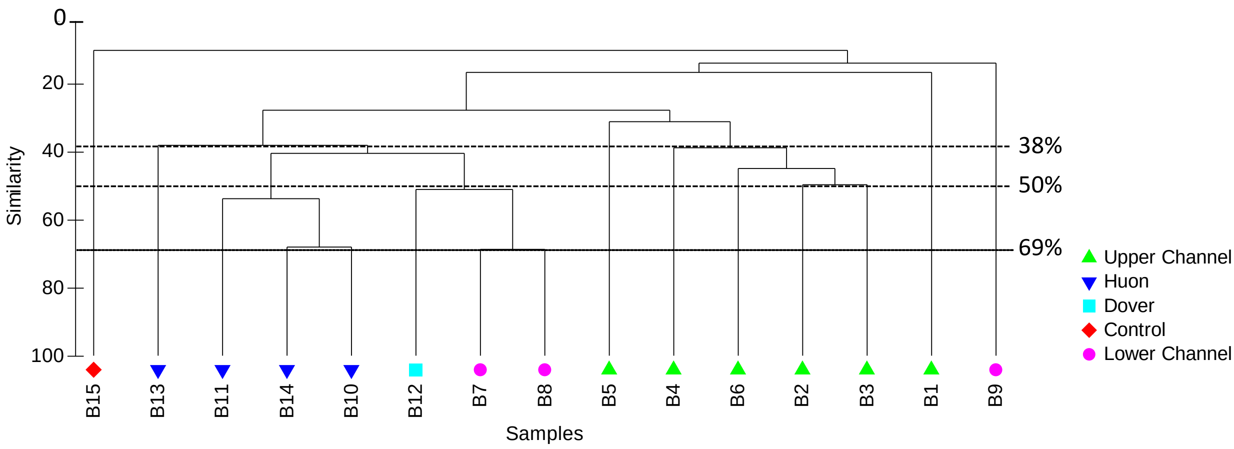


Figure 3.11: Cluster analysis (dendrogram) showing site separations based on average community structure at each site.

Multidimensional scaling allows the relationships between the benthic samples to be viewed more clearly (Figure 3.12). The community at the control location (B15) was quite different to that at any of the other sample locations. Recherche Bay is separate to the rest of the Huon and Channel systems and although the sampling site itself was quite sheltered within the bay, the overall location is more exposed to Southern ocean influences.

Sites B9 in the lower Channel and B1 in the upper Channel were also notably different from the other communities. B1 and B9 are the boundary sites at the top and bottom of the D'Entrecasteaux Channel respectively and as such may be subject to current flows and water exchange conditions that are more tempered in the rest of the system. B5 is quite close to Snake Island and also appears to be a little different to the rest of the upper channel sites. This site was in the mid-channel, adjacent to the reef system associated with Snake Island and had a relatively coarse sediment. As with sites B1 and B9, site B5 may be subject to increased water flow compared to the other sites this region positioned more to the margins of the Channel and in the embayment's.

The total number of species recovered from each region differed greatly. The control site had the lowest number of species overall, 24 species. The Huon and Port Esperance were similar with 36 and 38 species respectively. The lower channel had almost double this with 70 species in total but the diversity in the Upper Channel was significantly higher with a total of 168 different species recovered from sites in this region. The difference in number of species recovered at individual sites was much less, with individual sites in the lower Channel having between 18 to 36 species per site and those in the Upper Channel ranging from 19 to 50 species per site (Figure 3.8), which suggests that there was greater between site species variability in the upper Channel.

Port Esperance and the Upper Channel sites were polychaete dominated (Table 3.1), which is consistent with the findings of previous studies in this area (Macleod et al. 2004b, Edgar et al. 2005, 2010). These were generally burrowing deposit feeders with relatively few

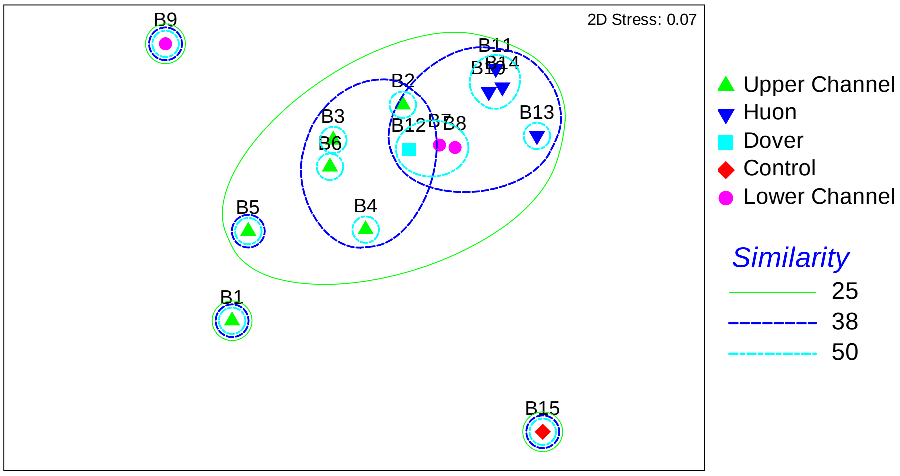


Figure 3.12: Multidimensional scaling ordination, calculated using Bray-Curtis similarities based on full species complement (replicates averaged), showing the relationship between the BEMP study sites.

suspension feeders in these systems. However, there is no evidence of any proliferation of opportunistic species which might be associated with increased organic enrichment. The polychaete community contained species from a broad variety of functional types; including tube building polychaetes (e.g. Maldanids, Ampharetids and Terrebellids) with the capacity to aerate the sediments, predatory species (e.g. Nephtyids, Syllids and Sigalionids) and the common soft-sediment deposit feeders (e.g. Paraonids, Capitellids and Spionids). It is worth noting that many of the species identified as being characteristic of the communities in the current study (i.e. *Lysilla jennacubinae*, *Theora lubrica*, *Callianassa limosa*, *Ennucula obliqua*, *Thyasira adelaideana*, Kalliapseudes sp., Melitid sp., Ampeliscid sp., Lumbrinereis sp., *Amphiura elandiformis*) were amongst those which have previously been shown to have a strong negative association with organic enrichment (Edgar et al. 2005). Relatively few species with a positive correlation to organic enrichment were present; the most common of these were the introduced species *Corbula gibba* and *Maoricolpus roseus* encountered in the Huon region.

The lower Channel had a high incidence of the amphipod *Byblis mildura*. This species was relatively common throughout the Channel, but was in very high numbers in all replicates from site B9, suggesting a localised preference for conditions at this site. Ampeliscids are tube-building amphipods which use their antenna as filters to extract organic material from the water column but can also scavenge detrital material from the seabed directly; they are often found in dense aggregations where resources are sufficient; (Sudo and Azeta, 1996). *Byblis* in particular has a relatively short life history under the right environmental conditions, with generations turning over in as little as 3 months (Sudo and Azeta, 1996). However, Ampeliscids can be readily overwhelmed with organic inputs and are rarely seen in abundance in locations with significant depositional loads. Ampeliscids and Phoxocephalids were the predominant amphipod species in all samples, but levels of these taxa were lower in the Huon. Other crustaceans also common included Tanaids, Ostracods and the ghost shrimps *Callianassa* sp. Ghost shrimps are a common feature of soft sediment communities and, when present in any numbers, can play an important ecological role, as their burrowing both bioturbates and aerates the sediments. Callianassids were common in all sites except Recherche Bay.

Molluscs were a key feature of the Huon and Port Esperance communities representing 36% and 30% respectively of the key functional groups at these sites. The most commonly encountered species were burrowing, deposit feeding bivalves such as *Theora lubrica*, *Thyasira adelaideana*, *Corbula gibba* and *Tellina margaritina.* Interestingly there were several introduced species amongst the characterising molluscs – *Corbula gibba, Theora lubrica* and *Maoricolpus roseus*. As pointed out in the Aquenal report (2012) the New Zealand screwshell (*Maoricolpus roseus*) was a significant species in the upper Channel system in particular, at some sites this species was sufficiently abundant that it could potentially have a major impact on the local ecology. There are several studies that have shown the potential for significant habitat modification with *Maoricolpus roseus* (Allmon et al. 1994; Bax et al. 2003) as well as recent evidence that this particular region of the Channel is an area of ecological concern with regard to the impacts of the New Zealand screwshell (Reid, 2010).

Overall, each of the regions appears to have a mix of species from a range of functional groups suggesting that the sediments have the capacity to be well aerated (as a result of bioturbating / burrowing and tube building species) and are not overly subject to organic deposition (indicated by the presence of filter and suspension feeding taxa). Tube building species in unconsolidated soft sediments tend to be more common in low-moderate flow environments, providing a double benefit to the ecosystem in that they both stabilise the surface sediments and provide a conduit to transfer oxygenated water deeper into the sediments.

The replicates collected at Port Esperance showed a very high degree of within group similarity (73%, Table 3.2) - it is important to note however that there was only a single site included in this grouping and this will influence that result. The control location also only contained a single site (3 replicates), but in this case the samples collected were more variable, with only 52% within group similarity. There was a slightly higher degree of similarity in the communities from the Huon than in those from the Upper Channel, and there appears to be a gradation in the Channel communities with those from the lower Channel generally being more similar to those in the Huon than to the samples from the Upper Channel (Figure 3.12, Table 3.2).

The greatest between group dissimilarities consistently occurred where the comparisons included the control site. This indicates that the underlying community at the control site differs fundamentally to those within the main channel and the Huon Estuary. Interestingly

Table 3.1: Total numbers of individuals and mean number per sample in each grouping for all species with mean abundance levels greater than 1.0. Percentages next to totals in sub-headings indicate the proportional representation of the key taxonomic and functional groups in this data subset and are based on the main sediment interaction strategies of these characterising species.

		Control		Huon		Lower Channel		Port Esperance		Upper Channel		Total	
Family/ Major Group	**Species Name**	Number Indiv's	Mean per Sample	Number Indiv's	Mean per Sample	Number Indiv's	Mean per Sample	Number Indiv's	Mean per Sample	Number Indiv's	Mean per Sample	Number Indiv's	Mean per Sample
Ampharetidae	Ampharetid sp.					12	1.3						
Capitellidae	Mediomastus australiensis			15	1.3	20	2.2	5	1.7	288	16.0	330	7.3
Lumbrinereidae	Lumbrinereis sp.	3	1.0			21	2.3	5	1.7	166	9.2	195	4.3
Maldanidae	Asychis sp.			17	1.4	9	1.0						
Nephtyidae	Nephtys sp. (TBC)					11	1.2						
Nephtyidae	Nephtys australiensis	12	4.0										
Nephtyidae	Nephtys gravieri									25	1.4		
Nephtyidae	Nephtys inornata	6	2.0					7	2.3				
Paraonidae	Aricidea sp.							5	1.7				
Paraonidae	Paraonid sp.					39	4.3			84	4.7	83	1.8
Paraonidae	Paraonides sp.			16	1.3	10	1.1	50	16.7	28	1.6	106	2.4
Polynoidae	Harmothoe sp.									18	1.0		
Sabellidae	Euchone limnicola							30	10.0	25	1.4	61	1.4
Sigalionidae	Sthenelais pettibonae			30	2.5			7	2.3				
Spionidae	Paraprionospio coora					13	1.4	10	3.3	59	3.3	89	2.0
Spionidae	Prionospio wambiri					19	2.1	12	4.0	19	1.1	51	1.1
Syllidae	Brania sp.									23	1.3		
Syllidae	Syllid sp.									47	2.6	51	1.1
Terebellidae	Amaena trilobata	**6**	**2.0**										
Terebellidae	Lysilla jennacubinae	3	1.0					27	9.0	54	3.0	100	2.2
Trichobranchidae	Artacamella dibranchiata							3	1.0	63	3.5	69	1.5
	Polychaetes	**30**	**23%**	**78**	**35%**	**154**	**14%**	**161**	**48%**	**899**	**58%**	**1135**	**39%**
Corbulidae	Corbula gibba							3	1.0				
Nassaridae	Nassarius nigellus							5	1.7				
Nuculidae	Ennucula obliqua					32	3.6	10	3.3			49	1.1
Semelidae	Theora lubrica			80	6.7	28	3.1	67	22.3	52	2.9	227	5.0
Tellinidae	Tellina margaritina	8	2.7										
Thyasiridae	Thyasira adelaideana					13	1.4	14	4.7				
Turritellidae	Maoricolpus roseus					10	1.1			101	5.6	111	2.5
	Molluscs	**8**	**6%**	**80**	**36%**	**83**	**7%**	**99**	**30%**	**153**	**10%**	**387**	**13%**
Ampeliscidae	Ampelisca sp.	4	1.3										
Ampeliscidae	Ampeliscid sp.					56	6.7						
Ampeliscidae	Byblis mildura					713	79.2			40	2.2	753	16.7
Corophidae	Photis sp.					12	1.3						
Melitidae	Ceradocus rubromaculatus									22	1.2		
Melitidae	Melitid sp.							3	1.0				
Oedicerotidae	Oedicerotid sp.	10	3.3										
Phoxocephalidae	Brolgus tattersalli							4	1.3	22	1.2		
	Amphipods	**14**	**11%**	**0**	**0%**	**781**	**69%**	**7**	**2%**	**84**	**5%**	**753**	**26%**
Anthozoa	Anthozoa sp.									49	2.7	49	1.1
Callianassidae	Callianassa limosa			38	3.2	66	7.3	49	16.3	103	5.7	256	5.7
Cumacea	Cyclaspis caprella	68	22.7									68	1.5
Echinodermata	Amphiura elandiformis					19	2.1	10	3.3	28	1.6	65	1.4
Nematoda	Nematoda sp.			12	1.0	17	1.9	8	2.7	28	1.6	65	1.4
Ostrocoda	Ostracod sp.	6	2.0										
Phoronida	Phoronida sp.			14	1.2								
Tanaidacea	Apseudid sp.									61	3.4		
Tanaidacea	Kalliapseudes sp.					9	1.0			141	7.8	150	3.3
Tanaidacea	Leptocuma sp.	3	1.0										
	Other	**77**	**60%**	**64**	**29%**	**111**	**10%**	**67**	**20%**	**410**	**27%**	**653**	**22%**
	TOTAL	**129**		**222**		**1129**		**334**		**1546**		**2928**	
	Functional Role	Number Recovered	% of Total	Number Recovered	% of Total	Number Recovered	% of Total	Number Recovered	% of Total	Number Recovered	% of Total	Number Recovered	% of Total
	Burrowing	106	82%	191	86%	298	26%	254	76%	1125	73%	1683	57%
	Epibenthic	10	8%	0	0%	22	2%	8	2%	220	14%	211	7%
	Tube Building	13	10%	31	14%	809	72%	72	22%	201	13%	1034	35%

the relationships between the communities in each of the main regions (Huon and Upper and Lower Channel) were quite consistent and the dissimilarity levels not as pronounced: the average dissimilarity between the Upper and Lower Channels = 76.79, between the Huon and Lower Channel = 75.47 and between Huon and Upper Channel = 82.92 (Table 3.2).

