SANFORD

16 November 2017

Environment Southland
Cnr North Road & Price Street
Waikiwi
Invercargill 9810

ENVIRONMENT SOUTHLAND
CK 16 NOV 2017
Cash $1350.00

Attention: Vin Smith

Dear Vin

RE: Sanford Limited – Big Glory Bay Salmon Farms – Change of Conditions Application

Please find enclosed three bound copies of a change of conditions application and Assessment of Environmental Effects by Sanford Limited ('*Sanford*') for changes to seven of its Big Glory Bay, Stewart Island marine farm sites.

A copy of the change of conditions application and Assessment of Environmental Effects is provided electronically on the enclosed USB.

In respect of the lodgement fee for the change of conditions application, Sanford provides a cash payment of $1,350.00 and requests that a receipt for this lodgement fee be provided to aundorf-lay@sanford.co.nz at your earliest convenience. Please use the following Purchase Order number with all future invoices 143791 and send to invoices@sanford.co.nz.

Sanford respectfully request that, due to the commercial sensitivity of this change of conditions application, it be treated as confidential until it has been accepted for processing in accordance with section 88 of the Resource Management Act 1991.

Please do not hesitate to contact the writer should you have any queries regarding this application.

Yours sincerely,

Alison Undorf-Lay
Industry Liaison Manager
Sanford Limited

Aundorf-lay@sanford.co.nz | 027 293 7795

environment SOUTHLAND

Te Taiao Tonga

Cnr North Road and Price Street
DX YX20175
(Private Bag 90116)
Invercargill

Telephone (03) 211 5115
Fax No. (03) 211 5252

Change (Variation) or Cancellation of Consent Conditions

This application is made under Section 127 of the Resource Management Act 1991

For Office Use Only

Received:

Application No:

Job No:

Officer in Charge:

To: The Chief Executive
Environment Southland
DX YX20175
(Private Bag 90116)
Invercargill 9840

Charges/Deposits

A deposit must accompany your application. If the costs incurred in processing this application exceed the deposit, the applicant will be invoiced for the balance.

1. Consent Holder(s) Details

Consent Holder(s) name(s) in full: Sanford Limited

Postal Address: PO Box 443
Shortland Street
Auckland
Post Code: 1140

Street Address (not PO Box No): 22 Jellicoe Street
Freemans Bay
Auckland
Post Code: 1010

Phone Number: Business: (09) 300 8443 Private:
Mobile: 027 293 7795 Fax:

Email Address: aundorf-lay@sanford.co.nz

2. Contact Details (if not consent holder)

Name of Contact Person: Alison Undorf-Lay

Postal Address: PO Box 443
Shortland Street
Auckland
Post Code: 1140

Phone Number: Business: (09) 300 8443 Private:
Mobile: 027 293 7795 Fax:

Email Address: aundorf-lay@sanford.co.nz

3. What is the Consent number(s) you wish to change/cancel the conditions of?

AUTH-20157616, 207256, 203236, 203237, 203240, 203241 and 203242.

4. List the Condition/s number/s and give details of the proposed changes/cancellation.

Condition 4(a) of AUTH-20157616.
Condition 5 of 207256, 203236, 203237, 203240, 203241 and 203242.

5. Describe any adverse effects that may result from the proposed change/cancellation to the condition/s. You must include an Assessment of Environmental Effects as outlined in the Fourth Schedule of the Resource Management Act 1991. The extent of detail required should be relative to the scale and significance of the potential adverse effects the activity may have on the receiving environment.

See the attached AEE.

6. Will the proposed change/cancellation to the condition/s result in any adverse effects that are different from those currently authorised by the consent?

See the attached AEE.

7. List any parties that you consider may be adversely affected by the proposed change/cancellation.

Declaration

In order to provide a complete application have you remembered to:

θ Fully complete this application form

θ Attach the required deposit.

I/we hereby certify that to the best of my/our knowledge and belief, the information given in this application is true and correct. **I/we undertake to pay all actual and reasonable application processing costs incurred by Environment Southland.**

Name/s: ALISON UNDORF-LAY
(Block capitals)

Signature/s: ______________________
(or person authorised to sign on behalf of applicant)

Designation: Industry Liaison Manager Sanford Limited
(e.g. owner, manager, consultant)

Date: 16.11.17

Costs

The charges shown below are a deposit to be paid on lodgement of a change of conditions application. The deposit will not usually cover the full cost of processing the application and further costs will be incurred. GST is included in all fees and charges.

Non-notified application (Deposit)

S127 Change or Cancellation of a Consent Condition	$1,350.00

Information Requirements

In order for any change of conditions application to be processed efficiently in the minimum time and at minimum cost, it is critical that as much relevant information as possible is included with the application. Where an application is significantly incomplete, the Consent Authority may decide not to accept the application for processing pursuant to s88 of the Resource Management Act 1991.

SANFORD LIMITED

BIG GLORY BAY SALMON FARMS

Change of Conditions Application and Assessment of Environmental Effects

16 November 2017

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C: Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume III – Water Quality, Aquadynamic Solutions Sdn Bhd, November 2017.

D: Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume IV – Seabed Deposition, Aquadynamic Solutions Sdn Bhd, October 2017.

E: Big Glory Bay Benthic and Water Quality Sampling 2016, Aquadynamic Solutions Sdn Bhd, September 2016.

F: Big Glory Bay Benthic and Water Quality Sampling 2016/2017, Aquadynamic Solutions Sdn Bhd, May 2017.

A

PART A

Change of Condition Application

FORM 10

APPLICATION FOR CHANGE OF RESOURCE CONSENT CONDITIONS

Sections 127 and 145, Resource Management Act 1991

To Environment Southland
Private Bag 90116
Invercargill 9840

1. **Sanford Limited ("Sanford") apply for a change of a condition of seven resource consents.**

2. **The full name and address of each owner or occupier (other than the applicant) of the site to which the application relates are as follows:**

   Her Majesty the Crown.

3. **The application relates to the following resource consents:**

   - AUTH-20157616;
   - 207256;
   - 203236;
   - 203237;
   - 203240;
   - 203241; and
   - 203242.

4. **The application relates to the following specific condition of the resource consents:**

   Condition 4(a) of AUTH-20157616 and Condition 5 of 207256, 203236, 203237, 203240, 203241, and 203242.

5. **The proposed changes are as follows:**

   Resource Consent AUTH-20157616, relating to MF 246

   4. (a) The nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to ~~73.84~~15.1 tonnes provided that:~~.~~

   (i) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

   (ii) a binding agent is contained within the feed.

   ~~Where the consent holder has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm sites provided that the~~

significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated.

(b) *Activities authorised by Condition 4(a) shall not:*

- *Increase the average excess total ammonia nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73 kg/m²/year more than 100 metres from the boundary of the site; or*
- *Result in total faeces and solid waste deposition greater than 5 kg/m²/year more than 100 metres from the boundary of the site.*

(c) *Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 4(b) to be assessed.*

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased above 332.064 tonnes/year.

(bd) *The consent holder shall provide an annual report summarising the:*

(i) *monthly volume of feed for salmon supplied to the marine farm site; and*

(ii) *monthly loading (in tonnes) of total nitrogen supplied to the marine farm site as a result of feeding salmon;*

Between 1 July and 30 June the following year. This report shall be provided to the Consent Authority by 31 July each year, or upon request.

Resource Consent 207256, relating to MF 249

5.(a) *Except where Condition 5(b) applies, Tthe nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 73.792 tonnes.*

(b) *Where the consent holder:*

(i) *holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input from feed; and/or*

(ii) *has the written agreement of another consent holder in Big Glory Bay that holds a resource consent with conditions specifying allowable nitrogen input;*

the consent holder may utilise that nitrogen input from feed has the right to

~~use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed,~~ either wholly or in part, between any or all of the consent holder's marine farm sites provided that:~~; the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.~~

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that authorised by Condition 5(a) shall not:

- *Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73 kg/m^2/year more than 100 metres from the boundary of the site; or*
- *Result in total faeces and solid waste deposition greater than 5 kg/m^2/year more than 100 metres from the boundary of the site; and*

(v) the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and

(vi) the feed deployed shall be consistent with the parameters of the feed modelled.

(c) Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

Resource Consent 203236, relating to LI 320

5.(a) The nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to ~~73.792~~200.6 tonnes provided that:~~.~~

(i) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

Where the consent holder has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm sites provided that the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.

(b) Activities authorised by Condition 5(a) shall not:

- *Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73 kg/m^2/year more than 100 metres from the boundary of the site; or*
- *Result in total faeces and solid waste deposition greater than 5 kg/m^2/year more than 100 metres from the boundary of the site.*

(c) Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased above 332.064 tonnes/year.

Resource Consent 203237, relating to LI 321

5.(a) Except where Condition 5(b) applies, Tthe nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 73.792 tonnes.

(b) Where the consent holder:

(i) holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input from feed; and/or

(ii) has the written agreement of another consent holder in Big Glory Bay that holds a resource consent with conditions specifying allowable nitrogen input;

the consent holder may utilise that nitrogen input from feed has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm *sites provided that: the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.*

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that authorised by Condition 5(a) shall not:

- *Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73 kg/m^2/year more than 100 metres from the boundary of the site; or*
- *Result in total faeces and solid waste deposition greater than 5 kg/m^2/year more than 100 metres from the boundary of the site; and*

(v) the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and

(vi) the feed deployed shall be consistent with the parameters of the feed modelled.

(c) Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

Resource Consent 203240, relating LI 338

5.(a) Except where Condition 5(b) applies, Tthe nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 73.792 tonnes.

(b) Where the consent holder:

(i) holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input

from feed; and/or

(ii) has the written agreement of another consent holder in Big Glory Bay that holds a resource consent with conditions specifying allowable nitrogen input;

the consent holder may utilise that nitrogen input from feed has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm sites provided that: the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that authorised by Condition 5(a) shall not:

- Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or
- Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;
- Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or
- Result in total organic carbon deposition greater than 0.73 kg/m^2/year more than 100 metres from the boundary of the site; or
- Result in total faeces and solid waste deposition greater than 5 kg/m^2/year more than 100 metres from the boundary of the site; and

(v) the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and

(vi) the feed deployed shall be consistent with the parameters of the feed modelled.

(c) Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

Resource Consent 203241, relating to LI 339

5.(a) Except where Condition 5(b) applies, Tthe nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 55.344 tonnes.

(b) Where the consent holder:

(i) holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input from feed; and/or

(ii) has the written agreement of another consent holder in Big Glory Bay that holds a resource consent with conditions specifying allowable nitrogen input;

the consent holder may utilise that nitrogen input from feed has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm sites provided that: the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that authorised by Condition 5(a) shall not:

- *Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73 kg/m^2/year more than 100 metres from the boundary of the site; or*
- *Result in total faeces and solid waste deposition greater than 5 kg/m^2/year more than 100 metres from the boundary of the site; and*

(v) the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and

(vi) the feed deployed shall be consistent with the parameters of the feed modelled.

(c) Notwithstanding Condition 16, a suitably qualified, experienced and

independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

Resource Consent 203242, relating to LI 340

5.(a) Except where Condition 5(b) applies, ~~T~~the nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 55.344 tonnes.

(b) Where the consent holder:

(i) holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input from feed; and/or

(ii) has the written agreement of another consent holder in Big Glory Bay that holds a resource consent with conditions specifying allowable nitrogen input;

the consent holder may utilise that nitrogen input from feed ~~has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed,~~ either wholly or in part, between any or all of the consent holder's marine farm sites provided that: ~~the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.~~

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that authorised by Condition 5(a) shall not:

- *Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73 kg/m^2/year more than 100 metres from the boundary of the site; or*

- *Result in total faeces and solid waste deposition greater than 5 kg/m^2/year more than 100 metres from the boundary of the site; and*

(v) *the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and*

(vi) *the feed deployed shall be consistent with the parameters of the feed modelled.*

(c) *Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.*

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

6. **The site that the resource consents relate to are as follows:**

The marine farm sites subject to this variation are located at the following New Zealand Map Grid co-ordinates:

MF 246

Site corner	Latitude S	Latitude E
NW	46 58.5436 S	168 07.8746 E
NE	46 58.5227 S	168 08.1047 E
SE	46 58.6300 S	168 08.1255 E
SW	46 58.6509 S	168 07.8953 E

MF 249

Site corner	Latitude S	Latitude E
NW	46 58.6817 S	168 06.3285 E
NE	46 58.6692 S	168 06.6843 E
SE	46 58.8124 S	168 06.6837 E
SW	46 58.8249 S	168 06.3279 E

LI 320

Site corner	Latitude S	Latitude E
N	46 58.3787 S	168 06.6433 E
E	46 58.3420 S	168 06.7483 E
S	46 58.4732 S	168 06.6777 E
S	46 58.4359 S	168 06.5727 E

LI 321

Site corner	Latitude S	Latitude E
NW	46 59.3765 S	168 06.4085 E
NE	46 59.3580 S	168 06.4994 E
SE	46 59.4852 S	168 06.5539 E
SW	46 59.5036 S	168 06.4630 E

LI 338

Site corner	Latitude S	Latitude E
NW	46 59.2216 S	168 06.5745 E
NE	46 59.2216 S	168 06.6930 E
SE	46 59.3810 S	168 06.6918 E
SW	46 59.3805 S	168 06.5741 E

LI 339

Site corner	Latitude S	Latitude E
N	46 59.1414 S	168 07.6613 E
E	46 59.0626 S	168 07.7651 E
S	46 59.2134 S	168 07.6474 E
W	46 59.1346 S	168 07.5437 E

LI 340

Site corner	Latitude S	Latitude E
N	46 59.2291 S	168 07.5154 E
E	46 59.1502 S	168 07.6200 E
S	46 59.3016 S	168 07.5031 E
W	46 59.2228 S	168 07.3985 E

7. **There are no other activities that are part of the proposal to which this application relates.**

8. **I attach an assessment of the proposed change's effect on the environment that—**

   (a) includes the information required by clause 6 of Schedule 4 of the Resource Management Act 1991; and

   (b) addresses the matters specified in clause 7 of Schedule 4 of the Resource Management Act 1991; and

   (c) includes such detail as corresponds with the scale and significance of the effects that the activity may have on the environment.

9. **I attach an assessment of the proposed changes against the matters set out in Part 2 of the Resource Management Act 1991.**

10. **I attach an assessment of the proposed changes against any relevant provisions of a document referred to in section 104(1)(b) of the Resource Management Act 1991, including the information required by clause 2(2) of Schedule 4 of that Act.**

11. **I attach the following further information required to be included in this application by the district plan, the regional plan, the Resource Management Act 1991, or any regulations made under that Act:**

- Assessment of Environmental Effects;
- Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume I – Summary Of Findings, Aquadynamic Solutions Sdn Bhd, October 2017;
- Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume II – Hydrodynamic Modelling and Flushing, Aquadynamic Solutions Sdn Bhd, October 2017;
- Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume III – Hydrodynamic Modelling and Flushing, Aquadynamic Solutions Sdn Bhd, November 2017;
- Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume IV – Seabed Deposition, Aquadynamic Solutions Sdn Bhd, October 2017;
- Big Glory Bay Benthic and Water Quality Sampling 2016, Aquadynamic Solutions Sdn Bhd, September 2016; and
- Big Glory Bay Benthic and Water Quality Sampling 2016/2017, Aquadynamic Solutions Sdn Bhd, May 2017.

Date: 16 November 2017

Signature: ....

Person authorised to sign on behalf of applicant)

Address for Service: Sanford Limited
PO Box 443
Shortland Street
Auckland 1140

Telephone: (09) 300 8443
Email: AUndorf-Lay@sanford.co.nz

Contact person: Alison Undorf-Lay

B

PART B

Assessment of Environmental Effects

1. INTRODUCTION

1.1 BACKGROUND

Sanford Limited ("**Sanford**") holds seven coastal permits that authorise the farming of quinnat salmon (*Oncorhynchus tshawytscha*) in Big Glory Bay, Stewart Island.[1] The location of each of these farms is shown in bold black outline in Figure 1 below.

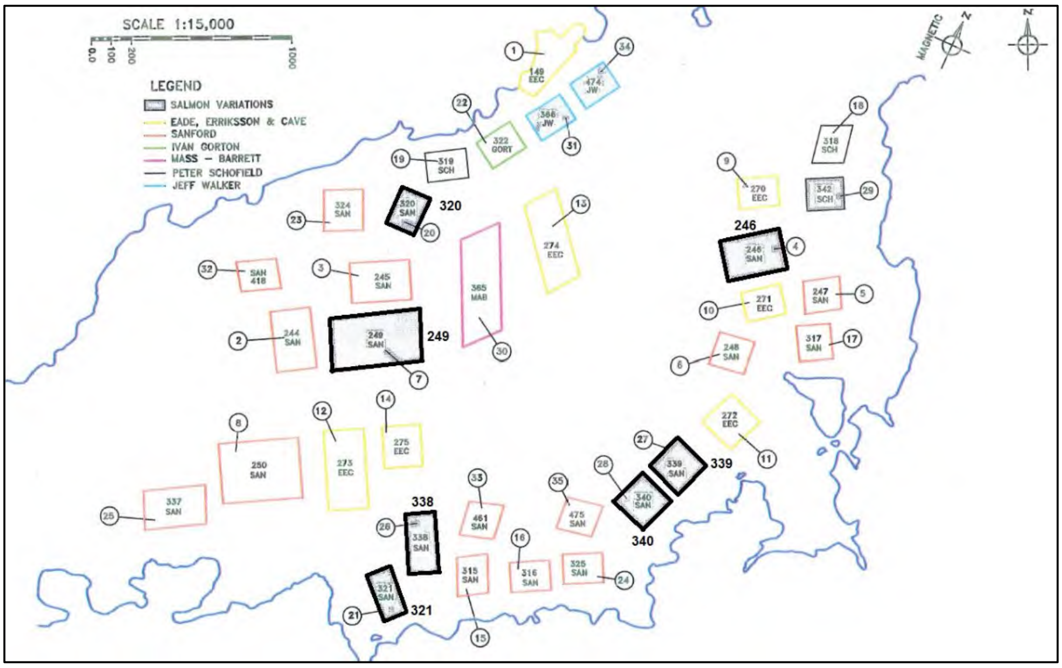

Figure 1: Big Glory Bay, Stewart Island marine farms.

The seven coastal permits are for sites referred to as LI 320, LI 321, LI 338, LI 339, LI 340, MF 246 and MF 249. The current coastal permits for those sites designated "LI" were granted 1 January 2005. They were previously authorised by Marine Farming Licences issued by the Ministry of Fisheries under the Fisheries Act 1996. The current coastal permits designated "MF" were granted on 29 January 2016 (MF 246) and 8 August 2011 (MF 249); previous consents for those sites related to mussel farming only.

Each coastal permit imposes a limit on the amount of nitrogen from feed that can be discharged. This in turn limits the level of salmon production. The coastal permits allow the nitrogen from feed to be aggregated across all the Sanford salmon farms, allowing 332.064 tonnes / year of nitrogen from feed to be discharged.

Table 1 provides a summary of Sanford's nitrogen allowance across all seven sites.

[1] AUTH-20157616, 207256, 203236, 203237, 203240, 203241 and 203242.

Table 1: Sanford's Big Glory Bay allowable nitrogen input.

Marine Farm	Allowable Nitrogen Input (tonnes)	Notes
LI 320	73.792	
LI 321	73.792	
LI 338	73.792	
LI 339	55.344	
LI 340	55.344	
Sub-Total	**332.064**	
MF 246	73.8 But no additional allowance to that above	The applications to allow salmon farming at these sites were made solely on the basis of relocating production from other farms in order to promote environmental sustainability. It did not increase the number of salmon farmed by Sanford in Big Glory Bay.
MF 249	73.792 But no additional allowance to that above	
Total	**332.064**	

Having commissioned comprehensive environmental assessments of the assimilative capacity of Big Glory Bay for nitrogen input from feed, Sanford now seeks to change the conditions of its existing consents to increase the total allowable nitrogen input from feed over all seven consents to 659 tonnes / year ("**the proposed changes**").

This application is made under s127 of the Resource Management Act 1991 ("**RMA**"), and is therefore an application for a discretionary activity.

1.2 THE APPLICANT – SANFORD LIMITED

Sanford is a long standing participant in the New Zealand seafood industry. Its operations include catching / farming, processing, packaging and exporting seafood products. Sanford has well established markets domestically and internationally and strives to develop and promote New Zealand seafood products at every opportunity. Sanford has substantial interest in marine farming and the associated processing of:

- Salmon in Big Glory Bay (Stewart Island); and
- Greenshell™ mussels in Tasman Bay, Golden Bay, Marlborough Sounds, Canterbury, Stewart Island, Coromandel, and Auckland.

1.3 PROJECT RATIONALE

Sanford has been farming salmon in Big Glory Bay since the 1990s, and has coastal permits to farm salmon at seven of its marine farm sites in Big Glory Bay. As outlined above, Sanford's current permits allow for the discharge of a total of 332.064 tonnes / year of nitrogen from feed.

Sanford seeks to increase its nitrogen allowance in Big Glory Bay to 659 tonnes / year but with site specific limits also proposed. It is noted that the Aquaculture Project for Southland, managed by the Southland Regional Development Strategy team has set a regional goal to increase salmon production in Southland to 25,000 tonnes by 2020. Currently approximately 3,000 tonnes is produced, all of which is produced by Sanford. Achieving this goal would result in nearly 370 new jobs, an additional $214m a year in export earnings and add $60m to Southland's gross domestic product. The proposed changes would assist the Southland region in achieving this goal.

1.4 SUPPORTING DOCUMENTS

Sanford commissioned Aquadynamic Solutions Sdn Bhd ("**ADS**") to undertake hydrodynamic and flushing, water quality, and seabed deposition modelling with regard to the proposed changes. In this regard, ADS have completed four reports, which are appended as **Volume 2, Appendices A – D**, and titled as follows:

- Volume I – Summary of Findings;
- Volume II – Hydrodynamic Modelling and Flushing;
- Volume III – Water Quality; and
- Volume IV – Seabed Deposition.

This AEE also draws on the 2015/16 and 2016/17 monitoring reports prepared by ADS under the Big Glory Bay Monitoring Programme (**Appendix A** to this AEE), which are appended as **Volume 2, Appendices E and F**.

By way of summary, the Big Glory Bay Monitoring Programme provides a monitoring framework to enable an annual survey of the seabed and water quality to assess the effects of marine farming in Big Glory Bay.

Appendix B to this AEE provides a checklist against the requirements of section 88 of the RMA. By way of summary, this AEE meets the requirements of the Fourth Schedule and section 88.

1.5 REPORT STRUCTURE

This AEE is set out in six sections as follows:

Section 1: Is this introduction.

Section 2:	Describes the change of consent conditions sought.
Section 3:	Outlines the environmental setting of the marine farms in Big Glory Bay, including the physical setting, hydrodynamics and flushing characteristics, water quality, benthic environment, landscape and visual amenity, wildlife, and cultural settings.
Section 4:	Provides an assessment of environmental effects of the proposed changes, including the effects on water quality, effects of seabed deposition, landscape and visual amenity effects, navigation and recreation effects, effects on wildlife, and cultural effects.
Section 5:	Sets out the statutory framework within which the consent condition change applications have been made and assesses the proposed changes in relation to the provisions of the RMA and the relevant provisions of the statutory planning documents administered by Environment Southland.
Section 6:	Provides a short concluding statement.

2. DESCRIPTION OF THE CHANGE

2.1 PURPOSE

As described in Section 1.1, Sanford is seeking to change the consent conditions of seven of its coastal permits relating to its marine farm sites in Big Glory Bay, so as to increase the allowable discharge of nitrogen from feed associated with salmon farming.

2.2 ASSESSMENT OF ALTERNATIVES

As this application seeks to increase the amount of nitrogen from feed discharged, an assessment of the alternatives is required in accordance with Schedule 4, Clause 6(1)(d)(ii) of the RMA.

Alternatives available to Sanford include:

- Changing the composition of feed such that nitrogen is no longer included; and
- Relocating salmon farming activities, or undertaking salmon farming at a new site.

Sanford's salmon feed is supplied by Skretting, and is the result of extensive research and development to ensure that feed is utilised in the most efficient way. In this regard, protein in the fish feed, which is required for fish growth, contains a percentage of nitrogen by default that is not able to be removed from the feed without compromising fish growth. As such, it is not consider that altering the feed composition is a practicable alternative.

Regarding the relocation of salmon farming activities or undertaking salmon farming at a new site, it is commercially and environmentally more efficient to consolidate activities at an existing location such as Big Glory Bay, than to relocate, or expand to a new site. Therefore, this is not considered to be a practicable alternative to the proposed changes.

In light of the above, Sanford does not consider that there are any practicable alternatives available.

2.3 PRACTICAL CHANGES

As outlined above, Sanford holds coastal permits at seven marine farm sites in Big Glory Bay that enable it to farm salmon. The key condition that enable this provides for the discharge of nitrogen from feed. This key condition limits the discharge of nitrogen from feed as outlined in Table 1, but also allows Sanford to aggregate its nitrogen allowance provided significant adverse effects are avoided and all others can be avoided, remedied or mitigated.

Sanford seeks to increase this limit to 659 tonnes/year, but also include site specific limits based on modelling, and environmental limits where appropriate.

2.4 CHANGE TO CONSENT CONDITIONS

Sanford seeks to change the following conditions of the following resource consents:

- Condition 4(a) of AUTH-20157616, relating to MF 246;
- Condition 5 of 207256, relating to MF 249;
- Condition 5 of 203236, relating to LI 320;
- Condition 5 of 203237, relating to LI 321;
- Condition 5 of 203240, relating to LI 338;
- Condition 5 of 203241, relating to LI 339; and
- Condition 5 of 203242, relating to LI 340.

The changes sought are set out in redline and ~~strikethrough~~ below:

Resource Consent AUTH-20157616, relating to MF 246

4. (a) *The nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to ~~73.84~~15.1 tonnes provided that:~~.~~*

   (i) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

   (ii) a binding agent is contained within the feed.

   ~~Where the consent holder has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm sites provided that the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated.~~

(b) *Activities authorised by Condition 4(a) shall not:*

- *Increase the average excess total ammonia nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73 kg/m^2/year more than 100 metres from the boundary of the site; or*
- *Result in total faeces and solid waste deposition greater than 5 kg/m^2/year more than 100 metres from the boundary of the site.*

(c) *Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 4(b) to* be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased above 332.064 tonnes/year.

(bd) The consent holder shall provide an annual report summarising the:

(i) monthly volume of feed for salmon supplied to the marine farm site; and

(ii) monthly loading (in tonnes) of total nitrogen supplied to the marine farm site as a result of feeding salmon;

Between 1 July and 30 June the following year. This report shall be provided to the Consent Authority by 31 July each year, or upon request.

Resource Consent 207256, relating to MF 249

5.(a) Except where Condition 5(b) applies, ~~T~~the nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 73.792 tonnes.

(b) Where the consent holder:

(i) holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input from feed; and/or

(ii) has the written agreement of another consent holder in Big Glory Bay that holds a resource consent with conditions specifying allowable nitrogen input;

the consent holder may utilise that nitrogen input from feed ~~has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed,~~ either wholly or in part, between any or all of the consent holder's marine farm sites provided that:~~ the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.~~

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that authorised by Condition 5(a) shall not:

- Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or
- Increase the average excess of chlorophyll-a in Big Glory Bay by

more than 4 µg/L at the surface or;

- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73 kg/m²/year more than 100 metres from the boundary of the site; or*
- *Result in total faeces and solid waste deposition greater than 5 kg/m²/year more than 100 metres from the boundary of the site; and*

(v) *the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and*

(vi) *the feed deployed shall be consistent with the parameters of the feed modelled.*

(c) *Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.*

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

Resource Consent 203236, relating to LI 320

5.(a) *The nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to ~~73.792~~200.6 tonnes provided that:~~.~~*

(i) *the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and*

~~Where the consent holder has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm sites provided that the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.~~

(b) *Activities authorised by Condition 5(a) shall not:*

- *Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73*

kg/m²/year more than 100 metres from the boundary of the site; or

- *Result in total faeces and solid waste deposition greater than 5 kg/m²/year more than 100 metres from the boundary of the site.*

(c) Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased above 332.064 tonnes/year.

Resource Consent 203237, relating to LI 321

5.(a) Except where Condition 5(b) applies, Tthe nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 73.792 tonnes.

(b) Where the consent holder:

(i) holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input from feed; and/or

(ii) has the written agreement of another consent holder in Big Glory Bay that holds a resource consent with conditions specifying allowable nitrogen input;

the consent holder may utilise that nitrogen input from feed has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm sites provided that: the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that authorised by Condition 5(a) shall not:

- *Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*

- *Result in total organic carbon deposition greater than 0.73 kg/m^2/year more than 100 metres from the boundary of the site; or*
- *Result in total faeces and solid waste deposition greater than 5 kg/m^2/year more than 100 metres from the boundary of the site; and*

(v) the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and

(vi) the feed deployed shall be consistent with the parameters of the feed modelled.

(c) Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

Resource Consent 203240, relating to LI 338

5.(a) Except where Condition 5(b) applies, ~~T~~the nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 73.792 tonnes.

(b) Where the consent holder:

(i) holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input from feed; and/or

(ii) has the written agreement of another consent holder in Big Glory Bay that holds a resource consent with conditions specifying allowable nitrogen input;

the consent holder may utilise that nitrogen input from feed ~~has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed,~~ either wholly or in part, between any or all of the consent holder's marine farm sites provided that: ~~the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.~~

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that

authorised by Condition 5(a) shall not:

- Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or
- Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;
- Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or
- Result in total organic carbon deposition greater than 0.73 $kg/m^2/year$ more than 100 metres from the boundary of the site; or
- Result in total faeces and solid waste deposition greater than 5 $kg/m^2/year$ more than 100 metres from the boundary of the site; and

(v) the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and

(vi) the feed deployed shall be consistent with the parameters of the feed modelled.

(c) Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

Resource Consent 203241, relating to LI 339

5.(a) Except where Condition 5(b) applies, Tthe nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 55.344 tonnes.

(b) Where the consent holder:

(i) holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input from feed; and/or

(ii) has the written agreement of another consent holder in Big Glory Bay that holds a resource consent with conditions specifying allowable nitrogen input;

the consent holder may utilise that nitrogen input from feed has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm sites provided that: the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant *adverse effect is considered to have occurred if no marine life exists under the salmon cages.*

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that authorised by Condition 5(a) shall not:

- *Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or*
- *Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;*
- *Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or*
- *Result in total organic carbon deposition greater than 0.73 kg/m²/year more than 100 metres from the boundary of the site; or*
- *Result in total faeces and solid waste deposition greater than 5 kg/m²/year more than 100 metres from the boundary of the site; and*

(v) the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and

(vi) the feed deployed shall be consistent with the parameters of the feed modelled.

(c) Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

Resource Consent 203242, relating to LI 340

5.(a) Except where Condition 5(b) applies, Tthe nitrogen input from feed at the marine farm site for salmon between 1 July and 30 June each year shall be restricted to 55.344 tonnes.

(b) Where the consent holder:

(i) holds additional resource consents that authorise salmon farming in Big Glory Bay that have conditions specifying allowable nitrogen input from feed; and/or

(ii) has the written agreement of another consent holder in Big Glory Bay

that holds a resource consent with conditions specifying allowable nitrogen input;

the consent holder may utilise that nitrogen input from feed has the right to use an additional site or sites consented for salmon farming within Big Glory Bay, the total nitrogen input from feed can be deployed, either wholly or in part, between any or all of the consent holder's marine farm sites provided that: the significant adverse effects on the seabed are avoided and other effects can be remedied or mitigated. A significant adverse effect is considered to have occurred if no marine life exists under the salmon cages.

(iii) the total nitrogen input from feed used in Big Glory Bay between 1 July and 30 June each year does not exceed 659 tonnes; and

(iv) modelling in DELFT3D, or alternative modelling software agreed to in writing by Environment Southland, has been undertaken by a suitably qualified, experienced, and independent person, which demonstrates that an additional amount of nitrogen input from feed above that authorised by Condition 5(a) shall not:

- Increase the average excess total ammoniacal nitrogen in Big Glory Bay by more than 30 µg/L at the surface; or
- Increase the average excess of chlorophyll-a in Big Glory Bay by more than 4 µg/L at the surface or;
- Reduce the average dissolved oxygen concentration in Big Glory Bay below 7 mg/L at the surface; or
- Result in total organic carbon deposition greater than 0.73 $kg/m^2/year$ more than 100 metres from the boundary of the site; or
- Result in total faeces and solid waste deposition greater than 5 $kg/m^2/year$ more than 100 metres from the boundary of the site; and

(v) the additional nitrogen input from feed allows compliance with criteria listed in Condition 5(b)(iv); and

(vi) the feed deployed shall be consistent with the parameters of the feed modelled.

(c) Notwithstanding Condition 16, a suitably qualified, experienced and independent person shall prepare a monitoring plan, the purpose of which is to enable compliance with those standards in Condition 5(b)(iv) to be assessed.

The monitoring plan shall be submitted to Environment Southland for approval in a technical capacity two months before the consent holder's total nitrogen input from feed is increased to a rate that would result in an exceedance of 332.064 plus any allowable nitrogen input from feed referred to in Condition 5(b)(ii).

3. ENVIRONMENTAL SETTING

3.1 OVERVIEW

This section is set out in the following subsections:

Section 3.2: Provides a physical description of Big Glory Bay and the marine farm sites.

Section 3.3: Describes the hydrodynamics and flushing characteristics of Big Glory Bay.

Section 3.4: Outlines the water quality of Big Glory Bay from monitoring reports undertaken in association with Sanford's existing marine farms.

Section 3.5: Describes the benthic environment beneath the marine farm sites, within their immediate vicinity, and at control sites within Big Glory Bay from monitoring reports undertaken in association with Sanford's existing marine farms.

Section 3.6: Describes the landscape and visual amenity of Big Glory Bay and the surrounding coastline.

Section 3.7: Outlines the wildlife potentially occurring in Big Glory Bay; including seals, sea lion, dolphins, whales and sharks, and seabirds.

Section 3.8: Outlines the cultural setting of Big Glory Bay.

Section 3.9: Discusses the sensitivity of the environment.

3.2 PHYSICAL SETTING

Big Glory Bay is located on the eastern side of Stewart Island, is a semi-enclosed arm of Paterson Inlet, is approximately 12 km^2 in area, and has a 700 m wide mouth, at its narrowest point (Figure 2). The land around Big Glory Bay is completely covered in native bush, from the shore to the tops of the surrounding hills, although there is some clearance and a building on the west side of Bravo Island, at the mouth of Big Glory Bay. The shoreline includes a number of small bays with sandy beaches.

The seabed of Big Glory Bay is relatively flat, with an average depth of approximately 20 m. Shallow, rocky reefs are present along the northern and southern sides, and along the western shoreline there is a flat shallow area, less than six metres deep, and approximately 2.5 km^2 in area.

There are 35 marine farms authorised in Big Glory Bay, which produce salmon, mussels and until recently oysters. Mussel farms predominate. There are typically a number of vessels operating on the marine farm sites in Big Glory Bay, or sheltering in the coves and bays around the shoreline. There is also some storage of farm equipment on shore and on barges.

A channel has been maintained through the middle of Big Glory Bay to allow access.

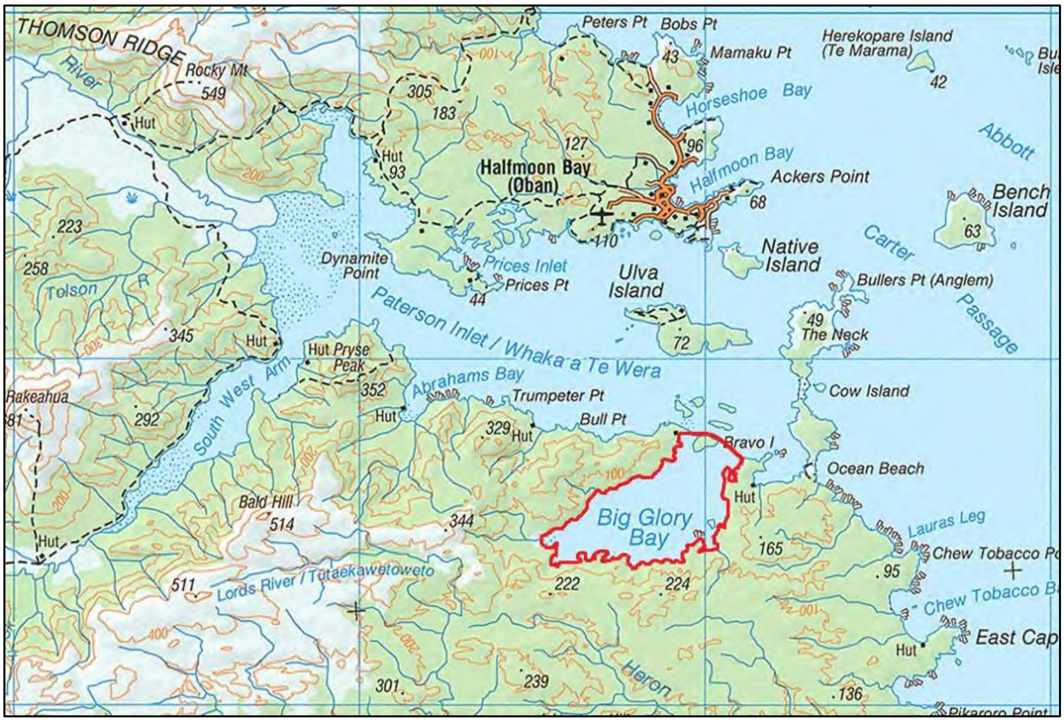

Figure 2: **Big Glory Bay location.**

3.3 HYDRODYNAMICS AND FLUSHING

Sanford commissioned ADS to undertake hydrodynamic and flushing modelling to inform an assessment of effects of the proposed changes. This section contains a summary of the hydrodynamics and flushing report presented by ADS (**Volume 2, Appendix B**).

The ADS report notes the following:

- Flow within Big Glory Bay is generally weak, on the order of less than 5 cm/s, and is stronger toward the mouth;
- Current direction is variable and there are several eddies within Big Glory Bay; and
- There is a general mouth-ward flow along the southern and northern banks of Big Glory Bay (Figure 3).

Flushing time is important as it indicates the exchange time of oxygen and nutrients between Big Glory Bay, Paterson Inlet, and the open ocean. For marine farming, faster flushing results in quicker dilution of nutrients, meaning that the standing concentration of nutrients is reduced, and oxygen within the marine farms will be replenished by the higher oxygen concentrations in the incoming water, raising the potential assimilative capacity of the waterbody.

Based on the release of a tracer at 100% on Day 1, the following is noted:

- At the end of Day 7, tracer concentrations do not exceed 70% at any point inside Big Glory Bay.
- By Day 14, concentrations are approximately 40%.
- By Day 28, 85-90% has been flushed out of Big Glory Bay, and the remaining water is slowly transported out over the next 20 – 30 days.
- There is little seasonal difference in flushing times.

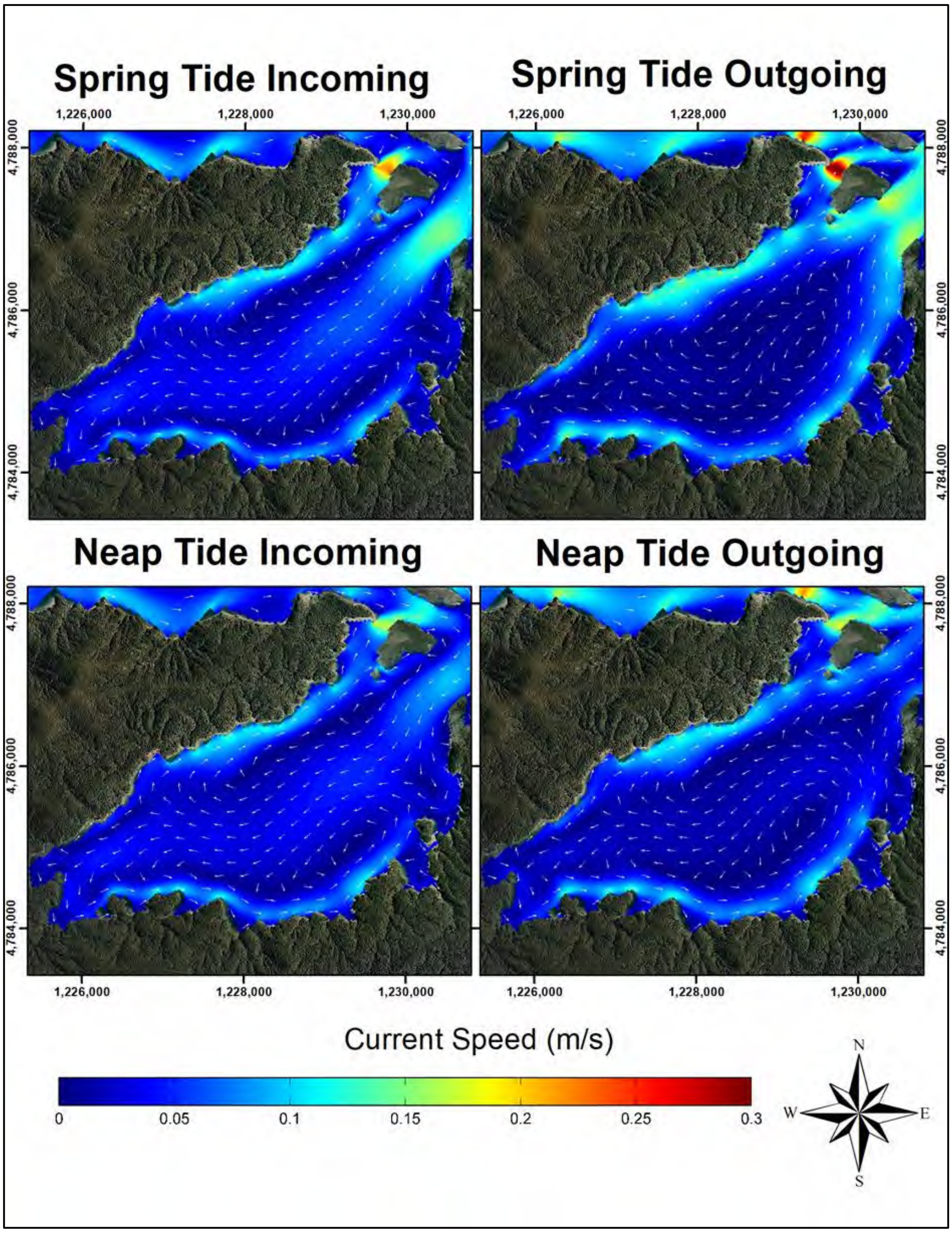

Figure 3: Big Glory Bay current patterns (during Spring) for spring and neap tides.

3.4 WATER QUALITY

Under the Big Glory Bay Monitoring Programme (**Appendix A**), Sanford was required to undertake monitoring of the water column on a monthly basis for two years, commencing 1 July 2011. After two years, monitoring was allowed to be scaled back to three times during the period of 1 November to 30 June each year and once during the period of 1 July to 31 October each year. However, Sanford opted to generally continue with monthly monitoring following the initial two year timeframe. There is accordingly a reasonable amount of information available on water quality within Big Glory Bay.

Parameters measured as part of the water quality monitoring are:

- Water temperature;
- Dissolved oxygen;
- Chlorophyll-*a*; and
- Vertical Secchi depth.

Furthermore, dissolved reactive phosphorus ("**DRP**"), ammoniacal nitrogen, suspended solids, particulate carbon, and particulate nitrogen are also measured at the two control stations.

For the past two monitoring reports, water quality monitoring was undertaken at six sites (WS1 – WS6) across Big Glory Bay, as shown in Figure 4.

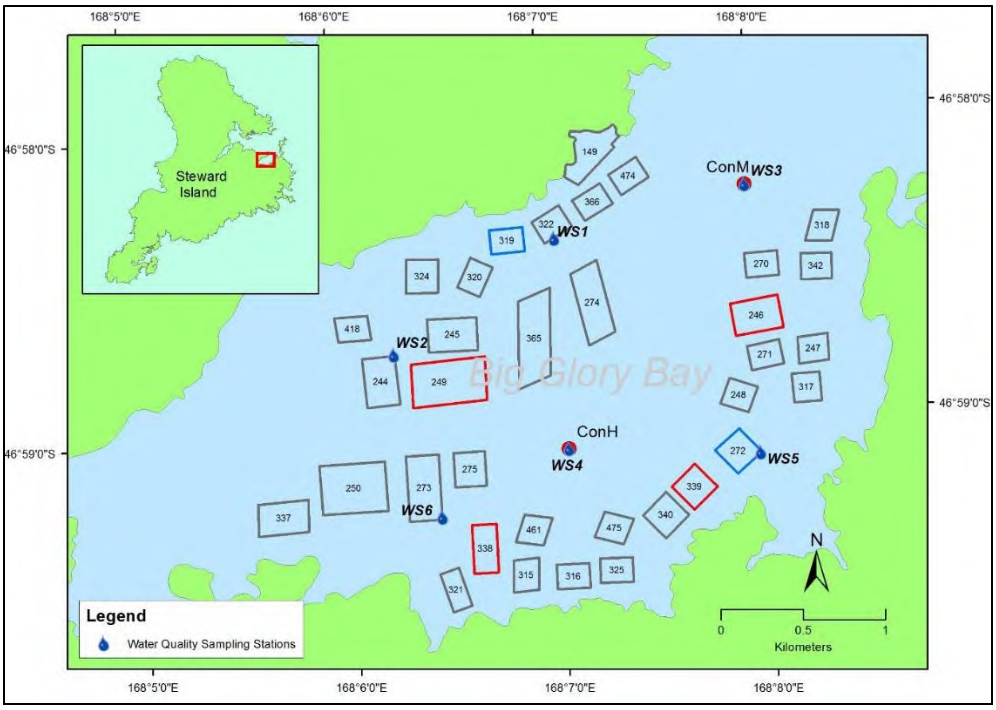

Figure 4: 2015/16 and 2016/17 water quality monitoring stations.

Water temperature varies seasonally, with an average high of 15 °C in summer, and an average low of 8.4 °C in winter.

Depending upon the season, dissolved oxygen levels are generally between 6 and 9 mg/L. In this regard, it is noted that 2 mg/L is the critical level for sustaining aerobic respiration, 4 mg/L is the threshold for stressing most aerobic organisms, and 6 mg/L is required to maintain healthy farmed salmon.

Total Ammonia Nitrogen ("**TAN**") displays a clear seasonal cycle, with average values ranging from the lower detection limit of less than 10 µg/L to 39 µg/L in spring/summer, and between 15.5 µg/L and 58.5 µg/L in autumn/winter (Figure 5).

Average monthly chlorophyll-*a* values have varied between 0.3 µg/L and 6.5 µg/L (Figure 6).

Vertical Secchi depths have generally ranged between 7 and 16 m.

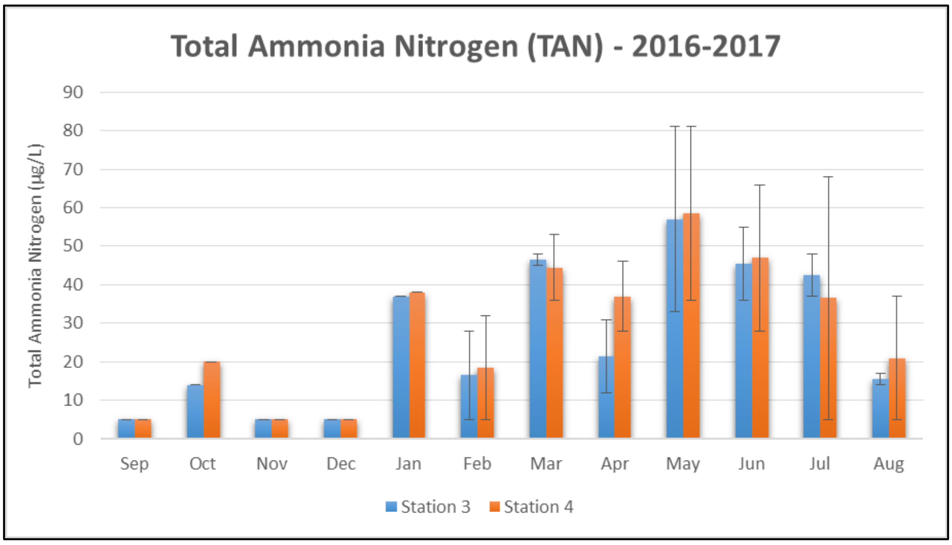

Figure 5: TAN concentrations in Big Glory Bay.

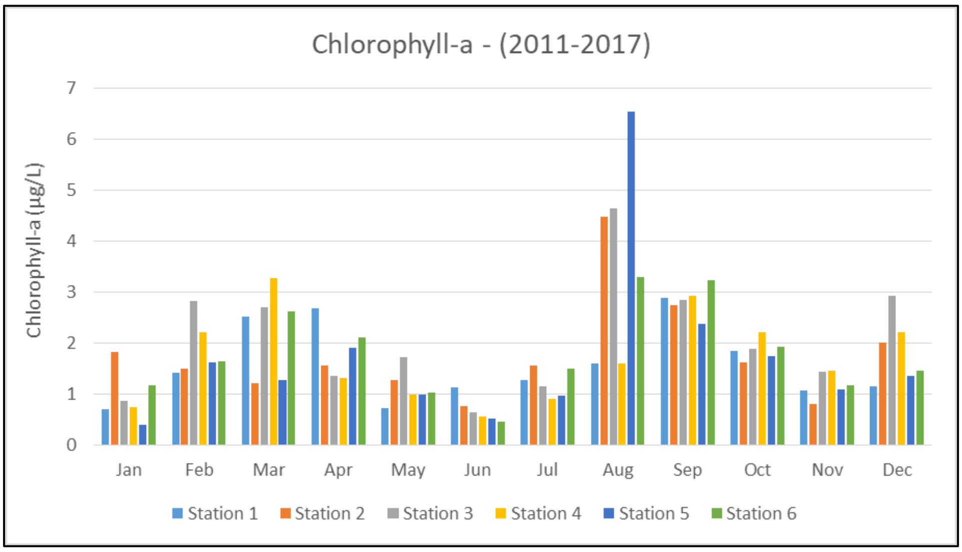

Figure 6: **Chlorophyll- *a* concentrations in Big Glory Bay.**

DRP concentrations in 2016/17 survey ranged from 0.004 to 0.026 ppm, and were at their highest in July 2016 (Figure 7).

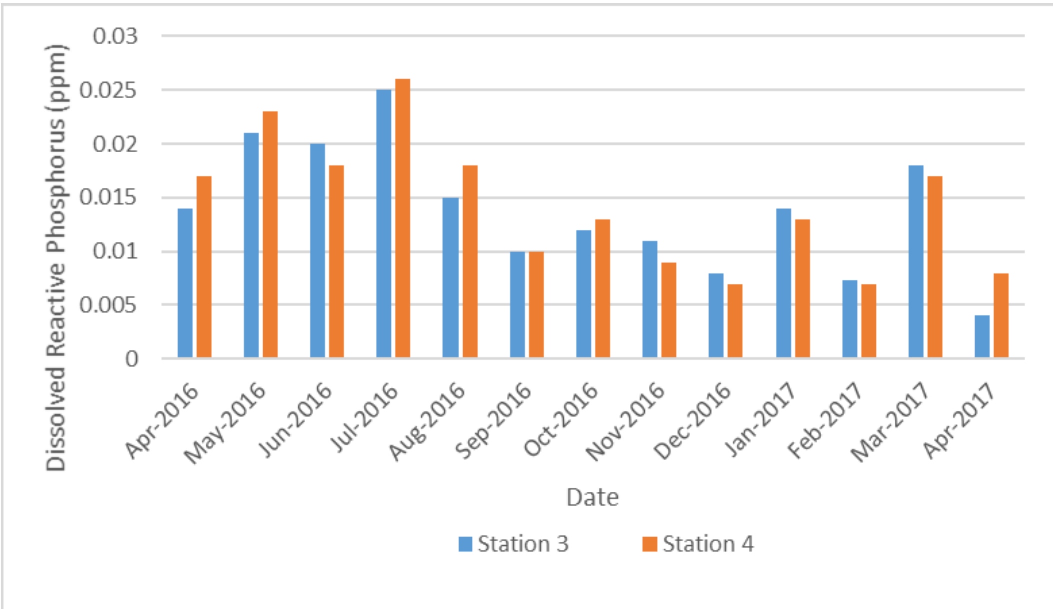

Figure 7: **Average DRP in Big Glory Bay – April 2017 – April 2017**

Ammoniacal nitrogen in the 2016/17 survey had the highest concentration recorded in May 2016, and the lowest in April 2017 (Figure 8).

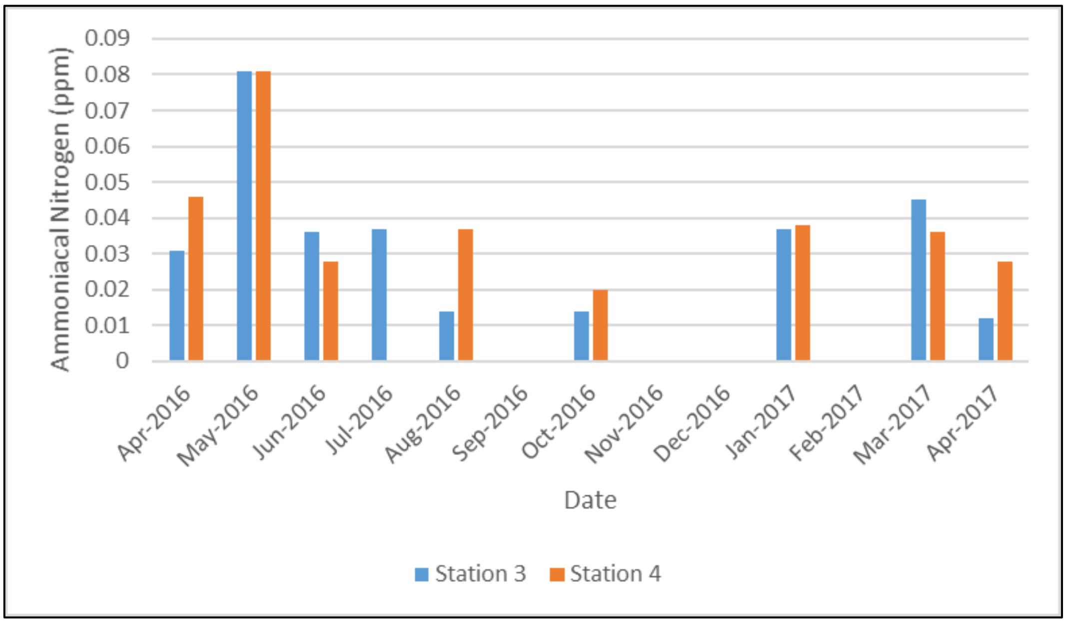

Figure 8: **Ammoniacal nitrogen in Big Glory Bay – April 2016 to April 2017.**

Suspended solids were at their highest in February 2017 with a concentration of 59 g/m^3 (Figure 9).

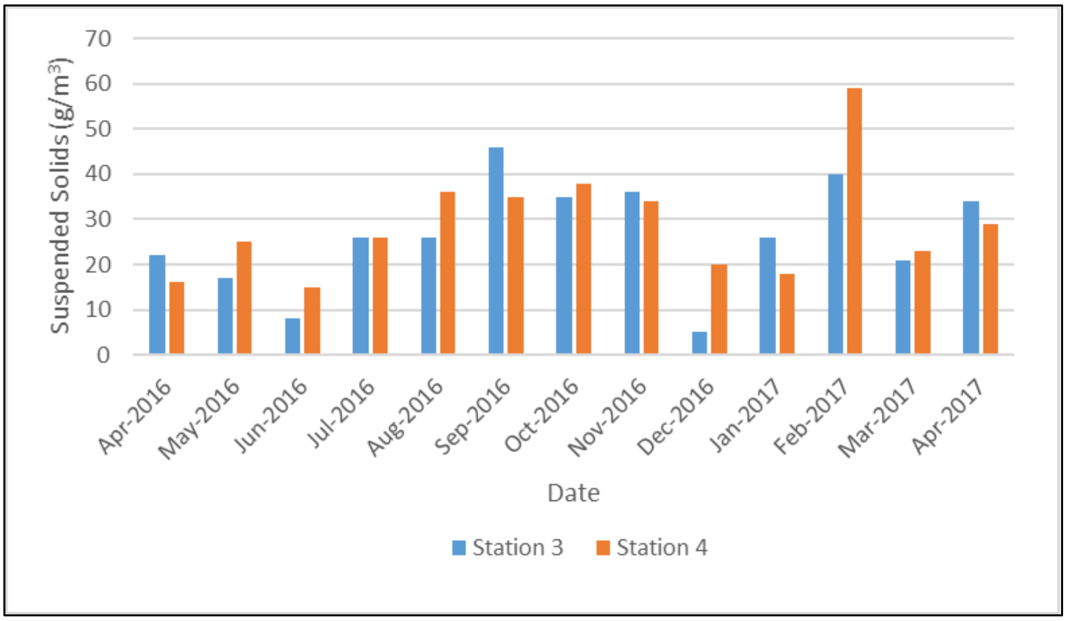

Figure 9: **Suspended solids in Big Glory Bay – April 2016 to April 2017.**

Particulate nitrogen concentrations were very low from October 2016 to January 2017, but were an order of magnitude higher in April 2016 and April 2017 (Figure 10).

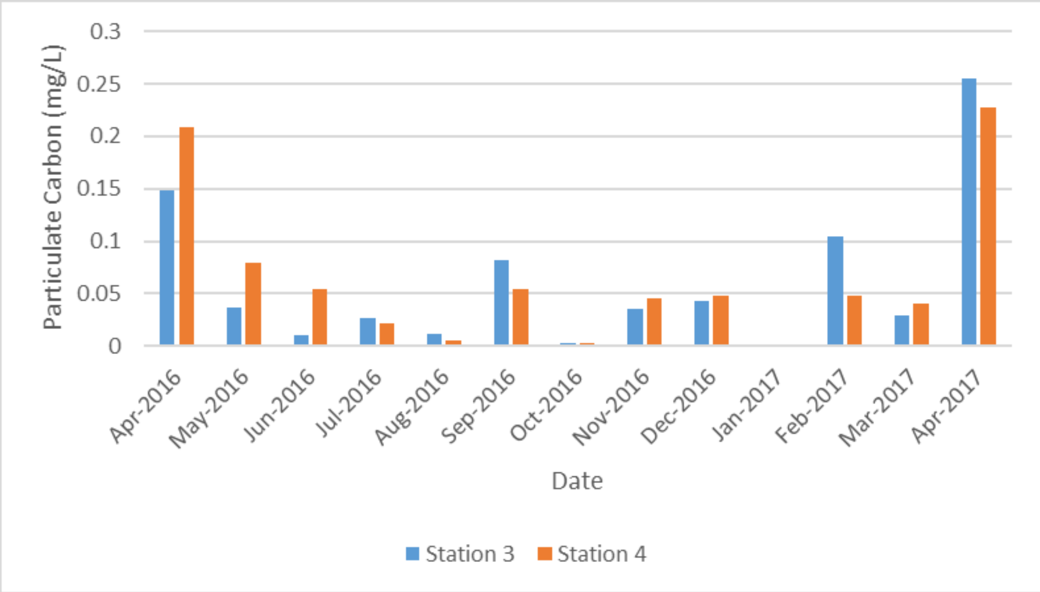

Figure 10: Particulate carbon in Big Glory Bay – April 2016 to April 2017.

Particulate nitrogen concentrations were found to be highest in February 2017, while much lower concentration were observed between June and August 2016 (Figure 11).

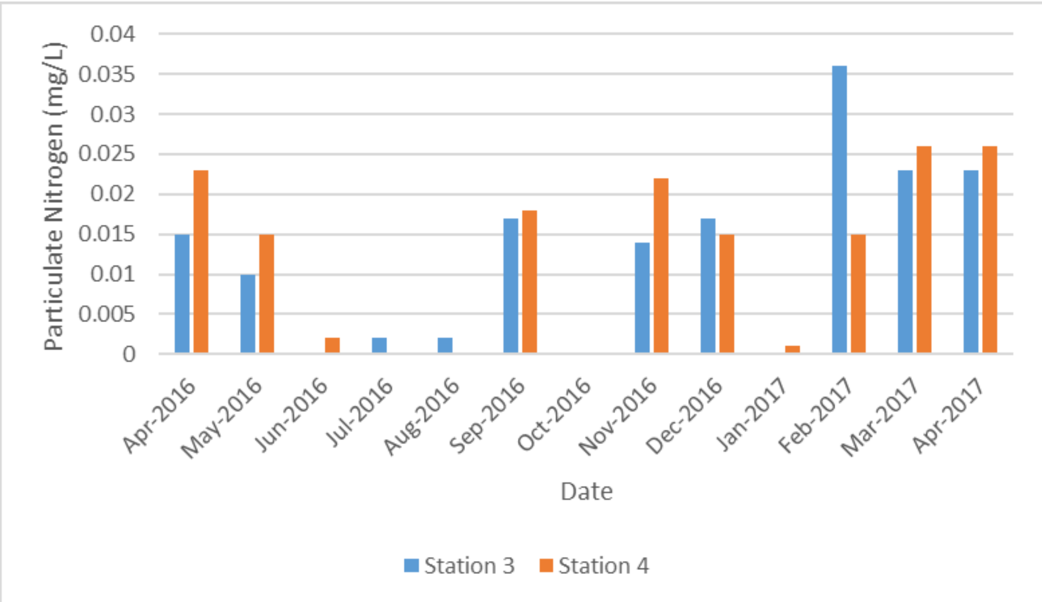

Figure 11: Particulate nitrogen in Big Glory Bay – April 2016 to April 2017.

Results from the 2015/16 and 2016/17 surveys (**Volume 2, Appendix E and F**) show that:

- Existing marine farming is not having an adverse effect on oxygen levels in Big Glory Bay.

- Temperature data indicates a slight thermal stratification (a change in temperature with depth) during summer periods (approximately one degree). This is natural, and not related to marine farming activities.
- Chlorophyll-*a* levels were lower in autumn.
- Higher chlorophyll-*a* levels were observed in spring (spring bloom) and late summer.
- During summer, nitrogen is being removed from the system, likely due to the increased mussel mass in Big Glory Bay at that time of the year.
- Overall water quality analysis indicates there are no detectable adverse water quality issues within Big Glory Bay.

3.5 BENTHIC ENVIRONMENT

3.5.1 Overview

The Big Glory Bay Monitoring Programme (**Appendix A**) also requires that monitoring of the seabed is undertaken at representative locations beneath sites farming salmon on an annual basis, and at five yearly intervals following fallowing. Samples are to be taken and are analysed for the following to assess the sediment quality:

- A sediment profile detailing the features of the sediment sample;
- Colour photographs of the sediment sample;
- Depth of the oxygenated layer below the sediment surface;
- Occurrence of hydrogen sulphide;
- Sediment texture and grain size;
- Total organic carbon content;
- Infauna and epifaunal community composition; and
- Zinc and copper trace metal levels.

Sanford commissioned ADS to undertake this monitoring in the 2015/16 and 2016/17 periods, and a summary of these reports is provided below.

The benthic monitoring surveys focussed on four salmon farm sites, two mussel farm sites (as it was these sites Sanford were farming at, or had recently farmed), and two control stations. Samples were taken from beneath each marine farm site, and in the case of the four salmon farms, 50 and 100 m from the boundary of those sites, as shown in Figure 12.

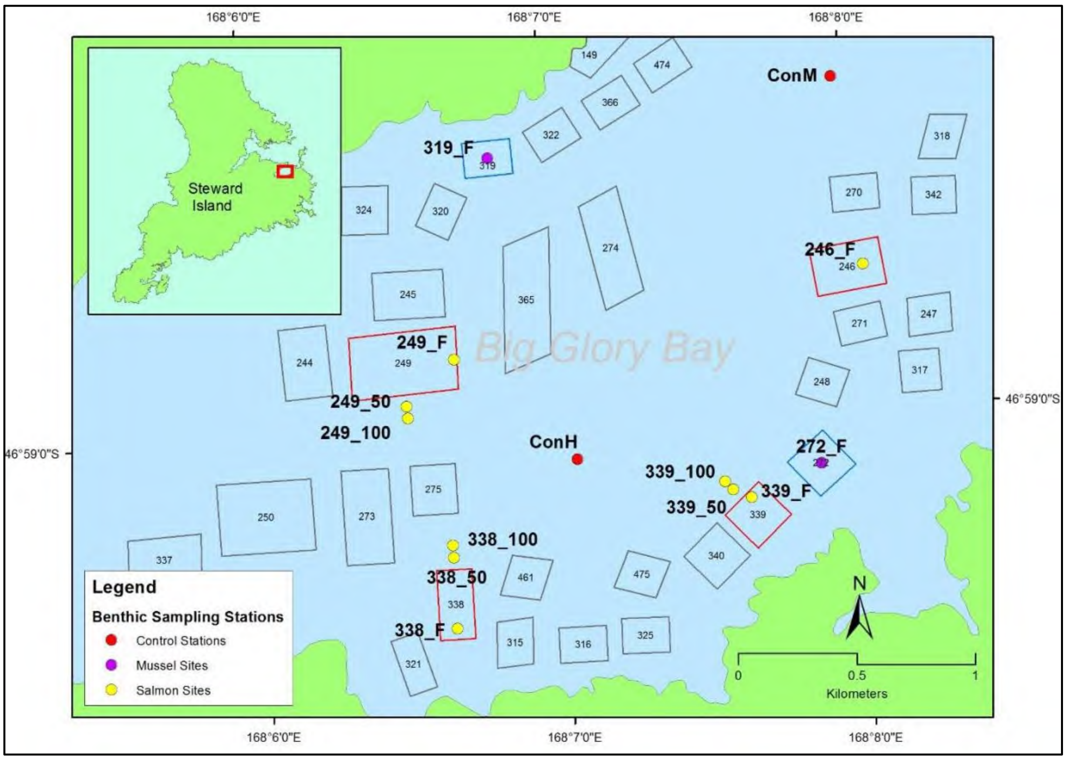

Figure 12: **2016/17 benthic monitoring locations.**

Each of the four mussel farm sites, MF 246, MF 249, LI 338 and LI 339, sampled in 2015/16, are directly relevant to the proposed changes as they are permitted to farm salmon, and it is these sites and the control sites that are focused on here.

3.5.1.1 Sediment Grain Size and Organic Matter

Sediment samples were taken from beneath each site, at 50 and 100 metres from the boundaries of MF 249, LI 338 and LI 340, and at the two control sites. It is noted that the sample beneath LI 339 returned only mussel shell, such that grain size analysis could not be undertaken.

Figure 13 compares the 2015/16 grain size distribution at each site, and shows that each site is generally within the range of the two control sites, with the exception of LI 338_F (directly beneath the LI 338 site), which has a lower percentage of mud.

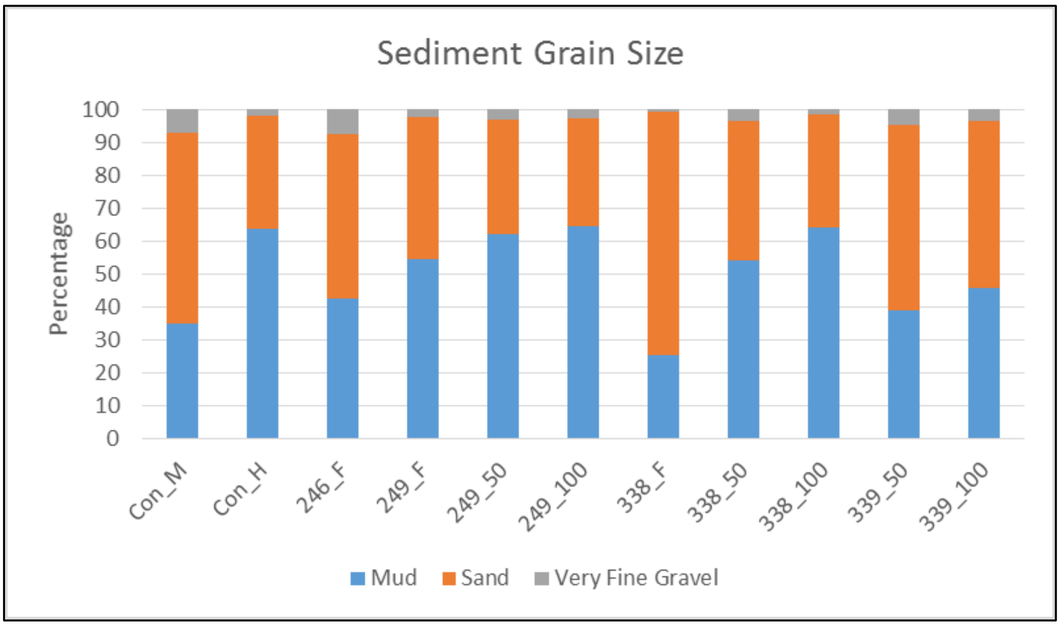

Figure 13: 2015/16 grain size analysis across Sanford's salmon farm sites.

Figure 14 compares the 2016/17 grain size distribution at each site, and shows that each site is slightly sandier that the control sites, with the exception of 338_50 and 338_100, which are muddier.

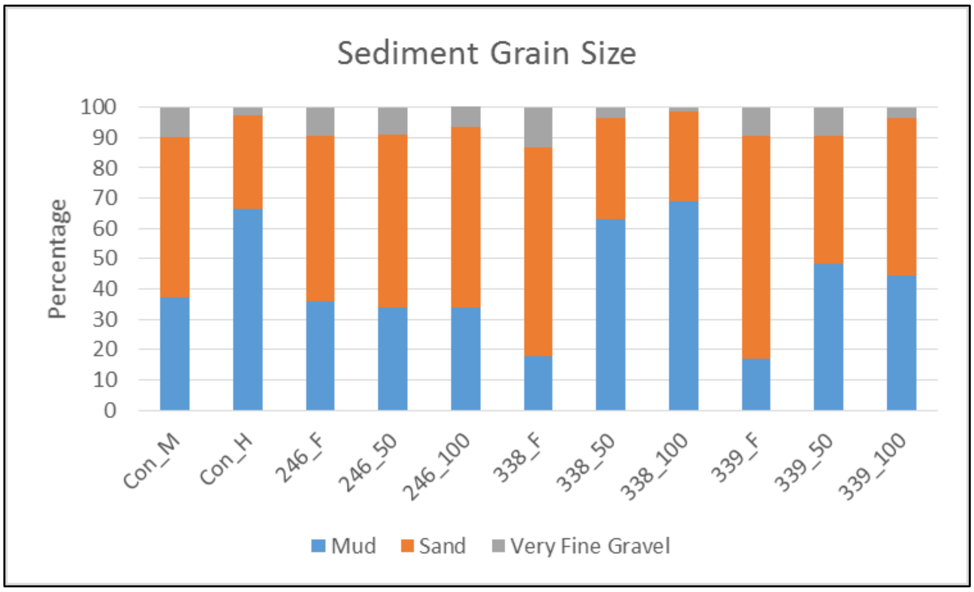

Figure 14: 2016/17 grain size analysis across Sanford's salmon farm sites.

Figure 15 compares the 2015/16 percentage of organic matter at each site, and shows that beyond the boundaries of the sites, organic matter is within the range of the two control sites. The levels of organic matter beneath the marine farm sites are not considered to be environmentally significant and are within natural variability.

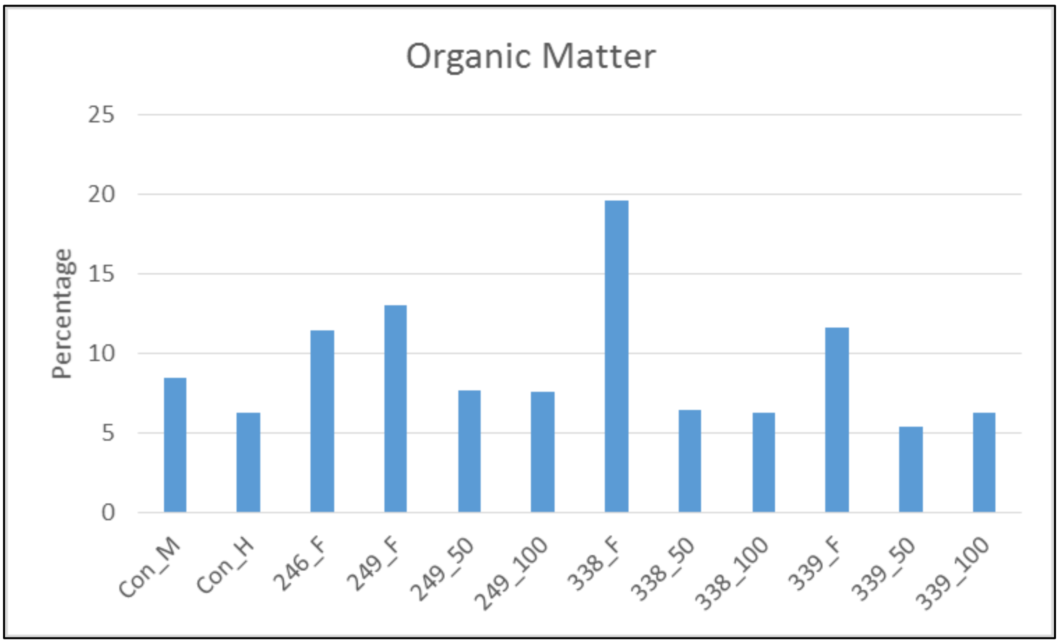

Figure 15: 2015/16 organic matter analysis across Sanford's salmon farm sites.

