Aquatic
Environmental
Sciences

Assessment of ecological effects of expanding salmon farming in Big Glory Bay, Stewart Island - Part 1 Description of aquatic ecology

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Prepared for Sanford Ltd

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Executive summary

Existing environment

A desktop study was carried out to describe the aquatic ecology of Big Glory Bay on Stewart Island. The study provides background for an application which has been made by Sanford Ltd to increase the nitrogen input from salmon farming in Big Glory Bay. The study was based largely on work carried out as part of consent compliance, with a particular focus on control or reference sites.

Big Glory Bay is influenced by local tides, winds and stream inputs as well as large scale currents. The main current affecting Paterson Inlet and Big Glory Bay is the Southland Current which entrains mainly sub-tropical waters off the west coast of the South Island and occasionally sub-Antarctic waters into Foveaux Strait. Currents in Big Glory Bay are generally weak (< 5 cm/s) with stronger flows along the northern and southern banks and towards the mouth of the Bay. There is little, if any, stratification in Big Glory Bay and residence time has been estimated as 28-30 days.

Water quality

Water quality data is available from 1988/89 (Jan/Feb), 1993-2010 (Nov-Feb), 2011-2013 (monthly – limited parameters), and 2015-2017 (monthly). The findings can be summarised as follows:

- Site averaged chlorophyll *a* (a proxy for phytoplankton biomass) in Big Glory Bay in 2015-17 ranged from 0.3 to 3.1 µg/L. There was a very high level in August 2017 but no bloom was observed. Summer chl-*a* concentrations overall in 2016/17 were similar to the period 1998-2005 but lower than in 1993/94, 1997/98 and the period 2006-2009. The relatively low summer concentrations in 1998-2006 (<1.5 µg/L) could have been due, at least in part to, larger scale climatic conditions leading to reduced inputs from deep-nutrient rich waters;

- Chl-*a* concentrations were generally higher in late winter/spring and lower in late autumn/early winter. The reverse was found for dissolved inorganic nitrogen, with levels increasing at the end of summer then decreasing in late winter/spring largely in response to phytoplankton growth. The ‘nuisance bloom’ in 1989 which caused fish deaths was attributed to pulses of nutrient-rich water from offshore during a period of low nutrient concentrations and warm water temperatures during the long daylight hours. Summer peaks in phytoplankton can also occur, for example in Jan 1989 and Feb 2017;

- Summer ammonia-N levels were higher in 1989 than 1988, but at similar levels in 2016/17 to those observed in 1989 (samples were not collected for ammonia-N in 2011-2013 or summer of 2014/15). Seasonal changes in 2015-2017 for ammonia-N levels showed concentrations were considerably higher in late autumn/winter and reached an average of 80 mg/m^3 in 2016 and 60 mg/m^3 in 2017. Concentrations were generally low in summer reflecting uptake by phytoplankton. There were occasions, mostly in winter, when ammonial-N was slightly higher in the Bay than at the entrance but for most of the year there was no gradient;

- Average summer nitrate-N concentrations were low (< 5 mg/m^3) in the period 1998-2005 and higher (7-10 mg/m^3) in other years, including pre- and post this period. Seasonally nitrate-N was higher in winter than summer in 2016/17, reaching a maximum of 90 mg/m^3 in July 2016, probably as a result of the input of nutrient-rich deep or offshore waters and uptake by phytoplankton in summer. There was no observed difference between the control site in the middle of the Bay and at the mouth; and

- Nitrogen is considered the limiting nutrient for phytoplankton growth in New Zealand's coastal waters. Median concentrations of ammonia-N and nitrate-N in Big Glory Bay in 2016/17 were 30 and 21 mg/m^3 respectively, which is higher than ANZECC (2000) guidelines for estuarine environments and coastal waters (15 and 5 mg/m^3 respectively), based on default values from south-east Australia. However median total nitrogen was lower than the ANZECC guidelines and dissolved inorganic nitrogen concentrations were lower than the level (89 mg N/m^3 and 105 g N/m^3) for ammonia-N and nitrate-nitrite-N respectively) accepted by Auckland Council as an objective for harbour waters (Vaughan & Walker 2014). Based on preliminary national objective framework triggers for New Zealand estuaries the concentrations in Big Glory Bay would be considered "Good" in terms of status.

Benthic environment

The benthic environment in Big Glory Bay is a patchwork of different habitats depending on the location in the Bay, history of the different sites and the activities carried out. In summary benthic monitoring to date shows:

- In recent years sites near the head of Big Glory Bay, including control sites, had a higher proportion of mud than those in the middle of the Bay or towards the entrance;

- The levels of organic matter and total organic carbon (TOC) at the control sites were in the range for similar sandy/mud environments elsewhere but interestingly were slightly higher at the mouth of the Bay than the head of the Bay;

- Organic enrichment of sediments was variable and generally below 10% (TOC <2.5%) depending on the site's history and location in the Bay. Generally, where there was enrichment at farm sites, sediment conditions improved within 100 m beyond the farm boundary to similar levels to controls. In most cases organic matter in the sediment below the farms was within the range of that at control sites;

- Concentrations of copper and zinc are high under some farms but below ANZECC (2000) thresholds within 100 m beyond the farm boundaries and at control sites;

- Species richness and diversity of infauna generally remained moderately high at most mussel and salmon farm stations, as well as at the control sites, and tended to be higher at the control or reference site in the mouth of the Bay than the control at the head of the Bay. Low diversity was recorded under salmon Farm 339 (recently moved and left to fallow);

- Opportunistic polychaetes were observed beneath all farms and a range of polychaetes and bivalves were observed at control sites as well as farm sites;

- The presence of mussel shells below mussel farms and those sites previously farmed for mussels has resulted in increased localised biodiversity, along with an increased abundance of opportunistic polychaetes beneath these sites;

- A wide range of infaunal polychaete and bivalve taxa and functional groups are generally found throughout the Bay. There tends to be more diversity and more of a "pristine" benthic environment (eg. red algae and brachiopods of conservation interest) near the entrance (eg around Bravo Island);

- Generally, there were few epifauna observed at all sites but conspicuous holes and burrows were found at the control site at the head of the Bay, yellow sponges at both the head and mouth of the Bay, and coralline, green and red algae at the mouth of the Bay;

- The presence of *Beggiatoa* mats (bacterial mats indicative of sulphur-rich sediments) were recorded recently at one site, a currently being fallowed salmon farm site in the middle of the Bay, in 2016. These mats, along with reduced species diversity and large numbers of opportunistic species around the farm, are indicative of relatively poor benthic conditions. However, no mats were observed in 2017 indicating improved conditions, at least for this site: and

- Salmon sites that have been fallowed, show an improvement in quality of benthic habitat between years and overall there appears to be an improvement between 2016 and 2017 at farm sites.

There has been little work carried out on fish resources and fishing in Big Glory Bay, but commercial fishing is banned in the Bay. However, there is likely to be some recreational and cultural fisheries. The fish community consists of a range of pelagic and demersal species, including blue cod, flatfish, moki, butterfish, terakihi, trumpeter, wrass and rig.

Stewart Island is home to a range of coastal bird species including several threatened species. The birds that rely on the aquatic environment include the Stewart Island, pied and spotted shags; yellow-eyed, little blue and Fiordland crested penguins; red-billed, black-billed and black-backed gulls; and sooty shearwaters (or muttonbird). Most of these birds feed on small fish in the bays, coastal areas or offshore. The sooty shearwater is an important species for Maori with large colonies found around Stewart Island.

A number of marine mammals have been recorded around Stewart Island, but most are transitory except for fur seals which have haulouts in Big Glory Bay and bottlenose dolphins which are known to frequent Big Glory Bay. The sea lion population has increased in recent years.

Assessment of effects

The effects of marine farming in New Zealand are well understood and have been extensively documented in recent years. In the case of Big Glory Bay, we also have extensive monitoring of the water column and benthic habitat from which to draw conclusions about effects. Key considerations with the current proposal is that it is to allow for an increase in feed levels in order to better use farm space, but that all activities will be within existing leases i.e no new space is requested. Also Big Glory Bay is the only area in Stewart Island in which aquaculture can occur. Only a small area of the Bay is used for salmon farming with the area of pens under the proposal representing only 0.28% of Big Glory Bay.

The key considerations for effects on the water column are from increased nitrogen inputs and changes in dissolved oxygen, which can impact on farmed salmon and naturally occurring biota. In terms of the benthic environment, the main concerns are deposition of faecal material and waste feed which can impact on organic matter, dissolved oxygen, biochemical reactions including release of hydrogen sulphide, and changes to floral and faunal communities. Other considerations are biosecurity and the effects on wild fisheries, mammals and birds.

The effects of the proposal on the environment from increased nitrogen inputs to the water column and deposition on the seabed have been modelled and can be summarised as follows:

Water column

- Effects on currents will be localised around farms and will not impact on overall circulation patterns;
- Excess total ammonia-N is predicted to increase by up to 0.030 g/m^3 with the additional inputs. This is on top of existing average levels of 0.005 to 0.080 g/m^3. There is no evidence that farming to date has impacted the overall water quality in the Bay. Levels of inorganic nitrogen will remain below levels identified as potentially leading to nuisance algal blooms;
- Assuming all the increase in nitrogen is converted into phytoplankton biomass (i.e very conservative) then chl-*a* could increase by up to 4 µg/L with existing levels at control sites being 0.01 to 5.2 µg/L in recent years but with one record of 16.8 µg/L (note no algal bloom was observed and thus this data point is questionable). Apart from this single high value levels will remain below the “proposed trigger level” of 15 µg/L (see below);
- With increased drawdown of oxygen with expanded farm production dissolved oxygen levels are predicted to remain over 6 mg/L, a level that will maintain healthy salmon and naturally occurring biota. There is no evidence that dissolved oxygen levels have been adversely affected in the Bay to date or will be as a result of this variation;
- There have been periods of relatively high and low phytoplankton biomass over the last 20-30 years but there is no significant trend in chl-*a* over that period that correlates with salmon farming development;
- Conservatively, mussel farms and their influence on nutrient-phytoplankton processes have not been included in the modelling but mussel farms will remove phytoplankton biomass and ultimately some of the nitrogen will be removed at harvest of both mussels and salmon;
- An initial upper limit for chl-*a,* developed as part of a 1988/89 study, suggested 15 µg/L as the “trigger level” above which could lead to nuisance levels of phytoplankton and which is indicative of eutrophic conditions. Based on a nitrogen budget developed at the time a critical concentration was assessed as 290 mg/m^3 of dissolved inorganic nitrogen (levels will remain below this with the proposed increase); and

- The maximum production now being sort for Big Glory Bay is 659 t of nitrogen sourced from salmon farming, which is considered to be sustainable.

Benthic environment

- Effects around salmon farms will depend on the history of the farm and type of activity (on-growing, smolt, brood or being fallowed);
- Existing information shows that effects on grain size, organic content and copper and zinc levels are restricted to within 50-100 m beyond the farm boundaries and are generally within the range at control sites. At least copper levels are likely to be due to historic, now discontinued anti-fouling practices. The remnant concentrations of copper will decrease in time and zinc which can also come from feed will decrease when sites are fallowed;
- Deposition modelling has shown that the deposition of faeces and waste feed will generally remain within the boundaries of the lease and deposition outside the lease will be confined to within 50-100m of the boundaries;
- Opportunistic polychaete worms are observed beneath all farms and in some cases overall diversity is low. These changes are not observed beyond 100 m of the pens and the same is predicted for the proposed variation;
- Mats of the bacteria *Beggiatoa* have been recorded in the past under farms but were not observed in 2017. It is likely that these will develop under some farms but not beyond the farm boundaries. Fallowing will ensure any future mats are able to be managed;
- Effects, if they were to occur are generally reversible. An important management strategy to avoid adverse effects at the farms themselves is development of a fallowing plan. To avoid long-term and irreversible effects it is recommended that farms be fallowed for up to 5 years after 2 years of occupation or if there are signs of adverse effects under farms.

Standards to be met for the water column and benthic environment are recommended along with an outline of monitoring and mitigation.

Biosecurity, wild fisheries and mammals

While the risk of adverse effects associated with biosecurity and effects on wild fisheries, mammals and birds are considered to be low in Big Glory Bay it is important that management plans are put in place to avoid or minimise the risk of disease, invasive species, and entanglement of birds and mammals.

Glossary of terms used:

AEE	Assessment of ecological effects
BGB	Big Glory Bay
Chl-*a*	Chlorophyll *a*
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
DRP	Dissolved reactive phosphorus
PN	Particulate nitrogen
POC	Particulate organic carbon
POM	Particulate organic matter
PP	Particulate phosphorus
PPR	Phytoplankton production measurements
RPD	Redox potential discontinuity depth
TN	Total nitrogen
TOC	Total organic carbon
TOM	Total organic matter
TP	Total phosphorus
TSS	Total suspended solids
VSS	Volatile suspended solids

Contents

1. BACKGROUND

Marine farming of shellfish in Big Glory Bay (BGB) began with small farming initiatives in the 1970s, with farming of caged salmon and mussels, on a larger commercial scale beginning in the 1980s. There are now a total of 36 consented sites for mussel and salmon farming in BGB (**Figure 1** and **2**). Sanford Ltd (Sanford) is the only company now farming caged salmon; these operations began in 1987. Salmon production has increased steadily from 186 tonnes (t) in 1987, to 515 t in 1990, 1400 t in 2000 and approximately 3,500 t current.

In 2017 Sanford had consents for farming salmon at seven marine farm sites, allowing for the cumulative discharge of 332.064 t of nitrogen (N)/yr (Sanford 2017). Additionally Sanford has recently acquired two existing salmon farm consents from another party that have a total nitrogen feed allowance of 110.699 t/yr, meaning that Sanford's current consented total discharge is 442.752 t N/yr. There is also one other site authorized to produce salmon and it has an allowance of 40.210 t N/yr, meaning that the current total allowance for the Bay is 483.002 t N/yr. Sanford are seeking to increase this total discharge allowance in BGB to 659 t N/yr with specific allowances applied at the different farms. Details of the application are provided in the Assessment of Environmental Effects (AEE) (Sanford 2017).

2. SCOPE

Aquatic Environmental Sciences Ltd (AES) has been commissioned to provide a report which describes the biological environment, a review of existing information on the aquatic environment of Big Glory Bay and an assessment of water quality and ecological effects. The report covers the following matters:

- Physical features;
- Water quality;
- Benthic communities;
- Fish resources; and
- Birds and mammals

The assessment involved a review of existing reports, published and unpublished data and information. This document summarises and builds upon the ecological investigations that were undertaken on behalf of Sanford and formed the basis for the AEE submitted in November 2017.

Figure 1. Map showing location of Big Glory Bay.