Table 3.2: Similarity of samples collected from major regional groups and between group dissimilarities for BEMP study sites, 2009 (SIMPER analysis, PRIMER - NB analysis conducted on replicate dataset).

Group	Within Group Similarity	Between Group Dissimilarity			
		Control	Huon	Lower Channel	Upper Channel
Control	52.05				
Huon	40.26	93.62			
Lower Channel	36.89	91.67	75.47		
Upper Channel	32.32	91.25	82.92	76.79	
Port Esperance	73.30	87.62	70.65	62.81	69.95

There was a lot of commonality in the dominant species from the Huon, lower Channel and Dover samples (Table 3.1). SIMPER analysis allows the identification of those species which contribute most to the similarities and distinctions between groups and suggests that of the species which broadly characterised the Huon samples, the bivalve *Theora lubrica* was a very consistent presence, contributing 28% of the overall similarity in the samples in this region. This bivalve was also common in the Dover samples (12% of the overall similarity) and the lower Channel samples (approximately 8% of the overall group similarity), and is one of the main species that overlaps between these regions. *Theora lubrica* was less common in the upper Channel sites. *Theora lubrica* is a small introduced bivalve, very well adapted to colonising and establishing in soft sediments and has been a reported feature of the benthic ecology of these systems for many years (Macleod et al, 1999, 2004). Several other molluscs (gastropods and bivalves) were also important in the Channel sites (upper and lower) although they were not particularly abundant - with the exception of the New Zealand screwshell (*Maoricolpus roseus)* mentioned earlier, which was abundant but patchy in its distribution. The Capitellid polychaete, *Mediomastus australiensis,* was present in all regions but was a key feature of the upper Channel sites, contributing approximately 17% of the overall similarity in sites from this group. *Mediomastus* are tube building polychaetes with the capacity to both stabilise and aerate the sediments as the tubes continue into the sediments allowing oxygenated water to penetrate (Hansen, 1993). Although this species is a member of the Capitellid family it does not have the same opportunistic association with organic enrichment as *Capitella capitata*.

The distinctions between the Upper and Lower Channel sites and the Huon were predominantly due to differences in abundance of shared species rather than an entirely different faunal complement. The Huon sites tended to have less species overall and the fauna was generally consistent with that found in depositional environments, with many deposit feeding and burrowing species. The community at the Port Esperance site appears to sit between that of the Channel and the Huon, with a greater level of overlap (lower dissimilarity) at this site than any other (Table 3.2). There were also many other deep burrowing and aerating species at all of these sites, suggesting a healthy and well integrated sediment fauna.

The control location, at Recherche Bay, contained a much greater representation of small crustaceans and amphipods than polychaetes, with a species mix more characteristic of sandy exposed sites than the depositional estuarine environments. The faunal complement at this site was quite different to that from other regions and contained several species that were not found at any other location; including the cumacean *Cyclapsis caprella*, the bivalve *Tellina margaritina* and a relatively large holothurian (*Stichopus* cf *mollis*). *Cyclapsis* species are members of the family Diastylidae and live at the sediment water interface where they feed on deposited material. They prefer areas with a sufficient flow to promote water exchange and bring in organic material but avoid energetic areas where the current flow or seabed turbulence is very high. *Tellina margaritina* is a deposit feeding bivalve often found near the mouths of estuaries (Boyd, 2011), and similarly the sea cucumber, *Stichopus* cf *mollis,* is common in shallow sub-tidal coastal areas and reef systems throughout SE Australia. Many of the molluscs, which were widespread throughout the Channel and Huon systems, were absent at the control site.

Of the environmental factors measured at these sites (depth, % silt-clay, sulphide concentration, redox potential, total organic carbon and stable isotope (C:N) ratio (Table 3.3), the drivers that most influenced the observed community distribution were depth, silt-clay and total organic carbon content (Pearson correlation = 0.500). As might be expected it is the factors that relate to the depositional characteristics of the site that appear to have the strongest influence on the community distribution.

Principal components analysis shows more clearly how the sites relate to one another based on the combined environmental data (Figure 3.13). The first two principle components account for 65% of the overall variation in the site distributions. Silt-clay, redox and C:N ratio distinguish between the Huon and Channel communities along PC1, whilst depth appears to be the primary influence on separation of sites within the regions (PC2).

Table 3.3: Environmental factors assessed for BEMP study sites 2009. ([*a] Note all data is from the 2009 surveys except %TOC data which is from 2011 survey as the 2009 data was questionable).

Site	Location	Depth (m)	% Silt-Clay	Redox (mV)	Sulphide (uM)	% TOC[*a]	C:N ratio
B15	Control	7	13.9	151	1.5	3.53	10.20
B10	Huon	32	69.3	147	3.8	19.87	12.92
B11	Huon	21	78.4	164	0.0	19.27	16.28
B13	Huon	11	80.5	72	6.0	22.50	28.04
B14	Huon	15	67.1	133	0.0	19.43	19.18
B12	Port Esperance	30	80.1	160	0.3	18.93	12.83
B7	Lower Channel	37	73.3	104	6.8	14.30	11.74
B8	Lower Channel	42	51.4	208	1.2	8.60	11.13
B9	Lower Channel	46	28.1	285	0.0	6.20	10.60
B1	Upper Channel	14	26.1	311	0.0	8.00	9.30
B2	Upper Channel	24	73.6	148	6.8	19.17	11.33
B3	Upper Channel	22	40.9	411	0.0	7.10	10.73
B4	Upper Channel	14	25.5	223	0.0	4.30	11.03
B5	Upper Channel	25	19.1	158	3.0	7.23	10.87
B6	Upper Channel	13	24.2	280	0.0	5.33	10.51

The environmental conditions suggest that the Huon sites are quite different to the Channel sites. However, the environmental data does not explain the marked difference in the ecology at the control site (B15) at Recherche Bay, and this may be why the correlation between the environmental and biotic matrices is relatively poor (Spearman Rank Correlation - 0.373). It appears that the sites between regions are discriminated by a range of factors whilst the sites within regions are mainly differentiating on the basis of depth. There are many subtle differences in other factors which may not have been measured directly but which will be affected by depth, and these have the potential to significantly influence the ecological response. For example depth will have an impact on light penetration, which in turn can have a marked effect on algal communities and microphytobenthic production. Depth will also influence wave/ wind disturbance of the sediments which can have major ecological implications. Consequently the underpinning

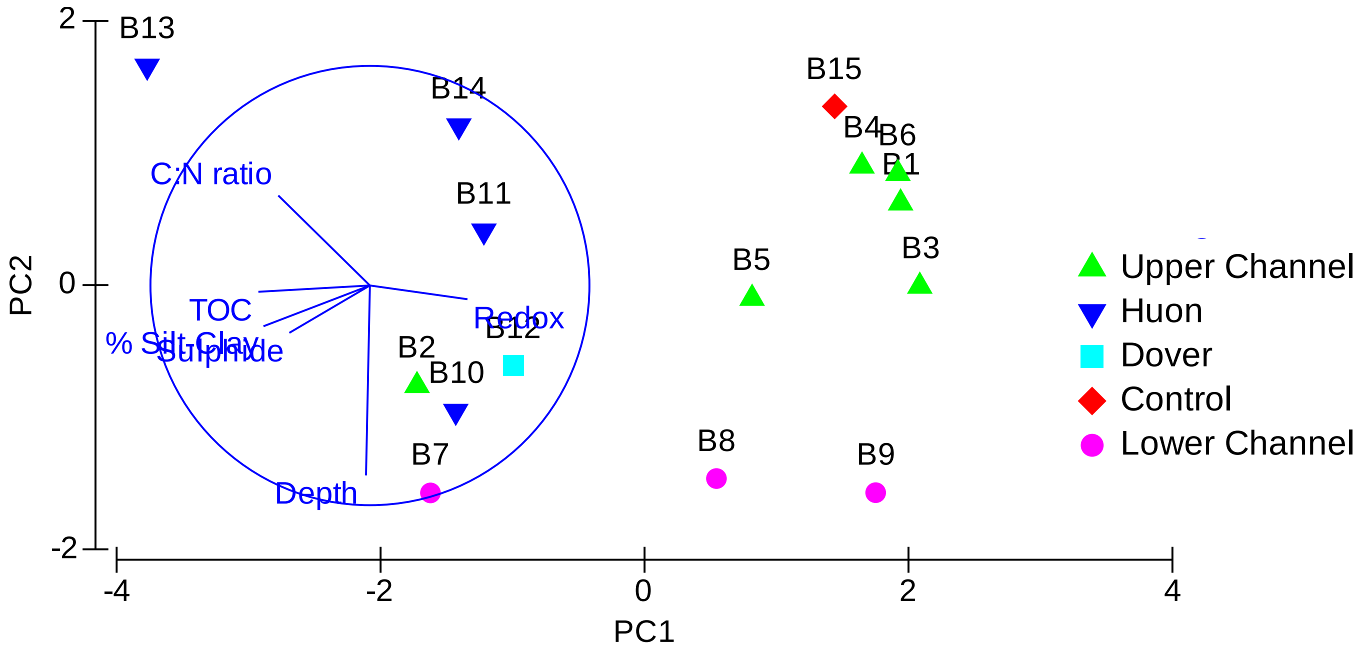


Figure 3.13: Principal component analysis ordination showing the relationship between the BEMP study sites based on environmental variables (Euclidean distance).
(*a Note all data is from the 2009 surveys except %TOC data which is from 2011 survey).

environmental drivers at the control site and in the upper Huon may be quite different to other sites. Although this would make direct comparison of the communities at these sites incongruous, it does not make the sites themselves irrelevant as they can still reflect system wide changes in the water and sediments. The multivariate analysis clearly highlights the strong regional differences between the infaunal communities, and suggests that any between site comparisons should take this into consideration. There is no indication in the species composition or community relationships to suggest that there was any significant anthropogenic impact at these sites, and the observed differences in the communities at the BEMP sites appear to be as a result of fundamental differences in underlying environmental conditions.

3.2.2 BEMP infaunal community data compared with pre-existing data from the same sites in this system

It is possible to compare the benthic data from the BEMP sites with infaunal community data from control locations previously collected as part of ongoing farm-based monitoring requirements throughout the Huon and Channel region. Although these sites were not always collected/ identified to the same taxonomic level, by comparing the data at family level it is possible to place the BEMP samples in a broader spatial and temporal context. The additional data included in this comparison are shown in (Table 3.4).

Table 3.4: Additional study sites included in the broader sample comparisons.