Figure 16 compares the 2016/17 percentage of organic matter at each site, and shows that that each site has less organic matter than the two control sites, showing these percentages are within natural variability. Of each of the three salmon farms, LI 339 had the most organic matter directly below the farm. This is likely due to LI 339 being previously utilised to farm mussels and being converted back to salmon farming

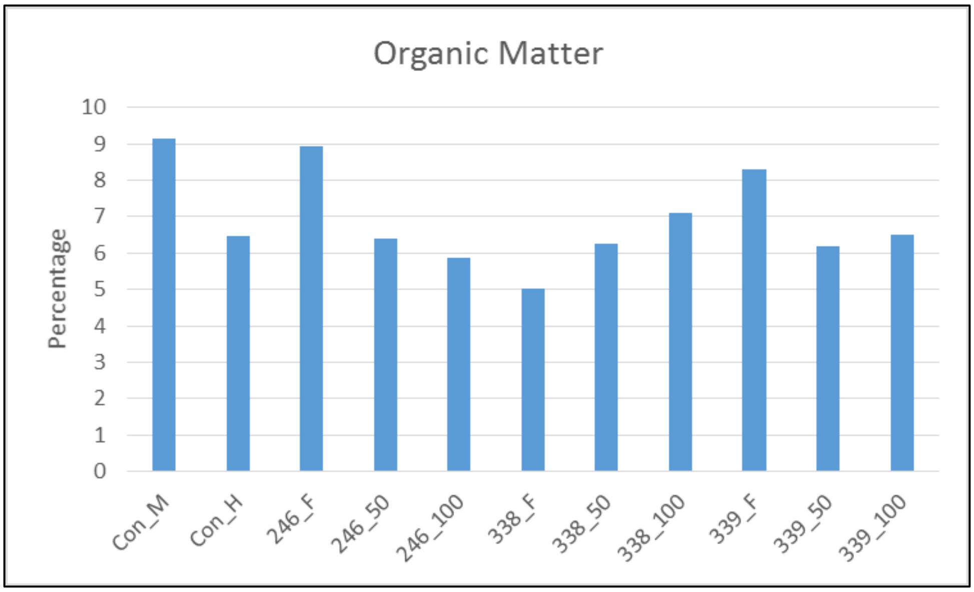

Figure 16: 2016/17 organic matter analysis across Sanford's salmon farm sites.

3.5.1.2 Total Organic Carbon

In comparison to the control sites total organic carbon ("**TOC**") was elevated at 338_F and 339_F. The levels of TOC at these sites is not considered to be environmentally significant beyond the boundaries of the marine farm sites.

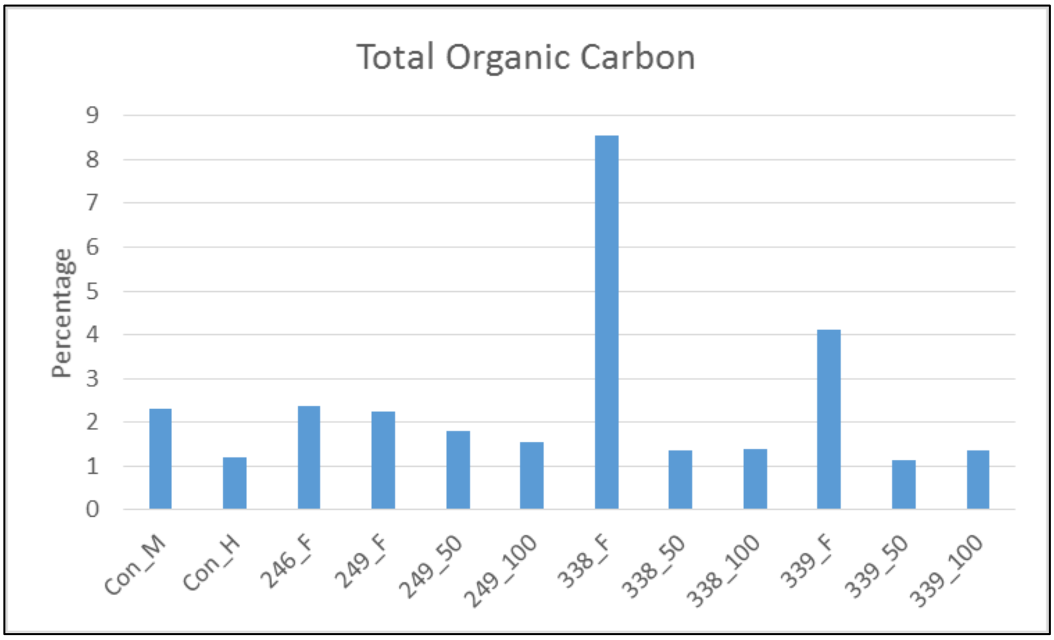

Figure 17: 2015/16 total organic carbon analysis across Sanford's salmon farm sites.

In 2016/17, TOC percentages across the salmon farms are generally less than or between the percentages measured at the two control sites, with the exception of 339_F, directly beneath LI 339 (Figure 18). As per the organic matter percentages, this is likely due to LI 339 being previously utilised to farm mussels and being converted back to salmon farming.

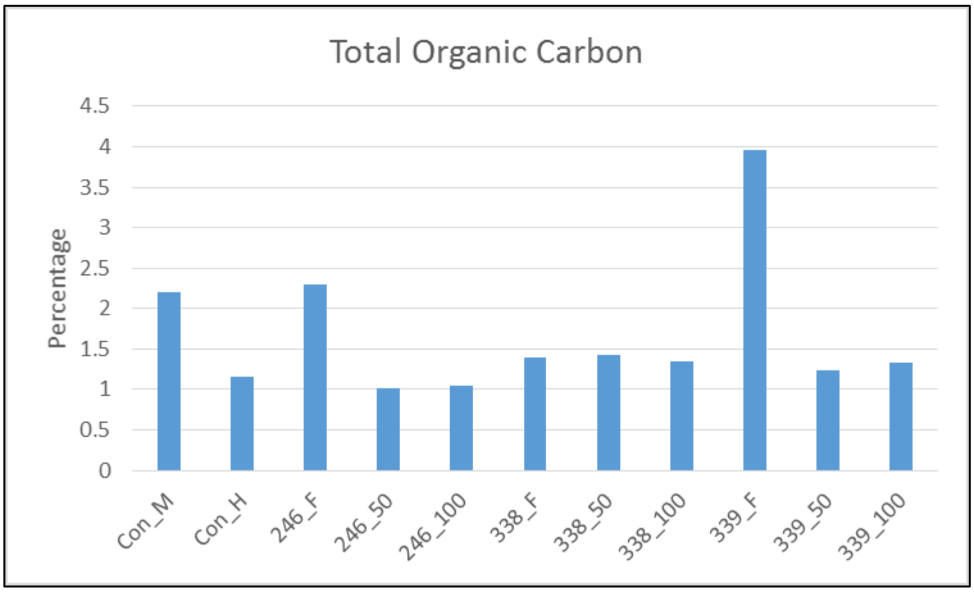

Figure 18: **2016/17 total organic carbon analysis across Sanford's salmon farm sites.**

3.5.1.3 Zinc and Copper

All of the sites set out in Figure 12 were analysed for their zinc and copper concentrations. Copper is used as anti-fouling agent in paint that is applied to fish nets while zinc is an ingredient in salmon feed.

Figure 19 shows the 2015/16 zinc concentrations, with the exception of LI 338_F and LI 339_F sites, where concentrations were 946.7 and 290.7 mg/kg (dry weight) respectively. These values are not having an impact 100 m beyond the boundary of the marine farm sites as shown by the concentrations being near background levels 100 m from the boundary.

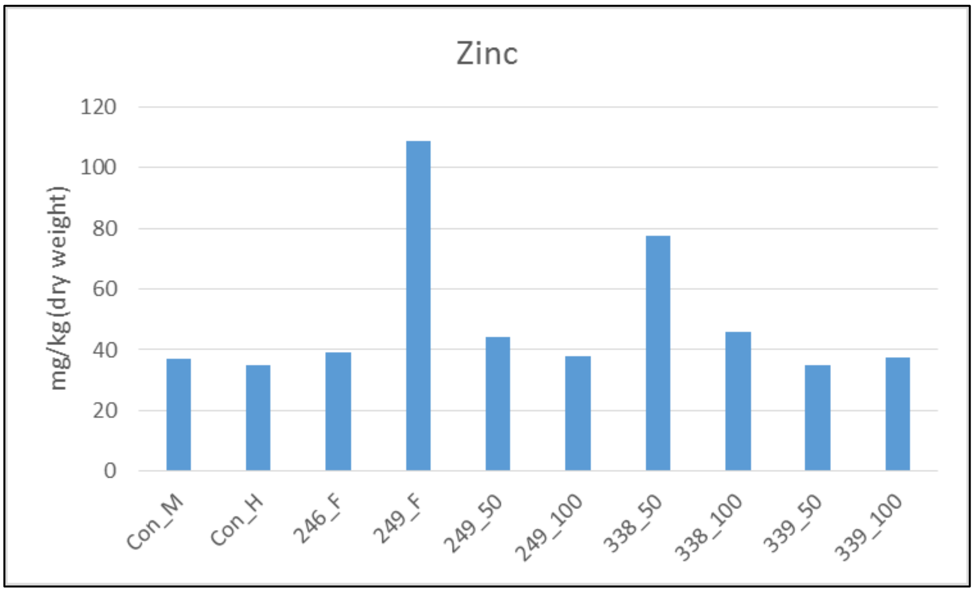

Figure 19: **Sanford's 2015/16 Big Glory Bay zinc concentrations.**

Figure 20 shows the 2016/17 zinc concentrations, with the exception of LI 338_F and LI 339_F sites, where concentrations were 284.7 and 357.7 mg/kg (dry weight) respectively. In the case of LI 338_F, this is a significant decrease on 2015/16, and in the case of LI 339_F, a slight increase on 2015/16. These values are not having an impact 100 m beyond the boundary of the marine farm sites as shown by the concentrations being near background levels 100 m from the boundary.

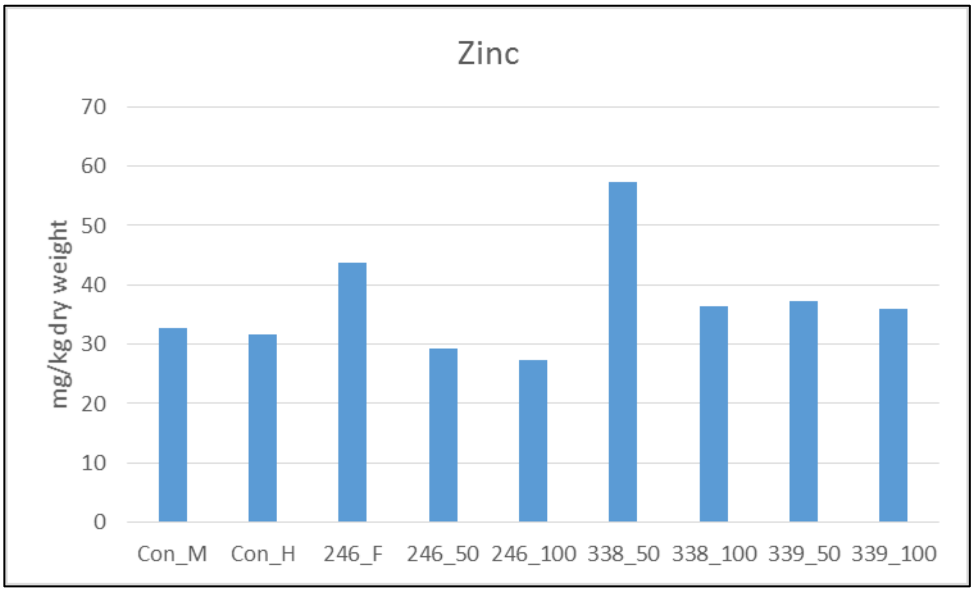

Figure 20: **Sanford's 2016/17 Big Glory Bay zinc concentrations.**

Figure 21 shows the 2015/16 copper concentrations, with the exception of the MF 249_F, LI 338_F and LI 339_F sites, where concentrations were 238.7, 893.3 and 1040.0 mg/kg (dry weight) respectively. These values are not having an impact 100 m beyond the boundary of the marine farm sites as shown by the concentrations being near background levels 100 m from the boundary.

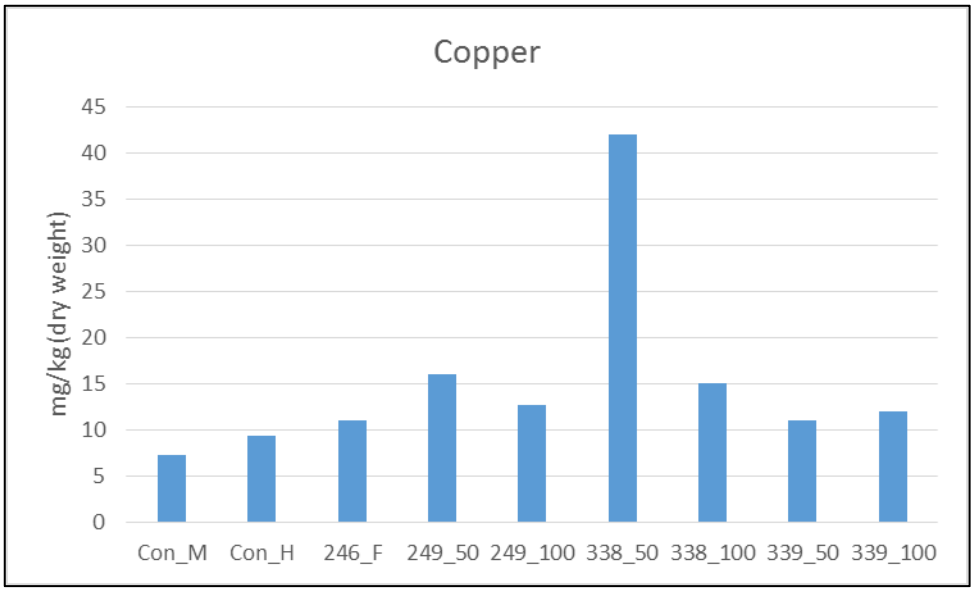

Figure 21: Sanford's 2015/16 Big Glory Bay copper concentrations.

Figure 22 shows the 2016/17 copper concentrations, with the exception of the LI 338_F and LI 339_F sites, where concentrations were 1,383.3 and 1,533.3 mg/kg (dry weight) respectively. These values are not having an impact 100 m beyond the boundary of the marine farm sites as shown by the concentrations being near background levels 100 m from the boundary.

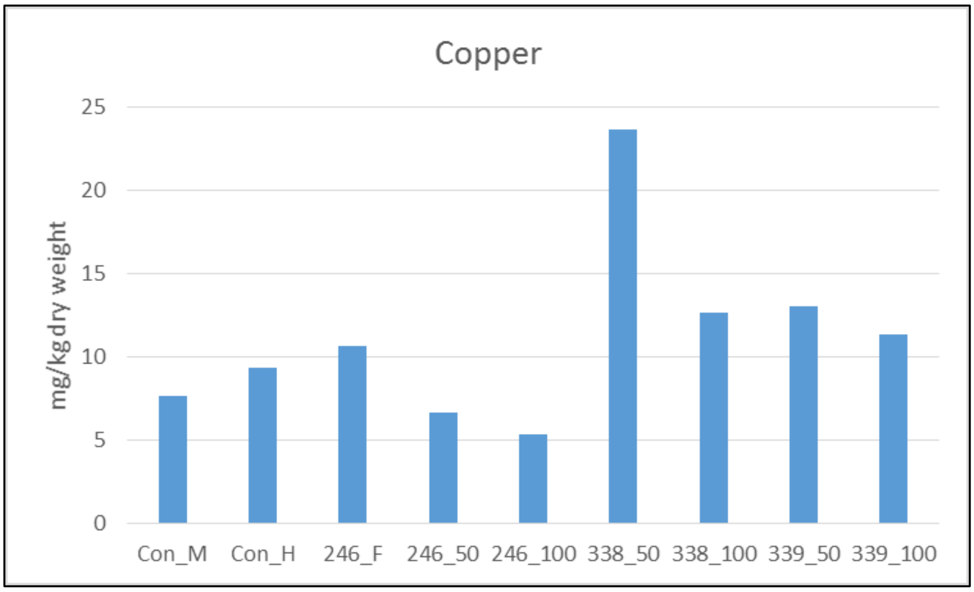

Figure 22: Sanford's 2016/17 Big Glory Bay copper concentrations.

3.5.1.4 Infauna

ADS undertook a SIMPER analysis to examine the similarity of infauna composition between the sites and the control sites. A wide range of polychaetes were found at these sites (e.g. *Capitellid sp*., *Maldanid sp., Dorvilleid sp., Lumbrinerid sp., Opheliid sp., Oweniid sp., Orbiniid sp., Glycerid sp., Goniadid sp., Nephtyid sp., Sabellid sp., Terebellid sp. and Ampharetid sp*.) and filter feeding bivalves were also common (*Nucula nitidula, Thracia vegrandis, Nuculidae sp 1, Leptomya retiaria, Veneridae, Solemya parkinsonii and Venericardia purpurata*).

When comparing Control H with the farm site samples Amphipod sp. was the most dominate species observed, while at Control H a large number of filter feeding polychaetes (unidentifiable as they were damaged in the sampling process) were present. Bivalves were present at both the control and farm site.

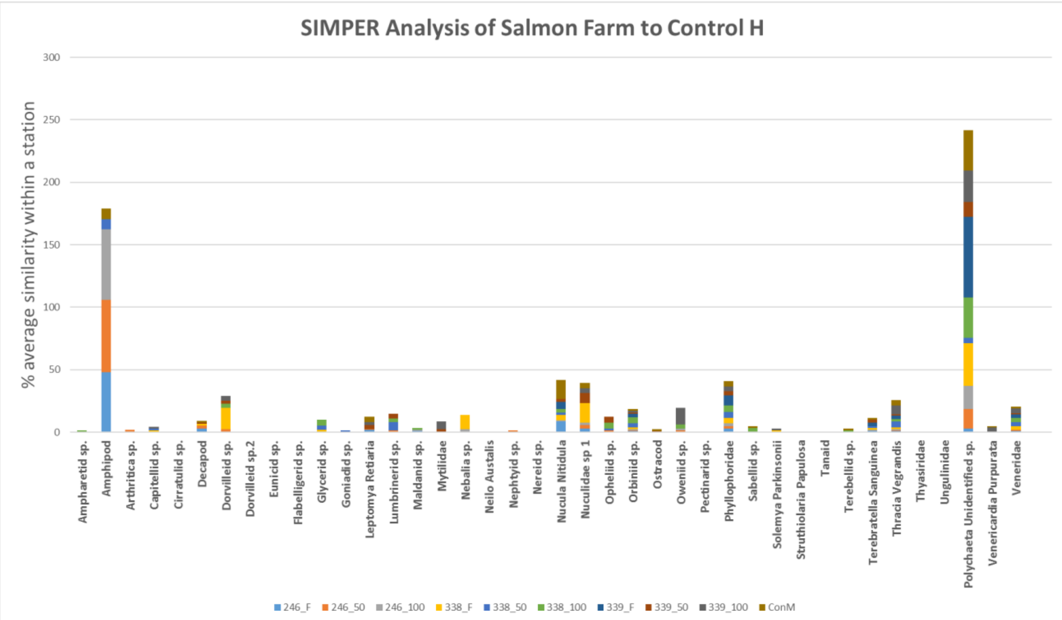

Figure 23: Salmon farm infauna compositions compared to Control H.

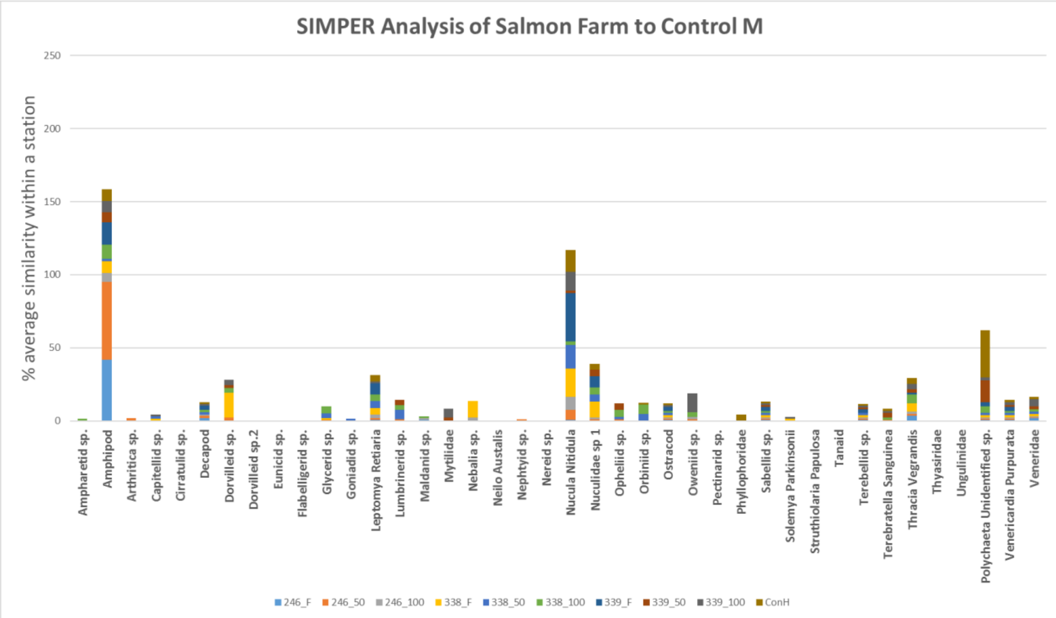

Figure 24: **Salmon farm infauna compositions compared to Control M.**

3.5.2 Summary

Results from the seabed surveys showed:

- Organic enrichment beneath all marine farms was occurring in comparison to the nearby central control stations.
- Opportunist polychaetes were observed beneath all marine farming stations.
- Marine farming stations retained moderately high benthic species richness and diversity.
- Organic matter decreases away from the farms.
- *Beggiatoa*[2] matting was observed beneath 249_50 and 249_100, beyond the farm site in 2015/16, but not 2016/17.
- Opportunist polychaetes were again observed beneath all marine farming stations, except for beneath MF 246, at which salmon farming has just begun.
- Several stations had amphipods (more than 40 per sample), which were not observed during the previous sampling period.
- In general, seabed conditions look to have improved across Big Glory Bay from 2015/16 to 2016/17.

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2 A form of bacteria that lives in sulfur-rich environments.

3.6 LANDSCAPE AND VISUAL AMENITY

Landscape and visual amenity of Steward Island, and by extension Big Glory Bay, has been assessed by Boffa Miskell Limited ("**BML**") in association with the Environment Southland and Ministry for Primary Industries proposed Port Pegasus / Pikihatiti Salmon Farms.[3] Furthermore, Appendix 4 of the Southland Regional Coastal Plan ("**Coastal Plan**") provides a coastal landscape assessment of Southland's coastline. The following subsections contain a summary of the BML report and Coastal Plan as they relate to Big Glory Bay and the proposed changes.

The BML report outlines that the natural character of Stewart Island (except for Halfmoon Bay / Oban and Big Glory Bay) is considered to be "Outstanding". Halfmoon Bay / Oban and Big Glory Bay are exempted from the "Outstanding" rating due to their relatively high level of development in Big Glory Bay's case this development is the marine farms.

The Coastal Plan includes Big Glory Bay in Landscape Unit 29 – Eastern Bays, which extends from the northern most head of Port William in the north, to East Cape in the south, as shown in Figure 25.

Figure 25: Coastal Plan – Landscape Unit 29 – Eastern Bays.

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[3] Boffa Miskell (2017). *Port Pegasus/ Pikihatiti Salmon Farms - Natural Character, Landscape and Visual Amenity Effects Assessment Prepared for Environment Southland & Ministry for Primary Industries.* 11 October 2017.

The Coastal Plan assesses the naturalness of each landscape unit using the following scale.

5	4	3	2	1
Natural	Semi-Natural	Modified	Cultural	Developed

The Coastal Plan assesses Unit 29 as having a naturalness rating of '3+', which is between modified (3) and semi natural (4). It also describes the key landscape elements, distinctive features and cultural elements, and potential activities that could adversely affect the natural character in that unit.

The key landscape elements relevant to Big Glory Bay are:

- A series of crescent shaped bays, containing golden sand beaches.
- A series of coastal ridgelines and "arms" that form the bays.
- Coastal lowlands, separated by ridgelines.

Big Glory Bay is not identified as having any distinctive features or cultural elements, and marine farming / aquaculture is not identified as a potential activity that could adversely affect the natural character.

A Land and Seascape Visual Impact Assessment ("**LSVIA**") was provided with an application by Sanford to merge MF 246 and LI 323 (previously located west of MF 246) at the MF 246 site and to enable salmon farming at MF 246. This LSVIA considered that Big Glory Bay, with marine farming present, has a landscape value of '4' when assessed in isolation.

Observations of the land and seascape fabric identified in the LSVIA are set out in Table 2 below.

Table 2: Big Glory Bay land and seascape fabric observations.

Visible Physical	• Open expanse of Big Glory Bay. • Some enclosed sandy beaches. • Vegetation to the water's edge. • Bush covered, low lying headlands and islands. • Settlement on the north-western shore.
Visible Spatial – scale, colour, pattern, texture	• Mussel farm floats dot the water. • Low headlands and islands indistinguishable from Stewart Island at distance. • Blues, grey, greens, blacks, dots for golden yellow and reds.

	Overall smooth texture dotted with green patterns.
Non-visible – sound, smell, cultural associations	Fresh air. Sound of wind, water lapping, and bird song. Large scale aquaculture development within Big Glory Bay. Popular hunting destination. Working vessels seen, and occasionally heard when close at hand. Historical settlement on Bravo Island.

Finally, Big Glory Bay is not identified as an Area Containing Significant Values ("**ACSV**")[4] in the Coastal Plan.

3.7 WILDLIFE

3.7.1 Overview

As set out in Section 3.6, Big Glory Bay is located in Landscape Unit 29 under the Coastal Plan. Wildlife of interest in Unit 29 includes seals, sea lions, dolphins, whales, sharks, seabirds, and tubeworms. Each of these species is addressed below.

3.7.2 Seals and Sea Lion

Three species of seal potentially found within Big Glory Bay are Fur, Leopard and Southern Elephant. All three species of seal, and Sea Lion, are granted protection under the Marine Mammals Protection Act 1978.

Fur seals are the most common seal found in New Zealand with a population estimated to be in the order of 200,000 in 2001. Populations were considered to be growing across New Zealand, such that the population is likely to be higher in 2017, but by how much is unknown.[5] The waters around Stewart Island are identified as being a breeding site for Fur seals[6] and observations indicate they haul out in Big Glory Bay. There are no breeding sites in Big Glory Bay.

Leopard seals are typically found along the Antarctic ice pack, but are transitory through New Zealand and Stewart Island waters but have never been sighted around aquaculture infrastructure around Stewart Island.

4 Areas identified by the Department of Conservation as containing significant values.
5 http://www.doc.govt.nz/nature/native-animals/marine-mammals/seals/nz-fur-seal/
6 https://www.teara.govt.nz/en/interactive/6187/distribution-of-seals-in-new-zealand

Southern Elephant seals are the largest seal species in the world. The New Zealand population is concentrated on the Antipodes and Campbell Islands, although they are transitory visitors to Stewart Island waters. Historically they have been sighted at marine farming sites around Stewart Island, but have not caused any predation concerns.

In general Sanford does not experience an issue with seal predation in regards to its salmon farming activities.

Sea Lion breed on the Antipodes and Campbell Islands and they prefer to haul out on sandy beaches, having very occasionally been seen hauling out on Stewart Island. The Sea Lion population is estimated to be approximately 12,000, with a conservation status of "Nationally Critical" and populations in decline.[7]

3.7.3 Dolphins, Whales and Sharks

Bottlenose dolphins are known to frequent Unit 29, including Big Glory Bay, and have been known to opportunistically pull an occasional mortality in salmon farms out through the bottom of pens. Population sizes are unknown, but they are relatively common worldwide.

Orca are very occasionally seen in Unit 29, 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.

Southern Right whales are circumpolar migratory animals and transitory visitors to Unit 29, typically present between 20ºS and 55ºS. The New Zealand population is distinct from neighbouring populations in Australia, based on genetic markers.

Three species of sharks are known to frequent the waters of Unit 29, White Pointer (vulnerable), Broadnose Sevengill (unclassified), and Porbeagle (vulnerable).

3.7.4 Seabirds

3.7.4.1 Shag

There are three species of shag found in Unit 29 – Stewart Island, Spotted, and Pied.

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 currently classified as vulnerable.[8]

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[7] http://www.doc.govt.nz/sealion

[8] http://nzbirdsonline.org.nz/species/stewart-island-shag

Pied Shag 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. It is classified as nationally vulnerable.[9]

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. They are currently classified as or least concern.[10]

3.7.4.2 Penguin

There are three species of penguin found in Unit 29 – Yellow Eyed, Little Blue, and Fiordland Crested.

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. There are known Yellow Eyed breeding sites on the Bravo Islands, at the mouth of Big Glory Bay, and they are classified as endangered.[11]

The Fiordland Crested penguin nests in colonies preferring hollows under fallen trees, roots, boulders or rock crevices. Their current population is estimated to be 2,500 – 3,000 breeding pairs and they are classified as vulnerable.[12]

Little Blue penguin is the smallest species of penguin, and populations are found around New Zealand and the Chatham Islands. They nest along the coastline in burrows in the banks of the coastline. Their population is estimated to be 350,000 – 600,000 around the world, and they are classified as of least concern.[13] There is a resident population in Big Glory Bay, which typically does not approach the farms.

3.7.4.3 Gull

Gulls are widespread around Unit 29, with the main species present being Black-billed, Red-billed, and Southern black-backed.

The Black-billed gull is endemic to New Zealand, and its natural habitat is sandy shores. The majority of the population nests in the Southland, with approximately 5% in the North Island, and the remainder across the rest of the South Island. Population is estimated to be 90,000 individuals in 2008, and it is currently classified as endangered.[14]

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9 http://nzbirdsonline.org.nz/species/pied-shag
10 http://www.nzbirdsonline.org.nz/species/spotted-shag
11 http://nzbirdsonline.org.nz/species/yellow-eyed-penguin
12 http://nzbirdsonline.org.nz/species/fiordland-crested-penguin
13 http://nzbirdsonline.org.nz/species/little-penguin
14 http://nzbirdsonline.org.nz/species/black-billed-gull

The Red-billed gull is a most common gull in New Zealand, and is found in coastal communities around the country. They breed in dense colonies mainly restricted to the eastern coasts of the North and South islands on stacks, cliffs, river mouths, and sandy and rocky shores.[15]

The Southern black-backed gull is one of the most abundant and familiar large birds in New Zealand. They are found around New Zealand except for forest and scrub habitats, and are abundant where there is a food source. The largest breeding colonies are 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.[16]

Sanford has experienced few seabird captures on its Big Glory Bay marine farms as netting utilised is grey in colour and visible to seabirds.

3.8 CULTURAL SETTING

The Marine and Coastal Area (Takutai Moana) Act 2011 ("**MACA Act**") provides a legal framework for iwi, hapu and whanau to have their customary marine title and/or protected customary rights recognised, via "Recognition Orders", in the marine and coastal areas around New Zealand.

Te Rūnanga o Ngāi Tahu ("**Ngāi Tahu**") has applied for customary marine title, as shown in Figure 26. Ngāi Tahu's application encompasses all of the South Island's coastal waters from White Cliffs, near Blenheim, on the east coast, around to Kahurangi Point (approximately 50 km south of Cape Farewell) on the west coast.

Two other applications have been made that cover the whole of New Zealand. These were by:

- Cletus Paul; and
- Rihari Dargaville.

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15 http://www.nzbirdsonline.org.nz/species/red-billed-gull
16 http://www.nzbirdsonline.org.nz/species/southern-black-backed-gull

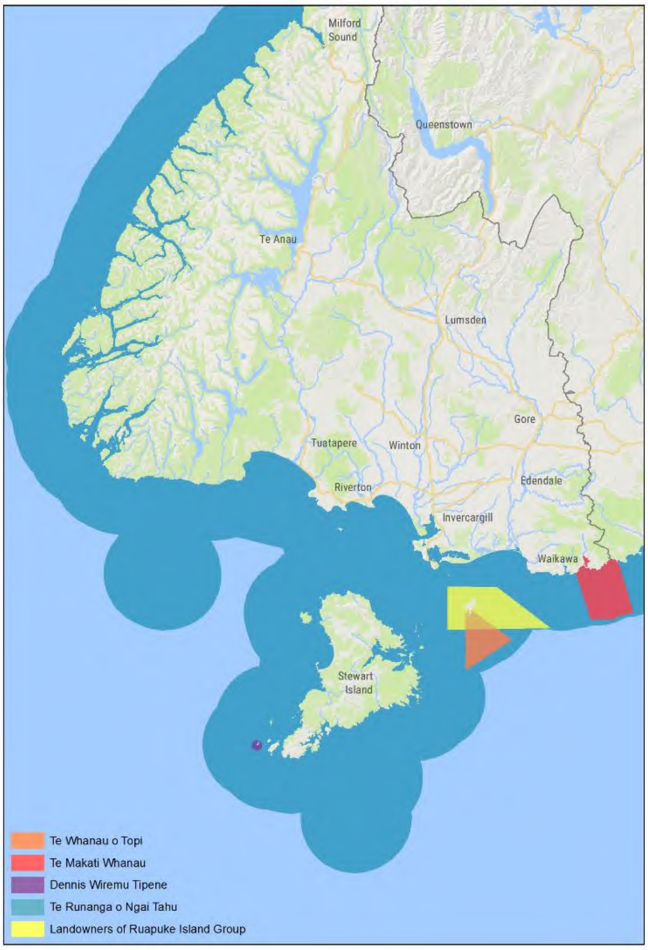

Figure 26: Southland Region Marine and Coastal Area Customary Marine Title application areas.

No Recognition Orders have been made in respect of Big Glory Bay. Sanford has notified and is seeking the views of applicants for customary marine title as required by section 62 of the MACA Act. Sanford will consider those views once they are received.

Ngāi Tahu are recognised in Chapter 3 of the Southland Regional Policy Statement as being tangata whenua of the entire Southland region, having occupied the area and used its natural resources for centuries, and as having a special relationship with the land, air, water and natural resources.

Ngāi Tahu is made up of 18 Papatipu Rūnanga who hold the rights and responsibilities to defined areas of land and waters within the area of Ngāi Tahu. In the Southland region, these are:

- Waihōpai Rūnaka;
- Te Rūnanga o Ōraka-Aparima;

- Hokonui Rūnaka; and
- Te Rūnanga o Awarua.

All of these are located on the South Island, and all four Papatipu Rūnanga hold rohe over Stewart Island. Sanford has a close working relationship with the people of Te Rūnanga o Awarua, whose whanau have visited Sanford's salmon farms in Big Glory Bay. Sanford appreciates the opportunity and privilege to host company meetings and staff events on Te Rau Aroha Marae, which is located near its processing plant in Bluff. Sanford also has a significant joint venture aquaculture development with Ngāi Tahu Seafoods – the Pegasus Bay Greenshell mussel farm in Canterbury.

3.9 SENSITIVITY OF THE ENVIRONMENT

In accordance with Schedule 4, Clause 6(1)(d)(i) of the RMA, a description of the sensitivity of the receiving environment for a discharge is required.

Overall, Section 3 of this AEE describes the environmental setting of the proposed changes, and on the basis of the conclusions reached above, Big Glory Bay is not considered to be a sensitive environment for the following reasons:

- Overall water quality analysis indicates there are no detectable adverse water quality issues within Big Glory Bay.
- From a nutrient and chlorophyll-a perspective, conditions appear to have remained similar, if not identical for the past 30 years, despite the increased fish biomass.
- Organic enrichment beneath all marine farms was occurring in comparison to the nearby central control stations.
- Seabed conditions look to have improved across Big Glory Bay from 2015/16 to 2016/17.
- Big Glory Bay is not an "Outstanding" landscape and marine farming has been occurring in Big Glory Bay for over 25 years.
- While marine mammals and birds may occur in Big Glory Bay, it does not provide important habitat, nor are these species adversely affected by marine farming activities.

Therefore, there are no aspects within the Big Glory Bay environment that would consider an increased nitrogen allowance to be inappropriate.

4. ASSESSMENT OF ENVIRONMENTAL EFFECTS

4.1 OVERVIEW

This section is set out in the following subsections:

Section 4.2: Provides an overview of the potential effects on water quality, and the results of water quality modelling undertaken in regard to the proposed changes.

Section 4.3: Outlines the potential depositional effects of the proposed changes, and the results of modelling undertaken in regard to the proposed changes.

Section 4.4: Discusses potential landscape and visual amenity effects proposed changes.

Section 4.5: Discusses potential navigation and recreation effects of the proposed changes.

Section 4.6: Discusses the potential effects on wildlife.

Section 4.7: Discusses the cultural effects of the proposed changes.

Section 4.8: Outlines the environmental limits relevant to the proposed changes.

Section 4.9: Provides a summary of the effects on the environment of the proposed changes.

4.2 EFFECTS ON WATER QUALITY

Sanford commissioned ADS to undertake water quality modelling regarding the proposed changes. Parameters modelled are the excess total ammonia nitrogen ("**TAN**") and dissolved oxygen, as these are the two main parameters that constrain the assimilative capacity of a marine embayment for fish farming from a water quality perspective.

This section contains a summary of the water quality report presented by ADS (**Volume 2, Appendix C**).

4.2.1 Model Calibration

The first stage of the modelling undertaken was to calibrate the model. This was achieved by comparing model outputs to what has been measured in the Big Glory Bay Monitoring Programme (**Appendix A**). Figure 27 – Figure 30 shows the calibration of the model with regard to current speed, current direction, water level, and total ammonia nitrogen. Calibration was considered by ADS to mean that the model was working well and therefore fit for purpose.

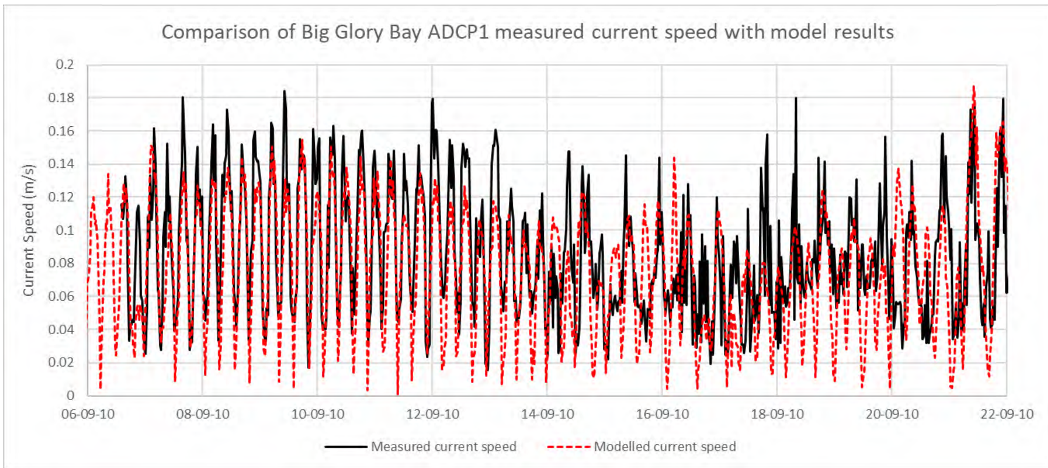

Figure 27: **Measured current speed vs. modelled current speed.**

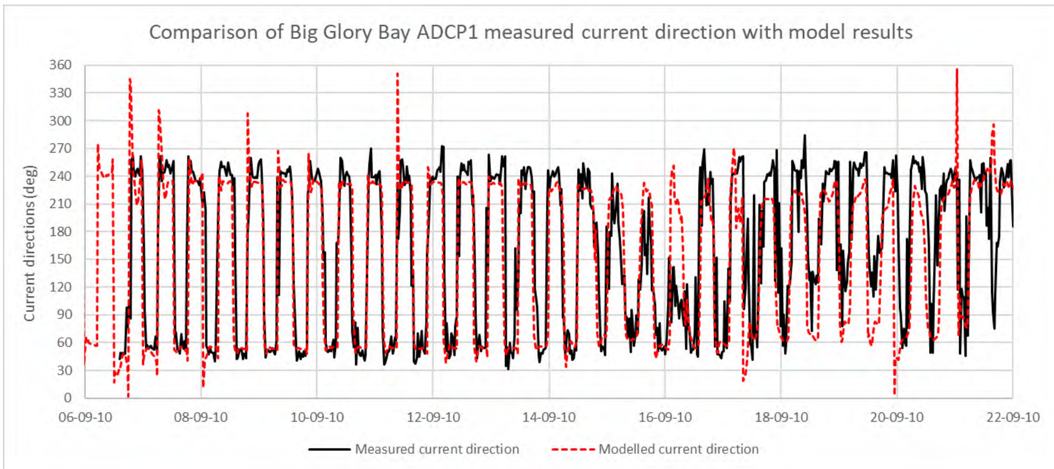

Figure 28: **Measured current direction vs. modelled current direction.**

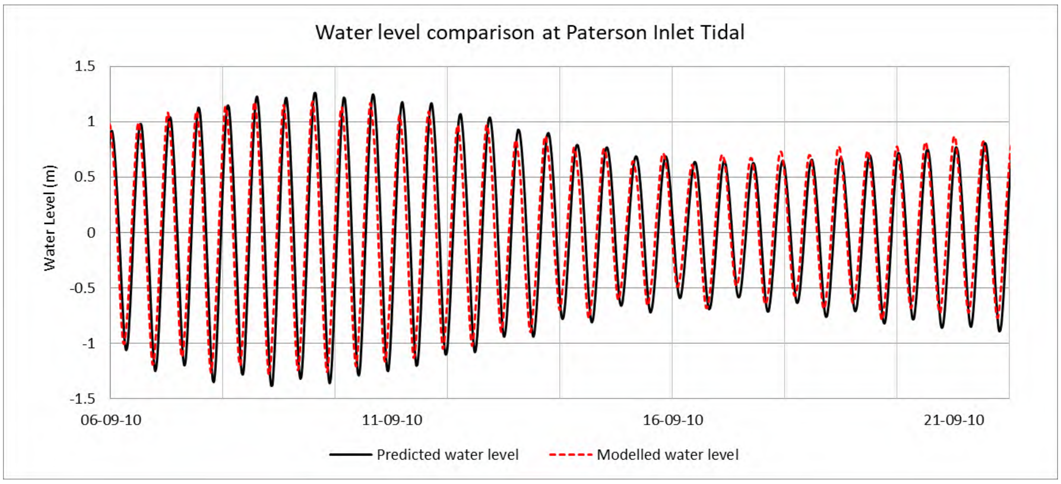

Figure 29: **Predicted water level vs. modelled water level.**

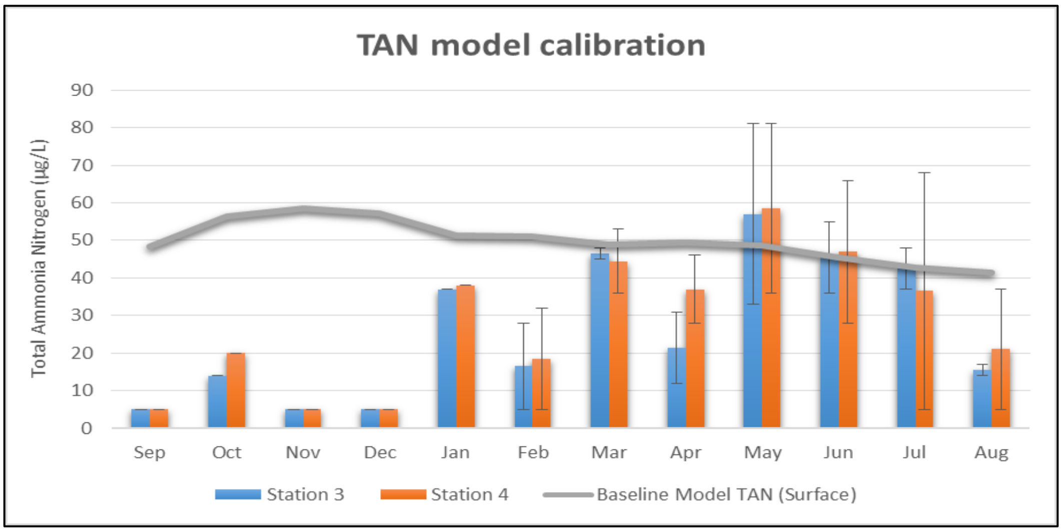

Figure 30: **TAN model calibration.**

4.2.2 Modelling Scenarios

ADS modelled TAN release and oxygen depletion in Big Glory Bay in two scenarios:

1. A mid-level expansion scenario, with nitrogen input from feed of 621.4 tonnes /year.
2. A high-level expansion scenario, with nitrogen input from feed of 659 tonnes/year (the amount sought by the proposed changes).

4.2.3 Results

4.2.3.1 Total Ammonia Nitrogen

TAN concentrations in Big Glory Bay from the model calibration have been deducted from that modelled for the proposed changes in order to determine the environment effect of the proposed changes.

Average excess TAN in Big Glory Bay as a result of the proposed changes has been modelled to be up to 30 µg/L. An increase in TAN was also observed in Paterson Inlet, in the order of less than 5 µg/L. ADS has determined that an excess TAN increase to be an environmentally acceptable level.

Should all of the excess TAN be converted to phytoplankton, a maximum possible chlorophyll-*a* increase of 2.5 – 4 µg/L is anticipated. This is likely an overestimate as it does not take mussel farming into account, which uptake phytoplankton, which in turn uptake TAN, and may provide improved mussel growing conditions. This is likely only possible in spring and summer, when seasonal conditions allow.

The excess concentrations of TAN and chlorophyll-*a* resulting from the proposed changes are within the assimilative capacity of Big Glory Bay, such that the effects of the proposed changes are considered the acceptable.

4.2.3.2 Dissolved Oxygen

ADS, in their monitoring reports, note that 2 mg/L is the critical level for sustaining aerobic respiration, and 4 mg/L is the threshold for stressing most aerobic organisms. ADS further notes that 6 mg/L is required to maintain healthy farmed salmon.

The proposed changes have been modelled to reduce dissolved oxygen by 0.25 mg/L in Big Glory Bay and up to 1.5 mg/L within the salmon pens.

Figure 31 shows that dissolved oxygen in Big Glory Bay will be above these values even under the high-level scenario, such that the environmental effects of the proposed changes will be acceptable.

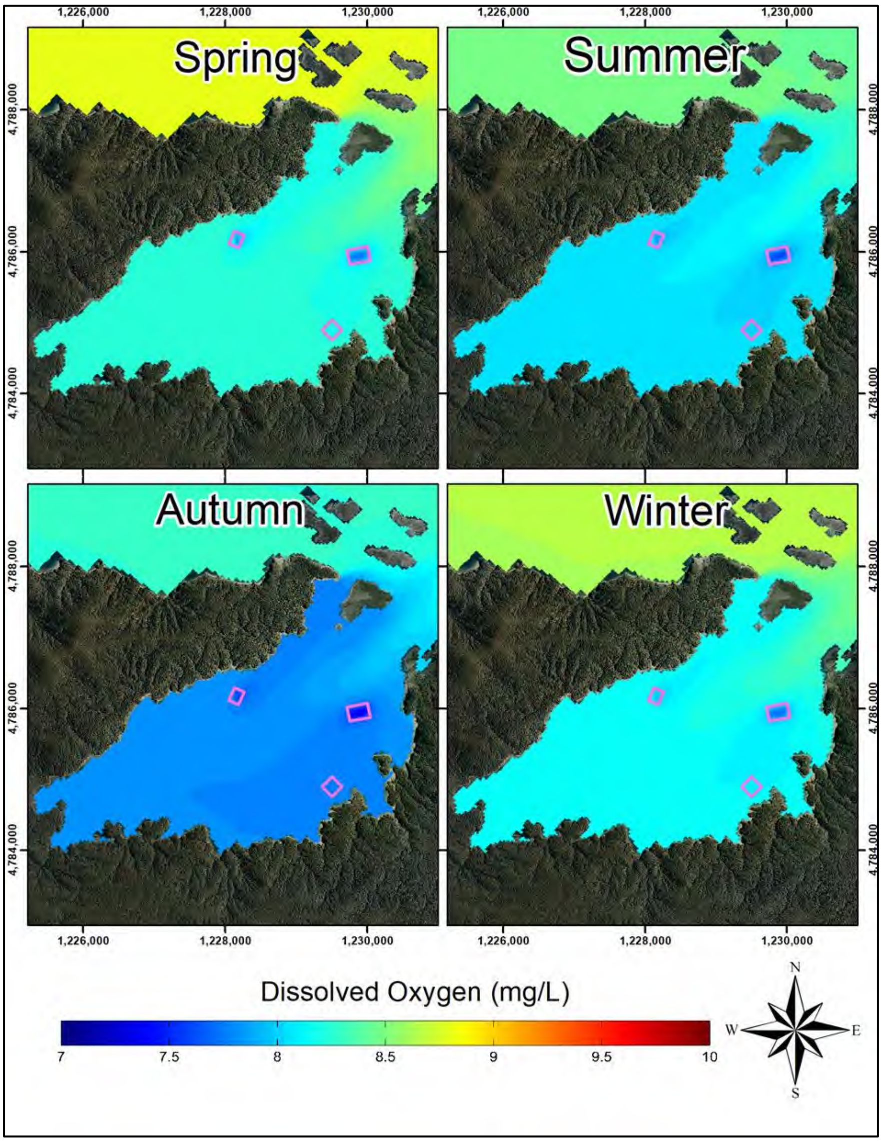

Figure 31: **Seasonal average dissolved oxygen in Big Glory Bay under the high-level scenario.**

4.3 SEABED DEPOSITION

Sanford commissioned ADS to undertake depositional modelling regarding the proposed changes. This section contains a summary of the seabed deposition report presented by ADS (**Volume 2, Appendix D**).

4.3.1 Modelling Scenarios

ADS modelled seabed deposition as a result of the proposed changes, i.e. a maximum nitrogen input from feed of 659 tonnes/year across three sites as a representative sample, being:

- 412.6 tonnes / year of nitrogen input from feed with a binding agent at MF 246;

- 200.6 tonnes / year of nitrogen input from feed at LI 320; and
- 45.8 tonnes / year of nitrogen input from feed at LI 339 when stocking smolt.

All modelling scenarios were simulated for one year.

4.3.2 Depositional Results

Under the scenarios presented in Section 4.3.1, deposition generally remains within the boundaries of the site, with some up to 100 m beyond the boundary.

Based on published literature, ADS conservatively note that carbon deposition of 0.73 kg/m^2/year represents a conservative zone of known ecological impact for carbon deposition.

Specific to each site, the following is noted:

MF 246

- The majority of the deposition is concentrated within the boundaries of the site, with the exception of some deposition up to 100 m beyond the eastern boundary.
- Organic carbon and solids deposition outside of lease boundary settled in concentrations ranging from 1 to 4 kgC/m^2/year and <5 to 20 kg/m^2/year respectively, see Figure 32 and Figure 33.

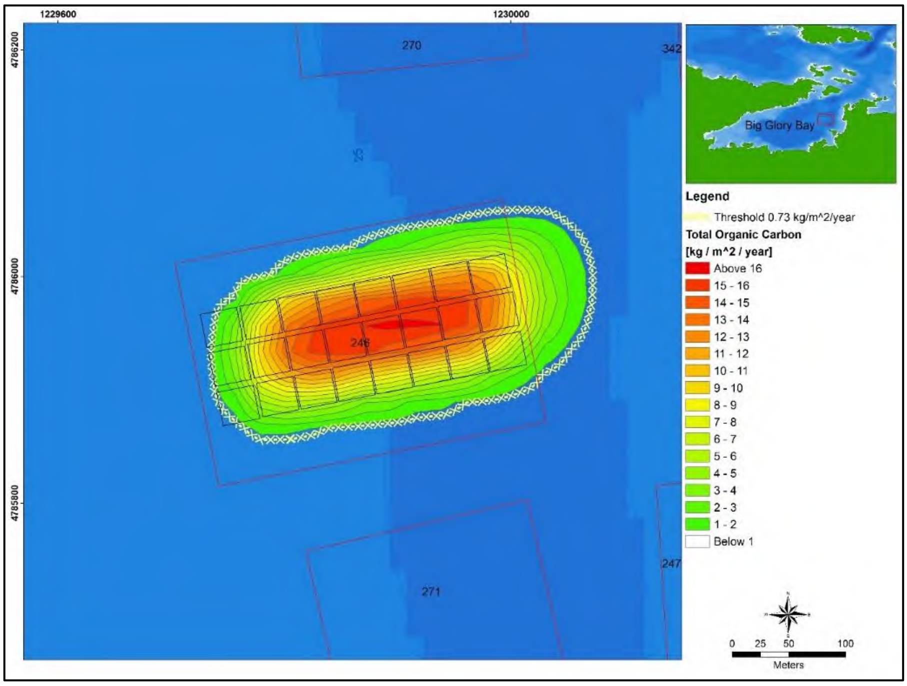

Figure 32: Total organic carbon deposition at MF 246.

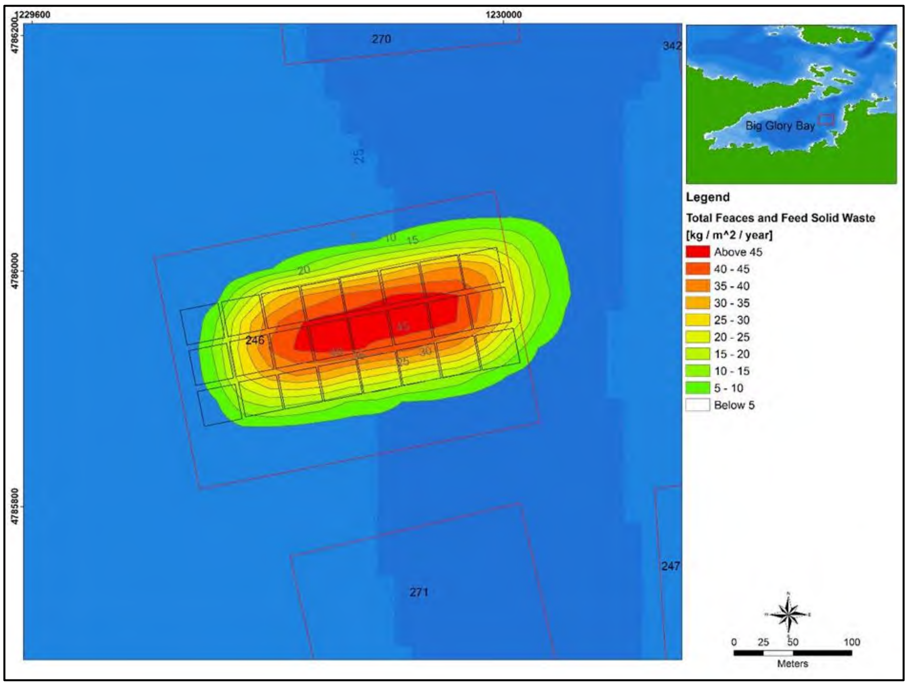

Figure 33: Total faeces and feed solid waste deposition at MF 246.

LI 320

- Most of the deposition is concentrated within the boundaries of the site, with a small amount occurring up to 20 m beyond the NW and SE boundaries.
- Organic carbon and solids concentrations, outside of lease boundary, are predicted to range from <1 to 4 kgC m^2/year and 5 to 15 kg m^2/year respectively, see Figure 34 and Figure 35.

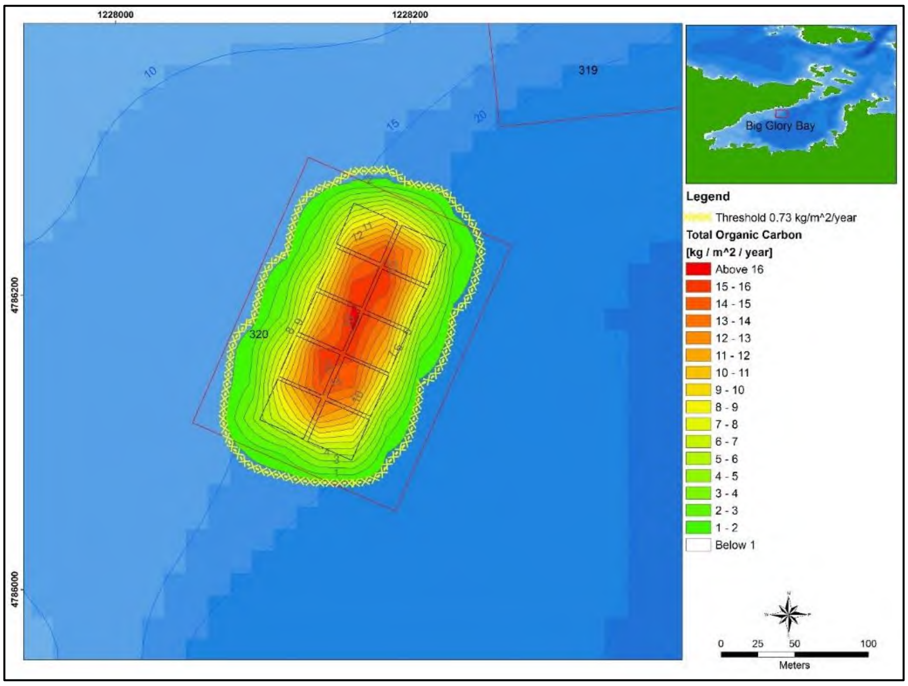

Figure 34: **Total organic carbon deposition at LI 320.**

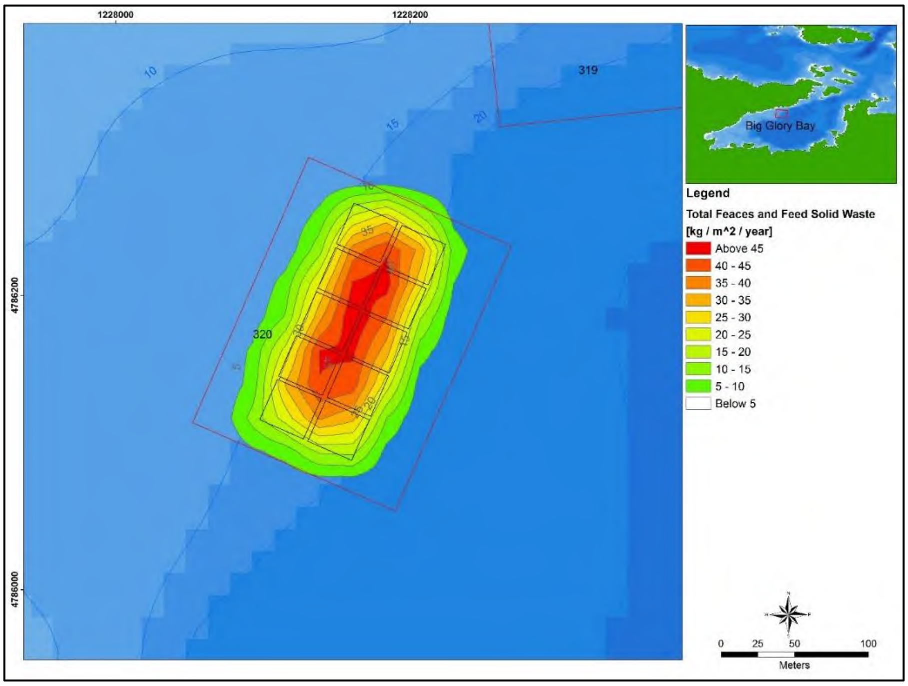

Figure 35: **Total faeces and feed solid waste deposition at LI 320.**

LI 339

- Nearly all of the deposition should be concentrated within 100 m of the boundaries of the site.

- Organic carbon and solids concentrations are predicted to range from <1 to 7 kgC m^2/year and <5 to 25 kg m^2/year respectively, see Figure 36 and Figure 37.

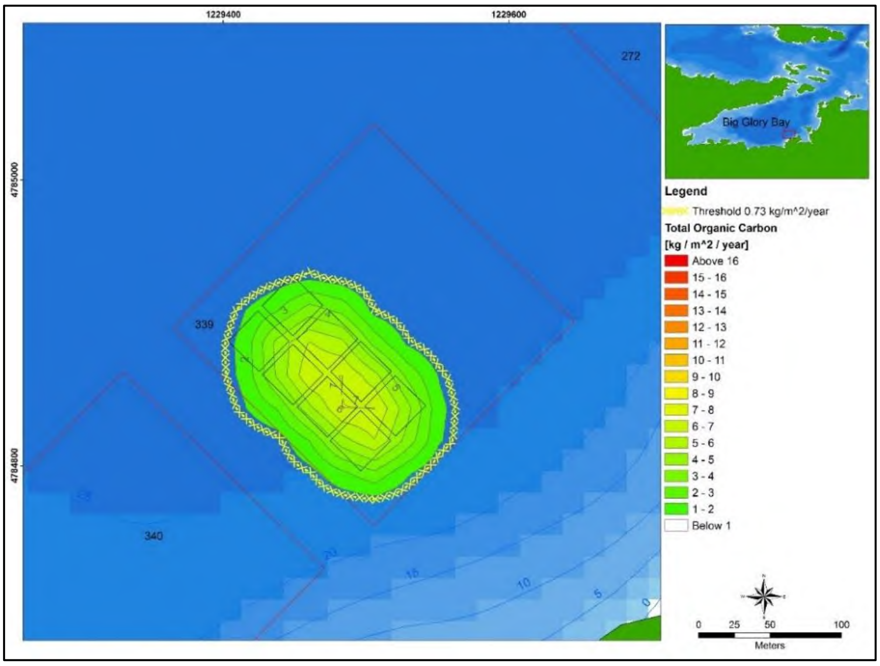

Figure 36: Total organic carbon deposition at LI 339.

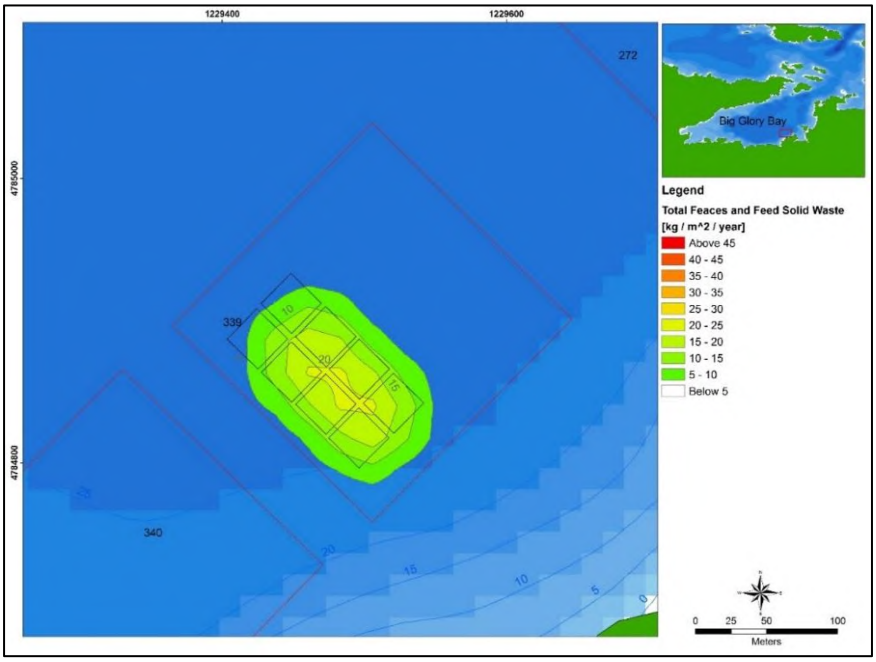

Figure 37: Total faeces and feed solid waste deposition at LI 339.

On the basis of the depositional results presented by ADS, the following depositional limits are considered appropriate for the proposed changes:

- Total organic carbon deposition of no more than 0.73 kg/m^2/year more than 100 metres from the boundary of a site; or
- Total faeces and solid waste deposition of no more than 5 kg/m^2/year more than 100 metres from the boundary of the site.

Provided these limits are complied with, the effects of the proposed changes will be acceptable, and generally confined to the boundaries of the marine farm sites.

4.4 LANDSCAPE AND VISUAL AMENITY EFFECTS

The proposed changes are limited to the nitrogen allowance of Sanford's Big Glory Bay marine farms. As such, the marine farm sites will continue to be confined to their current extent and location, and any change to the number of pens, other infrastructure, or vessels is already authorised and not affected by this application.

4.5 NAVIGATION AND RECREATION EFFECTS

Sanford is not proposing to increase the extent or location of its marine farm sites and the effects on navigation and recreation are already authorised by existing resource consents and are not being changed by this application. Marine farming has been occurring in Big Glory Bay for more than 25 years, as such recreational activities that once located in Big Glory Bay have long since relocated to Paterson Inlet.

4.6 EFFECTS ON WILDLIFE

Sanford is not proposing to increase the extent or location of its marine farm sites. Therefore any effects on wildlife, such as habitat exclusion, are the effects on natural character are already authorised by existing resource consents and are not being changed by this application. It is also noted that the effects on water quality and seabed deposition effects have been assessed as acceptable, such that the wider ecosystem effects are acceptable.

4.7 CULTURAL EFFECTS

Ngāi Tahu's Environmental Management Plan (**"EMP"**), *Te Poha o Tohu Raumati*[17], addresses aquacultures and marine farming in section 3.6.15. The EMP does not seek to preclude marine farming however, it does seek to address issues such as:

- Protection and recognition of customary rights;
- What is to be fed to the farmed species; and
- Impact on local biodiversity (introducing species from outside the area).

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[17] http://ngaitahu.iwi.nz/wp-content/uploads/2013/08/Te-Runanga-o-Kaikoura-Environmental-Management-Plan.pdf

The proposed changes are not considered to result in an adverse effect on customary rights, significantly alter the type of feed except where is will result in the avoidance of an adverse effect (such as the inclusion of a binding agent), nor will it introduce any new species that are not already being farmed in Big Glory Bay.

Policies set out in the EMP generally address new applications, however, the following is relevant to the proposed changes:

- To require comprehensive, periodic monitoring of all aquaculture and marine farms, in addition to regular compliance monitoring.

The proposed changes include a requirement for comprehensive monitoring, such that they are consistent with this requirement.

4.8 COMPLIANCE LIMITS

Overall, the proposed changes have been modelled to be within the assimilative capacity of Big Glory Bay. ADS has modelled 659 tonnes/year of nitrogen input from feed spread over three of Sanford's marine farm sites. Compliance limits for key parameters above those currently experienced are:

- Increase the average excess TAN in Big Glory Bay by no more than 30 µg/L at the surface;
- Increase the average excess of chlorophyll-a in Big Glory Bay by no more than 4 µg/L at the surface;
- Reduce the average dissolved oxygen concentration in Big Glory Bay below 6 mg/L at the surface;
- Result in total organic carbon deposition greater than 0.73 kg/m^2/year more than 100 metres from the boundary of the site; and
- Result in total faeces and solid waste deposition greater than 5 kg/m^2/year more than 100 metres from the boundary of the site.

As such, compliance with these limits has been incorporated into the proposed changes, as has a modelling and monitoring framework to ensure compliance with these limits.

4.9 SUMMARY

The proposed changes have been designed to be within the assimilative capacity of Big Glory Bay, and compliance with the environmental limits set out in Section 4.8 will ensure that overall the effects of the proposed changes will be acceptable.

5. STATUTORY CONSIDERATIONS

5.1 INTRODUCTION

Form 10 of the Resource Management (Forms, Fees, and Procedure) Regulations 2003 requires a variation application to include an assessment against the matters set out in Part 2 of the RMA, and any relevant provisions of a document referred to in section 104(1)(b) of the RMA. This section of the AEE addresses these matters.

5.2 REQUIREMENTS OF A CHANGE APPLICATION

Section 88 of the RMA requires that a change application be made in the prescribed form and manner, and include, in accordance with Schedule 4, the information relating to the activity, including an assessment of the effects of the change on the environment.

The application for the proposed changes accompanying this AEE are in the prescribed form, as set out in Form 10 of the Resource Management (Forms, Fees, and Procedure) Regulations 2003.

Clauses 2, 3, 6 and 7 of Schedule 4 of the RMA specify information requirements that are relevant to these applications and this AEE. **Appendix B** outlines where that information is provided in this AEE.

By way of summary, the AEE meets the requirements of the Fourth Schedule, and the requirements of section 88.

5.3 SECTION 104(1)(B)

Schedule 4 of the RMA requires this application to be assessed against relevant provisions of a document referred to in section 104(1)(b) of the RMA. Documents relevant to this proposed changes are:

- New Zealand Coastal Policy Statement ("**NZCPS**");
- Southland Regional Policy Statement 2017 ("**Southland RPS**"); and
- Regional Coastal Plan for Southland ("**Coastal Plan**").

The provisions relevant to this application are set out below.

5.3.1 New Zealand Coastal Policy Statement

5.3.1.1 Overview

The NZCPS was issued by gazette notice and took effect on 3 December 2010. It sets out a number of objectives and policies for achieving the purpose of the RMA in relation to the coastal environment. It contains provisions which address the following matters of relevance to the proposed changes:

- Aquaculture and the provision for social and economic wellbeing;
- The precautionary approach;
- Indigenous biodiversity;
- Natural character and landscape values;
- Amenity and access;
- Treaty of Waitangi; and
- Discharges.

The NZCPS provisions relating to each matter are addressed below.

5.3.1.2 Provision for Aquaculture and Social and Economic Wellbeing

Objective 6 and Policies 6 and 8 of the NZCPS seek to, amongst other things, enable people and communities to provide for their social and economic wellbeing through the use and development of natural and physical resources in the coastal environment.

The relevant aspects of Objective 6 and Policies 6 and 8 to the proposed changes are set out below:

> ***Objective 6***
> *To enable people and communities to provide for their social, economic, and cultural wellbeing and their health and safety, through subdivision, use, and development, recognising that:*
> - *the protection of the values of the coastal environment does not preclude use and development in appropriate places and forms, and within appropriate limits;*
> - *some uses and developments which depend upon the use of natural and physical resources in the coastal environment are important to the social, economic and cultural wellbeing of people and communities;*
> - *functionally some uses and developments can only be located on the coast or in the coastal marine area;*
> - *...*
> - *the protection of habitats of living marine resources contributes to the social, economic and cultural wellbeing of people and communities;*
> - *...*
> - *the proportion of the coastal marine area under any formal protection is small and therefore management under the Act is an important means by which the natural resources of the coastal marine area can be protected; and*
> - *....*
>
> ***Policy 6 Activities in the coastal environment***
> *(1) In relation to the coastal environment:*
> *...*
> *(j) where appropriate, buffer areas and sites of significant indigenous biological diversity, or historic heritage value.*
> *(2) Additionally, in relation to the coastal marine area:*
> *(a) recognise potential contributions to the social, economic and cultural*

wellbeing of people and communities from use and development of the coastal marine area, ...:

(b) recognise the need to maintain and enhance the public open space and recreation qualities and values of the coastal marine area;

(c) recognise that there are activities that have a functional need to be located in the coastal marine area, and provide for those activities in appropriate places;

(d) ...

(e) promote the efficient use of occupied space, including by:

(i) requiring that structures be made available for public or multiple use wherever reasonable and practicable;

(ii) requiring the removal of any abandoned or redundant structure that has no heritage, amenity or reuse value; and

(iii) considering whether consent conditions should be applied to ensure that space occupied for an activity is used for that purpose effectively and without unreasonable delay.

Policy 8 Aquaculture

Recognise the significant existing and potential contribution of aquaculture to the social, economic and cultural well-being of people and communities by:

(a) including in regional policy statements and regional coastal plans provision for aquaculture activities in appropriate places in the coastal environment, recognising that relevant considerations may include:

(i) the need for high water quality for aquaculture activities; and

(ii) the need for land-based facilities associated with marine farming;

(b) taking account of the social and economic benefits of aquaculture, including any available assessments of national and regional economic benefits; and

(c) ensuring that development in the coastal environment does not make water quality unfit for aquaculture activities in areas approved for that purpose.

Key directives of these provisions when considering the proposed changes include:

- The social and economic benefits of the proposed changes are to be recognised[18] and taken into account; and[19]
- That the protection of the values of the coastal environment does not preclude use and development where it is located in an appropriate place and form, and within appropriate limits.[20]

Aquaculture generates around $500 million in revenue to New Zealand,[21] approximately $39 million of which is generated from salmon in Southland.

[18] Policy 6(2)(a).

[19] Policy 8(b).

[20] Objective 6.

[21] Aquaculture New Zealand.