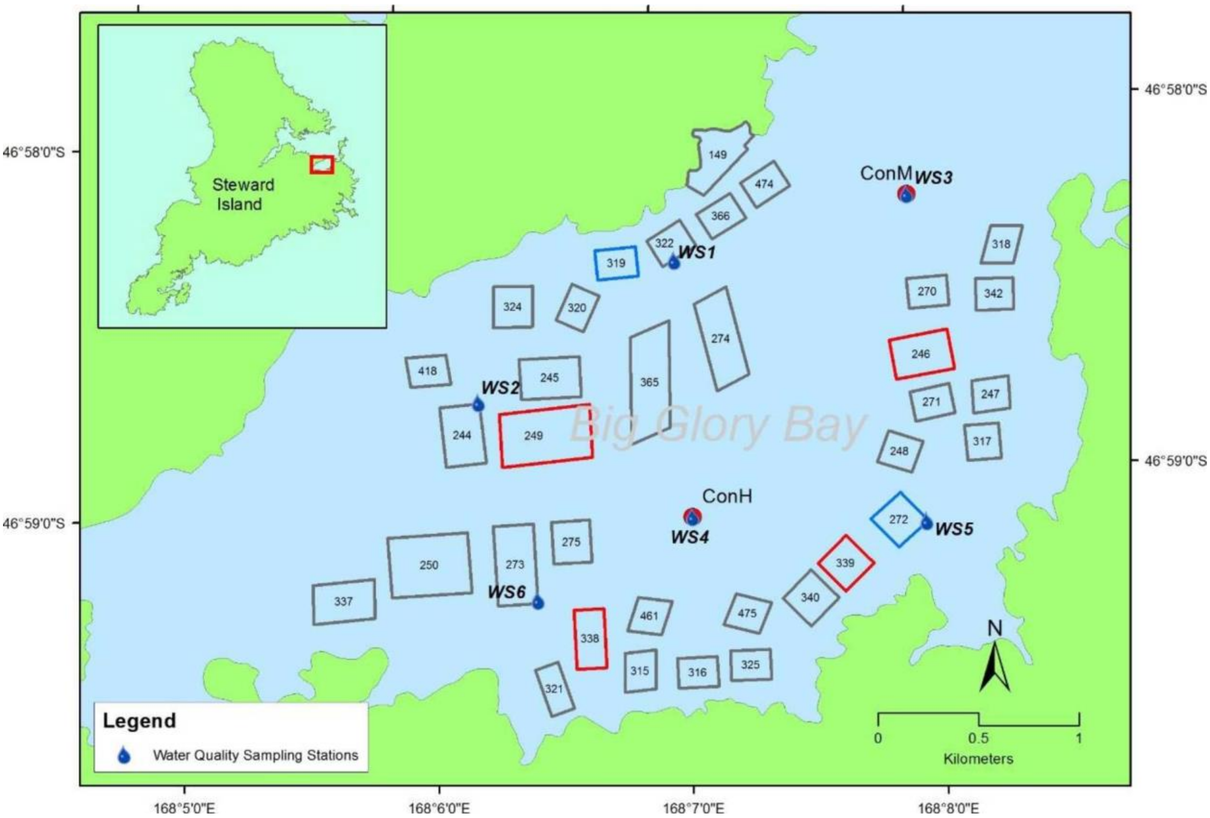

Figure 2. Map showing location of the BGB farms and water quality sites sampled in 2016. (ADS 2016). The farms in red are active salmon farm sites, noting that Site 249 is currently being fallowed.

3. DESCRIPTION OF ENVIRONMENT AND VALUES

3.1 General

Paterson Inlet is a large body of water in the north-east of Stewart Island. BGB is an embayment of Paterson Inlet (**Figure 1**), 4.8 km long by 2.8 km wide and with a surface area of 12 km^2. The mouth of the Bay is 700 m wide, the volume at mid-tide is 0.189 km^3 and the tidal range is 1.34 for a neap tide and 1.95 m for a spring tide. Most of the Bay is shallow with water depths less than 20 m and an average depth of 15.9 m. Rocky reefs occur along the northern and southern shores.

Like most New Zealand coastal systems and embayments nitrogen is considered to be the limiting nutrient with ratios of nitrogen: phosphorus (N:P) generally less than 16.1 indicating phosphorus is relatively abundant.

The catchment is mainly bush covered and thus nutrient inputs from the land are minor relative to other sources naturally occurring. Nitrogen inputs were estimated by Rutherford et al. (1988) and are shown in **Table 1.**

Table 1. Estimated nutrient inputs to Big Glory Bay (from Rutherford et al. 1988).

	Nitrogen (kg/d)
Rainfall	12
Freshwater	20
Sediment release	200
Total	232

Note: This excludes the input from salmon farms.

3.2 Hydrodynamics

The hydrodynamics of BGB is influenced by a number of physical features including larger regional-scale strong boundary forcing by major currents running through Foveaux Strait, as well as sub-Antarctic water from the south, and upwelling off the west coast and to the south-east. Localised forcing of water flows will be through winds, and more locally tides, winds and river inflows.

The main current which flows west to east through Foveaux Strait is the Southland Current which is generally dominated by sub-tropical waters (see **Figure 3**) but can be influenced by colder nitrate-rich sub-Antarctic waters at times (Houtman 1974, Heath 1975, Vincent et al. 1991, Chiswell 1996). Similarly, easterly flows will be dominated by the same mix of processes and water masses. Measurements of physical properties through Foveaux Strait by Vincent et al. (1991) found the water column was well mixed vertically and showed a gradient from warm, saline waters in the west to cooler, less saline waters in the east. There was also evidence of freshwater riverine inputs at sites closer to the coast of the South Island. The well mixed water column helps explain the relatively high levels of nitrate-N in Foveaux Strait. Water circulation and movement (hydrodynamics), as well as the general physical characteristics of bays, are important parameters when considering marine farming activities, as they determine the distribution of plankton groups and flushing rates, and therefore replenishment of new water into harbours and bays. The time it takes for the water within a bay to replenish can have a major influence on availability of food for farmed and naturally occurring shellfish, as well as on natural populations of filter and suspension feeders and the capacity of embayments to assimilate and dilute contaminants and nutrients.

Tidal and wind-generated currents

Currents in BGB are generally weak (< 5 cm/s). Drogue measurements by Rutherford et al (1988) showed tidal excursions were low out of the Bay on ebb tides, and in moderate and strong winds a strong surface flow develops at the entrance with reverse flow at depth. For example, during moderate westerlies surface flow was out of the Bay and the deep bottom flow was into the Bay. Currents tend to increase around the entrance to the Bay (up to 10-12 cm/s) and Bravo Island which is at the mouth of BGB, and are also stronger along the northern and southern shorelines.

The 1988 work has recently been augmented by modelling (Kerroux & Hartstein 2017) which has found that current direction is variable, with eddies occurring in several places, and a general flow along the northern and southern coastline towards the mouth of the Bay (see **Figure 4** for an example). Currents tend to be stronger in spring, especially around the mouth of BGB, but there is generally little seasonal pattern.

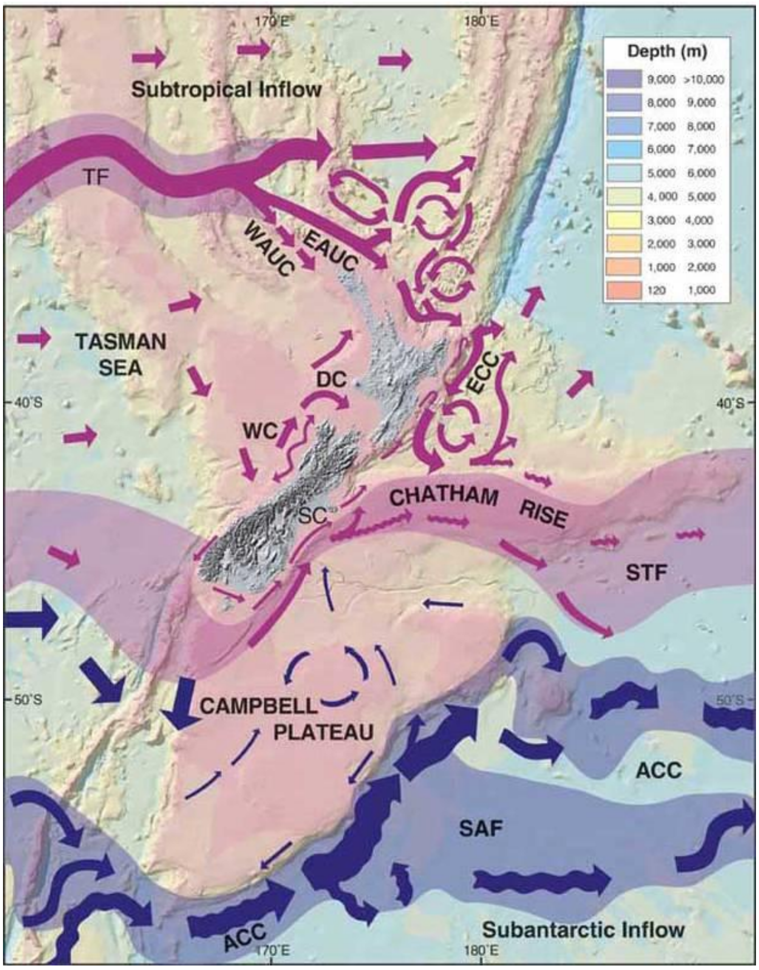

Figure 3. The Subtropical Front is shown here, running along the bottom of the South Island. Others shown are the East Cape Current (ECC), Tropical Front (TF), Antarctic Circumpolar Current (ACC), Subantarctic Front (SAF), East and West Auckland Currents (EAUC and WAUC), D'Urville Current (DC), Westland Current (WC) and Southland Current (SC). Image / Niwa

Stratification

Stratification occurs when light, buoyant water overlies heavy dense water and is caused either by temperature differences (warm water is lighter than cold water), or by differences in salinity (freshwater is lighter than seawater). There is some evidence of slight thermal stratification in summer in BGB but most of the time the water column will be well mixed. Freshwater inputs to BGB are small[1] and there has been no observed density stratification.

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[1] Pridmore & Rutherford (1992) estimated the mean annual freshwater inflow as 0.85 m^3/s compared with a volume in the bay of ~190 x 10^6 m^3

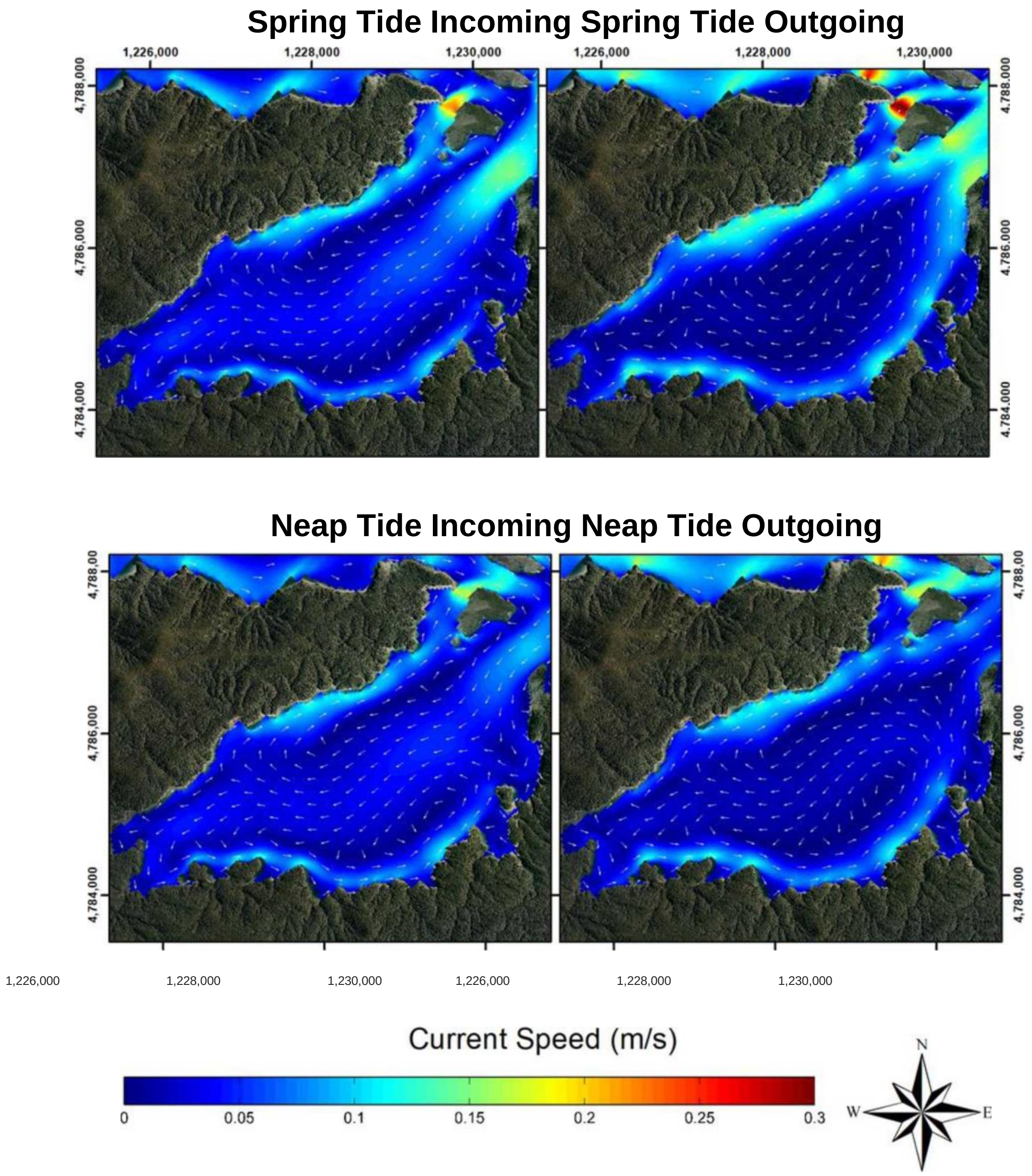


Figure 4. Big Glory Bay current patterns (during Spring) for spring and neap tides (from Kerroux & Hartstein 2017)**.**

Flushing

An important consideration with embayments, such as BGB, is the time it takes to replenish water in the Bay, which in turn impacts on retention and uptake capacity of nutrients, and dispersal and dilution of contaminants and nutrients. Rutherford et al. (1988) estimated the tidal prism as 10% of the volume of the Bay which translates to a residence time of about five days while estimates based on flow measurements were 10-13 days and 7-9 days for light and moderate winds respectively.

New estimates based on recent 3-D hydrodynamic modelling and dispersion of particles as part of this application, calibrated and validated with recent current measurements (September 2010), indicate full flushing could take longer and could be more like 28-30 days (Kerroux & Hartstein 2017).