Site	Year	Season	Region	Site	Year	Season	Region
BEMP	2009	Autumn	All Regions				
22	1997	Spring	Huon	51	2001	Summer	Dover
34	1998	Autumn	Dover	49	2001	Autumn	Huon
21	1998	Winter	Huon	50	2001	Spring	Huon
23	1998	Summer	Huon	56	2001	Spring	Huon
17	1998	Spring	Upper Channel	59	2001	Spring	Huon
19	1998	Autumn	Upper Channel	60	2001	Spring	Huon
37	1998	Summer	Upper Channel	52	2001	Winter	Lower Channel
29	1999	Summer	Dover	53	2001	Summer	Lower Channel
26	1999	Autumn	Huon	44	2001	Winter	Upper Channel
27	1999	Summer	Huon	46	2001	Winter	Upper Channel
41	1999	Spring	Huon	48	2001	Summer	Upper Channel
42	1999	Spring	Huon	65	2001	Summer	Upper Channel
43	1999	Spring	Huon	64	2002	Autumn	Dover
31	1999	Winter	Lower Channel	55	2002	Winter	Huon
36	1999	Summer	Lower Channel	47	2002	Winter	Upper Channel
20	1999	Summer	Upper Channel	54	2002	Spring	Upper Channel
32	1999	Spring	Upper Channel	57	2002	Winter	Upper Channel
33	1999	Summer	Upper Channel	63	2003	Summer	Dover
40	1999	Autumn	Upper Channel	61	2003	Autumn	Huon
24	2000	Winter	Huon	62	2003	Summer	Huon
25	2000	Autumn	Huon	30	2003	Spring	Upper Channel
45	2000	Winter	Huon	58	2003	Summer	Upper Channel
16	2000	Winter	Upper Channel	18	2004	Spring	Lower Channel
38	2000	Autumn	Upper Channel	35	2004	Summer	Lower Channel
39	2000	Autumn	Upper Channel	28	2005	Spring	Lower Channel

Site specific identities have been removed, and the data classified by regional location, the year / season the data was collected and a numeric identifier for individual sites. This allowed for incorporation of data from a total of 65 sites and times.

Comparison of the communities from all of these sampling times indicates that the BEMP samples collected in 2009 are broadly consistent with samples collected previously from this system (Figure 3.14). The control site continues to stand alone, once again emphasising that Recherche Bay is ecologically quite different to the communities found in the broader Huon estuary and D'Entrecasteaux Channel systems.

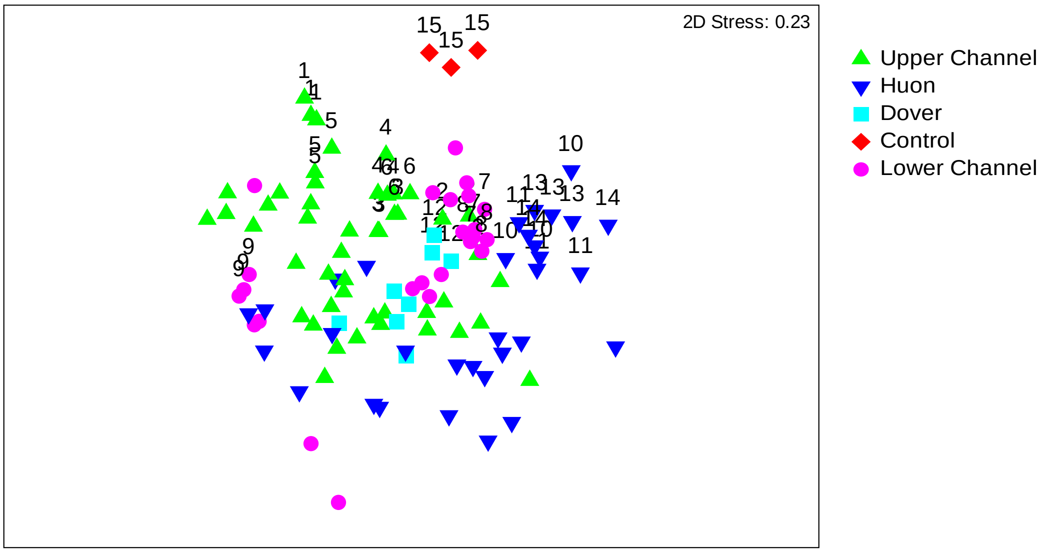


Figure 3.14: Multidimensional scaling ordination, calculated using Bray-Curtis similarities, showing the relationship between the BEMP sites and the community structure at sites sampled from the same regions in other years. Numbers denote replicate samples for BEMP sites.

Comparing the communities temporally in each region (Figure 3.15) suggests that the biological communities associated with the BEMP samples collected in 2009 may be slightly different from those collected in previous years. ANOSIM identified significant differences between the communities in each region (Global R=0.457) and over time (Global R=0.545). The only region that didn't differ significantly from the others was Port Esperance, which appears to have a community midway between those found in both the Huon and Channel. The samples from the BEMP survey in 2009 were significantly different to the samples collected at all other times ($p<0.05$). However, it is hard to say conclusively that this is as a result of a temporal shift in the ecological conditions, as there are several other factors that may have influenced this outcome (e.g. the timing of the sampling, differences in sampling technique etc.). It does not appear as though the differences in the sediment communities are extreme; in this broader analysis the key faunal differences both between the regions and over time were largely as a result of changes in abundance and relatively minor changes in species composition. There is no evidence of major species shifts or communities

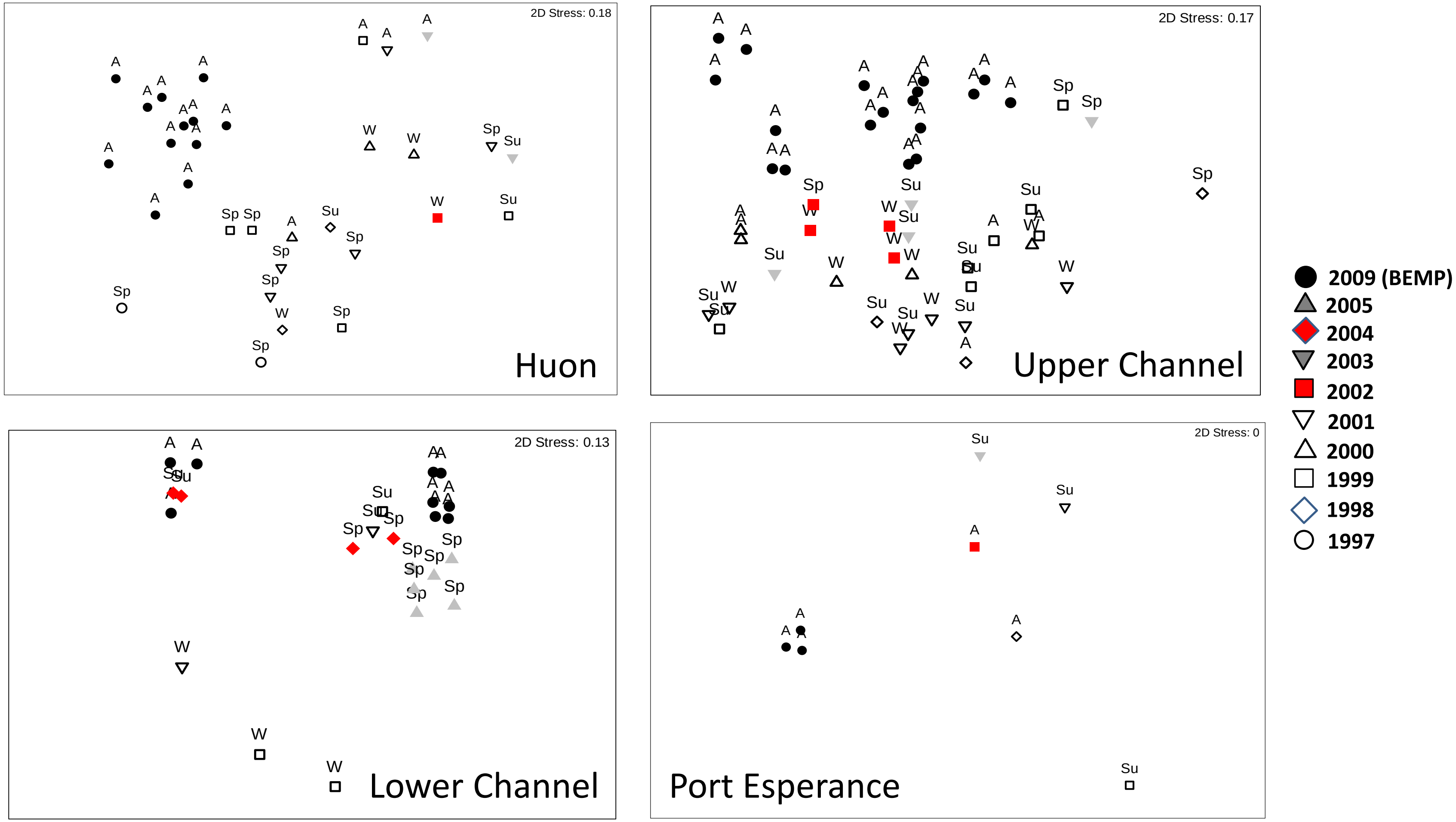


Figure 3.15: Multidimensional scaling ordination, calculated using Bray-Curtis similarities on square root transformed data, showing the relationship between the benthic infaunal communities for BEMP and control study sites collected at different times in the Huon, Upper Channel, Lower Channel and Port Esperance regions. Letters denote seasonal timing of sampling: Sp - Spring, Su – Summer, A – Autumn, W – Winter.

characteristic of organically enriched and impacted conditions. As suggested above this may simply reflect technical differences in sampling approaches, seasonal influences or even longer term interannual trends which may affect the broadscale community structure. However, it is important to note that the sampling undertaken in 2009 represents a valuable broadly based spatial assessment of the ecological conditions, and a reliable temporally fixed baseline upon which the ongoing assessment of such trends can be undertaken.

For the purposes of discerning the lowest level of change and response in community structure and ecological function the analysis presented here has been undertaken at species level. However, the requirement for monitoring the sediment biota under the BEMP schedule is for family level (see Appendix 1).

In this case there is a very strong correlation (Pearson rank correlation >0.90) between the community composition and site relationships as represented at family and species level (Figure 3.16). This suggests that not much information would be lost in representing the community at family level and that changes might still be detected. However, species level assessment may be more useful in interpreting those changes as it can allow fine scale functional differences to be considered.

3.3 COMPARISON WITH RECOMMENDED TRIGGER LEVELS

One of the objectives of this BEMP evaluation project is to provide advice on the relationship between observational data collected within the D'Entrecasteaux Channel and Huon River and Port Esperance Marine Farming Development Plan (MFDP) areas and the trigger levels proposed by Thompson et al. 2008. The recommended trigger levels for sediment conditions and the rationales upon which they were selected are outlined in detail in Thompson et al. 2008, but a summary is provided below (Table 3.5, 3.6).

Once again it is important to note that although the planning authority has not adopted these recommended trigger levels as statutory limits, they are being used to inform regulatory management of the industry. In the following section we discuss the 2009-2012 BEMP sediment assessment data in relation to the recommended trigger levels (Thompson et al. 2008). The trigger levels for the sediment chemistry parameters basically propose that significant change in one indicator at one site over time constitutes a low level risk, whilst change in two or more sites or indicators represents a more marked response / risk level. Change in multiple indicators or at more than one site at a time would suggest a high risk and a level 3 response.

There is no capacity to compare the stable isotope data over time, as this data has only been collected once in the current BEMP period. Similarly, as noted earlier, it

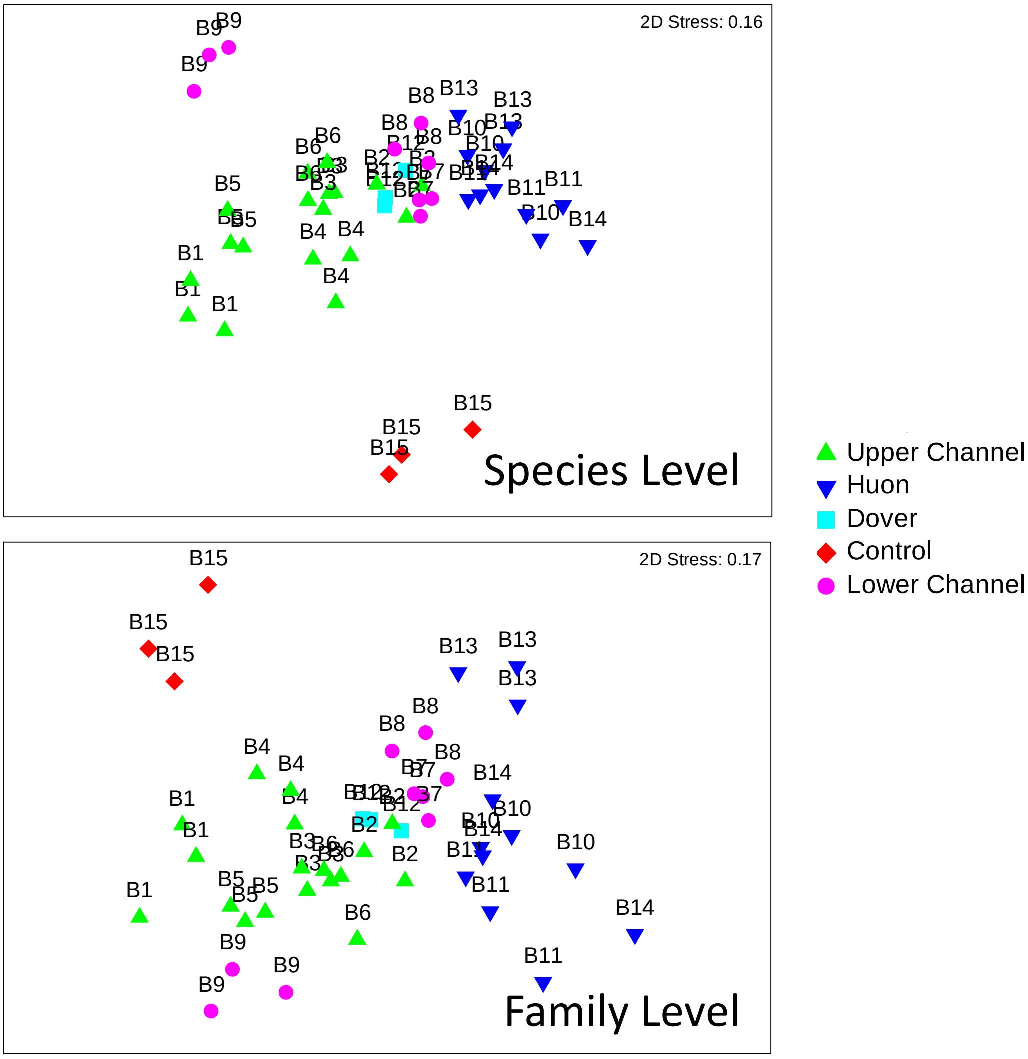


Figure 3.16: Multidimensional scaling ordination, calculated using Bray-Curtis similarities, showing the relationship between the BEMP sites with identification to species and family levels.