In Southland, Sanford generates approximately $66 million annually, of which approximately $60 million is returned to the local economy through wages, salaries, operating expenses and purchases. Sanford also directly employs 193 full-time-equivalent ("**FTE**") workers in the Southland region.

The Aquaculture Project for Southland (see Section 1.3) has set the goal of Southland producing 25,000 tonnes of salmon per year by 2020, the proposed changes sought by Sanford would contribute significantly to that whilst maximising salmon production in Big Glory Bay. It had been estimated that achieving this goal would create up to an additional 367 direct FTE positions and 180 indirect FTEs, generate export earnings of $214 million, add $60 million to Southland's gross domestic product, and generate about $500 million in salmon value.

The proposed changes will provide further social and economic benefits through the provision of additional domestic and export revenue, and will assist in the objective of growing the economic value of the aquaculture industry. In addition, the increase in salmon farming volumes will provide direct and indirect job opportunities in the Southland. These jobs will be associated with farming and processing activities, and the employment of people in supporting services (e.g. transport and logistics).

In light of the above, the proposed changes will assist in enabling people and communities to provide for their social and economic wellbeing through the appropriate use and development of natural and physical resources in the coastal environment.

5.3.1.3 Precautionary Approach

Policy 3 of the NZCPS addresses the precautionary approach. It states:

Policy 3 Precautionary approach

(1) Adopt a precautionary approach towards proposed activities whose effects on the coastal environment are uncertain, unknown, or little understood, but potentially significantly adverse.

(2) In particular, adopt a precautionary approach to use and management of coastal resources potentially vulnerable to effects from climate change, so that:

- *(a) avoidable social and economic loss and harm to communities does not occur;*
- *(b) natural adjustments for coastal processes, natural defences, ecosystems, habitat and species are allowed to occur; and*
- *(c) the natural character, public access, amenity and other values of the coastal environment meet the needs of future generations.*

Clause (1) of Policy 3 is considered most relevant to the proposed changes in that it directs decision-makers to adopt a precautionary approach towards proposed activities whose effects on the coastal environment are *"uncertain, unknown, or little understood, but potentially significantly adverse."*

In this regard, the modelling undertaken by ADS has determined that the proposed changes are within the assimilative capacity of Big Glory Bay. Notwithstanding this, Sanford has proposed a number of environmental standards as recommended by ADS (see Section 4.7) that must be complied with, and that monitoring shall be undertaken to confirm this on an ongoing basis. This approach is consistent with Policy 3.

5.3.1.4 Indigenous Biodiversity

Objective 1 and Policy 11 of the NZCPS are its key provisions in respect of the management of indigenous biodiversity in the coastal environment. They state:

> ***Objective 1***
>
> *To safeguard the integrity, form, functioning and resilience of the coastal environment and sustain its ecosystems, including marine and intertidal areas, estuaries, dunes and land, by:*
>
> - *maintaining or enhancing natural biological and physical processes in the coastal environment and recognising their dynamic, complex and interdependent nature;*
> - *protecting representative or significant natural ecosystems and sites of biological importance and maintaining the diversity of New Zealand's indigenous coastal flora and fauna; and*
> - *maintaining coastal water quality, and enhancing it where it has deteriorated from what would otherwise be its natural condition, with significant adverse effects on ecology and habitat, because of discharges associated with human activity.*
>
> ***Policy 11 Indigenous biological diversity (biodiversity)***
>
> *To protect indigenous biological diversity in the coastal environment:*
>
> *(a) avoid adverse effects of activities on:*
>
> *(i) indigenous taxa[4] that are listed as threatened[5] or at risk in the New Zealand Threat Classification System lists;*
>
> *(ii) taxa that are listed by the International Union for Conservation of Nature and Natural Resources as threatened;*
>
> *(iii) indigenous ecosystems and vegetation types that are threatened in the coastal environment, or are naturally rare;*
>
> *(iv) habitats of indigenous species where the species are at the limit of their natural range, or are naturally rare;*
>
> *(v) areas containing nationally significant examples of indigenous community types; and*
>
> *(vi) areas set aside for full or partial protection of indigenous biological diversity under other legislation; and*
>
> *(b) avoid significant adverse effects and avoid, remedy or mitigate other adverse effects of activities on:*
>
> *(i) areas of predominantly indigenous vegetation in the coastal environment;*
>
> *(ii) habitats in the coastal environment that are important during the vulnerable life stages of indigenous species;*
>
> *(iii) indigenous ecosystems and habitats that are only found in the coastal environment and are particularly vulnerable to modification, including*

estuaries, lagoons, coastal wetlands, dunelands, intertidal zones, rocky reef systems, eelgrass and saltmarsh;

(iv) habitats of indigenous species in the coastal environment that are important for recreational, commercial, traditional or cultural purposes;

(v) habitats, including areas and routes, important to migratory species; and

(vi) ecological corridors, and areas important for linking or maintaining biological values identified under this policy.

In summary, Objective 1 and Policy 11 of the NZCPS seek to avoid the adverse effects of activities on significant or important indigenous biodiversity values in the coastal environment, and avoid the significant adverse effects of activities on other indigenous biodiversity values in the coastal environment.

In this regard the proposed changes have been modelled as being within the assimilative capacity of Big Glory Bay, such that they will have no adverse effects on indigenous biodiversity.

The proposed changes will not adversely affect the life-cycle of the species and taxa identified in Clause (a) of Policy 11 of the NZCPS, and ADS have not identified significant adverse effects on habitats and areas of the coastal environment in accordance with Clause (b) of Policy 11 of the NZCPS.

5.3.1.5 Natural Character and Landscape Values

Objective 2 of the NZCPS addresses natural character and landscape values. It states:

Objective 2

To preserve the natural character of the coastal environment and protect natural features and landscape values through:

- *recognising the characteristics and qualities that contribute to natural character, natural features and landscape values and their location and distribution;*
- *identifying those areas where various forms of subdivision, use, and development would be inappropriate and protecting them from such activities; and*
- *encouraging restoration of the coastal environment.*

Policy 13 provides direction on how natural character is to be preserved. It states:

Policy 13 Preservation of natural character

(1) To preserve the natural character of the coastal environment and to protect it from inappropriate subdivision, use, and development:

(a) avoid adverse effects of activities on natural character in areas of the coastal environment with outstanding natural character; and

(b) avoid significant adverse effects and avoid, remedy or mitigate other adverse effects of activities on natural character in all other areas of the coastal environment; including by:

(c) assessing the natural character of the coastal environment of the region or district, by mapping or otherwise identifying at least areas of

high natural character; and

(d) ensuring that regional policy statements, and plans, identify areas where preserving natural character requires objectives, policies and rules, and include those provisions.

(2) Recognise that natural character is not the same as natural features and landscapes or amenity values and may include matters such as:

(a) natural elements, processes and patterns;

(b) biophysical, ecological, geological and geomorphological aspects;

(c) natural landforms such as headlands, peninsulas, cliffs, dunes, wetlands, reefs, freshwater springs and surf breaks;

(d) the natural movement of water and sediment;

(e) the natural darkness of the night sky;

(f) places or areas that are wild or scenic;

(g) a range of natural character from pristine to modified; and

(h) experiential attributes, including the sounds and smell of the sea; and their context or setting.

Policy 15 contains direction on how natural features and landscapes in the coastal environment are to be protected. It states:

Policy 15 Natural features and natural landscapes

To protect the natural features and natural landscapes (including seascapes) of the coastal environment from inappropriate subdivision, use, and development:

(a) avoid adverse effects of activities on outstanding natural features and outstanding natural landscapes in the coastal environment; and

(b) avoid significant adverse effects and avoid, remedy, or mitigate other adverse effects of activities on other natural features and natural landscapes in the coastal environment; including by:

(c) identifying and assessing the natural features and natural landscapes of the coastal environment of the region or district, at minimum by land typing, soil characterisation and landscape characterisation and having regard to:

(i) natural science factors, including geological, topographical, ecological and dynamic components;

(ii) the presence of water including in seas, lakes, rivers and streams;

(iii) legibility or expressiveness—how obviously the feature or landscape demonstrates its formative processes;

(iv) aesthetic values including memorability and naturalness; (v) vegetation (native and exotic);

(vi) transient values, including presence of wildlife or other values at certain times of the day or year;

(vii) whether the values are shared and recognised;

(viii) cultural and spiritual values for tangata whenua, identified by working, as far as practicable, in accordance with tikanga Māori; including their expression as cultural landscapes and features;

(ix) historical and heritage associations; and

(x) wild or scenic values;

(d) ensuring that regional policy statements, and plans, map or otherwise identify areas where the protection of natural features and natural landscapes requires objectives, policies and rules; and

(e) including the objectives, policies and rules required by (d) in plan

As set out in Section 4.4, the proposed changes will not impact natural character and landscape values as Sanford is not proposing to alter the extent or location of its marine farm sites. Therefore, the proposed changes are in accordance with the management expectations set out in Clause (1)(b) of Policy 13 and Clause (b) of Policy 15 of the NZCPS.

5.3.1.6 Amenity and Access

Objective 4 of the NZCPS addresses the public open space and recreation values attributed to the coastal environment. It states:

Objective 4

To maintain and enhance the public open space qualities and recreation opportunities of the coastal environment by:

- *recognising that the coastal marine area is an extensive area of public space for the public to use and enjoy;*
- *maintaining and enhancing public walking access to and along the coastal marine area without charge, and where there are exceptional reasons that mean this is not practicable providing alternative linking access close to the coastal marine area; and*
- *recognising the potential for coastal processes, including those likely to be affected by climate change, to restrict access to the coastal environment and the need to ensure that public access is maintained even when the coastal marine area advances inland.*

The NZCPS contains no clear policy direction as to how activities should be managed to achieve Objective 4. However, Policy 6 does contain the following relevant matters that should be had regard to when considering the proposed changes.

Policy 6 Activities in the coastal environment

...

(2) Additionally, in relation to the coastal marine area:

...

(b) recognise the need to maintain and enhance the public open space and recreation qualities and values of the coastal marine area;

...

(e) promote the efficient use of occupied space, including by:

(i) requiring that structures be made available for public or multiple use wherever reasonable and practicable;

(ii) requiring the removal of any abandoned or redundant structure that has no heritage, amenity or reuse value; and

(iii) considering whether consent conditions should be applied to ensure that space occupied for an activity is used for that purpose effectively and without unreasonable delay.

Section 4.5 of this AEE discusses the potential effects of the proposed changes on navigation and recreation in Big Glory Bay. Because the marine farm sites location or extent is not being sought to be changed there will be negligible effects on navigation and recreation.

Public access will be available around the marine farms sites, and between mussel lines however, due to the nature of salmon farming, public access within the sites will be excluded during salmon farming. The level of exclusion, which is for biosecurity, animal welfare, and health and safety reasons, will be generally in line with that currently occurring.

Given the above, any adverse effects on navigation and public access will not be significant and that the proposed changes align with the management expectations of Policy 6(2)(b) of the NZCPS.

With respect to Policy 6(2)(e) of the NZCPS, the site's extent and location will remain unchanged, such that they will remain an efficient occupier of space.

5.3.1.7 Treaty of Waitangi

Objective 3 of the NZCPS addresses the Treaty of Waitangi, and states:

> ***Objective 3:***
>
> *To take account of the principles of the Treaty of Waitangi, recognise the role of tangata whenua as kaitiaki and provide for tangata whenua involvement in management of the coastal environment by:*
>
> - *recognising the ongoing and enduring relationship of tangata whenua over their lands, rohe and resources;*
> - *promoting meaningful relationships and interactions between tangata whenua and persons exercising functions and powers under the Act;*
> - *incorporating mātauranga Māori into sustainable management practices; and*
> - *recognising and protecting characteristics of the coastal environment that are of special value to tangata whenua.*

> ***Policy 2: The Treaty of Waitangi, tangata whenua and Māori***
>
> *In taking account of the principles of the Treaty of Waitangi (Te Tiriti o Waitangi), and kaitiakitanga, in relation to the coastal environment:*
>
> *a. recognise that tangata whenua have traditional and continuing cultural relationships with areas of the coastal environment, including places where they have lived and fished for generations;*
>
> *b. involve iwi authorities or hapū on behalf of tangata whenua in the preparation of regional policy statements, and plans, by undertaking effective consultation with tangata whenua; with such consultation to be early, meaningful, and as far as practicable in accordance with tikanga Māori;*
>
> *c. with the consent of tangata whenua and as far as practicable in accordance with tikanga Māori, incorporate mātauranga Māori1 in regional policy statements, in plans, and in the consideration of applications for resource consents, notices of requirement for designation and private plan changes;*

d. provide opportunities in appropriate circumstances for Māori involvement in decision making, for example when a consent application or notice of requirement is dealing with cultural localities or issues of cultural significance, and Māori experts, including pūkenga2, may have knowledge not otherwise available;

e. take into account any relevant iwi resource management plan and any other relevant planning document recognised by the appropriate iwi authority or hapū and lodged with the council, to the extent that its content has a bearing on resource management issues in the region or district; and

i. where appropriate incorporate references to, or material from, iwi resource management plans in regional policy statements and in plans; and

ii. consider providing practical assistance to iwi or hapū who have indicated a wish to develop iwi resource management plans;

f. provide for opportunities for tangata whenua to exercise kaitiakitanga over waters, forests, lands, and fisheries in the coastal environment through such measures as:

i. bringing cultural understanding to monitoring of natural resources;

ii. providing appropriate methods for the management, maintenance and protection of the taonga of tangata whenua;

iii. having regard to regulations, rules or bylaws relating to ensuring sustainability of fisheries resources such as taiāpure, mahinga mātaitai or other non commercial Māori customary fishing;

g. in consultation and collaboration with tangata whenua, working as far as practicable in accordance with tikanga Māori, and recognising that tangata whenua have the right to choose not to identify places or values of historic, cultural or spiritual significance or special value:

i. recognise the importance of Māori cultural and heritage values through such methods as historic heritage, landscape and cultural impact assessments; and

ii. provide for the identification, assessment, protection and management of areas or sites of significance or special value to Māori, including by historic analysis and archaeological survey and the development of methods such as alert layers and predictive methodologies for identifying areas of high potential for undiscovered Māori heritage, for example coastal pā or fishing villages.

Objective 3 and Policy 2 of the NZCPS seek to take account of the principles of the Treaty of Waitangi, recognise the role of tangata whenua as kaitiaki and provide for tangata whenua involvement in management of the coastal environment.

Due to the commercial sensitivity of this application, Sanford advised Ngāi Tahu of this application and provided a copy of it to Ngāi Tahu on 16 November 2017. Sanford's is committed to full consultation with Ngāi Tahu, consistent with their existing relationship.

This approach will ensure consistency with Objective 3 and Policy 2 of the NZCPS.

5.3.1.8 Discharges

Policy 23 of the NZCPS addresses discharges to water in the coastal environment, and states:

Policy 23: Discharge of contaminants

1 In managing discharges to water in the coastal environment, have particular regard to:

a. the sensitivity of the receiving environment;

b. the nature of the contaminants to be discharged, the particular concentration of contaminants needed to achieve the required water quality in the receiving environment, and the risks if that concentration of contaminants is exceeded; and

c. the capacity of the receiving environment to assimilate the contaminants; and:

d. avoid significant adverse effects on ecosystems and habitats after reasonable mixing;

e. use the smallest mixing zone necessary to achieve the required water quality in the receiving environment; and

f. minimise adverse effects on the life-supporting capacity of water within a mixing zone.

...

As the proposed changes related to the discharge of nitrogen from feed, Policy 23 of the NZCPS is relevant. In regards to each of the matters outlined above, the following is noted:

- Section 3 of this AEE considered the sensitivity of the receiving environment (Policy 23(1)(a)).
- Section 4 provides an assessment of environmental effects of the proposed changes and concludes that they are within the assimilative capacity of Big Glory Bay (Policy 23(1)(c) and Policy 23(1)(d)).
- Regarding a mixing zone for the nitrogen from feed (Policies 23(1)(d) – 23(1)(f)), water quality monitoring has not found any detectable adverse water quality issues within Big Glory Bay as a result of marine farming. Given that the proposed changes are within the assimilative capacity of Big Glory Bay, this is anticipated to continue to be case.

5.3.2 Southland Regional Policy Statement 2017

The Southland Regional Policy Statement 2017 ("**Southland RPS**") became operative on 9 October 2017 and contains 17 chapters. The following chapters are relevant to the proposed changes:

- Chapter 6 – Biodiversity;
- Chapter 7 – Coast; and
- Chapter 10 – Natural Features and Landscapes.

5.3.2.1 Chapter 6 – Biodiversity

Objective BIO.2 – Maintain and protect

Maintain indigenous biodiversity in Southland and protect areas of significant indigenous vegetation and significant habitats of indigenous fauna for present and future generations.

Policy BIO.1 – Identification of significant areas

Identify areas of significant indigenous vegetation and significant habitats of indigenous fauna using the following:

(a) the Schedule of Threatened, At Risk and Rare Habitat Types in Appendix 2 which provides an indication of areas likely to be significant.

(b) Ecological assessments undertaken by a suitably qualified ecologist using the ecological significance criteria listed in Appendix 3 to ascertain whether an area listed is significant or otherwise.

(c) the ecological significance criteria listed in Appendix 3 which incorporate the following matters:

(i) representativeness;

(ii) rarity or distinctiveness;

(iii) diversity and pattern; and

(iv) ecological context;

(d) in collaboration with landowners the investigation and identification of areas of indigenous vegetation on private land that are likely to be significant.

Policy BIO.3 – Protect coastal indigenous biodiversity

Protect indigenous biodiversity from adverse effects in the coastal environment as set out in Policy 11 of the New Zealand Coastal Policy Statement 2010.

Policy BIO.4 – Maintain indigenous biodiversity

Manage a full range of indigenous habitats and ecosystems to achieve a healthy functioning state, and to ensure viable and diverse populations of native species are maintained while making appropriate provisions for lawful maintenance and operation of existing activities.

In giving effect to this policy, regard will be had to the following potential adverse effects:

(i) fragmentation of, or reduction in the extent of, significant indigenous vegetation or significant habitats of indigenous fauna;

(ii) fragmentation or disruption of connections and linkages between significant ecosystems or significant habitats of indigenous fauna;

(iii) loss of, or damage to, buffering of significant ecosystems or significant habitats of indigenous fauna;

(iv) loss or reduction of rare or threatened indigenous species populations or habitats.

Objective BIO.2 seeks to maintain indigenous biodiversity and enhance significant biodiversity. In the coastal environment, this is to be achieved by Policy BIO.3, which seeks to protect indigenous biodiversity from adverse effects in the coastal environment. Furthermore, Policy BIO.4 seeks to achieve a healthy functioning state, ensuring populations of native species are maintained, and making appropriate provision for the lawful operation of existing activities.

The following is noted:

- Big Glory Bay is classified as "non-outstanding" by Boffa Miskell and is identified as not being an ACSV under the Coastal Plan as set out in Section 3.6.
- The proposed changes have been modelled as being within the assimilative capacity of Big Glory Bay.
- No adverse effects on indigenous biodiversity have been identified as a result of the modelling undertaken by ADS in regard to the proposed changes, noting that Objective COAST.5 makes provision for aquaculture.
- The proposed changes are considered to maximise the appropriate operation of an existing activity, particularly in light of the Aquaculture Project for Southland goal discussed in Section 1.3.
- None of the adverse effects identified in Policy BIO.4 will occur as a result of the proposed changes.

5.3.2.2 Chapter 7 – Coast

Chapter 7 of the Southland RPS addresses the coastal environment, and contains five objectives and seven policies. Those relevant to the proposed changes are set out and analysed below.

> ***Objective COAST.2 – Activities in the coastal environment***
>
> *Infrastructure, ports, energy projects, aquaculture, mineral extraction activities, subdivision, use and development in the coastal environment are provided for and able to expand, where appropriate, while managing the adverse effects of those activities.*
>
> ***Objective COAST.3 – Coastal water quality and ecosystems***
>
> *Coastal water quality and ecosystems are maintained or enhanced.*
>
> ***Objective COAST.4 – Natural character***
>
> *The natural character of the coastal environment is restored, rehabilitated or preserved.*
>
> ***Objective COAST.5 – Aquaculture***
>
> *Recognise the contribution of aquaculture to the well-being of people and communities in appropriate locations while protecting coastal indigenous biodiversity by making provision for aquaculture in accordance with Policy*

BIO.3, protecting outstanding natural features, landscapes and natural character in accordance with Policy COAST.3 and avoiding, remedying, or mitigating other adverse effects.

Policy COAST.2 – Management of activities in the coastal environment

Ensure adequate measures or methods are utilised within the coastal environment when making provision for subdivision, use and development to:

(a) protect indigenous biodiversity, historic heritage, natural character, and natural features and landscape values;

(b) maintain or enhance amenity, social, intrinsic, ecological and cultural values, landscapes of cultural significance to tangata whenua and coastal dune systems;

(c) maintain or enhance public access; and

(d) avoid or mitigate the impacts of natural hazards, including predicted sea level rise and climate change.

Policy COAST.3 – Protection of the coastal environment

Ensure that subdivision, use and development activities:

(a) avoid adverse effects on areas of outstanding natural features and landscapes, and/or outstanding natural character;

(b) avoid significant adverse effects, and avoid, remedy or mitigate other adverse effects on other natural features and landscapes and/or natural character in the coastal environment;

Policy COAST.5 – Management of effects on coastal water quality and ecosystems

Avoid, remedy or mitigate adverse effects of land-based and marine activities on coastal water quality and its ecosystems.

The following is noted:

- The proposed changes will not result in a physical expansion of salmon farming in Big Glory Bay, they only provide for an increase in the allowable nitrogen from feed and as a consequence facilitate a greater tonnage of salmon farmed. Furthermore the changes have been made on the basis that they will be within the assimilative capacity of Big Glory Bay, such that the adverse effects are acceptable and can be managed (Objective COAST.2).
- The effect of the proposed changes on the water quality of Big Glory Bay has been modelled by ADS, and while the proposed changes will result in increased TAN and chlorophyll-*a*, this is within the assimilative capacity of Big Glory Bay. Furthermore, it is anticipated that some of the increase will be consumed by mussel farms (Objective COAST.3 and Policy COAST.5).

- Although not "natural", marine farming is well established in Big Glory Bay and authorised by existing resource consents, and has been since the 1980's. The proposed changes are not inconsistent with Objective COAST.4.
- The contribution of the proposed changes to the well-being of people and communities are set out in Section 5.3.1.2, Policy BIO.3 is analysed in Section 5.3.2.1, and Policy COAST.3 is analysed below (Objective COAST.5).
- The management and monitoring measures (both those currently in place and proposed changes) have regard to those matters set out in Policy COAST.2.
- The proposed changes will not result in adverse effects on natural features, landscapes or character in the coastal environment as the extent and location of the marine farm sites will be unchanged (Policy COAST.3).

5.3.3 Regional Coastal Plan for Southland

The Coastal Plan became operative on 16 March 2013, and contains 20 chapters. The chapters containing objectives and policies relevant to the proposed changes include:

- Section 5.4 – General Matters – Vegetation and Fauna;
- Section 5.6 – General Matters – Tangata Whenua O Murihiku;
- Section 7.3 – Coastal Water – Discharges; and
- Section 15 – Marine Farming.

5.3.3.1 Section 5.4 – General Matters – Vegetation and Fauna

> ***Objective 5.4.1.1 - Protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna***
>
> *To protect areas of significant indigenous vegetation and significant habitats of indigenous fauna within the coastal marine area*
>
> ***Objective 5.4.1.2 - Protect intrinsic values of ecosystems***
>
> *To protect the intrinsic values of ecosystems in the coastal marine area.*
>
> ***Policy 5.4.1.2 - Protection of habitats of important species***
>
> *Protect the habitats of species in the coastal marine area which are important for commercial, recreational, traditional or cultural purposes.*

The following is noted:

- Big Glory Bay is classified as "non-outstanding" by Boffa Miskell, and is identified in the Coastal Plan as not being an ACSV, nor it has not been assessed as providing significant habitats for indigenous fauna (Objective 5.4.1.1).
- The proposed changes have been assessed as being within the assimilative capacity of Big Glory Bay, such that they are not considered to be inconsistent with Objective

5.4.1.2 and Policy 5.4.1.2, which seek to protect intrinsic values and the habitats of species in the CMA.

5.3.3.2 Section 5.6 – General Matters – Tangata Whenua O Murihiku

> ***Objective 5.6.1 - Recognise values of Ngai Tahu***
>
> *To recognise and provide for cultural, spiritual and traditional values and uses of Ngai Tahu in the coastal marine area.*
>
> ***Objective 5.6.2 - Consultation with tangata whenua***
> *To ensure that consultation takes place with tangata whenua in appropriate circumstances.*

Objectives 5.6.1 and 5.6.2 of the Coastal Plan seek to recognise the values of Ngāi Tahu, and ensure consultation takes place where appropriate.

Due to the commercial sensitivity of this application, Sanford advised Ngāi Tahu of this application and provided a copy of it to Ngāi Tahu on 16 November 2017. Sanford's is committed to full consultation with Ngāi Tahu, consistent with their existing relationship. This will ensure the proposed changes can be undertaken in a manner that aligns with Objectives 5.6.1 and 5.6.2.

5.3.3.3 Section 5.8 – General Matters – Efficient Use of Natural and Physical Resources

> ***Objective 5.8.1 - Efficient use and development of natural and physical resources***
>
> *To provide for efficient use and development of natural and physical resources in the coastal marine area where adverse effects are avoided, remedied or mitigated.*
>
> ***Policy 5.8.1 - Efficient use and development of natural and physical resources***
>
> *To recognise and have regard for the efficient use and development of natural and physical resources in the coastal marine area, while having regard to the finite character of some natural and physical resources.*

Objective 5.8.1 and Policy 5.8.1 seek the efficient use and development of natural and physical resources in the coastal marine area. As outlined in Section 4 of this AEE, the proposed changes are within the assimilative capacity of Big Glory Bay. Therefore, they are considered to be an efficient use of the natural and physical resources in accordance with Objective 5.8.1 and Policy 5.8.1.

5.3.3.4 Section 7.2 – Coastal Water – Water Quality

> ***Objective 7.2.2.1 - Maintenance of coastal water quality***
>
> *To maintain the quality of coastal waters in those areas where ambient water quality is suitable for:*

a contact recreation;

b the growth of shellfish, the human consumption of which is not limited by pathogenic or chemical contamination;

c the health and vitality of aquatic ecosystems; and

d a fishery, including aquaculture, the produce of which is not limited for human consumption by pathogenic or chemical contamination:

...

Objective 7.2.2.1 seeks the maintenance of coastal water quality where it is suitable for a range of activities and to ensure a healthy aquatic ecosystem.

In this regard, the proposed changes have been modelled as being within the assimilative capacity of Big Glory Bay, such that the water quality of Big Glory Bay will be maintained for the activities listed in Objective 7.2.2.1, and to ensure a healthy aquatic ecosystem.

5.3.3.5 Section 7.3 – Coastal Water – Discharges

Policy 7.3.8.1.1 – Feeding of farmed species

Encourage the efficient application of nutrients discharged to the coastal marine area as a food source.

The proposed changes are an efficient application of nutrients as the current operational and food conversion ratio of the salmon being farmed will be maintained.

5.3.3.6 Section 15 – Marine Farming

Objective 15.1.1 - Avoid, remedy or mitigate any adverse effects

Avoid, remedy or mitigate any adverse effects of marine farming operations.

Policy 15.1.2 - New and changing activities in the same area

Where new and changing activities are proposed in areas within which there is a current occupation right, preference will be given to the current occupier provided that the effects of the new and/or changing activity are avoided, remedied or mitigated as required under the policies and rules of this Plan.

Policy 15.1.4 - Monitoring the effects of marine farming

To require monitoring of individual marine farm sites

The following is noted:

- The proposed changes are within the assimilative capacity of Big Glory Bay, and the monitoring proposed to ensure operations remain within this capacity are considered to ensure that adverse effects will be avoided (Objective 15.1.1).
- Sanford is the current occupier of the seven marine farm sites at which the proposed changes are located. As a current occupier and farmer of salmon in Big Glory Bay,

Sanford considers that preference should be given to it in regard to any additional nitrogen input from feed able to be assimilated within Big Glory Bay. The modelling and monitoring framework within the proposed changes will ensure effects are avoided, remedied or mitigated.

- Working with other users in Big Glory Bay, Sanford currently undertakes the Big Glory Bay Monitoring Programme (**Appendix A**) on an annual basis (**Volume 2, Appendix E and F**) at each site that is farming salmon. As part of the proposed changes, Sanford will undertake specific monitoring to ensure the effects of the proposed changes are in line with those modelled by ADS (Policy 15.1.4).

5.4 OTHER MATTERS

5.4.1 Ngāi Tahu Environmental Management Plan

The Ngāi Tahu EMP, Te Poha o Tohu Raumati[22], was developed to enable Ngāi Tahu to articulate their aspirations for managing natural resources within their takiwa. It provides a resource document for applicants who wish to consult with tangata whenua as part of lodging resource consent or other applications, and is therefore relevant to the proposed changes.

As set out in Section 4.7, section 3.6.15 of the EMP addresses aquaculture and marine farming. It notes that aquaculture is growing industry, but that in some areas there has been little control over where it should be allowed. While it does not seek to preclude marine farming, it does consider issues such as:

- Protection and recognition of customary rights;
- What is to be fed to the farmed species; and
- Impact on local biodiversity (introducing species from outside the area).

These issues have been addressed in Section 4.7, and given the environmental limits proposed the proposed changes are not considered to have an adverse effect regarding these.

Sanford has had, and continues to have an excellent relationship with Ngāi Tahu, and is committed to ensuring this remains the case.

[22] http://ngaitahu.iwi.nz/te-runanga-o-ngai-tahu/papatipu-runanga/kaikoura/environmental-management-plan/

5.5 PART 2 MATTERS

5.5.1 Section 5

The provisions of section 104 of the RMA are all *"subject to Part 2"*. The purpose of the RMA (section 5) is to promote the sustainable management of natural and physical resources. The Act defines *"sustainable management"* as:

> *(2) …managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while—*
>
> *(a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
>
> *(b) Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
>
> *(c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment.*

Applying section 5 of the RMA, and the other relevant matters under Part 2 of the Act, can involve the assessment of conflicting considerations – Including the positive and adverse effects associated with the use, development and protection of resources. In addition, the consideration of the matters in sections 5(2)(a) – (c) is often informed by the direction provided in the objectives and policies in the relevant statutory planning documents, which have been considered in detail in Section 5.3 of this AEE.

With respect to the requirement that any adverse effects of activities be avoided, remedied or mitigated, case law has established that it is not required that all effects be avoided, or that there is no net effect on the environment. Rather, section 5(2)(c) of the RMA is concerned about doing what is reasonably necessary, given the circumstances of the particular case, to lessen the severity of the effects of an activity. The approach to managing effects of the proposed changes is consistent with this requirement.

5.5.2 Section 6 – Matters of National Importance

Section 6 of the RMA identifies matters deemed to be of national importance. In exercising their functions and powers under the RMA, consent authorities must recognise and provide for the relevant matters. Section 6 states:

> ***6 Matters of national importance***
>
> *In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing the use, development, and protection of natural and physical resources, shall recognise and provide for the following matters of national importance:*
>
> *(a) The preservation of the natural character of the coastal environment (including the coastal marine area), wetlands, and lakes and rivers and their margins and the protection of them from inappropriate subdivision, use and*

development:

(b) The protection of outstanding natural features and landscapes from inappropriate subdivision, use and development:.

(c) The protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna:

(d) The maintenance and enhancement of public access to and along the coastal marine area, lakes and rivers:

(e) The relationship of Maori and their culture and traditions with their ancestral lands, water, sites, wahi tapu, and other taonga:

(f) The protection of historic heritage from inappropriate subdivision, use, and development:

(g) the protection of protected customary rights:

(h) the management of significant risks from natural hazards.

Section 6(a)

The preservation of natural character of the coastal environment and its protection from inappropriate use and development is a matter of national importance under section 6(a) of the RMA. Of particular note when considering the proposed changes:

- The definition of what constitutes natural character has evolved over the period since the enactment of the RMA. It has become generally accepted that natural character derives from the presence of natural elements, biophysical features and perceptual aspects;
- Protection in a section 6(a) context means keeping safe from injury or harm, rather than absolute protection, prevention or prohibition; and
- An assessment of 'appropriateness' in a section 6(a) context must be made on a case by case basis in terms of the values that contribute to the natural character of a site.

It is noted that the marine farms are not located in an area of high or outstanding natural character and have been part of the Big Glory Bay landscape for more than 25 years. Also the effects on natural character are already authorised by existing resource consents and are not being changed by this application.

Section 6(b)

Section 6(b) seeks to protect outstanding natural features and landscapes from inappropriate use and development. As already noted in this AEE, Big Glory Bay is classified as "non-outstanding" by Boffa Miskell, and is identified as not being an ACSV under the Coastal Plan, nor is it considered that aquaculture development in Big Glory Bay is out of character with the rest of the bay such that it would constitute an inappropriate use or development. Furthermore, the effects on natural character are already authorised by existing resource consents and are not being changed by this application.

Section 6(c)

Section 6(c) of the RMA seeks to protect areas of significant indigenous vegetation and significant habitats of indigenous fauna.

As previously noted, Big Glory Bay is classified as “non-outstanding” by Boffa Miskell, and is identified as not being an ACSV however, it is acknowledged that marine mammals that are “Nationally Critical”, Vulnerable” or “Endangered” may occur in Big Glory Bay, but it is not an important habitat in this regard.

Based on the effects assessment in Section 4 of this AEE, the proposed changes will not affect the protection of areas that are significant habitats of indigenous fauna. Habitat exclusion, and underwater noise are a negligible issue in Big Glory Bay, and exclusion is not an issue regarding the proposed changes as these effects are already authorised by existing resource consents and are not being changed by this application.

With respect to potential effects on birds, Section 3.7.4 identifies three species of shag, three species of penguin and two species of gull that occur around Stewart Island. Big Glory Bay is not identified as being a particularly important area to any of these species. The proposed changes will not have an effect on any of these species.

Section 6(d)

Section 6(d) relates to the maintenance and enhancement of public access to, and along, the CMA.

Section 4.5 of this AEE discusses the potential effects of the proposed changes on navigation and recreation in Big Glory Bay. It notes that the extent and location of the marine farms will be unchanged.

Public access in and around the marine farm sites will not be changed by the proposed changes. The public will continue to be excluded, with access only being possible during times of fallow or when mussels are being farmed.

Given the above, any potential adverse effects on navigation and public access will be negligible or unchanged.

Section 6(e)

Section 6(e) of the RMA refers to the relationship of Māori and their culture and traditions with their ancestral lands, water, sites, wahi tapu and other taonga.

Section 3.8 of this AEE sets out the cultural setting of Big Glory Bay. As outlined in Section 4, the proposed changes are within the assimilative capacity of Big Glory Bay and will not give rise to increased effects beyond those currently occurring. Ngāi Tahu’s EMP has been addressed in Sections 4.7 and 5.4.1.

Due to the commercial sensitivity of this application, Sanford advised Ngāi Tahu of this application and provided a copy of it to Ngāi Tahu on 16 November 2017. Sanford's is committed to full consultation with Ngāi Tahu, consistent with their existing relationship. This will ensure the proposed changes can be undertaken in a manner that aligns with section 6(e) of the RMA. Sanford has had, and continues to have an excellent relationship with Ngāi Tahu, and is committed to ensuring this remains the case.

Section 6(f)

Section 6(f) is not relevant.

Section 6(g)

Section 6(g) of the RMA relates to the protection of protected customary rights.

Ngāi Tahu is currently engaged with the Crown for recognition of a customary marine title for that area shown in Figure 26, although this is not yet finalised. In any event this application does not involve the use of any additional areas of Big Glory Bay beyond those already subject to existing resource consents.

Sanford has recognised Ngāi Tahu's application (along with applications by Rihari Dargaville and Cletus Paul) in the preparation of this consent though notifying and seeking their views on the application in accordance with section 62 of the Marine and Coastal Area (Takutai Moana) Act. Sanford will consider any response received.

Section 6(h)

Section 6(h) is not relevant to the proposed changes.

5.5.3 Section 7 – Other Matters

Section 7 of the RMA identifies additional matters that consent authorities shall have particular regard to when exercising their functions and powers under the Act. With respect to the proposed changes, the following matters in section 7 of the RMA are considered to be relevant:

(a) Kaitiakitanga:
(aa) The ethic of stewardship:
(b) The efficient use and development of natural and physical resources:
(ba) …
(c) The maintenance and enhancement of amenity values:
(d) Intrinsic values of ecosystems:
(e) [Repealed]
(f) Maintenance and enhancement of the quality of the environment;
(g) Any finite characteristics of natural and physical resources:
…

Sections 7(a) and (aa)

Sections 7(a) and (aa) of the RMA require particular regard to given to kaitiakitanga and the ethic of stewardship.

As above in respect of section 6(e) of the RMA, the views of Ngāi Tahu have been sought, and Sanford intends to further engage with Ngāi Tahu in order to ensure they can continue to exercise kaitiakitanga.

Section 7(b)

Section 7(b) of the RMA is concerned with the efficient use and development of natural and physical resources.

The proposed changes are considered to result in the most efficient use of natural and physical resources as they will maximise the production of salmon in Big Glory Bay, whilst staying within the assimilative capacity of Big Glory Bay.

Section 7(c)

The potential effects of the proposed changes on amenity values will be negligible as they will result in minimal operational changes at the sites.

Sections 7(d), (f) and (g)

Sections 7(d), (f) and (g) of the RMA relate to the intrinsic values of ecosystems, the quality of the environment, and the finite characteristics of natural and physical resources. Based on the conclusions outlined in Section 4 of this AEE, particular regard has been given to the intrinsic values of ecosystems and to the maintenance of the quality of the environment in the modelling of the proposed changes, and the monitoring and management regime currently in place at the marine farm sites.

5.5.4 Overall Conclusion Regarding Part 2

There are two general elements of sustainable management in the context of Section 5 of the RMA that must be considered when assessing an application. They are whether a proposal will enable people and communities to provide for their social, economic and cultural wellbeing, and (at the same time) whether the environment will be safeguarded through the avoidance, remediation or mitigation of adverse effects.

The proposed changes will contribute towards significant and demonstrable positive effects in terms of sustaining the social and economic wellbeing of the local and regional community.

In addition, extensive consideration has been given to the natural and physical resource values of Big Glory Bay in developing the proposed changes, which have been designed to be within its assimilative capacity. Adverse effects will be avoided, remedied or mitigated through the imposition of environmental limits and monitoring to ensure compliance with these.

Overall, the proposed changes will promote the sustainable management of natural and physical resources in accordance with Part 2 of the RMA.

6. CONCLUDING STATEMENT

Sanford is applying to increase the nitrogen allowance at their Big Glory Bay salmon farms to a combined 659 tonnes/year, along with site specific limits. The proposed changes will significantly contribute to the Aquaculture for Southland Projects goal of salmon production in Southland reaching 25,000 tonnes/year by 2020, which will have significant demonstrable positive effects in terms of sustaining the social and economic wellbeing of the local and regional community.

Extensive hydrodynamics and flushing, water quality and depositional modelling has been undertaken by ADS to determine the maximum assimilative capacity of Big Glory Bay regarding nitrogen loading from feed. The proposed changes here have been designed to ensure they do not exceed the assimilative capacity of Big Glory Bay.

A

APPENDIX A

Big Glory Bay Monitoring Programme

APPENDIX ONE
Big Glory Bay Monitoring Programme

1. The consent holder shall monitor the effects of the marine farming activities on the seabed, as follows:

(a) (i) except for LI339, LI340, MF249, MF250, MF271, MF272 and MF365, monitoring of the seabed at representative locations under the marine farm site shall be undertaken at least once prior to 1 January 2025.

Note: It is the Council's intention that the Programme shall monitor at least two marine farm sites per year within the bay from the following marine farm sites LI149, LI315, LI316, LI317, LI318, LI319, LI320, LI321, LI322, LI323, LI324, LI325, LI337, LI338, LI342, LI366, LI418, LI461, LI474, LI475, MF244, MF245, MF246, MF247, MF248, MF273, MF274, MF275 and MF326 so each site is monitored at least once prior to 1 January 2025.

(ii) an exception to Clause 1(a)(i) is if the marine farm site is actively farming salmon at the site, then monitoring of the seabed under the salmon cage as close as possible, and at 50 metres and 100 metres from that salmon cage shall be undertaken annually.

If the marine farm site is fallowed, the monitoring of the seabed shall be undertaken at five years, 10 years and 15 years from the date of the last annual monitoring occurring at the site. If the marine farm site is reactivated to farm salmon then the annual monitoring regime recommences and replaces this fallowing monitoring regime.

(iii) in addition to Clause 1(a)(ii), no longer than one year prior to the marine farm site erecting structures to farm salmon, monitoring of the seabed under where the salmon cages are to be located as close as possible, and at 50 metres and 100 metres from where salmon cage are be located shall be undertaken. The monitoring report shall be furnished to the Council's Director of Environmental Management at least three months prior to the marine farm site erecting structures to farm salmon.

Note: this condition also applies to the site if it had been vacated of structures and stock for the purpose of fallowing the seabed. This condition does not apply to fallowing certain sections of the marine farm site by moving structures around within the same site.

(iv) in addition to Clause 1(a)(i), monitoring of the seabed at two control sites identified in the Programme and approved, in writing, by the Council's Director of Environmental Management. The monitoring shall occur every year for the first three years, then once every three years thereafter.

(b) the samples will be analysed for the following to assess the sediment quality:

- sediment colour, including providing a colour photograph of the sediment sample;
- depth of the oxygenated layer below the sediment surface;
- occurrence of hydrogen sulphide;

- sediment texture and grain size;
- total organic carbon content;
- infaunal and epifauna community composition; and
- zinc and copper trace metal levels pursuant to Clause 1(a)(ii) and (iii) listed above when relates to salmon farming.

2. The consent holder shall monitor the effects of the marine farming activities on the water quality, as follows:

(a) (i) monitoring of the water column shall be undertaken monthly for the first two years, commencing from 1 July 2011, by taking samples at four sites within Big Glory Bay and two control sites inside the bay, at a depth of 5 metres, as identified in the Programme and approved, in writing, by the Council's Director of Environmental Management.

(ii) after the first two years outlined in clause 2(a)(i), monitoring of the water column shall be undertaken three times during the period of 1 November to 30 June each year and once during the period of 1 July to 31 October each year at four sites within Big Glory Bay and two control sites inside the bay, at a depth of 5 metres, as identified in the Programme and approved, in writing, by the Council's Director of Environmental Management.

(b) the water quality samples will be analysed for the following:

- water temperature;
- chlorophyll *a;*
- vertical secchi depth; and
- dissolved oxygen.

B

APPENDIX B

Schedule 4 Requirements

Schedule 4: Clause 2 – Information required in all applications.

		Information Requirement	Location Addressed in AEE
(1)		An application for a resource consent for an activity (the activity) must include the following:	
	(a)	a description of the activity:	See Section 2.
	(b)	a description of the site at which the activity is to occur:	See Section 3.
	(c)	the full name and address of each owner or occupier of the site:	Her Majesty the Crown.
	(d)	a description of any other activities that are part of the proposal to which the application relates:	Not applicable.
	(e)	a description of any other resource consents required for the proposal to which the application relates:	Not applicable.
	(f)	an assessment of the activity against the matters set out in Part 2:	See Section 5.
	(g)	an assessment of the activity against any relevant provisions of a document referred to in section 104(1)(b).	See Section 5.
(2)		The assessment under subclause (1)(g) must include an assessment of the activity against—	
	(a)	any relevant objectives, policies, or rules in a document; and	See Section 5.
	(b)	any relevant requirements, conditions, or permissions in any rules in a document; and	See Section 5.
	(c)	any other relevant requirements in a document (for example, in a national environmental standard or other regulations).	See Section 5.
(3)		An application must also include an assessment of the activity's effects on the environment that	
	(a)	includes the information required by clause 6; and	See table below.
	(b)	addresses the matters specified in clause 7; and	See table below.
	(c)	includes such detail as corresponds with the scale and significance of	This assessment of environmental effects

Information Requirement	Location Addressed in AEE
the effects that the activity may have on the environment.	draws from modelling and monitoring reports that directly address the proposed changes and is also informed by assessments previously undertaken in association with marine farming activities in Big Glory Bay.

Schedule 4: Clause 3 – Additional information required in some applications.

Information Requirement	Location Addressed in AEE
An application must also include any of the following that apply:	
(a) if any permitted activity is part of the proposal to which the application relates, a description of the permitted activity that demonstrates that it complies with the requirements, conditions, and permissions for the permitted activity (so that a resource consent is not required for that activity under Section 87A(1)):	No permitted activities are relied upon.
(b) if the application is affected by section 124 or 165ZH(1)(c) (which relate to existing resource consents), an assessment of the value of the investment of the existing consent holder (for the purposes of section 104(2A)):	Not applicable.
(c) if the activity is to occur in an area within the scope of a planning document prepared by a customary marine title group under section 85 of the Marine and Coastal Area (Takutai Moana) Act 2011, an assessment of the activity against any resource management matters set out in that planning document (for the purposes of section 104(2B)).	Not applicable.

Schedule 4: Clause 6 – Information required in assessment of environmental effects.

Information Requirement	Location Addressed in AEE
(1) An assessment of the activity's effects on the environment must include the following information:	
(a) if it is likely that the activity will result in any significant adverse effect on the environment, a description of any possible alternative locations or methods for undertaking the activity:	As outlined in Section 4 the proposed changes are within the assimilative capacity of Big Glory Bay.
(b) an assessment of the actual or potential effect on the environment of the activity:	See Section 4.
(c) if the activity includes the use of hazardous substances and installations, an assessment of any risks to the environment that are likely to arise from such use:	Not applicable.
(d) if the activity includes the discharge of any contaminant, a description of	See Sections 2 - 4.
(i) the nature of the discharge and the sensitivity of the receiving environment to adverse effects; and	
(ii) any possible alternative methods of discharge, including discharge into any other receiving environment	
(e) a description of the mitigation measures (including safeguards and contingency plans where relevant) to be undertaken to help prevent or reduce the actual or potential effect	See Section 4.7.
(f) identification of the persons affected by the activity, any consultation undertaken, and any response to the views of any person consulted:	Under section 62 of the Marine and Coastal Area (Takutai Moana) Act 2011, Sanford are required to notify and seek the view of Te Rūnanga o Ngāi Tahu as a Customary Marine Title Group. Sanford notified Te Rūnanga o Ngāi Tahu of this application on 16 November 2017, but did not receive an official response with regard to their views at this time. Should these views be forthcoming, Sanford will provide Environment Southland with the views.
(g) if the scale and significance of the activity's effects are such that monitoring is required, a description of how and by whom the effects will be monitored if the activity is approved:	

Information Requirement			Location Addressed in AEE
	(h)	if the activity will, or is likely to, have adverse effects that are more than minor on the exercise of a protected customary right, a description of possible alternative locations or methods for the exercise of the activity (unless written approval for the activity is given by the protected customary rights group).	
(2)	A requirement to include information in the assessment of environmental effects is subject to the provisions of any policy statement or plan.		See Section 5.
(3)	To avoid doubt, subclause (1)(f) obliges an applicant to report as to the persons identified as being affected by the proposal, but does not—		
	(a)	oblige the applicant to consult any person; or	
	(b)	create any ground for expecting that the applicant will consult any person.	

Schedule 4: Clause 7 – Matters that must be addressed by assessment of environmental effects.

Information Requirement			Location Addressed in AEE
(1)	An assessment of the activity's effects on the environment must address the following matters:		
	(a)	any effect on those in the neighbourhood and, where relevant, the wider community, including any social, economic, or cultural effects:	See Section 4.
	(b)	any physical effect on the locality, including any landscape and visual effects	See Section 4.
	(c)	any effect on ecosystems, including effects on plants or animals and any physical disturbance of habitats in the vicinity	See Section 4.
	(d)	any effect on natural and physical resources having aesthetic, recreational, scientific, historical, spiritual, or cultural value, or other special value, for present or future generations	See Section 4.

Information Requirement		Location Addressed in AEE
	(e) any discharge of contaminants into the environment, including any unreasonable emission of noise, and options for the treatment and disposal of contaminants	See Section 4.
	(f) any risk to the neighbourhood, the wider community, or the environment through natural hazards or the use of hazardous substances or hazardous installations.	Not applicable.
(2)	The requirement to address a matter in the assessment of environmental effects is subject to the provisions of any policy statement or plan	See Section 5.

SANFORD LIMITED

BIG GLORY BAY SALMON FARMS

Volume 2

16 November 2017

LIST OF APPENDICES

A: Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume I – Summary Of Findings, Aquadynamic Solutions Sdn Bhd, October 2017.

B: Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume II – Hydrodynamic Modelling and Flushing, Aquadynamic Solutions Sdn Bhd, October 2017.

C: Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume III – Water Quality, Aquadynamic Solutions Sdn Bhd, November 2017.

D: Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume IV – Seabed Deposition, Aquadynamic Solutions Sdn Bhd, October 2017.

E: Big Glory Bay Benthic and Water Quality Sampling 2016, Aquadynamic Solutions Sdn Bhd, September 2016.

F: Big Glory Bay Benthic and Water Quality Sampling 2016/2017, Aquadynamic Solutions Sdn Bhd, May 2017.

A

Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume I – Summary Of Findings, Aquadynamic Solutions Sdn Bhd, October 2017.

Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand

Volume I – Summary of Findings

October 2017

Report prepared by

Aquadynamic Solutions Sdn Bhd (ADS)

For

Sanford Limited

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List of Figures

1 INTRODUCTION

Currently Sanford limited is growing King Salmon across a number of leases in Big Glory Bay, Stewart Island, New Zealand (**Figure 1**). ADS have been requested to undertake a carrying capacity study of the bay in order to provide an estimation of the maximum sustainable Nitrogen (N) input by fish farming activities. Particular focus has been given to potential seabed deposition impacts and the impact of the N release into the surrounding water body.

This assessment will assist both Sanford, and relevant regulators in understanding potential environmental impacts of an increase in fish farming on the surrounding environment.

To calculate an estimate of a maximum carrying capacity within Big Glory Bay, a number of numerical modelling tools have been utilised along-side several production scenarios (In the form of N release) to predict the environmental impacts of expanding production.

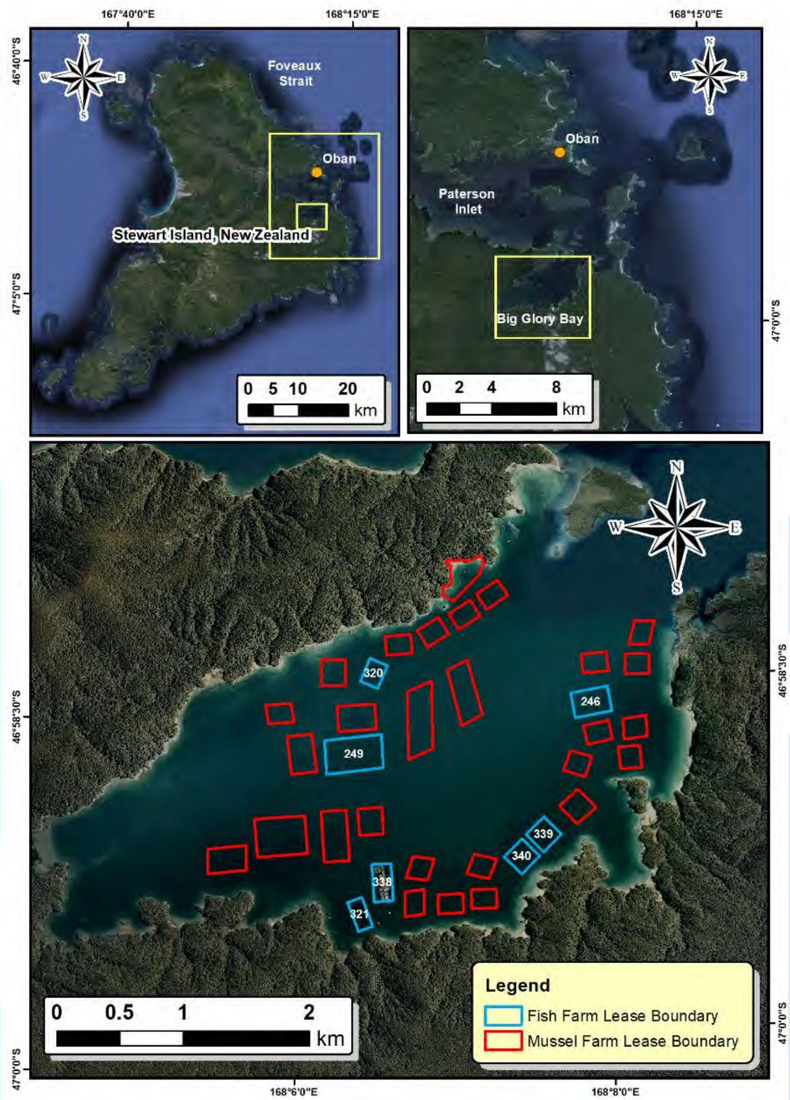

Figure 1 –Overview of Big Glory Bay and Paterson Inlet on Stewart Island, South Island, New Zealand.

1.1 Reporting Structure

ADS have divided the report structure into 5 short volumes, with the present volume (Volume I) summarising the results of the entire carrying capacity study.

The 4 volumes are as follows:

- Volume I - Summary Report
- Volume II - Hydrodynamic Modelling and Flushing
- Volume III - Water Quality

- Volume IV - Seabed Deposition

1.2 Existing Environmental Conditions

Big Glory Bay is located on the east side of Stewart Island, New Zealand and shares a channel with Paterson Inlet connecting it to Foveaux Strait. The bay is about 12km^2 in area and the mouth of the bay is 700 meters wide. Big Glory Bay is sheltered and well protected from ocean derived waves.

Bathymetry in Big Glory Bay is comparatively flat, and the bay has an average depth of approximately 20 meters. Shallow rocky reefs lie along the northern and southern sides of the bay. Along the western shoreline there is a flat shallow area (<6m deep and approximately 2.5km^2) which appears to have been formed by riverine deposition. Currents within the bay are low (generally less than 5cm s^{-1}) and stronger towards the mouth of the bay.

Oxygen levels, a requirement for life and healthy environmental conditions, are generally observed between 6 and 9 mg L^{-1} depending on the season (ADS, 2016 & 2017).

Over the last 18 months, Total Ammonia Nitrogen (TAN) measurements have been collected as part of Sanford's monthly water quality monitoring program. The values display a clear seasonal cycle, with average values ranging between below the detection limit (< 10 µg L^{-1}) and 38 µg L^{-1} in spring/summer, and between 15.5 µg L^{-1} and 58.5 µg L^{-1} in autumn/winter (**Figure 2**).

These values are similar to values previously reported in various documents and summarized in the literature review of DHI, 2010. A mussel monitoring programme (**Stenton-Dozey and Brown, 2010**) showed TAN values ranging between below detectable level (< 1 µg L^{-1}) and 81 µg L^{-1}; further back in time, **Pridmore (1995)** recorded available Nitrogen (equivalent to the sum of TAN and Nitrate, *i.e.* nitrogen available for plankton growth) between 60 µg L^{-1} in summer and close to 200 µg L^{-1} at the end of winter.

Estimated Total Nitrogen (which does not include Dissolved Organic Nitrogen) calculated from the same recent ongoing monitoring dataset has been observed to vary month to month from 20 to 170 µg L^{-1} (**Figure 3**). This is similar to observations made in the 1980's and 1990's.

For the same period (2016-2017), average monthly chlorophyll-a values have varied between 0.3 µg L^{-1} and 6.5 µg L^{-1} (**Figure 4**). In the past, the mussel monitoring programme has shown summer chlorophyll-a values ranging between 0.4 and 6.7 µg L^{-1}, again a very similar range. In **Pridmore, 1992**, chlorophyll-a values of 9 µg L^{-1} were reported in 1989.

Overall, both from a nutrient and a chlorophyll-a (proxy for algae biomass) perspective, the environmental conditions appear to have remained similar if not identical for nearly 30 years, despite the significant increases in farmed fish biomass. A potential reason for this is apparent in the Total N cycle presented in **Figure 3**. During summer, it appears that something is removing N from the system. Based on literature and a simple N budget, it seems quite likely that the difference is due to farmed mussels present in large quantities in Big Glory Bay. Missing nutrients correspond to the timing of the mussels' largest growth (when water temperatures are high). This is an important point moving forward in attempting to determine the likely carrying capacity of Big Glory Bay.

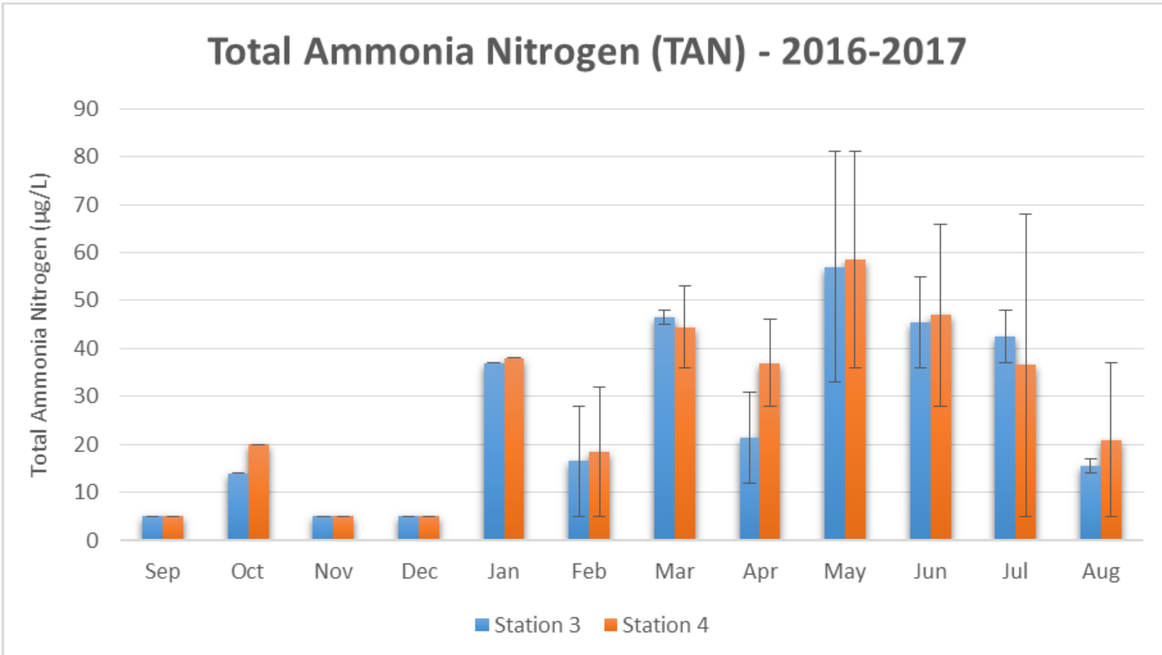

Figure 2 - Total Ammonia Nitrogen (TAN) concentrations in 2016-2017 from Sanford monthly monitoring.

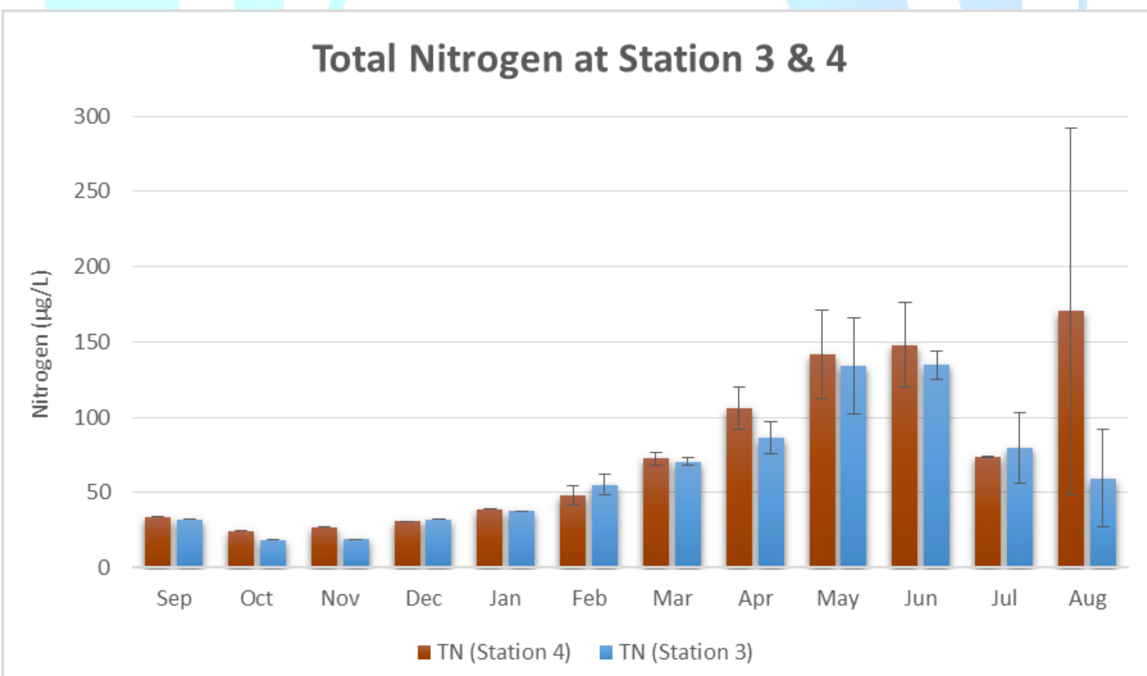

Figure 3 - Total Nitrogen (sum of TAN, nitrate and Particulate Nitrogen). Note: the estimated Total Nitrogen does not include Dissolved Organic Nitrogen (DON) for which measurements are not available.

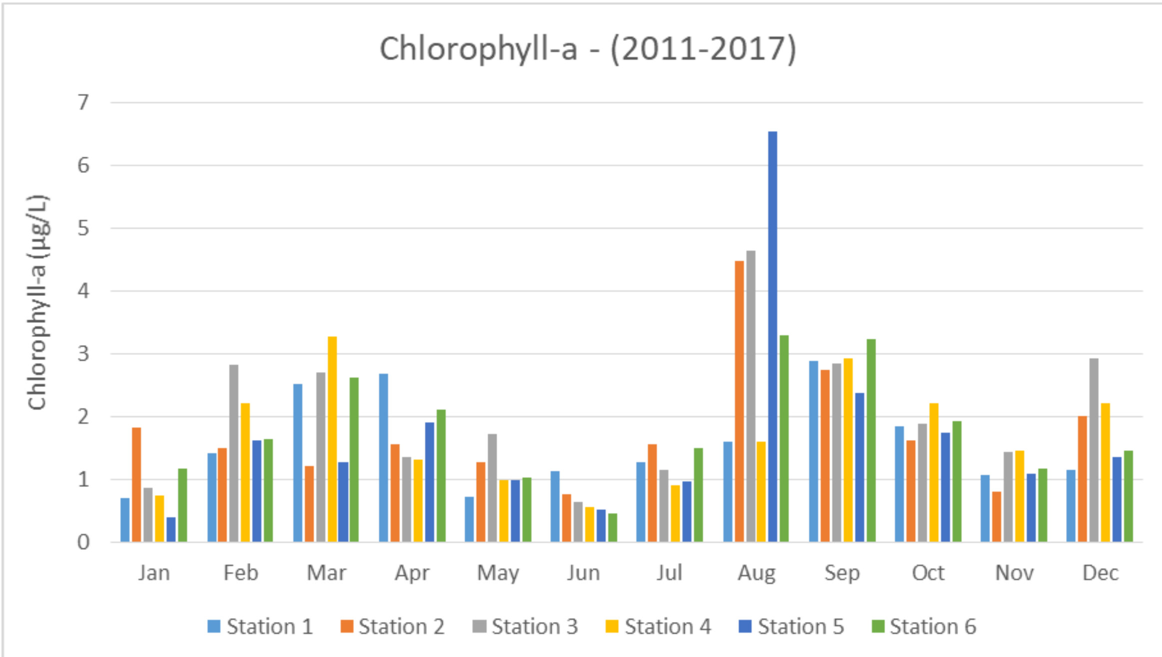

Figure 4 – Monthly averaged Chlorophyll-a concentrations collected as part of Sanford's monthly water quality monitoring program.

2 METHODS

This carrying capacity assessment relies heavily on a combination of numerical modelling techniques alongside *in-situ* field measurements. Field measurements including ADCP current meter speed and direction data along with water column nutrient measurements were used to calibrate the numerical models.

The modelling software predominately used in this study is DELFT3D (Deltares 2017 [1]). Delft is a suite of modelling tools that have undergone over 30 years of development. DELFT3D offers the flexibility to develop numerical models of different dimensions (2D, 3D) and has a number of modules to answer almost any water related question (**Figure 5**).

Further details on the modelling software are provided below and/or are found in Volumes II, II and IV of this study.

[1] DELFT3D: URL https://oss.deltares.nl/web/delft3d/).

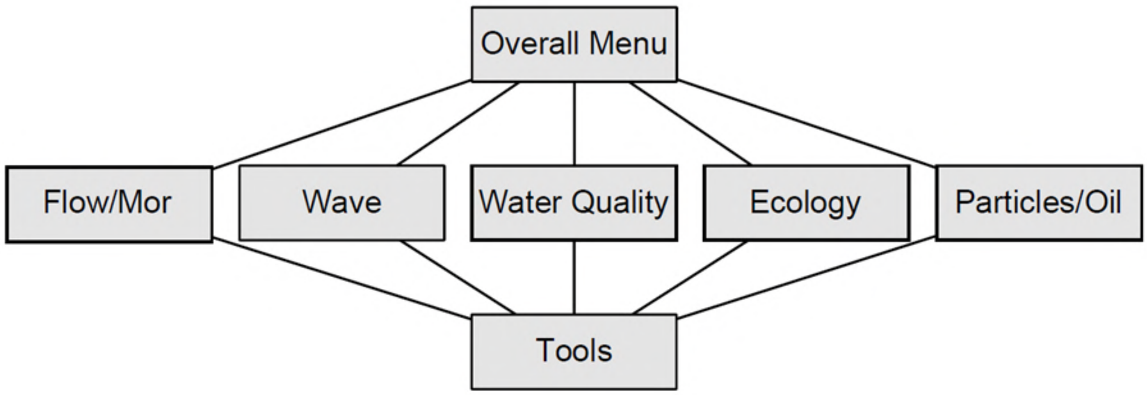

Figure 5 - DELFT3D Modules

2.1 Hydrodynamic Modelling

The hydrodynamics model is used to simulate water movement within Big Glory Bay and across the entire model domain. The hydrodynamic model was run for a period of one year to allow for full seasonal effects. Results of these simulations were also used to drive water movement within the water quality module and to determine flushing.

A 2D regional model was constructed to cover the waters around Stewart Island (**Figure 6**). This model included regional tidal, wind, and current information provided by international recognised global models such as HYCOM, GFS and TXPO. The regional model was used to transfer information to a smaller, but more detailed, local three-dimensional model that included the waters within Big Glory Bay and its immediate surrounds (**Figure 6**). Unlike the regional model, the local model can be used to account for both thermal stratification and variations in current speed and direction with depth. The local model has a horizontal resolution of 40 meters in Big Glory Bay and is comprised of 10 vertical layers, with higher vertical resolution at the surface.

The hydrodynamic model was calibrated against current speed and direction collected at two locations within the bay and water level from tidal harmonics in Paterson Inlet (**Figure 7**).

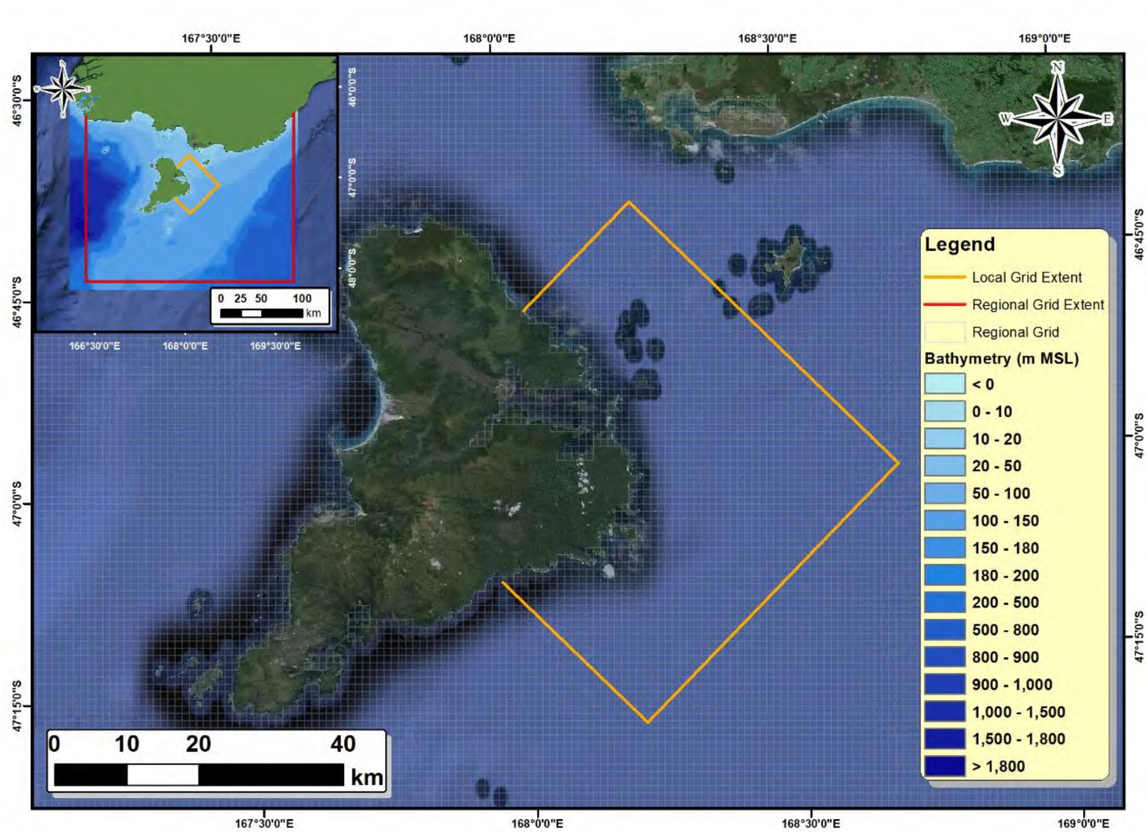

Figure 6 - Extent of regional and local grids, with regional bathymetry.

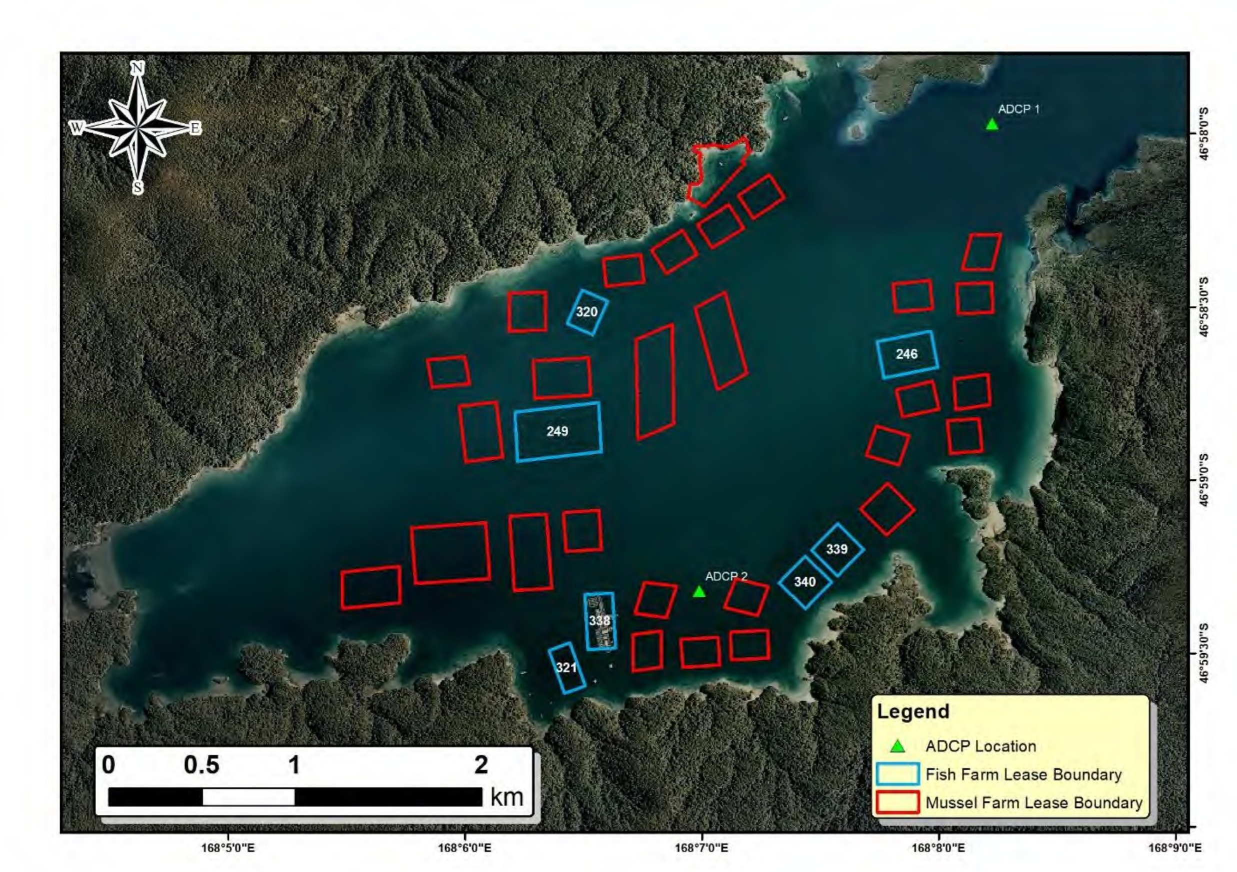

Figure 7 - Location of the two ADCP used for model calibration and validation.