3.3 Water quality and plankton

Nutrient Status and chlorophyll **a**

Water quality data has been collected in BGB since 1988 but only sporadically until a summer monitoring programme was put in place by Sanford in 1997. A more intensive monthly programme has been in place since July 2013. Results from these monitoring programmes are summarised below.

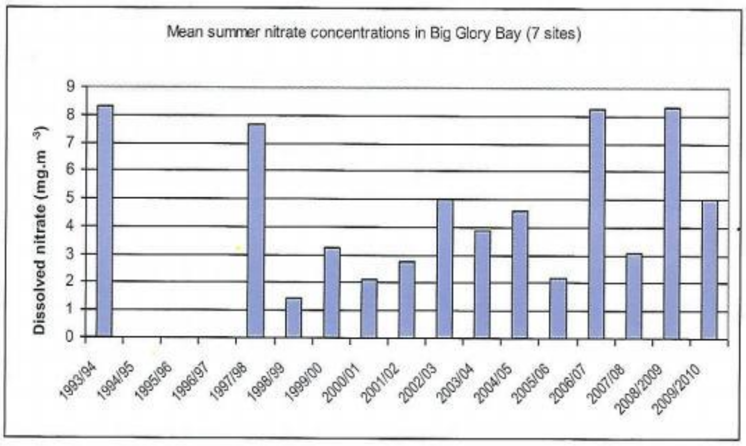
1988/1989

A limited sampling programme was carried out in BGB in February 1988 as part of an early modelling study looking at factors affecting phytoplankton abundance (Pridmore & Rutherford 1990). Chlorophyll *a* (Chl-*a*) concentrations (a proxy for phytoplankton biomass) reached a maximum of 4.9-5.4 µg/L, with ammonia-N concentrations of 0.026 ± 0.004 g/m^3 observed in Feb of 1988 and Jan 1989. Nitrogen concentrations were 34 and 23% higher than those measured in Paterson Inlet at the same time. Based on a nitrogen budget, about 90% of this increase was attributed to inputs associated with salmon farming, but importantly this did not seem to be contributing substantially to the nitrogen budget in Paterson Inlet, possibly because of the short residence time of water exiting BGB.

Vincent et al. (1991) found low ammonia-N levels in Foveaux Strait but there was a marked increase towards the seabed which was attributed to secondary production in the sediments and lack of dispersion.

1993-2010

Stenton-Dozey & Brown (2009, 2010) provide a summary of water quality data in BGB over summer periods (Nov-Feb) from 1994-2010, although there was no data collected from 1995-1997 and the studies were focused on assessing the effects of mussel farms. Changes over this period are shown in **Figure 5.**



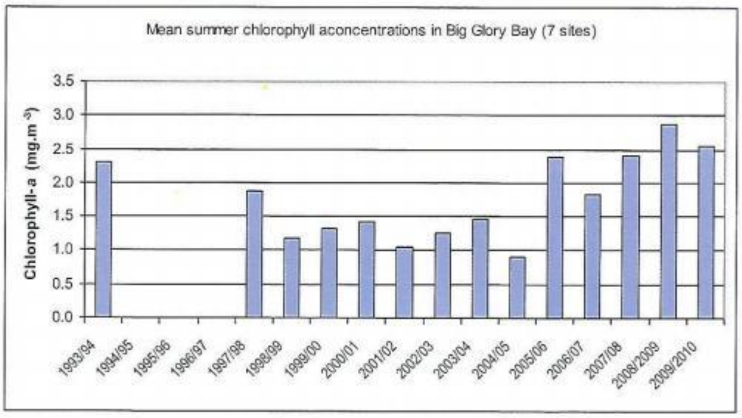
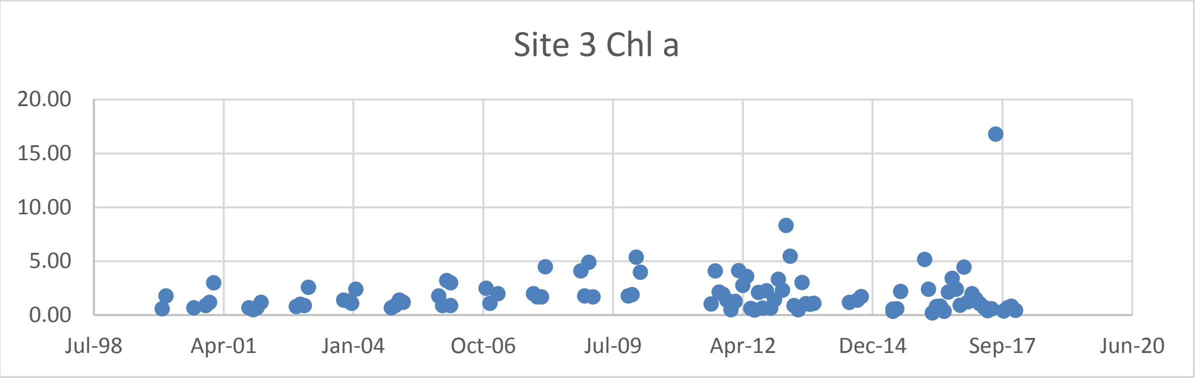


Figure 5. Average summer nitrate-N (top) and chl-*a* (bottom) concentrations in Big Glory Bay (1993-94 data from R Pridmore NIWA, 1997-2010 from Stenton-Dozey & Brown 2010).

Mean summer concentrations of nitrate-N, which comes from nitrification of ammonia-N and inputs from upwelling offshore, were higher (over 7 mg/m^3) in 1993/94, 1997/98, 2006/07 and 2008/09 and below 0.005 g/m^3 from 1998-2006 and in 2009/10 (Stenton-Dozey & Brown 2009, 2010). Concentrations were lower in BGB than in Foveaux Strait, eg.in 2008/09 levels were 0.029 g/m^3 in the Strait but only 0.008 g/m^3 in BGB. Chl-*a* was highest in 1993/94, 1997/98 and 2005-2010 (>1.5 µg/L) probably reflecting periods of phytoplankton blooms and potentially climatic conditions and upwelling. Levels were less than 1.5 µg/L from 1998-2005.

Although it doesn't show up in the average values (**Figure 5**) there was a high chl-*a* concentration in the centre of the Bay in January 2010 (6.7 µg/L **Figure 6**). This was consistent with an observed bloom down the centre of the Bay.



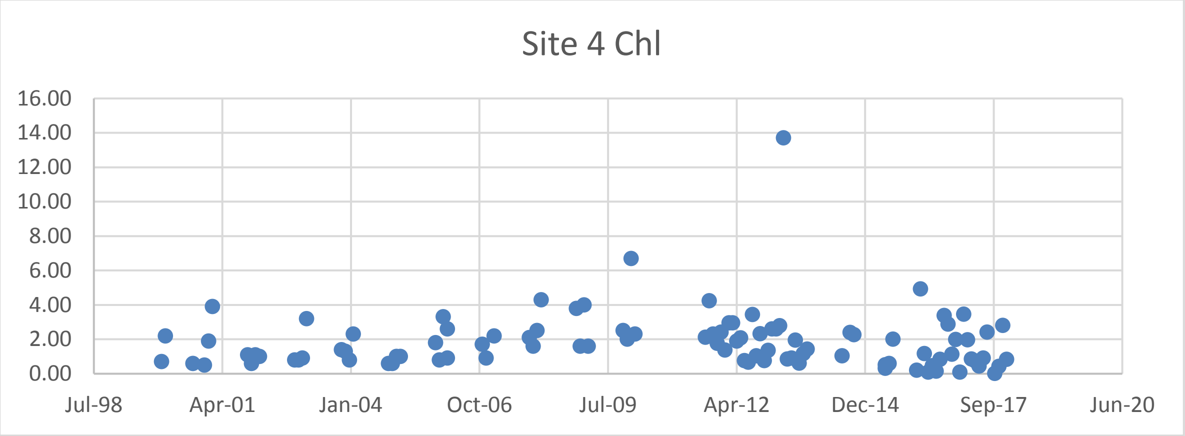


Figure 6. Chl-*a* concentrations (µg/L) at control sites (Sites 3 and 4) in Big Glory Bay 1998-2017 (1998-2015 from Stenton-Dozey & Brown 2010, Stenton-Dozey et al. 2012, Stenton-Dozey 2013, 2014, 2015, ADS 2016, 2017a).

Figure 6 shows chl-*a* concentrations at the control sites (Sites 3 and 4) from 1998-2017. Chl-*a* would appear to be more variable in recent years but this is likely to be because of the difference in sampling regime (now monthly). Generally levels were lower at the entrance to the Bay than at the head of the Bay and the highest levels at those locations did not coincide, with a peak in April 2013 in the head of the Bay of 13.7 µg/L and 16.8 µg/L in August 2017 at the mouth of the Bay. On both occasions the peaks were single samples and at least in the case of Aug 2017 a bloom was not observed, which suggest the data may have been erroneous.

Dissolved oxygen over the 13 years shows the Bay is well flushed with little change with depth. There is no indication of trends in water quality data in the 13 years that would indicate an effect of salmon farming.

The changes in chl-*a* and nitrate-N, which showed similar temporal patterns over the 1993-2009 period, were attributed by Stenton-Dozey & Brown (2009) to possible large-scale processes associated with the El Nino/La Nina cycles. These large-scale processes determine the degree of nutrient input from upwelling offshore. The period 1990-1998 was a strong El Nino period (**Figure 7**), conditions which can result in upwelled water off the west coast driven into areas like Foveaux Strait and the Marlborough Sounds, which in turn can enhance productivity. There was then a period when relatively strong La Nina conditions developed which favour east/south-east winds, particularly during 1999-2001. This was followed by weak El Nino or La Nina years through until 2007, and then a stronger La Nina developed in 2008. Thus the lower nitrate-N and chl-*a* levels during 1998-2006 period could at least in part have been attributed to the ENSO cycle (El Nino Southern Oscillation) and the resulting lower inputs of nutrients to BGB. However short-term natural variability within the Bay is likely to drive much of the between year variability, such as that for nitrate between 2006/07 and 2007/08.

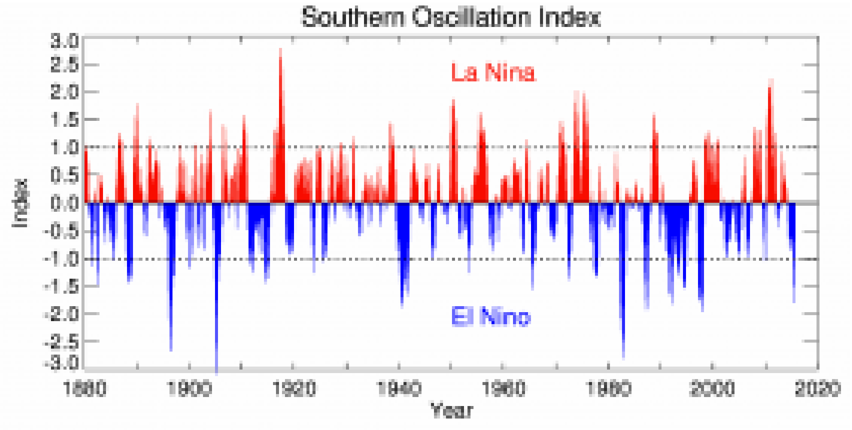


Figure 7. Southern Oscillation Index 1880-2016.

Monthly water quality data was also collected in 1999-2000 at nine sites and reported in Key (2001). This data showed chl-*a* was higher in spring/summer with a peak in Jan of 2.1 µg/L and lower in winter (0.12 µg/L). Ammonia-N and nitrate-N were the opposite with higher concentrations in winter and lowest in summer, again probably reflecting periods of phytoplankton growth.

2011-14

A new monitoring programme was instigated in 2011 following a review by Environment Southland. The programme was rationalised across all marine farms for water column and benthic habitat monitoring.

The 2011-13 sampling of water quality was for chl-*a,* dissolved oxygen, water clarity and temperature and only for July-October in 2013. Accordingly, no seasonal pattern could be assessed and there is no summer data for the 2013/14 year (Stenton-Dozey 2014).

Temperature profiles showed a well-mixed water column except over some months in spring and summer when there were thermoclines (temperature change down the water column) present with changes of up to 4^oC down the water column. DO profiles showed changes down the water column in all periods reflecting natural processes of growth and decay of phytoplankton, but were always above 6 mg/L.

For both 2011/12 and 2012/13 peaks in chl-*a* occurred in September and March i.e a spring and autumn period. Concentrations for 2011/12 averaged 2.2 – 3.1 µg/L with peaks in September of up to 4 µg/L and March up to 7.0 µg/L, both at Site 6 in the south near Farm 338. The control at the entrance (Site 3) peaked at just over 4 µg/L in September and March and showed the same pattern as sites near farms. Concentrations for 2012/13 averaged 2.2 – 2.8 µg/L with peaks in March of up to 14 µg/L at the control site at the head of the Bay and in September of up to 6.8 µg/L at Site 1. The control at the entrance (Site 3) peaked at 8 µg/L in March and showed the same seasonal pattern as sites near farms.

2014/15

Water quality sampling in 2014/15 was limited to two winter, two spring and one late autumn months and for a limited set of water quality parameters. Parameters measured were water clarity, dissolved oxygen (DO) and chl-*a*, making it difficult to compare with the earlier periods. Similar to previous years, however, chl-*a* was lowest in winter (0.2-0.6 µg/L) and highest in spring when levels were up to 2.4 µg/L, due to increased algal growth from longer daylight and warmer temperatures (Stenton-Dozey 2015).

2015-2017

A new comprehensive monthly monitoring programme for water quality began in 2015. Parameters measured include temperature, DO, water clarity, nutrients (ammonia-N, nitrate-N, dissolved reactive phosphorus (DRP)), TSS (Total Suspended Solids) and VSS (Volatile suspended Solids). The sites sampled are shown in **Figure 2**. The control sites at the mouth and middle of the Bay (WS 3 and 4 respectively) provide a good indication of the background state of BGB. Results from this monitoring programme are discussed in the following paragraphs.

Water clarity (as measured by secchi disk) and DO concentrations varied seasonally across all sites with higher values in winter and lower values in summer. DO was always > 6 mg/L and along with temperature was generally well mixed down the water column although some slight stratification was apparent at times. Mean monthly chl-*a* concentrations for all sites from Jul 2015 to Aug 2017 are shown in **Figure 8**. Levels ranged from 0.3 µg/L in May 2016 to 3.1 µg/L in Sept 2016, with a very high spike in chl-*a* in Aug 2017 (11.3 µg/L averaged across all stations), which is normally indicative of a large algal bloom (note that this was not visually observed). Overall the data shows chl-*a* levels were highest in late winter/early spring (Aug/Sept), similar to previous years, but with some smaller peaks in Feb/Mar. However, concentrations were highly variable between sites and over time (**Figure 9**).