would be inappropriate to compare the organic carbon loadings given the differences in analytical approach used. The measures of redox potential did not differ significantly between years at any site. However, under the conditions outlined above the sulphide levels triggered at site B7 in 2009, where the concentration in 2009 was in fact significantly higher than in subsequent years. Sites B3, B12 and B14 triggered in 2012 with sulphide levels at all sites being significantly higher in 2012 than in previous years. However, it is important to note that the trigger response was in relation to a significant difference being observed with previous and subsequent measures as opposed to any major elevation of sulphide per se. The levels at B12 (Port Esperance) and B14 (Huon) were still very low, and within the range of variability encountered at other sites, and well within the normal range observed within their respective MFDP regions (Figure 3.2). B3 in 2012 appears to have triggered as a response to a very high sulphide measure in a single replicate, and as such may be as a result of an isolated event. Similarly the difference at site B7 in 2009 appears to be as a result of a single anomalous replicate and moreover the levels triggered as a result of significant decrease in sulphide concentration in subsequent years. This highlights the importance of understanding both the scale and direction of any triggered changes in sediment geochemistry, and interpreting the result accordingly.

The particle size composition showed a high degree of interannual variability across regions, sites and times, and consequently applying the recommended response guidelines would suggest a high risk level "trigger" response in most years. The level of fines (i.e. silt-clay) varied markedly with all of the Huon sites showing a significant increase in silt-clay in 2011 and a subsequent decline in 2012. However, the pattern was less consistent in the Channel, with sites in this region varying markedly with respect to particle size structure, and no obvious temporal or spatial trend. Given the increase in fines in 2011 in the Huon and the subsequent decline in the following year it seems more likely that this is associated with variations in river inputs (see Chapter 2). If this is the case it would suggest that sediment composition may not be a particularly sensitive response variable for monitoring changes as a result of aquaculture operations, and consequently the response level may need to be adjusted.

Table 3.5: Recommended benthic monitoring program parameters for sampling, spatial and temporal frequency (TBC= to be confirmed, may be recommended depending on farming circumstances in area). Modified from Thompson et al. 2008.

Parameter	**Temporal**	**Spatial**	**Parameter**
Sediment Chemistry	Annual	14 sites	• redox potential • organic content • stable isotopes • particle size • sulphide concentration • *metal concentration (TBC)* • *antibiotics (TBC)*
Benthic Infauna	Annual	14 sites	
Other benthic biota	Annual	1 site	• Seagrass shoot density (TBC) • % chlorophytes (TBC)

It is important to note that the key objective of the BEMP sediment monitoring programme was to establish a reliable baseline against which future sampling results can be compared. Although sediment chemistry parameters were collected from all sites in each year (2009-2012) the benthic infauna has only been assessed once in that timeframe. Consequently the sampling undertaken in 2009 cannot by itself determine whether there has been any change in the system ecology, other than where clear and established indicators of impact are apparent. However, with respect to the sediment sampling a large number of the BEMP sites have been sampled previously as baseline control sites for farm-based environmental monitoring and as such there is additional data (geochemical and biological) for many sites.

Table 3.6: Recommended trigger levels for benthic monitoring program parameters with 3 levels of trigger values. Modified from Thompson et al. 2008

Parameter	**Baseline Value**		**Level 1**	**Level 2**	**Level 3**
	Huon Estuary	D'Entrecasteaux Channel	(Low risk)	(Moderate risk)	(High risk)
Sediment Biota (infauna)	TBD	TBD	Significant change over time at one or more sites Other indicators TBD	Significant change in multivariate community structure at one site Other indicators TBD	Significant change in multivariate community structure at two or more sites Other indicators TBD
Seagrass and other macrophytes	TBD	TBD	Significant change over time or relative to control	As level 1 & TBD	As level 1 & TBD
Sediment Chemistry	ANZECC guidelines & TBD	ANZECC guidelines & TBD	Significant change over time at one site	Significant change over time at 2 sites/ 2 indicators Exceeding ANZECC low guidelines	Significant change over time at > 3 sites/ 2 indicators Exceeding ANZECC high guidelines

The data from control locations already collected as part of the ongoing farm-based monitoring requirements represent an important baseline dataset with which to assess longer-term ecosystem changes. The biological data was made available for this study and the resultant longer-term relationships have already been discussed in the previous section. However, the sediment geochemical data for the equivalent sites and times is more problematic; the potential for extrapolation of this data is diminished as a result of the data having been collected by a range of operators. As discussed earlier, some measures can be very sensitive to the changes in sampling technique and, consequently, where multiple operators are employed the reliability of this data may be reduced. This is not to say that the data is flawed, it may still be quite adequate for determining major impacts, such as those associated more directly with fish cage impacts, but would be unsuitable for distinguishing subtler changes.

Overall the results from the sediment chemistry surveys undertaken as part of the BEMP do not suggest that there has been any significant environmental change at any particular site or time. The only result that came close to formerly recommended benchmark levels as proposed by previous research (Table 3.7) or the ANZECC trigger levels (ANZECC, 1997, 2000) would be the sulphide level at site B1 in 2012, where one site was found to have a significantly increased level relative to the level in the previous year. However, as outlined earlier this would appear to be an anomalous result from a single replicate, and the sulphide concentration was still well within the acceptable range (Wildish et al. 2001, Macleod & Forbes, 2004, Table 3.7).

Comparison with samples collected at control sites from the Huon and D'Entrecasteaux Channel in previous years indicates that the levels of both total organic carbon and percentage silt-clay sampled as part of the BEMP were consistent with previous observations (Figures 3.17 and 3.18). Sites did not appear to be markedly higher or lower than the conditions observed from either region in previous years; although sites in the Huon had in general higher organic carbon levels than those from the Channel and there was no evidence of any temporal trend up or down. As the individual sites have not been sampled consistently in each year (i.e. the samples were collected at different locations in each region in each year) it is not relevant to make statistical comparisons between years.

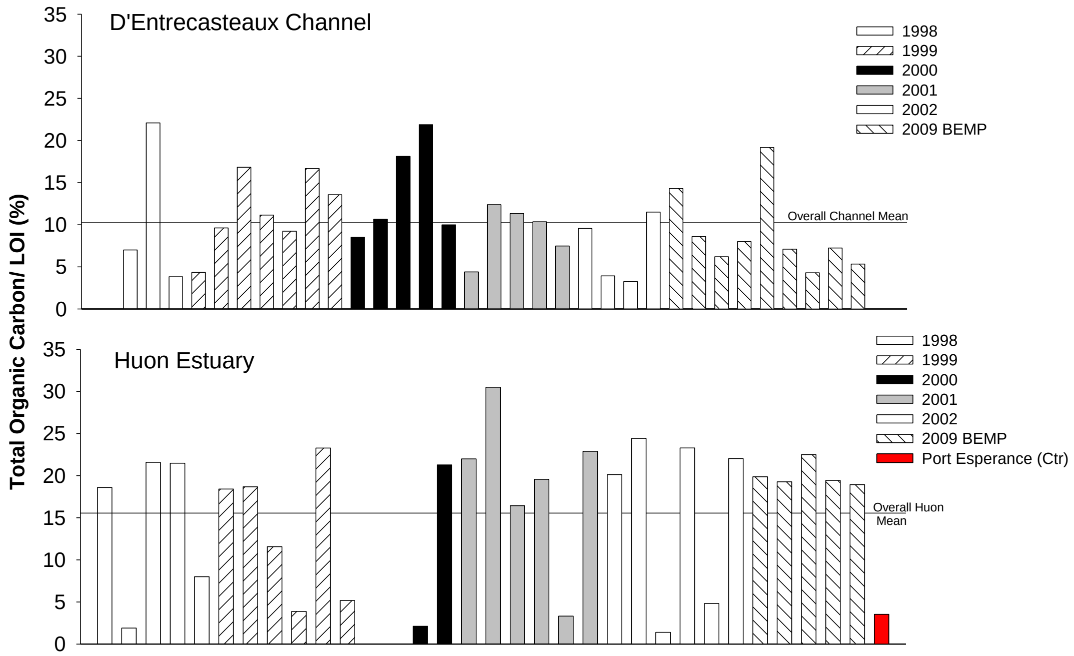


Figure 3.17: Percentage total organic carbon at control sites sampled from each region between 1998 – 2002 and the BEMP sites sampled in 2009.

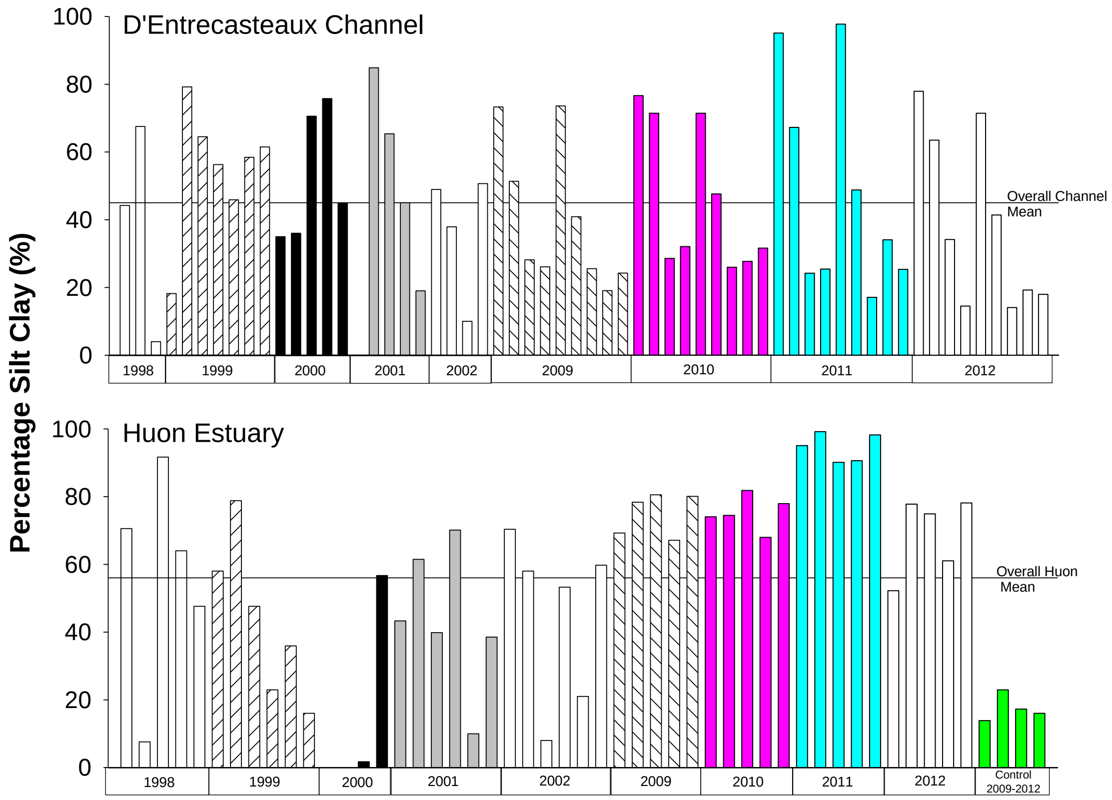


Figure 3.18: Percentage silt-clay at control sites sampled from each region between 1998 – 2002 and the BEMP sites sampled in 2009.

3.3.1 General Sediment Condition

The sediment chemistry measures (redox potential, particle size, sulphide concentration, and total organic content) will be judged against each other (i.e. in the context of the current broader condition of the system) and in relation to performance measures established in previous research projects (e.g. Macleod et al 2004a, b) as potential enrichment indicators for this regional system (Table 3.7). However, it is important to note that these enrichment indicators have been established through research, and represent fine scale levels of change in sediment condition which are not used in a regulatory context, although this research understanding did underpin the development of the recommended trigger levels.

The results from the current BEMP study do not suggest any major cause for concern with respect to the basic sediment biogeochemistry. All samples were well oxygenated, sulphide levels were low and redox potential was high. Total organic carbon content was comparable with levels previously reported from these areas. Isotope signals did not show anything untoward and were also consistent with the other sediment measures.

Consequently, there was no evidence in the sediment biogeochemistry assessment of any sites having exceeded previously recommended benchmark levels (Table 3.7) or the ANZECC guidelines (ANZECC, 1997, 2000).