Examples of both the model calibration and validation are provided below (**Figure 8-Figure 10**). For simplicity, both time periods are shown on the one plot for water level and current speed at ADCP (Acoustic Doppler Current Profiler) 1 & 2.

Over all there is a good match between the measured data and model results. Subsequently the model is fit for purpose. Further details of the calibration and validation process can be found in Volume II.

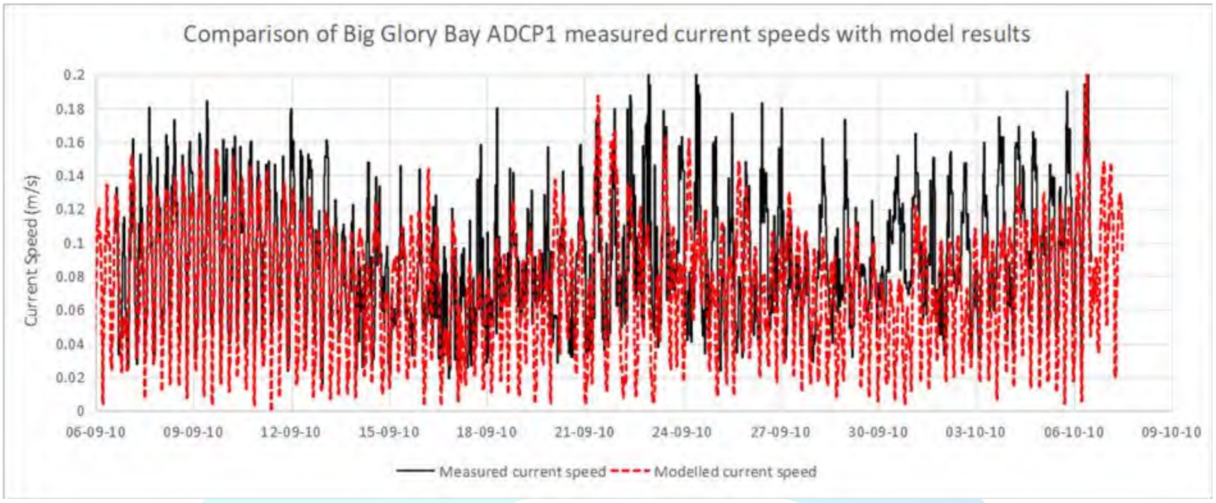

Figure 8 - Current speed comparison at ADCP1 between measured data and modelled results (entire record). Showing model calibration and validation periods on one plot.

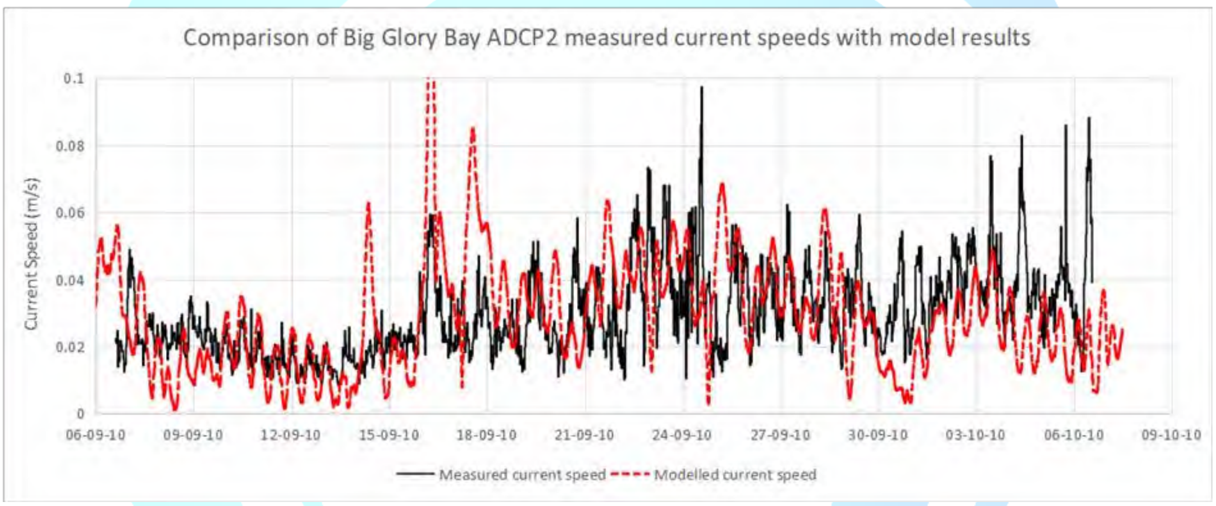

Figure 9 - Current speed comparison at ADCP2 between measured data and modelled results (entire record). Showing model calibration and validation periods on one plot.

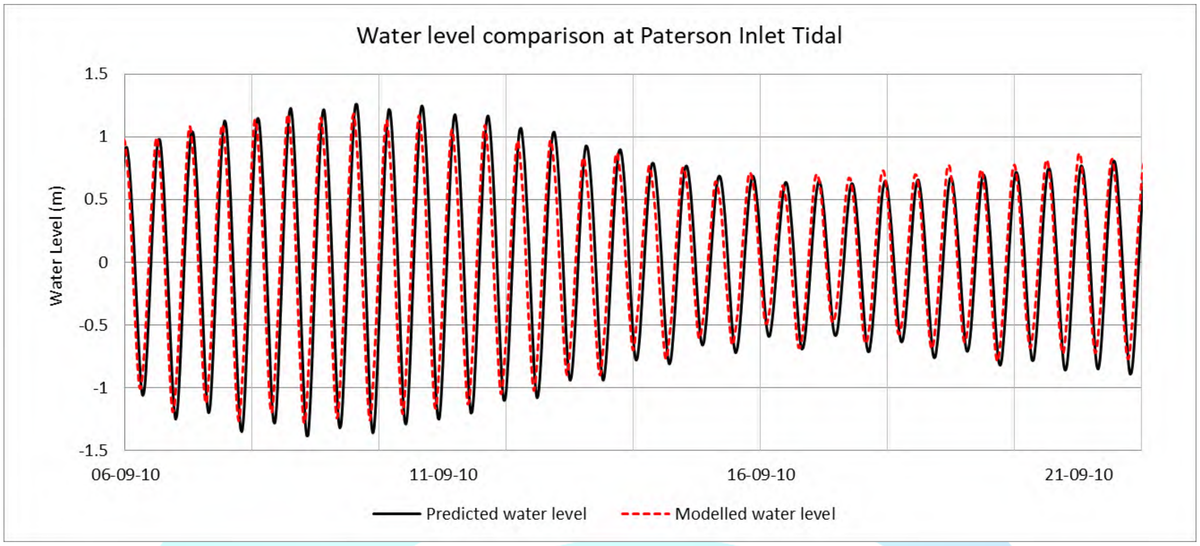

Figure 10 - Comparison of water level at Paterson Inlet tidal station between predicted tide and modelled results.

2.2 FLUSHING MODELLING

Flushing is defined as the average time it takes a conservative (not decaying over time due to biology or chemistry) substance to leave a water body (time it takes to exchange the water within Big Glory Bay).

Flushing time is important as this provides an indication of how rapidly oxygen and nutrients will be exchanged within the farming area and the ocean. Faster flushing will result in more rapid diluting of nutrient releases (*i.e. Total Ammonia Nitrogen* for solute fish waste) within the bay.

In this part of the study, a conservative tracer was used to represent the entire water column of Big Glory Bay. The hydrodynamic model was then run to calculate how long this tracer takes to be exchanged (flushed out) with water from outside of the bay. Given that there may be seasonal differences in the flushing time, four flushing simulations were run to represent each season (Spring, Summer, Autumn and Winter). Each simulation was run for a period of 90 days

Previous attempts to estimate the retention time of Big Glory Bay by Rutherford et al. (1988) mentioned "10-13 days during light winds (<5 m s^{-1}) to 7-9 days during moderate winds (5-10 m s^{-1})". These estimates were obtained solely on the basis of simple desktop calculations using the tidal prism and with the assumption that water leaving the bay does not return. The new estimates presented in this study correspond to more robust calculations based on physical equations and a calibrated three dimensional model.

2.3 WATER QUALITY MODELLING

DELFT3D's water quality module was used to predict the impacts of the farm-derived release of TAN, its impact on chlorophyll a and the consumption of dissolved oxygen as a result of expanded farming activities in Big Glory Bay. To accomplish this, a tracer approach was used which focuses solely on the excess loadings from the farms, while foregoing the natural background concentrations. This approach was used during the New Zealand King Salmon new lease application in the Marlborough Sounds.

New water column data have been collected in Big Glory Bay by Sanford, monthly since February 2015. These data are part of Sanford's internal environmental monitoring program. This dataset provides more than a year of dissolved nutrient and particulate information from 4 stations (**Figure 11**) within the bay.

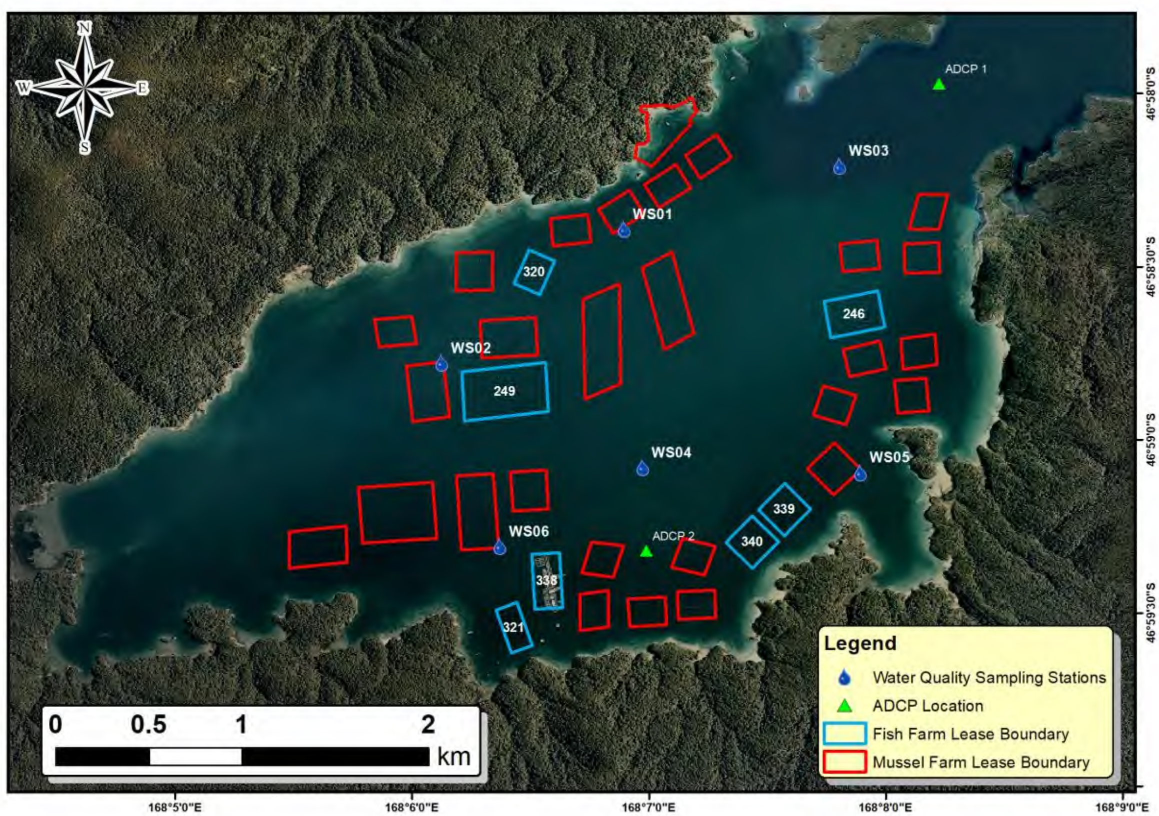

Figure 11 – Sanford water quality sampling locations from February 2015 until present.

Key results were predictions of dissolved oxygen, TAN, and chlorophyll a around farms and within Big Glory Bay as a whole.

In order to test the robustness of the tracer model, a baseline scenario corresponding to existing farming operations was undertaken.

The model was run for an entire year and also included associated variations in the farming schedule. Model results were compared to measured *in-situ* results (**Figure 12**).

Following model calibration runs, two future scenarios were modelled:

1. **Mid-level expansion Scenario:** Proposed scenario representative of farming releases of TAN under conditions just below the maximum carrying capacity. Total TAN release in this scenario into the system totalled 358.28 tons which corresponded to a feed input of 621.4 tons. The baseline oxygen drawdown was set to 8.85 tons day^{-1}.

2. **Higher-level expansion Scenario:** Proposed scenario representative of the upper limit of farming TAN release according to the current assessment of Big Glory Bay's carrying capacity. Total TAN release in this scenario into the system totalled 381.2 tons which corresponded to a feed input of 659 tons. The baseline oxygen drawdown was set to 9.315 tons day^{-1}.

All water quality modelling scenarios were simulated for one year.

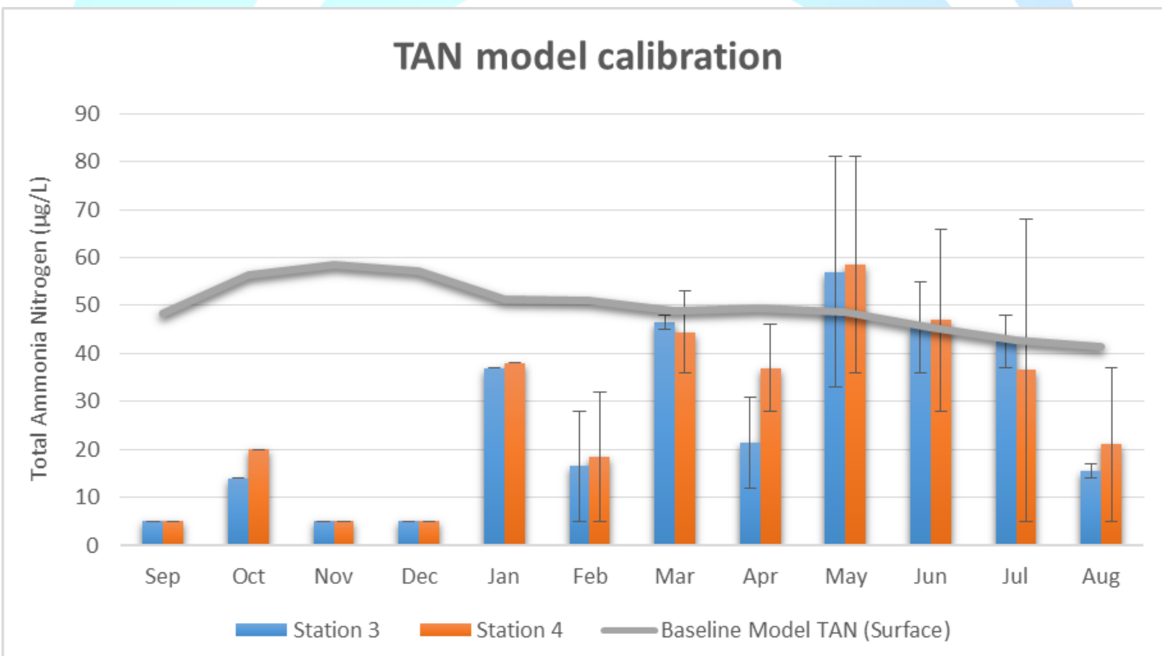

Figure 12 – Comparison between the measured TAN concentrations from the Sanford monitoring and the conservative tracer model results (model results are monthly averaged).

2.4 Seabed Deposition Modelling

Depositional footprints around farm leases were predicted using the software newDEPOMOD, a widely used and internationally recognized (**SEPA 2005, ASC 2012**) particle tracking model designed for predicting salmon farm deposition (**Cromey et al. 1998, Thetmeyer et al. 2003, Cromey and Black 2005, Cook et al. 2006, Magill et al. 2006**).

This software is a stand-alone package, meaning that it does not interface with DELFT3D, as described in Section 2.3 - Water Quality Modelling above. Instead, newDEPOMOD incorporates the same sources of data describing local bathymetry and current fields into its own particle tracking features.

In this modelling study six scenarios were modelled across three farm sites. The three sites, Lease 246, 320 and 339 were chosen based on their location and existing use. Lease 246 is located near the mouth of the bay and has the best flushing. This lease is also the existing grower farm in the bay. Two scenarios were modelled for this lease including the use of traditional feed properties (without the use of binding agents), and the other with the use of binding agents.

Two scenarios where modelled for Lease 320, a mid level stocking density scenario of 12 kg m^{-3} and a high level stocking density scenario of 14 kg m^{-3}. This lease was chosen as it was previously an existing farm and has been fallowed for a number of years. The seabed has now recovered.

The final two scenarios were modelled for Lease 339, which is the existing smolt farm.. A mid level stocking density scenario of 3 kg m^{-3} and a high level stocking density scenario of approximately 4.2 kg m^{-3} was modelled for this smolt farm. All modelling scenarios were simulated for one year.

The key results from the deposition models were predictions of the extent and concentrations of both carbon and solids (feed and faeces wastes) deposition as a result of a possible farm expansion in Big Glory Bay.

3 RESULTS

3.1 Hydrodynamic Modelling

Model results indicate that flow within the bay is weak and generally less than 5cm s^{-1} (**Figure 13**). Flow is stronger towards the mouth of the bay, reaching speeds up to 10-12cm s^{-1}. The strongest flows in the bay appear to occur along the northern and southern shoreline with current speeds reaching up to 12cm s^{-1} in some locations.

Current direction is variable and there are several eddies within the bay. There are potentially a number of additional eddies not identified by the model due to the number of mussel farm long lines sitting within the bay (**Plew et al 2005**). In all scenarios, there is a general mouth-ward flow along the northern banks of the embayment, as well as along the southern banks.

Regional currents appear to be strongest in spring, but show very little difference in speed and direction with season around of Stewart Island (**Figure 14)**.

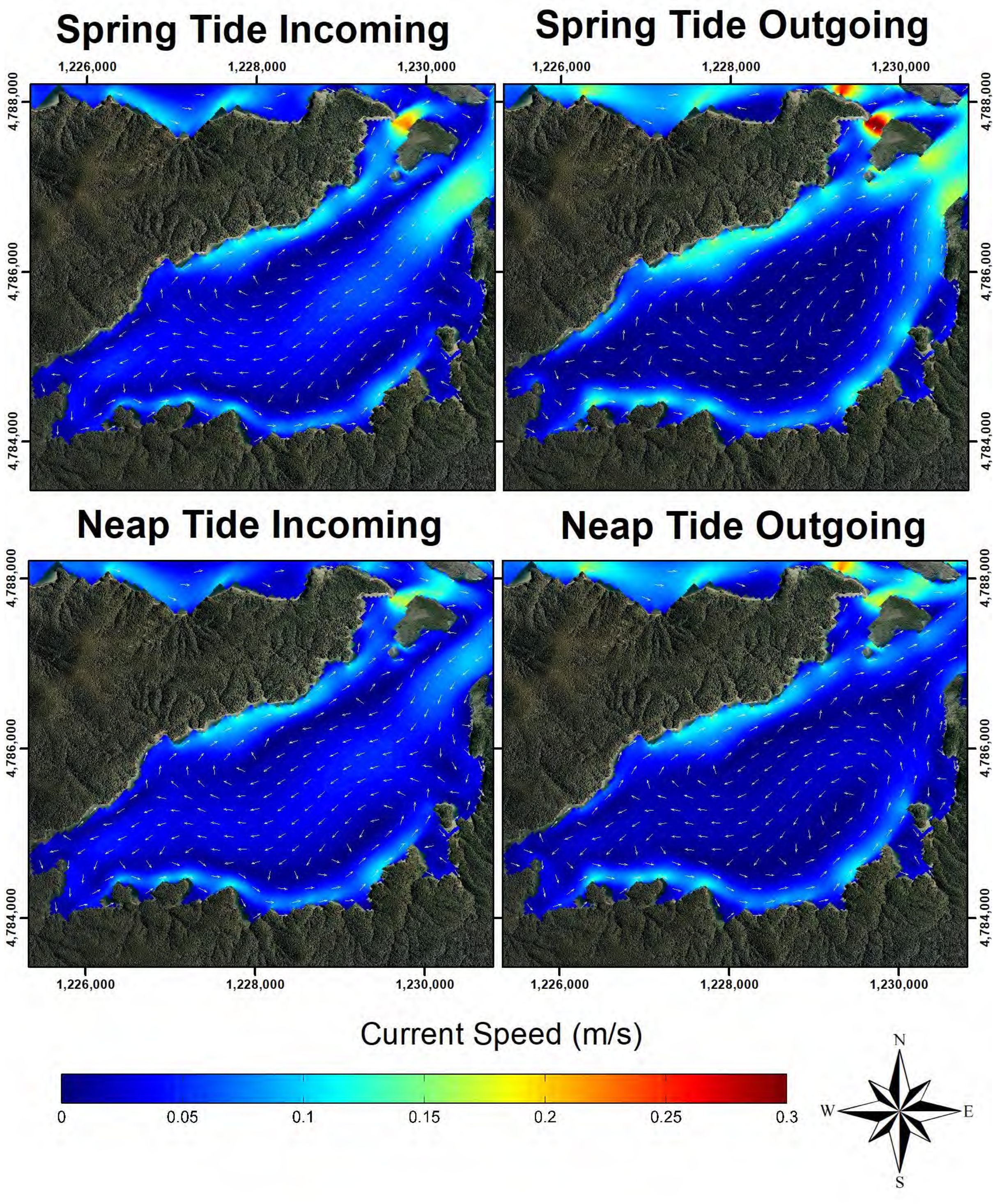

Figure 13 - Depth averaged local current patterns (during Spring/October conditions) for spring and neap ebb and flood tides.

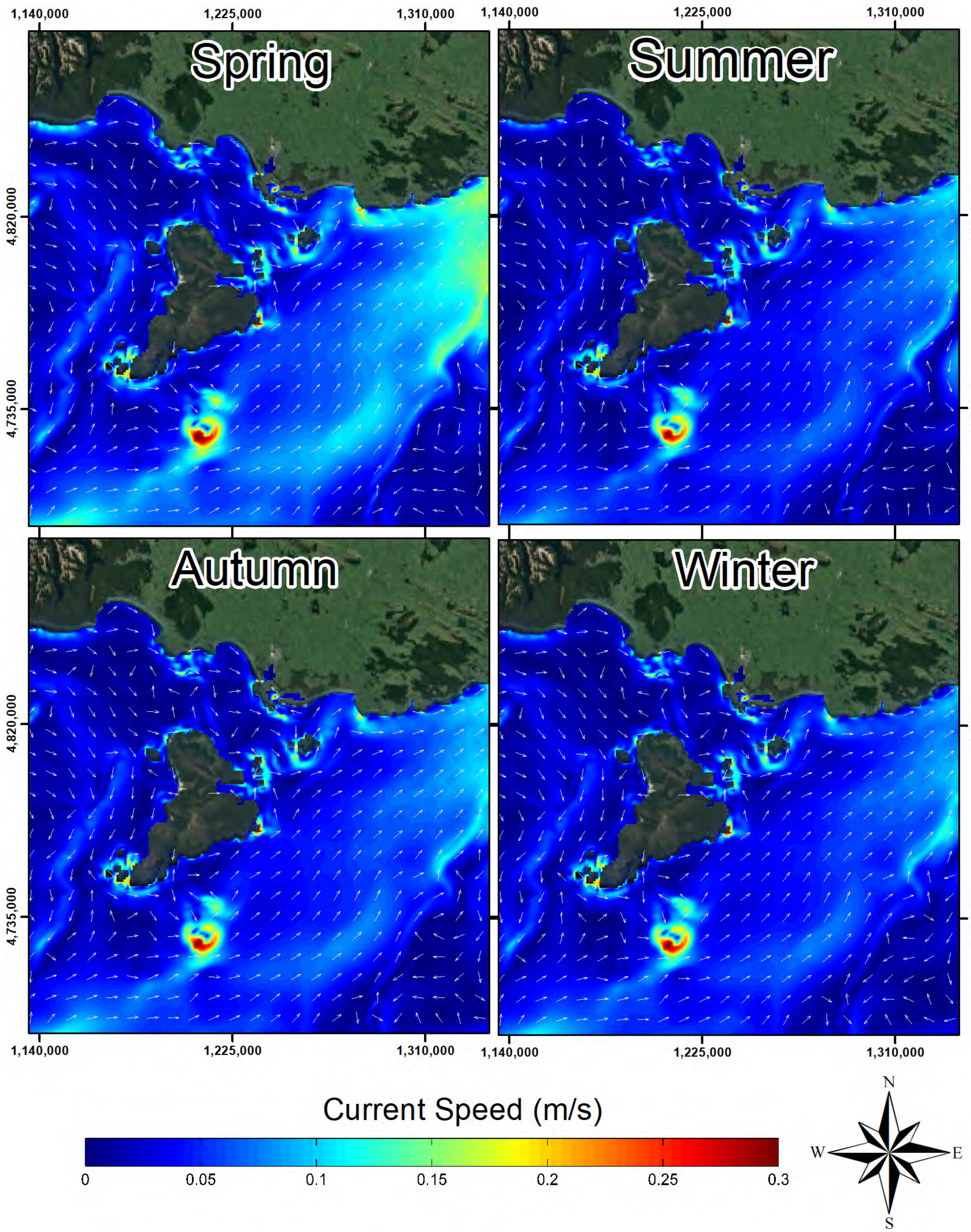

Figure 14 - Seasonal regional flow patterns around Stewart Island and the southern portion of South Island.

3.2 Flushing Modelling

Model results indicate that there is a significant change in concentration between Day 0 and Day 7 for all 4 scenarios modelled. Model results indicate that there appears to be little difference in the retention time between seasons.

At the end of Day 7, tracer concentrations do not exceed 70% at any point inside Big Glory Bay (**Figure 15**). By day 14 tracer concentrations are approximately 40% **(Figure 16)**. After 28 days approximately 85-90% of water within Big Glory Bay has been flushed out. Results indicate a flushing time of approximately 28-30 days.

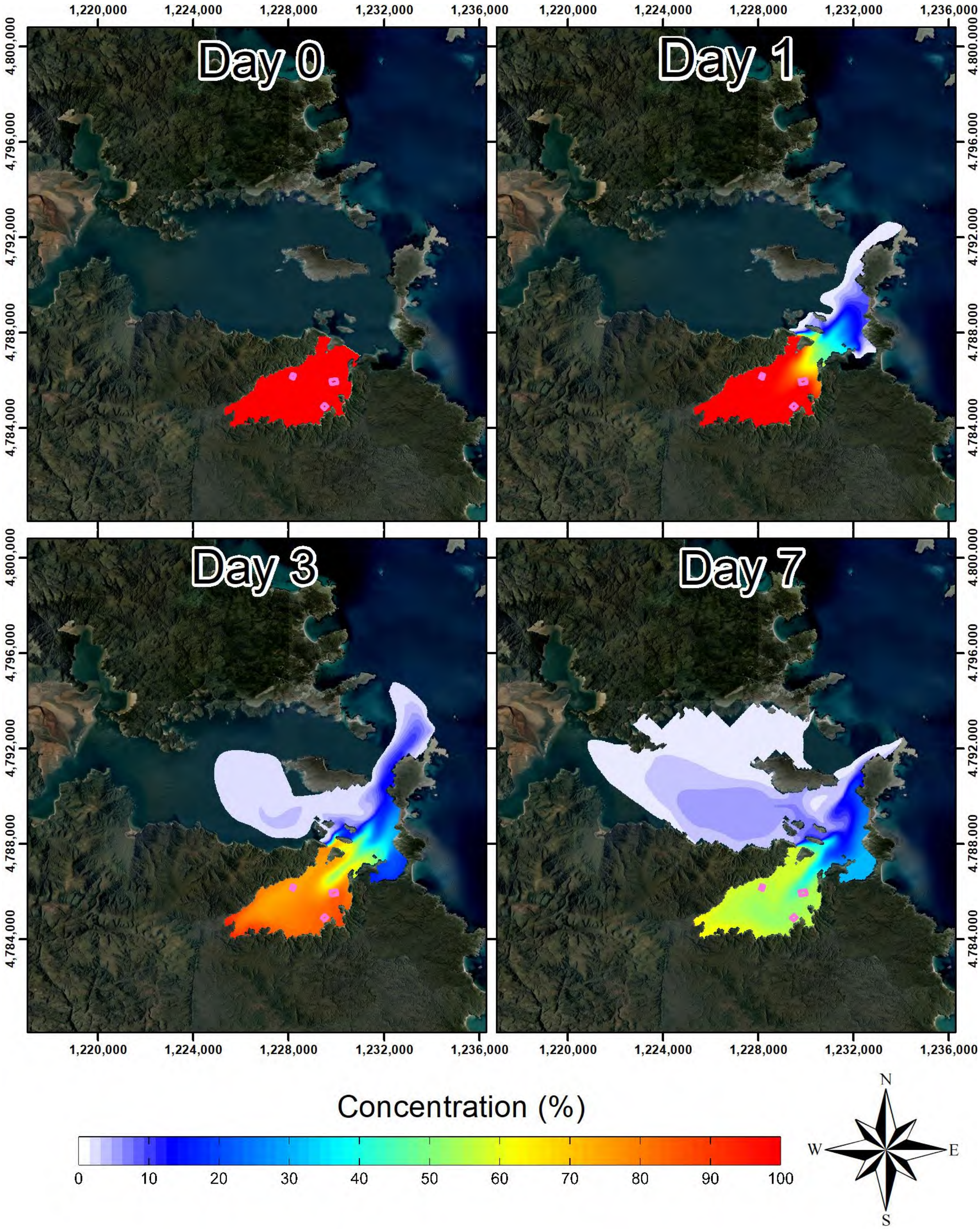

Figure 15 - Full bay flushing results for spring, day 0 to day 7.

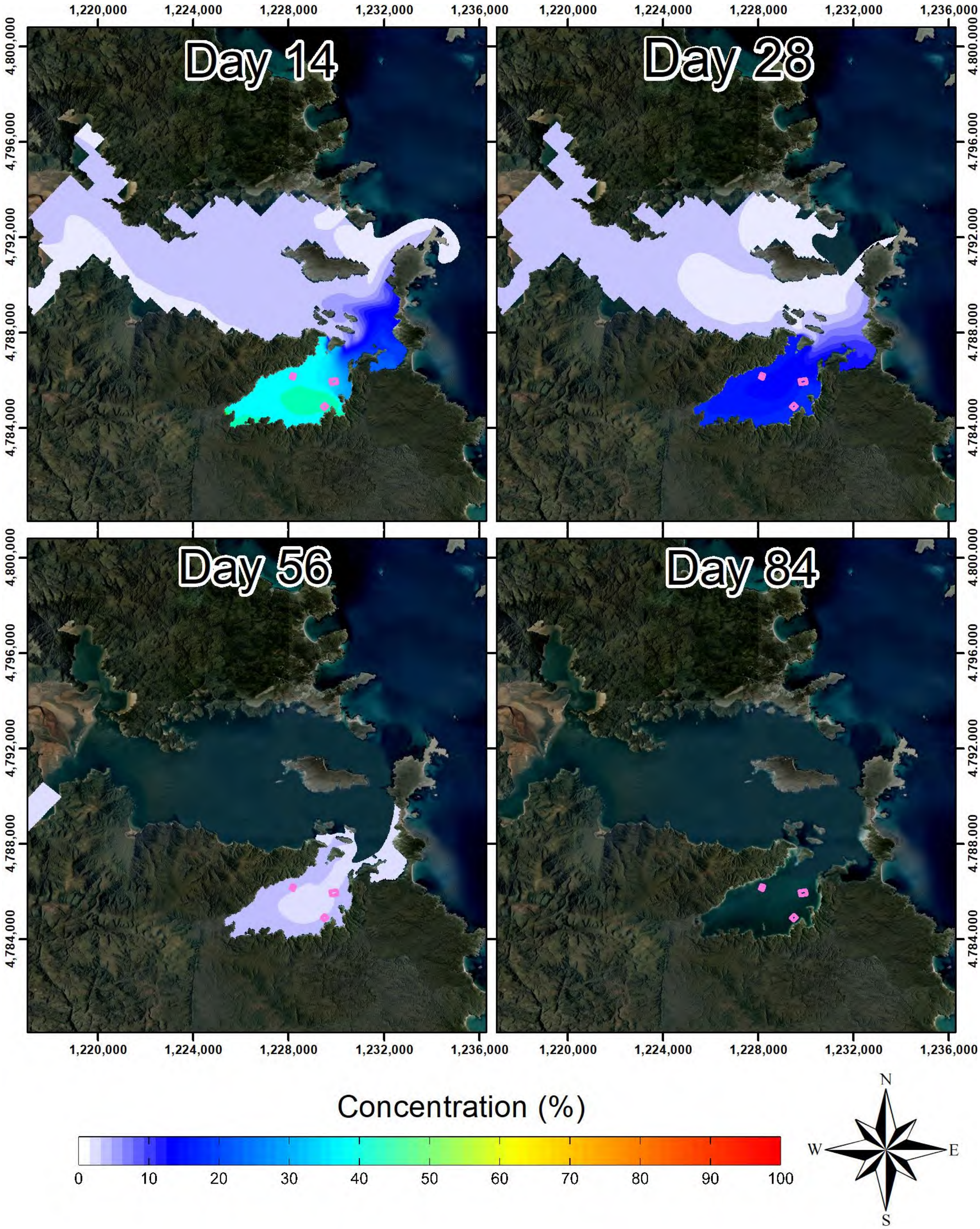

Figure 16 - Full bay flushing results for spring, day 14 to day 84.

3.3 Water Quality Modelling

3.3.1 TAN Results

Water quality modelling indicates that TAN levels would increase in Big Glory Bay by up to 30µg L^{-1} (**Figure 17**) during the maximum feeding scenario. Small TAN concentrations (less than 5 µg L^{-1}) were also observed in Paterson Inlet.

For the maximum feeding scenario, the model is predicting Total N levels to increase by approximately 10% when compared to Total N observations made during Sanford's monthly water quality monitoring program. Interestingly higher levels of available N (TAN and nitrate) have been recorded in the past (*i.e.* **Pridmore, 1995 <**200 µg L^{-1}).

There is also evidence from the same Total N data that there is either (or both) a mechanism consuming N in the Bay, which could point at mussel consumption of plankton and particulates, and/or a large source of external influx N during Autumn-Winter. Given the large number of mussel farms in the bay these more than likely have a significant impact on the N budget.

Results suggest that excess N released during both proposed scenarios is not likely to destabilize the system in any measurable way. The system is classified according to ANZECC guidelines as slightly to moderately disturbed due to the long-term presence of fish/mussel farms, and the addition of the proposed loadings will not cause a change of trophic state.

Overall, the excess TAN release in all modelled scenarios is within acceptable ranges considering the flushing capacity of Big Glory Bay, and generally agree with the DHI model conclusions of 2010.

Model results indicate an increase in chlorophyll-*a* of between 2 and 4 µg L^{-1} (**Figure 18**). However, it is clear that this is an overestimation (especially during spring and summer) as mussels grown in the bay will contribute to keep the measured levels down (by consuming phytoplankton).

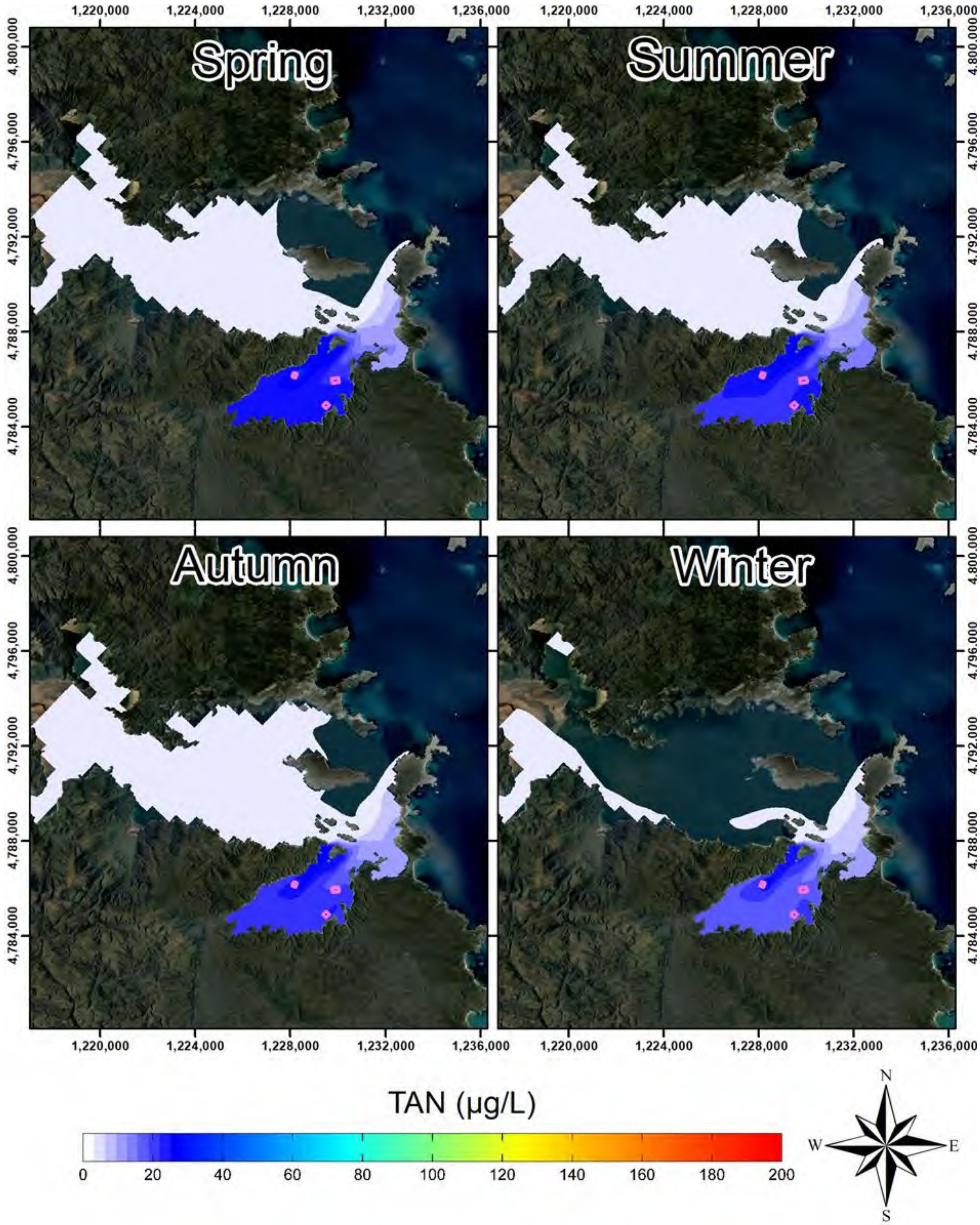

Figure 17 - Seasonal average excess concentrations of TAN for the higher level scenario (maximum minus baseline) at the surface.

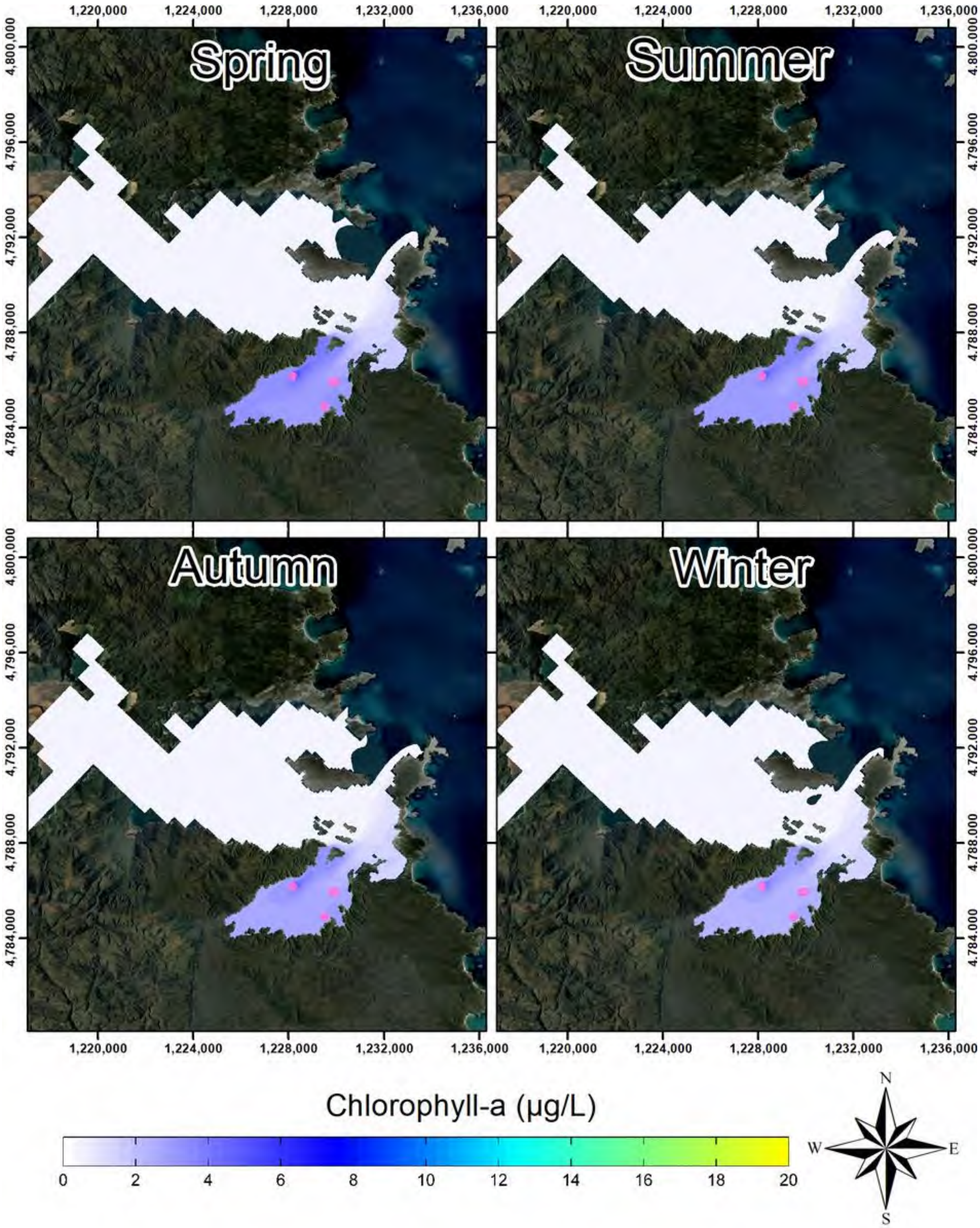

Figure 18 - Seasonal average excess concentration of chlorophyll-a for the higher level scenario (maximum minus baseline) at the surface.

3.3.2 Oxygen Results

Dissolved oxygen effects from the model shows that there is no significant variation in dissolved oxygen drawdown between surface and bottom layers, except near the cage groups. There are predicted temperature driven seasonal variations in oxygen drawdown (**Figure 19)**, with oxygen concentrations towards the end of summer and beginning of autumn reaching minimum values of close to 6 mg L^{-1} (**Figure 20)**. Dissolved oxygen concentrations of this magnitude are needed for maintaining healthy farmed salmon (**Stein *et al.* 2013**).

The difference between the two modelled scenarios is only marginal. Dissolved oxygen reductions are expected to reach 0.25mg L^{-1} inside the Bay and up to 1.5mg L^{-1} within the cages.

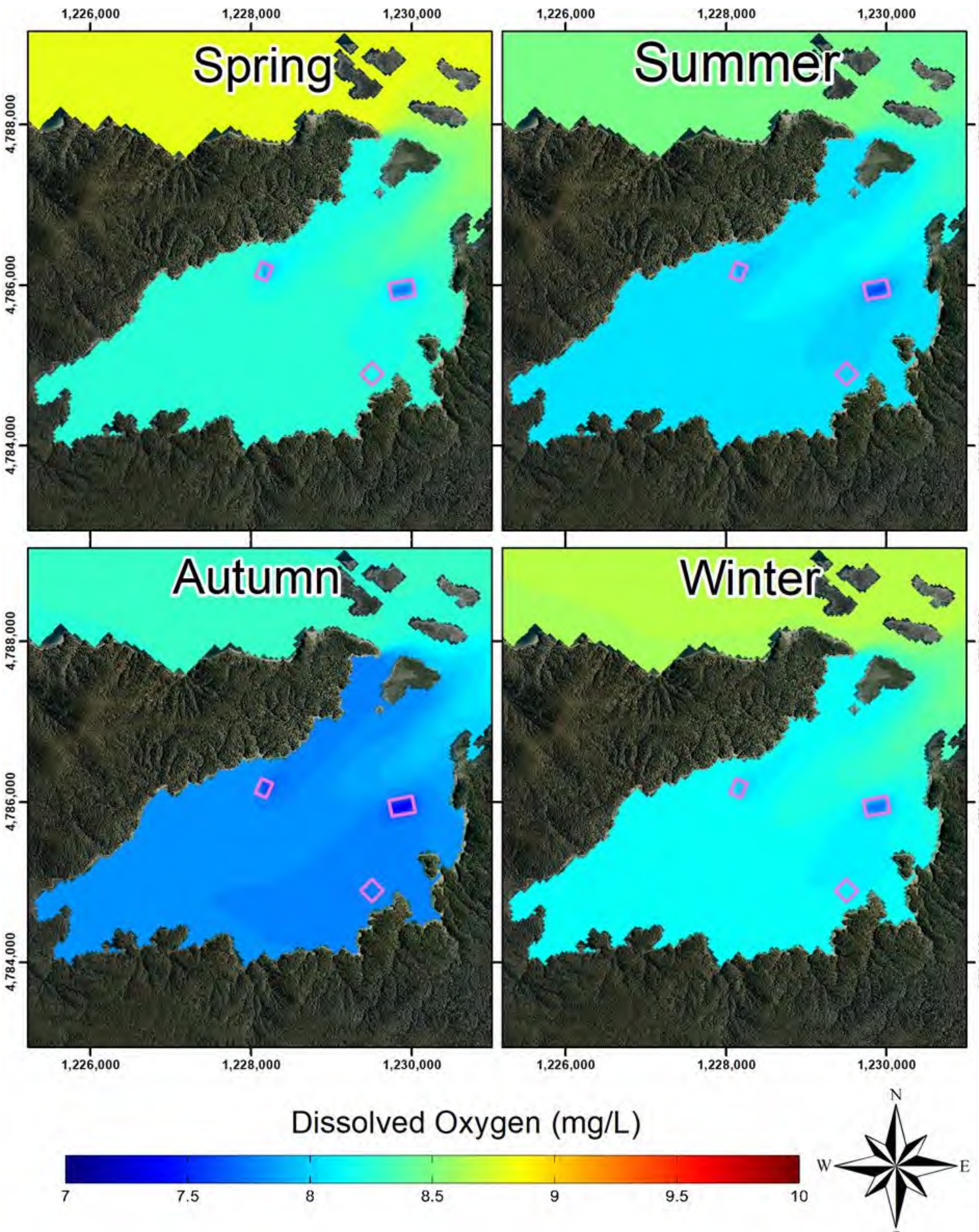

Figure 19 - Seasonal average dissolved oxygen concentration for the higher level scenario at the surface.

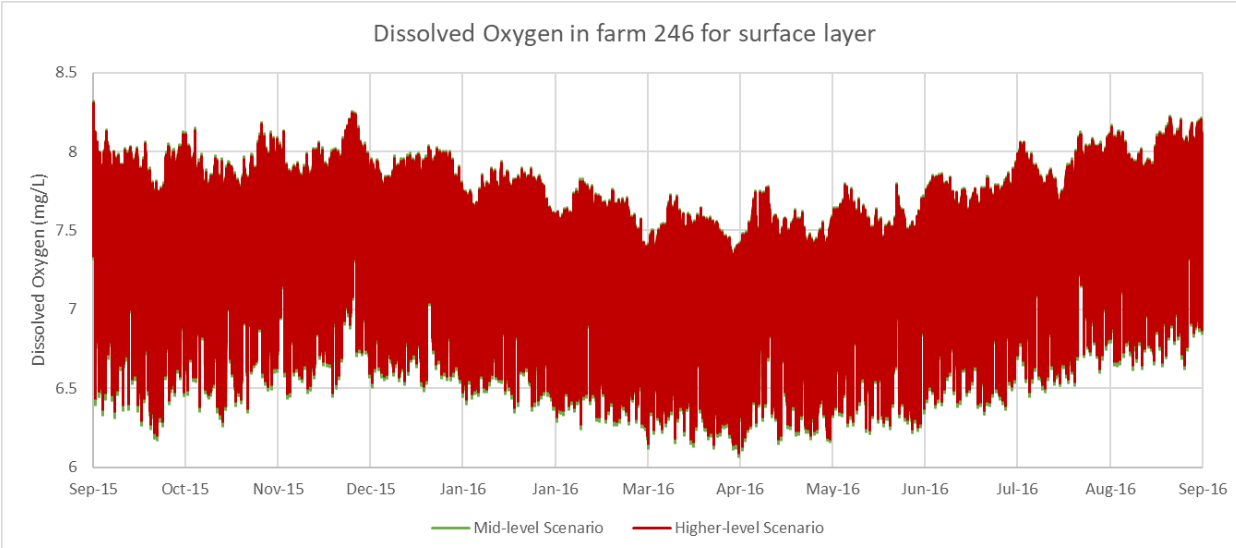

Figure 20 - Comparison of dissolved oxygen in farm 246 at the surface 2 proposed scenarios.

3.4 Seabed Deposition Modelling

The deposition models show that faeces and solids deposition would generally remain within the boundaries of the lease. This is true of lease 246 provided binding agents are used in the feed (**Figure 21**). Without binding agents, higher current flows due to the proximity to the mouth of the bay are predicted to skew the depositional footprint of lease 246 100's of meters NNE of the lease boundary (**Figure 22**).

All depositional footprints (assuming only the scenario using a feed binder for lease 246) show that fish feed and faeces accumulates directly under the pens with only limited (less than 100m) excursions outside lease boundaries (**Figure 21, Figure 23 and Figure 24**). Depositional footprints are generally distributed throughout most of the available area within the boundaries of leases 246 and 320.

While the majority of the N release from farming activities is from soluble emissions, some (up to 3%; **Hall *et al.* 1992**) of the N deposited to the sediments as faeces and feed wastes will be mineralised and rereleased to the water column as the efflux of NH_4^+ (**Blackburn 1988**).

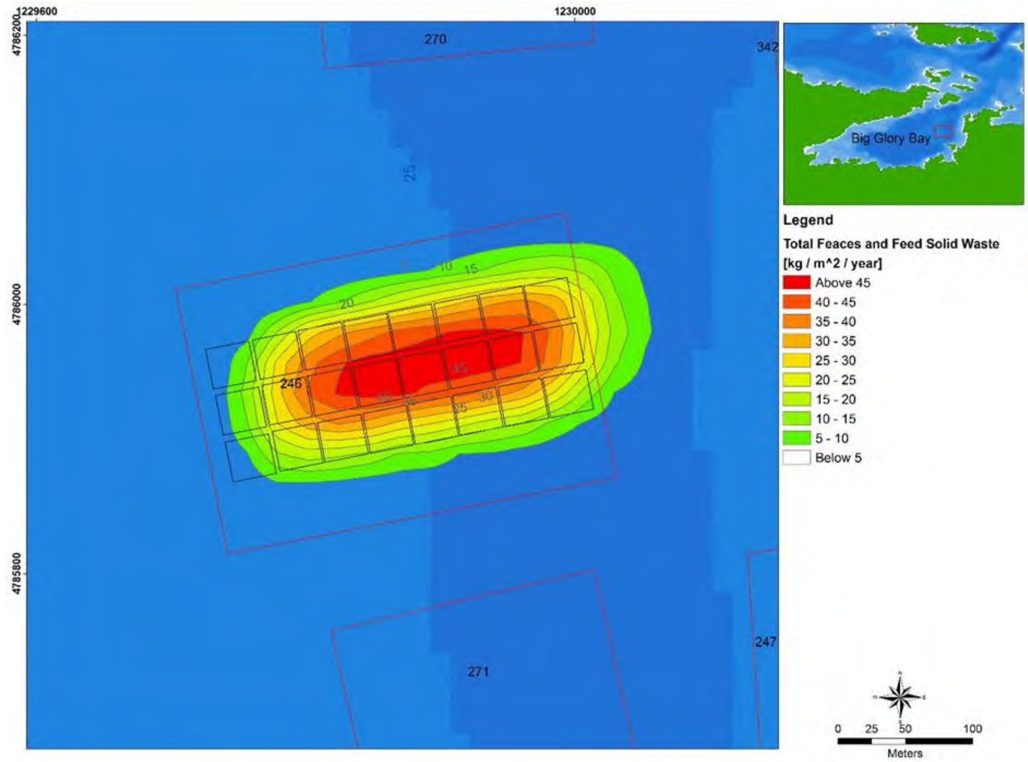

Figure 21 - Lease 246 depositional footprint prediction assuming the use of feed binding agents.

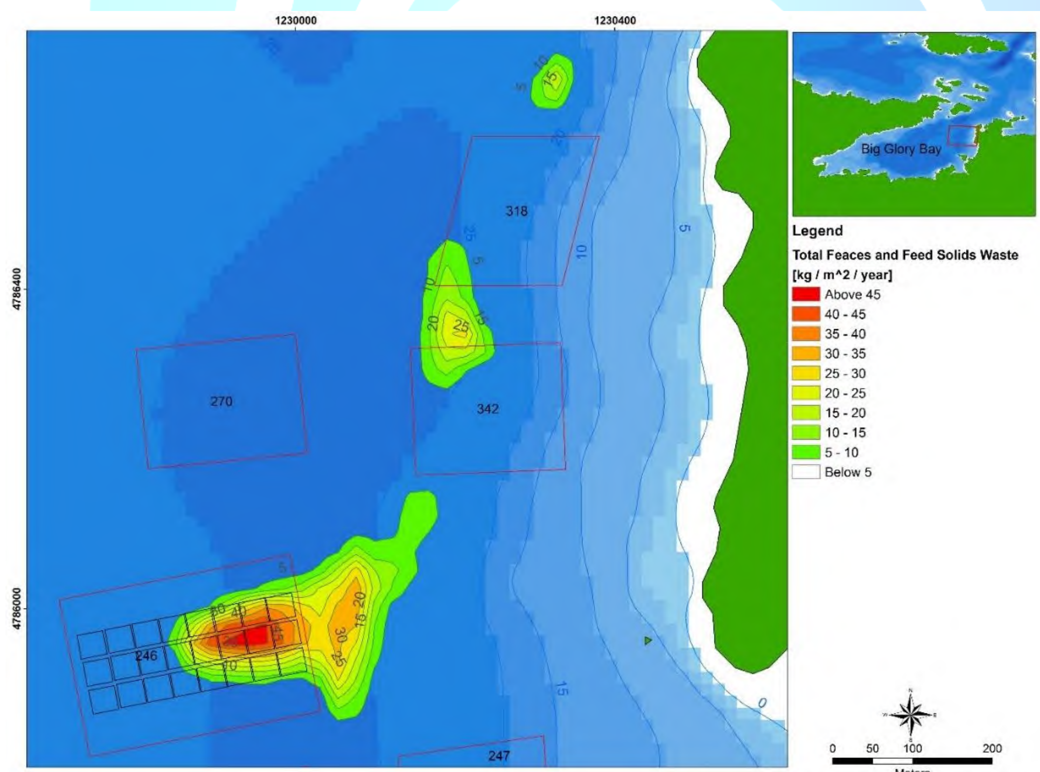

Figure 22 - Lease 246 depositional footprint prediction using traditional feed properties (without binding agents in the feed).

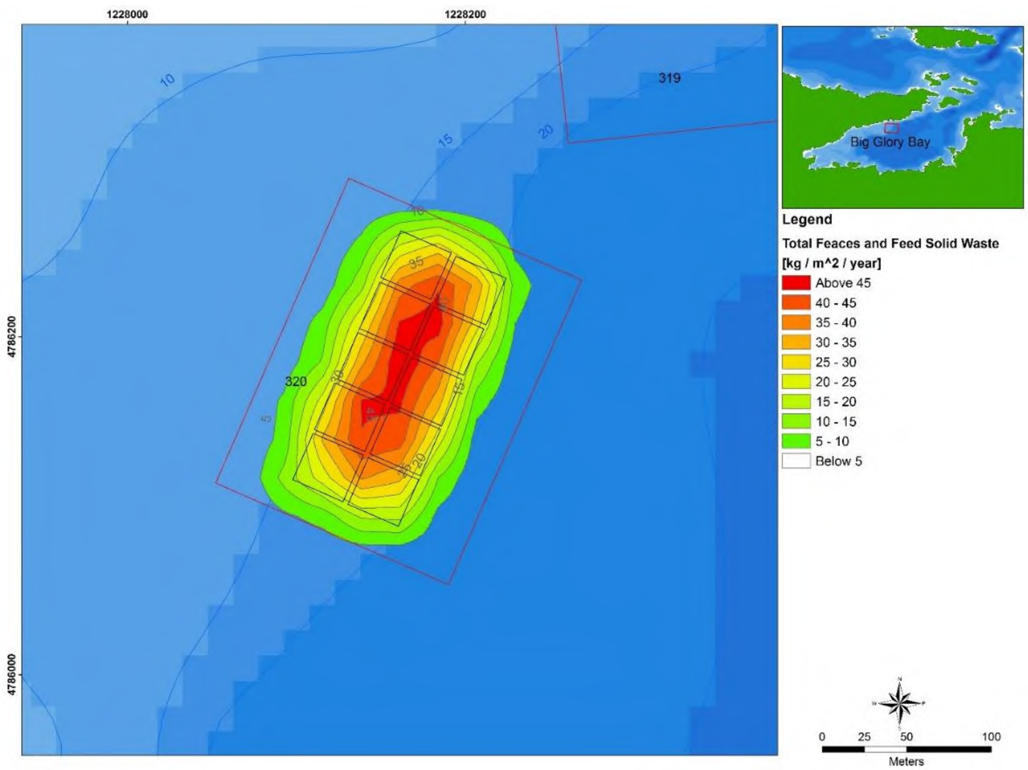

Figure 23 - Lease 320 depositional footprint prediction from the higher level Stocking (14 kg m^{-3}) scenario.

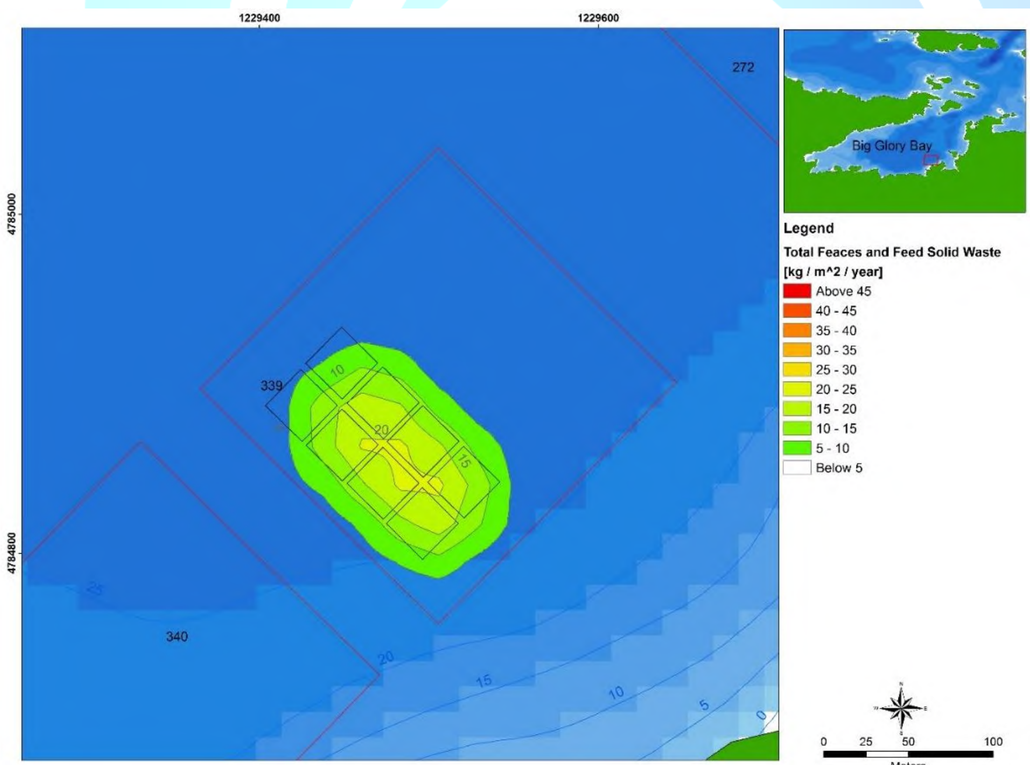

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Figure 24- Lease 339 depositional footprint prediction from the higher level Stocking (4.3 kg m^{-3}) scenario.

4 CONCLUSIONS

4.1 Previous Carrying Capacity Studies in Big Glory Bay

Two carrying capacity studies of Big Glory Bay preceded this study. The first was a **1988 study from Rutherford *et al*.** and a series of papers published by **Pridmore and Rutherford in 1990 and 1992**.

The second carrying capacity study for the bay was performed in **2011 by DHI**, which improved upon the simple N budget techniques employed Rutherford *et al.* by using three dimensional hydrodynamic and ecological models to describe salmon farming in Big Glory Bay. With the fine-tuned modelling tools available, some 23 years later, the carrying capacity of the system was re-examined.

In addition, it should be pointed out that feed technology has also reduced the feed conversion ratio and the percentage of nitrogen within the feed. This means that the same feed can now feed more fish than during the 1980's (Skretting 2017 pers.com B. Wybourne).

While production is regulated by a N cap, it was low DO around the farms, in addition to high levels of TAN release, that brought cause for concern in regard to fish welfare and potential phytoplankton blooms, and thus limited production to these figures. **DHI 2011** also recommended relocating the majority of the salmon production to the mouth of the bay to take advantage of the stronger flow observed there. Stronger currents provide better flushing, improve oxygen levels and quickly disperse TAN. This relocation occurred during the spring of 2016.

4.2 Summary of Conclusions

Big Glory Bay has generally weak currents (5cm s^{-1}) across much of the bay but stronger flows towards the mouth of the bay (including at the existing 246 farm lease. Flushing models indicate that after 7 days, the bay is approx. 30% flushed and after 14 days the bay is approx. 60% flushed. After 28 days only 10-15% of the original water remains in the bay.

Given this flushing capacity, excess TAN levels in the bay are predicted to increase up to 30µg L^{-1} with additional N inputs from feed of 659 tons, resulting in 381.2 tons of released TAN in the higher production scenario. Assuming all excess released TAN is converted to phytoplankton biomass, chlorophyll-a levels are predicted to increase by up to 4 µg L^{-1}. This is in agreement with the DHI model conclusions of 2011.

With predicted temperature driven seasonal drawdown of oxygen in conjunction with expanded farm production, oxygen levels in the water towards the end of summer and beginning of autumn are predicted to reach minimum values of close to 6 mg L^{-1}, this being the level needed to maintain healthy farmed salmon (**Stein *et al.* 2013**). Dissolved oxygen reductions are expected to reach 0.25mg L^{-1} inside the Bay and up to 1.5mg L^{-1} within the cages.

The deposition models show that faeces and solids deposition should generally remain within the boundaries of the lease, with only limited (<100m) deposition outside lease boundaries, provided binding agents are used in higher flow sites (specifically lease 246). Without binding agents, higher current flows due to the proximity to the mouth of the bay are predicted to skew the depositional footprint of lease

246 100's of meters NNE of the lease boundary. Some of this deposition (up to 3%) will be mineralised by the benthic microbial community and released back into the water column as NH_4^+.

Based on observations of nutrients and chlorophyll-a evolution for the last 30 years through various datasets, and even though farmed fish biomass has increased over the years, the overall range of measurements appears to have remained the same. This highlights the fact that the Big Glory Bay ecosystem has assimilated the increases in nutrient loading occurring over the years, without signs of adverse effects.

Based on the calculations of estimated Total N (without DON, **Figure 2**), there is evidence that N consumption occurs, and this is hypothesized to be a direct consequence of the large amount of mussels biomass in the bay, as filter feeders need to extract the food for their growth from their surrounding environment. Mussel farms act, albeit indirectly, as a mitigation measure limiting the impacts of extra loadings to the environment by consuming the algae as they grow from the additional nutrient loadings from the fish farms.

Finally, taking into account, flushing, oxygen levels, TAN, and Chlorophyll a concentrations we have assessed a maximum carrying capacity of N sourced from fish feed as being 659 tons.

Currently, 3 key knowledge gaps could be addressed to improve the understanding of the carrying capacity of Big Glory Bay:

1. Knowledge of natural background levels related to import and export of nutrients from natural sources such as ocean and bay itself through rain/runoff, and the adjacent Paterson Inlet. The offshore nutrient exchange with the bay should also be examined.
2. Knowledge about mussel farming total N export at harvest are currently not being quantified as part of the overall budget.
3. While previous ecological modelling was carried out in the past, it was based on old data sources. New data are available, but lack the necessary parameters and spatial coverage to be able to carry out a full-fledged ecological model. Namely the effects of mussel farming and exchange between Big Glory bay and the neighbouring ocean (both issues mentioned above).

Addressing these knowledge gaps may allow future assessments to be improved as well as optimise/ maximise stocking levels in the bay without breaching the N cap. If proposed variations to stocking or farm layouts are proposed ADS strongly suggests that modelling is undertaken to examine the specific environmental impacts.

5 REFERENCES

ASC (2012) ASC Salmon Standard. Version 1.0 June 2012. In. Salmon Aquaculture Dialogue

Blackburn, T.H.,1988. Benthic mineralization and bacterial production. In: Blackburn, T.H. Sorensen, J. (eds.) Nitrogen Cycling in Coastal Environments, Wiley, New York, p. 175-190

Cook EJ, Black KD, Sayer MDJ, Cromey CJ, Angel DL, Spanier E, Tsemel A, Katz T, Eden N, Karakassis I, Tsapakis M, Apostolaki ET, Malej A (2006) The influence of caged mariculture on the early development of sublittoral fouling communities: a pan-European study. ICES J Mar Sci 63:637 649

Cromey CJ, Black KD, Edwards A, Jack IA (1998) Modelling the deposition and biological effects of organic carbon from marine sewage dischargees. Estuar Coast Shelf Sci 47:295-308

Cromey, C.J., Nickell, T.D. and Black, K.D., 2002. DEPOMOD - Modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture. 214, 211-239.

Cromey CJ, Black KD (2005) Modelling the impacts of finfish aquaculture. Environmental Effects of Marine Finfish Aquaculture 5:129-155

DHI., 2011. Summary Carrying capacity assessment of Big Glory Bay. Client Report.

Hall, P.O., Holby, O., Kollberg, S. and Samuelsson, M.O., 1992. Chemical fluxes and mass balances in a marine fish cage farm. IV. Nitrogen. Marine Ecology Progress Series, pp.81-91.

J. Key. 2001. Growth and condition of the greenshell mussel Perna canaliculus, in Big Glory Bay, Stewart Island: relationships with environmental parameters. MSc thesis Otago Univeristy.

Magill SH, Thetmeyer H, Cromey CJ (2006) Settling velocity of faecal pellets of gilthead sea bream (Sparus aurata L.) and sea bass (Dicentrarchus labrax L.) and sensitivity analysis using measured data in a deposition model. Aquaculture 251:295-305

Plew.D., Stevens. C., Spigel. R and Hartstein N.D, 2005. “Hydrodynamic Implications of Large Offshore Mussel Farms” IEEE Journal of Oceanic Engineering. Vol 30, (1) 95-108.

Pridmore, R.D. and Rutherford, J.C., 1990. Factors influencing phytoplankton abundance in Big Glory Bay, Stewart Island: a modelling study. Water Quality Centre Consultancy Report No 6107. Hamilton. 30pp.

Pridmore, R.D., and Rutherford, J.C., 1992. Modelling phytoplankton abundance in a small enclosed bay used for salmon farming. Aquaculture and Fisheries Management 23: 525-542

Pridmore, R.D., 1995. Eutrophication Monitoring Programme – Big Glory Bay. Unpublished report. National Institute of Water and Atmospheric Research Ltd, Hamilton, New Zealand: 6 pages.

Rutherford, J.C., Pridmore, R.D. and Roper, D.S. 1988. Estimation of Sustainable Salmon Production in Big Glory Bay, Stewart Island. Water Quality Centre of the DSIR Consultancy Report: T7074/1. Prepared for MAFFish July 1988. 36pp

SEPA (2005) Regulation and monitoring of marine cage fish farming in Scotland, Annex H: Method for modelling In-feed Anti-Paritics and Benthic effects. Scottich Environmental Protection Agency

Stenton-Dozey, J. and Brown, S., 2010. Monitoring environmental effects of longline mussel farming in Big Glory Bay, Stewart Island: Thirteenth annual report. NIWA Client Report: CHC2010-139, November 2010. 41pp.

Stien, L.H., Bracke, M., Folkedal, O., Nilsson, J., Oppedal, F., Torgersen, T., Kittilsen, S., Midtlyng, P.J., Vindas, M.A., Øverli, Ø. and Kristiansen, T.S., 2013. Salmon Welfare Index Model (SWIM 1.0): a semantic model for overall welfare assessment of caged Atlantic salmon: review of the selected welfare indicators and model presentation. Reviews in Aquaculture, 5(1), pp.33-57.

Thetmeyer H, Pavlidis A, Cromey CJ (2003) Development of monitoring guidelines and modelling tools for environmental effects from Mediteranean aquaculture. The MERAMED Project. Interactions between wild and farmed fish.

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Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume II – Hydrodynamic Modelling and Flushing, Aquadynamic Solutions Sdn Bhd, October 2017.

Aquadynamic Solutions Sdn Bhd

Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand

Volume II – Hydrodynamic Modelling and Flushing

October 2017

Report prepared by

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1 INTRODUCTION

This volume focuses on the description of the numerical modelling tools developed to address the hydrodynamic regime of Big Glory Bay as well as the assessment of its retention time (flushing capacity).

The hydrodynamic model is arguably the core of the numerical modelling and is used to simulate water movement within Big Glory Bay and across the entire model domain. The hydrodynamic model was run for a period of one year to allow for full seasonal effects. Retention time/flushing simulations were conducted individually for each of the four seasons. Results of these simulations were also used to drive water movement within the water quality module.

Hydrodynamics were modelled using Delft modelling software (see full description in section 1.1). A 2D regional model was constructed to cover the waters around Stewart Island. This model included regional tidal, wind and current information provided by international recognised global models (see Section 1.2 below). This regional model was used to transfer information to a smaller, but more detailed, local three-dimensional model that included the waters within Big Glory Bay and its immediate surrounds. Unlike the regional model, the local model could be used to account for both thermal stratification and variations in current speed and direction with depth. The local model has a horizontal resolution of 40 meters in Big Glory Bay and is comprised of 10 vertical layers, with higher vertical resolution at the surface. Each layer in Big Glory Bay has an average thickness of approximately 2.3m, and ranges from approximately 1m at the surface to 4m towards the seabed.

The hydrodynamic model was calibrated against current speed and direction collected at two locations within the bay and water level from tidal harmonics in Paterson Inlet. Current measurements were collected by the Cawthron Institute and the data is presented in Section 3 of this report.

A detailed description of the modelling software, methodology, model calibration/validation and a presentation of the current speed and Big Glory Bay's retention time are presented in the following sections.

1.1 DESCRIPTION OF THE CARRYING CAPACITY MODELLING PROCESS

Impacts to the water column and seabed impacts are the primary components of any assessment dealing with open cage aquaculture. The fate of both soluble and solid wastes released by farming operations is determined by the flow conditions prevailing at the locations of the farms and their surroundings.

Predicting potential impacts requires not only knowledge about the current, or historic, flow conditions, but also the ability to predict future conditions or scenarios. Hydrodynamic models can simulate any period of time, provided that sufficient inputs of bathymetry for the model extent as well as forcings (tides, wind, *etc*.) are available for model use. Since the model is based on sets of physical equations it will compute results based on inputs and the quality of the output is a direct consequence of the quality and accuracy of the inputs used. To make sure that the model is accurately depicting *in-situ* conditions, a calibration/validation process is required.