The control sites (WS 3 and WS 4) provide a good indication of the background environmental conditions. Highest chl-*a* concentrations in mid-bay (Site 4) occurred in Mar and Sept 2016 and Feb 2017 with the highest concentration occurring in Mar 2016 (4.9 µg/L). Highest levels at the mouth of the Bay were in Feb 2016 (5.1 µg/L), Dec 2016 (4.5 µg/L) and during the bloom in Aug 2017 (16.8 µg/L). The average chl-*a* concentrations at the mouth of BGB (WS3) were the highest across the sites (**Figure 10**) over the 2015-17 period, with lower concentrations observed in the middle of the Bay. This may in part be due to localised depletion at the edge of mussel farms (Sites 1, 2, 5 and 6) and differences in physical characteristics.

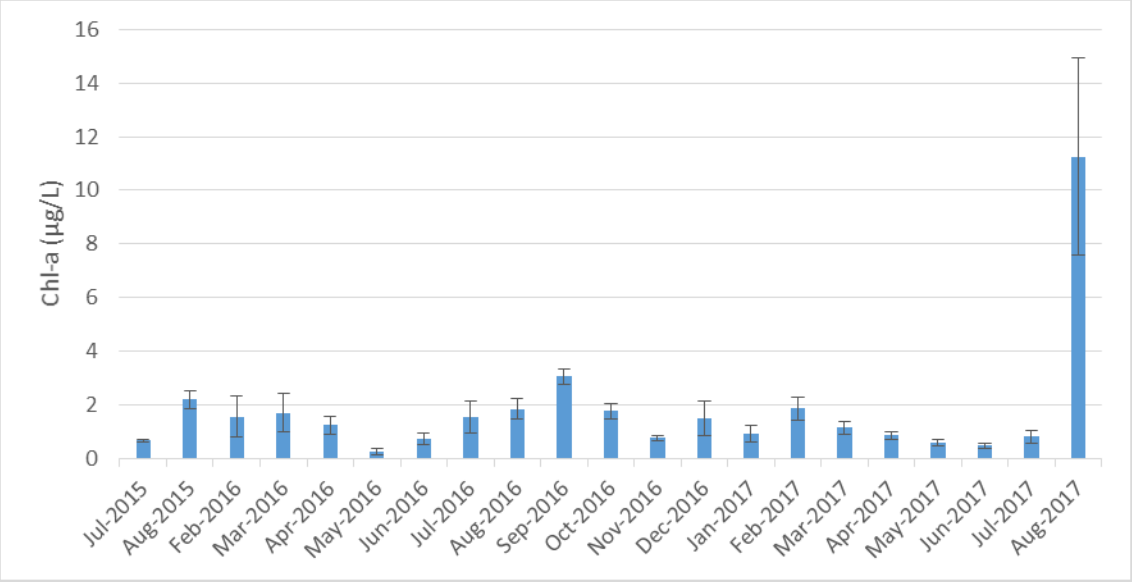


Figure 8. Site-averaged Chlorophyll-a concentrations collected as part of Sanford's monthly water quality monitoring program 2015-2017, averaged for all stations.

The average chl-*a* concentrations for Feb and Mar 2016 (no data for Sept 2015 to Jan 2016) were 1.8 and 2 µg/L respectively and during Nov 2016 to Feb 2017 averaged 1.3 ug/L. Compared with earlier data (1993-2009) chl-*a* concentrations in the summer of 2016/17 was more comparable with the less productive period 1997-2005, than 1993 and 2005-2009.

Interestingly 2015/16 was a strong El Nino period when we would expect higher nitrate levels and enhanced phytoplankton growth, and the limited data suggests this may have been the case for chl-*a* and nutrients in 2015/16.

DRP showed a similar pattern for both control sites (stations WS 3 and 4) and generally increased from a low in summer to higher levels in autumn/winter (0.026-0.027 g/m^3) (**Figure 11**). Note that the figures are for the control sites as these are most relevant to background conditions.

The concentration of ammonia-N was similar at both control sites from Feb 2016 to Aug 2017 although tended to be higher at the site in the middle of the Bay in winter, which would likely be due to internal ammonia-N release (**Figure 12**). Levels were generally higher in autumn and early winter when phytoplankton growth would be lower and lowest in spring and summer following uptake by phytoplankton. The average concentration ranged from 0.005-0.081 g/m^3 with highest levels in May 2016 (**Figure 12**).

Nitrate-N increased from March to July in both 2016 and 2017 probably as a result of declining phytoplankton growth, was highest in July 2016 (0.09 g/m^3) and lowest in summer (undetectable in Dec 2016 and Feb 2016) (**Figure 13**). The average levels in summer of 2016/17 (0.004 g/m^3) were in the mid-range of summer levels recorded between 1997-2009 (0.001 to 0.008 g/m^3).

Plankton

The water column is inhabited by planktonic algae (phytoplankton) and microscopic animals (zooplankton). Phytoplankton, which are the major source of food for filter-feeding bivalves and zooplankton, occur as single planktonic cells, colonies or chains in the water column. When phytoplankton die they sink to the seafloor, thereby contributing to the sedimentation of organic matter, which in turn provides a food source for deposit feeding animals living on or in the sediments.

Plankton communities are highly variable and dynamic in space and time, undergoing relatively predictable seasonal cycles. There is very little reported data on the phytoplankton community composition in BGB, except for when the micro-flagellate *Heterosigma* reached bloom proportions in January 1989 and resulted in large losses of salmon in the Bay (Chang 1990). Twenty-six species of phytoplankton were recorded at the time of the bloom, with co-dominants being the diatoms *Nitzschia pseudoseriata* and *Skeletonema costatum*. A number of other dinoflagellate species were also commonly observed during this period.

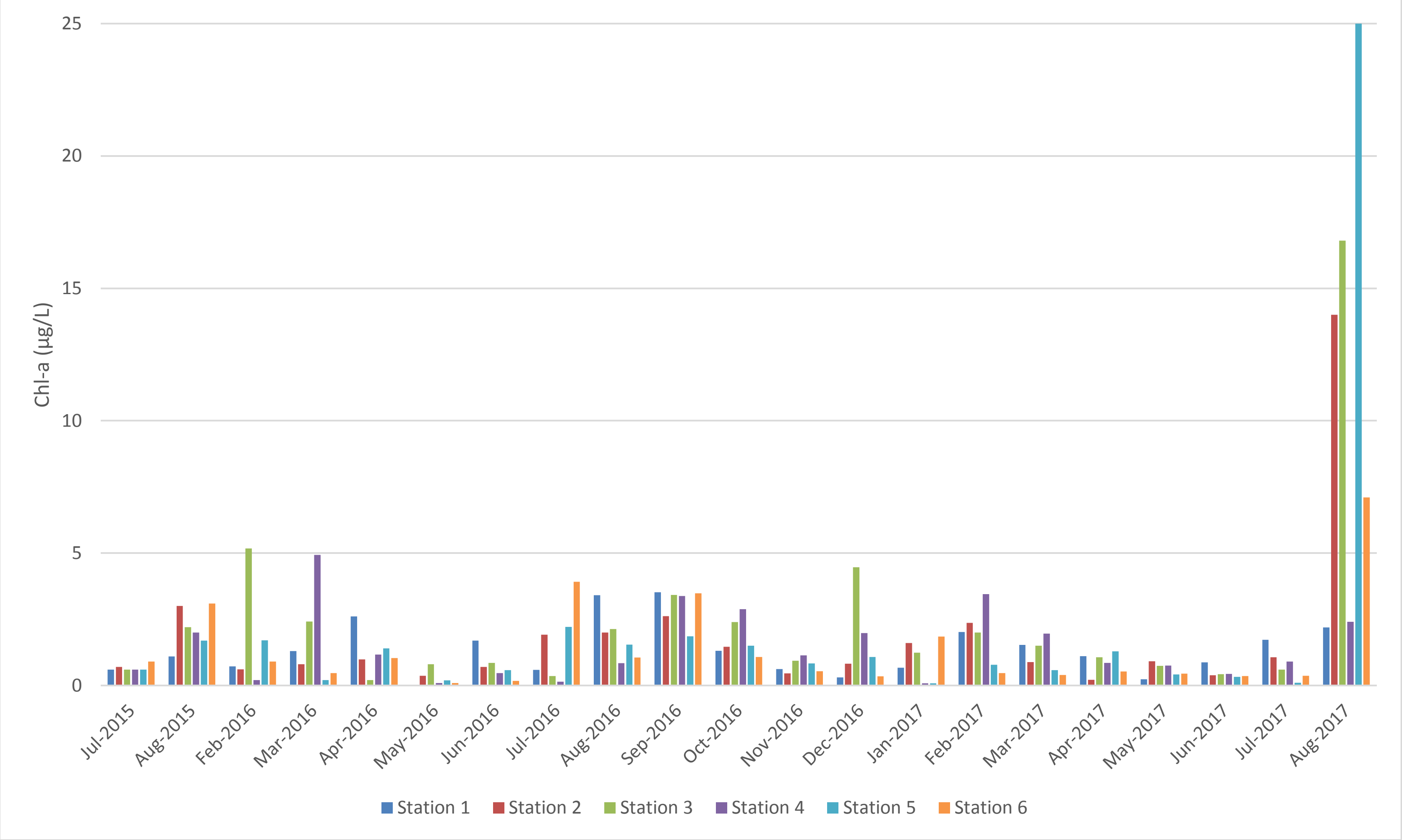


Figure 9. Site-specific chl-*a* concentrations collected as part of Sanford's monthly water quality monitoring program (2015-2017).

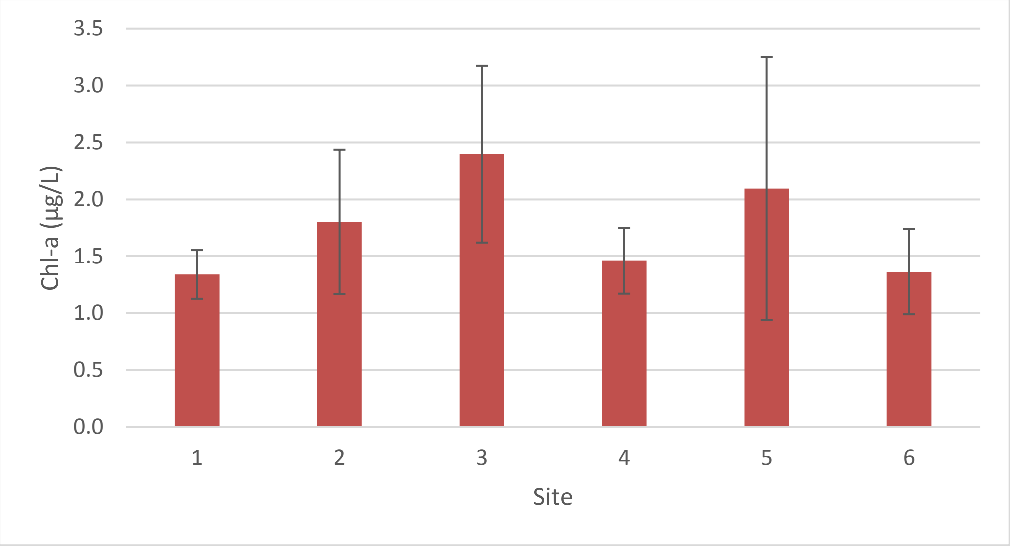
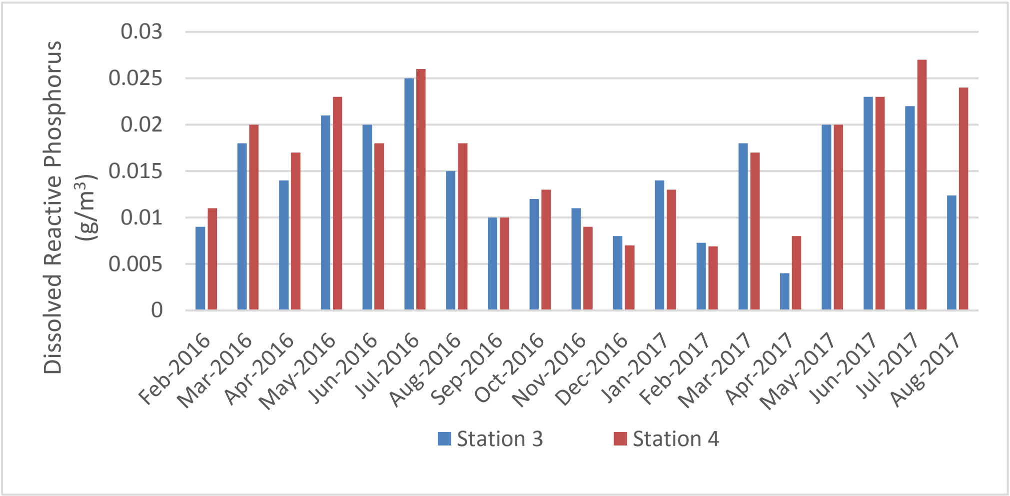


Figure 10. Time-averaged Chl-*a* concentrations for each site collected as part of Sanford's monthly water quality monitoring program (2015-2017).

The only phytoplankton production measurements (PPR) made in BGB were in Feb 1998 and reported in Pridmore & Rutherford (1990). PPR was high and all above 3.5 mg C/mg Chl-*a*/hr which is at the upper end of assimilation rates under light saturation for marine systems. At the time Pridmore & Rutherford (1990) concluded that as nutrient additions made little difference, it was unlikely that light or nutrient availability was limiting primary production in 1988, with other factors, such as zooplankton grazing, also likely to be important. This contrasted with 1989 when nutrient levels were low (DIN <3 mg/m^3) and there was strong evidence of phytoplankton growth being limited by nitrogen supply. Pridmore & Rutherford (1990) concluded that the sporadic input of cold high salinity nutrient-rich water from the south into Paterson Inlet caused the differences observed between 1988 and 1989, and that input at that time from salmon farms produced only a "marginal effect".

A



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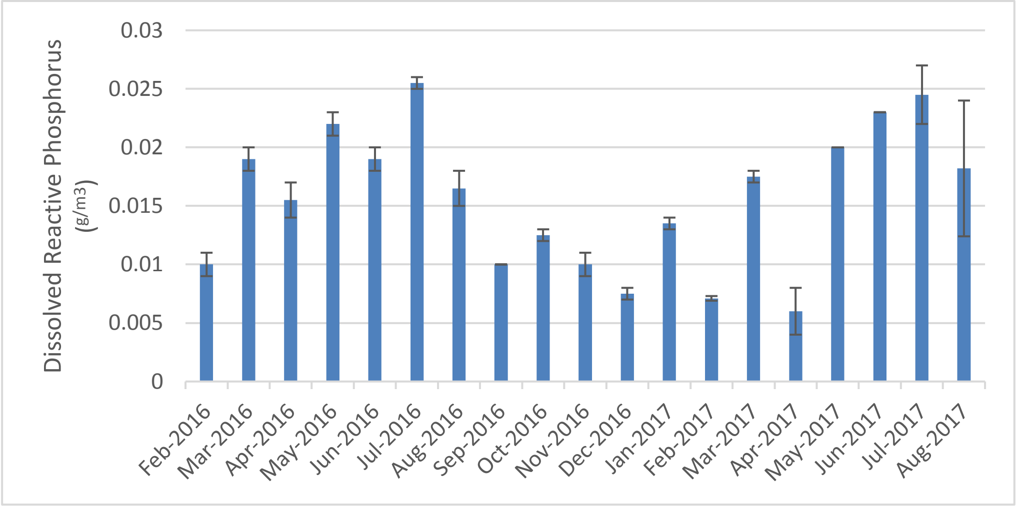


Figure 11. Site specific (A) and average (B) DRP concentrations for control sites 2016-2017.