Table 3.7: Redox potential and sulphide concentration associated with impact stage and compared with organic enrichment model as defined by Wildish et al. (2001). Based on Macleod et al. 2004.

	Impact Stage	I	II	III	IV / V	VI
Current Study	**Category**	**Unimpacted**	**Minor**	**Moderate**	**Major**	**Severe**
	Redox Potential	>100mV	>100mV OR >50% Ref	0-100mV OR <50% Ref	-ve	Not encountered
	Sulphide	below detection	below detection	>50uM	>100uM	Not encountered
Wildish et al. (2001)	**Category**	**Normal**	**Transitory**		**Polluted**	**Grossly Polluted**
	Redox Potential	>100mV	0-100mV		-100-0mV	<-100mV
	Sulphide	<300uM	300-1300uM		1300-6000uM	>6000uM

However, several of the sediment sampling sites and times did “trigger” according to the risk levels and criteria proposed by Thompson et al. (2008). Unfortunately the recommendations as stated fail to take into account the importance of the direction and scale of change for the sediment assessments. Consequently we would suggest that the BEMP recommendations be modified to indicate, that although significant differences in sediment conditions over time should be noted, it is only significant deterioration in conditions, to levels below those recommended as benchmarks in previous research (Table 3.7), that need be cause for concern. In addition the spatial distinctness of the sedimentary environment, as compared to the connectedness of water column, would suggest that it may be inappropriate to place the same level of emphasis on observations of significant change at more than one site as is necessary in the water column assessments.

There would appear to be some redundancy in the sediment biogeochemical analyses, with the key measures providing very similar assessments of the overall sediment condition. Consequently it may be sufficient to only run a subset of analyses to obtain the same level of system understanding.

The TOC measures required significant post-processing and were subject to a greater level of inter-laboratory variability than the other measures, which may bring in to question the value of this analysis.

Redox and sulphide were relatively easy to obtain in the field, providing a relatively rapid assessment, which provides a clear indication of the oxygen condition in the sediments and, which can be readily cross-referenced. A recent study in New Zealand has shown that not only are sulphide and redox strongly negatively correlated but also that they are reasonably well aligned with benthic enrichment stage (Keeley et al. 2012). Whilst this relationship does not hold so well for the subtle changes in sediment condition it would appear that sulphide / redox is a very effective indicator of any major changes. However, previous experience with redox assessment in Tasmania has shown that both redox and sulphide measurements are highly susceptible to inter-operator variability. The redox technique, in particular, is highly sensitive to slight variations in methodology. Consequently the reliability of this measure may be called into question when comparisons are to be made between multiple projects / operators; broad categorisations and major changes in sediment condition should still be possible to differentiate but it will be much harder to establish subtle changes.

Isotope analysis was undertaken on only a single occasion, but the results appear to be very much consistent with those from previous studies (Macleod and Forbes, 2004a, Edgar et al. 2005, Macleod et al. 2008a). However, the value of this analysis might be questioned on the basis of the low levels of spatial variability and discrimination possible relative to other measures and the lack of evidence of any site-specific differentiation.

3.3.2 Biological Condition

There have not, to date, been two complete infaunal community surveys and therefore it is not actually possible to determine how the BEMP data itself compares to the recommended trigger levels. However, it is possible to both assess the nature of the communities in the surveys and, by reference to previous sampling undertaken as part of the "farm-based monitoring", to compare some sites over time.

The 2009 survey has clearly established several key communities in this system and provides a very valuable baseline for the broadscale dataset. Whilst there would appear to be some obvious distinctions in the environmental conditions underpinning these communities, these differences appear to be regionally focussed rather than as a result of any specific anthropogenic or farming influences. The assessment of the infaunal community structure suggests that proposed trigger and response levels as recommended by Thompson et al. (2008) would, for the most part, seem to be useful, and the potential effect levels consistent with previous research (Table 3.7, Figure 3.19, 3.20).

Although the biological samples are relatively expensive to analyse and more time consuming, it is important to consider the level of system understanding that can be gained from such assessments. The biological data when reliably collected, analysed, and subject to expert review can provide a much greater insight into the subtleties and potential causality of any observed ecological changes; providing a meaningful interpretation of the response, that is simply not possible with biogeochemical measurements alone. Expert review of the benthic data allows the information to be assessed for faunal changes that are real and mean something in the context of the change anticipated, rather than just a purely quantitative evaluation of “any change”. We would suggest that this advantage and the fact that the full benthic assessments are only conducted once every 4 years make the benthic assessments cost effective.

Probably the most significant finding from this component of the review would be that the current control location appears not to be a meaningful ecological comparison point for the other sites in the Huon and D’Entrecasteaux system. The environmental conditions associated with this site are so different as to make it unsuitable as a comparative reference for this purpose. The site is considerably shallower that any other study site and as such, given its location, is likely to be subject to more dynamic wave / weather conditions than elsewhere in this system. If the primary purpose of the control is to act as a monitor for the influence of changes in the broader current conditions / influences then this site could still have some value as a temporal control. However, if there was any option to review this site and perhaps select an alternate control or relocate to a position with comparable depths and sediment composition to other broadscale study sites, then this could markedly improve the usefulness of the control site for subsequent comparisons.

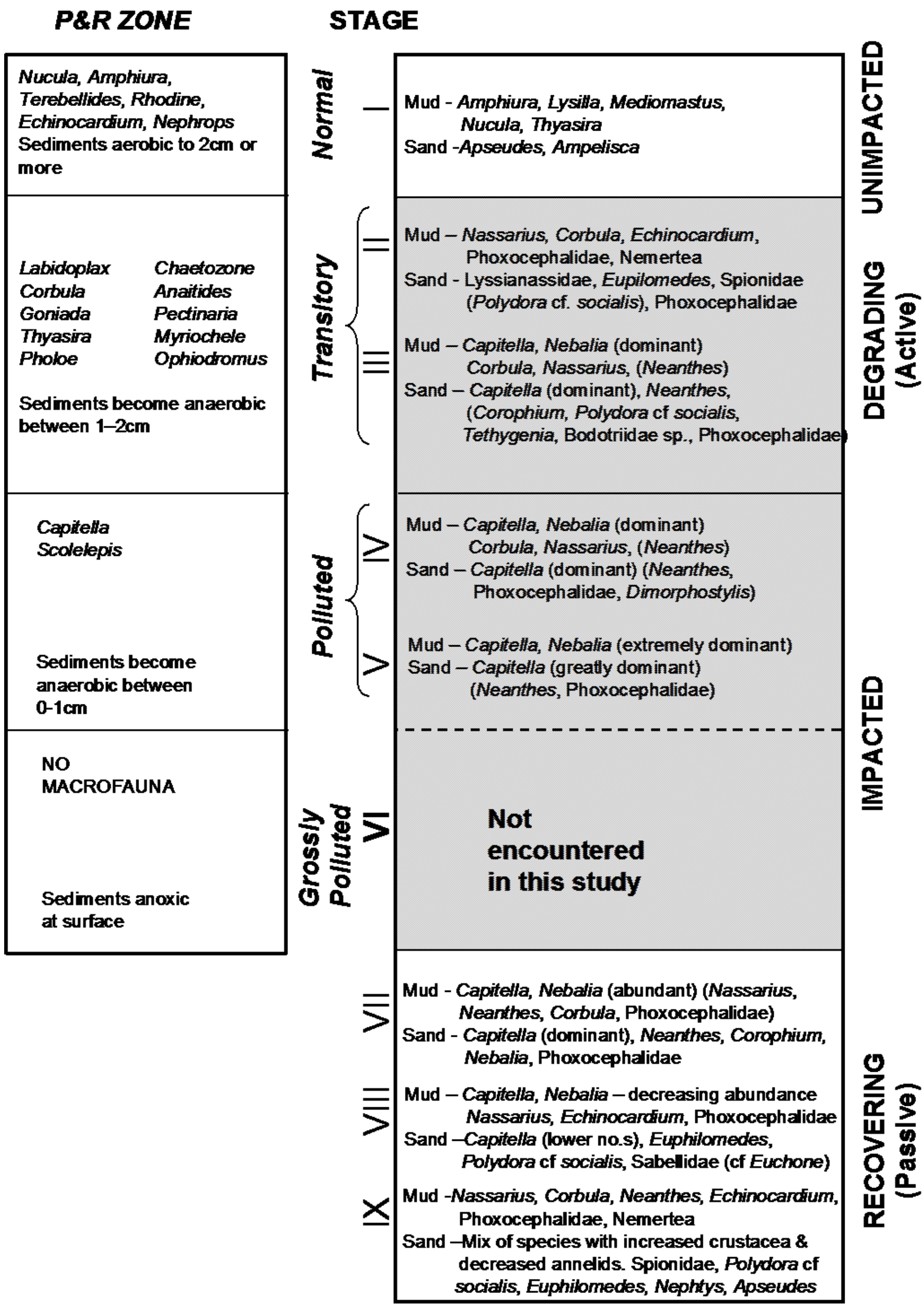
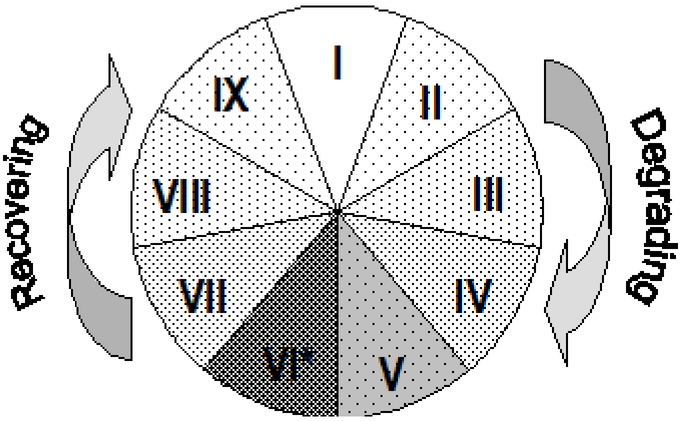


Figure 3.19: Comparison of main indicator organisms with P&R model (1978) identified as part of previous research undertaken in this region (Macleod et al. 2004).



* Indicates conditions not observed in this study
Suggest stage IX is sufficiently recovered for restocking

STAGE – Category		STAGE – Description	
I	- Unimpacted	I	- No evidence of farm impact
II	- Minor Effects	II	- Slight infaunal & community change observed
III	- Moderate Effects	III	- Clear change in infauna & chemistry
IV	- Major Effects (1)	IV	- Major change in infauna & chemistry
V	- Major Effects (2)	V	- Bacterial mats evident, outgassing on disturbance
VI*	- Severe Effects	VI*	- Anoxic/ abiotic, spontaneous outgassing
VII	- Major Effects	VII	- Monospecific fauna, major chemistry effects
VIII	- Moderate Effects	VIII	- Fauna recovering, chemistry still clearly effected
IX	- Minor Effects	IX	- Largely recovered, although slight faunal/ chemical effects still apparent

Figure 3.20: Impact and recovery stages identified as part of previous research undertaken in this region (Macleod et al. 2004).

Chapter 4 Recommendations With Respect To Knowledge Gaps and Future Monitoring

4.1 WATER COLUMN ASSESSMENT

4.1.1 Assessment of Current Monitoring Approach

The current water column monitoring program that includes monthly sampling (fortnightly in Feb/Mar/Apr) at 15 sites, 9 in the D'Entrecasteaux Channel MFDP and 5 in the Huon MFDP areas and a control site at Recherche Bay is providing a robust whole of ecosystem assessment. This includes an assessment of current ecological functioning and the capacity to assess longer term changes using data from previous studies. However, there does appear to be redundancy in some of the parameters measured and there are clear efficiencies to be gained in data handling and assimilation that will help facilitate a more responsive and informative monitoring program.

Data handling

- A huge part of compiling this review was spent extracting and compiling data into a format that would allow meaningful comparisons between related ecological parameters within and between data sets. Essentially, for the BEMP alone 5 separate data sets come in via different sources, AST- nutrients/Chl a, CSIRO-nutrients, Aquenal-physiochemical parameters, AST phytoplankton count data, CSIRO HPLC. Whilst there was reasonable consistency, differences in dates, label formats, site names etc. made merging the data incredibly time consuming. Going forward it will be important to develop new procedures for providing results that will assist data assimilation and analysis more time efficient. This could also include the development of a more sophisticated central data base.
- Methodology and analytical techniques will inevitably change to some extent through time. It is critical that detailed procedures of the methods/analysis are documented and accessible from a central source/location to assist reviews such as this.
- There have been ongoing discussions surrounding the compatibility of ammonium analysis from the CSIRO and AST laboratories, including an inter-laboratory comparison. Given the recent move to have AST analyse future samples it is important that a potential correction factor is fully investigated to ensure the benefits of a long term data set of this key system indicator.