Hydrodynamics govern the prevailing patterns of flow at the area of interest, however hydrodynamic results are not sufficient by themselves to define the potential impacts to the water column and seabed. The current flow fields need to be associated with additional numerical modelling modules in order to simulate the fate of waste generated by the farms. Water column and seabed impacts are both described in their relevant volumes. However, aside from these, the concept of flushing can be used on its own to describe the ability of an embayment to dilute and disperse an effluent via exchange with the ocean, by tidal and wind driven flows for example. Flushing simulations have been carried out for Big Glory Bay and are presented below.

1.2 Model Description

DELFT3D (Deltares 2017 [1]), is a suite of modelling tools that have undergone over 30 years of development. DELFT3D offers the flexibility to develop numerical models of different dimensions (2D, 3D) and has a number of modules to answer almost any water related question.

With DELFT3D, Deltares has developed a unique, fully integrated computer software suite suitable for multi-disciplinary studies, focusing on 3D computations of coastal, river and estuarine areas. It can carry out simulations of flow, sediment transport, waves, water quality, morphological development, and ecology. It has been designed for experts and non-experts alike. The Delft3D suite is composed of several modules, grouped around a mutual interface, which allows for interaction between each module (**Figure 1** & **Table 1**). The core module is Delft3D-FLOW.

Delft3D-FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid. In 3D simulations, the vertical grid is defined following the σ coordinate (terrain following) approach. An example of the output is provided in **Figure 2**.

The model is widely accepted by the scientific community with a growing number of peer reviewed articles referring to the software (more than 300 are registered with Science Direct). Unlike some commercial modelling packages, the scientific community is also actively involved in the development of DELFT3D since its release as an open source platform in 2011.

DELFT3D FLOW is routinely used for the following applications:

- Tide and wind-driven flows (*i.e*. storm surges).
- Stratified and density driven flows.
- River flow simulations.
- Simulations in deep lakes and reservoirs.
- Simulation of Tsunamis, hydraulic jumps, bores and flood waves.
- Freshwater river discharges in bays.
- Salt intrusion.
- Thermal stratification in lakes, seas and reservoirs.
- Cooling water intakes and waste water outlets.
- Transport of dissolved material and pollutants including nutrients and bio-pests.
- Online sediment transport and morphology.

[1] DELFT3D: URL https://oss.deltares.nl/web/delft3d/).

- Wave-driven currents.
- Non-hydrostatic flows.

Due to its modular structure DELFT3D can also be used to assess water quality, ecological impacts and littoral transport.

Table 1 - DELFT3D modules.

Module	Description
Delft3D-WAVE	Short Wave Propagation
D-Water Quality	Far-field Water Quality
D-Waq PART	Mid-field Water Quality and Particle Tracking
Delft3D-ECO	Ecological Modelling
Delft3D-SED	Cohesive and non-Cohesive Sediment Transport

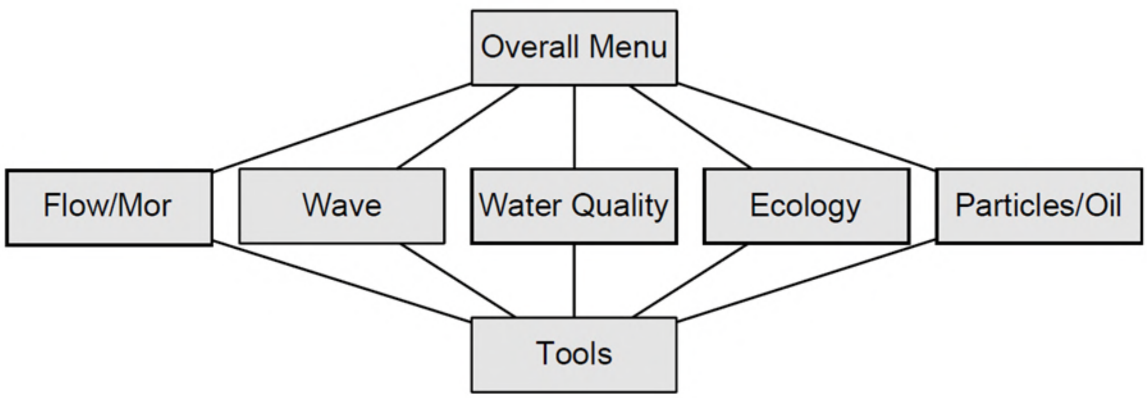

Figure 1 - DELFT3D modular interface.

Standard features included in the hydrodynamic software include:

- Tidal forcing.
- The effect of the Earth's rotation (Coriolis force).
- Density driven flows (pressure gradients terms in the momentum equations).
- Advection-diffusion solver included to compute density gradients with an optional facility to treat very sharp gradients in the vertical.
- Space and time varying wind and atmospheric pressure.
- Advanced turbulence models to account for the vertical turbulent viscosity and diffusivity based on the eddy viscosity concept. Four options are provided: k-", k-L, algebraic and constant model.

- Time varying sources and sinks (*e.g*. river discharges).
- Simulation of the thermal discharge, effluent discharge and the intake of cooling water at any location and any depth.
- Drogue tracks.
- Robust simulation of drying and flooding of inter-tidal flats.

More advanced features encompass:

- Various options for the co-ordinate system (rectilinear, curvilinear or spherical).
- Built-in automatic switch converting 2D bottom-stress coefficient to 3D coefficient.
- Built-in anti-creep correction to suppress artificial vertical diffusion and artificial flow due to σ-grids.
- Built-in switch to run the model in either σ-model or in Z-model.
- Various options to model the heat exchange through the free water surface.
- Wave induced stresses and mass fluxes.
- Influence of waves on the bed shear stress.
- Optional facility to calculate the intensity of the spiral motion phenomenon in the flow (*e.g*. in river bends) which is especially important in sedimentation and erosion studies (for depth averaged — 2DH — computations only).
- Optional facility for tidal analysis of output parameters.
- Optional facility for special points such as 3D gates, Current Deflecting Wall (CDW) floating structures, bridges, culverts, porous plates and weirs.
- Optional facility to switch between a number of advection solvers.
- Optional facility for user-defined functions.
- Domain decomposition.

Figure 2 - Example output from DELFT3D software package.

2 HYDRODYNAMIC MODEL SET-UP

2.1 DEVELOPMENT OF REGIONAL AND LOCAL HYDRODYNAMICS

Two model grids were created which comprise a larger scale regional model and a local model that only covers the south-east of Stewart Island. As stated in the introduction, the larger regional model is a 2D model while the finer resolution model is three dimensional. Both the regional and local models were run for a period of one year from September 2015 to September 2016.

Boundary conditions (water level, wind, pressure, current speed and direction) for the local model were provided by the regional model (grid resolution of 1 km) whose domain covers the entire Stewart Island and its surrounding waters. The local model has been set up with a maximum grid resolution of 40 m in Big Glory Bay to predict localised water level and current variations in Big Glory Bay. The extent for both grids is shown in **Figure 3** and **Figure 4**. Orange lines indicate the transfer boundary between the local and regional model.

This approach has been used recently by ADS for the establishment of aquaculture farms in Storm Bay Australia, Okehampton Bay Australia, and an aquaculture research facility in Okiwi Bay, New Zealand.

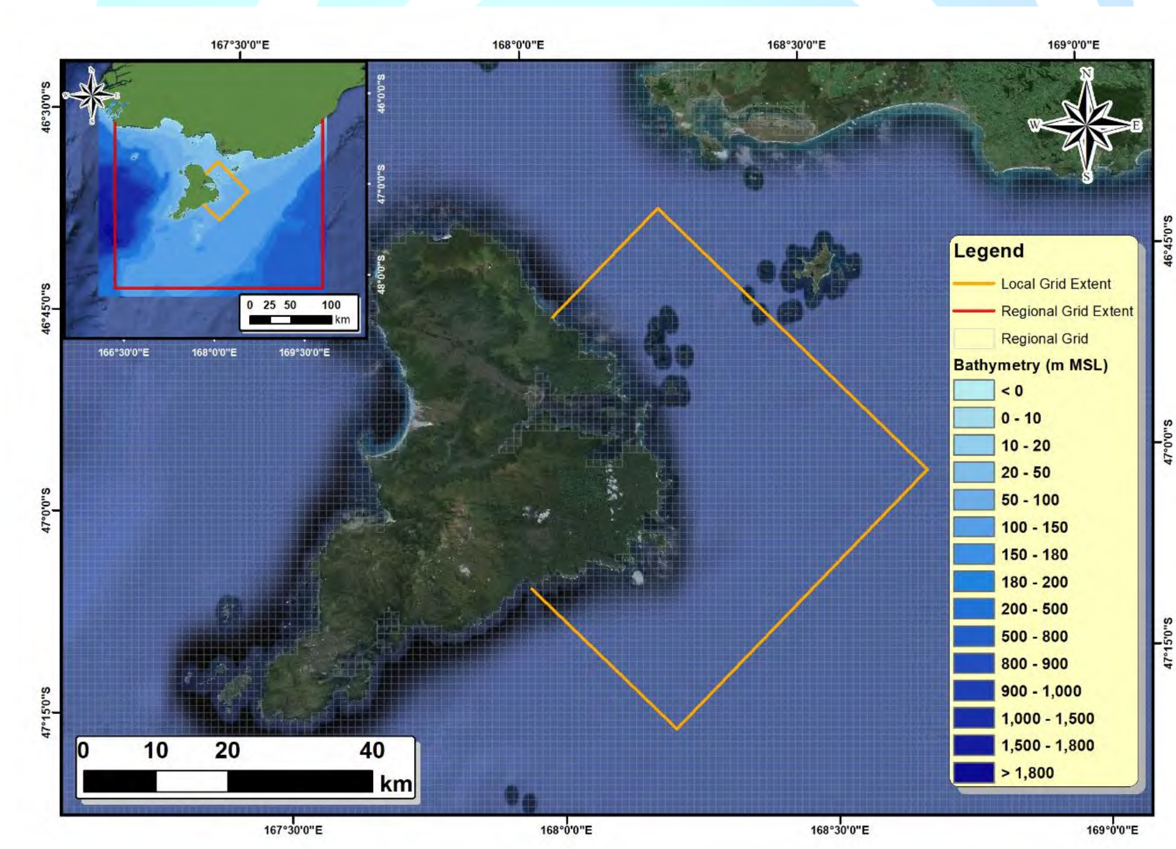

Figure 3 - Extent of regional and local grids, with regional bathymetry.

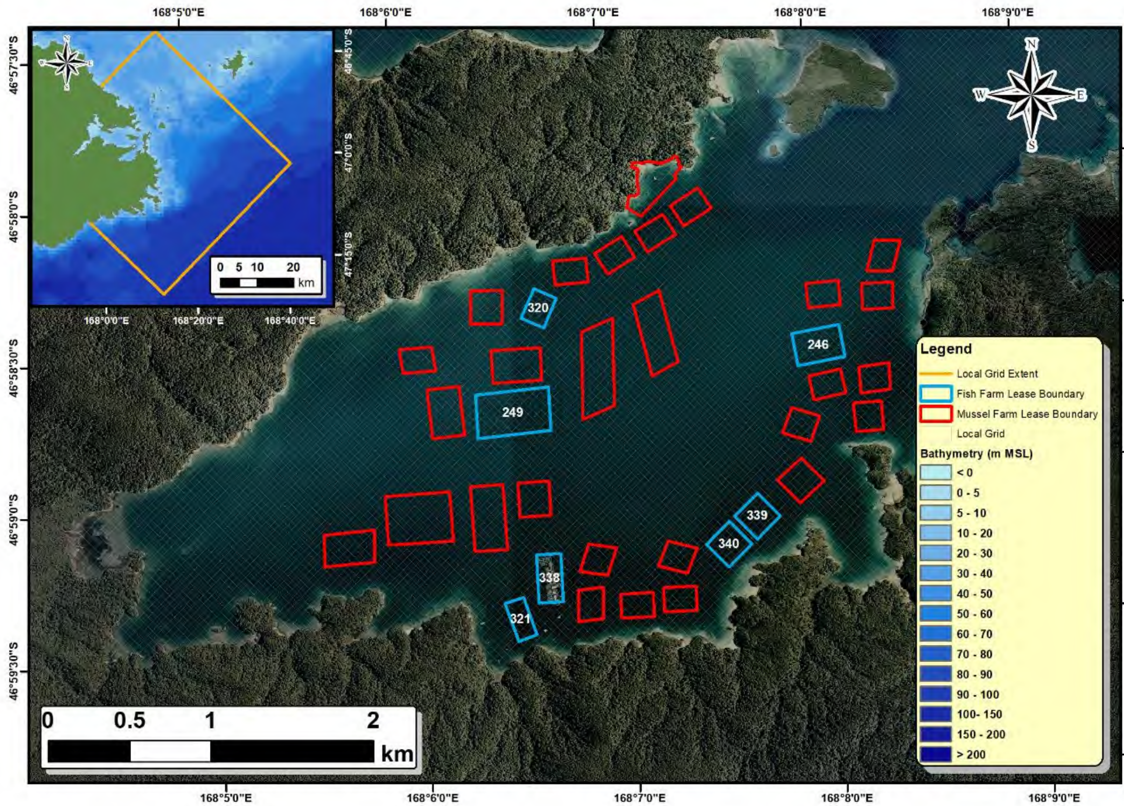

Figure 4 - Extent of local grid (40m resolution and 10 vertical layers), with bathymetry and farm leases.

2.2 Boundary and Climatic Conditions

For the present study, regional drivers of wind, currents, and tide data (water level) are provided by high-quality, globally vetted models designed to be integrated into coastal hydrodynamic models, such as the one developed for this study (note data was extracted for the period between September 2015 and September 2016). The data extraction period matches the model run length of 1 year. Separate data were utilised for the model calibration/validation period (see **Section 3** below).

Regional and model boundary tide data (water level data) were provided by the Oregon State University's TOPEX/Poseidon Global Inverse Solution (**TPXO, Egbert 1997**; **Egbert and Erofeeva 2002**), a global oceanic tidal model (**Figure 5**). The model provides amplitudes of 8 primary harmonic constituents, 2 long-period constituents, and 3 non-linear constituents on a ¼ degree resolution global grid (total of 13 constituents). Additional descriptions and detailed information concerning the TPXO model can be found at http://volkov.oce.orst.edu/tides/global.html. For the purpose of this study, no Admiralty tide was utilised due to the lack of correction coefficients (usually only 2-4 unlike TPXO which has 13).

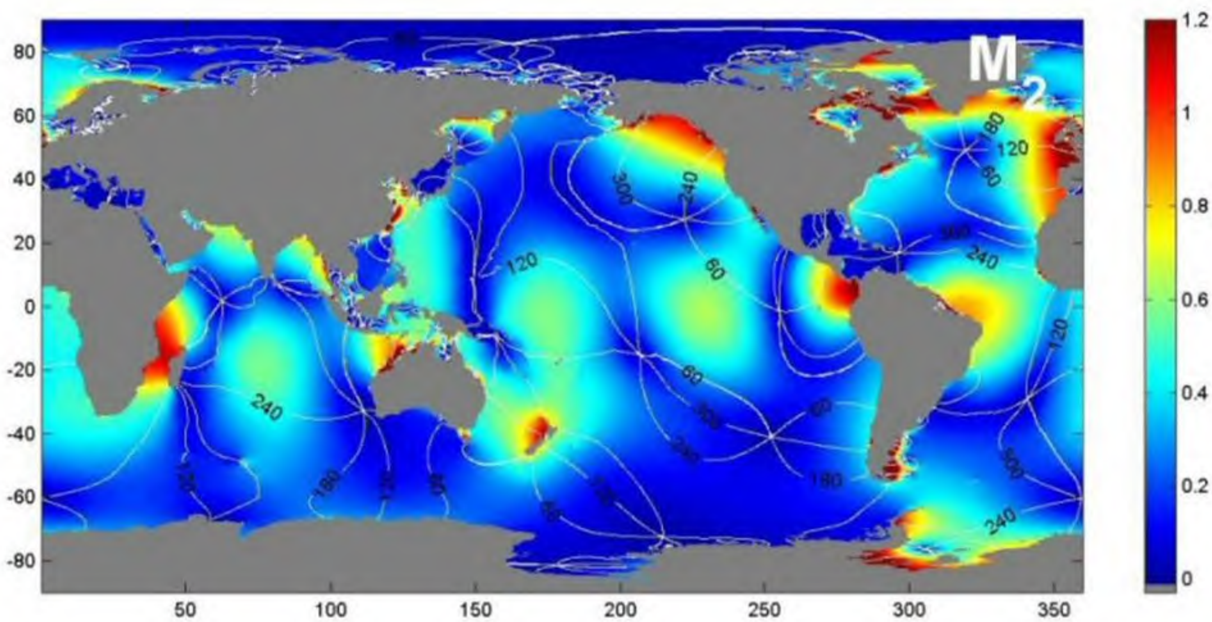

Figure 5 - Image depicting a sample output from the TPXO model.

Offshore wind forcing's for the regional model are provided by the National Oceanic and Atmospheric Administration (NOAA) National Centre for Environmental Information (NCEI) Global Forecast System (GFS) model (**Figure 6**). The GFS is a weather forecast model that covers the entire globe at a base resolution of ~28 km and is used worldwide for weather predictions (*e.g.* **Sela 1980; Kanamitsu 1989; Kalnay et al. 1990**). The GFS model is composed of 4 separate models (atmospheric, oceanic, land/soil, and sea-ice models) that provide an accurate depiction of weather conditions and is constantly updated to improve its performance and accuracy. Additional descriptions and detailed information concerning the GFS data sets can be found at https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs. The GFS model provided both wind (see **Figure 7** and **Figure 8** below for wind speed and direction data used in this particular model) and atmospheric pressure data for the regional model domain in 3 hour intervals.

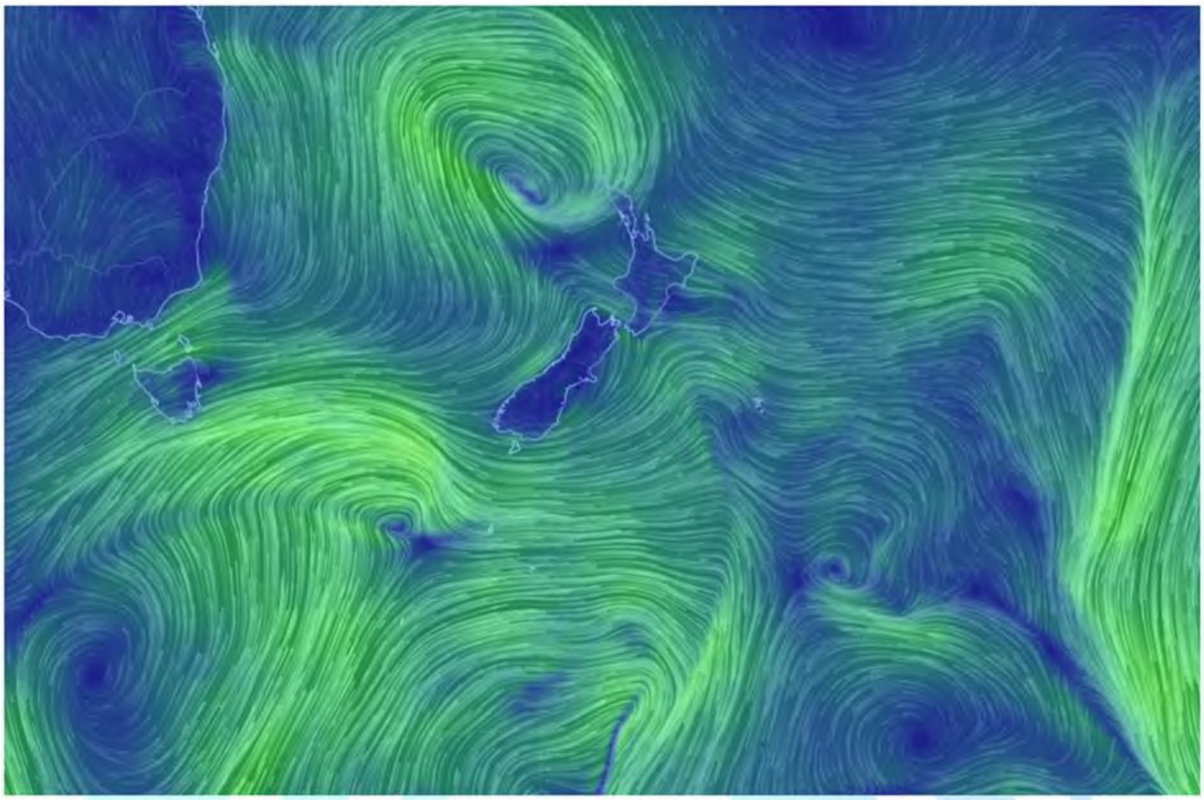

Figure 6 - Example of GFS wind data centered on New Zealand at 2015-09-04 at 0600 GMT (source: http://earth.nullschool.net/).

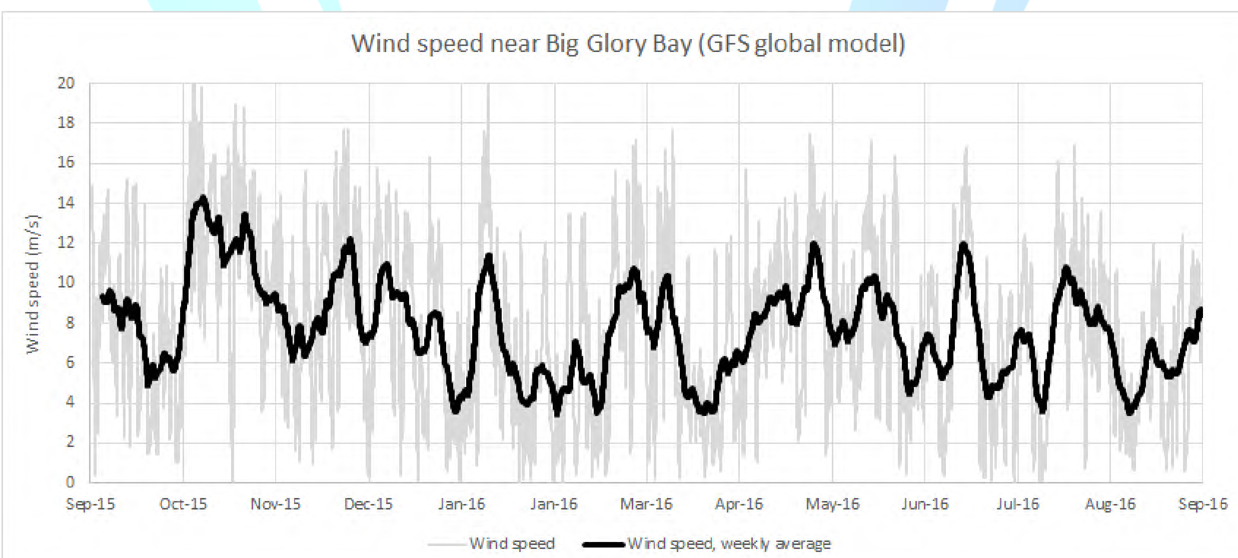

Figure 7 - GFS wind speed extracted near Big Glory Bay, from GFS global model input into local and regional model.

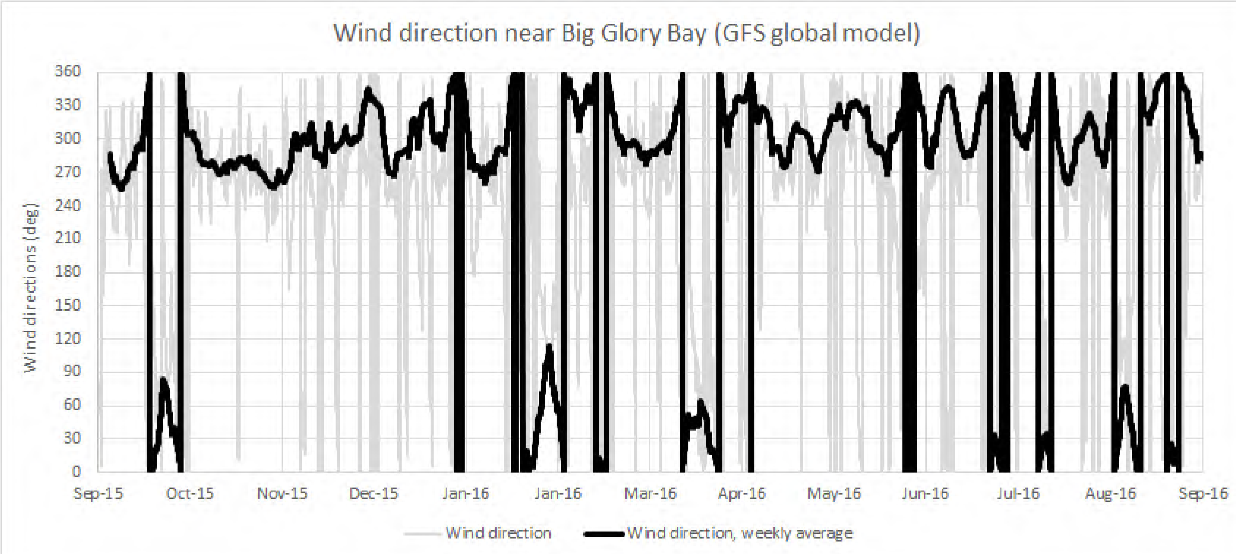

Figure 8 - GFS wind direction extracted near Big Glory Bay, from GFS global model input into local and regional model.

Bathymetry data were obtained across the model domain from data collected by Land Information New Zealand and Sanford (within Big Glory Bay itself). A summary of the main data sources used to build both the regional and local hydrodynamic models is provided in **Table 2** below.

Table 2 - Summary of main data sources used to build the Hydrodynamic model.

Data Type	Sources
Predicted Tidal Elevation	TPXO Global Tidal Solution and WX tidal data
Current (ADCP)	ADCP1: 168.140293, -46.965581 ADCP2: 168.117658, -46.987192
Wind	Global Forecast System by National Oceanic and Atmospheric Administration (GFS)
Regional Current data	HYCOM
Bathymetry	Chart data from Land Information New Zealand

3 HYDRODYNAMIC MODEL CALIBRATION/VALIDATION

3.1 INTRODUCTION TO CALIBRATION AND VALIDATION

An accurate calibration is vital to ensuring the accuracy of the hydrodynamic model and its ability to simulate real world conditions within Big Glory Bay. The calibration is an iterative process in which model parameters such as wind drag and seabed roughness are adjusted until comparison between simulated results and measurements (currents and water level) result in a suitable fit.

The calibration process in this study included comparing model results with predicted water levels, and against Acoustic Doppler Current Profiler (ADCP) collected at two sites within the bay (**Figure 9**). The calibration period was from the 6th of September 2010 to the 22nd of September 2010. As described in **Section 2**, GFS wind and TXPO tidal forcings were also extracted for this period and used to drive the model during the calibration period.

In addition to the calibration process, the model was also validated against current meter and water level data. In this case as the ADCP data collection period was a month, the first 17 days were used to calibrate the model (6th to 22nd of September). For Validation, the model was then run (without altering any parameters) and compared against ADCP and water level data from the last 15 days of the ADCP deployment (22nd of September to the 6th of October). Model calibration and validation plots can be found below in **Sections 3.2** and **3.3**.

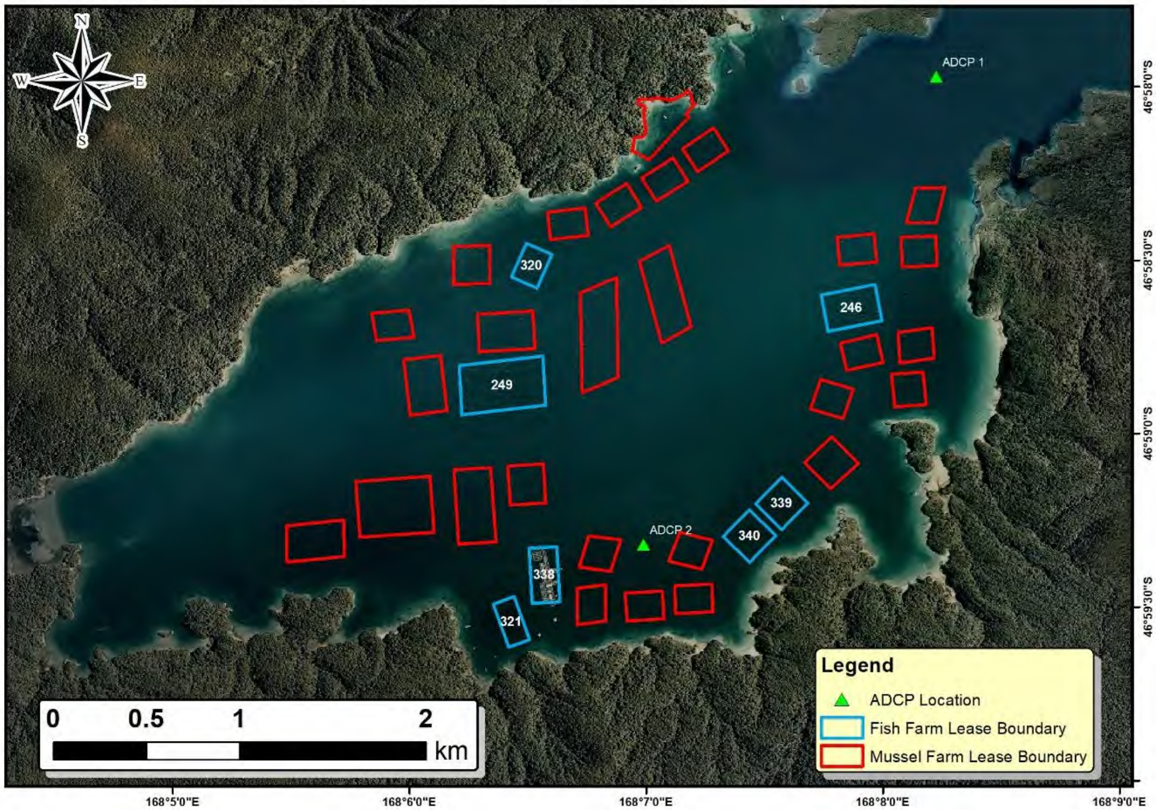

Figure 9 - Location of the two ADCP deployments conducted by the Cawthron Institute from the 6th of September to the 6th of October 2010.

Calibration parameters for the model in this study are listed in **Table 3** below. Most of the parameters were maintained as default (and hence not presented below), except for wind drag coefficient, roughness and horizontal eddy viscosity.

Table 3 - 2D model calibration parameters

Calibration Parameter	Value(s)
Calibration Period	6st September to 6th October 2010
Time step	0.1 minutes
Initial Conditions	0 m for water level.
Boundaries	Nested boundary from regional model.
Wind Drag Coefficient	0.002425
Roughness Formula	50, uniform Chezy across whole domain.
Horizontal Eddy Viscosity	0.28 m^2 s^{-1}

Table 4 - 3D model calibration parameters

Calibration Parameter	Value(s)
Calibration Period	6th September to 6th October 2010
Timestep	0.1 minutes
Initial Conditions	0 m for water level.
Boundaries	Nested boundary from regional model
Wind Drag Coefficient	0.002425
Roughness Formula	50, uniform Chezy across whole domain.
Horizontal Eddy Viscosity	0.28 m^2s^{-1}

3.2 Model Calibration

At ADCP 1 (the mouth of Big Glory Bay) the model matches current speed well, though tends to slightly under predict the flow in places (**Figure 10**). When comparing the current direction between the model and actual ADCP measurements, there is a very good comparison (**Figure 11**). At ADCP 2 (to the south and centre of the bay) there is a good comparison in places between the modelled current speed and a relatively poor comparison in current direction (**Figure 12** & **Figure 13**).

The reason that the current directions are not well calibrated is that there are numerous mussel farm and fish farm structures within Big Glory Bay. A number of studies have observed that such structures can affect localised current flow and current direction (**Hartstein 2003, Plew et al 2005, Stevens et al 2008**). It is beyond the capabilities of the model to take into account hundreds of mussel lines and other associated structures that can be found within the Big Glory Bay water column, noting that this has minimal implications for the overall modelling results.

The model utilised for this study replicates water level data collected from Paterson Inlet very well in terms of both amplitude and phase during spring and neap tidal periods (**Figure 14**).

Overall the model is well calibrated and fit for purpose.

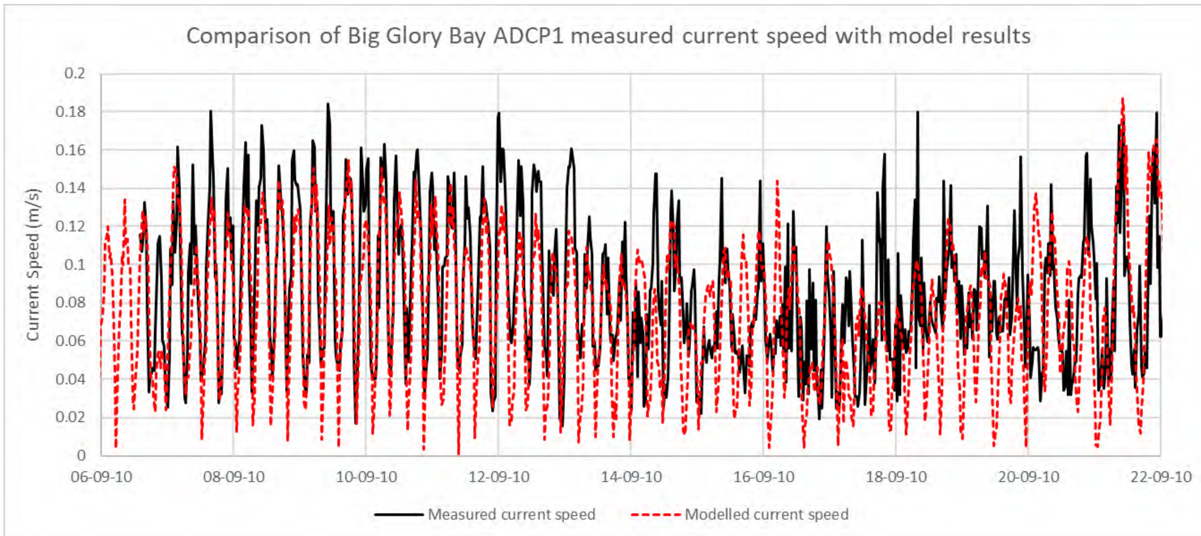

Figure 10 - Current speed comparison at ADCP1 between measured data and modelled results.

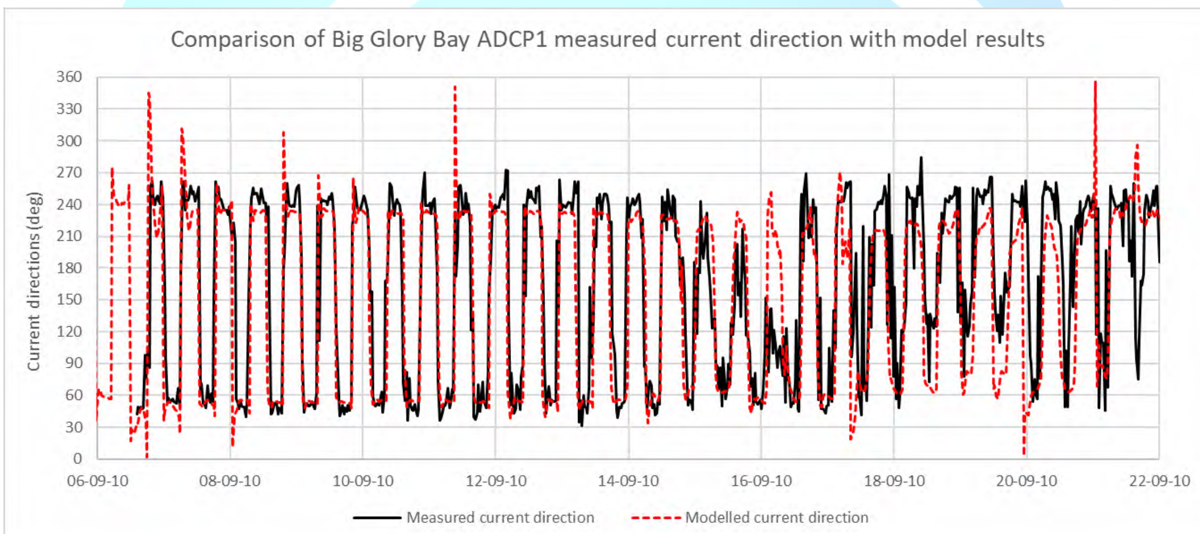

Figure 11 - Current direction comparison at ADCP1 between measured data and modelled results.

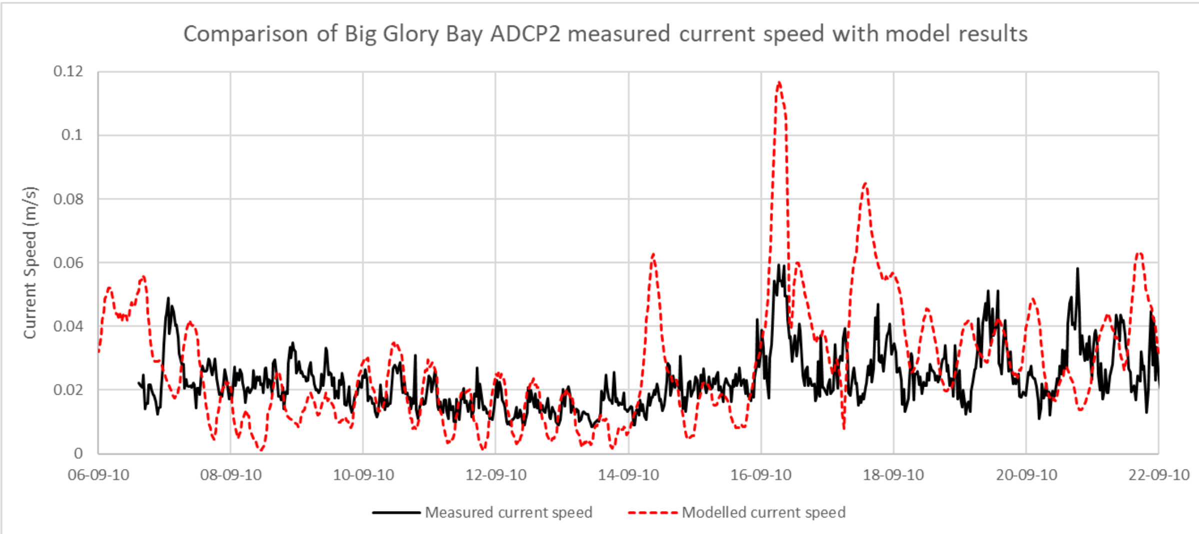

Figure 12 - Current speed comparison at ADCP2 between measured data and modelled results.

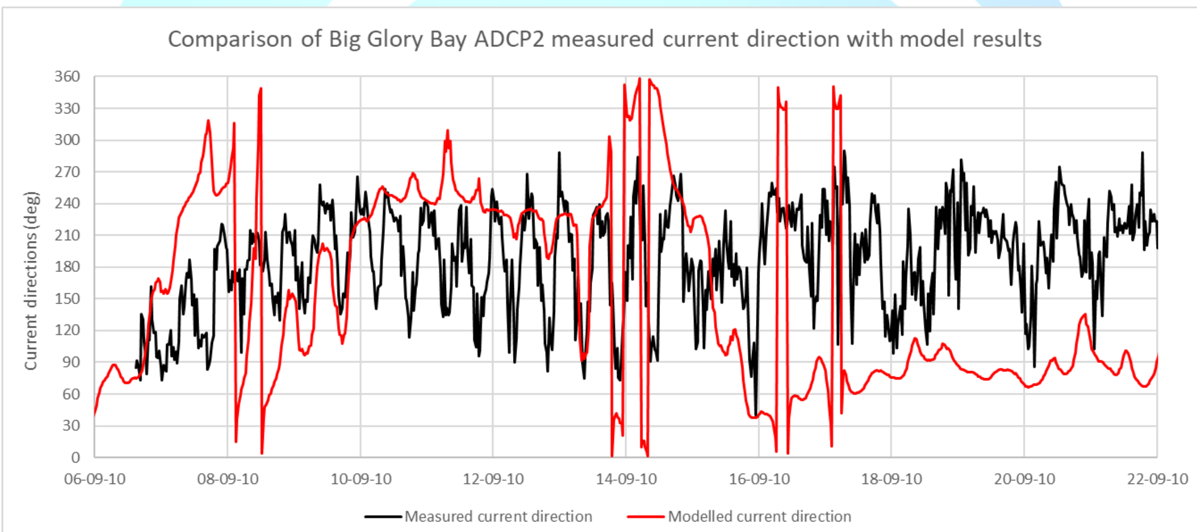

Figure 13 - Current direction comparison at ADCP2 between measured data and modelled results.

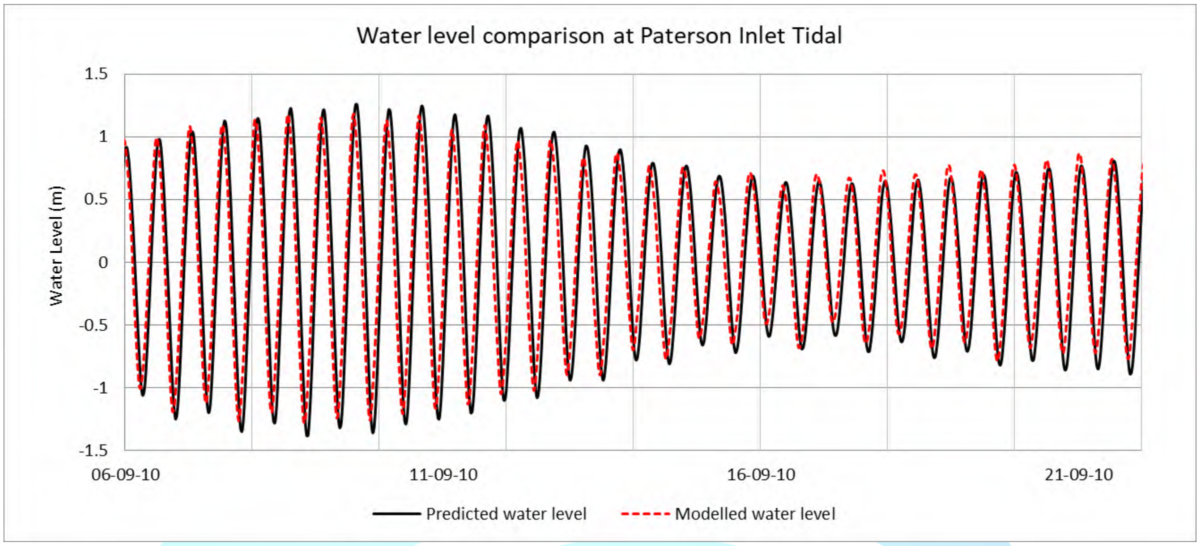

Figure 14 - Comparison of water level at Paterson Inlet tidal station between predicted tide and modelled results.

3.3 Model Validation

At ADCP 1 (the mouth of Big Glory Bay) the model generally matches, or under predicts, current speed (**Figure 15**). When comparing the current direction between the model and actual ADCP measurements, there is a good comparison across much of the validation period (**Figure 16**). At ADCP 2 (to the south and centre of the bay) there is a good comparison in places between the modelled current speed and a relatively poor comparison in current direction (**Figure 17** & **Figure 18**), as observed in the calibration plots above.

Again, as with the calibration period, the model utilised for this study replicates water level data collected from Paterson Inlet very well in terms of both amplitude and phase during spring and neap tidal periods (**Figure 19**).

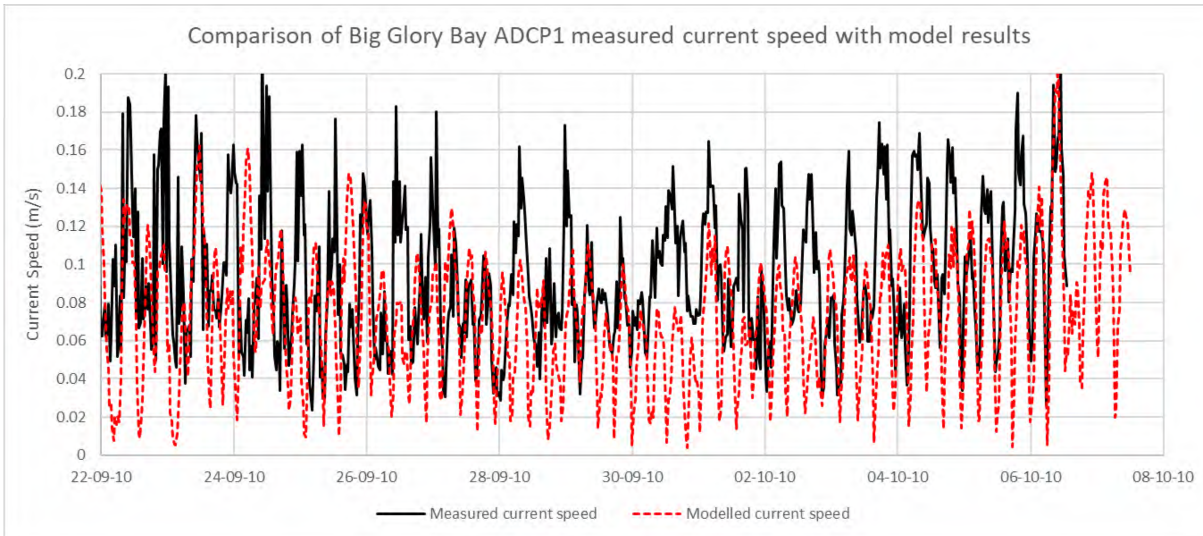

Figure 15 - Current speed comparison at ADCP1 between measured data and modelled results.

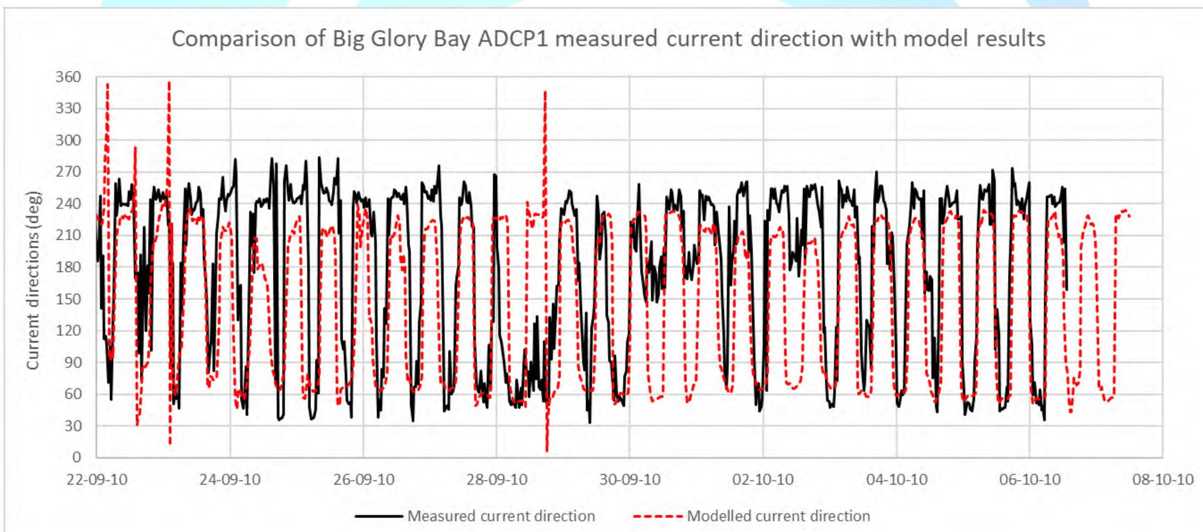

Figure 16 - Current direction comparison at ADCP1 between measured data and modelled results.

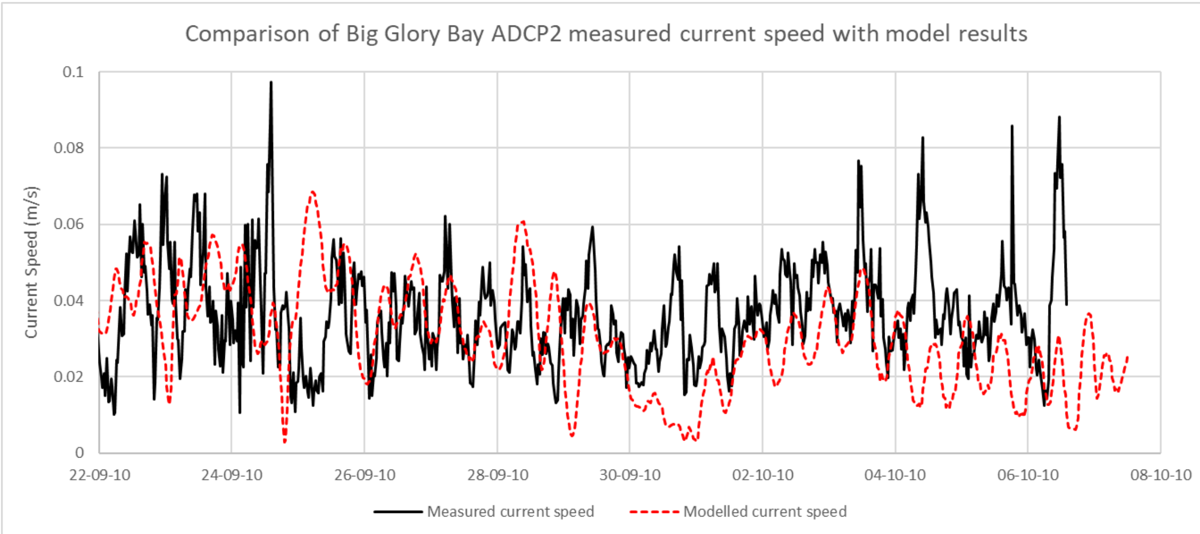

Figure 17 - Current speed comparison at ADCP2 between measured data and modelled results.

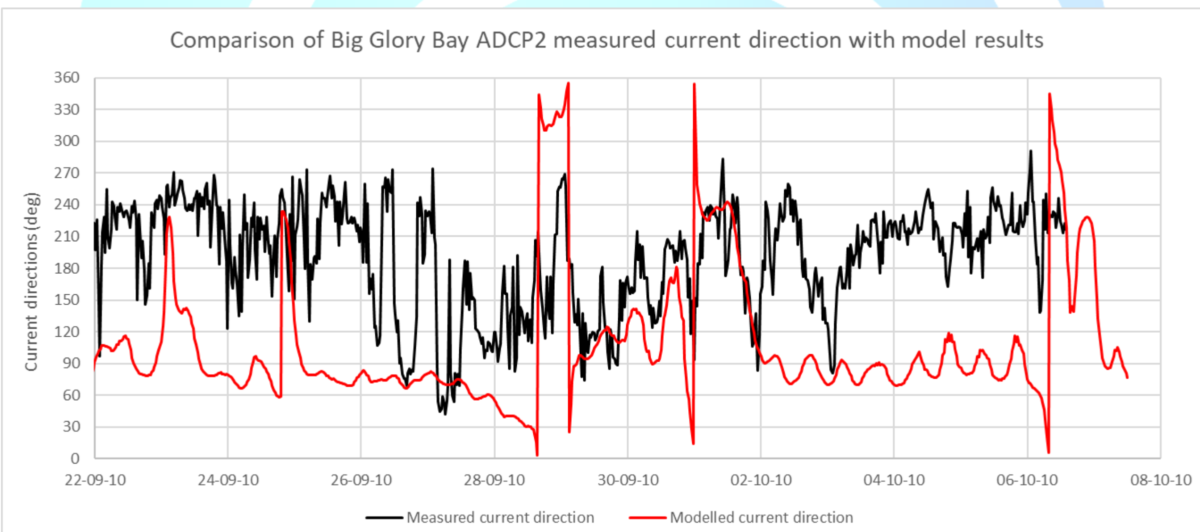

Figure 18 - Current direction comparison at ADCP2 between measured data and modelled results.

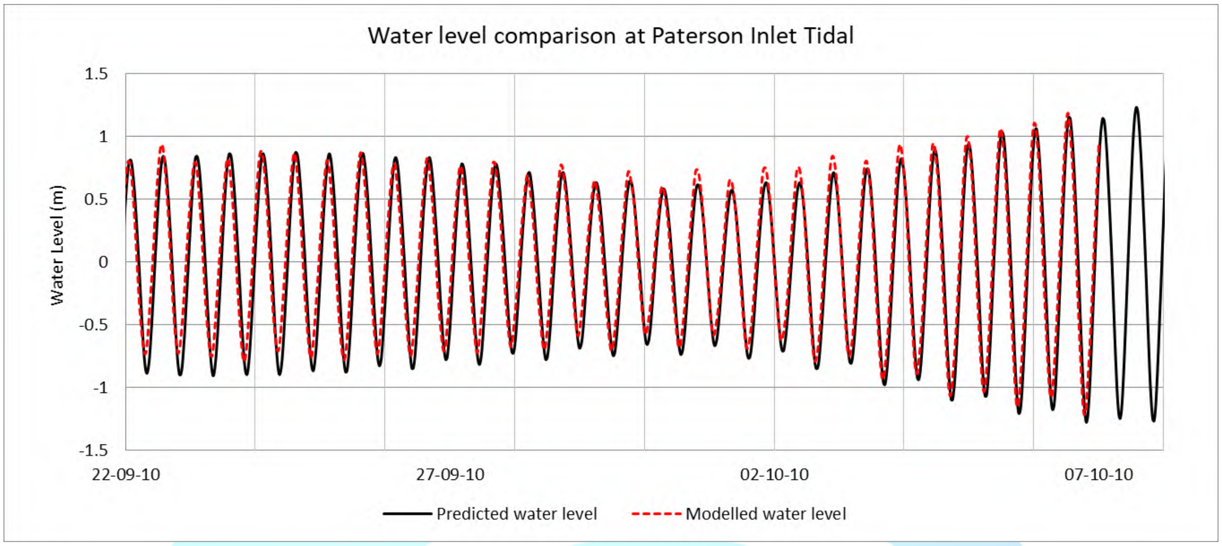

Figure 19 - Comparison of water level at Paterson Inlet tidal station between predicted tide and modelled results.

4 HYDRODYNAMIC MODEL RESULTS

Representative depth averaged local current patterns (during Spring/October conditions) are presented for spring and neap ebb and flood tidal periods within Big Glory Bay (**Figure 20**). Model results indicate that flow within the bay is weak (generally less than 5cm s^{-1}) and that flow is stronger towards the mouth of the bay. Current direction is variable and there are several eddies within the bay. In all scenarios, there is a general mouth-ward flow along the northern banks of the embayment, as well as along the southern banks.

Representative seasonal regional model results are presented in **Figure 21**. Regional model results indicate that the regional flow is generally to the east around the bottom of Stewart Island and heads up along the east coast of the South Island.

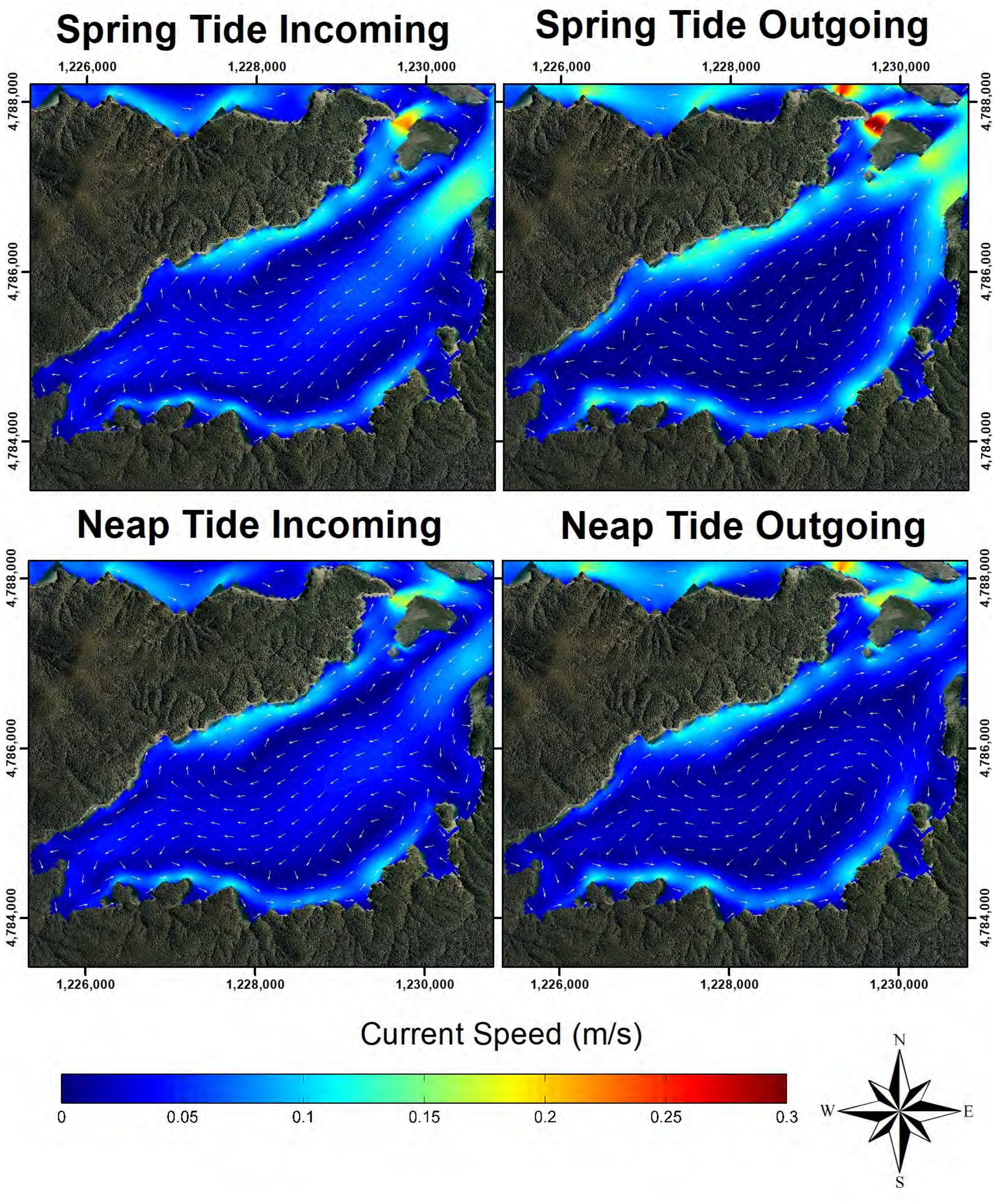

Figure 20 - Depth averaged local current patterns (during Spring/October conditions) for spring and neap ebb and flood tides.

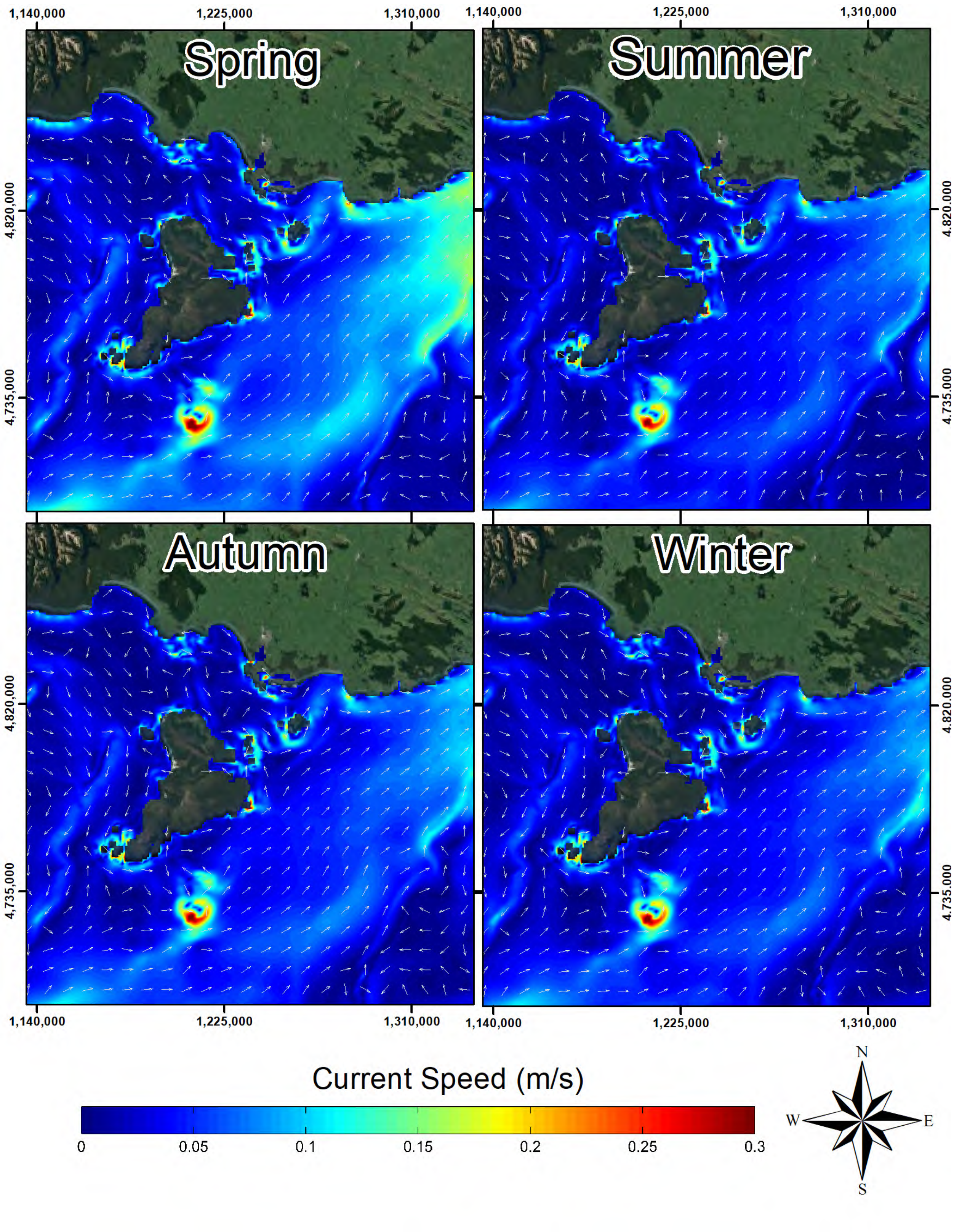

Figure 21 - Seasonal regional flow patterns around Stewart Island and the southern portion of South Island.

5 FLUSHING/RETENTION TIME

5.1 DESCRIPTION OF FLUSHING TIME

Flushing is defined as the average time it takes a conservative (not decaying over time due to biology or chemistry) substance to leave a water body (time it takes to exchange the water within Big Glory Bay).

Flushing time is important as this provides an indication of how rapidly oxygen and nutrients will be exchanged within the farming area and toward the ocean. Faster flushing will result in more rapid diluting of nutrient releases (*i.e. Total Ammonia Nitrogen* for solute fish waste) within the bay. The water outside of coastal embayments (like Big Glory Bay) generally has less nutrients and more dissolved oxygen than the water inside the bay, especially Total Ammonia Nitrogen which is rare at the surface of the ocean.

More rapid dilution of farm-derived nutrients from incoming flushing waters means that the standing concentration of those substances are reduced. This also means that oxygen within the cages can be more rapidly replenished by the generally higher oxygen concentrations found in the incoming water, raising the potential carrying capacity of the water body.

In this part of the study, a conservative tracer was used to represent the entire water column of Big Glory Bay. The hydrodynamic model was then run to calculate how long this tracer takes to be exchanged (flushed out) with water from outside of the bay. Given that there may be seasonal differences in the flushing time, four flushing simulations were run to represent each season (Spring, Summer, Autumn and Winter). Each simulation was run for a period of 90 days and plots are provided to show results after day 0, 1, 3, 7, 14, 28, 56 and day 84.

The goal of this modelling exercise is to determine the number of days required for the tracer to be flushed out of the bay for each of the 4 seasons modelled (see **Figure 22** to **Figure 29**).

5.2 SEASONAL RETENTION TIME

Model results indicate that there is a significant change in concentration between Day 0 and Day 7 for all 4 scenarios modelled. At the end of Day 7, tracer concentrations do not exceed 70% at any point inside Big Glory Bay. By day 14 tracer concentrations are approximately 40%.

After 28 days approximately 85-90% of water within Big Glory Bay has been flushed out. The remaining water is slowly transported out over the next 20-30 days or so. Results indicate that the initial exchange of the tracer is quite rapid and that the remaining 10-15% of the tracer take considerably longer.

Model results indicate that there appears to be little difference in the retention time between seasons.

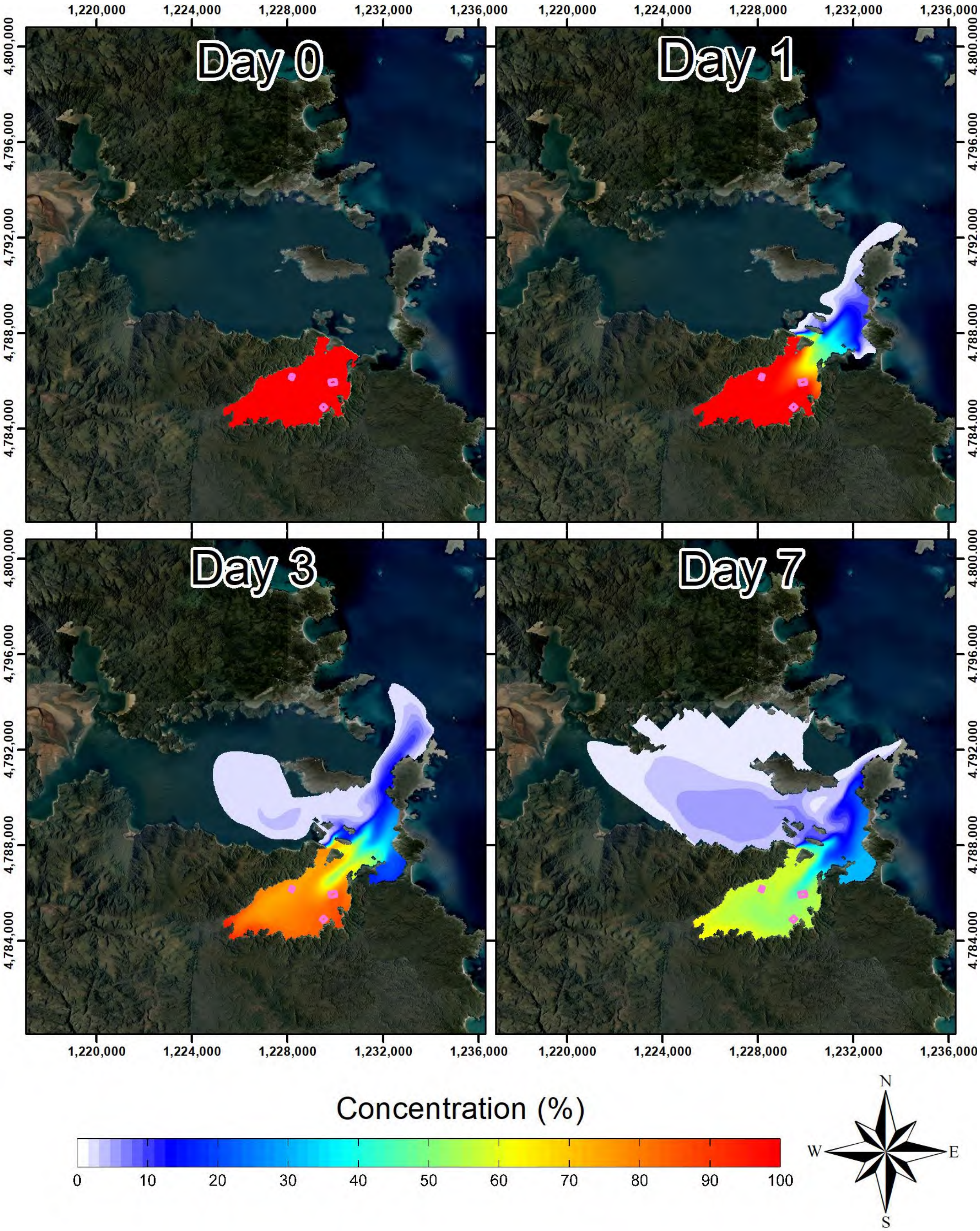

Figure 22 - Full bay flushing results for spring, day 0 to day 7.

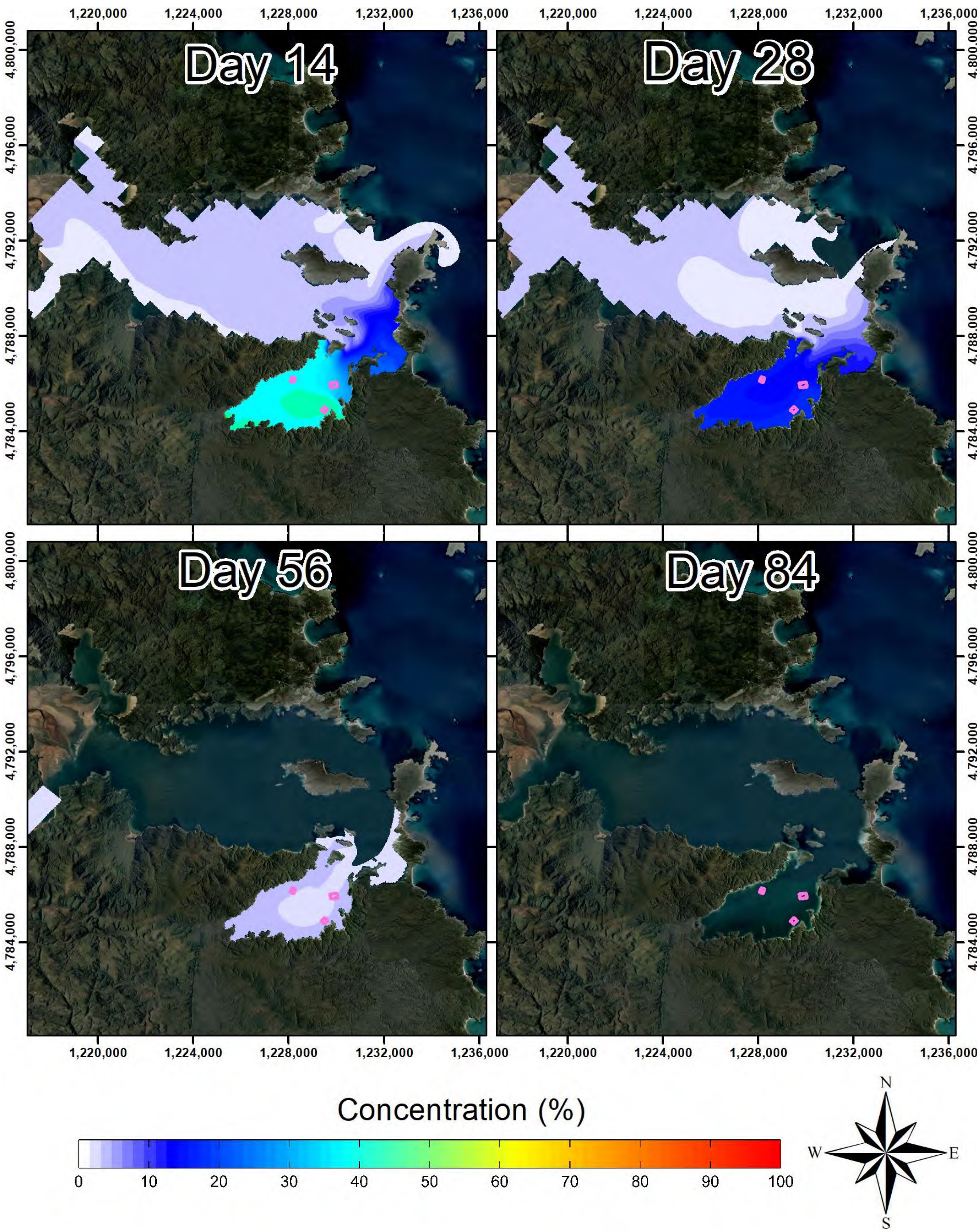

Figure 23 - Full bay flushing results for spring, day 14 to day 84.