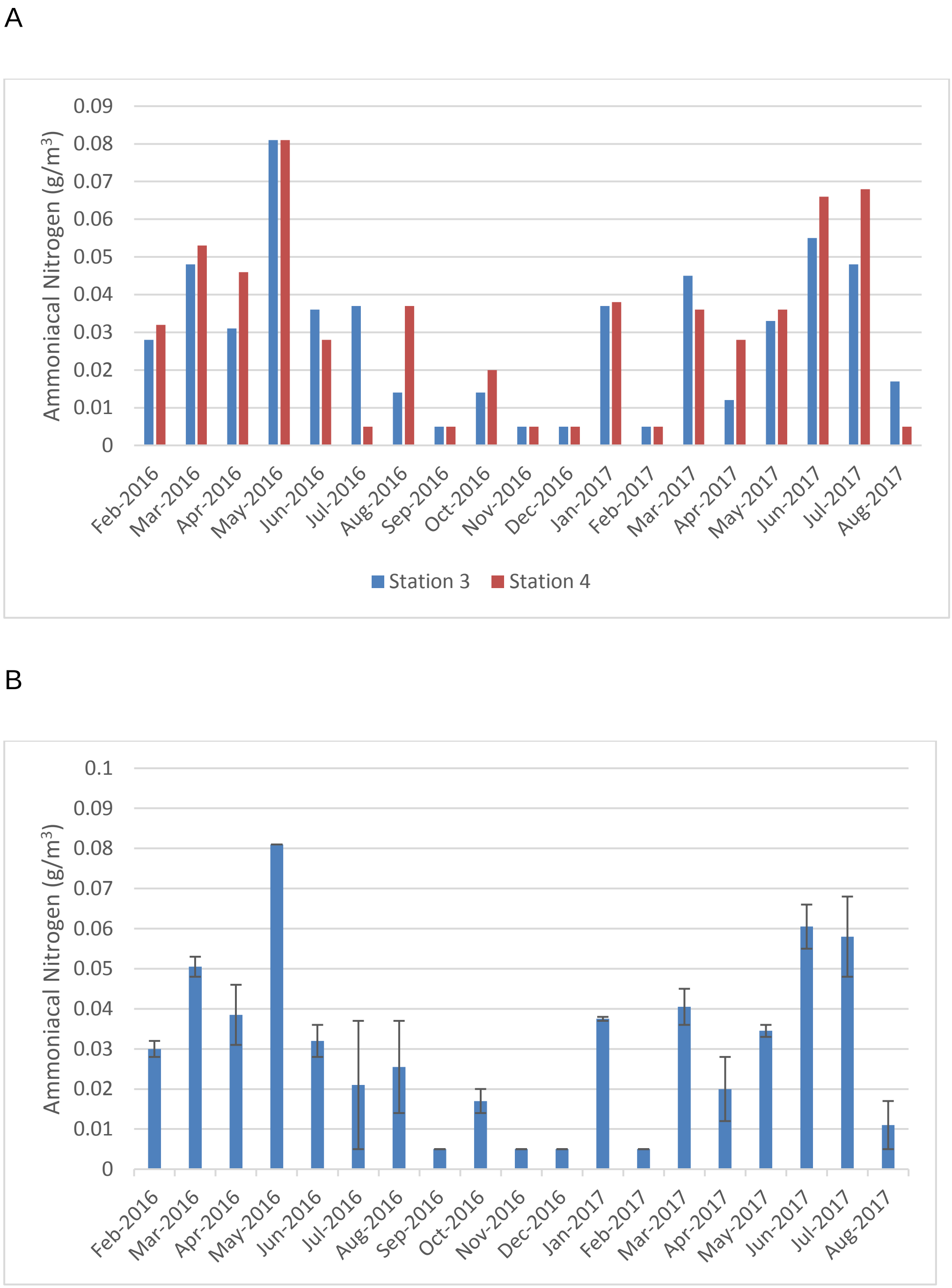
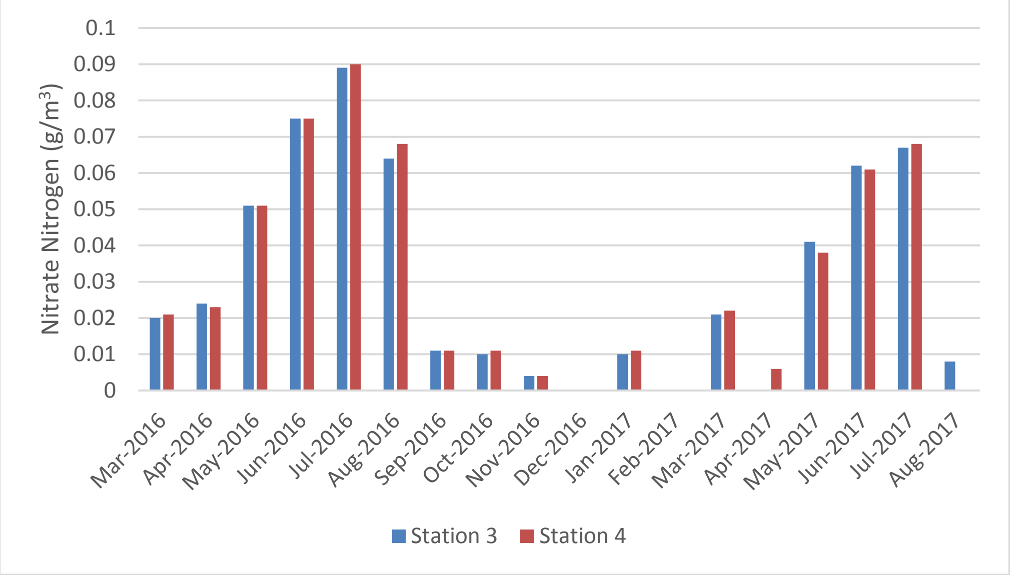


Figure 12. Site specific (A) and average (B) ammonia-N concentrations for control sites 2016-2017.

A



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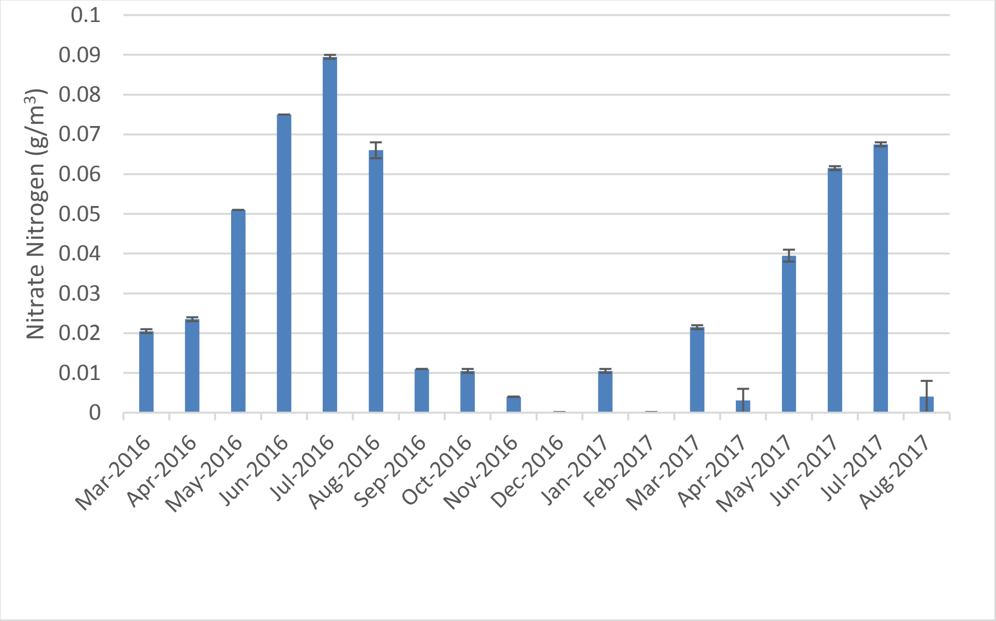

Figure 13. Site specific (A) and average (B) nitrate-N concentrations for control sites 2016-2017.

3.4 Benthic environment

The nature of the seabed in BGB has been described in numerous reports and papers, mostly related to compliance monitoring of long-line mussel and caged salmon farms. A new monitoring programme was instigated in 2011 following a review by Environment Southland.

The programme was rationalised across all marine farms for water column and benthic habitat monitoring. Surveys of the benthic habitat are now being carried out at two control sites, at least two mussel farm sites annually and active salmon farms as well as those which are being fallowed. Sediments are monitored annually at sites under the mussel farms, close to the edge of the pens for salmon farms and at 50 and 100 m from the boundary of the salmon farms.

The presence of mussel and salmon farms can alter the seabed, with the magnitude and extent of effects differing depending on the local physical characteristics (currents, flushing rates), the physical structure of the seabed and the type of marine farming. This creates a patchwork of benthic habitats, with some natural and not enriched while others are under varying influence from enrichment and mussel drop off. The following description is focused on the control sites in BGB, but also includes observations below and around farms. The total area consented for marine farming in BGB is 162 ha (14% of the 1200 ha area of BGB) of which 26.5 ha is consented at present for caged salmon farming.

Results from benthic monitoring surveys undertaken in BGB are summarized and discussed in the following paragraphs.

1998-2009

Stenton-Dozey & Brown (2009, 2010) report the results of 12 years of monitoring (1997-2009) the seabed in BGB at sites directly impacted by mussel farming and control or reference sites which would only be subject to low far-field effects, if any. Sediment samples were collected and analysed for moisture content, particulate organic matter (POM), VSS, particulate nitrogen (PN) and particulate phosphorus (PP) at seven sites, and by video for epifauna at 13 sites.

The sediment characteristics varied over the period 1998 to 2009, with high levels of organic matter (as a %) at the control site at the head of the Bay (over 10% and up to 18%) except for 1998/99 and 2005 when the percentage was less than 5%. Organic matter was less than 10% at other sandier sites including the control at the mouth of the Bay (up to 9%).

The level of particulate nitrogen (PN), particulate phosphorus (PP) and N:P ratios in the sediment mirrored the organic content and generally indicated low benthic primary production levels and little difference between farmed and reference sites.

The most common epifaunal taxa were cushion stars (*Patiriella regularis*) and ascidians, along with sea cucumbers (*Stichopus mollis*). Lamp shells (brachiopods) were abundant at the mouth of the Bay and fan shells (*Chlamys* sp.) at the head of the Bay. As would be expected the most abundant taxa in the sediments at the farm sites was the greenshell mussel (*Perna* *canaliculus*) (live and dead shells). The presence of greenshell mussels separated out farmed from control sites in multidimensional scaling analyses (MDS) but when greenshell mussels were excluded there was little difference between the epifauna communities at farmed and control sites (Stenton-Dozey & Brown 2009, 2010).

2012-2015

Following a review of the monitoring programme for BGB by Environment Southland in 2011 a Bay-wide programme covering the benthic environment around salmon and mussel farms was initiated in 2011/2012 (see **Figure 14** for sites). Benthic parameters measured are sediment grain size, total organic matter (TOM), particulate organic carbon (POC), copper and zinc (not sampled previously), redox potential discontinuity depth (RPD), presence of sulphur odour, depth of oxygenated layer, presence of mat forming bacteria, epifauna (animals living on or near the surface) and infauna (animals within the sediment).

The control sites along the axis of the Bay are particularly instructive for describing the background benthic environment, while other sites are located beneath mussel farms, and at the edge of salmon pens as well as at 50 and 100 m away and thus describe sites with varying impact. The latter sites for salmon farms need to be interpreted carefully as salmon farms can be managed on a rotational basis, with some farms left to fallow to allow recovery of the benthic environment, and some sites have switched between mussel and salmon farming. In particular, Farm 338 in the south of BGB has been a salmon farm for most of its time, Farm 339 in the south-east was a salmon farm, then was converted to a mussel farm and then back to a salmon farm (pens were recently moved to another lease), while the farm in the middle of the bay (Farm 249) is a mussel farm that has been converted to a salmon farm, then left to fallow from 2016.

The results of benthic surveys at and around these farms are presented in Stenton-Dozey et al. (2012) and Stenton-Dozey (2013, 2014, 2015), and are summarised below and in **Table 2.** As an example, sediment characteristics are plotted for 2015 for control and salmon farm sites, in **Figure 15**.

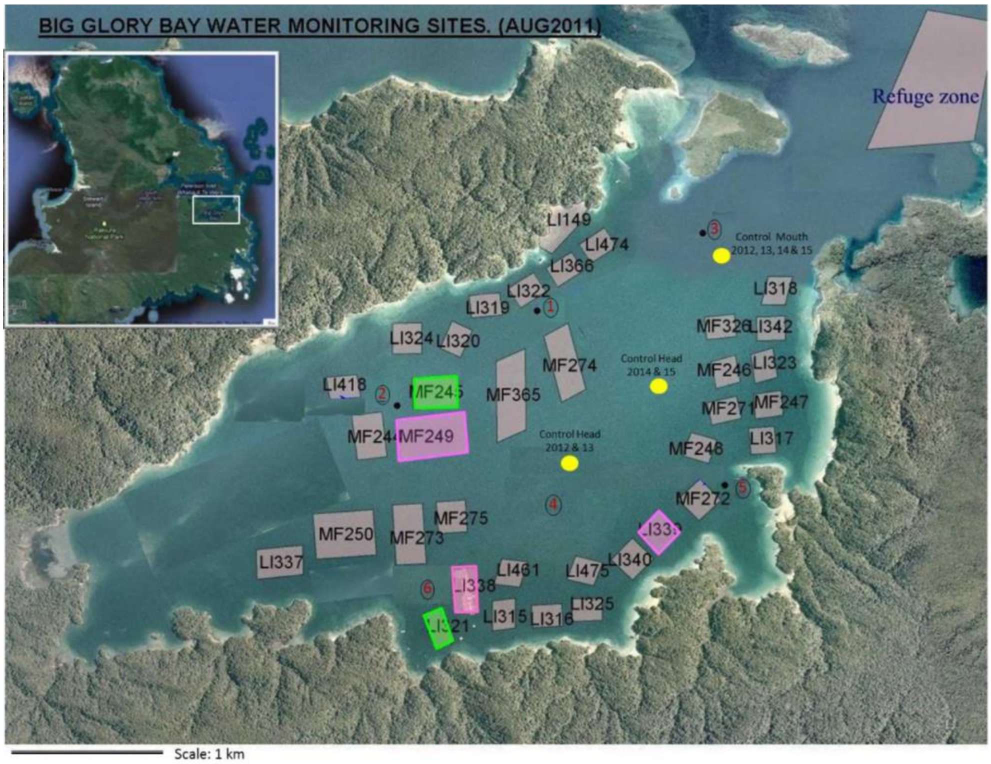

Figure 14. Marine farms in Big Glory Bay (supplied by Sanford Ltd). Numbers 1 - 6 (red) are water quality sampling stations. The three salmon farms (MF249, Li339, Li338 - pink), two mussel farms (Li321, Li245 - green) and two control stations, one near the bay mouth (Control Mouth: CONM) and the other in the middle of the bay (Control Head 2014 & 15: CONH2) (yellow). (From Stenton-Dozey 2015)

Sediment characteristics

Sediment composition at the control site at the head of the Bay was generally similar to that at the mouth, although there appeared to be higher organic content and TOC at the mouth of the Bay. Apart from 2013 the sand content was higher than for mud/silt for the control site at the head of the Bay but at the entrance control site mud/silt dominated in 2012-2014, but sand from 2015. 2013 appears to be an anomaly as the mud/silt content averaged 80% across all sites (57 and 85% at control sites).