Monitoring

- The current monitoring program was based on the best available information at the time of development. The data now available through the BEMP period provides an ideal opportunity re-assess the efficacy of the current suite of parameters, spatial distribution of sites and sample frequency to detect changes in ecological function
- Salinity measured during the 2009-2012 BEMP sampling exceeds what is probable in the field. The cause has since been identified and rectified for subsequent sampling.
- Phytoplankton biomass measured via HPLC and spectrophotometry give extremely similar results and hence there is redundancy in the monitoring program (but see following point).
- Phytoplankton composition is currently measured via two techniques HPLC and cell counts. Whilst they clearly provide different insights into plankton dynamics, running both comes at considerable costs to the program. From a system understanding, HPLC provides a more comprehensive assessment of phytoplankton dynamics whereas the counts data provides detail at the species level, critical to ongoing farm management. Further discussion of the relative merits of these 2 techniques going forward is warranted in the context of key stakeholder needs.

Evaluation

- The development of proposed baseline and trigger values for the region provided by Thompson et al. (2008) is comprehensive, however moving forward it will be important to clarify the degree of pooling of data (or lack of) across spatial and temporal scales used to develop the baselines and trigger values to ensure comparable calculations and statistics are used when assessing performance. The BEMP data also suggests that some modifications to the proposed trigger levels are warranted.
- This assessment only represents the tip of the ice berg in terms of mining the wealth of data now available for the Huon-Channel. For instance, the data was presented and reviewed largely at the regional (MFDP) and seasonal scales given that this largely reflects the optimal scales for detecting system wide responses. There is much information contained at the site level that could greatly assist local management e.g. at the farm scale.
- For 2 key ecosystem indicators, dissolved oxygen and phytoplankton composition, time did not permit extraction of additional data sets from the HES (count data) and Aquafin CRC (count data and DO). Access to this data will enhance our understanding of long term system dynamics including the influence of finfish aquaculture in the region.

4.2 SEDIMENT ASSESSMENT

4.2.1 Assessment of Current Monitoring Approach

Redox and sulphide measurements provide a credible and convincing assessment of the biogeochemistry underpinning sediment condition over the study system through time. These measurements provide a complementary picture of environmental status: redox providing a picture of the oxidative capacity of the sediments, and sulphide providing an indication of the anaerobic context. Redox and sulphide are relatively inexpensive to obtain, as measurement is made on sediment samples directly using ion selective electrodes in the field or laboratory; neither measure requires samples to be processed through commercial analytical laboratories. As a consequence the results can be available almost immediately. Because these are considered as “field measures” there may be a perception that the analytical approach and measurement are more robust and that such approaches can tolerate more flexibility in the techniques than would be the case with samples sent to an accredited lab. In fact this is not the case. Both redox and sulphide measures need to be taken very carefully, as the techniques are highly sensitive to operator/experimental variability. The redox/sulphide data in the present study are particularly valuable because the data are highly reliable; all samples were collected and processed by the same operator, the method and approaches used were consistent throughout and have been outlined in detail. We would suggest that for redox/sulphide data to be considered reliable this level of attention to detail is essential, if not then the risk of triggering on these measures (i.e. Type I error – false positive) is greatly increased.

It is difficult to assess the value of the stable isotope analysis as it was only conducted at a single point during the study period. Therefore, there was no opportunity to make temporal comparisons. As a one off measure it does not appear to yield any increase in understanding of system conditions or performance over that obtained through other measures (i.e. biogeochemical analyses and the biological assessments in combination).

Recommended geochemical trigger levels need to be adjusted for the sediment assessments to take into account the importance of the direction, scale and magnitude of any change where a significant difference is observed.

The benthic infaunal assessments were only undertaken once at the start of the survey period, but that data set has been very useful. The ecological information has provided a clear assessment of the condition of the sedimentary environment at that point in time. Comparison with control site data from previous surveys suggests that there have been some changes over time, however, the interrogation of community data indicates no evidence of organic enrichment or any specific deterioration in environmental condition. The fact that we were able to assess the conditions at species level allows us to be more confident that observed changes are not indicative of deterioration in conditions. Earlier research on farm-based impacts of fin-fish aquaculture suggested that comparisons at family level provided sufficient taxonomic distinction to be able to detect farm based effects and major ecological changes (Macleod and Forbes, 2004b). Whilst this recommendation still applies comparison at species level allows more subtle variations to be assessed.

With respect to the BEMP, as it is currently defined, it is proposed that full infaunal assessments be undertaken every 4 years (Thompson et al. 2008). This would see the benthic infaunal survey repeated in the coming year. Whilst the farm-based monitoring controls do provide points of comparison for many of the BEMP sites the timeframes and seasonality of sampling are inconsistent and therefore make it harder to discern broader temporal trends where they might exist. Benthic community analysis of all sites at regular intervals (i.e. 4-5 year timeframe) has value in that it provides the ability to compare how biogeochemistry relates to ecology along with some level of interpretation as to the cause and trajectory of any observed changes/trends.

The value and relevance of the current control location has been questioned at several points in this review. We suggest that it may be worth considering an alternate control site. In doing so we recommend taking into account:

- the stated program objectives

- the compatibility with other study sites (in ecological terms and in relation to potential influences).

4.3 KNOWLEDGE GAPS

Understanding the major sources, sinks and internal transformation of nutrients is integral to interpreting the spatial and temporal patterns of the key ecosystem indicators and the likely drivers. Following this evaluation a number of knowledge gaps were evident:

Hydrodynamics

A significant amount of nutrients are exchanged with the ocean at the southern and northern boundaries of the D'Entrecasteaux Channel. The ability to evaluate the role of oceanic exchange and how this might influence ecological processes in the region is limited without a hydrodynamic/transport model. Such a model, in combination with nutrient data collected at the boundary sites, would enable a more accurate estimation of the fluxes across the oceanic boundaries.

Benthic mineralisation

Benthic sediments play a crucial role in determining the transformation and fate of organic matter and nutrients. At present, our understanding of the contribution of sediment remineralisation of organic matter (e.g. from catchment sources, fish faeces and feed, and internal phytoplankton production) to water column nutrient pools is limited.

Reactivity of river inputs

River inputs represent a major source of nitrogen to the D'Entrecasteaux Channel and the Huon Estuary (700-1100 TN t/y during BEMP) but only a small portion (44-65 DIN t/y during BEMP) is in dissolved inorganic form. The dissolved inorganic form is considered to represent the biological available fraction. However, there is growing evidence that dissolved organic nitrogen, which is a major component of river nitrogen entering the system, is more biologically available than previously suspected (e.g. Seitzinger & Sanders 1997, Seitzinger et al. 2002). This may have important implications for how we consider riverine inputs of nitrogen relative to other sources and may warrant further investigation.

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Appendix 1

SCHEDULE 3 BEMP – D'Entrecasteaux Channel and Huon River and Port Esperance Marine Farming Development Plan areas.

BROAD SCALE MONITORING REQUIREMENTS

1. Outline of Requirements

This monitoring is to be undertaken, according to the specifications in this Schedule or as otherwise directed by the Director Marine Resources, Department of Primary Industries, Parks, Water and Environment (the Department).

In this schedule:

"the Secretary" means the Secretary, Department of Primary Industries, Parks, Water and Environment or any person authorised to act on the Secretary's behalf

"the Director" means the Director, Marine Resources, the Department of Primary Industries, Parks, Water and Environment or any person authorised to act on the Director's behalf "the Department" means the Department of Primary Industries, Parks, Water and Environment.

Monitoring required by this licence schedule must be undertaken by a consultant. All finfish licence holders in the Marine Farming Development Plan area to which this licence relates are required to participate in this monitoring. The Department recognises that there are potential efficiencies by having the same consultant represent all licence holders in the MFDP area.

Reporting of monitoring data is to be submitted by the licence holder on a monthly basis, with an annual report to be provided in July each year.

Each sampling event will involve obtaining samples at all sites shown on the enclosed map. Site positions must be located and recorded using differential GPS (DGPS). Coordinate projections are specified in GDA 94, MGA Zone 55. The frequency of sampling events and sequence of sampling must be consistent with the requirements outlined in this schedule.

The licence holder must notify the Marine Farming Branch [ph (03) 62 33 3370, or e-mail: mfarming.environment@dpipwe.tas.gov.au] of the sampling date chosen at least 48 hrs prior to conducting the survey to enable a Marine Environmental officer to be present to audit the survey.

The monitoring must include the following components, as detailed in Section 2 of this Schedule unless otherwise directed by the Secretary:

	Matrix	Component	Analyte/Parameter
2.1	Sediment	Biota	Infauna
		Chemistry	Redox, Stable Isotopes, Particle size, Sulphide
2.2	Water	Nutrients	Ammonia (total ammoniacal nitrogen), Nitrate, Phosphate, Silica, Total Nitrogen, Total Phosphorous
		Dissolved Oxygen	DO, Temperature, Salinity, Saturation
		Phytoplankton	Pigments by way of HPLC, cell counts, chlorophyll *a,* abundance

2. Broad scale Monitoring Survey Specifications

Sampling details:

Samples must be collected at the prescribed sampling locations. A differential GPS (DGPS) must be used on sampling events when sediment *and* water quality samples are being collected and a non-differential unit can be used when sampling water quality sites only. Sample positions are specified using GDA 94, MGA Zone 55.

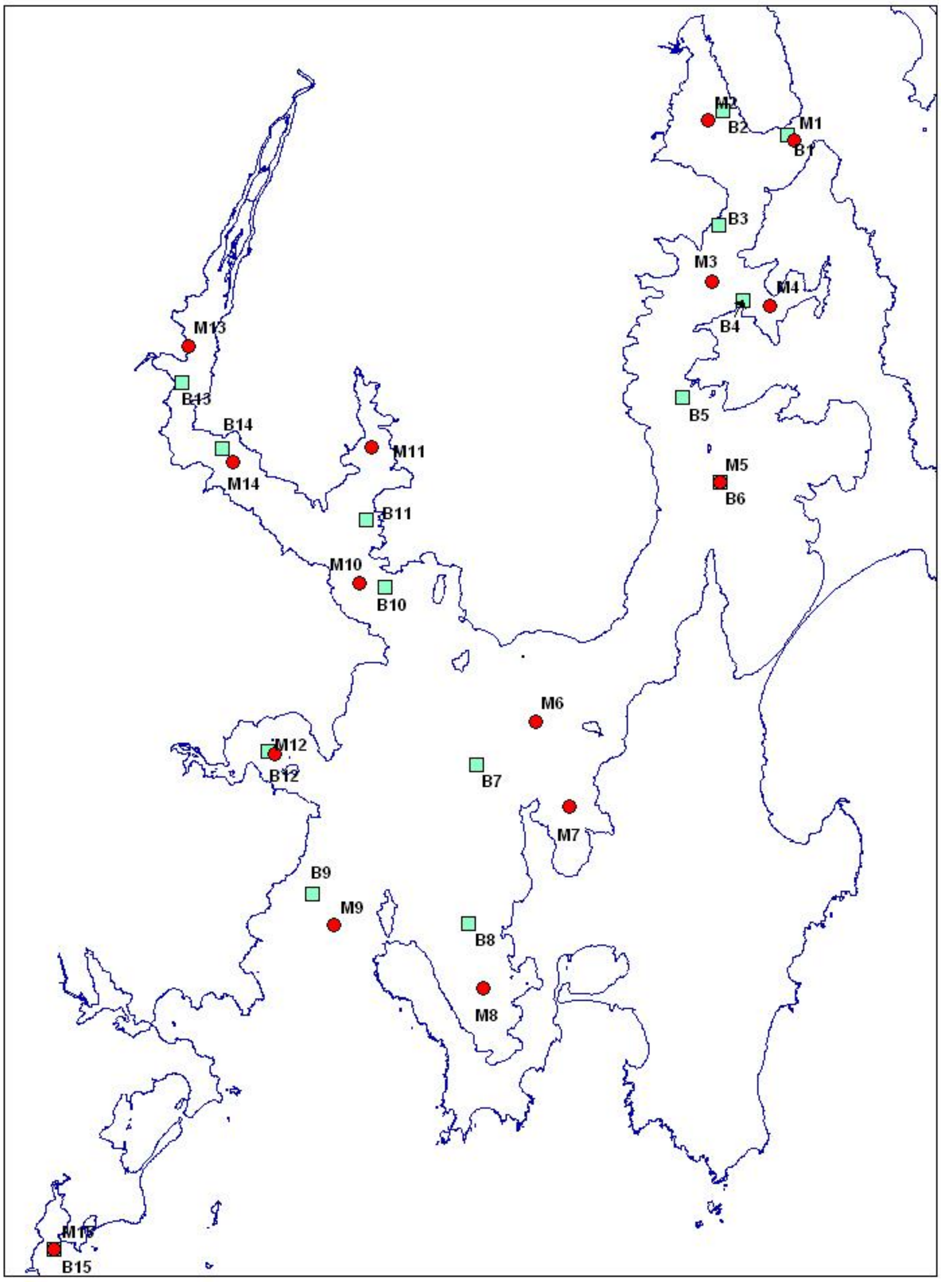

Figure 1: Broadscale environmental monitoring program sampling stations. ● water quality sites □ sediment sites

All sites in the D'Entrecasteaux Channel MFDP must be sampled first, followed by the Huon MFDP sites. Huon River sampling should commence no earlier than 10.00 am and no later than 12.00 pm to allow for diurnal migration effects in phytoplankton.

Table 1: Sample site descriptions.