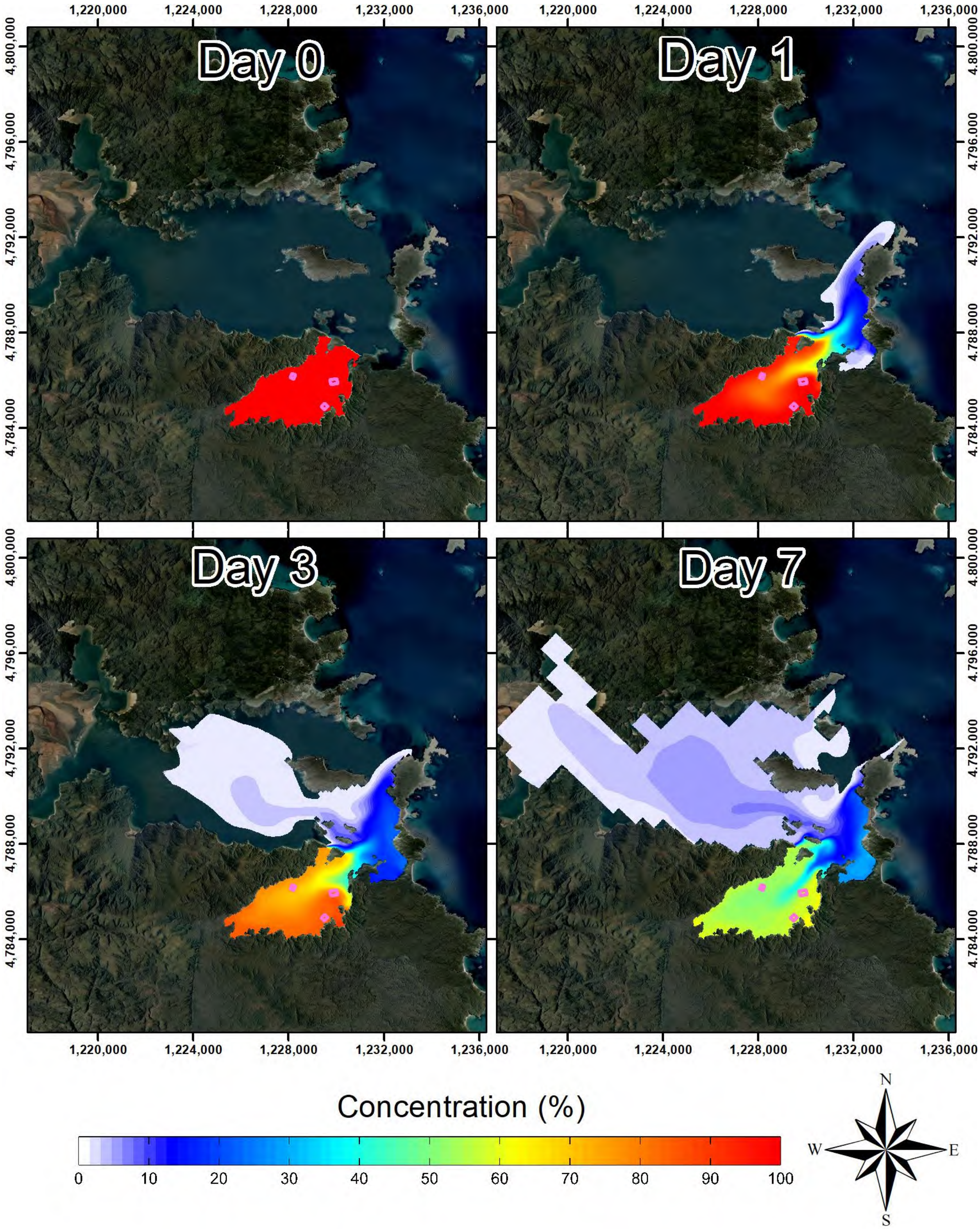

Figure 24 - Full bay flushing results for summer, day 0 to day 7.

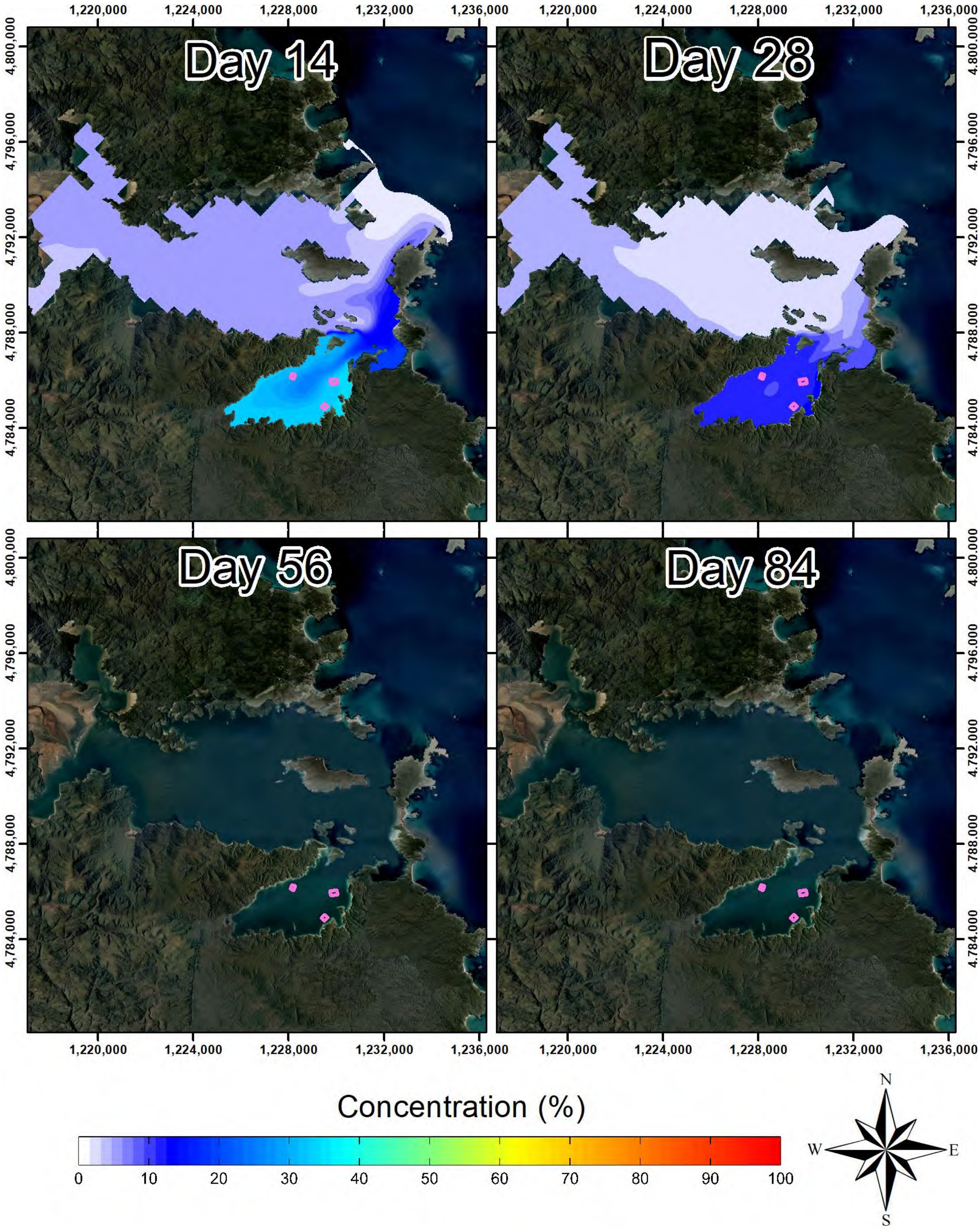

Figure 25 - Full bay flushing results for summer, day 14 to day 84.

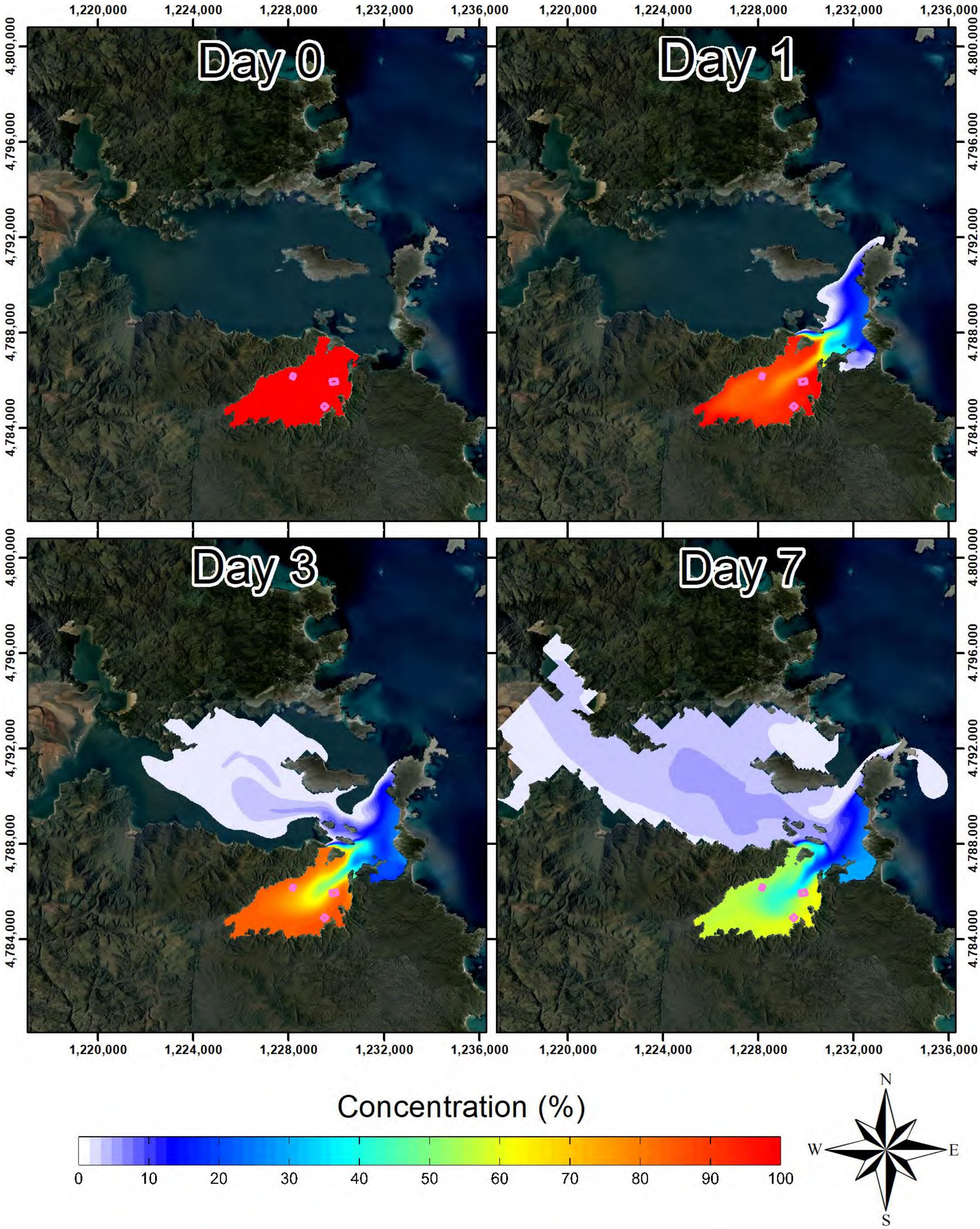

Figure 26 - Full bay flushing results for autumn, day 0 to day 7.

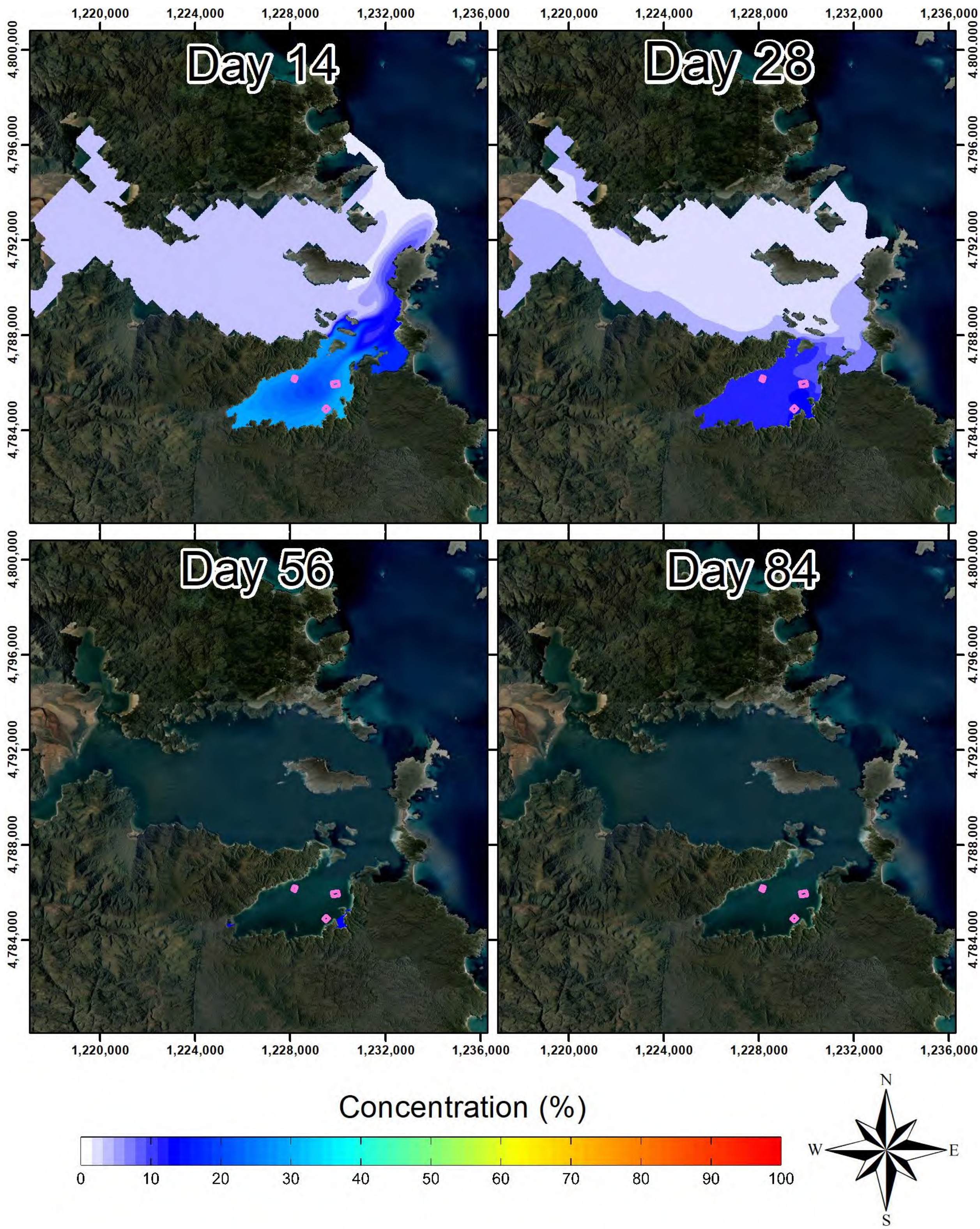

Figure 27 - Full bay flushing results for autumn, day 14 to day 84.

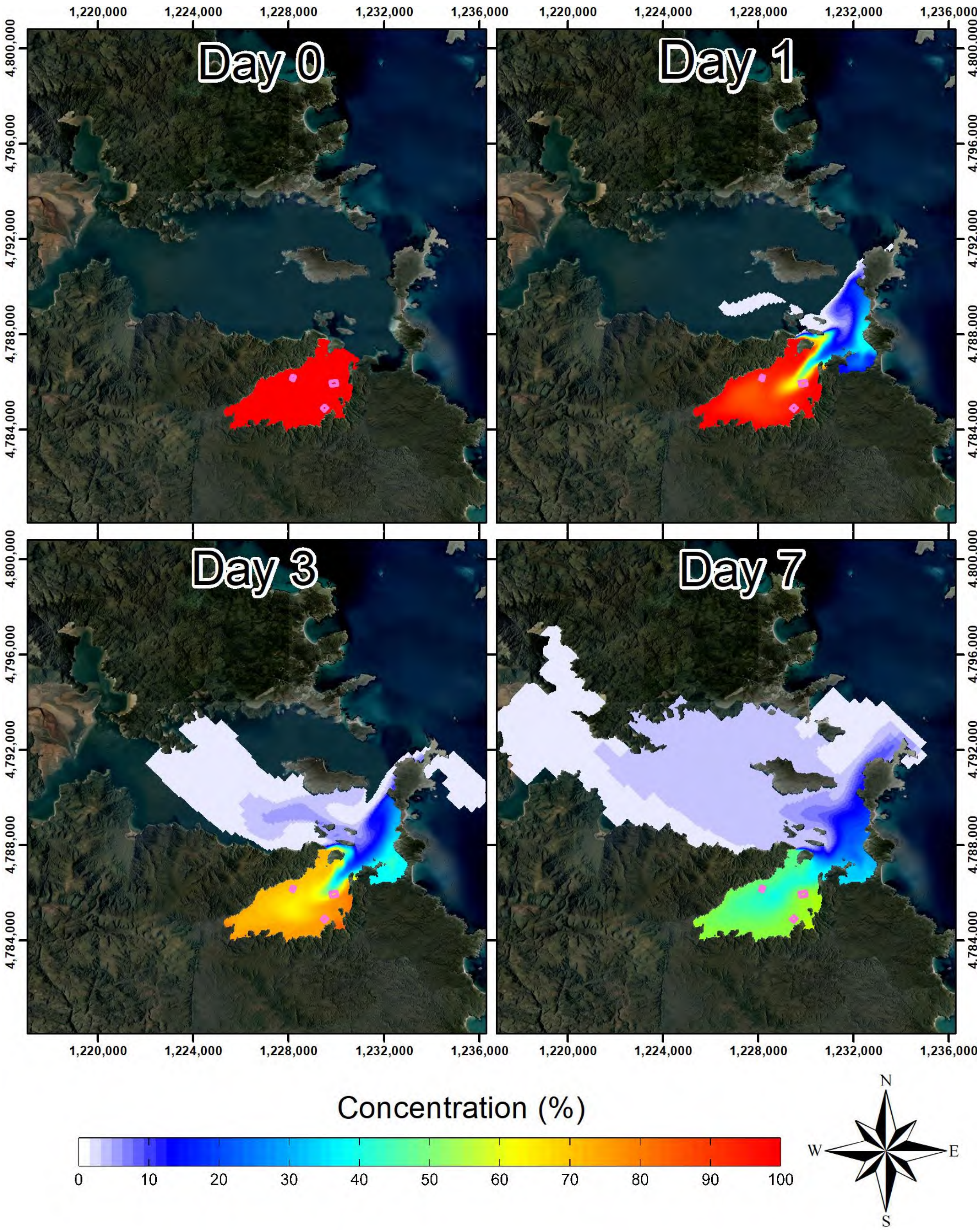

Figure 28 - Full bay flushing results for winter, day 0 to day 7.

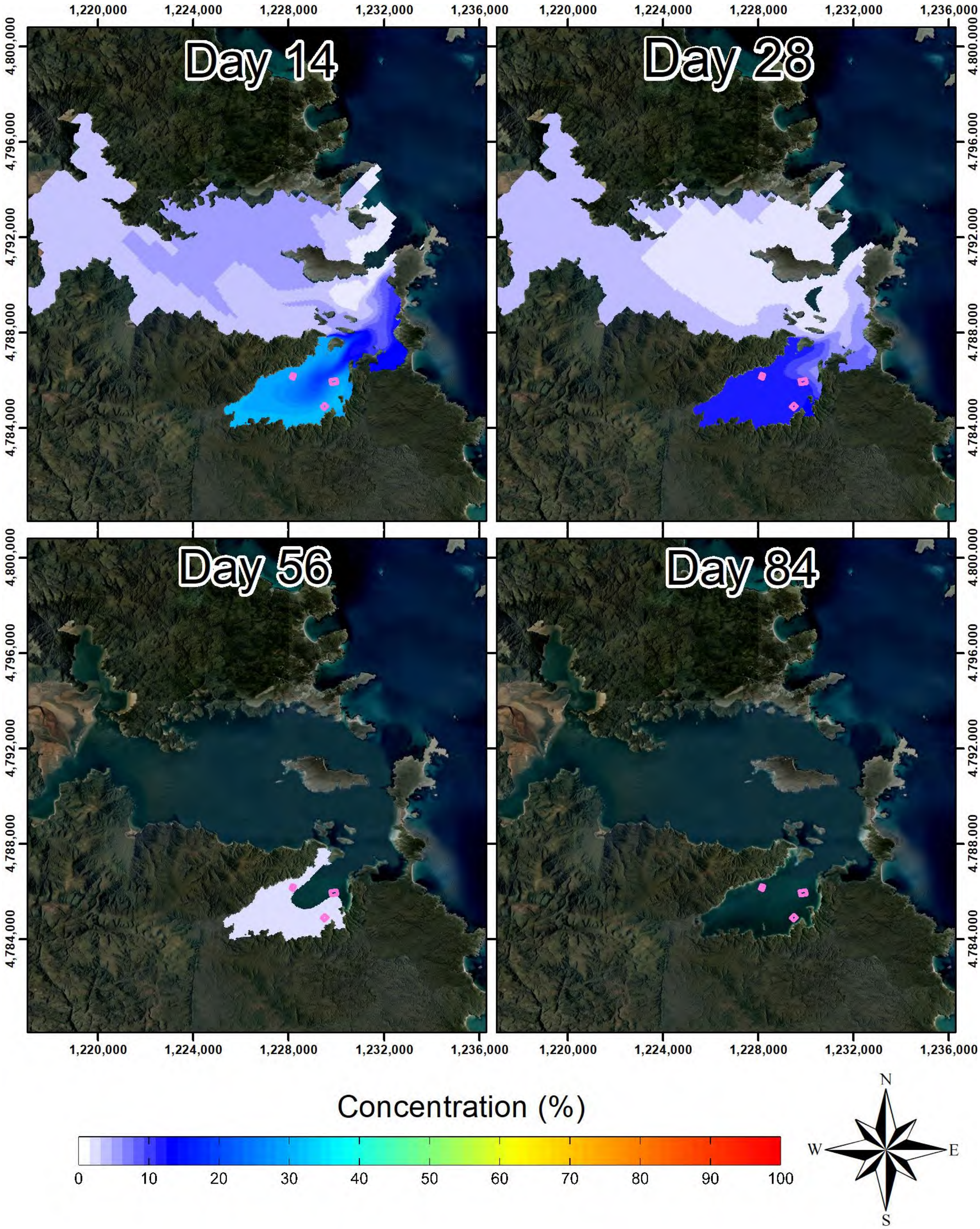

Figure 29 - Full bay flushing results for winter, day 14 to day 84.

6 CONCLUSIONS

Hydrodynamics were modelled using DELFT3D modelling software. A 2D regional model was constructed to cover the waters around Stewart Island. This model included regional tidal, wind and current information provided by internationally recognised global models. This regional model was used to transfer information to a smaller, but more detailed, local three-dimensional model that included the waters within Big Glory Bay and its immediate surrounds.

The hydrodynamic model was successfully calibrated against current speed and direction collected at two locations within the bay and water level generated from tidal harmonics in Paterson Inlet. Overall the hydrodynamic model is well calibrated and there is a good match between the ADCP current flow and direction data and that predicted by the model. This hydrodynamic model will be used to drive the water quality module (see volume 3).

Current speeds within the bay are generally low (<5cm/s) and stronger flows can be observed towards the mouth of the bay due to the narrow constriction. The flushing time of Big Glory Bay is in the order of 30 days.

7 REFERENCES

Egbert, G.D., 1997. Tidal data inversion: interpolation and inference, Progress in Oceanography 40, 81-108.

Egbert, G.D., Erofeeva, S.Y., 2002. Efficient inverse modelling of barotrophic ocean tides. Journal of Atmospheric and Oceanic Technology 19 (2), 183-204.

Hartstein, N. D, 2003. Supply and dispersal of mussel farm debris in contrasting hydrodynamic regimes. Unpublished PhD thesis. 189p.

Kalnay, E, M Kanamitsu, and WE Baker, 1990. Global numerical weather prediction at the National Meteorological Center. Bulletin of the American Meteorological Society 71:1410-1428.

Kanamitsu, M. 1989. Description of the NMC global data assimilation and forecast system. Weather and Forecasting, 4:335-342.

Plew.D., Stevens. C., Spigel. R and Hartstein N.D, 2005. Hydrodynamic Implications of Large Offshore Mussel Farms. IEEE Journal of Oceanic Engineering. Vol 30, (1) 95-108.

Rutherford, J.C., Pridmore, R.D. and Roper, D.S., 1988. Estimation of sustainable salmon production in Big Glory Bay, Stewart Island. A study conducted for MAFFish. Water Quality Centre, DSIR, Hamilton. Consultancy Report T7074/1.

Sela, J. 1980. Spectral modeling at the National Meteorological Center. Monthly Weather Review 108:1279-1292.

Stevens, C.; Plew, D.; Hartstein, N.; Fredriksson, D., 2008. The physics of open-water shellfish aquaculture, Aquaculture Engineering, 38:145-160.

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Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume III – Water Quality, Aquadynamic Solutions Sdn Bhd, November 2017.

Aquadynamic Solutions Sdn Bhd

Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand

Volume III – Water Quality

November 2017

Report prepared by

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For

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1 EXECUTIVE SUMMARY

This report describes water quality modelling studies using the DELFT3D modelling suite undertaken for Sanford Limited in Big Glory Bay, Stewart Island. This executive summary provides a summary of the main findings with particular emphasis on the release of farm-derived nitrogen (in the form of total ammonia nitrogen or "TAN") and its subsequent effects on chlorophyll-*a* as a result of expanding salmon production in Big Glory Bay.

This study also examines the potential impacts of the proposed farm expansion on dissolved oxygen levels within Big Glory Bay as a result of increased fish respiration.

1.1 APPROACH TO MODELLING

The specific modelling tool used in this report is DELFT3D, a suite of modelling tools that benefits from over 30 years of international development, and has several modules to answer almost any water related question.

Water quality modelling is used in this report to predict farm-derived release of TAN, the potential for that release to fuel phytoplankton growth, and the consumption of dissolved oxygen as a result of expanded farming activities in Big Glory Bay. To accomplish this, a tracer approach was used.

In order to test the robustness of the tracer model, a baseline scenario corresponding to existing farming operations was undertaken.

The model was run for an entire year and also included associated variations in the farming schedule. Model results were compared to measured *in-situ* results (**Figure 3**).

Following model calibration runs, two future scenarios were modelled:

1. **Mid-level expansion Scenario:** Proposed scenario representative of farming releases of TAN under conditions just below the maximum carrying capacity. Total TAN release in this scenario into the system totalled 358.28 tons which corresponded to a feed input of 621.4 tons. The baseline oxygen drawdown was set to 8.85 tons day^{-1}.

2. **Higher-level expansion Scenario:** Proposed scenario representative of the upper limit of farming TAN release according to the current assessment of Big Glory Bay's carrying capacity. Total TAN release in this scenario into the system totalled 381.2 tons which corresponded to a feed input of 659 tons. The baseline oxygen drawdown was set to 9.315 tons day^{-1}.

All water quality modelling scenarios were simulated for one year.

All modelling scenarios were simulated for one year.

1.2 WATER QUALITY RESULTS

Calibration suggests that the TAN tracer baseline model serves as a good indication of current existing TAN levels in Big Glory Bay, and that the model is robust and fit for purpose.

Baseline Scenario results show little difference in TAN, chlorophyll-*a*, and dissolved oxygen concentrations between the surface and bottom layer, except at the cage location where nutrients were released only on the top layers (reflecting cage location). Depletion of oxygen was only predicted to occur in the immediate vicinity of the farms as ambient levels are rapidly reached further away from cages.

Inside Big Glory Bay, TAN concentrations were predicted to range from 30 to 60 µg L^{-1}, and chlorophyll-*a* concentrations are in the range of 4 to 8 µg L^{-1}. The concentrations for both TAN and chlorophyll-*a* decreased slowly from spring to winter. Oxygen concentrations are approximately 0.25 mg L^{-1} lower inside the bay than outside. Small differences in dissolved oxygen concentrations were predicted between seasons due to temperature modifying the amount of oxygen water can hold.

An increase in ambient TAN concentrations between 10 and 20 µg L^{-1} is observed in the mid-level expansion Scenario. Spring and summer seasons are predicted to have additional loadings of approx. 20 µg L^{-1} excess TAN compared to the Baseline Scenario, while autumn and winter are predicted to have approx. 10 µg L^{-1} excess TAN. Small excess TAN concentrations are observed to reach Paterson Inlet (less than 5 µg L^{-1}). Should all the excess TAN be converted to plankton growth (only likely in spring and summer), excess chlorophyll-*a* would range from 2 to 3.5 µg L^{-1}.

The depletion of oxygen in the mid-level Scenario only has an effect in the immediate vicinity of the farms. Oxygen concentrations in the bay are approximately 0.25 mg L^{-1} lower than outside of the bay, and only small differences between seasons are observed (temperature effect on saturation). Oxygen depletion of up to 1.5 mg/l was observed within the cage area.

TAN increase predicted during the higher-level Scenario are slightly higher to those from the Conservative Scenario with excess TAN concentrations around 20 to 30 µg L^{-1}. A small increase in TAN concentrations (less than 5 µg L^{-1}) is also observed in Paterson Inlet, but is no higher compared to the mid-level Scenario. In the event that all the TAN is used by plankton for growth (only likely in spring and summer), excess chlorophyll-*a* is predicted to arrange range from 2.5 to 4 µg L^{-1}.

The oxygen depletion is again only seen in the immediate vicinity of the farms and ambient levels are rapidly reached further away from cages, but the difference between the mid-level and higher-level Scenario is negligible

2 INTRODUCTION

2.1 DESCRIPTION OF THE MODELLING PROCESS

For a description of the hydrodynamic modelling process, cf. Volume II – Hydrodynamic Modelling and Flushing.

Once a calibrated/validated hydrodynamic model has been finalised, extra modules can be added (*i.e.* to combine the flow field with nutrient release) in order to define the concentrations of the effluent released from the farms. The assessment of the ecological (water quality) impacts of fish farming can be addressed using a variety of different methods.

The most comprehensive method to assess farming impacts typically involves developing a fully-fledged ecological model using *in-situ* measured data. In an ideal case, this would be the preferred option, provided data are available with optimal quality and sufficient quantity. In reality, datasets that fulfil the requirements of ecological models of medium to high complexity are rarely available.

Figure 1 illustrates an example of an ecological model of low to medium complexity from **Kishi *et al.* (2007)**. This model has 11 variables which need to be set throughout the domain and 38 processes that describe the interactions between the variables

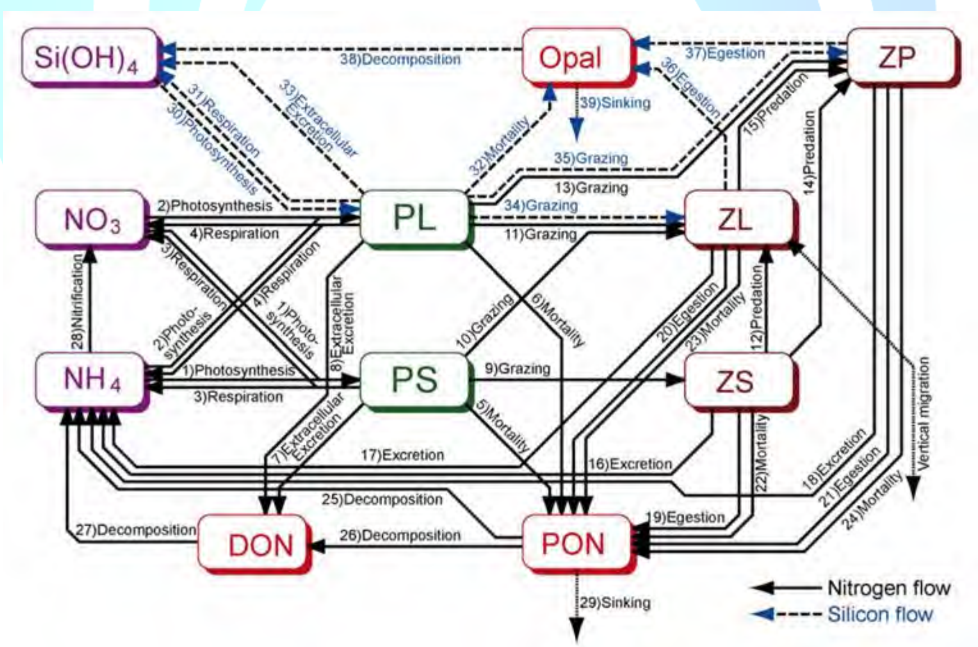

Figure 1 - Example of an ecological model of low to medium complexity (Kishi et al., 2007). Note: the boxes are variables and the arrows are processes.

2.2 Choice of Water Quality Modelling Parameters

The carrying capacity of marine embayments for fish farming (from a water quality perspective) is limited by 2 main parameters: nutrients and oxygen and are hence the focus of this water quality assessment.

Nutrients refer to the soluble wastes released by the fish, while oxygen refers to the degradation of ambient oxygen conditions due to fish respiration. While oxygen is relatively straightforward (it involves no chemical reaction), the handling of nutrients need to consider the biogeochemical reactions that occur in the water column.

Feed composition is complex, however, the waste substances can be broken down into 3 main elements, Carbon (C), Nitrogen (N) and Phosphorus (P). The main limiting nutrient in marine systems is Nitrogen (**Boynton *et al*. 1982**). This was confirmed by analysis of the *in-situ* data. Hence the modelling of water quality impacts focused solely on N.

Solute N is released by the fish in the form of Total Ammonia Nitrogen (TAN), a term that corresponds to both the innocuous ionized version of Ammonia (NH_4^+) and the toxic variety (NH_3^-). Both coexist in the water column in quantities defined by an equilibrium.

Upon being released into the water column, TAN is subjected to a few potential processes. One of them is the previously discussed uptake by algae, while the second major pathway involves nitrification, a process in which TAN is transformed into nitrates (NO_3^-).

2.3 Model Description

DELFT3D (Deltares 2017 [1]), a suite of modelling tools that benefits from over 30 years of development and offers the flexibility to develop numerical models of different dimensions (2D, 3D) and a number of modules to answer almost any water related questions.

For a complete description of the DELFT3D modelling suite, cf. Volume II – Hydrodynamic Modelling and Flushing.

[1] DELFT3D: URL https://oss.deltares.nl/web/delft3d/).

3 WATER QUALITY MODEL SET-UP

3.1 MODEL DOMAIN

The modelling extent remains the same as the local hydrodynamic model (cf. Volume II – Hydrodynamic Modelling and Flushing).

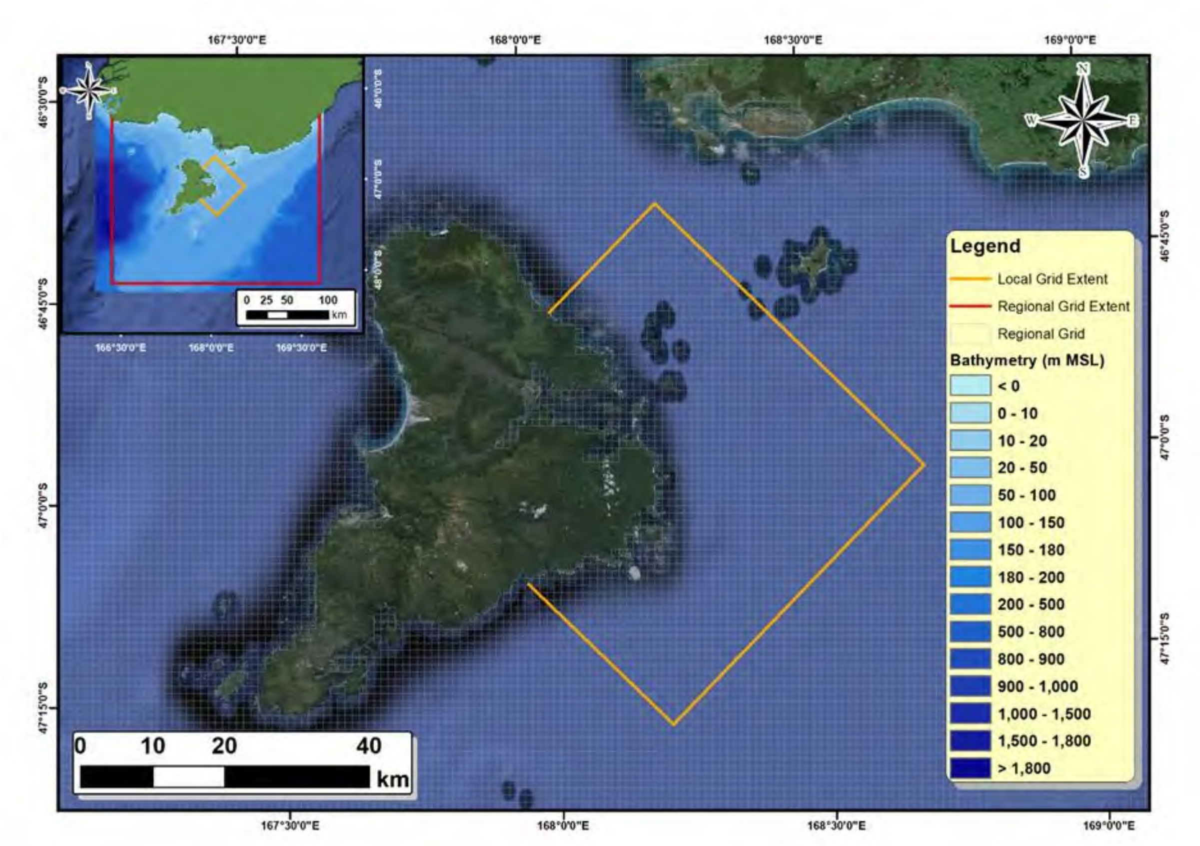

Figure 2 - Extent of regional and local grids.

3.2 MODELLING PERIOD

The modelling period remains the same as that of the local hydrodynamic model and runs from September 2015 to September 2016.

3.3 BOUNDARY CONDITIONS

3.3.1 TAN

As the model is using a conservative tracer, boundary conditions have been set to zero as the only source of the nutrients inside the model domain are the farms.

3.3.2 Oxygen

Oxygen impacts from fish farming are modelled as reductions in oxygen as a result of respiration from the fish held in cages. While the model could output negative concentrations, it is more meaningful to have realistic background levels of oxygen on top of which drawdown is calculated to produce predicted *in-situ* concentrations. The boundaries have been set to replenish the model with oxygen based on data from the global HYCOM[2] model.

3.4 Initial Conditions (inside the model domain)

In a tracer model, the aim is to simulate the excess concentrations of a particular effluent. Initial conditions (values that the model starts with) are typically set to 0 throughout the domain. This leads to a so-called "warm-up period" during which the model will adjust the start conditions towards a point at which the model is in "equilibrium".

In order to prevent this, the water quality models were run once with initial conditions set to zero, and then a second time with starting conditions taken the final time step of the first run (*i.e.* first day of September). This way, the initial conditions at the start of September are representative of the existing farm conditions.

The initial conditions for oxygen are based on HYCOM model records and measurements collected in BGB.

3.5 Water Quality Parameters

The key calibration parameters for the Water Quality Model, are displayed in **Table 1**.

Table 1 – Calibration parameters for the Water Quality Model.

Calibration Parameter	Value(s)
Uniform dispersion (1st direction) [m^2 s^{-1}]	1
Uniform dispersion (2nd direction) [m^2 s^{-1}]	1
Vertical diffusion [m^2 s^{-1}]	$1.00E^{-07}$
Decay rate [day^{-1}]	0
Integration method	15-iterative solver, backward differences

[2] HYCOM (HYbrid Coordinate Ocean Model) : https://hycom.org/

3.6 Water Quality Scenarios and Load Inputs

3.6.1 Water column nutrient release (TAN)

For the TAN release modelling, 2 scenarios were undertaken:

1. Mid-level Scenario : Corresponding to a feed input of 621.4 tons of N.
2. Higher-level Scenario : Corresponding to the maximum carrying capacity of Big Glory Bay and a maximum feed input of 659 tons of N.

All scenarios were based on feed data supplied by Skretting and Sanford in the form of monthly schedules.

The load inputs for the 2 scenarios expressed as tons of TAN and total N in the feed per month are presented in **Table 2**.

Table 2 – Big Glory Bay Model TAN Load Inputs

	Mid-level	Higher-level
January	32.18	34.03
February	31.05	32.68
March	29.61	32.33
April	30.21	32.80
May	31.49	33.36
June	29.16	30.69
July	27.50	29.05
August	26.03	27.45
September	26.13	27.55
October	27.66	28.21
November	32.86	35.69
December	34.40	37.42
TOTAL TAN	358.28	381.2
TOTAL N in FEED	621.4	659

3.6.2 Oxygen

Modelling of oxygen impacts consists in subtracting quantities of oxygen in farming leases based on fish respiration. The oxygen drawdown is set to match a daily feeding schedule with feeding occurring twice daily for approximately 30 minutes. The rates of oxygen consumption are in line with values from the literature which were also used in the previous carrying capacity assessment (**DHI, 2010**): 50 mgO_2 kg $fish^{-1}$ $hour^{-1}$ for non-feeding time and 450 mgO_2 kg $fish^{-1}$ $hour^{-1}$ during feeding. The high rates of oxygen consumption during feeding were adjusted to reflect the intense energy expenditure of the feeding process (fish swim faster). The final quantities of oxygen consumption in the model (**Table 3**) were based on the N release, using typical cage stocking rates varying between 12 and 14 kg m^{-3}.

Table 3 – Big Glory Bay Model Oxygen Drawdown Inputs

Big Glory Bay Oxygen Drawdown Inputs (tons day^{-1})

	Mid-level	Higher-level
	8.85	9.315

4 WATER QUALITY MODEL CALIBRATION

4.1 WATER QUALITY MODEL CALIBRATION SCENARIO

In order to test the robustness of the tracer model, a calibration scenario corresponding to existing farming operations was undertaken.

The model was run for an entire year and also included associated variations in the farming schedule.

4.2 CALIBRATION RESULTS

Model results are compared with measurements taken near the centre of the bay. The model displays only gradual variations in monthly averaged TAN concentrations, with a mean value centred around 50 µg L^{-1} (**Figure 3**).

Despite the use of a conservative tracer, which is not subjected to biogeochemical processes such as nitrification (conversion of TAN to nitrate) or algal growth (consumption by algae), model results are in reasonable agreement with the measurements from the Sanford water quality monitoring programme. The best agreement occurs at the end of summer and through autumn and winter, with an exception for August which displays anomalously low levels of TAN. During these months, nutrients cannot be efficiently utilized as cool temperatures and lower levels of sunlight limit phytoplankton photosynthesis. In short nutrients are behaving somewhat like a conservative tracer (there is no demand and they will slowly accumulate).

During warmer months when days are long and therefore light is not a limiting factor, algae maximize their production and use the available nutrients, until they are depleted (September, November and December). During these months, TAN does not behave like a conservative tracer anymore. It appears to have been removed from the water column, but N that was in the form of TAN is actually still present in the biomass of the plankton.

Big Glory Bay also contains a large number of mussel farms which grow by filtering particulate organic matter out of the water column. As was pointed out by **Key (2001)**, there is a significant statistical correlation between water temperature and mussel growth, indicating that spring and summer months see the fastest increase in mussel mass due to the availability of plankton. Thus, the amount of plankton ingested by mussels, and the concomitant mass of N removed from the system, is highest in spring and summer, something that is reflected in the total N levels during these months (**Figure 4**).

As a summary, the conservative TAN tracer baseline model serves as a good indication of current existing TAN levels in Big Glory Bay. The TAN modelled during spring and summer will most likely not be measurable in the water column, and instead be taken up by plankton, some of which will end up removed from the system due to mussel ingestion and their subsequent harvest. As a tool, this model approach allows predicting future potential levels of TAN in Big Glory Bay under different fish farming scenarios.

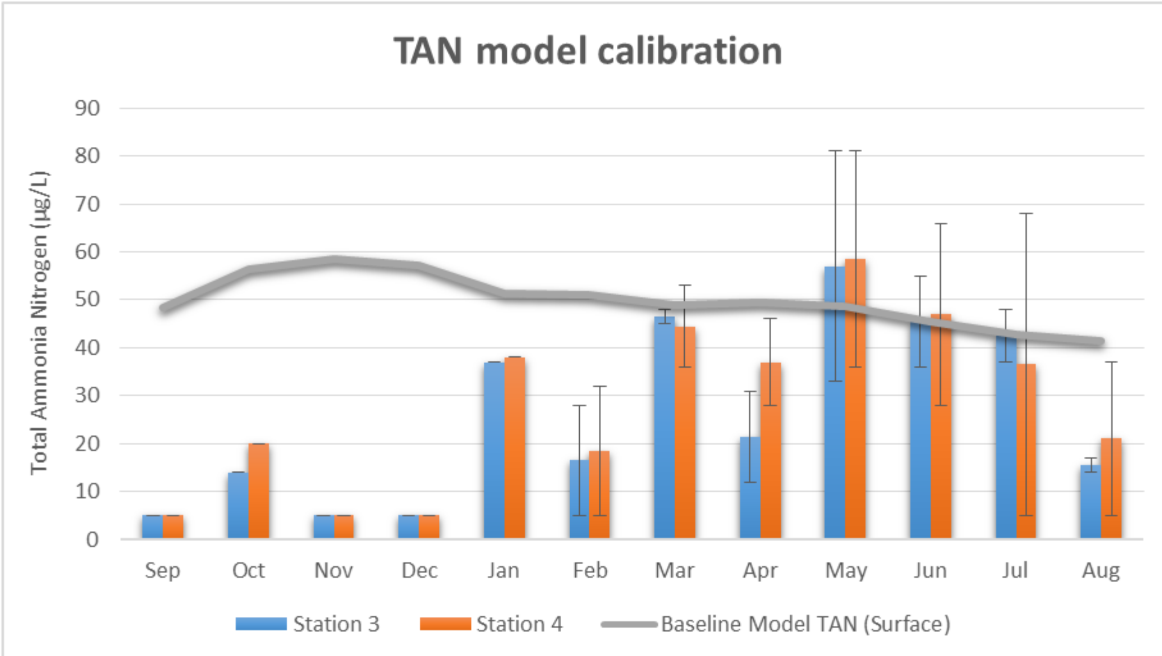

Figure 3 – Comparison between the measured TAN concentrations from the Sanford monitoring and the conservative tracer model results (model results are monthly averaged).

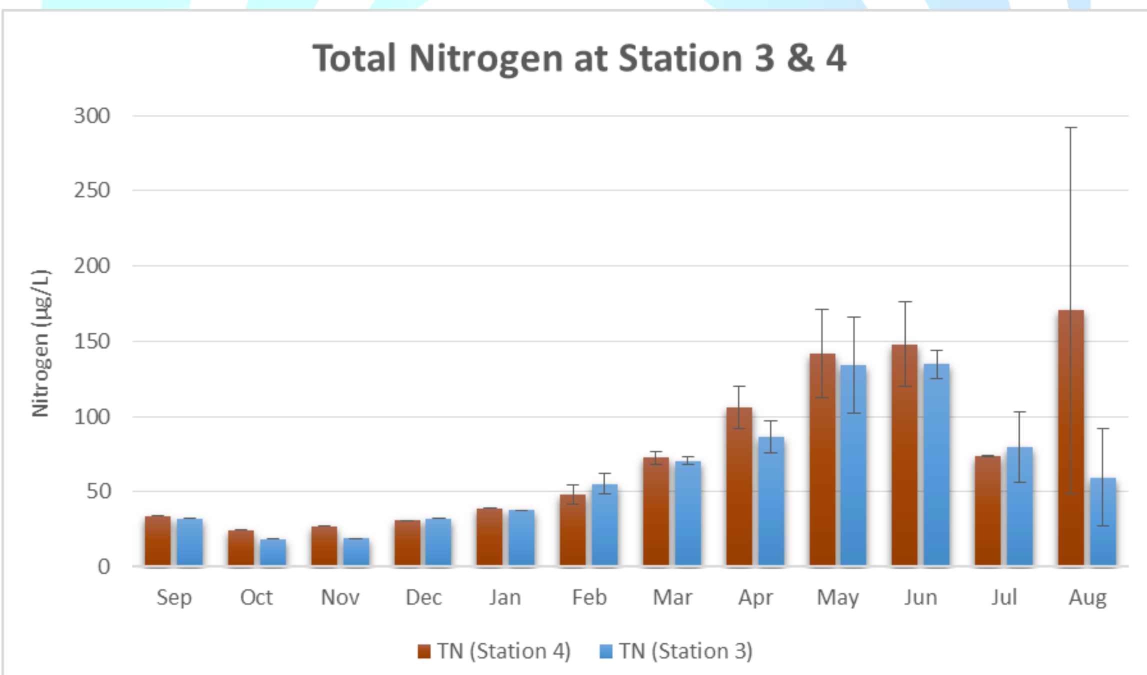

Figure 4 – Total Nitrogen (sum of TAN, nitrate and Particulate Nitrogen). Note: the estimated Total Nitrogen does not include Dissolved Organic Nitrogen (DON) for which measurements are not available.

5 WATER QUALITY MODEL RESULTS

5.1 WATER QUALITY MODEL OUTPUTS DESCRIPTION

The model provides three dimensional maps of the predicted TAN and dissolved oxygen concentrations within the entire domain. Results were aggregated and presented as two dimensional seasonal averages (Spring, Summer, Autumn and Winter) or as time series data.

While TAN maps can be presented for both the surface and bottom, as shown in the calibration scenario results, the differences between the surface and bottom were observed to be insignificant outside of the immediate vicinity of the farm(s). In order to keep this report concise only surface maps (showing concentrations in the upper 2 meters of the water column are presented. Comparison maps between the scenarios are also presented.

In order to illustrate the potential implications of an increase in TAN on phytoplankton, maps of a corresponding increase in chlorophyll-*a* were also created using those TAN outputs.

5.2 DESCRIPTION OF CHLOROPHYLL-A ASSUMPTIONS

As a conservative worst case, all TAN has been assumed to be converted to phytoplankton biomass and represented by an increase in the chlorophyll-*a* concentration.

In reality, only some nutrients will be used for plankton growth, as the nutrient seasonal cycle clearly shows that winter algae concentrations are generally depressed compared to spring and summer. Furthermore, while the sampling datasets show that levels of TAN are sometimes depleted below detectability, TAN levels rarely fall to zero. This indicates that there are factors that limit algal consumption of nutrients.

Converting the TAN results from the model to chlorophyll-a was a 2 step process. First, the TAN (nitrogen) was converted to its C equivalent in plankton. This is done using the widely used Redfield ratio which corresponds to the statistical average composition of plankton in the sea, with a ratio of C to N of 106:16. The second step consists in calculating the amount of chlorophyll-a associated with algal C, using a C to Chlorophyll-*a* ratio for phytoplankton.

The C to Chlorophyll-*a* ratio is subject to significant variability. In the Marlborough Sounds, it was found to vary between 25 and 500 seasonally depending on the algal species composition (**Ren and Ross, 2005**). Data collected in Big Glory Bay varied between 1 and almost 900. Given this large variability, a C:Chl-*a* ratio was applied that is representative of average conditions within the bay. Based on the work **Sathyendranath et al., 2005** and information on the various algae groups within the bay a value of 50 was selected.

5.3 TAN Results

5.3.1 Model Calibration

As previously described, the calibration is based on the existing nutrient input, occurring predominately in Lease 246. **Table 2**, **Figure 5** and **Figure 6** show the simulated seasonally averaged concentration of TAN at the surface and bottom layers respectively. From these TAN results, seasonally averaged chlorophyll-*a* concentrations were estimated using the previously described assumptions (**Figure 7** and **Figure 8**).

Modelled results show little difference between the surface and bottom layer, except within cage locations where nutrients were released only in the top layers of the 3D model. Inside Big Glory Bay, TAN concentrations are in the 30 to 60 µg L^{-1} range, and chlorophyll-*a* concentrations are in the range of 4 to 8 µg L^{-1}. The concentrations for both TAN and chlorophyll-*a* decreases slowly from spring to winter. The chlorophyll-a levels of 8 µg L^{-1} seen in the centre of the bay are significantly higher than what has been measured as part of the Sanford monitoring programme. While higher levels of chlorophyll-a have been occasionally sampled, phytoplankton was observed to quickly reduce (**per.com Phi. Nicolson**). The model appears to be overly conservative in regard to chlorophyll-*a* and likely a significant portion of the phytoplankon is being consumed by the farmed mussels that are growing within the bay.

In the seaonsally averaged results, small concentratons of TAN and chlorophyll-*a* can be observed in Paterson Inlet, with an approximate maximum of 5 µg L^{-1} for TAN, and 0.5 µg L^{-1} for chlorophyll-*a*.

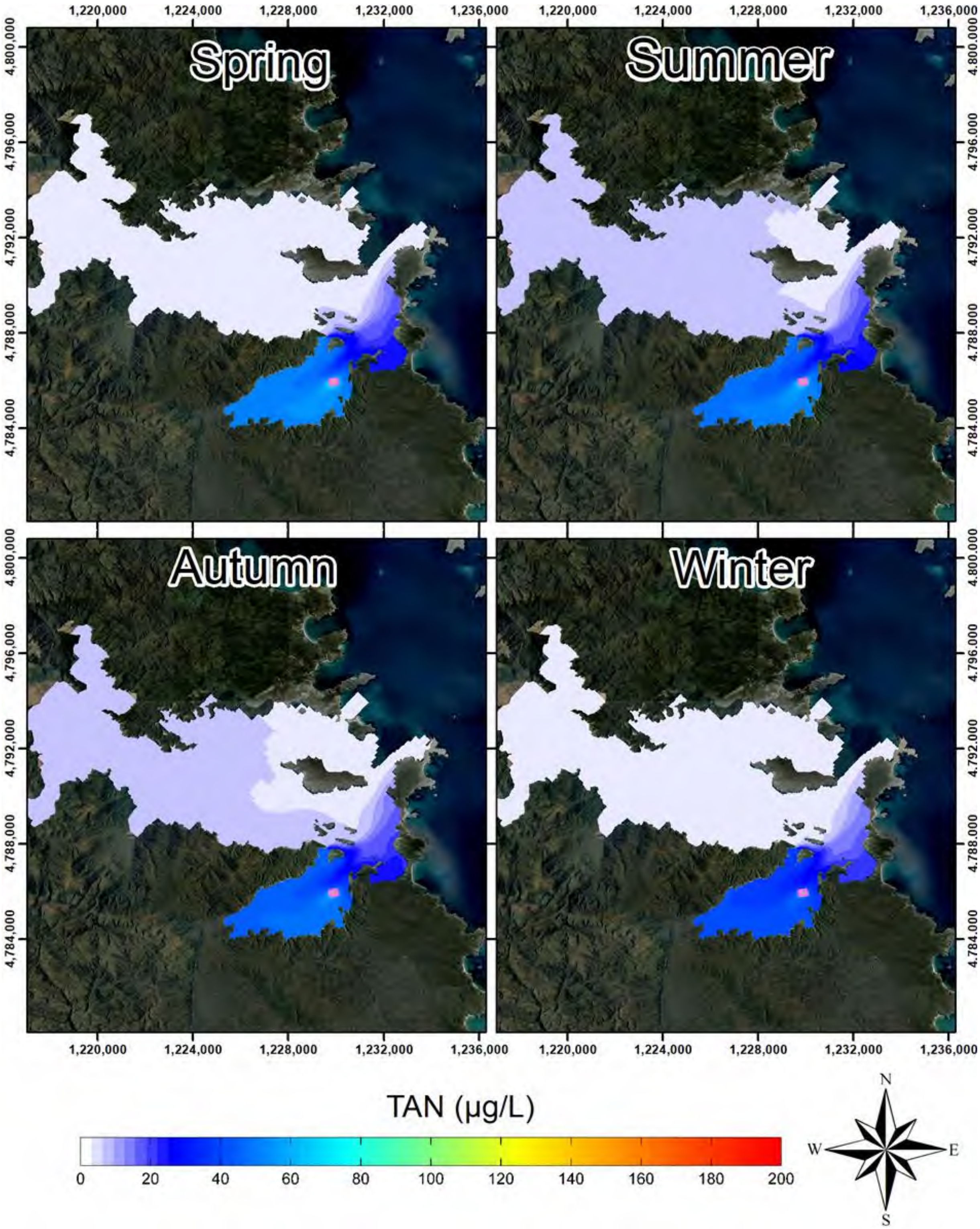

Figure 5 - Seasonal average surface concentrations of total ammonia nitrogen (TAN) during the calibration scenario.

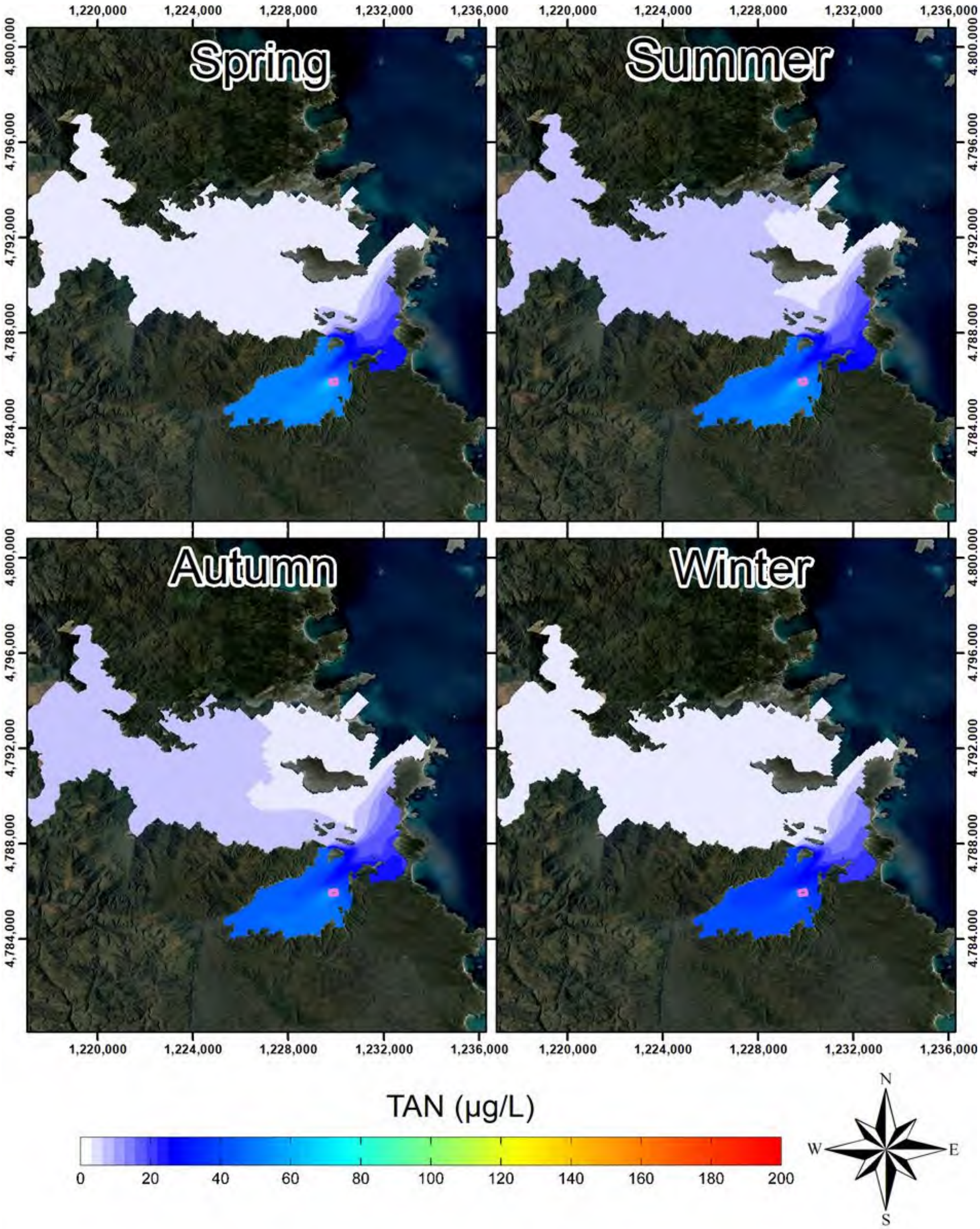

Figure 6 - Seasonal average bottom concentrations of total ammonia nitrogen (TAN) during the calibration scenario.

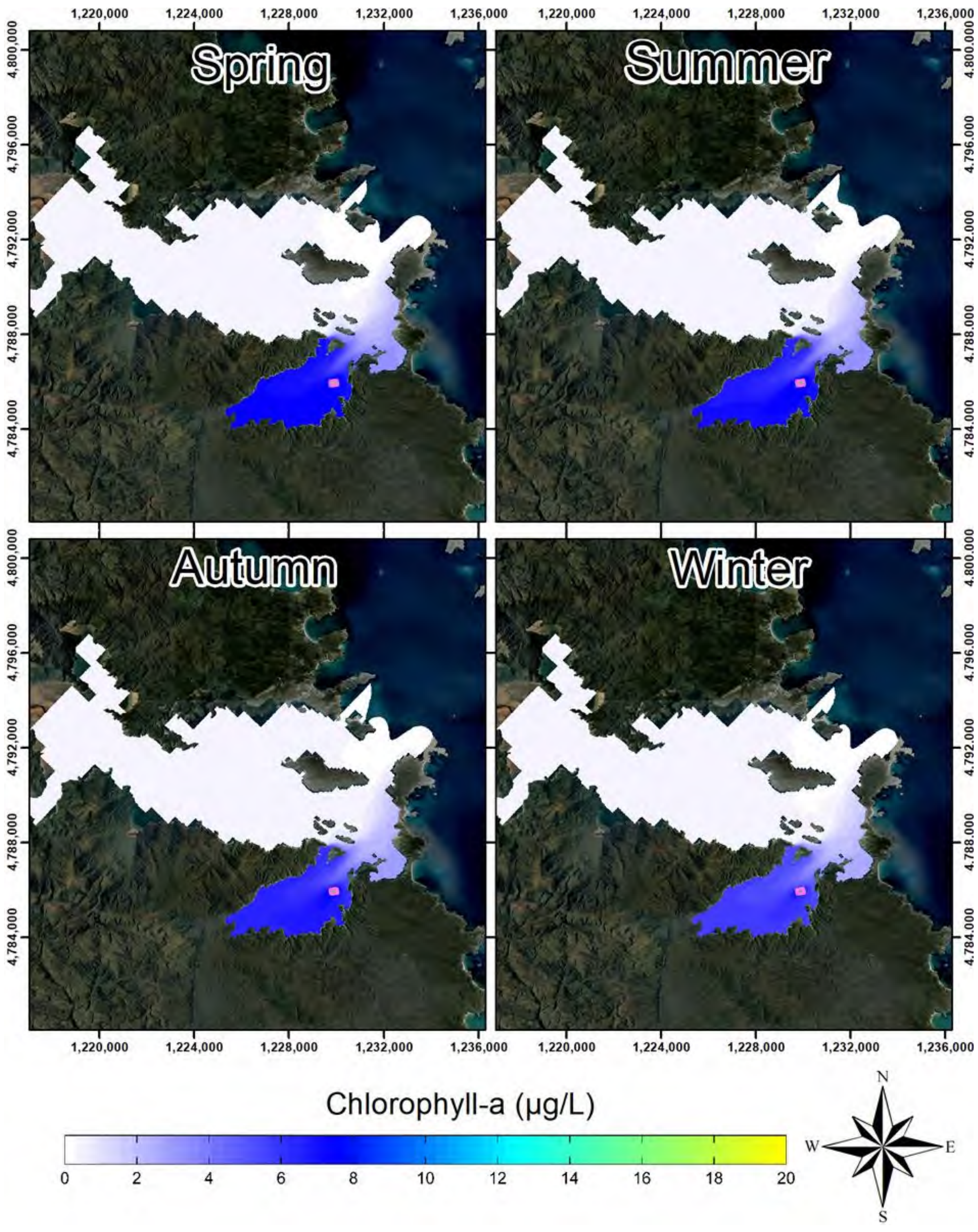

Figure 7 - Seasonal average surface chlorophyll-a concentrations during the calibration scenario.

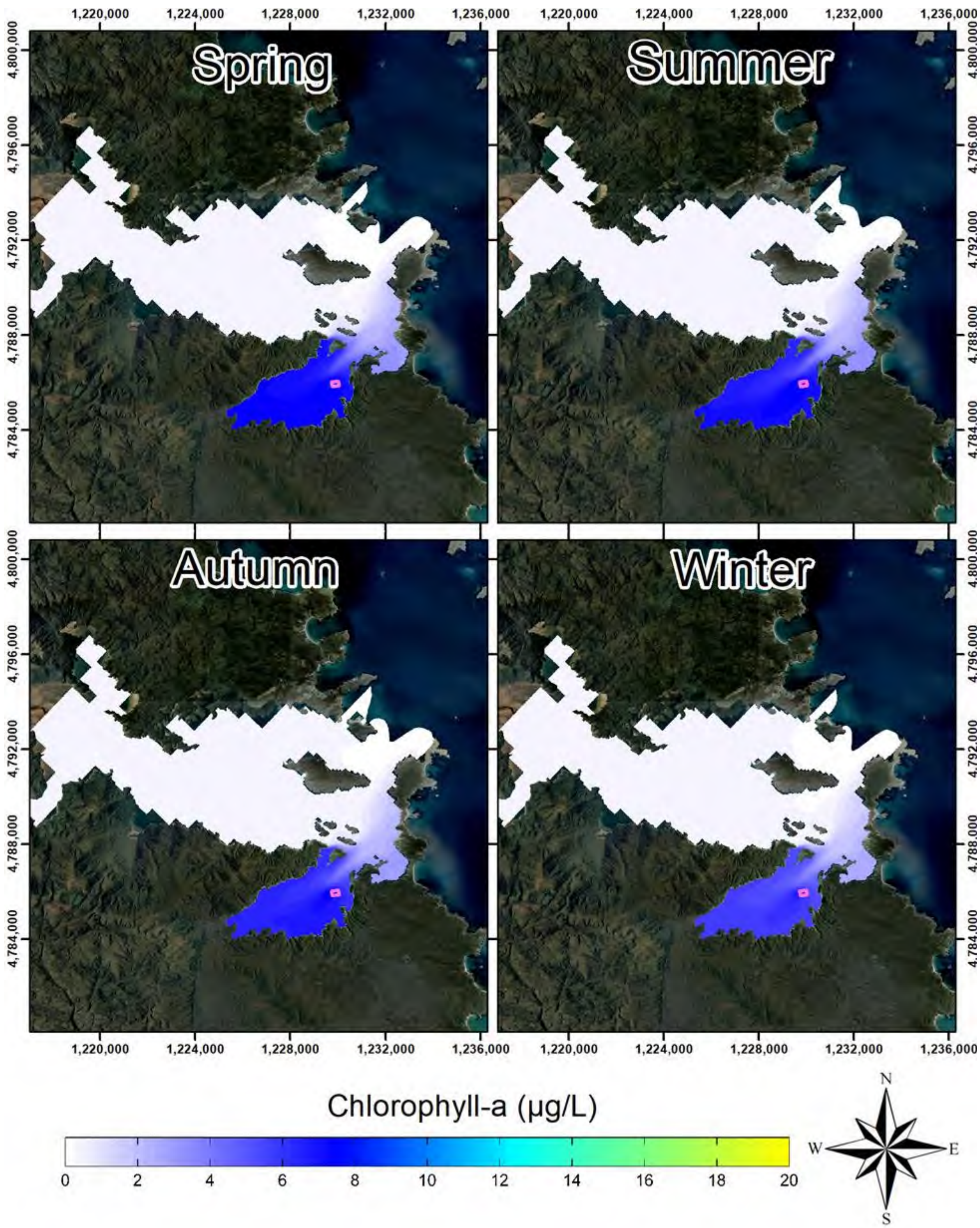

Figure 8 - Seasonal average bottom chlorophyll-a concentrations during the calibration scenario.

5.3.2 Mid-level Scenario

The nutrient release from three leases 246, 320 and 339 was modelled during the mid-level scenario. Detailed inputs can be found in **Table 2** for TAN, and for dissolved oxygen in **Table 3**. Lease location maps can be found in volume II.

Modelled results were processed and analysed to determine the difference between the mid-level scenario, and calibration scenario (existing conditions). Results from the calibration were subtracted from the mid-level scenario to visualise the potential impacts.

An increase in ambient TAN concentrations between 10 and 20 µg L^{-1} is observed. Spring and summer show a nutrient level increase of approximately 20 µg L^{-1} compared to the calibration scenario, while autumn and winter indicate a smaller increase of about 10 µg L^{-1} TAN.

Small excess TAN concentrations are observed to reach Paterson Inlet (less than 5 µg L^{-1}).

Should all the excess TAN be converted to plankton growth (measured as chlorophyll-*a*), a scenario only likely in Spring and Summer, we would expect a maximum possible chlorophyll-*a* increase of between 2 and 3.5 µg L^{-1} above the calibration before taking mussel farming into consideration.

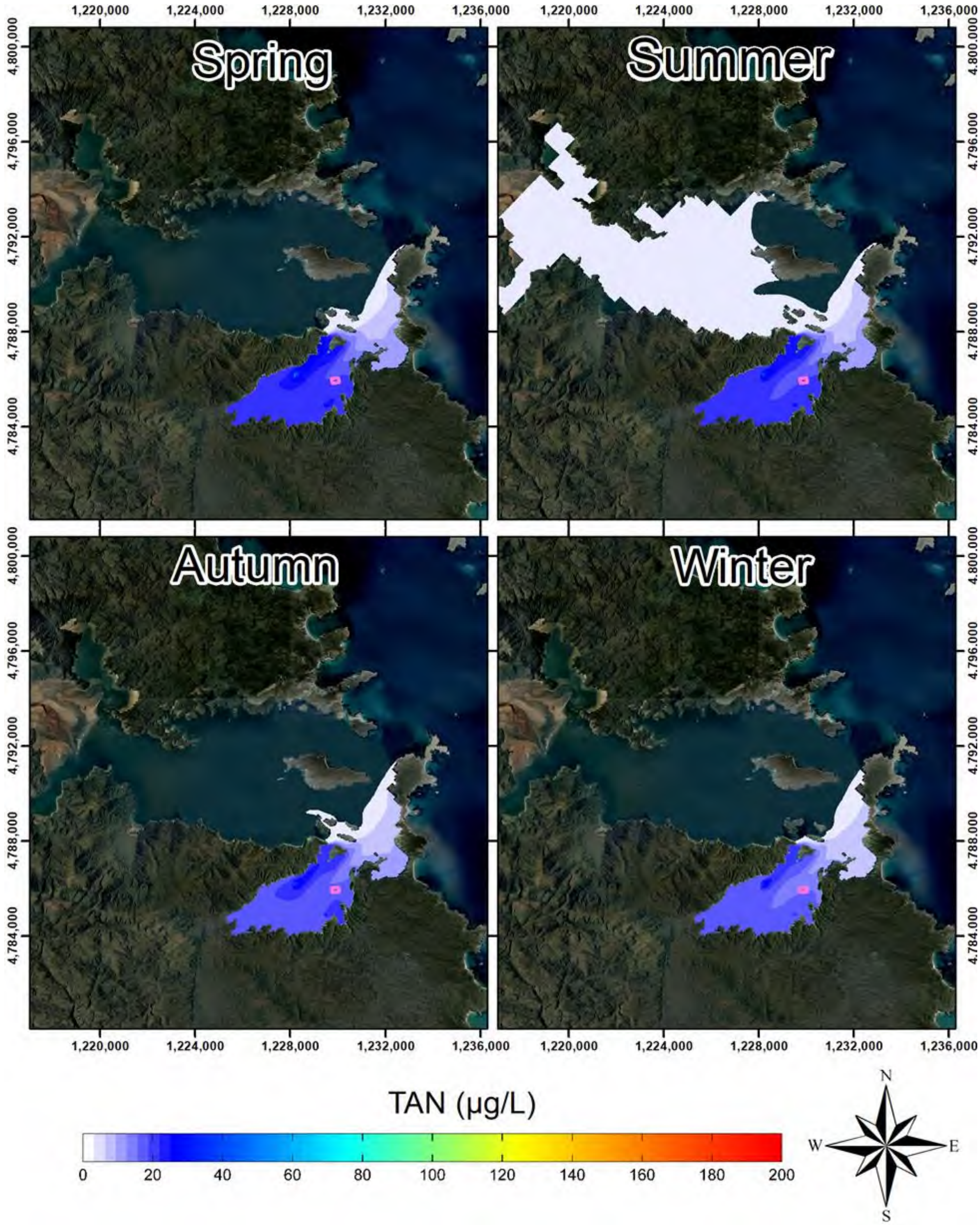

Figure 9 - Seasonal average excess concentrations of total ammonia nitrogen (TAN) during the mid level scenario (mid-level minus calibration) at the surface.