All sites were predominantly sand in 2015 with the highest proportion observed at Farm 338 (over 65%) in the south of the Bay. The percentage silt/mud was similar at the mouth of the Bay (control) to sites 100 m away from Farms 339 and 249 (>35%) in 2015. Sites under mussel farms generally showed organically enriched sediments, low subsurface DO levels, well-formed redox potential discontinuity (RPD) layers and moderate sulphur odour compared to controls.

Enrichment at sites at the edge of salmon pens and 50-100 m away varied depending on the farming history and location. The percentage organic matter was low at both the control sites at the head and mouth of the Bay (<7%), but was lower at the head of BGB compared with the mouth of the Bay. TOC was low (< 2%) at control sites and away from salmon farms, except for high levels at Farm 338. TOC was higher at the mouth of the Bay than at the head of the Bay.

In general, the sediment characteristics at the salmon farm in the south-east (Farm 339) had not changed between 2013 and 2015 but DO had declined beneath the pens at the time of sampling. Over the four years of monitoring the farm in the middle of the Bay (Farm 249), sediment properties have also remained the same. Measurements around the salmon farm near the southern shores of BGB (Farm 338) reflect the farms history, with most parameters showing degraded habitat at the edge of the pens and 50 and 100 m away. The farm was being fallowed at the time, and the sediments have changed over the four years since fallowing began, with the percentage of silty/mud reducing significantly (down to 12-20% from 80%) and sand increasing to 69-83% (from 18%), TOM has decreased significantly, POC decreased, and while DO was lower at all sites at this farm compared with the control sites, DO levels have improved.

Copper and zinc was highly variable over this period and showed no consistent differences between the years. High levels of copper and zinc in the sediments (exceeding the ISQC-High threshold (ANZECC 2000)) at salmon Farm 338 and Farm 249 and near Farm 338 over 2012-2015 reflect the long history of use of antifouling chemicals on the marine farms, a practice that has now been discontinued which will mean a decrease the levels at least of copper in time. Levels of copper and zinc at the control sites were very low (mean <10 mg/kg for copper and <35 mg/kg for zinc). Zinc will also reduce in sediments when farms sites are fallowed.

Twenty-six benthic epifaunal taxa were observed in 2015 including sea squirts, scallops, sea cucumbers, star fish, crabs and various algae (Stenton-Dozey 2015). Thirteen taxa were observed at control sites and 11 beneath mussel farms. The bacterium *Beggiatoa*, sponges and algal mats were evident close to pens at Farms 249 and 338. Burrows, which are evidence of the presence of crustaceans and polychaetes and a healthy well-oxygenated benthic environment, were evident at control sites and those at 50 and 100 m from the farm site in the south-east (Farm 339).

Benthic infauna at the control sites were patchily distributed with mean abundances in 2015 at the head of the Bay of 120/core and 56/core at the entrance (**Figure 16** shows values for control sites for 2012-2015). The number of taxa per core was lower in 2014 and 2015 (13 and 14 taxa) than 2012 and 2013 (16 and 18) at the head of the Bay, variable between years at the mouth of the Bay (9-18 taxa) and overall generally lower at the mouth of the Bay than at the head of the Bay. Abundance was higher at the head of the Bay in 2012 and 2013 (100 and 121/core) compared with 2014 and 2015 (52 and 58/core) and lower at the mouth of the Bay (27-57/core) over the 2012-15 period. Species richness followed the same pattern as number of species.

High numbers of infauna species were observed in 2015 below one of the mussel farms, and abundance was considerably higher beneath the salmon pens and 50 and 100 m away from the farm at the southern end of the Bay (Farm 338) (used as a smolt farm then brood stock from 2015, was fallowed 2013-2015). There were few infaunal species associated with the salmon farm in the middle of the Bay (1-6 spp., Farm 249), more species were found at the salmon farm in the south-east (Farm 339) but highest diversity was at the control stations (9 and 12 spp) and the mussel farm towards the north (Farm 245). Based on species richness and the ecological status at the control sites, the benthic community at the northern mussel farm (Farm 245) and south-east salmon farm (Farm 339) were classified as “good” by Stenton-Dozey (2015).

The paucity of species beneath one of the mussel farms and a lack of worm holes was potentially related to earlier salmon on-growing and the resulting potential hypoxia of the sediments, although this has not been corroborated, and in any event, relates to historic farm management practice. At the other mussel farm in the centre of the Bay (Farm 245), the infaunal community was dominated by polychaete taxa, crustaceans and bivalves. Species richness was greater at this site than the control site. This greater species richness was attributed to the shell hash and heterogeneous environment which harboured a number of species, also found at control sites, as well as some that were more abundant epifauna at this site such as some crab species, the sea squirt *Corella eumyota* and various crustaceans, decapods, brittle stars and bivalves.

Over the four years Stenton-Dozey (2015) reported a dominance of the infauna by amphipods and ostracods with greater abundances at the head of the Bay. Some polychaete taxa (Lumbrinerid, Maldanid and Cossurid spp.) were also abundant at the head of the Bay.

Table 2. Characteristics of the benthic environment at control stations in 1998-2009 (Stenton-Dozey & Brown 2009), 2015 (Stenton-Dozey 2015), 2016 (ADS 2016) and 2017 (ADS 2017a). [1] Note that for 2012-2015 the grab sizes may have been different so cannot compare with other years.

Parameter/Site	**Control at head of Bay**					**Control at mouth of Bay**				
	1998-2010	2012-2014	2015	2016	2017	1998-2010	2012-2014	2015	2016	2017
Organic matter (%)	Over 10% most years and up to 18%	4.2-5.7	4.4	6.3	6.5	Generally around 5% and up to 9%	6.3-7.4	6.6	8.4	9.1
Mud content (%)	36-96	38-85 (2013)	34	63	66	18-65	50-57	36	35	37
Sand content (%)	36-96	12-56	60	35	31	20-73	31-46	53	57	53
TOC (% of dry weight)	2.9-17	1.1-1.3	0.9	2.5	1.2	3.8-8.9	1.2-2.2	1.8	2.3	2.2
Mean # infauna species per grab	ns	13-18[1]	14[1]	10	7		9-18[1]	12[1]	11	12
Numbers infauna/grab	ns	50-100[1]	120[1]	12	12	N/A[1]	25-60[1]	60[1]	21	12

Species richness index (Margalef’s *d*)	ns	2.8-4.2	2.8	3.7	2.5		2.2-4.4	2.9	3.3	4.3
Copper (mg/kg DW)		5.5-9	7	9	9		6.6-8.3	8	7	7
Zinc (mg/kg DW)		27-34	34	37	32		26-35	31	38	33

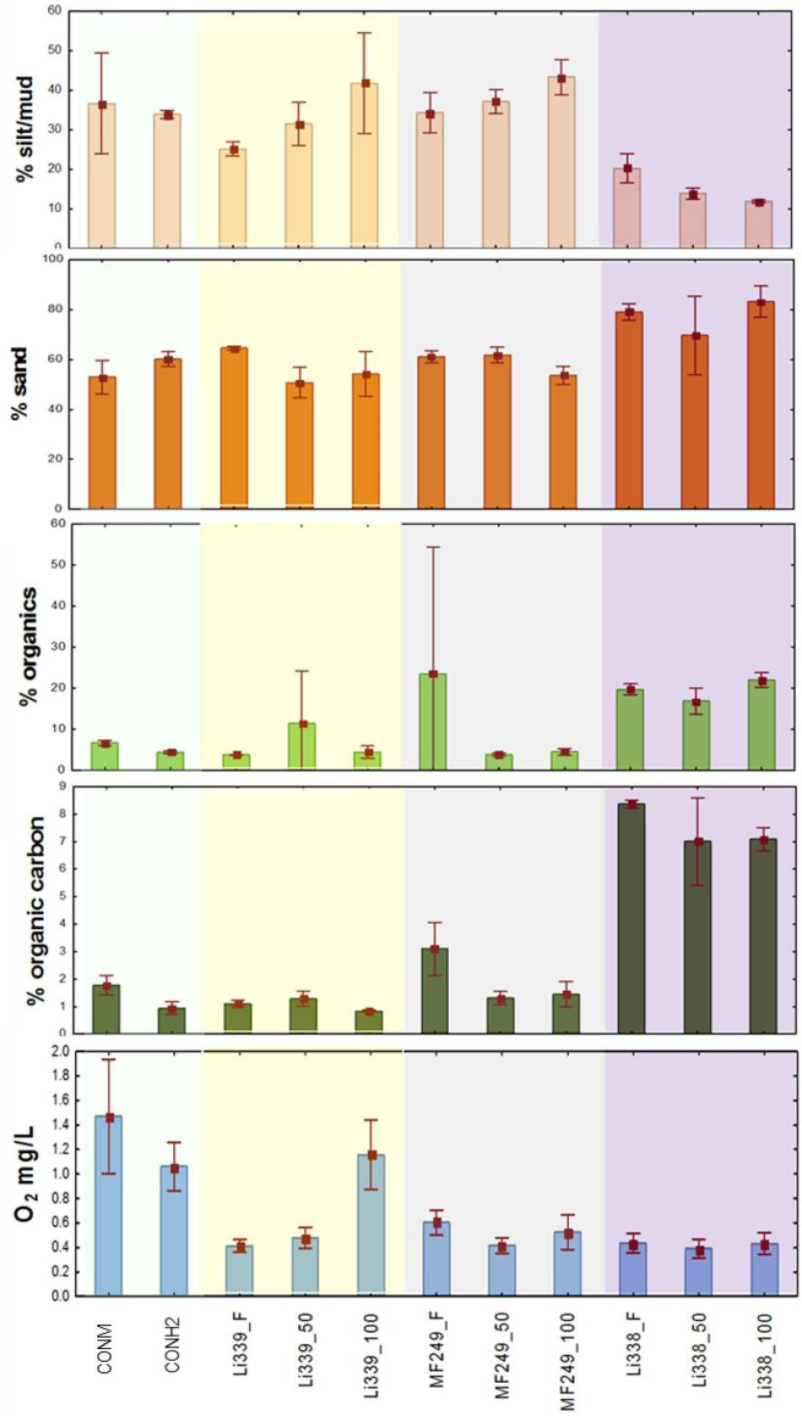

Figure 15. Sediment properties (% silt/mud, % sand, % organic matter, % organic carbon, subsurface O2 mg/L) from the area under the salmon farms 339, 249 and 338 (_F), and 50 m (_50) and 100 m (_100) away, and at the two control stations for 2015. CONH2 = Control Head and CONM = Control Mouth. (From Stenton-Dozey 2015)

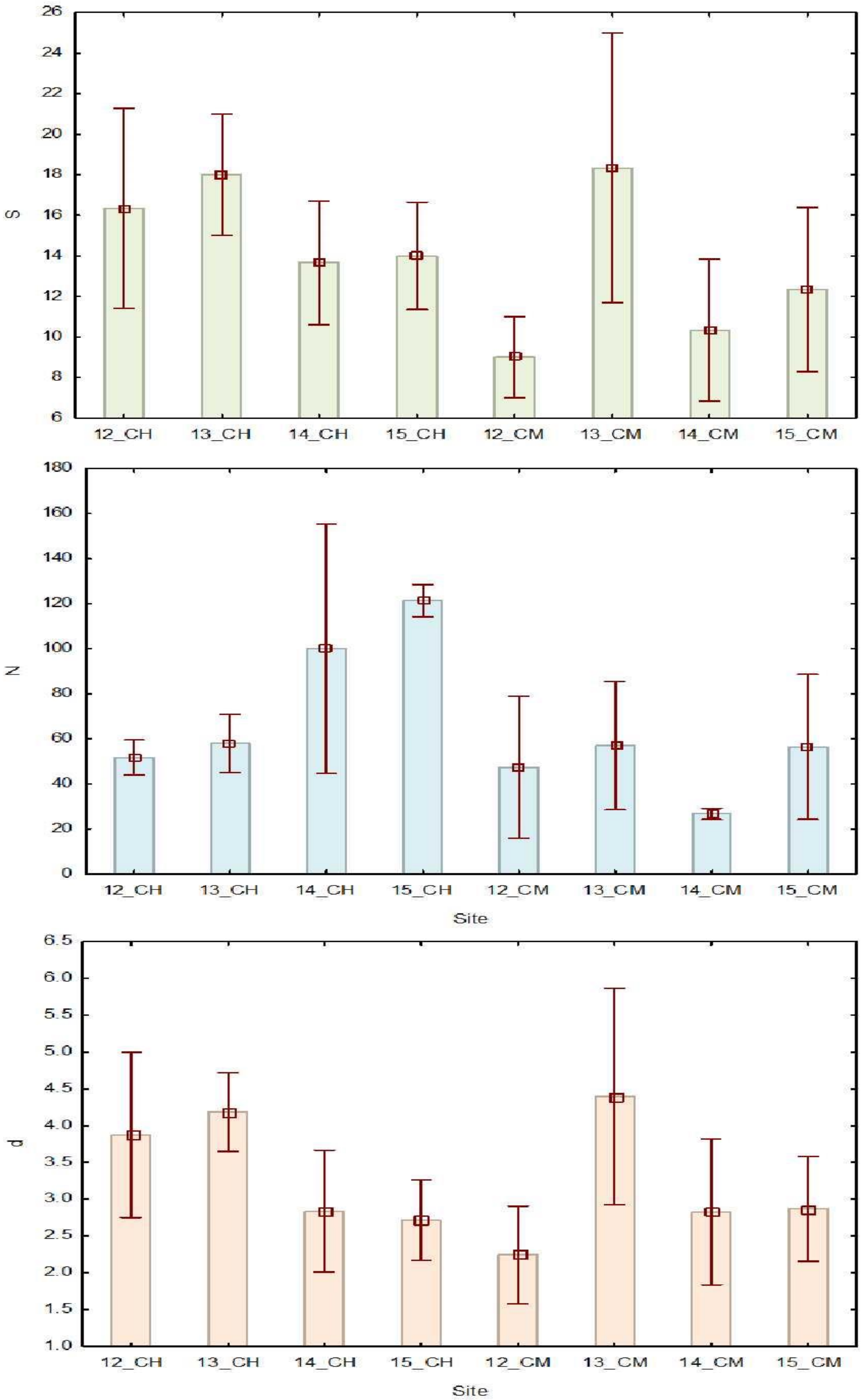

Figure 16. Infauna: mean number (±1 SD, n=3) of individuals (N) and species (S) per core and Margalef's species richness index (d) from sediments at each control station for each year from 2012 to 2015. The years 2012 = 12, 2013 = 13, 2014 = 14 and 2015 = 15. CH =control head and CM Control Mouth. (From Stenton-Dozey 2015)

The status of the benthic environment was assessed in 2013 for two new proposed salmon farms, one was a mussel farming site which it was proposed to convert to a salmon site (Farm 246) and the other was a new farm close to Bravo Island at the mouth of Big Glory Bay (Stenton-Dozey 2013). Potential horse mussel beds and rocky reefs were observed by side-scan sonar close to the site near Bravo Island. Otherwise sediments were described as featureless muddy/sand with the outer site having more sand substrate. The number of epibenthic taxa at the Bravo Island site was double that at any other site. A wide range of species was found associated with a red algae abundant at the Bravo Island site including brachiopods (important species but not listed as a protected species). Filter feeders dominated the control site at the mouth of the Bay (crustaceans including ostracods and bivalves) along with polychaetes.