Site Name	Type	Location	MFDP area	Classification	Easting	Northing
M1	Water	Northern Boundary	Boundary	Channel	527684.3	5232077.5
M2	Water	Northwest Bay	D'Entrecasteaux	Bay	523534.9	5233037.0
M3	Water	Upper Mid Channel	D'Entrecasteaux	Channel	523752.2	5225262.6
M4	Water	Barnes Bay	D'Entrecasteaux	Bay	526513.4	5224119.7
M5	Water	Green Island	D'Entrecasteaux	Channel	524124.6	5215636.6
M6	Water	Central Mid Channel	D'Entrecasteaux	Channel	515244.9	5204098.0
M7	Water	Little Taylors Bay	D'Entrecasteaux	Bay	516856.5	5200018.5
M8	Water	Great Taylors Bay	D'Entrecasteaux	Bay	512706.9	5191231.9
M9	Water	Southern Boundary	Boundary	Channel	505506.1	5194295.7
M10	Water	Lower Huon	Huon	Channel	506737.0	5210741.8
M11	Water	Cygnet	Huon	Bay	507312.3	5217304.4
M12	Water	Dover	Huon	Bay	502675.3	5202537.7
M13	Water	Upper Huon	Huon	Channel	498550.0	5222185.0
M14	Water	Mid Huon	Huon	Channel	500649.9	5216586.4
M15	Water	Recherche	Control	Control (Bay)	492064.0	5178637.0
B1	Sediment	Northern Boundary	Boundary		527388.0	5232358.0
B2	Sediment	Northwest Bay	D'Entrecasteaux		524236.0	5233512.1
B3	Sediment	Sheppards Point	D'Entrecasteaux		524089.1	5227962.0
B4	Sediment	Roberts Point	D'Entrecasteaux		525224.1	5224328.0
B5	Sediment	Soldiers Point	D'Entrecasteaux		522337.1	5219689.9
B6	Sediment	Green Island	D'Entrecasteaux		524124.6	5215636.6
B7	Sediment	Zuidpool	D'Entrecasteaux		512422.5	5202009.5
B8	Sediment	Great Taylors Bay	D'Entrecasteaux		512028.0	5194349.6
B9	Sediment	Lippies Point	Boundary		504494.8	5195744.8
B10	Sediment	Garden Island	Huon		507993.2	5210570.8
B11	Sediment	Deep Bay	Huon		507095.0	5213795.3
B12	Sediment	Dover	Huon		502357.1	5202638.7
B13	Sediment	Pillings Bay	Huon		498167.8	5220383.2
B14	Sediment	Brabazon Point	Huon		500172.0	5217257.8
B15	Sediment	Recherche Bay	Control		492064.0	5178637.0

The following details should be recorded and reported for each sample site on each sampling event:

- time & date (the noted time must be used for all samples collected at the site, including samples collected at depth)
- vessel
- location (including logged DGPS fix in GDA 94, Zone 55)
- personnel
- weather conditions (wind, rain, cloud cover)
- what samples were collected

- sample identification codes (detailing the site name/date or survey number) for each type of sample recorded on data sheet. With the exception of date and time, these site codes must remain the same for all sampling events.
- any miscellaneous notes or observations, including replicate or any additional QA/QC sampling included.

2.1 Sediment Monitoring

Benthic sampling is to be conducted at all sites in March each year.

Table 2: Parameters to be assessed by way of benthic sampling.

	Matrix	Component	Analyte/Parameter
2.1	Sediment	Biota	Infauna
		Chemistry	Redox, Stable Isotopes, Particle size, Sulphide

Any person(s) undertaking monitoring must be covered by appropriate permits specific to the work. Permits include:

1. *Living Marine Resources Management Act 1995* (LMRMA): Pursuant to s12 LMRMA, any person undertaking environmental monitoring in State waters must obtain a permit to do so insofar as such monitoring involves a breach of that Act.

2. *Threatened Species Protection Act 1995* (TSPA): Any person knowingly collecting any specimen of a listed taxon of flora or fauna can only do so if covered by a permit issued pursuant to s51 of the TSPA. Further details can be obtained from threatenedspecies.enquiries@dpipwe.tas.gov.au.

2.1.1 Infauna

Infaunal samples must be collected and retained (suitably preserved) every March. A full assessment of collected infauna must be undertaken on the initial sample collection and every 4 years thereafter. Assessment of the samples retained from the intervening years may be required where sediment geo-chemistry parameters and/or the 4-yearly benthic faunal parameters are triggered. This assessment is to be performed in accordance with the "benthic faunal analysis" protocols outlined below.

Individual benthic grab samples for each annual sampling event must be processed (but not identified) and retained for at least 4 years in accordance with "Preservation/Retention of samples" below.

Benthic faunal analysis:

Triplicate Van Veen grabs or diver collected wide-diameter core samples (150mm diameter x depth 100mm) are to be taken at each of the sample sites specified. Each benthic sample should be sieved through a 1 mm sieve and all fauna identified to family level and counted. It will be necessary however, to take the identification of several taxa down to species level. These groups currently include (but are not limited to) the Family Capitellidae, Family Turitellidae and all introduced marine species.

Each benthic sample must be processed separately and identically.

Preservation/Retention of Samples:

All fauna collected must be preserved in formaldehyde solution. Organisms must be transferred to 70 % alcohol for long-term storage. Storage jars must be labelled (inside using waterproof paper annotated in pencil, and outside) with details of date of collection, site location, collection method, and collectors' and identifiers' name (where applicable). The jars are to be stored for at least 4 years in a readily accessible place so that confirmation of identification can be undertaken at a later date if required.

2.1.2 Sediment Chemistry

Visual assessment, redox and sulphide

Triplicate sediment cores are to be taken using a perspex corer with an internal diameter of at least 50 mm at each sample site specified. A written description of each core recording the following parameters is required:

- length of core measured in millimetres with a ruler;
- sediment colour, from the surface to deeper layers using a Munsell soil chart;
- visible animal and plant life;
- gas vesicles if present and the size and position of the vesicles in the sediment;
- any sediment smell indicating for example, the presence/absence of hydrogen sulphide;

Redox and sulphide

The following protocols for redox and sulphide measurement have been drawn from Macleod *et al.* (2004). Redox potential and sulphide concentration measurements are to be taken from each sediment core. Both redox and sulphide should be measured at 3cm depth. There are a variety of redox probes available; single cell and combination electrodes. For ease of sampling the combination electrodes are recommended. Prior to each set of measurements being taken the probe should be calibrated. Pre-packaged calibration solutions can be purchased. As calibration is sensitive to temperature it is important to note the temperature of both the calibration solution and the sample at the time of sampling. It is best if these temperatures are comparable.

Corrected redox results and raw data for each core are to be reported in millivolts at 3cm depth. Depending on the sediment condition the measurement may settle quickly or it may take a few minutes. Redox measures the oxidation/reduction potential of the sediments by determining the availability of free hydroxyl ions. Measurement will itself affect this level and therefore the reading on the meter will continue to decline (albeit slowly) whilst the measurement is being made. Consequently it is not necessary for the probe to stabilise completely before taking a reading, simply ensure that the rate of decline has steadied. Note: that an error level of +/- 10-20mV in the final reading is acceptable.

There are a variety of different probes available for the measurement of sulphide concentration, but again a combination electrode is recommended. Each manufacturer will have slightly different specifications regarding use, sensitivity and calibration and these should be followed carefully. Prior to each sampling occasion, a Sulphide Anti-Oxidant Buffer (SAOB) must be prepared (see technique below) and standard curves should be established for calibration.

A sediment sub-sample (2ml) is extracted from the port in the side of the core tube using a 5ml syringe, and placed in a glass vial. SAOB (2ml) is added to each jar and sulphide concentration measured (mV) by placing the probe into the jar, and slowly stirring the sediment/buffer mix until the reading stabilises. The mV readings can be converted to sulphide concentration using the calibration curve. Samples should be collected and converted sulphide results (μM) and raw data (mV) are to be reported for 3cm depth. (TAFI, 2004).

Preparation of Sulphide Anti-Oxidant Buffer Solution (SAOB):

The SAOB solution can be purchased or it can be prepared by adding 20.0g of NaOH (Sodium Hydroxide pellets) and 17.9g of EDTA (Ethylenediaminetetra-acetic acid) in a 250ml volumetric flask and diluting to volume with distilled water. This solution should be refrigerated until required. Just prior to use add 8.75g of ascorbic acid for every 250ml of solution required. Once ascorbic acid has been added, the solution will only remain viable for 3 hours.

Calibration of the Sulphide Probe

Macleod *et al.* (2004) provides information on calibration procedures for a Cole-Parmer 27502-40 silver/sulphide electrode. If an alternative probe is to be used, it is recommended that manufacturer guidelines are referred to for specific calibration details. Details of the probes used should be included in the report.

Particle size Analysis

A subsample of sediment from the top 100mm of each core should be placed in container of known volume (fill to top). Gently wet sieve each sample through a sieve stack of 4, 2, 1 mm, 500 μm, 250 μm, 125 μm, 63 μm either by hand or using a sieve shaker. The less than 63 μm fraction is allowed to drain away, i.e. not collected. The material remaining on each sieve is carefully removed and placed in a graduated cylinder. A known volume of water is added (this volume should remain consistent throughout the procedure). The volume of sediment from this fraction is measured as the displaced volume. This process should be repeated for all sieve fractions.

The sum of all sieve fractions subtracted from the initial volume will give the less than 63 μm fraction. The data is to be provided in an Excel spreadsheet and graphed as cumulative percentages.

Alternatively samples can be provided to an external laboratory for analysis, in which case the resultant analytical report should be submitted.

Stable Isotope Analysis

Analysis of collected stable isotope samples must be undertaken in March every 4 years (commencing in 2009). In all other instances individual stable isotope samples must be collected and retained in appropriate storage for at least 3 years.

The top 3cm of each core is to be oven dried at 60 °C prior to analysis of total organic carbon (loss on ignition at 450 °C in a muffle furnace for 4 hours), 0.5-1.0g of the upper 3cm layer is to be retained for combined ^{12}C: ^{13}C, ^{14}N: ^{15}N stable isotope analysis and C:N analysis. The analysis of carbon and nitrogen isotopes and C:N ratios are to be conducted simultaneously by stable isotope mass spectrometry.

2.2 Water Quality Monitoring

Frequency of sampling

There will be a total of 15 sampling events on an annual basis. Sampling is to be undertaken on a monthly basis from May through January, and fortnightly in February, March and April.

At each sampling site nutrient and phytoplankton samples must be collected, and dissolved oxygen , temperature and salinity profiles measured, at the depths specified in Table 3, also refer Appendix 1.

Appropriate sample containers for all aspects of the water quality analyses must be sourced from a NATA accredited laboratory. Contact the laboratory for relevant storage, transport and sample submission protocols.

Table 3: Sampling depths for particular analytes/parameters.

Matrix	*Parameter*	*Analyte*	*Sample depth*			
2.2 Water	Nutrients		Surface (0.1m)	5m	1m above seabed	12m depth integrated
		TN	x		x	

		TP	x		x	
		Ammonia (total ammonical nitrogen)	x		x	
		nitrate	x		x	
		phosphate	x		x	
		silica	x		x	
	Dissolved Oxygen	DO	x	x	x	
		Temperature	x	x	x	
		Salinity	x	x	x	
		DO saturation (derived from temp/sal)	x	x	x	
	Phytoplankton	Pigments by way of HPLC (including Chlorophyll *a)*				x
		cell counts				x
		Abundance/diversity				x

2.2.1 Nutrients

For all testing, laboratories must be NATA accredited, or recognised research laboratories and be able to report all dissolved nutrients to < or equal to 0.005 mg/L as N or P as applicable. The following requirements reflect standard sampling protocols for a NATA accredited laboratory, however the chosen laboratory(s) should be contacted for specific sample collection, handling and submission requirements. The laboratory(s) must be willing to perform spikes on at least 5% of samples submitted and provide QC data to clients.

Analytical Services Tasmania (AST) is a NATA accredited laboratory available to do the above testing and CSIRO marine laboratories (Hobart) is a recognised research laboratory.

Sample Collection for Nutrient Determination

A Niskin bottle must be used for the collection of all bottom samples. Surface samples can be collected using a pole sampler with Teflon sampling bottle. This bottle must be rinsed 3 times (whilst attached to the pole) at each site before collecting a sample. A single nutrient sample must be collected at the surface and 1m above the seabed at each site. The analytes to be measured in each sample are specified in Table 3 and appendix 1.

All methods and equipment used in water quality sampling must meet the relevant Australian and/or ISO Standard (AS/NZS 1998: Australian/New Zealand AS/NZS 5667.1:1998. *Water Quality – Sampling – Guidance on the design of sampling Programs, Sampling Techniques and the Preservation and Handling of samples.*

Field filtration of samples should be instigated at the time of collection to guarantee the soluble nutrient concentrations do not alter. Filtration can be undertaken in the field using disposable hermetically sealed syringes and 0.45μm PES filters.

Before collecting any samples the following contamination issues must be noted and field personnel advised accordingly.

Contamination prevention

- Disposable powder free, vinyl (or latex, nitrile) gloves must be worn during sampling.
- Glass containers must **not** be used for nutrient samples to be analysed for silica.
- Do not touch the filter or syringe tips, Niskin bottle spigot, insides of the sample containers or caps.
- Do not smoke. Avoid vapours from the engine or any other source (if safe to do so, turn engine(s) off whilst collecting samples).
- Ensure eski/transport container is clean.
- Leave bottle lids upside down while sub sampling.
- *Do not store samples or sampling equipment near fish products*.
- Be mindful of potential contamination from the boat, prop wash and fuel. Aim for a representative sample from each site by observing wind, tide and current conditions.