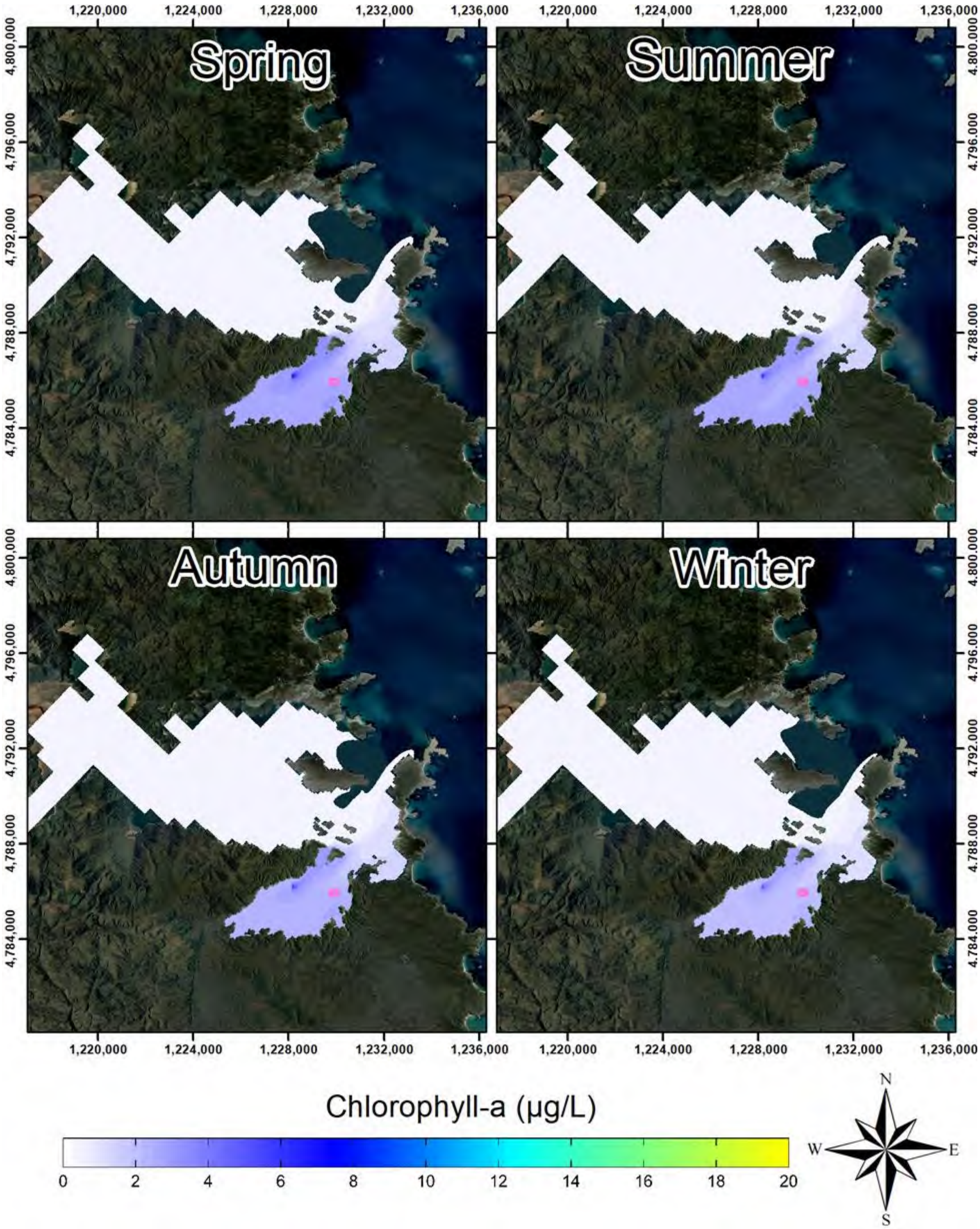

Figure 10 - Seasonal average excess concentrations of chlorophyll-a during the mid-level scenario (mid-level minus calibration) at the surface.

5.3.3 Higher-level Scenario

This scenario was modelled to represent the maximum carrying capacity in Big Glory Bay and assumed a feed input of approximately 659 tons of nitrogen. The nutrient and oxygen consumption inputs can be found in **Table 2** and **Table 3**.

As with the mid-level Scenario, TAN concentrations from the higher-level scenario were deducted from the calibration scenario results to determine the incremental impact.

Inside Big Glory Bay, the impacts are similar to those from the mid-level scenario but as expected slightly higher, with excess TAN concentrations of approximately 20 to 30 µg L^{-1}.

Small TAN concentrations (less than 5 µg L^{-1}) were also observed in Paterson Inlet.

Should all excess TAN be converted to plankton growth (measured as chlorophyll-*a*), a scenario only likely in Spring and Summer, we would expect a maximum possible chlorophyll-*a* increase of between 2.5 and 4.0 µg L^{-1} above baseline before taking mussel farming into consideration.

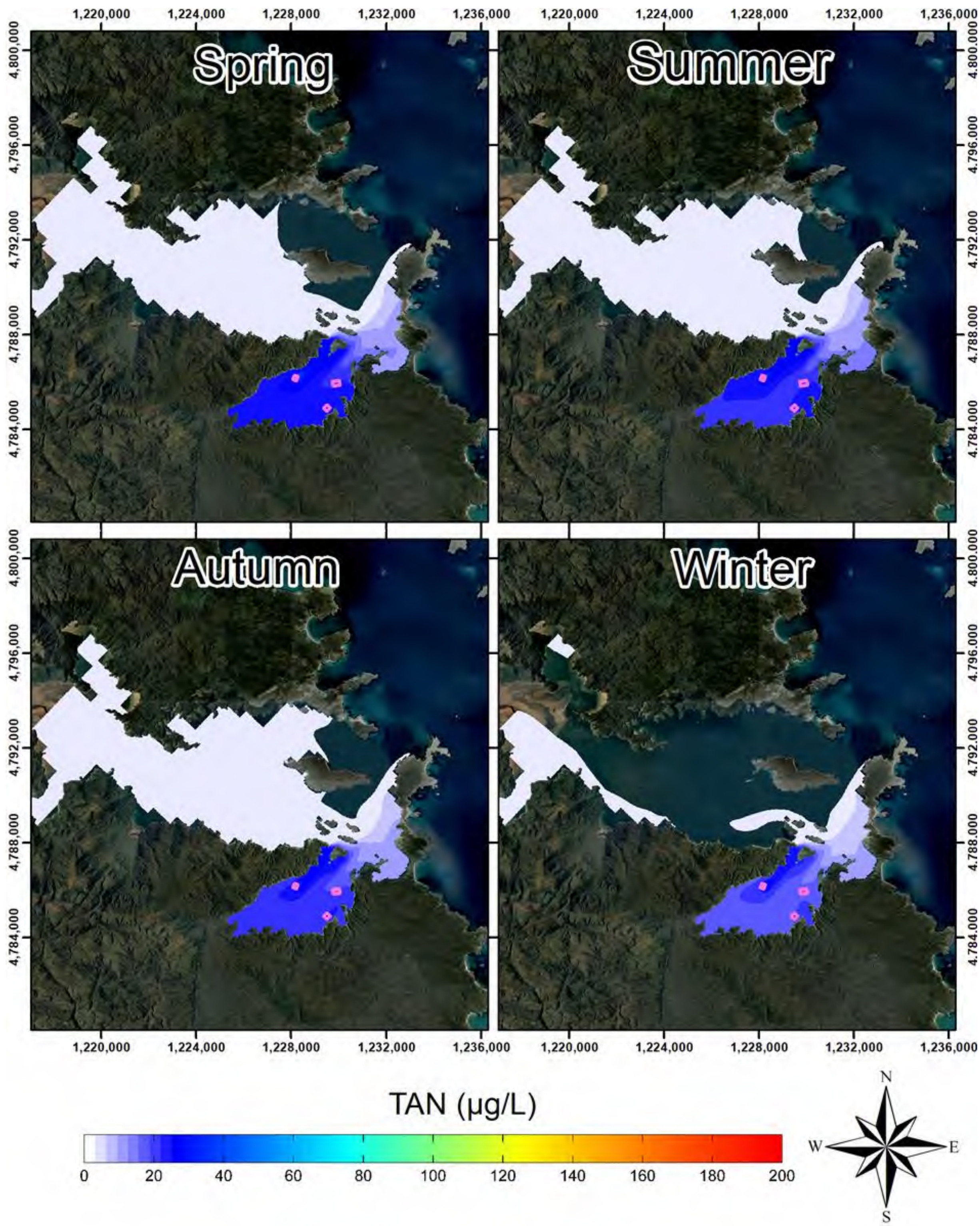

Figure 11 - Seasonal average excess concentrations of total ammonia nitrogen (TAN) during the higher-level scenario (higher-level minus calibration scenario) at the surface.

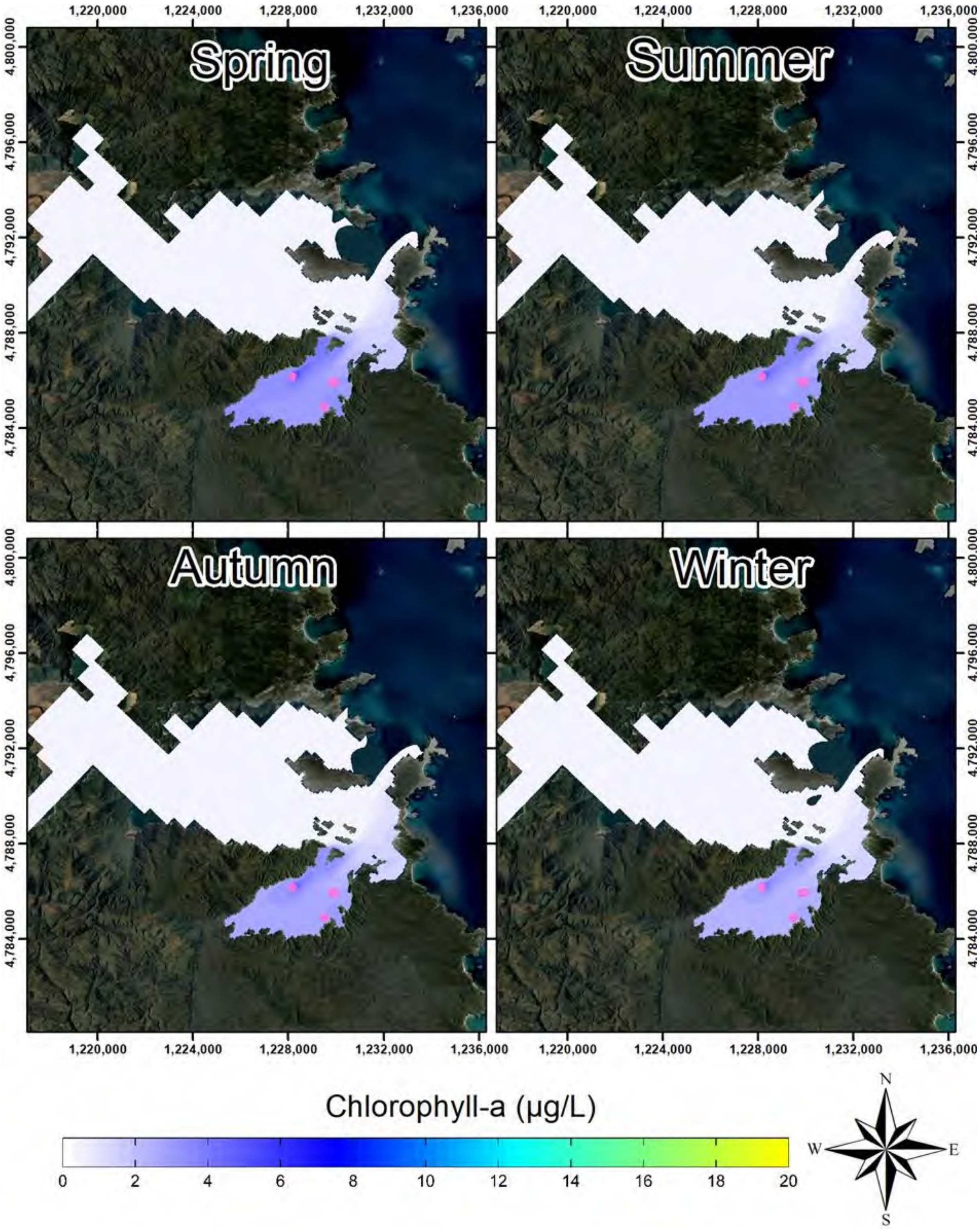

Figure 12 - Seasonal average excess concentrations of chlorophyll-a during the higher-level scenario (higher-level minus calibration scenario) at the surface

5.4 OXYGEN RESULTS

5.4.1 Mid-level Scenario

Dissolved oxygen depletion was only observed in the immediate vicinity of the farms as ambient levels are rapidly reached further away from cages due to aeration and mixing. In Big Glory Bay the oxygen concentrations are approximately 0.25 mg L^{-1} lower than outside of the bay. Oxygen levels within the cages are observed to drop by up to 1.5 mg L^{-1}. During the peak of summer this maybe significant and as such this is arguably the acceptable limit. Dissolved oxygen concentrations of this magnitude are needed for maintaining healthy farmed salmon (**Stein *et al.* 2013**).

Dissolved oxygen shows small differences between seasons that are related to the changes in temperature modifying the amount of oxygen water can hold.

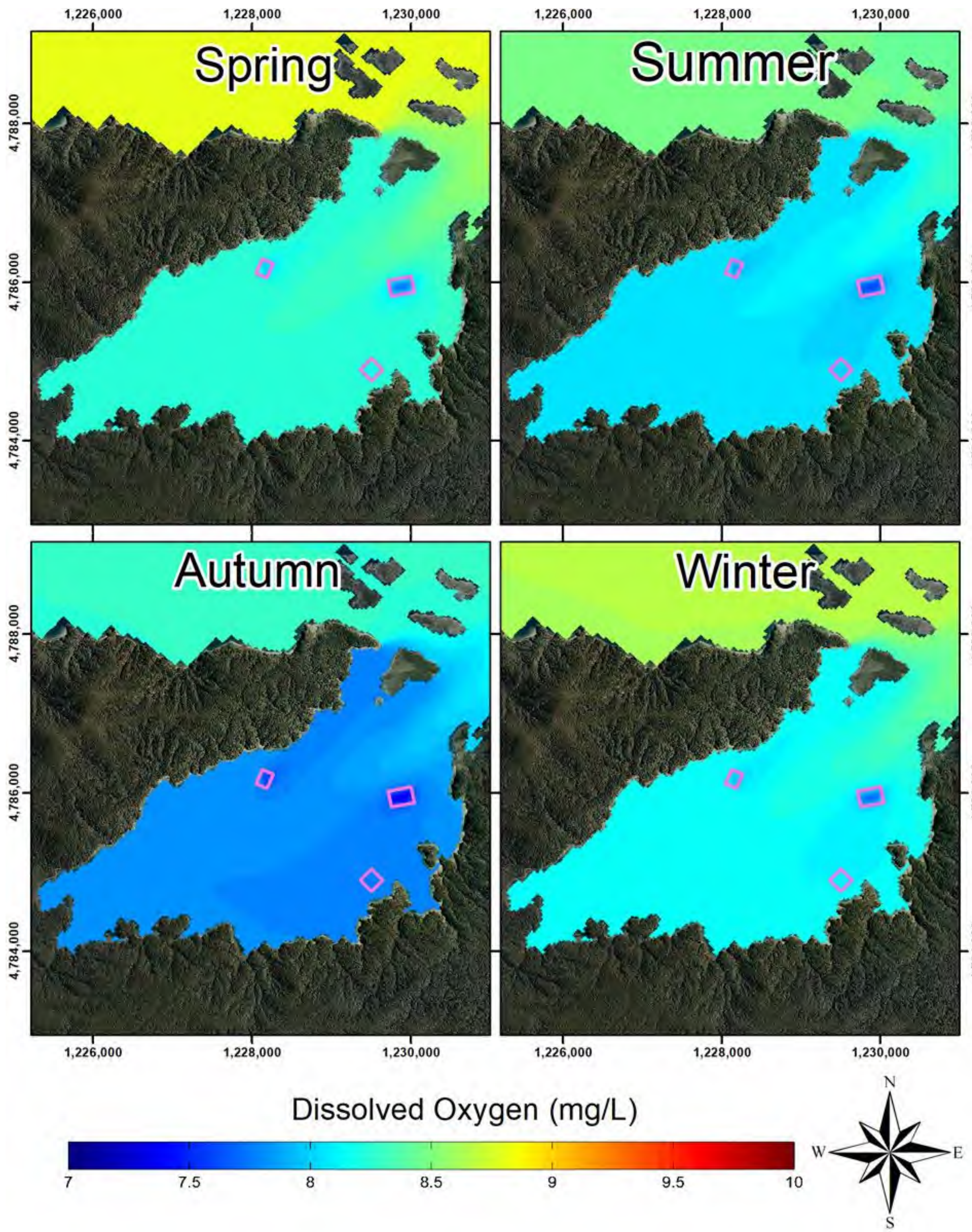

Figure 13 - Seasonal average surface dissolved oxygen concentrations during the mid-level scenario.

5.4.2 Higher-level Scenario

The oxygen depletion is again only seen in the immediate vicinity of the farms and ambient levels are rapidly reached further away from cages. The difference between the mid-level and higher-level Scenario is not clearly visible in the seasonal maps as it is extremely small.

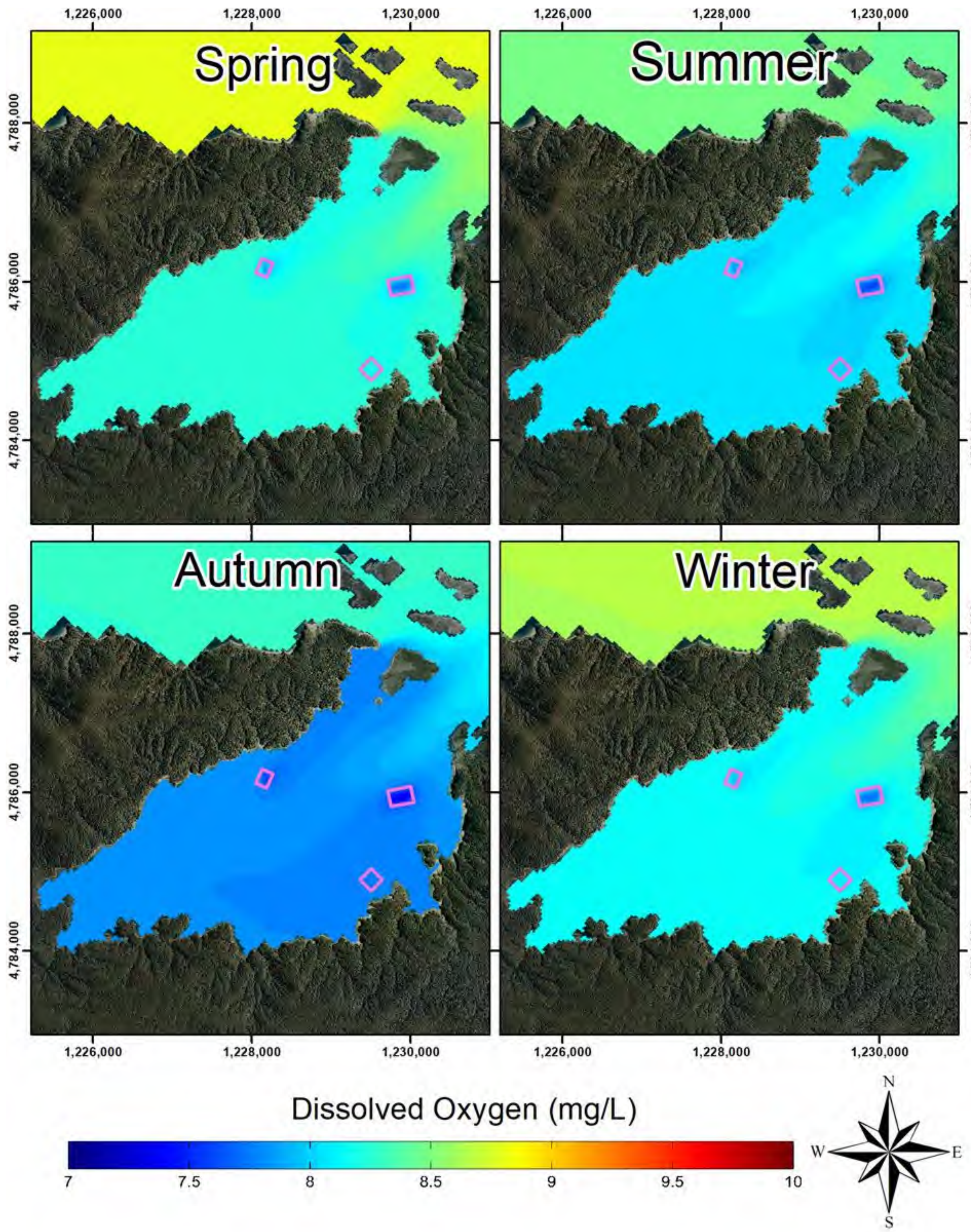

Figure 14 - Seasonal average dissolved oxygen concentration for the higher-level scenario at the surface.

6 CONCLUSIONS

The water quality modelling indicates that TAN levels are predicted to increase in Big Glory Bay by up to 25 µg L^{-1} to 30µg L^{-1} for the mid-level and higher-level scenarios respectively. As a result, chlorophyll-*a* levels are predicted to increase in Big Glory Bay by up to 4 µg L^{-1}. Much of this increase is expected to be consumed by mussel farm aquaculture present in the bay.

Dissolved oxygen effects from the model shows that there is no significant variation in dissolved oxygen drawdown between surface and bottom layers, except near the cage groups. As observed in the TAN data, there was seasonal variation in oxygen drawdown, which is related to temperature changes that control how much oxygen can dissolve in water. Dissolved oxygen reductions are expected to reach 0.25mg L^{-1} inside the Bay and up to 1.5mg L^{-1} within the cages.

Overall, the excess TAN release in all modelled scenarios is within acceptable ranges considering the flushing capacity of Big Glory Bay, and generally agree with the DHI model conclusions of 2010. Dissolved oxygen, however, will adversely affect the performance and welfare of fish if values dropped below what was modelled. *In-situ* dissolved oxygen levels must be appropriately managed at the farm level with regular monitoring of in-situ conditions.

Currently, 3 key knowledge gaps could be addressed to improve the understanding of the carrying capacity of Big Glory Bay:

1. Knowledge of natural background levels related to import and export of nutrients from natural sources such as ocean and bay itself through rain/runoff, and the adjacent Paterson Inlet. The offshore nutrient exchange with the bay should also be examined.
2. Knowledge about mussel farming total N export at harvest are currently not being quantified as part of the overall budget.
3. While previous ecological modelling was carried out in the past, it was based on old data sources. New data are available, but lack the necessary parameters and spatial coverage to be able to carry out a full-fledged ecological model. Namely the effects of mussel farming and exchange between Big Glory bay and the neighbouring ocean (both issues mentioned above).

7 References

Bergheim, A., Gausen, M., Næss, A., Hølland, P.M., Krogedal, P. and Crampton, V., 2006. A newly developed oxygen injection system for cage farms. Aquacultural engineering, 34(1), pp.40-46.

Beveridge, M.C., 1984. Cage and pen fish farming: carrying capacity models and environmental impact (No. 255-259). Food & Agriculture Org.

Crampton V, Hølland PM, Bergheim A, Gausen M, Næss A., 2003. Oxygen effects on caged salmon. Fish Farming International, Jun 2003, pp. 26–27.

Boynton, W.R., Kemp, W.M. and Keefe, C.W., 1982. A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production.

J. Key. 2001. Growth and condition of the greenshell mussel Perna canaliculus, in Big Glory Bay, Stewart Island: relationships with environmental parameters. MSc thesis Otago Univeristy.

Kishi, M.J., Kashiwai, M., Ware, D.M., Megrey, B.A., Eslinger, D.L., Werner, F.E., Noguchi-Aita, M., Azumaya, T., Fujii, M., Hashimoto, S. and Huang, D., 2007. NEMURO—a lower trophic level model for the North Pacific marine ecosystem. Ecological Modelling, 202(1), pp.12-25.DHI, 2010 the model referenced in the intro

O'Callaghan, M., 1998. Exchange of nutrients in Big Glory Bay, Stewart Island. Unpublished MSc thesis. University of Otago, New Zealand. 174pp.Pedersen, C.L., 1987. Energy budgets for juvenile rainbow trout at various oxygen concentrations. Aquaculture, 62(3), pp.289-298.

Pridmore, R.D., and Rutherford, J.C., 1992. Modelling phytoplankton abundance in a small enclosed bay used for salmon farming. Aquaculture and Fisheries Management 23: 525-542.

Ren, J.S., Ross, A.H., 2005. Environmental influence on mussel growth: A dynamic energy budget model and its application to the greenshell mussel Perna canaliculus. In Ecological Modelling, Volume 189, Issues 34, 2005, Pages 347-362, ISSN 0304-3800, https://doi.org/10.1016/j.ecolmodel.2005.04.005.

Sathyendranath, S., Stuart, V., Nair, A., Oka, K. and others, 2009. Carbon-to-chlorophyll ratio and growth rate of phytoplankton in the sea. Mar Ecol Prog Ser 383:73-84. https://doi.org/10.3354/meps07998

Stien, L.H., Bracke, M., Folkedal, O., Nilsson, J., Oppedal, F., Torgersen, T., Kittilsen, S., Midtlyng, P.J., Vindas, M.A., Øverli, Ø. and Kristiansen, T.S., 2013. Salmon Welfare Index Model (SWIM 1.0): a semantic model for overall welfare assessment of caged Atlantic salmon: review of the selected welfare indicators and model presentation. Reviews in Aquaculture, 5(1), pp.33-57.

Wu, R.S.S., 1995. The environmental impact of marine fish culture: towards a sustainable future. Marine pollution bulletin, 31(4), pp.159-166.

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Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand, Volume IV – Seabed Deposition, Aquadynamic Solutions Sdn Bhd, October 2017.

Aquadynamic Solutions Sdn Bhd

Big Glory Bay Carrying Capacity Update, Stewart Island, New Zealand

Volume IV – Seabed Deposition

October 2017

Report prepared by

Aquadynamic Solutions Sdn Bhd (ADS)

For

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1 INTRODUCTION

This volume introduces the depositional modelling undertaken to determine the maximum acceptable seabed faeces and feed salmon farm impacts within Big Glory Bay.

1.1 DESCRIPTION OF DEPOSITION IMPACTS

Fish farming primarily impacts the seabed through over-enrichment of the benthos through the deposition of organic rich faeces and uneaten food wastes. This deposition results in a change to the seabed chemistry as these wastes are processed by the sediment microbial community. These bacteria utilise aerobic metabolic pathways and consume dissolved oxygen (DO) until the supply of DO is extinguished. After the available supply DO is exhausted, decomposition will occur via anaerobic pathways, the products of which are toxic compounds such as H_2S (hydrogen sulphide) and NH_4^+/NH_3 (ammonium/a, the sum of which is also referred to as Total Ammonia Nitrogen or TAN).

Shifts in the physiochemistry of sediments results in ecological shifts in the benthos whereby species rich, well-oxygenated sediment communities shift to species poor, but opportunistically dominated oxygen-poor sediment communities. Extreme organic enrichment of the seabed can lead sediments to become anoxic (devoid of oxygen). The severity of the impacts to the benthos is directly related to the degree of organic deposition.

The "assimilative capacity" of the seabed can be defined, as the rate of organic matter flux to the benthos that can be sustained without major disruption to natural benthic processes (**GESAMP 2001**). This definition is highly subjective and does not necessarily acknowledge the uncoupling of benthic community diversity and the benthos' ability to process organic inputs.

At elevated enrichment levels, the overall diversity of the benthic infaunal communities begins to diminish, and become dominated by opportunistic fauna (albeit with much less diversity) (**Figure 1**). Peak faunal abundance occurs when diversity is in a decreased state, but it is at this state where the benthos has the greatest potential for processing farming wastes (**Keeley and Taylor 2011**). Beyond this stage of enrichment (*i.e.* greater organic matter deposition) the functional capacity for the benthos to process farm wastes diminishes as the infaunal biomass decreases until the benthos becomes azoic (devoid of life) and eventually shifts to an anaerobic state.

These effects are most prominent at the source of the enrichment (*e.g.* area of seabed impacted by farm wastes) and decrease with increasing distance / time from the enrichment source.

Depositional footprints (those areas of the seabed impacted by farming activities) associated with farms are often used as a basis for management. The local bathymetry and hydrodynamic regime are the primary drivers controlling the shape, extent, and waste concentration of the deposition field. Depositional footprints associated with fish farms are often skewed in an elliptical pattern, fanning out in the direction of the prevailing currents and with the greatest deposition observed directly under the farm pens. Strong gradients in physiochemical conditions and ecological community composition/function occur along gradients in organic matter deposition. **Pearson and Rosenberg 1978**, **Hartstein and Stevens**

2004 describe the ecological shifts in benthic faunal communities associated with farming deposition (**Figure 1**).

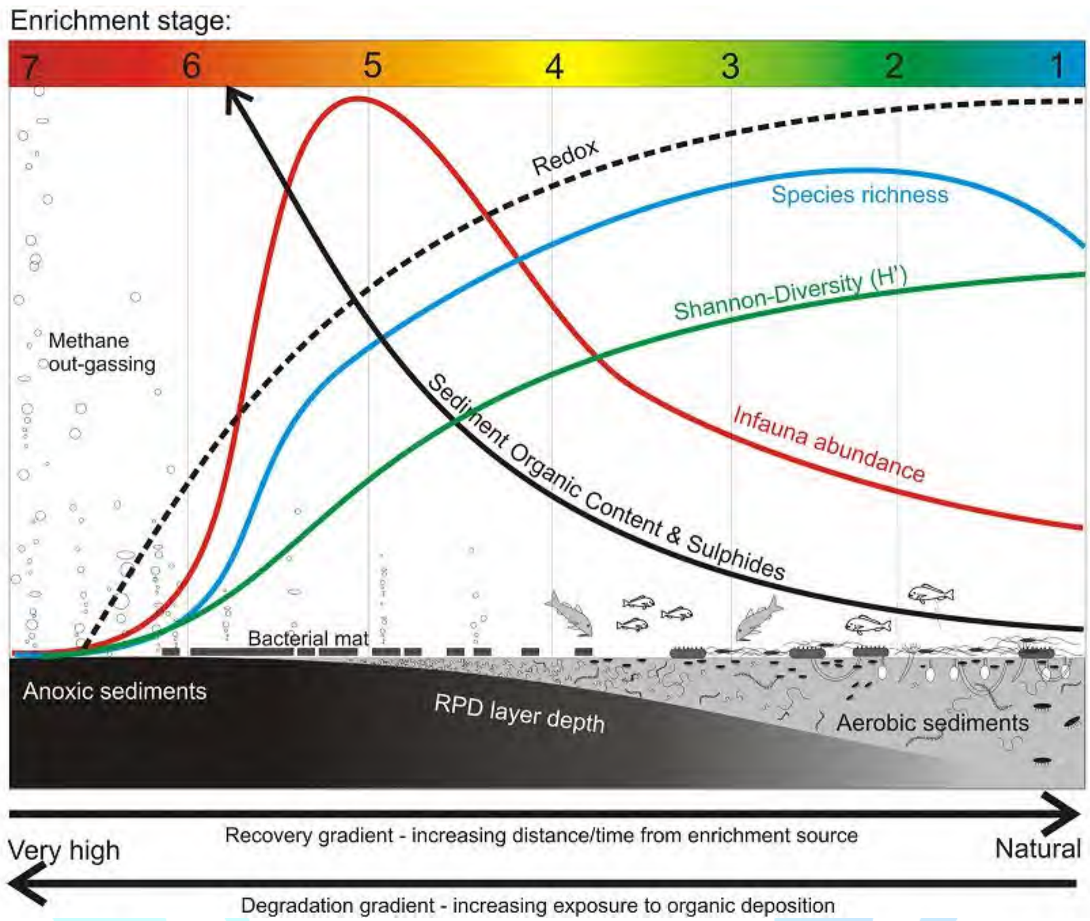

Figure 1 – Seabed effects with increasing organic enrichment. Modified from Pearson and Rosenberg 1978

1.2 Model Description

Depositional modelling is a useful tool for predicting farm associated faeces deposition to the seabed while accounting for specific bathymetric characteristics and the hydrodynamic regime of a particular site. Depositional modelling enables industry stakeholders and environmental managers to optimise production, while minimising adverse environmental impacts to the surrounding ecosystem, by using predictive scenarios (siting of farms and production rates *i.e.* production tonnage) for farm planning.

Depositional modelling is used to predict organic carbon and solids deposition, resulting from feed wastage and fish faeces production. These tools have been widely used to predict seabed effects and the extended impact area of proposed farms across the globe (*i.e.* **Hartstein and Stevens 2004; Cromey *et al.* 2005, Keeley *et al.* 2013**).

Models presented in this report were performed using New DEPOMOD (SAMS 2017 [1]). DEPOMOD (**Cromey et al 2002**) is a widely used and credible (**SEPA 2005**, **ASC 2012**) particle tracking model designed for predicting salmon farm deposition (**Cromey et al. 1998**, **Thetmeyer et al. 2003**, **Cromey and Black 2005**, **Cook et al. 2006**, **Magill et al. 2006**). This modelling tool requires background information from the site that includes the local bathymetry, local current fields, and specific information regarding farming practices such as pen layouts, feed input, and stocking density.

1.3 Modelling Scenarios

Three farm locations have been modelled each with varying amounts of feed input. These leases are 246, 320, and 339 (**Figure 2**).

For lease 246, two model simulations were undertaken. The first of these was to assume typical feed properties (feed without the use of binding agents) at a daily feeding rate of 18.6 tons. Stronger current flows observed at this site resulted in resuspension and subsequent scattering of feed and faeces wastes along the seabed. Upon observing this it was decided to try a second scenario that modelled the effect of a binding agent in the feed. Binding agents are added to the feed to ensure that the feed falls more rapidly (and is stickier so once on the seabed it is more difficult to erode) to the seabed thereby restricting the spread of the depositional footprint to areas within the farm lease. The total yearly Nitrogen input is 415.1 tons which is representing the maximum potential carrying capacity of this site.

Feed property data were provided by Skretting from a series of settling tank tests performed at the University of Tasmania Institute of Marine and Antarctic Studies in May 2017 (Ben Wybourne pers. comm.).

For Lease 320 two scenarios were modelled representing a mid-level and higher-level stocking density. The mid-level stocking density scenario (12 kg m^3) had a daily feeding rate of 7.76 tons per day, and the higher stocking density scenario (14 kg m^{-3}) had a daily feeding rate of 9.05 tons.

Lease 339 was assumed to be used for growing out smolts and thus a relatively reduced set of stocking densities (3.0 kg m^{-3} and 4.3 kg m^{-3}) was used for the mid-level and higher-level stocking scenarios. Neither lease 320 nor lease 339 were observed to display any significant resuspension and thus there was no need to include the use of feed binders in those simulations.

[1] New DEPOMOD: URL http://science.sams.ac.uk/trevor-carpenter/newdepomod/).

2 MODEL SET-UP

2.1 MODEL DOMAIN

The domain of this depositional model consisted of bathymetric data provided by C-Map and interpolated to 15m grid resolution. Specific location coordinates of the domain boundary along with the positions of the pens referenced by their respective lease number can be found in **Figure 2** below.

	NZGD 2000
Domain X max	1230942.774
Domain Y max	4787766.302
Domain X min	1225242.774
Domain Y min	4783836.302
# cells X	380
# cells X	262

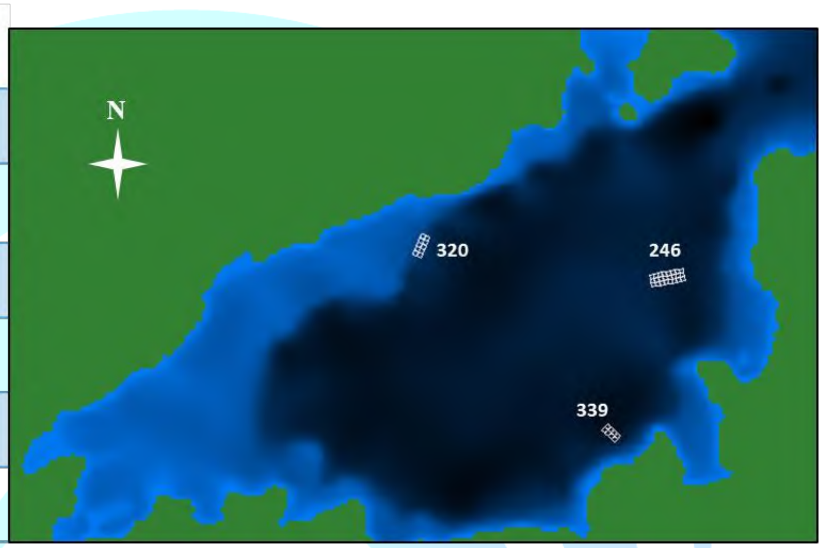

Figure 2 - Domain bounds used in this depositional mode along with pen positions and groups referenced by lease number. All coordinates expressed in NZGD 2000. Specific information regarding pen layout and positioning is referenced in Table 2.

2.2 FLOW CONDITIONS

ADCP 1 was located at the mouth of the system where Big Glory Bay joins Paterson Inlet. Currents are generally stronger at this site compared to the currents observed with ADCP 2, which was positioned well inside the system near Big Glory Bay's southern banks. ADCP 2's more sheltered position make this data set ideal to use for lease 320 and 339's flow fields for their respective depositional models. ADCP 1's more exposed position is more representative of the current fields experienced at lease 246

2.3 PEN SETUP AND INPUTS FOR DEPOSITION MODELLING

This depositional model employed square pens 30m x 30m on each side and 15m deep (pen volume of 13,500 m^3). While this basic pen design was shared among all the leases modelled, each lease had a different number of pens (and resulting total pen volume on the lease) and its own unique layout and orientation in the bay.

Lease 246 was modelled with 3 rows of 8 pens, giving this a total pen volume of 324,000 m^3 (**Table 1**). Lease 320 was modelled with 2 rows of 5 pens giving a total pen volume of 135,000m^3. Lease 339 was modelled with 2 rows of 4 pens giving this lease a total pen volume of 108,000m^3. Specific lease locations and orientations can be found in **Table 1** below.

Table 1 - Pen designs, locations, layouts, and volumes used for this depositional model. Pens locations are reported as they are entered into DEPOMOD (i.e. referencing the center of the top left pen before adjusting the bearing of the pen set). Coordinates are given in NZGD2000.

	Lease 246 Pens	Lease 320 Pens	Lease 339
X Position	1229774.23	1228119.06	1229441.56
Y Position	4785964.45	4786123.51	4784879.658
Layout (row x column)	3 x 8	2 x 5	2 x 4
Pen Dimensions (m)	30 x 30	30 x 30	30 x 30
Pen Depth (m)	15	15	15
Bearing (°N)	79.15	23.35	44.38
Total Volume (m^3)	324,000	135,000	108,000

2.4 Farming Inputs and Waste Scenarios

Table 2 below shows the pen setup used in all DEPOMOD scenarios for all pens. Stocking density was set to 12 kg m^{-3} for both scenarios for lease 246and the mid-level stocking density scenario for lease 320. The higher-level stocking density scenario for lease 320 ran with 14 kg m^{-3}. Both mid-level and higher-level stocking scenarios on Lease 339 were assumed to house smolts and thus the stocking densities was set to 3 kg m^{-3} and 4.3 kg m^{-3} respectively. All pens assume a stock to feed ratio (average daily feed input divided by the annual stocking) of 0.479.

The DEPOMOD software computes the feed mass inputs and biomass for the pen internally based on pen volume, stocking density, and stock to feed ratio. Both scenarios (traditional feed and feed with binders) for Lease 246 were computed to have a daily feed input of 18.6 tons (**Table 2**). The mid-level stocking scenario for lease 320 has a daily input of 7.76 tons and the higher-level stocking scenario was computed to have a daily feed input of 9.05 tons. Both the mid-level and higher-level stocking density scenarios for the smolt pens on lease 339 had daily inputs of 1.55 tons and 2.1 tons respectively. Each of the scenarios use a stock to feed ratio of 0.479. Specific feed loadings, C and N content, computed biomass, and other input parameters can be found in **Table 2** below.

Table 2 - Depositional model loading input parameters. Stock to Feed Ratio is defined as the average daily feed rate (tons day^{-1}) divided by the annual production (tons yr^{-1}).

	Lease 246 all scenarios	**Lease 320** Mid-level scenario	**Lease 320** Higher-level scenario	**Lease 339** Mid-level scenario	**Lease 339** Higher-level scenario
Stocking Density/Biomass in the cage *(kg m^{-3})*	12.0	12.0	14.0	3.0	4.3
Stock: Feed	0.479	0.479	0.479	0.479	0.479
Feed Mass *(tons day^{-1})*	18.6	7.76	9.05	1.55	4.1
% Feed Wastage	3	3	3	3	3
% Feed Digested	85	85	85	85	85
% Water Content	9	9	9	9	9
Feed % C	49	49	49	49	49
Faeces % C	30	30	30	30	30
Feed % N	6.1	6.1	6.1	6.1	6.1
Faeces % N	17.3	17.3	17.3	17.3	17.3
Bay Salinity *(ppt)*	35	35	35	35	35
Bay Temperature	10	10	10	10	10

DEPOMOD assumes that all feed inputs are distributed evenly across all pens from the duration of the model simulation; in this case the model simulated 1 year of farm faeces and feed waste deposition.

In practice feeding schedules and individual pen stocking will vary, with pens unevenly stocked throughout the growing season and feeding schedules adjusted to growth phase and the surrounding environmental conditions present at the farm.

3 Deposition Results

Results are expressed in kilograms of carbon per meter squared per year (kgC m^{-2} yr^{-1}) and total mass of feed and faeces solid waste in kilograms per meter squared per year (kg m^{-2} yr^{-1}). A number of studies have observed the impact of organic deposition on macrobenthic communities. **Cromey *et al.* (2001)** observed macro-faunal community responses at carbon deposition rates of approximately 3.3g m^{-2} day^{-1}. Other studies such as **Hargrave (1994)** and **Gilibrand *et al.* (2002)**, concluded that long term benthic loading of approximately 2g m^{-2} day^{-1} of carbon deposition would start to have some impact on benthic conditions.

Based on these observations, we have placed a 0.73 kg per year (2 g C m^2 day^{-1}) contour which represents a conservative zone of known ecological impact in all carbon deposition plots below. Areas inside this line are expected to experience an impact (and are, by definition, within the depositional footprint), while areas outside of the line can be considered free of measurable impacts, as they are within the assimilative capacity of the seabed. Regular monitoring (**ADS, 2016, 2017**) of near bed oxygen levels indicates that seabed oxygen is good (generally greater than 6 mg/L). Such levels of oxygen will aid in assimilating fallen faeces material and uneaten food.

Information regarding nitrogen (N) inputs from feed, N removal via fish harvests (biomass removal), and N release into the surrounding environment is listed in **Table 3** below.

Table 3 - Depositional model outputs in terms of C, Solids (feed and faeces), and N release. N content of the feed is provided by Skretting

	Lease 246 (binding agent)	**Lease 320** Mid-level scenario	**Lease 320** Higher-level scenario	**Lease 339** Mid-level scenario	**Lease 339** Higher-level scenario
Carbon Released (tons)	361.1	150.49	175.6	30.01	42.2
Solids Released (tons)	1,086	452	528.1	90	126.6
Nitrogen in from feed (tons)	412.6	171.9	200.6	34.4	45.8
Nitrogen out as biomass (tons)	102.6	42.8	49.9	8.6	11.4
Nitrogen released to environment (tons)	310	129.1	150.7	25.8	34.4
Nitrogen in Faeces (tons)	71.3	29.7	34.7	5.9	7.9
Soluble Nitrogen release (tons)	238.7	99.4	116	19.9	26.5

One point worth noting is the amount of soluble nitrogen released from the farms is approximately 381.2 tons yr^{-1}. The rest of the N is either in the form of fish biomass (and comes out of the water during harvest) or sequestered in the sediment, where it can be buried or released slowly over time (depending a number of factors such as oxygen, deposition rates *etc*). The total nitrogen released into the bay through feed per annum for the maximum sustainable carrying capacity scenario is 661.5 tons.

3.1 Lease 246 without a Feed Binding Agent

Error! Reference source not found. and Error! Reference source not found. below show the depositional footprint of farm 246 using traditional feed properties (*i.e.* without the use of binding agents). The total annual feed input modelled is identical to the scenario above (Lease 246 with binding agents).

The majority of the deposition in this scenario was concentrated well outside of the boundaries of the lease, and dispersed in three large patches NNE of lease 246. The depositional footprint also is predicted to cross into the boundaries of leases 342 and 318 (Error! Reference source not found. and Error! Reference source not found.). Organic carbon and solids concentrations, outside of lease boundary, are predicted to range from 1 to 12 kgC m^{-2} yr^{-1} (Error! Reference source not found.Figure 5) and <5 to 35 kg $m^{-2}yr^{-1}$ (Error! Reference source not found.) respectively.

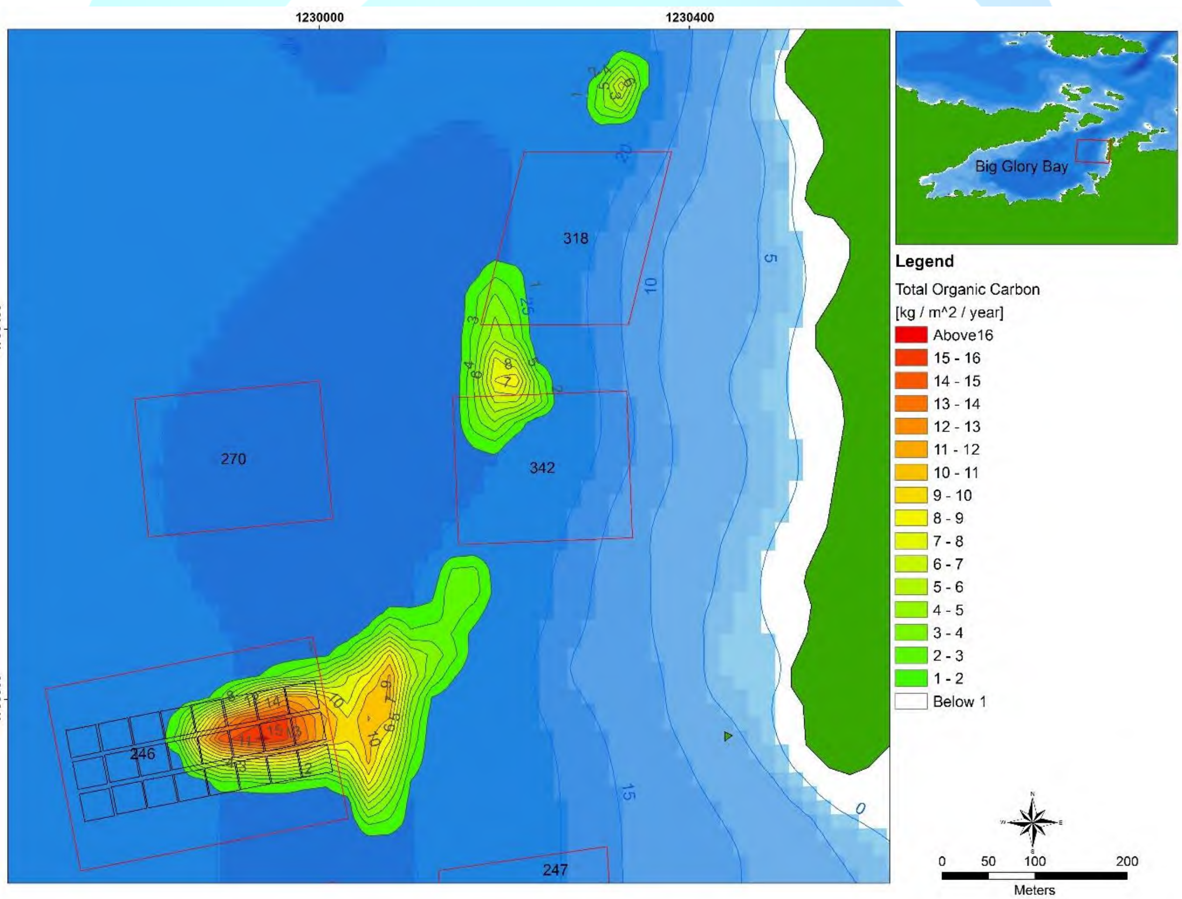

Figure 3 - Lease 246 total carbon deposition with a 12.0 kg m^{-3} stocking density. This scenario assumes traditional feed properties (i.e. no binding agent is assumed to be in the feed) and an annual feed mass of 6,798 tons.

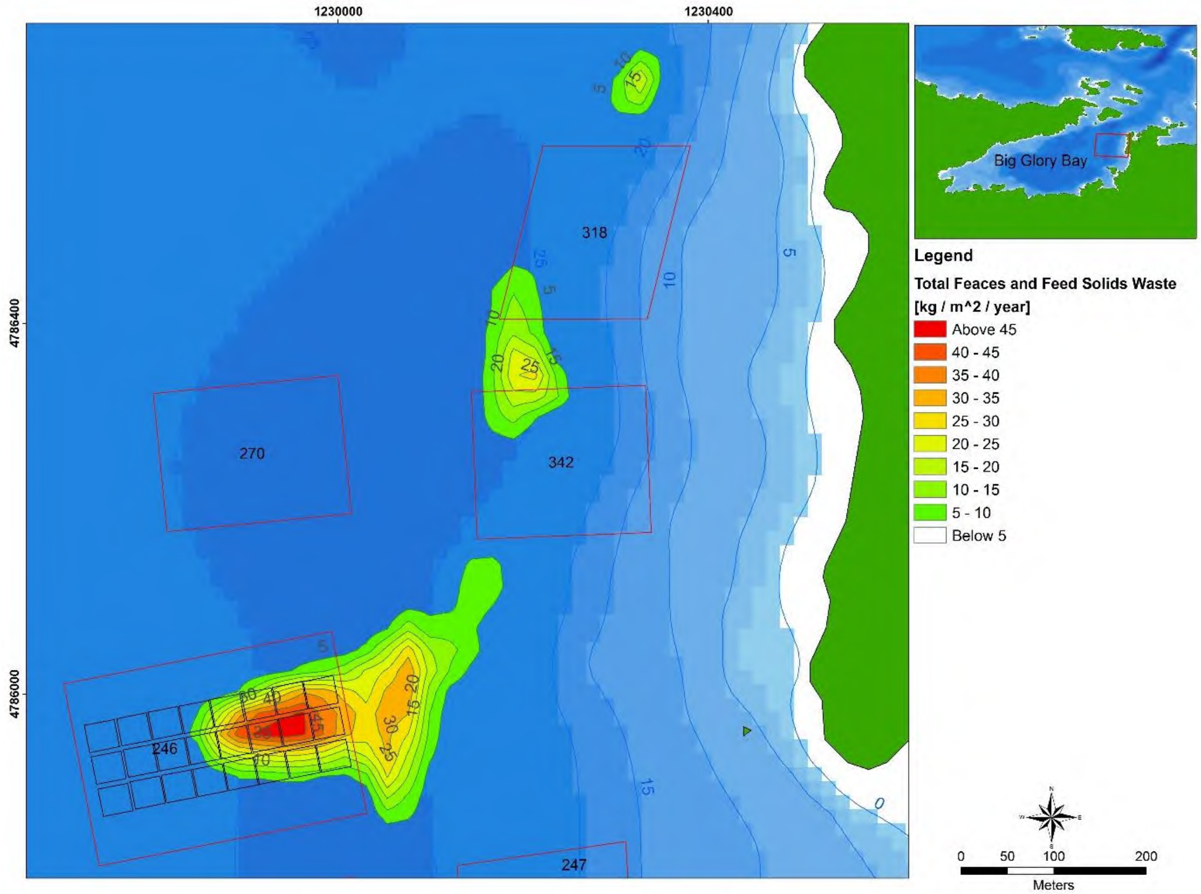

Figure 4 - Lease 246 total faeces and solids deposition with a 12.0 kg m^{-3} stocking density. This scenario assumes traditional feed properties (i.e. no binding agent is assumed to be in the feed) and an annual feed mass of 6,798 tons.

3.2 Lease 246 with a Feed Binding Agent

Figure 5 and **Figure 6** below show the depositional footprint of Lease 246 with the use of binding agents in the feed. Total annual feed inputs into this particular farm were modelled at 6,798 tons (including 415.1 tons of N).

The majority of the deposition was concentrated within boundaries of the lease, with the exception of the eastern lease boundary, where the depositional footprint was moderately skewed in the direction of the prevailing currents. Much of the organic carbon and solids deposition outside of lease boundary settled in concentrations ranging from 1 to 4 kgC m^{-2} yr^{-1} (**Figure 5**) and <5 to 20 kg $m^{-2}yr^{-1}$ (**Figure 6**) respectively.

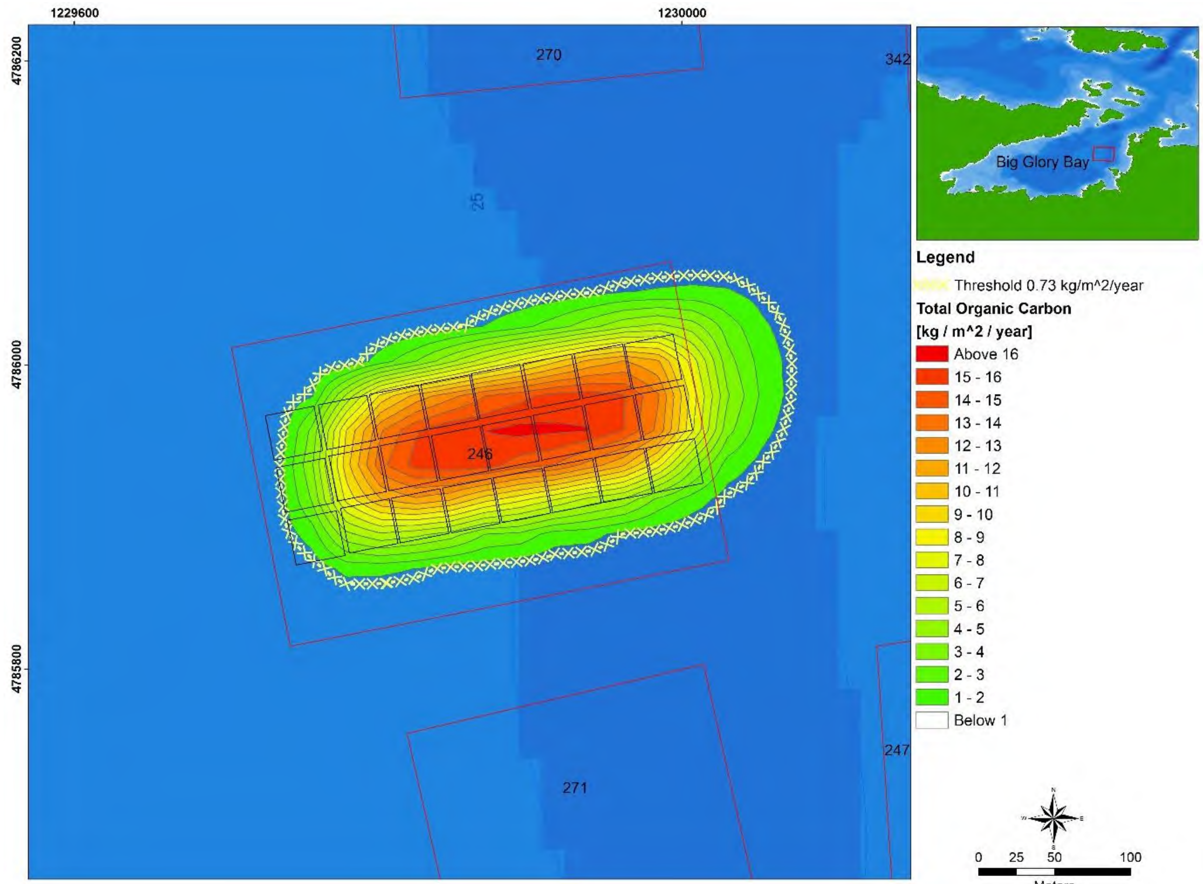

Figure 5 – Lease 246 total carbon deposition with a 12.0 kg m^{-3} stocking density. A binding agent is assumed to be in the feed. This scenario assumes an annual feed mass of 6,798 tons. Yellow hatched lines highlight the extent of the 2g C m^{-2} day^{-} depositional footprint.

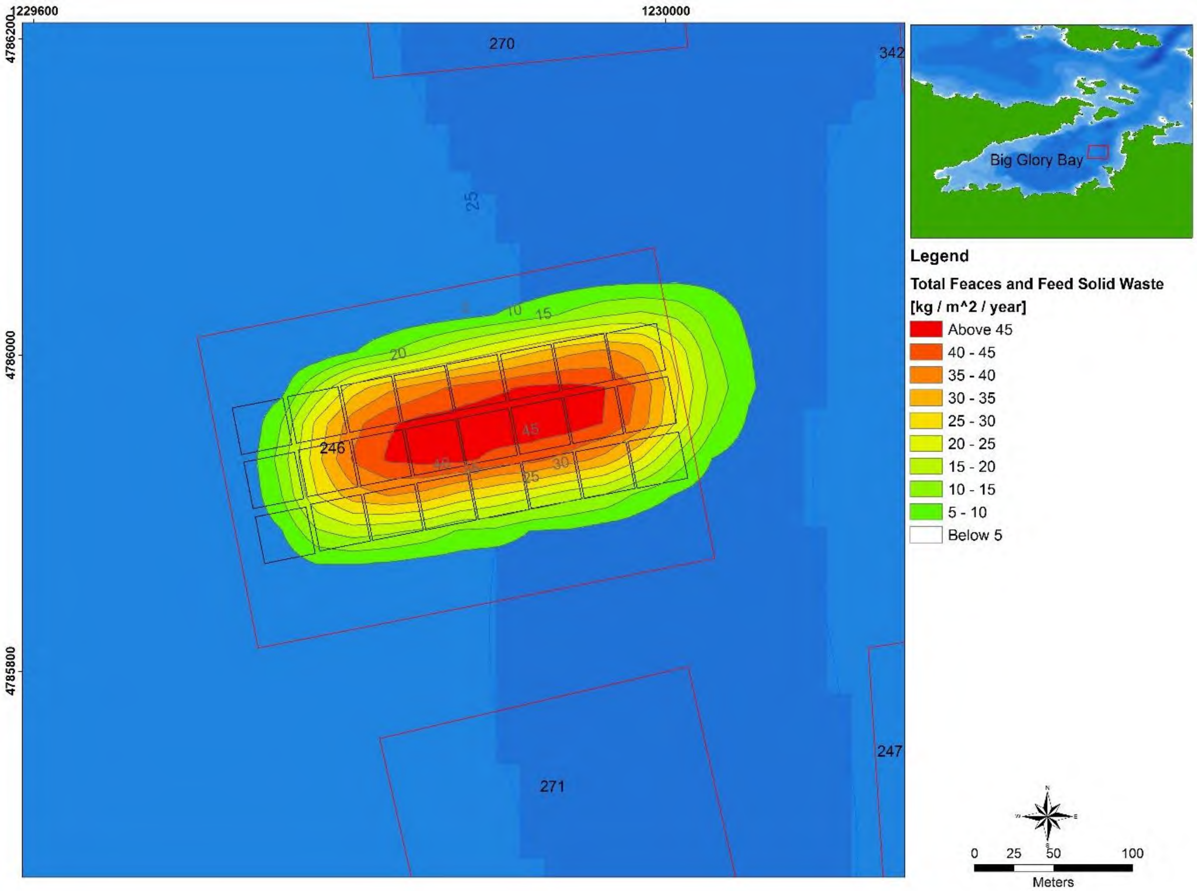

Figure 6 – Lease 246 total faeces and solids deposition with a 12.0 kg m^{-3} stocking density. A binding agent is assumed to be in the feed. This scenario assumes an annual feed mass of 6,798 tons.

It should be noted that the skewed footprint encroached more than 50m from the eastern edge of the lease, but less than 100m.

3.3 Lease 320 Mid-level Scenario

Figure 7 and **Figure 8** below show the depositional footprint from the id-level scenario of farm 320. The total annual feed input modelled in this scenario is 2,832 tons (171.4 tons of N).

Most of the deposition was concentrated well within the boundaries of the lease, with only a small footprint extending a few meters outside of the lease along its NE and SW boundary (<20m). Organic carbon and solids concentrations, outside of lease boundary, are predicted to range from <1 to 2 kgC m^{-2} yr^{-1} (**Figure 7**Figure 5) and 5 to 10 kg m^{-2}yr^{-1} (**Figure 8**) respectively.

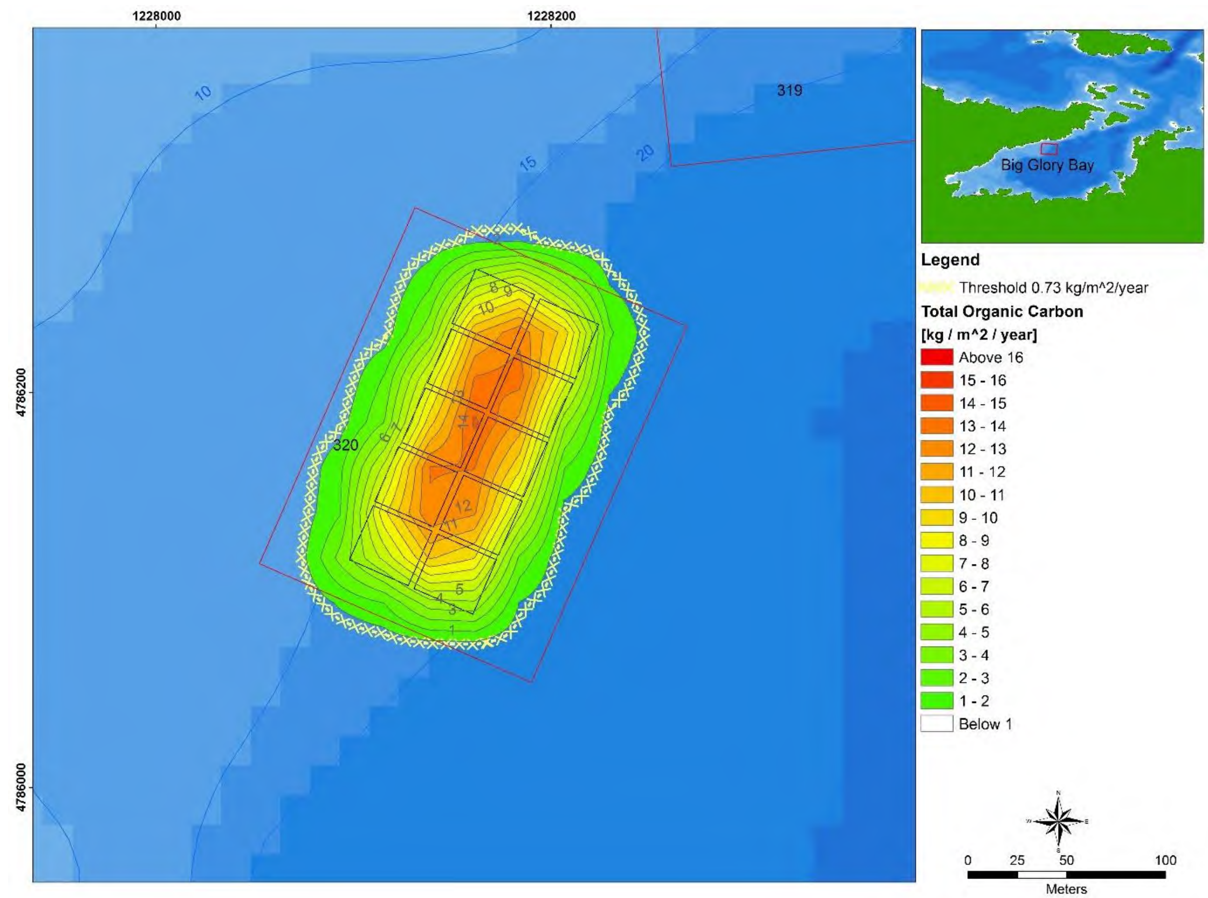

Figure 7 - Lease 320 total carbon deposition with a 12.0 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 2,832 tons. Yellow hatched lines highlight the extent of the 2g C m^{-2} day^{-1} depositional footprint.

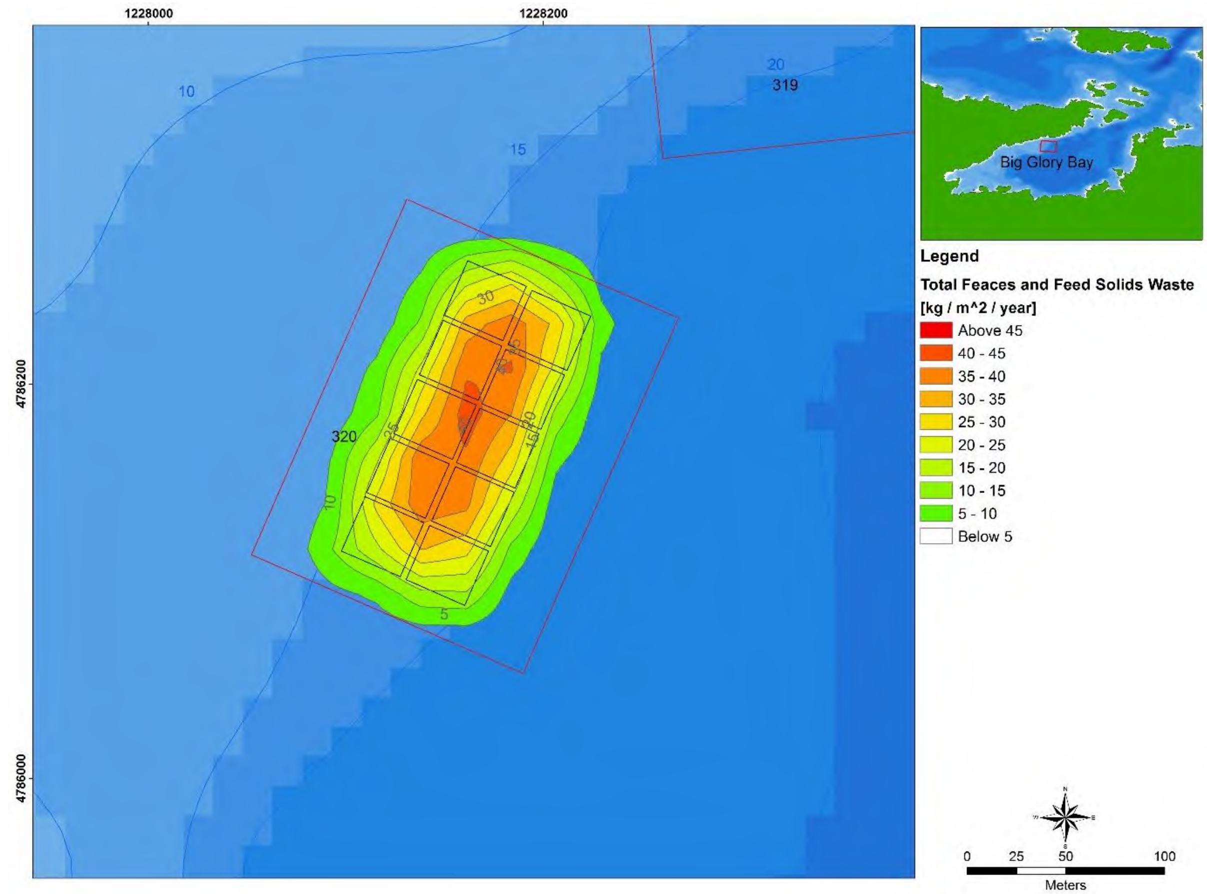

Figure 8 - Lease 320 total faeces and solids deposition with a 12.0 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 2,832 tons.

3.4 LEASE 320 MAXIMUM STOCKING DENSITY

Figure 9 and **Figure 10** below show the depositional footprint from the higher-level scenario at farm 320. The total annual feed input modelled in this scenario was 3,303 tons (200.6 tons of Nitrogen).

Again most of the deposition was concentrated well within the boundaries of the lease, with only a small footprint extending a few meters outside of the lease along its NE and SW boundary (<20m). Organic carbon and solids concentrations, outside of lease boundary, are predicted to range from <1 to 4 kgC m^{-2} yr^{-1} (**Figure 9**Figure 5) and 5 to 15 kg $m^{-2}yr^{-1}$ (**Figure 10**) respectively, slightly higher concentrations are predicted when compared to the conservative stocking scenario.

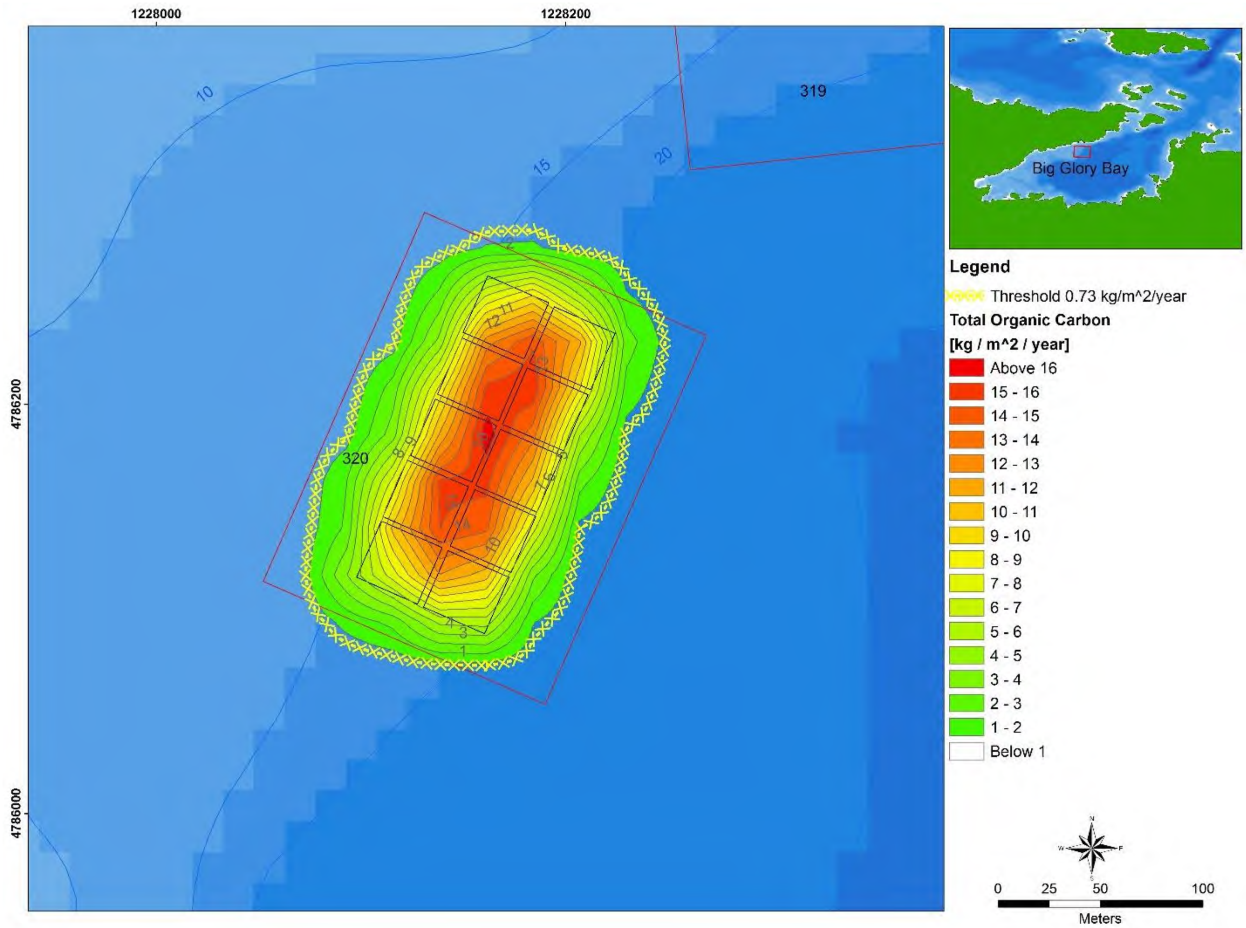

Figure 9 - Lease 320 total carbon deposition with a 14.0 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 3,303 tons. Yellow hatched lines highlight the extent of the 2g C m^{-2} day depositional footprint.