2016/2017

Surveys in 2016 were carried out at two control sites, two mussel farms (Farms 319, 272) and four salmon farms (Farms 246, 249, 338 and 339). The two mussel farms surveyed in 2017 were Farms 244 and 340 and for salmon farms Farms 246, 338 and 339, along with the two control sites. Note that Farm 246 is additional to those measured in 2012-2015. Parameters measured were the same as those for 2012-2015 and for salmon sites including at the edge of the pens, as well as 50 and 100 m from the pens. Results have been reported in ADS 2016 and ADS 2017a.

Sediment characteristics

For the mussel farm sites surveyed in 2016 sediments could be characterised as:

- Composed predominantly of sand (56-58%) but significant quantities of mud (34-39%);
- Organically enriched compared with controls, especially the site at the head of the Bay;
- There was no or little RPD and a sulphur odour emanated from the sediments;
- For most parameters farm sites were within the range for control sites.

The sites surveyed under mussel farms in 2017 were different to 2016. Sediments below Farm 340 were predominantly composed of sand (49%), with 29% mud and little evidence of enrichment compared with control sites, whereas the sediment composition below farm Farm 244 was 71% mud and 21% sand and it was organically enriched compared with controls.

Sediment composition was highly variable at and around the salmon farms in 2016 and 2017 and, at least in part, could be related to the specific site characteristics. As an example, the results from 2017 are plotted in **Figure 17**. The sediments can be characterised as:

- Composed predominantly of sand, then mud, in 2016 with a greater proportion of mud at 50 and 100 m from Farm 338, attributed to natural characteristics of the site. In 2017 the control site at the head of the Bay and away from salmon Farm 338 was predominantly mud (**Figure 17**) but predominantly sand at the other sites including the control at the entrance;

- Organically enriched beneath the farms in 2016 (TOC generally 2-5% but up to 8.5% at Farm 338) compared with controls and in some cases at 50 and 100 m from the farms. Levels were similar at all locations and less than 1.5% in 2017, except for at Farm 246 (2.3%), Farm 339 (3.9%) and the control site at the mouth of the Bay (2.4% **Figure 17**). Apart from at Farm 339, which was previously a mussel farm, TOC levels at the salmon sites were within the range for control sites. Interestingly TOC (and organic matter) at the mouth of the Bay was higher than at the head of the Bay. Note that the enrichment at Farm 338 was within the range for controls, compared with in 2009 when there was 15-20% organic matter;

- TOM was higher under farms in 2016 (12-19%) but reduced away from the farms. Organic matter was highest at farm sites but also very high at the control site at the head of the Bay in 2017 (9.1%). In 2017 TOM at Farm 339 was lower (8.2%) than 2016, and higher at the farm itself than 50 and 100 m away, but similar at 50 and 100 m to the control site at the head of the Bay. TOM beneath Farm 246 was similar to the control at the mouth but did decrease away from the farm in 2017. Organic matter was lower at the control site at the head of the Bay than at the control site at the mouth and farm sites were in the range for controls sites;

- There was no or small levels of RPD at sites in 2016 and 2017;

- Sulphur emanated from the sediments at least under the farms and sometimes at 50 m in 2016. There was no sulphur odour from sediments at Farm 338 or Farm 246 in 2017 but a strong odour at Farm 339, reducing at sites away from the farm; and

- Organic matter was enriched at the farm sites, but along with most parameters beneath the farms or on the edge of salmon farms were within the range for at least one of the control sites.

Copper and zinc, which formed part of anti-fouling operations until recently and salmon feed respectively, are measured annually at salmon farm sites. Levels were low at all 50 and 100 m sites away from the farms in 2016 and 2017 but levels of copper were above the ISQG-Low threshold at Farm 249 in 2016 and above the ISQG-High threshold for Farms 338 and 339 in both years. Zinc was above the ISQG-Low threshold at Farm 339, and well above the ISQG-High threshold at 338 in 2016 and above the ISQG-Low threshold for both 338 and 339 in 2017. Away from the farms and at control sites, copper and zinc levels were below thresholds.

The characteristics of the benthic environment at control sites are shown in **Table 2**. The site at the mouth of the Bay had stronger currents and thus coarser sediments compared to sites elsewhere further into the Bay. There appears to have been a shift to a muddier substrate at the head of the Bay since 2015.

Organic matter and TOC varied at control sites from 4.4 to 9.1% and 0.9 to 2.5% respectively and tended to be higher at the mouth of the Bay. TOC was lower in 2016 and 2017 than that recorded in 2015 at both control sites. Levels for organic matter and TOC are in the range for similar environments elsewhere with similar substrates (Marlborough Sounds – Forrest 2001, outer Firth of Thames - Sim-Smith et al. 2017). There has been no sulphur odour observed and little if any RPD at control sites in BGB.

Compared with 1998-2009, enrichment at the control site at the head of the Bay in 2016 and 2017 (as well as 2015) was considerably lower (<8% organic matter) compared with over 10% in most years between 2000 and 2009, but similar to 1998/99 and 2005 (**Table 2**). Enrichment at the mouth of the Bay in 2016 and 2017 (8-9% organic matter) was at the higher end of that recorded between 1998 and 2009.

Biological communities

Despite the poor visibility during sampling in 2016, following a recent storm, fifteen taxa comprising epifaunal invertebrates and benthic algae were recorded in photoquadrats, including nine epifauna taxa at both control sites. Infauna species richness and biodiversity were moderately high at all mussel and salmon sites sampled, with a wide range of polychaete species and functional groups present. Similar observations have been made in other regions where marine farming occurs (ie. Marlborough Sounds – mussels and salmon; Firth of Thames – mussels).

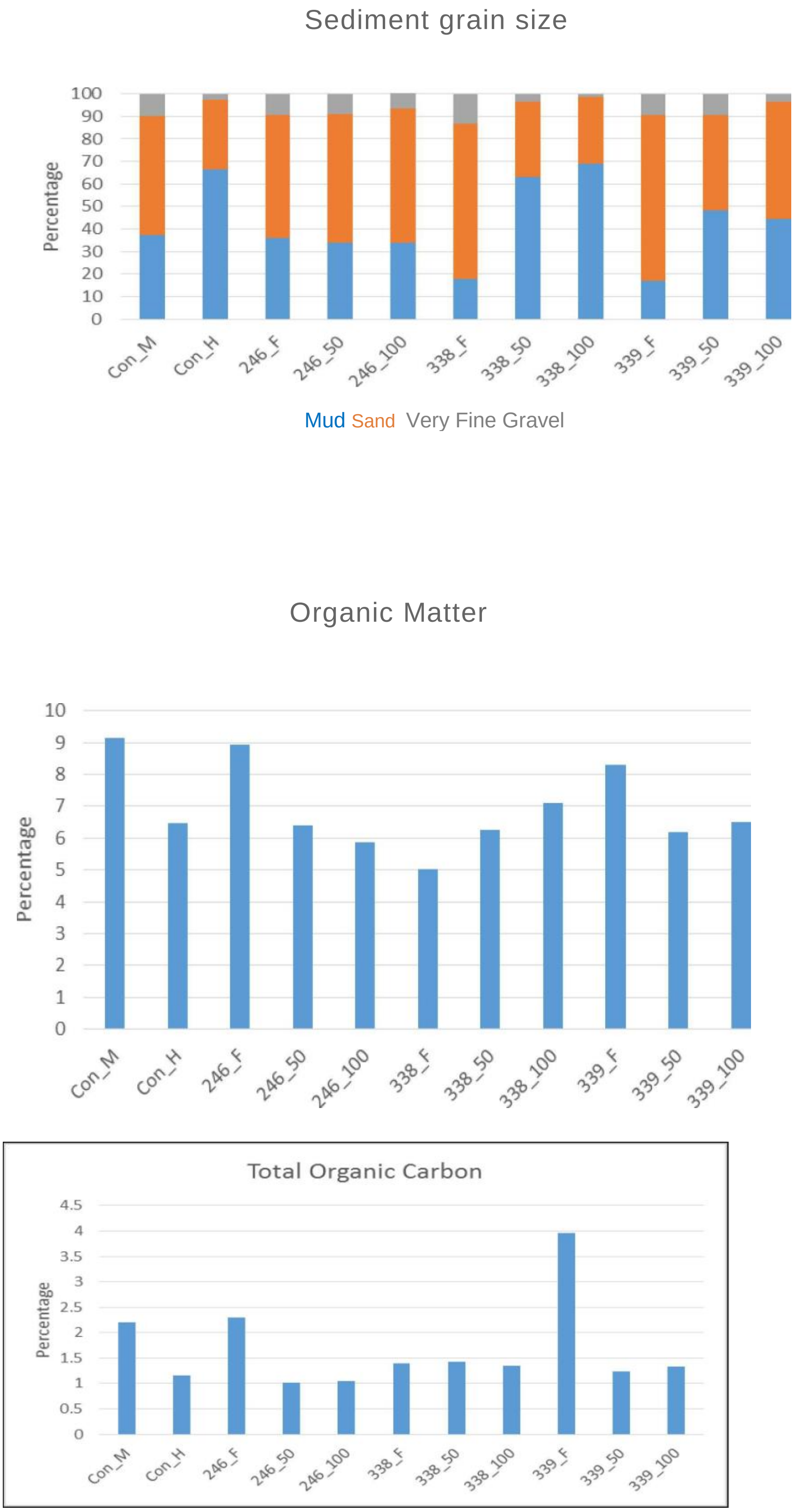

Figure 17. Sediment characteristics for control and salmon farm sites in 2017 (from Sanford 2017).

As with sediment organic matter concentrations, biological communities were observed to be more diverse and 'healthier' with distance from the farm boundaries. The stronger currents at the control site at the mouth of BGB result in several additional taxa only being found at this site. *Beggiatoa* mats were only observed beneath mussel Farm 272 and salmon Farm 249 at 50 and 100 m from the farm, indicating possible anoxia and hydrogen sulphide production in the sediments. Generally ADS (2016) concluded that the sediment quality is not "badly impacted" by marine farms and control sites "appear to be un-impacted".

In 2017 thirteen different epifaunal taxa were recorded in total at the farm sites, and six epifauna taxa were observed at the control sites. Only two epifaunal species were recorded at the mussel farm sites, one of which was *Perna canaliculus*. Coralline algae were observed at the control site at the mouth of the Bay, an area subject to stronger currents. Species richness and biodiversity were similar to 2016 (moderately high at all mussel and salmon sites), and in 2017 were lower at Farms 246 and 338 than at 50 and 100 m away but within the range of control sites, and were very low at Farm 339 itself (two species present). Note that the pens at Farm 339 had recently been moved to another site. A wide range of polychaete species and filter feeding bivalves, and moderately high species richness and diversity were found beneath both mussel farms. The communities below salmon farms generally retained a "moderately high species richness and diversity" with a wide range of polychaetes and filter feeding bivalves (seven spp.) (ADS 2017a).

Infauna structure for control sites, two mussel farm sites and all salmon farm sites in 2017 is shown as an example in **Figure 18**. Although the control site at the head of the Bay was muddier than at the mouth, due to the stronger currents at the mouth, and had lower organic matter concentrations, the infaunal structure was similar for all indices measured at both control sites in 2016 and 2017. The number of infaunal species was similar across all years between 2015 and 2017 (**Table 2**). Numbers per grab were similar at the site at the head of the Bay, but were higher in 2016 at the mouth of the Bay and species richness tended to be higher at the mouth of the Bay. Infaunal communities were relatively diverse and abundant at control sites and similar to sites away from the farms. A range of polychaete species, including large numbers of an unidentified filter feeding species, and bivalves were common at control sites and a number of farm sites. Amphipods were more common at farm sites.

There were no *Beggiatoa* mats observed in 2017, and generally ADS (2017a) concluded that the benthic environment at sites where 'mats' had previously been observed had improved compared with 2016.

A community with low diversity and dominated by polychaete worms and in some cases amphipods and bivalves (eg *Nucula*) are characteristic of soft-sediment sandy/mud habitats in sheltered Bays around New Zealand (eg Menzies Bay and Little Akaloa on Banks Peninsula (Fenwick 2002, Davidson 2002), and Firth of Thames (Morrisey et al. 2016)), but are lower than those measured in embayments in the Marlborough Sounds (22-54 taxa/core Keeley & Taylor 2011). Benthic communities in soft sediments generally have low species abundance and taxonomic diversity, which is sometimes indicative of a slightly stressed environment, however differences in grab equipment and methodologies can also confound comparisons.

3.5 Fish populations

No commercial fishing is permitted in Paterson Inlet or BGB and there are no mataitai reserves or taiapure-local fisheries in BGB.