Note that due to the sensitivity of the analysis required and the risks of contamination, smokers must not be involved in handling any of the sampling gear, containers or equipment, particularly the Niskin bottle.

Sample collection and Filtration procedure for soluble nutrients

- Before collecting the sample to be filtered, the sample container should be rinsed three times with sampled water from the niskin bottle, shaking with the cap loosely in place after each rinse.
- Once the container has been rinsed as above, collect a sample
- Shake sample bottle thoroughly
- *Assemble the filtration equipment:* Remove 30mL syringe from packet. Open the sealed package containing the filter unit and connect the filter unit to the end of the syringe by screwing it on to the syringe Luer lock.
- *Rinse syringe:* Shake the sample bottle thoroughly. Remove the plunger from the syringe and pour ~5 - 10mL of sample into the syringe. Rinse syringe barrel by swirling with the sample. Discard rinse water from the top of the syringe (not through the filter unit).
- *Collect the filtered sample:* Fill the syringe with the well-mixed sample. Replace the plunger and discard the first 5 – 10 drops. Collect the remainder of the filtered water in a 50mL tube labelled "Filtered for Dissolved Nutrients".
- If the syringe filter fouls before the sample has been completely filtered withdraw the plunger 1 – 2mm, invert the syringe so that the point is up, remove the filter unit and replace with a new unit. Discard ~5 drops and continue to filter. If this continues to be a problem discuss this with the laboratory staff.
- One pass through the syringe will deliver ~ 30mL of sample. This is sufficient for analysis of soluble nutrients.
- Discard used syringe and filter.

Total nutrients

- The remainder of the sample (~ 150 - 200mL) is used for total nutrient determination.
- Leave a headspace (~ 10 % of the container volume) for aeration, mixing and thermal expansion that occurs during freezing.
- Samples should be bagged in clean plastic bags in the field to prevent contamination.

Preservation

- Return to laboratory immediately in a chilled container (4°C or less for < 24h). If this is not possible, freeze (-20°C) as soon after collection and as rapidly as possible (ensure containers are not overfilled causing containers to bulge excessively). **Ensure the freezer has not been used for storage of material that could contaminate the sample, e.g. fish products.**

2.2.2 Dissolved Oxygen

Dissolved oxygen is to be measured using an optical probe or membrane meter. Measurements must be taken at the prescribed depths in accordance with the operation manual supplied by the manufacturer. The dissolved oxygen probe or meter must be calibrated in accordance with the manufacturer's requirements and any calibration procedures documented for future reference and verification. Calibration solutions should be obtained from a NATA accredited laboratory.

All DO recording is to be undertaken at the same time of day for each site (+/- 2 hours). All sites in the D'Entrecasteaux Channel MFDP must be sampled first, followed by the Huon MFDP sites.

2.2.3 Phytoplankton

Sampling should be undertaken in the morning and samples collected from a site at approximately the same time of day each month. **Given the variability in detection of *Gymnodinium catenatum* due to diurnal vertical migration in the Huon River, it is critical that sampling in this region commence no earlier than 10am and no later than 12pm.**

Analysis of phytoplankton must be undertaken by a NATA accredited laboratory. Note that HPLC must be used for pigment analyses. CSIRO laboratories, Hobart have the capacity to analyse samples using this methodology,

Depth integrated samples must be collected at each sample site. A 14 m length of flexible clear plastic tubing (minimum external diameter 30mm), with 1m graduations should be used. The tube should be weighted at the bottom end and lowered through the water column at approximately 1m/sec to reach a depth of 12 m or within 2 m of the bottom (whichever is deepest). The tube should then be sealed using a bung at the surface to trap the water in the tube. A rope attached to the open (bottom) end is used to retrieve the tube and sample. When brought aboard the boat, the contents of the tube must be poured into a container. Multiple deployments may be necessary to acquire sufficient sample volume. Should this occur, the sampling depth and total sampled volume (including number of dips) must be recorded for the particular sample site. The sample(s) should be gently mixed to achieve homogeneity and an appropriate amount transferred to a suitable storage container for each analytical process (refer to Aquafin CRC broadscale technical report (2005) for detail on integrated sampling methodology).

Once collected, samples must be stored in a chilled light proof container (4°C or less for < 24h). Where possible, samples should arrive at the laboratory on the same day they are collected. Contact the laboratory(s) for specific sample volume, preservation, storage and transport requirements for the analysis of the following:

- Phytoplankton taxonomy – full count (including relative abundance).
  Chlorophyll and carotenoid pigments by way of HPLC

2.2.4 QA/QC Requirements

QA/QC requirements specific to this monitoring schedule are detailed in Table 4. Where applicable, laboratory reports must provide detail on the reporting limits for analytes.

Table 4: Details of QA/QC requirements for monitoring conducted.

Parameter	Required QA/QC	Minimum frequency	Variation
Positioning	A State Permanent Mark (SPM) and recorded sample site positions including site position, time and date information as attribute data and be in DXF/ESRI shape file format	Each sampling event	<3m
Nutrients	A duplicate filtered sample from one randomly selected sample site (surface and bottom).	x1 per sampling event	<20%
	Field blank (should be a seawater equivalent blank from laboratory). Transferred and filtered on board.	x1 per sampling event	<10%

	Trip blank (should be a seawater equivalent blank from laboratory), taken out of eski, bagged and frozen, but not opened until analysis.	x1 per sampling event	<10%
	Lab spiked	>5% of all samples submitted	80-120%
	Laboratory intercomparison. Duplicate split samples from 3 random stations (both surface and bottom) should be analysed in an alternative independent laboratory.	x1 per year	<10%
Phytoplankton	Analysis of a duplicate sample, drawn from a single integrated sample.	10% of all samples submitted	± 20%
	Staff from the same laboratory to conduct a 'blind' recount of the same sample. Recounts should yield precisions (density of top 10 species) that average ± 10% of initial count.	x1 for every 3 sampling events.	± 20%

Note: The Department must be advised of any intended interlaboratory comparative sample analyses **prior** to the sampling event.

Sampling Equipment Maintenance

Sampling apparatus such as Niskin™ bottles must be inspected monthly prior to sampling for evidence of biological or inorganic films on the interior walls, valves or end caps. Springs (latex, silicon or metal) need to be regularly inspected and replaced. Metal springs whose coatings have worn through must be replaced and any other sources of rust must be eliminated or adequately protected from corrosion. Accumulated microbial films should be removed using suitable brushes, scouring agents and detergent solutions. The scouring agents and/or detergents used should be checked to be certain they are nutrient-free. Rinse thoroughly and store dry.

3. Reporting of Results to the Department

3.1.1 Routine data reporting

Routine monthly data reporting must be provided in accordance with Annexure I to this monitoring schedule.

An annual report must be submitted to the Department in July according to Annexure II to this monitoring schedule, and must include the analyses of all data collected through to the end of April for the reporting year.

All relevant permit details must be reported and all documents lodged with the Department must be *approved by and submitted in full by the lease holder*

References

Macleod, C., Forbes, S., Bisset, A., Burke, C., Crawford, C., Holdsworth, D., Nichols, P., Revill, A., and Volkman, J. (2004) Guide to the assessment of sediment condition at marine finfish farms. Aquafin CRC Project 4.1 Extension report to FRDC. Tasmanian Aquaculture & Fisheries Institute.

Thompson, P., Wild-Allen, K., Macleod, C., Swadling, K., Blackburn, S., Skerratt, J. and Volkman, J. Monitoring the Huon Estuary and D'Entrecasteaux Channel for the Environmental Effects of Finfish Aquaculture. *June 2008*
Aquafin CRC Project 4.2(2)(FRDC Project No. 2001/047)

AS/NZS 5667.1:1998: Water quality - Sampling - Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples.

Annexure I

MONTHLY BROADSCALE MONITORING REPORT

Water quality monitoring data must be reported to the Marine Farming Branch on a monthly basis, within one week of laboratory results being reported by the laboratory.

In the event that any unusual observations are made either during sampling, as a result of laboratory analyses (eg QA/QC issues) or in any aspect of the preparation of reported data, these should be noted and accompany the data files reported by email.

Email coversheet including the following details

Lease holders' names

Name of Person(s) / organisation conducting environmental assessment:

Details of permits held authorising sampling (LMRMA/TSPA), including permit numbers and expiry dates.

Details of all equipment used for sampling.

Data: A list specifying all data files supplied (lab reports, original data, data plots etc). Original, raw data shall be in electronic form (either on disc or via email) which is compatible with the database system and software currently used by the Department.

The data must include:

- Information consistent with the "Sampling Details" section of the monitoring schedule to which this annexure relates, for the most recent sampling event in excel format;
- DGPS files DXF (Drawing Exchange Format)/ESRI (Environmental Systems Research Institute) shape file format providing position fixes and at least one spm (State permanent mark)reference fix. Data files are to include date and time attributes.

Water Quality:

- Full laboratory reports in PDF and csv file format for the most recent sampling event, together with an excel based data template file (as determined by the Department) including temporal analyte data collected from sample sites specified in the monitoring schedule to which this Annexure relates;
- Graphical and tabular presentation of all analytes referred to in the monitoring schedule to which this Annexure relates. The presentation of results is to include reported analyte values (by site, MFDP area and Bay/mid-channel sites) on a temporal basis (monthly/seasonal/annual).

Annexure II

ANNUAL BROADSCALE MONITORING REPORT

Lease holders' names

Name of Person(s) / organisation conducting environmental assessment:

Details of permits held authorising sampling (LMRMA/TSPA), including permit numbers and expiry dates.

Introduction:

Methods and results: The methods used for the assessment of each parameter, including laboratory sample collection protocols, sampling equipment. Results are to be presented in the same order as in the monitoring schedule requirements.

Data must be summarised in tables and graphs.

Interpretation: A comprehensive interpretation of the reported data and observed results must be included in the report. Any unusual results should be highlighted.

Data: Original, raw data shall be provided as hard copy and in electronic form (either on disc or via email) which is compatible with the database system and software currently used by the Department.

The data must include:

- Information consistent with the "sampling Details" section of the monitoring schedule to which this annexure relates, for the most recent sampling event;
- DGPS files DXF (Drawing Exchange Format)/ESRI (Environmental Systems Research Institute) shape file format providing position fixes and at least one spm (State permanent mark)reference fix. Data files are to include date and time attributes.

Where site-specific temporal data exists for any of the following parameters, comparative statistical analyses must be undertaken and an interpretation of results provided.

Sediment:

- description and interpretation of core profiles;
- interpretation (written and graphical) of redox results recorded from cores;
- interpretation (written and graphical) of sulphide results recorded from cores;
- interpretation (written and graphical) of sediment particle size analysis;
- interpretation (written and graphical) of stable isotope
- where relevant, an interpretation of results (written and graphical) and multivariate analyses of infaunal data.

Water Quality:

- Full laboratory reports in PDF and csv file format for the most recent sampling event, together with a Microsoft Excel based data template file (as determined by the Department) including temporal analyte data collected from sample sites specified in the monitoring schedule to which this Annexure relates;
- Interpretation (written and graphical/tabular) of all analytes referred to in the monitoring schedule to which this Annexure relates. The presentation of results is to include reported analyte values (by site, MFDP area and Bay/mid-channel sites) on a temporal basis (monthly/seasonal/annual). *Where relevant, an interpretation of analyte data must be presented relative to standard/baseline levels (% difference) and the trigger levels specified by the DPIPWE. The person(s) responsible for compiling the annual report must contact the DPIPWE for details on baseline and/or trigger levels prior to compiling the report.*
- Interpretation of QA/QC data specific to analyses performed over the previous 12 period.
- Discussion of any calibration-specific issues over the previous 12 month period.

APPENDIX I

Table 1: Sampling summary of each analyte:

Matrix	Component	Analyte/Parameter	Frequency	Total number of sites for each sampling event	Total number samples per site for each sampling event	Method
Sediment	**Biota**	• Infauna (baseline collection+id/ongoing collection only with infaunal re-evaluation every 4 years)	annual	**15**	**x 3 (seabed)**	benthic grab
	Chemistry	• Redox • stable isotopes (frequency of sample processing consistent with infauna, above) • particle size • sulphide	annual	**15**	**x 3 (seabed)**	benthic corer
Water Quality	**Nutrients**	• Ammonia (total ammoniacal nitrogen) • Nitrate • Phosphate • Silicon • TN • TP	monthly May-Jan, fortnightly Feb, March, April	**15**	**x 2 (surface/1m above seabed)**	Niskin bottle
	Dissolved Oxygen	• DO • Temperature • Salinity • DO saturation	monthly May-Jan, fortnightly Feb, March, April	**15**	**x 3 (Surface, 5m, 1m above seabed)**	DO/Temp/Salinity Meter.
	Phytoplankton	HPLC cell counts chlorophyll a Abundance/diversity	monthly May-Jan, fortnightly Feb, March, April	**15**	**x 1 (12m depth integrated)**	Integrated sampler