There is very little data available on fish resources in BGB. However, a recent report by MPI (2016) in response to an application to extend salmon Farm 246 provides some information on the species that may be present. It is notable that no submissions identified the area, at least around this farm, as important for recreational fishing. However MPI (2016) do note that Paterson Inlet is “moderately popular” for amateur fishing and thus it is likely that there is at least some recreational fishing in BGB. Most recreational fishing would target blue cod. Other species found in Paterson Inlet and BGB are likely to be flatfish, moki, butterfish, tarakihi, trumpeter, wrass and rig. Most of these species, and in particular blue cod, moki, and butterfish will be associated with reef and inshore habitats rather than the soft-sediment where marine farms are located.

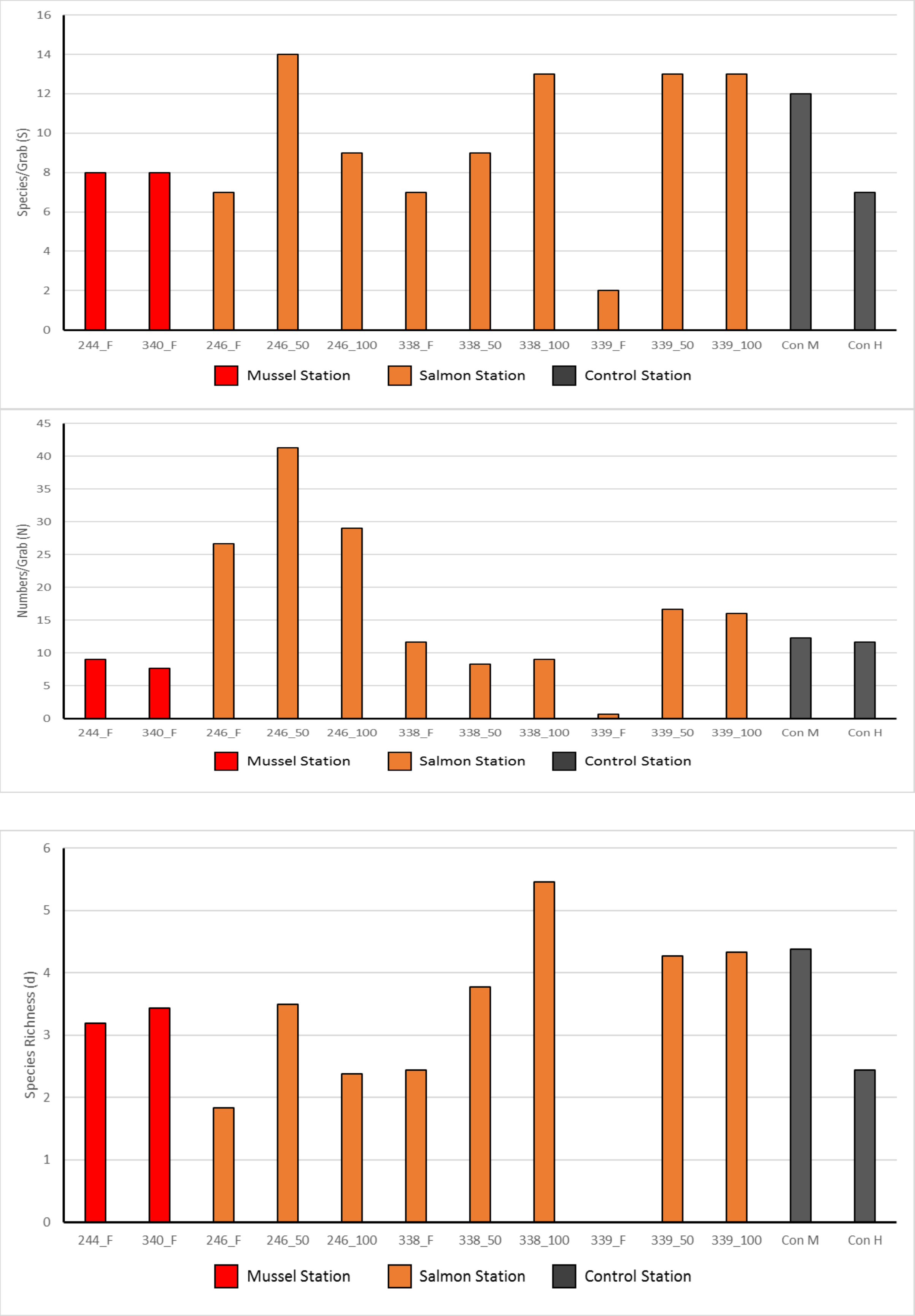

Figure 18. Benthic infauna community structure for all sites in 2017 (from ADS 2017a)

3.6 Birds

Stewart Island is home to a large number of coastal birds including several threatened species (**Table 3**) (DoC 2012). The Stewart Island/Rakiura area also supports nationally significant populations of the sooty shearwater, which are culturally important to Maori. The intertidal area of Paterson Inlet is noted as a significant habitat for wading birds, including the Southern New Zealand dotterel.

The main birds of interest in BGB are likely to be various shag, penguin and gull species. The distribution of these species in New Zealand, and in particular Stewart Island and BGB, are described in the AEE (Sanford 2017) based on information sourced from http://nzbirdsonline.org.nz and, along with information on their feeding and habitats, are summarised in this section.

Shags

There are three species of shag found in the Paterson Inlet /BGB area - Stewart Island, spotted, and Pied shag.

The Stewart Island shag has an estimated population of 1,600 - 1,800 breeding pairs, and breeds and roosts on steep cliffs and rugged islets. They are found from southern Stewart Island as far north as the Waitaki River. Stewart Island shags feed up to 15 km offshore and are mainly demersal feeders on small fish such as cockabullies and flatfish (Lalas 1983).

Table 3. Threatened indigenous bird species in the Stewart Island/Rakiura management area. (Threat status from Robertson et al. 2016).

Species	**Threat ranking**
Southern NZ dotterel (*Charadrius obscurus obscurus*)	Nationally critical
Fiordland crested penguin (*Eudyptes pachyrhynchus*)	Nationally vulnerable
Stewart Island shag (*Leucocarbo chalconotus*)	Nationally vulnerable
Yellow-eyed penguin (*Megadyptes antipodes*)	Nationally vulnerable
Sooty shearwater (*Puffinus griseus*)	Declining
Southern blue penguin (*Eudyptula minor minor*)	Declining

Black-billed gull (*Chroicocephalus bulleri*)	Nationally critical

Pied shag are found around New Zealand's coastline and typically breed in coastal evergreens overhanging the sea. A national population count has not been undertaken, however the population is estimated to be 1,000 - 5,000 mature individuals. Pied shag feed mainly on small fish and crustaceans.

Spotted shag are a sub-species found on Stewart Island and nest in colonies of up to 700 pairs. The estimated population is up to 50,000 breeding pairs. Spotted shags are also demersal feeders, feeding mainly on deep water ahuru (small cod species), sprats, and red cod.

Shearwater

Sooty shearwater (Māori name tītī, muttonbird) breed on islands around New Zealand but all the large colonies are around Stewart Island or on The Snares. The sooty shearwater forages widely offshore where they dive to depths of over 40 m. They feed mainly on small fish, squid, krill and other crustaceans.

Penguins

There are three species of penguin found in the Paterson Inlet /BGB area - Yellow eyed, little blue, and Fiordland crested penguins.

Yellow eyed penguins are equally dependant on marine and land habitats. Their population is estimated to be 6,000 - 7,000, however, the number of breeding pairs is estimated at 630. They breed along the eastern and south-eastern coastlines of the South Island, as well as Stewart Island, Auckland Islands, and Campbell Islands. Yellow-eyed penguins are predominantly pelagic feeders but forage close to the seabed (Marchant & Higgins 1990, Moore 1999). They feed mainly at depths of 40-80 m on sprat, red and blue cod but some will feed closer inshore. There are known yellow-eyed penguin breeding sites on the Bravo Islands, at the mouth of Big Glory Bay.

The Fiordland crested penguin nests in colonies along the south-west of the South Island and on Stewart Island, preferring hollows under fallen trees, roots, boulders or rock crevices on inaccessible headlands and islets. Their current population is estimated to be 2,500 - 3,000 breeding pairs. The main prey species are squid, crustaceans and fish.

The little blue penguin is the smallest species of penguin, and populations are found around the New Zealand and the Chatham Islands coastlines. They nest along the coastline in burrows in banks on the coastline. Their population is estimated to be 350,000 - 600,000 around the world. They feed on a variety of surface-schooling fish and squid. There is a resident population in Big Glory Bay.

Gulls

Gulls are widespread in the Paterson Inlet /BGB area, with the main species present being black-billed, red-billed, and southern black-backed gulls all present.

The black-billed gull is endemic to New Zealand and the majority of the population nests in Southland, with approximately 5% in the North Island, and the remainder across the rest of the South Island. Most black-billed gulls breed in large colonies on inland river beds but some will breed in coastal habitats. Their population was estimated to be 90,000 individuals in 2008 with 70% occurring in the Southland region. Black-billed gulls feed mainly on land but can also feed in coastal areas on fish and invertebrates.

The red-billed gull is the most common gull in New Zealand, and is found in coastal communities around the country. They breed in dense colonies mainly along the eastern coasts of the North and South Islands on stacks, cliffs, river mouths, and sandy and rocky shores. Red-billed gulls scavenge for a wide range of food including small fish and shellfish.

The southern black-backed gull is one of the most abundant and familiar large birds in New Zealand. They are found all around New Zealand except for in forest and scrub habitats, and are abundant where there is a food source. They breed throughout New Zealand with the largest breeding colonies on islands, steep headlands, sand or shingle spits, or on islands in shingle riverbeds. They are very abundant with a number of colonies with more than 100 breeding pairs and a few with more than 1000. Black-backed gulls feed on a range of foods including marine invertebrates, fish and in some cases they predate on other birds.

3.7 Mammals

The distribution and populations of marine mammals that occur in Paterson Inlet and BGB are described in the AEE (Sanford 2017), based on http://www.doc.govt.nz/nature/native-animals/marine-mammals. That information and some additional information on distribution and feeding are presented in this section. Marine mammals that have been recorded around Stewart Island regularly are listed in **Table 4** in order of decreasing concern**.**

Table 4. Marine mammals recorded around Stewart Island (DoC 2015 and Sanford 2017, Threat status from Baker et al. 2016))

Marine mammal	**Scientific name**	**NZ Threat classification**	**IUCN status**	**Residency category in Southland**
New Zealand sea lion/Hooker's sea lion	*Phocarctos hookeri*	Nationally critical	Endangered	Seasonal to year-round resident
New Zealand fur seal	*Arctocephalus forsteri*	Not threatened	Least concern	Year-round resident
Bottlenose dolphin	*Tursiops truncatus*	Nationally endangered	Least concern / critically endangered (Fiordland population)	Seasonal to year-round resident
Southern right whale	*Balaene australis*	Nationally vulnerable	Least concern	Seasonal Migrant
Humpback whale (Oceanic subpopulation)	*Megaptera novaeangliae*	Migrant	Endangered	Seasonal Migrant

Seals and Sea Lion

There are four species of pinnipeds found within Big Glory Bay; New Zealand sea lion and fur, leopard and southern elephant seals. Both NZ sea lions and fur species are known for their strong attraction to salmon farms both in New Zealand and Australia as a food source and haul-out area. All three species of seal, and the New Zealand sea lion, are granted protection under the Marine Mammals Protection Act 1978.

Stewart Island supports a growing breeding population of the New Zealand sea lion with the main breeding location being Port Pegasus. Most sea lion breed on the Antipodes and

Campbell Islands and they prefer to haul out on sandy beaches. The number present in Big Glory Bay has increased in recent years, particularly around The Neck in outer Big Glory Bay. The sea lion population is estimated to be approximately 12,000, with a conservation status of "Nationally Critical" and populations in decline. Sea lion feed on small fish, squid and invertebrates, none of which are adversely affected by this proposal.

Fur seals are the most common seal found in New Zealand estimated at a population of around 100,000 (Goldsworthy & Gales 2008) and on the order of 200,000 across New Zealand and Australia (Chilvers & Goldsworthy 2015). Local populations across New Zealand are considered to be growing by as much as 12-25% a year. The waters around Stewart Island are identified as being a breeding site for fur seals and while there are no breeding sites in Big Glory Bay, observations indicate they haul out in Big Glory Bay. Fur seals forage over large areas on a range of foods including squid, octopus, and mackerel generally over continental shelf areas, none of which are adversely affected by this proposal.

Dolphins

Bottlenose dolphins occur around New Zealand in at least three distinct groups: Fiordland, Marlborough Sounds and in the Bay of Islands, but they also regularly frequent the Paterson Inlet area, including Big Glory Bay. A recent photo-id study in Paterson Inlet (Brough et al 2015) suggests these individuals are likely part of a larger, wide-ranging southern population with a minimum abundance of 80 to 111 dolphins. Most bottlenose dolphin groups are generalists in their feeding preferences, and can be quite adaptive in their feeding styles. For instance, this species have been known to opportunistically pull salmon out through the bottom of pens in the Marlborough Sounds. Again the food for these mammals will not be adversely affected by this proposal.

Orca (killer whales) are very occasionally seen in the Paterson Inlet/BGB area, and have an estimated population in New Zealand of 150 - 200 in three groups. One group spends its time in North Island waters, one in South Island waters, and one between both island's waters. Killer whales have a diverse diet with some feeding on fish, rays, seals and dolphins. Again the food for these mammals will not be adversely affected by this proposal.

Whales

Whales are likely to be very transient visitors to the Paterson Inlet/BGB area. The main concern for marine farms and large whales is whether they overlap within traditional migration route. In Australia, both a southern right whale and a humpback have travelled straight through finfish farm structures, destroying the cages and/or entangling themselves while following their main migration route, which in these cases was more offshore in open waters

(Kemper & Gibbs 2001; Kemper et al. 2003).

Southern right whales are circumpolar migratory animals and transitory visitors to the Paterson Inlet/BGB area, typically present between 20°S and 55°S. Within New Zealand, a recovery in population numbers has been observed within breeding grounds of the sub-Antarctic islands and throughout mainland New Zealand which is being re-established as a secondary wintering ground (mainly between June and October). Carroll et al. (2014) noted that the highest concentrations of southern right whale sightings, between 2003 and 2010, was Foveaux Strait, the Otago Peninsula and the Northland coast. Southern right whales can be slow migrators, especially cow / calf pairs, with a tendency to remain in sheltered bays or protected waters for several days and / or weeks. Right whales' tendency to remain within coastal surface waters while breeding and migrating, and their natural curiosity, places this nationally vulnerable species at greater risk from some human impacts.

Humpback whales (*Megaptera novaeangliae*) are also known to seasonally migrate through these waters on their way north in winter and south again in the spring. Unlike right whales, humpbacks tend to travel in straight lines from headland to headland only occasionally passing inshore to bays, bights, and / or harbours.