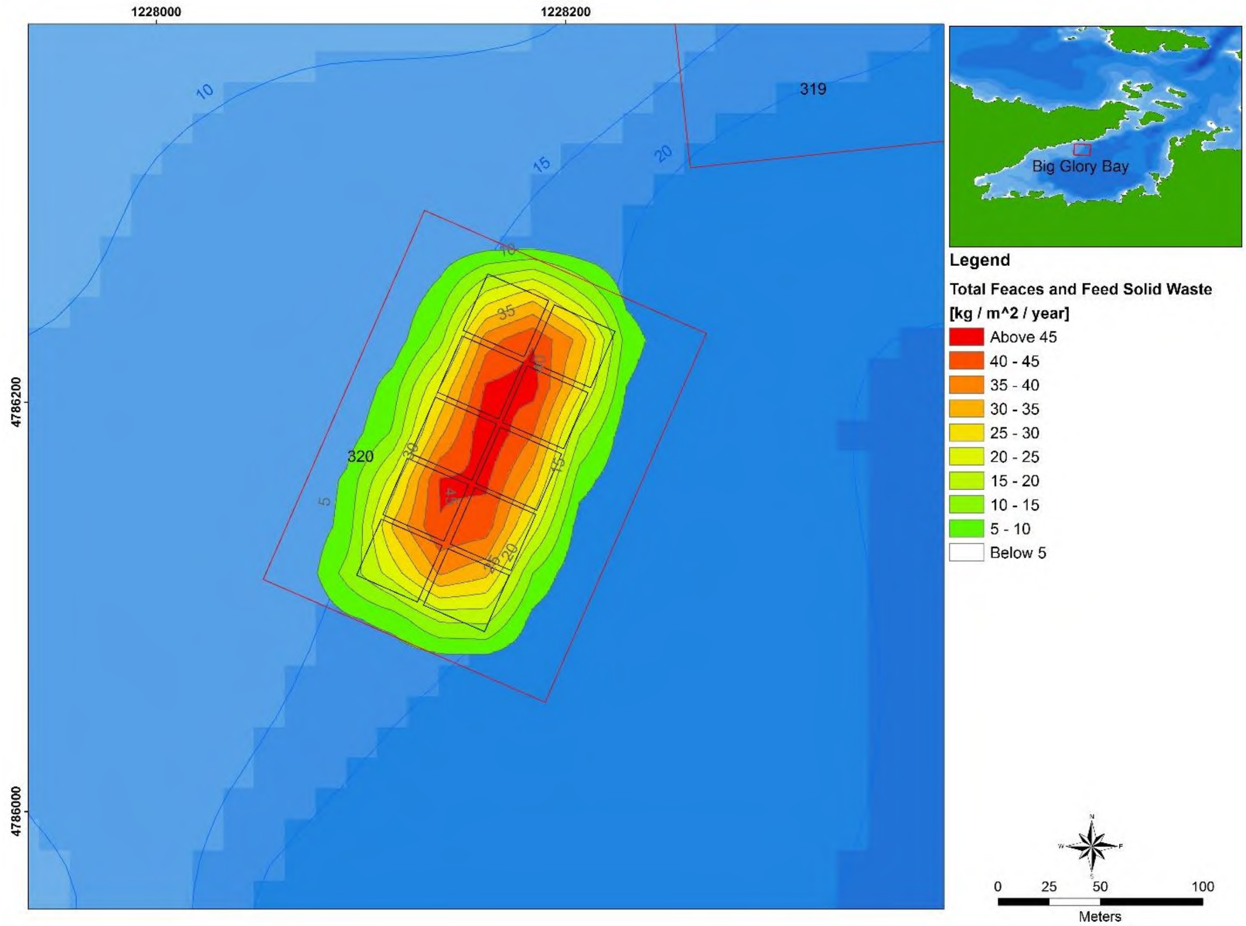

Figure 10 - Lease 320 total faeces and solids deposition with a 14.0 kg m-3 stocking density. This scenario assumes an annual feed mass of 3,303 tons.

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3.5 LEASE 339 MID-LEVEL SCENARIO

Figure 11 and **Figure 12** below shows the depositional footprint for the mid-level scenario run at farm 339, with total modelled annual feed input of 567 tons.

All of the deposition should be concentrated well within the boundaries of the lease. Organic carbon and solids concentrations are predicted to range from <1 to 4 kgC m^{-2} yr^{-1} (**Figure 11**Figure 5) and <5 to 15 kg $m^{-2}yr^{-1}$ (**Figure 12**) respectively.

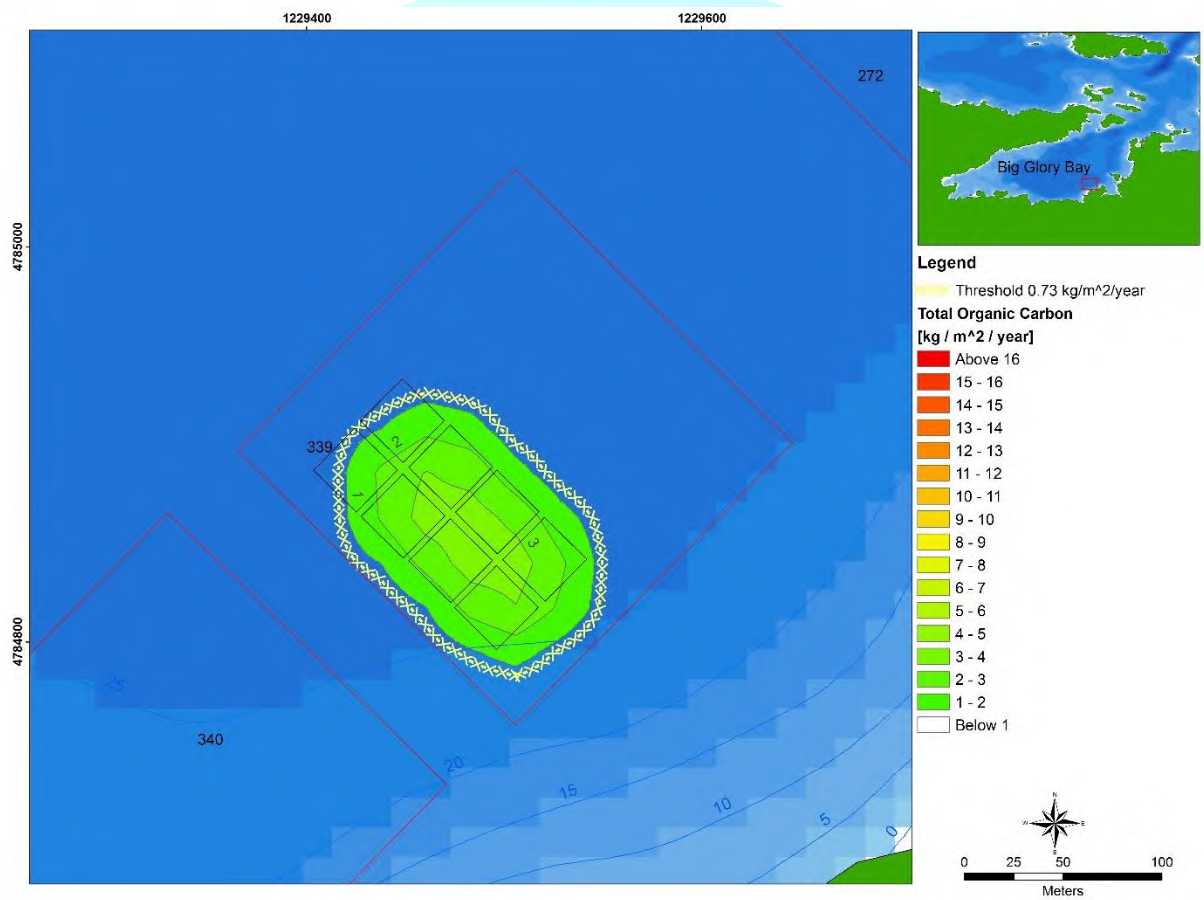

Figure 11 - Lease 339 total carbon deposition with a 3.0 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 567 tons. Yellow hatched lines indicate the parameter of the depositional footprint receiving 2g C m^{-2} day^{-1}.

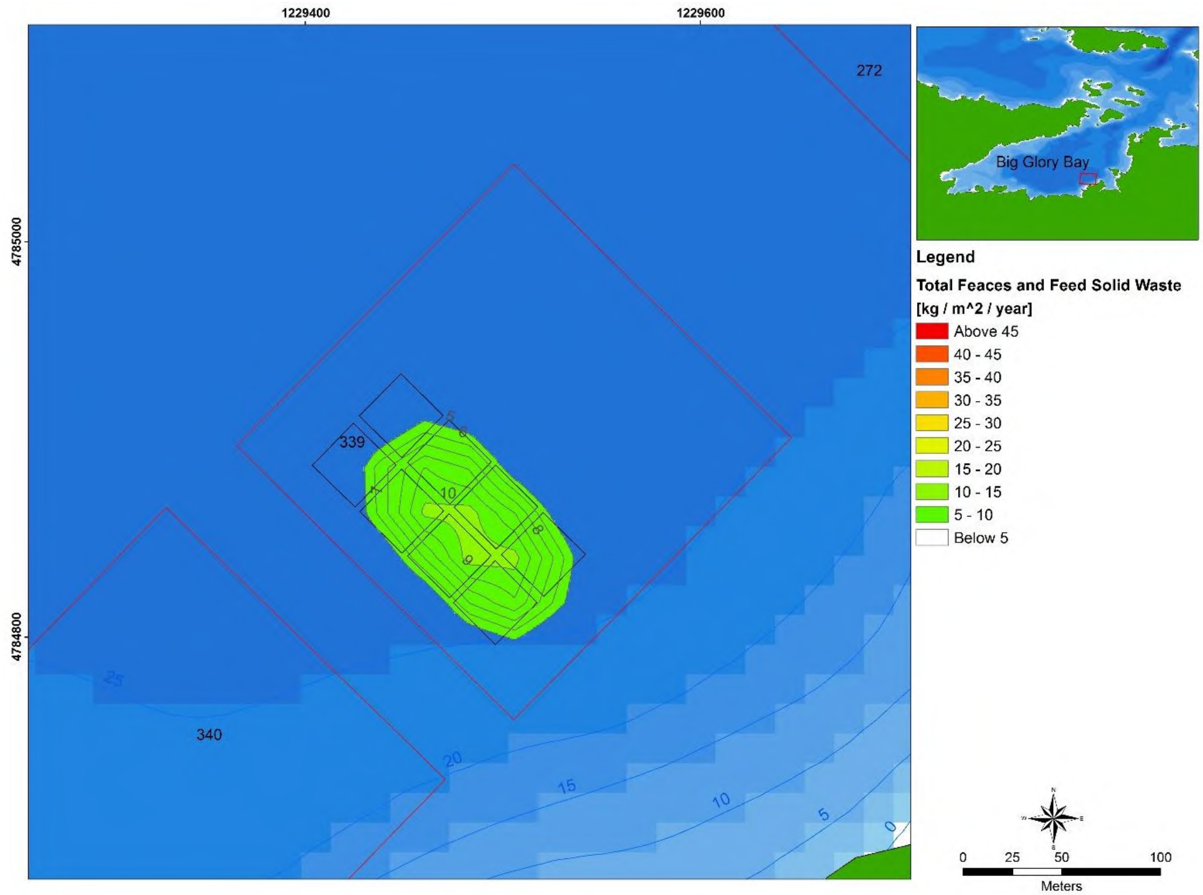

Figure 12 - Lease 339 total faeces and solids deposition with a 3.0 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 567 tons.

3.6 LEASE 339 HIGHER-LEVEL SCENARIO

Figure 13 and **Figure 14** below shows the depositional footprint for the maximum stocking scenario at farm 339, with total annual feed input of 1,132 (tonnes of total feed).

Again nearly all the deposition is concentrated well within the boundaries of the lease. Organic carbon and solids concentrations are predicted to range from <1 to 7 kgC m^{-2} yr^{-1} (**Figure 13**) and <5 to 25 kg m^{-2} yr^{-1} (**Figure 14**) respectively.

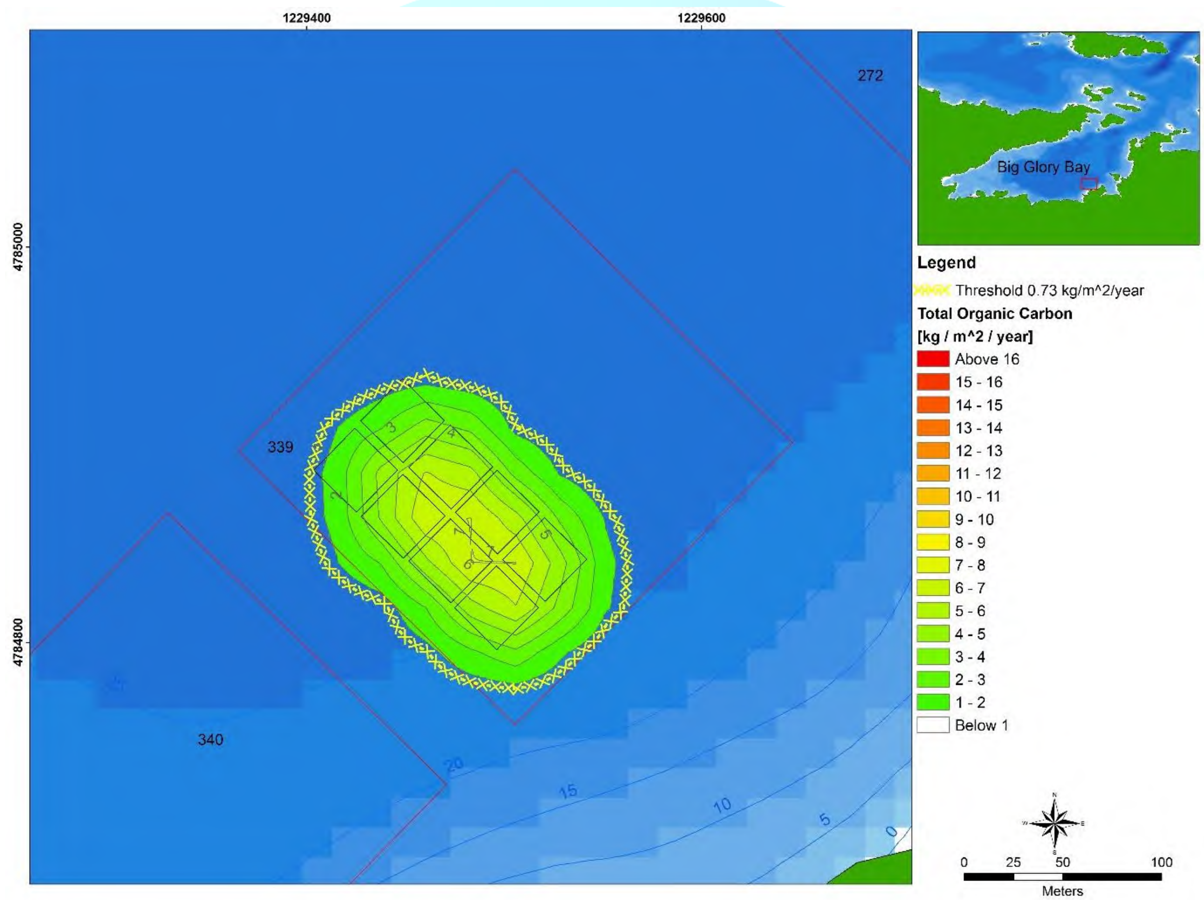

Figure 13 - Lease 339 total carbon deposition with a 4.3 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 567 tons. Yellow hatched lines highlight the extent of the 2g C m^{-2} day depositional footprint.

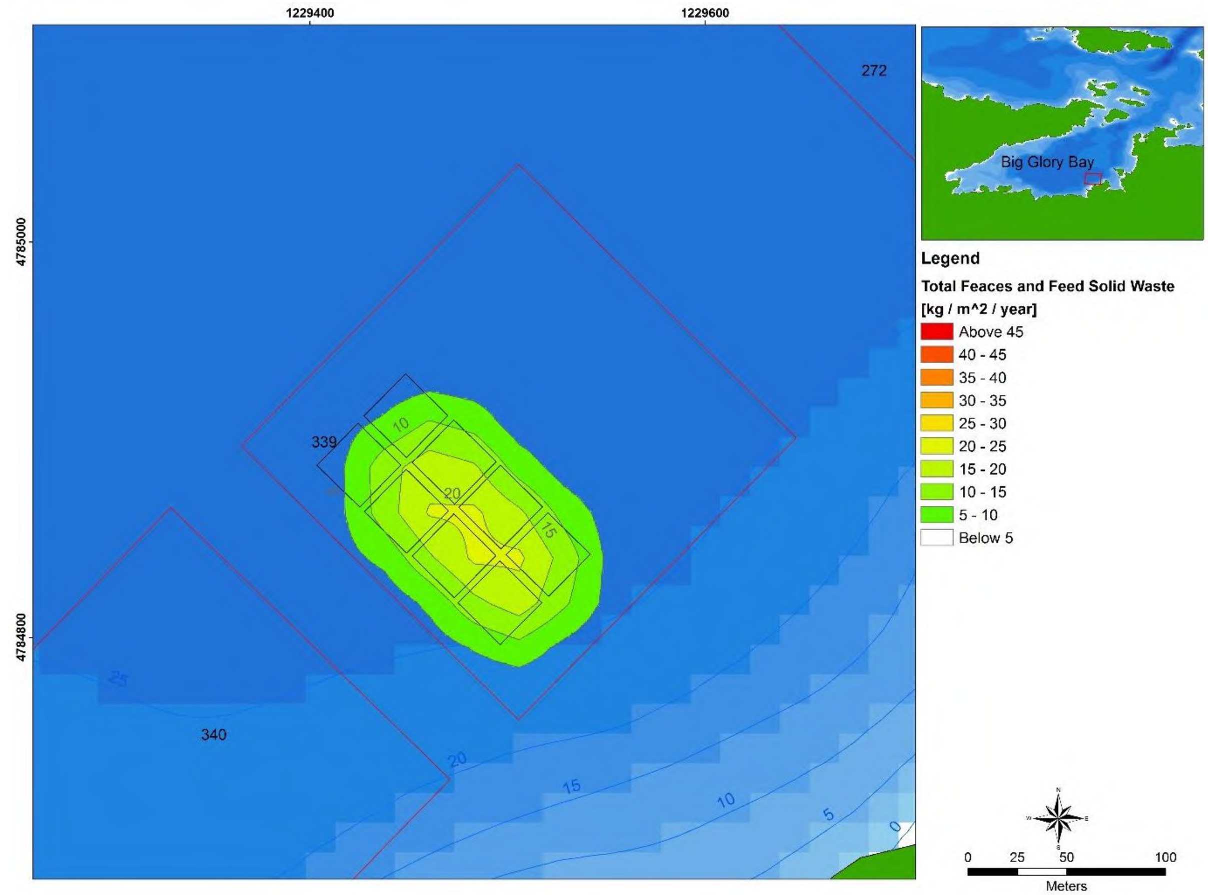

Figure 14 - Lease 339 total faeces and solids deposition with a 4.3 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 567 tons.

4 Conclusion / Discussion

The deposition models show that faeces and solids deposition should generally remain within the boundaries of the lease. This is true of lease 246 provided binding agents are used in the feed (**Figure 5** and **Figure 6**). Without binding agents higher current flows due to the proximity to the mouth of the bay skew the depositional footprint of lease 246 hundreds of meters NNE of the lease boundary (Error! Reference source not found. and Error! Reference source not found.).

All depositional footprints (assuming only the scenario using a feed binder for lease 246) show that fish feed and faeces accumulates directly under the pens with only limited (less than 100m) excursions outside lease boundaries. Depositional footprints are generally distributed throughout most of the available area within the boundaries of leases 246 and 320. This may limit the number options for the positioning of pens within the lease (in order to minimise deposition outside of the lease boundaries) and fallowing strategies that include repositioning pens over less impacted areas of the lease.

The model predictions presented in this report were derived from the New DEPOMOD software which assumes all pens within a lease are farmed uniformly and that feeding schedules are constant throughout the year. It relies on water current data provided by ADCPs that are deployed for a significantly shorter period than a year and which may not detect sporadic extreme weather events that may briefly increase dispersal and resuspension of farm wastes.

The higher-level scenario results in sustainable seabed deposition provided a binding agent is used in high-flow sites (*e.g.* lease 246) as demonstrated above.

5 REFERENCES

Aquadynamic Solutions Sdn. Bhd., 2016. Big Glory Bay Benthic and Water Quality Sampling 2016. Client report.

Aquadynamic Solutions Sdn. Bhd. , 2017. Big Glory Bay Benthic and Water Quality Sampling 2016. Client report.

ASC, 2012. ASC Salmon Standard. Version 1.0 June 2012. In. Salmon Aquaculture Dialogue.

Blackburn, T.H.,1988. Benthic mineralization and bacterial production. In: Blackburn, T.H. Sorensen, J. (eds.) Nitrogen Cycling in Coastal Environments, Wiley, New York, p. 175-190

Boynton, W.R., Kemp, W.M. and Keefe, C.W., 1982. A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production.

Cook E.J., Black K.D., Sayer M.D.J., Cromey C.J., Angel D.L., Spanier E., Tsemel A., Katz T., Eden N., Karakassis I., Tsapakis M., Apostolaki E.T., Malej A., 2006. The influence of caged mariculture on the early development of sublittoral fouling communities: a pan-European study. ICES J Mar Sci 63:637 649.

Cromey C.J., Black K.D., Edwards A., Jack I.A., 1998. Modelling the deposition and biological effects of organic carbon from marine sewage discharges. Estuar Coast Shelf Sci 47:295-308.

Cromey C.J., Nickell T.D., Black K.D., 2000. DEPOMOD. A model for predicting the effects of solids deposition from mariculture to the benthos, Vol. SAMS. The Scottish Association for Marine Science. OBAN.

Cromley, C.J., Nickell, T.D. and Black, K.D., 2002. DEPOMOD - Modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture. 214, 211-239.

Cromey C.J., Black K.D., 2005. Modelling the impacts of finfish aquaculture. Environmental Effects of Marine Finfish Aquaculture 5:129-155.

GESAMP (2001) The state of the marine environment. Group of Experts on the Scientific Aspects of Marine Pollution, Regional Seas Reports and Studies. UNEP, Nairobi

Gillibrand, P.A., Gubbins, M.J., Greathead, C. and Davies, I.M., 2002. Scottish executive locational guidelines for fish farming: predicted levels of nutrient enhancement and benthic impact. Scottish Fisheries Research Report, 63, p.2002.

Hall, P.O., Anderson, L.G., Holby, O., Kollberg, S. and Samuelsson, M.O., 1990. Chemical fluxes and mass balances in a marine fish cage farm. I. Carbon. Marine Ecology Progress Series, pp.61-73.

Hall, P.O., Holby, O., Kollberg, S. and Samuelsson, M.O., 1992. Chemical fluxes and mass balances in a marine fish cage farm. IV. Nitrogen. Marine Ecology Progress Series, pp.81-91.

Hartstein, N.D. and Stevens, C.L., 2005. Deposition beneath long-line mussel farms. Aquacultureal engineering, 33(3), pp.192-213.

Hargrave B.T., 1994. A benthic enrichment index, p. 79-91. BT Hargrave (Ed.), Modelling benthic impacts of organic enrichment from marine aquaculture. Can Tech Rep Fish Aquat Sci 1949:125 p.

Holby, O. and Hall, P.O., 1991. Chemical fluxes and mass balances in a marine fish cage farm. II. Phosphorus. Marine Ecology Progress Series, pp.263-272.

Keeley N.B., Cromey C.J., Goodwin E.O., Gibbs M.T., Macleod C.M., 2013b. Predictive depositional modelling (DEPOMOD) of the interactive effect of current flow and resuspension on ecological impacts beneath salmon farms. Aquaculture Environment Interactions 3:275-291.

Keeley N., Taylor, D., 2011. The New Zealand King Salmon Company Limited: Assessment of Environmental Effects - Benthic. Prepared for New Zealand The New Zealand King Salmon Company Ltd. Cawthron Report No. 1983. 74p. plus appendices.

Magill, S.H., Thetmeyer, H., Cromey, C.J., 2006. Settling velocity of faecal pellets of gilthead sea bream (Sparus aurata L.) and sea bass (Dicentrarchus labrax L.) and sensitivity analysis using measured data in a deposition model. Aquaculture 251:295-305.

Pearson, T.H., Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography & Marine Biology Annual Review 16:229-311.

SEPA, 2005. Regulation and monitoring of marine cage fish farming in Scotland, Annex H: Method for modelling In-feed Anti-Paritics and Benthic effects. Scottisch Environmental Protection Agency.

Thetmeyer, H., Pavlidis, A., Cromey, C.J., 2003. Development of monitoring guidelines and modelling tools for environmental effects from Mediteranean aquaculture. The MERAMED Project. Interactions between wild and farmed fish.

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Big Glory Bay Benthic and Water Quality Sampling 2016, Aquadynamic Solutions Sdn Bhd, September 2016.

CONFIDENTIAL REPORT

Aquadynamic Solutions Sdn Bhd

Big Glory Bay Benthic and Water Quality Sampling 2016

September 2016

Report prepared for Sanford Limited by Aquadynamic Solutions Sdn Bhd.

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1 SUMMARY

The 2016 Big Glory Bay (BGB) seabed benthic monitoring survey was conducted on the 12th and 13th of March 2016 on a Sanford crewed vessel. This monitoring program focussed on 4 salmon farm sites, two mussel farm sites and two control stations. Sediment samples were taken from stations at each site and analysed for sediment grain size, percentage total organic matter (TOM), particulate organic carbon (POC), zinc (Zn) and copper (Cu) concentrations. Seabed samples were also collected and analysed for microbenthic invertebrate assemblages and epifauna (using a splash camera). Additional samples were also collected 50 and 100m away from each of the four fish farm sites.

Organic enrichment of the sediment (when compared to the nearby central bay control station ConH) was observed beneath all farming stations (both mussel and fish farm), along with mussel shells (at both mussel farms and one of the salmon farms, which was once a mussel farm). Opportunist polychaetes i.e. *Dorvilleid* were also observed beneath all farming stations and similar species have been observed in and around many farms in the Marlborough Sounds.

Both the mussel and salmon stations still retained a moderately high species richness and diversity. A wide range of polychaetes were found at these sites including, grazer's, detritus feeders, opportunists and predators. Conditions were generally observed to improve (i.e. organic matter content decreased away from the farm site) at distances of 50 and 100m from the site boundaries. Ostracods were also observed at several stations.

There were however two surprises in that *Beggiatoa* matting was observed both beneath farm station 249_50 and 249_100m from the edge of the site boundary. In addition, patchy *Beggiatoa* was also observed (via the underwater video camera) beneath mussel farm station 272. As far as ADS is aware the 249 lease has been farmed for a significant period of time and is about to be fallowed with the cages moving east across the bay to farm site 246. Fallowing the site will allow seabed process to breakdown the existing *Beggiatoa* matting.

In addition to the benthic survey, water sampling has been conducted monthly from August 2015, to August 2016 by Sanford personal at six sampling stations within Big Glory Bay.

In-situ oxygen, salinity, water visibility and temperature profiles were collected with a multi parameter sonde. Results indicate that the oxygen levels within the Bay were above 6mg/l during all sampling periods and at all depths. There is no indication that the fish farming activities are having any adverse impacts on oxygen levels within the bay. Temperature data indicates a slight thermal stratification during summer periods (of approximately 1 degree). Such heating is purely related to natural variation and isn't related to farming activities.

In addition to the *in-situ* sonde profiles water samples were collected every month and sent to the laboratory for analysis. Samples were analysed for nutrients including phosphorus, ammoniacal nitrogen, nitrate nitrogen, suspended solids, volatile suspended solids, particulate carbon, particulate nitrogen, and chlorophyll-*a*.

Unfortunately, sampling was not undertaken every month and there are hence gaps in the data. The chlorophyll-*a* and nutrient data that were collected do indicate that there is variability between nutrient uptake and phytoplankton. Higher chlorophyll-*a* levels were observed in late summer and corresponded to lower levels of soluble and particulate nutrients. In Autumn chlorophyll-*a* levels were lower while both soluble and particulate nutrient concentrations increased (perhaps as a result of die off and cooler temperatures). Other seasonal patterns are impossible to assess due to the lack of data.

Overall water quality analysis indicates there are no detectable adverse water quality issues within Big Glory Bay.

2 INTRODUCTION

Big Glory Bay has been used for the sea cage rearing of King Salmon (*Oncorhynchus tshawytscha*) since the early 1980's (and was one of the pioneer fin-fish aquaculture production areas within New Zealand), while Green Shell mussel culture (*Perna canaliculus*) has been farmed in the bay since 1987 (Environmental Southland 2011).

In 2011 Environment Southland reviewed the existing monitoring conditions outlined in Hopkins (2008) and developed a new bay-wide monitoring programme that would encompass all farming activities in the bay, looking at both the ***seabed*** and the ***water column***. This new monitoring programme would be conducted once per year. A slight amendment to this review was conducted in January 2016 and these amendments have been undertaken in this year's (2016) monitoring. The new monitoring program specifics can be found in Appendix A.

The seabed monitoring program is designed to assess all marine farms within BGB for a period of 13 years. All fish farms within the Bay are monitored yearly along-side two mussel farms. The mussel farms monitored at any given year are chosen on a rotational 13 year cycle (i.e. two different mussel farms are sampled each year). Two control stations at fixed locations in the middle of the bay and at the mouth of the bay are also monitored each sampling period (Figure 3).

Several farm sites within Big Glory Bay have had varying uses, alternating from salmon culture to mussel culture and *vice versa*. Historically site 339 was a salmon farm that was converted into a mussel farm, and now recently has been converted back into a salmon farm. Site 319 was a salmon farm that has been converted into a mussel farm. Sites 246 and 249 were mussel farms that have been converted into salmon farms. Site 338 has been a salmon farm for much of its history, but was a mussel farm for a brief period. Previous farming on these sites can result in changes to seabed sediment composition beneath the farms i.e. mussel shells are observed in sediment grab samples collected under the 246 or 249 fin-fish farm sites.

The 2016 benthic survey reported here was conducted on the 12th and 13th of March 2016 on a Sanford Ltd, crewed vessel. Weather was clear with a light breeze, however two days prior to sampling a southerly weather system passed through BGB and winds were reported to exceed 120km/h.

In addition to the seabed sampling, water quality samples are collected each month by Sanford Ltd staff along with *in-situ* measurements collected by a hand held YSI Sonde. ADS have presented the water quality data collected over the last year in Section 4 below.

3 Methods

3.1 Compliance Requirements

Consent compliance requirements for marine farming in BGB involve assessment of the water column and the seabed benthic environment (Environment Southland (ES) 2016, Appendix A).

Monthly water column monitoring was initially required for a period of two years starting in July 2011 (see Appendix A). Although this two-year period has expired, Sanford Ltd and other resource users within the Bay have decided to continue the monthly water quality monitoring as part of their sustainability program.

As stated in Section 2 benthic monitoring occurs at every salmon farm site every year along with two mussel farm site. The two mussel farm sites sampled each year are different and chosen on a rotational basis. This report includes benthic assessments for four salmon and two mussel farm sites and presents water column data collected over the last 12 months. Several additional water column water quality parameters are also reported and listed below (beyond those required on the compliance requirements). Statistical analyses were also undertaken looking at the variability of seabed community composition between fish farm stations, controls and mussel farm stations.

3.2 Monitoring Indicators

As highlighted in Appendix A, several environmental indicators were used in BGB to assess the potential impacts on water quality. These indicators are temperature, chlorophyll-*a* (chl-*a*) as a proxy to phytoplankton, water transparency and dissolved oxygen (DO). Sanford Ltd also collects and analyses additional samples for the following water quality parameters: dissolved reactive phosphorus, ammoniacal nitrogen, nitrate nitrogen, suspended solids (HFR/TSS), volatile suspended solids, particulate carbon and particulate nitrogen which are also presented in section 4 of this report.

The status of the physical and biogeochemical quality of the sediments within BGB is determined by examining the sediment grain size, % total organic matter (TOM), particulate organic carbon (POC), zinc (Zn) and copper (Cu) concentrations, presence of sulphide, depth of the oxygenated layer and presence or absence of bacterial mats on the surface of BGB sediments. An increase in the proportion of the sediments comprising mud sized particles, % organic matter, sulphide odour, and/or presence of bacterial matting are indicators that the sediments are experiencing increased organic matter loading and may be harmful to benthic fauna. A change in grain size may also indicate a shift in the physical forcing's of the system such as a flood or storm events or seasonal changes in sediment depositional patterns.

The ecological quality of seabed sediments is also assessed by examining the invertebrate taxa present, their abundance, and diversity (and sometimes flora, though camera footage during the presented survey suffered from poor visibility due to a high volume of suspended sediments in the lower few meters of the water column) on the seabed surface and within seabed sediments.

A summary of these indicators is provided in Table 1 and has been modified from the descriptions provided in (NIWA, 2016).

Figure 1 presents a schematic of the enrichment gradient extending from an aquaculture production site (Modified after Pearson and Rosenberg 1976, Hartstein 2003, Black 2008). As discussed in previous BGB reports, the concept of an allowable zone of effect can be utilized in BGB. This concept represents an area around a farm where some deterioration is acceptable by the managing authority. This concept has been adapted by the World Wildlife Foundation (WWF) and is used by aquaculture consenting authorities in Australia and Canada. In New Zealand, these zones have been customized to suit site specific criteria (i.e. Hopkins et al 2008) or are based on model results using such tools as DEPOMOD, MIKE or Delft (Cromey et al 2002, Hartstein and Stevens 2005, DHI, 2012).

Table 1 Water and benthic quality indicators for the environment monitoring of marine farms in Big Glory Bay as stipulated by the Southland Regional Council (Modified from NIWA 2016).

WATER QUALITY	INDICATOR RATIONALE
Temperature	Indicates physical process affecting the system (e.g., oceanic intrusions/upwelling, river flow, thermal stratification). General following a seasonal pattern
Transparency	Water clarity
Phytoplankton (Chl-*a*)	Used for obtaining an indication of phytoplankton abundance
Dissolved oxygen (DO)	Dissolved oxygen (DO) levels can be impacted by temperature and the addition of organic material from the farms (increases biological oxygen demand). Additional oxygen can be consumed by biological oxygen demand in the seabed and through the conversion of ammonium released by the fish to nitrate. Low levels of oxygen can cause stress to fish and benthic faunal communities. Oxygen is also consumed directly by the fish themselves with higher consumption usually occurring during and directly after feeding

BENTHIC QUALITY	INDICTOR RATIONALE
Sediment grain size	Percentage of silt/clay (also known as mud) to sand and gravels in sediments beneath marine farms. Can provide some indication of organic enrichment if the mud content increases, or other changes due to physical forcing's i.e. floods or seasonal forcing's
Total Organic Matter content (TOM)	All organic matter including the organic carbon fraction. Buildup of total organic matter can lead to losses in biodiversity and abundance due to the depletion of oxygen and release of toxic metabolic waste products associated with the breakdown of this organic matter.
Particulate Organic Carbon content (POC)	A good indicator of the presence of organic-rich material originating from marine farming. It reflects the accumulated and more stable fraction of total organic matter buried in marine sediments.
Copper and zinc	Copper from anti-fouling paints and zinc from fish products can be a major environmentally significant metal contaminants within New Zealand finfish stations.
Appearance of sulphide depth and general colour of sediment	Depth of RPD (Redox Potential Discontinuity) layer: usually represents where sediments are no longer oxygenated. As the level of organic enrichment increases, the biological oxygen demand in the

	sediments increases, and they become increasingly anoxic, the RPD moves closer towards the sediment surface.
Sulphide odour	Presence indicates predominance of sulphate reduction (oxygen has already been consumed in the sediments and organic matter is processed using sulphate instead).
Depth of oxygenated layer below the sediment surface	ADS proposes to use the depth of the redox layer to determine how deep sediments are oxygenated. Normally this is only a few mm in nearshore environments, where there is an abundance of organic material.
Mat-forming. Filamentous bacteria	Their presence provides an indication that the sediments are highly anaerobic and sulphide-rich at the sediment surface, but that the overlying water column still contains some oxygen (Pearson and Rosenberg 1976, Sayama 2001).
Epifauna	These are organisms that live on the surface of the sediment. Their presence/absence, species diversity and abundance collectively provide an indication of the biological quality of the seabed.
Infauna	Infauna are animals living within the sediment. For the purpose of this assessment these are animals greater than >0.5 mm (called macrofauna). Their presence/absence, species diversity and abundance collectively provide an indication of biological quality of the seabed and the surrounding environmental forcings. There is usually a strong link between the volume of organic deposition and the corresponding benthic community structure (Pearson and Rosenberg 1976, Hartstein and Rowden 2004 and many others).

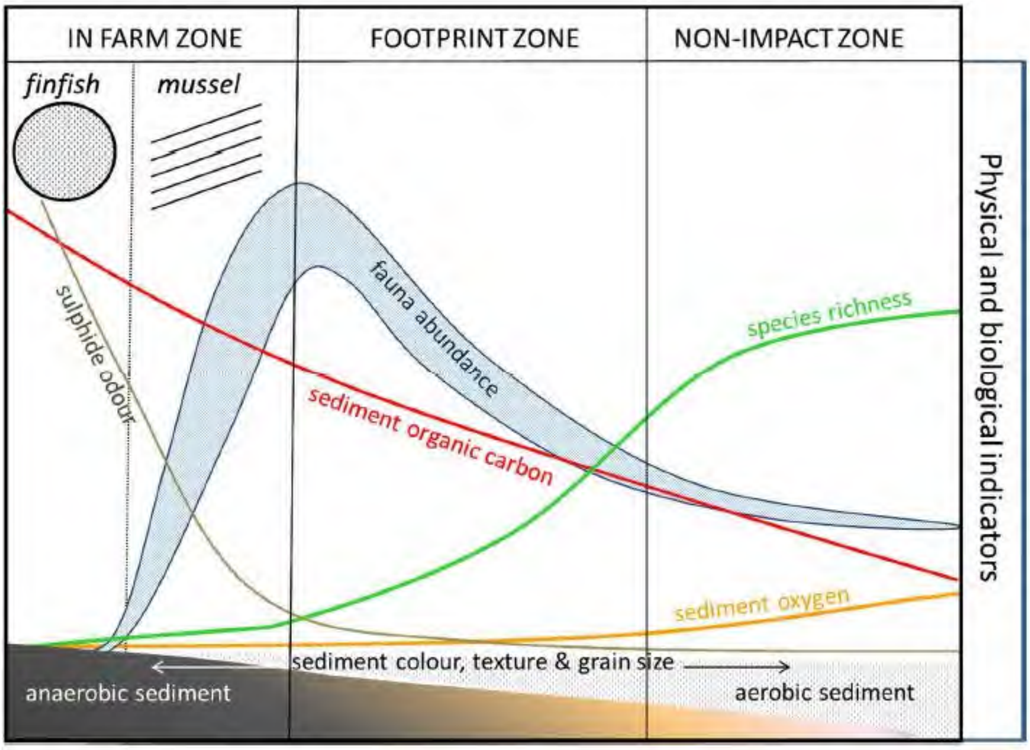


Figure 1 Schematic representation of physical and biological indicator responses to a decreasing enrichment gradient from within farms to beyond the farm footprint. The lines refer to the expected indicator. (Adapted from Pearson and Rosenberg 1976, Hartstein 2003, Hartstein and Rowden 2004, Black et al. 2008, Hopkins 2008, and Hargrave et al. 2008)

3.3 Monitoring Stations

Environmental monitoring in BGB has been divided into water and benthic sampling, and as stated above, all water quality monitoring is undertaken by Sanford Ltd staff. The results from that monitoring program have been passed to ADS to present in this report. A total of six water quality stations were sampled in the bay on a monthly basis with their locations shown in Table 2 and Figure 2.

Fourteen benthic sampling stations were also sampled. Of these stations two were located beneath leases 272 and 319 (mussel farms) while 9 more are located across three fish farm leases (249, 338 & 339). At each of these leases, samples were collected at the site boundary 0m (F), 50 m and 100 m from the site boundary (Table 2 and Figure 3). An additional fin-fish benthic station was located near the middle of lease 246 which is soon to be utilized for fin-fish farming. Previously the lease was used for mussel farming. There are two control stations, one at the mouth of the bay (ConM) and the other in the middle (ConH) of the bay (see Figure 2 & Figure 3).

Table 2 Co-ordinates for the water quality and benthic sampling stations (NZMG) in Big Glory Bay. Co-ordinates are in WGS 84 datum and given as easting and northings, and latitude in degrees and decimal minutes.

Stations	Name	New Zealand Map Grid		World Geodetic System 1984	
		Northing	Easting	Latitude (S)	Longitude (E)
Water sampling					
WS1	WS1	5348527	2138255	-46° 58.29485’	168° 07.05104’
WS2	WS2	5347816	2137279	-46° 58.64655’	168° 06.24941’
WS3	WS3	5348861	2139414	-46° 58.15204’	168° 07.97891’

WS4	WS4	5347245	2138349	-46° 58.98857’	168° 07.06492’
WS5	WS5	5347224	2139516	-46° 59.03728’	168° 07.98269’
WS6	WS6	5346826	2137577	-46° 59.18951’	168° 06.43746’
Benthic sampling					
Control stations					
ConM	ConM	5348861	2139414	-46° 58.15204’	168° 07.97891’
ConH	ConH	5347245	2138349	-46° 58.98857’	168° 07.06492’
Mussel sites					
Centre of site 319	319_F	5348513	2137968	-46° 58.29318’	168° 06.82449’
Centre of site 272	272_F	5347231	2139378	-46° 59.02909’	168° 07.87438’
Salmon sites					
Site 246					
Centre of old 246 before salmon	246_F	5348071	2139552	-46° 58.58209’	168° 08.05062’
Site 249					
site boundary	249_F	5347664	2137827	-46° 58.746065’	168° 06.673647’
Transect two					
50m out from south site boundary	249_50	5347467	2137628	-46° 58.845805’	168° 06.507737’
100m out from south site boundary	249_100	5347418	2137633	-46° 58.872365’	168° 06.509371’
Site 338					
site boundary about 2015 location	338_F	5346533	2137842	-46° 59.355892’	168° 06.632339’
50m out from north site boundary	338_50	5346831	2137826	-46° 59.194826’	168° 06.633739’
100m out from north site boundary	338_100	5346881	2137823	-46° 59.167791’	168° 06.633726’
Site 339					
site boundary about 2015 location	339_F	5347085	2139084	-46° 59.100000’	168° 07.634000’
50m out from W-N site boundary	339_50	5347117	2139006	-46° 59.078603’	168° 07.576170’
100m out from W-N site boundary	339_100	5347153	2138970	-46° 59.058054’	168° 07.549513’

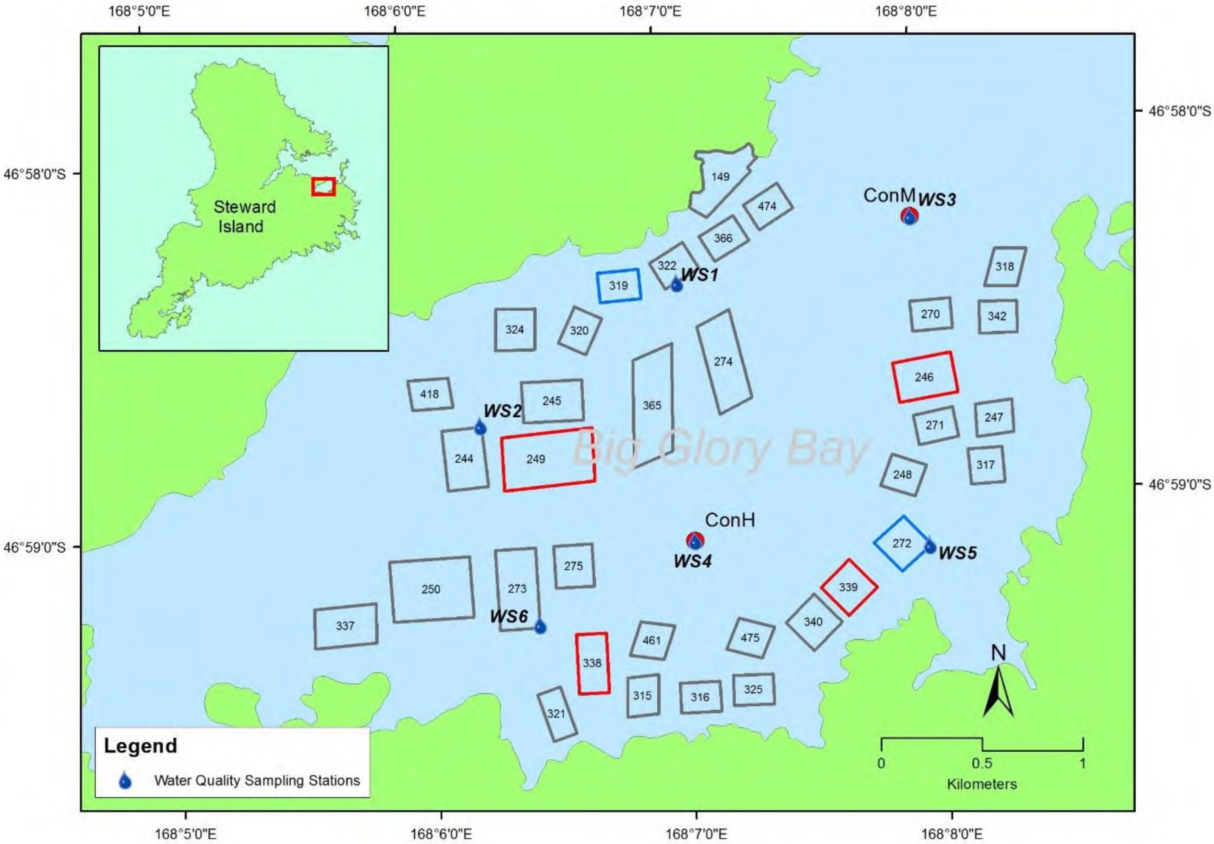


Figure 2 Marine farms in Big Glory Bay (supplied by Stanford Ltd). The four salmon farms (red rectangles: 246, 249, 338 and 339), two mussel farms (blue rectangles: 272 and 319) and two control stations (red circles), one near the bay mouth (Control Mouth: ConM) and the other in the middle of the bay (Control Head: ConH)

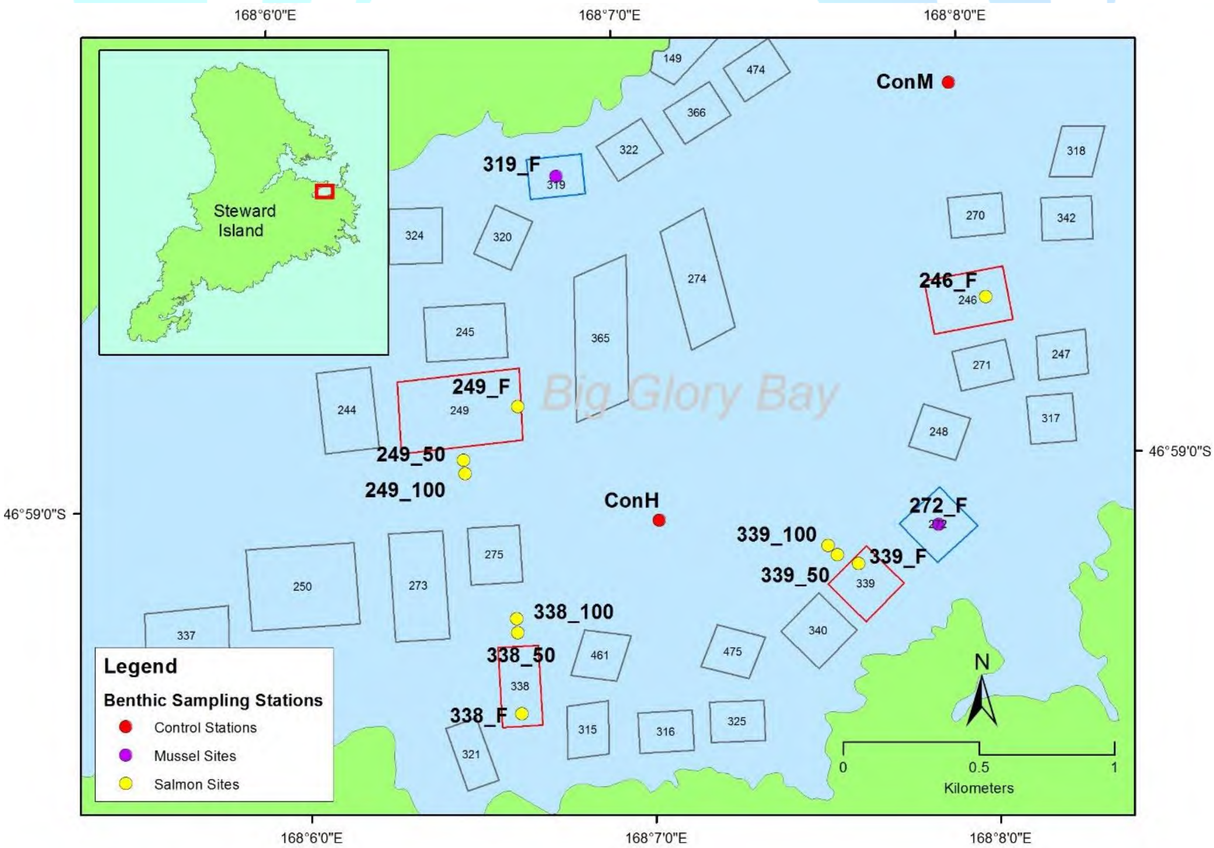


Figure 3 Marine farms in Big Glory Bay (supplied by Stanford Ltd). Location of the benthic sampling stations associated with the salmon farms (246, 249, 338 and 339) and the mussel farms (272 and 319) in Big Glory Bay. The four salmon farms (red rectangles: 246, 249, 338 and 339), two mussel farms (blue rectangles: 272 and 319) and two control stations (red circles), one near the bay mouth (Control Mouth: ConM) and the other in the middle of the bay (Control Head: ConH)

3.4 Sampling Methodology

3.4.1 Water Quality Sampling

Monthly water quality sampling has been conducted at 6 stations. Temperature and dissolved oxygen levels (mg O_2/L) were measured every 2 meters from the sea surface to the seabed with a water quality probe/sonde, while a Secchi disc was used to measure water transparency/turbidity.

Monthly samples for the analysis of Chl-*a*, and dissolved nutrients were collected at 5 meters depth using a Van Dorn sampler.

3.4.2 Benthic Sampling

At each benthic station the following sampling methods were employed (further description can be found in Appendix B).

- Three drop camera photographs were collected within a 10 m radius to visually assess the seabed and identify epifaunal communities;
- Three Van Veen grabs (bite area ca. 0.1 m^2, max bite depth 16 cm) were collected within a radius of 5 m.
- One core (maximum depth of 12 cm, diameter 15 cm) extracted from each grab sample for analyses of infauna.
- Three sediment cores (depth 12 cm, 6 cm internal diameter) extracted from each grab for sediment analyses including metals and grainsize.

Trace metal concentrations were compared against national sediment quality criteria derived by the Australia and New Zealand Environment and Conservation Council (ANZECC 2000). ANZECC have derived low interim sediment quality guideline (ISQG) values (ISQG-Low) and high interim sediment quality guideline values (ISQG-High) for each trace element and organic compound.

The ISQG-Low threshold is the level below where adverse effects on sediment-dwelling organisms are deemed unlikely and thus, exceedance of these concentrations is not necessarily cause for concern, but indicates the need for further investigation (i.e. resampling or a review of recent farm practices/physical forcing's etc). The ISQG-High value is the level at which adverse effects on some animals are known to occur. If sampled concentrations of a particular substance fall between the ISQG-Low value and ISQG-High this indicates the potential for adverse biological effects.

Water quality and sediment differences between farm sampling stations and control stations, along with all infaunal data, were analysed using the statistical analysis software (PAST3. Measures (or indices) of community structure were calculated using the DIVERSITY feature in PAST).

To assess the similarity between infauna assemblages from the different stations, species density data were square-root transformed to de-emphasise the influence of the dominant species and comparisons made using clustering (Bray-Curtis similarities) (Clarke and Warwick 1994) and nonmetric multidimensional scaling ordination (MDS; Kruskal and Wish 1978). Each mussel farm station was compared to the control stations and each salmon farm compared to the sample stations located 50 m and 100 m from the site boundary and the two control stations. Analyses of similarity (ANOSIM) tested the significance of differences between infauna assemblages from different stations. If significant differences were found, then the major species contributing to the similarities within each group and the differences between groups were identified using analysis of similarities (SIMPER; Clarke and Warwick 1994).

Table 3 Methodologies for analyzing sediment samples

Sediment Core for:	Measure	Method
Grain size	% clay and silt, % sand, % organic matter	Core size (12 cm deep and 6 cm diameter): Oven drying at 100 °C overnight and washing a weighed subsample through stacked 2000 µm and 63 µm sieves. The fraction retained on each sieve was dried and weighed and the weight of material passing the 63 µm sieve obtained by subtraction from the original weight. The amount of organic matter in the sediments was determined by freezing-drying each sample, grinding, combusting in a furnace at 500 °C for 4 hours, and reweighing. The weight of organic matter was determined by subtracting the combusted weight from the original (freeze-dried) weight and expressed as a percentage. Conducted at Hill Laboratories.
Total Organic Matter	% organic content (TOM)	Freeze-drying followed by oven drying 60 °C for 2 hours; combustion at 500 °C for 4 hours to burn off organic matter; TOM content by difference between dry weight and ash weight
Particulate Organic Carbon	% particulate organic carbon (POC)	CHN analyser at Hill Laboratories: this provided POC and PON simultaneously
Copper and zinc	Cu and Zn as mg/kg dry weight sediment from control salmon farm stations only	Hill Laboratories: Air-dried at 35 °C and sieved, <2 mm fraction. Nitric/hydrochloric acid digestion
Appearance of sulphide depth and general colour of sediment	Depth of RPD (Redox Potential Discontinuity layer)	Measurement of RDP layer (black colour demarcation) from surface of sediment in each of 3 cores from each grab sample. Depths are normally in the range of a few millimeters for coastal sediments. These depths were measured in-situ directly from the core itself
Sulphide odour	Presence or absence	Odour detection
Depth of oxygenated layer below the sediment surface	Core measurement in millimeters	Measure the thickness of the oxygenated surface layer (usually only a few millimeters thick in nearshore soft sediments). Again measured *in-situ* directly from the core itself
	Fauna	
Epifauna	Presence/absence on the surface of the sediment Identification of surface features such as burrows and bacterial mats	Three drop camera photo quadrats (35 x 50 cm) per station to describe the presence of conspicuous epifauna. The presence of other seabed features such as burrows and holes made by seabed-

		dwelling organisms, and shell debris within each quadrat were also recorded
Infauna	Numbers and taxa per core Number per taxon	Core depth 12 cm pushed into the sediment (diameter 15 cm). Sieve sediment core samples though a 0.5 mm mesh. Retained infauna counted and taxa identified

4 RESULTS

4.1 WATER QUALITY

All water quality data are provided in Appendix B.

4.2 WATER CLARITY, TEMPERATURE AND OXYGEN LEVELS

Monthly Secchi depth (m) measurements from July 2015 to August 2016 (averaged across all stations) are between 7.6 and 15.1 m (Figure 4). The deepest Secchi depth measurements were taken during July 2015 (winter time), which may be related to a lack of phytoplankton in the water column (higher Chl –*a* values are normally observed in spring and summer compared to winter months). Monthly water temperatures (averaged over all stations and depths) varied seasonally, with a high of 15 °C observed in summer compared to a low of 8.4 °C in winter (Figure 5).

Monthly average dissolved oxygen concentrations varied seasonally with higher values observed in winter and lower values in summer (Figure 5). Measured DO concentrations in Big Glory Bay are above critical levels for sustaining aerobic respiration (<2 mg/L) and for stressing most aerobic organisms (4 mg/L) (USEPA 2012).

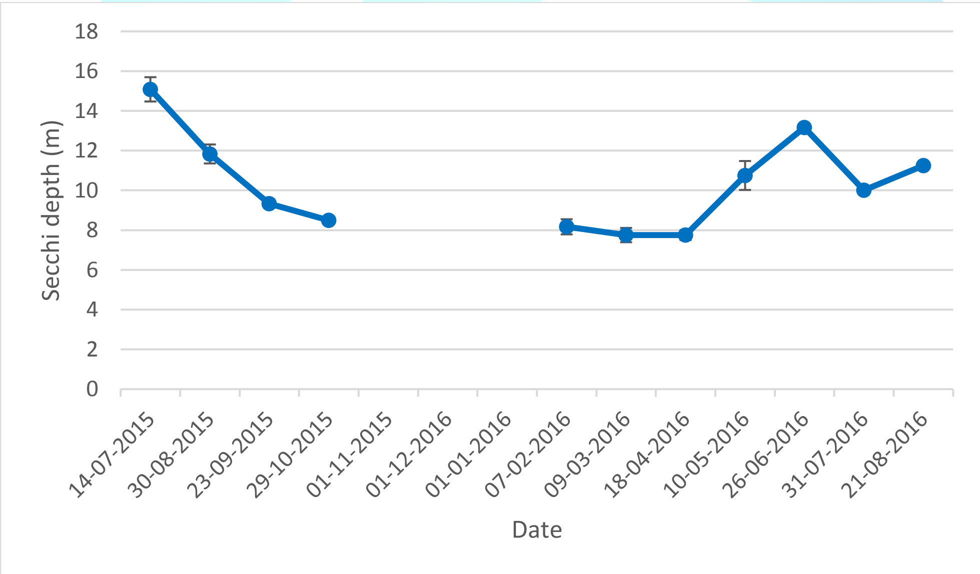


Figure 4 Water clarity (mean Secchi depth) (m) across all six water quality stations Big Glory Bay. Vertical bars are ±1 SE (n=11). Note no data is available from November 2015 to January 2016.

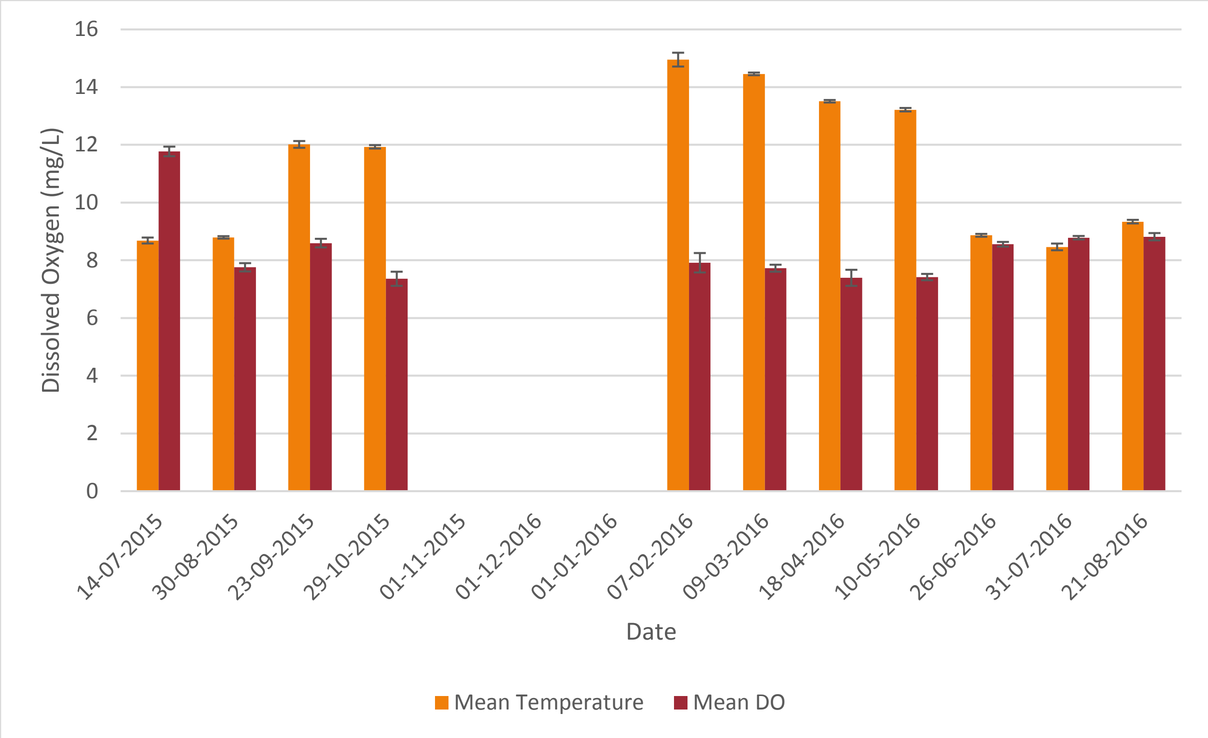


Figure 5 Monthly mean temperature (°C) and mean dissolved oxygen concentrations (mg/L) for all stations and depths. Vertical bars are ±1 SE (n=11). Note no data is available from November 2015 to January 2016.

There was generally little change in water temperature with depth across all stations sampled though there were changes from month to month (Figure 6. Figure 7 and Figure 8). In February 2016, a weak thermocline was evident with a difference of approximately 1 °C between the surface waters and measurements taken at 5-7 meters depth. Dissolved oxygen (DO) changed little with depth in the summer months, but DO levels increase markedly with depth in autumn and early winter (Figure 9, Figure 10 and Figure 11).

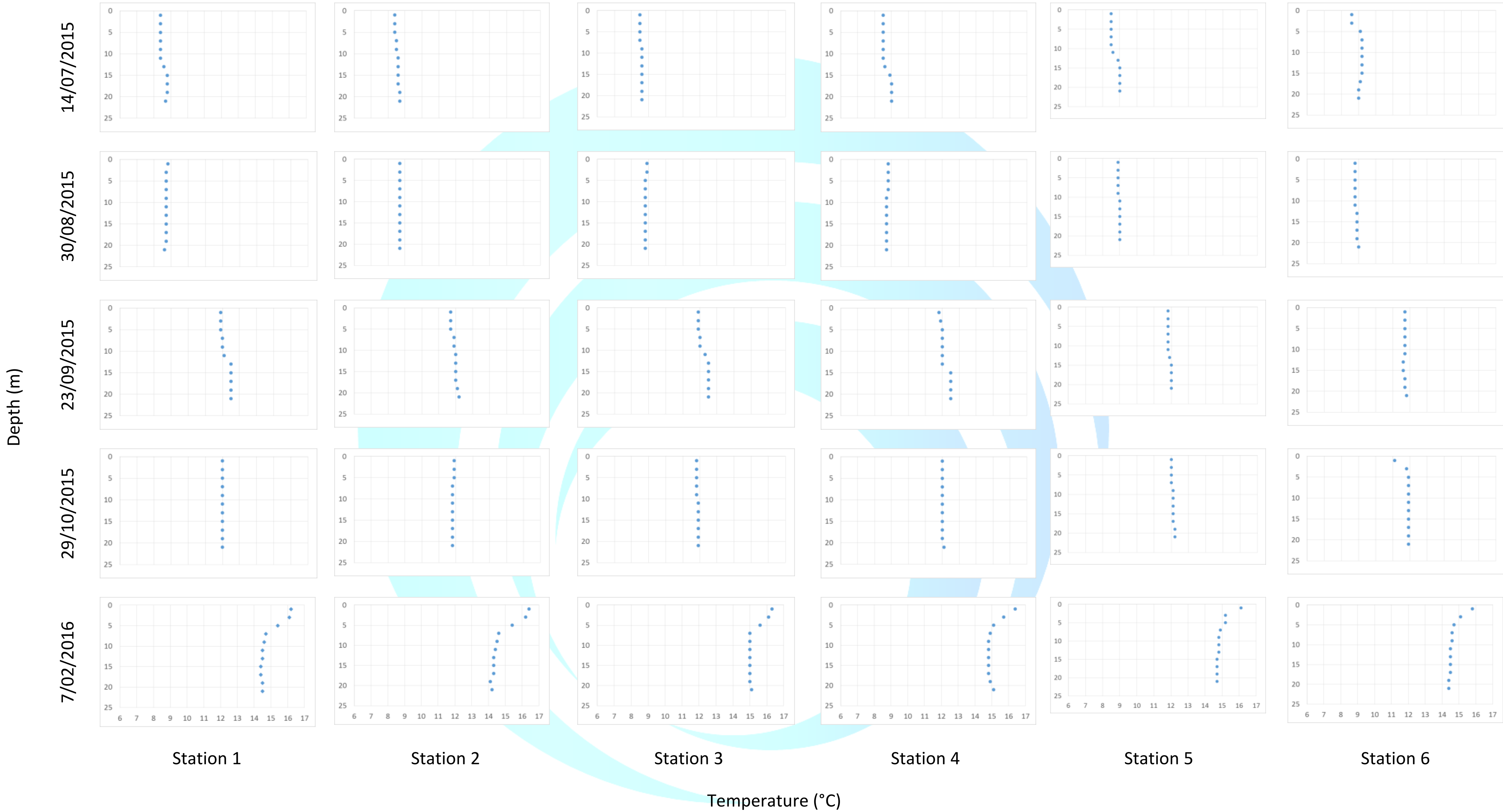


Figure 6 Changes in temperature from 1 m below the surface to 21 m depth in each month at each station (columns 1 to 6) in Big Glory Bay from July 2015 to February 2015

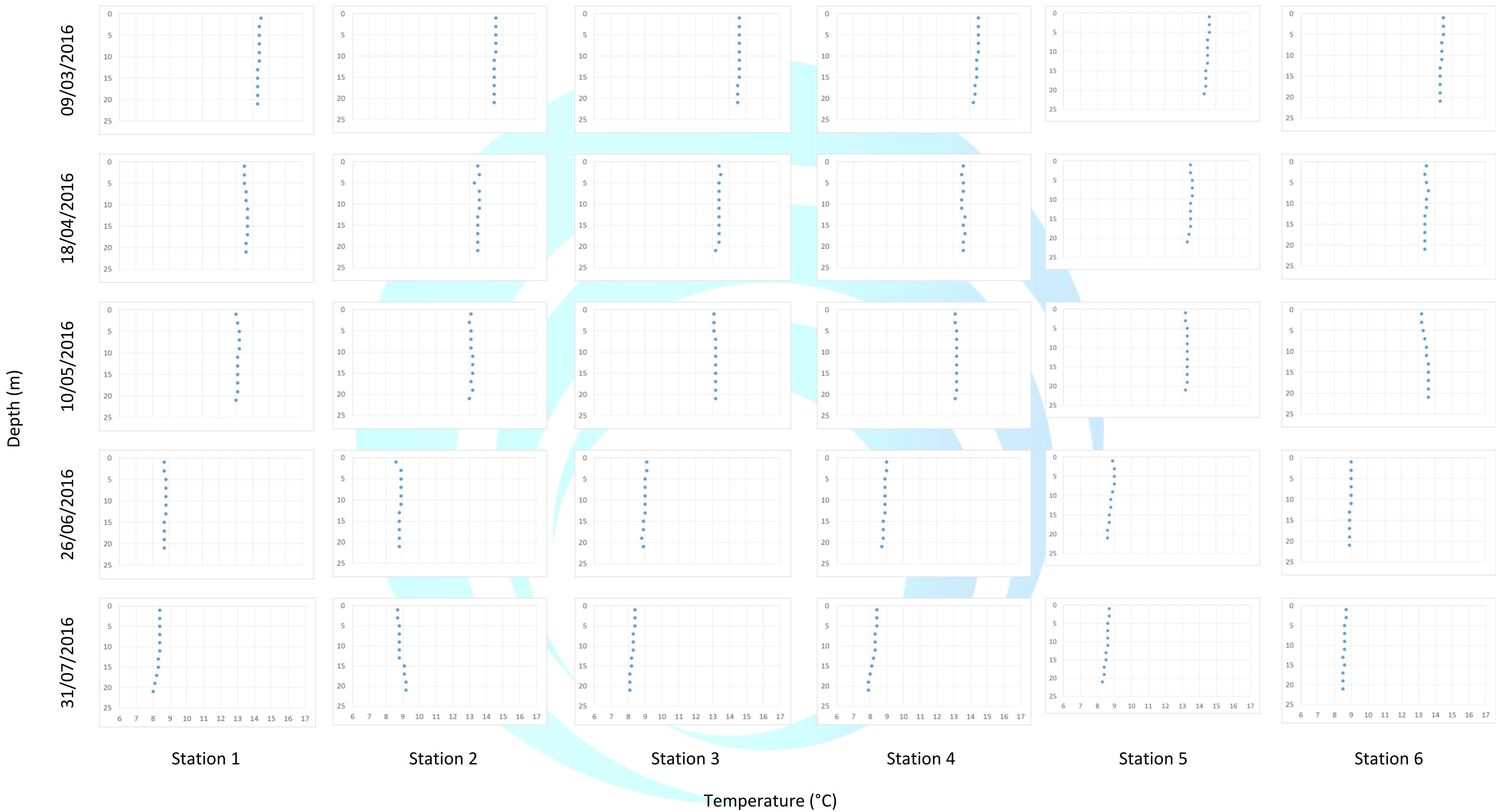


Figure 7 Changes in temperature from 1 m below the surface to 21 m depth in each month at each station (columns 1 to 6) in Big Glory Bay from March 2016 to July 2016

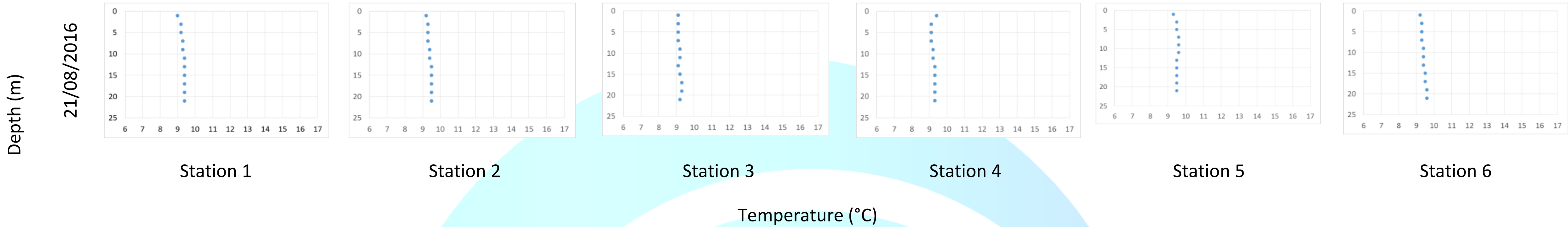


Figure 8 Changes in temperature from 1 m below the surface to 21 m depth in each month at each station (columns 1 to 6) in Big Glory Bay for August 2016

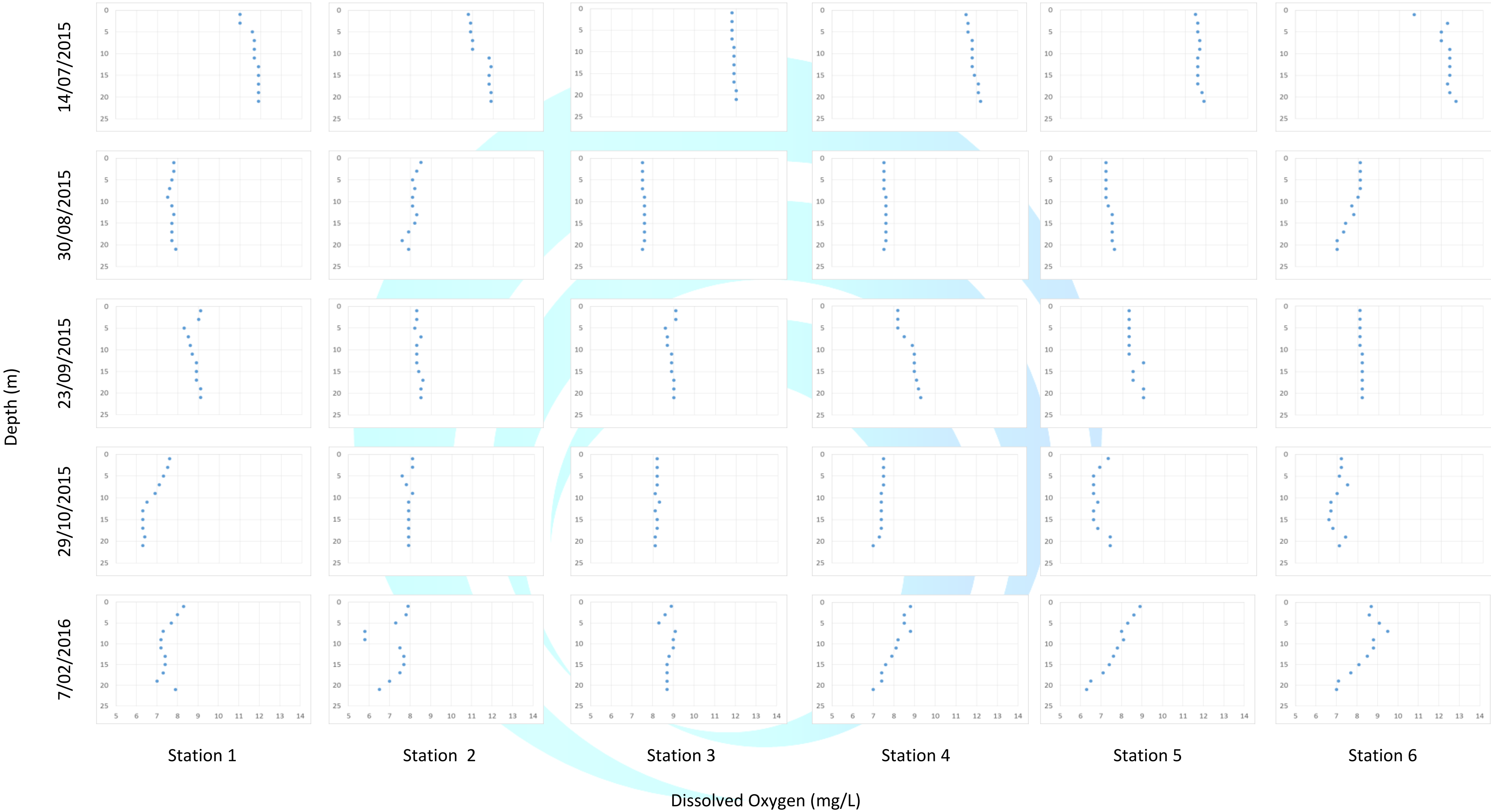


Figure 9 Changes in dissolved oxygen (mg/L) from 1 m below the surface to 21 m depth each month at each station (1 to 6) in Big Glory Bay from July 2015 to February 2016

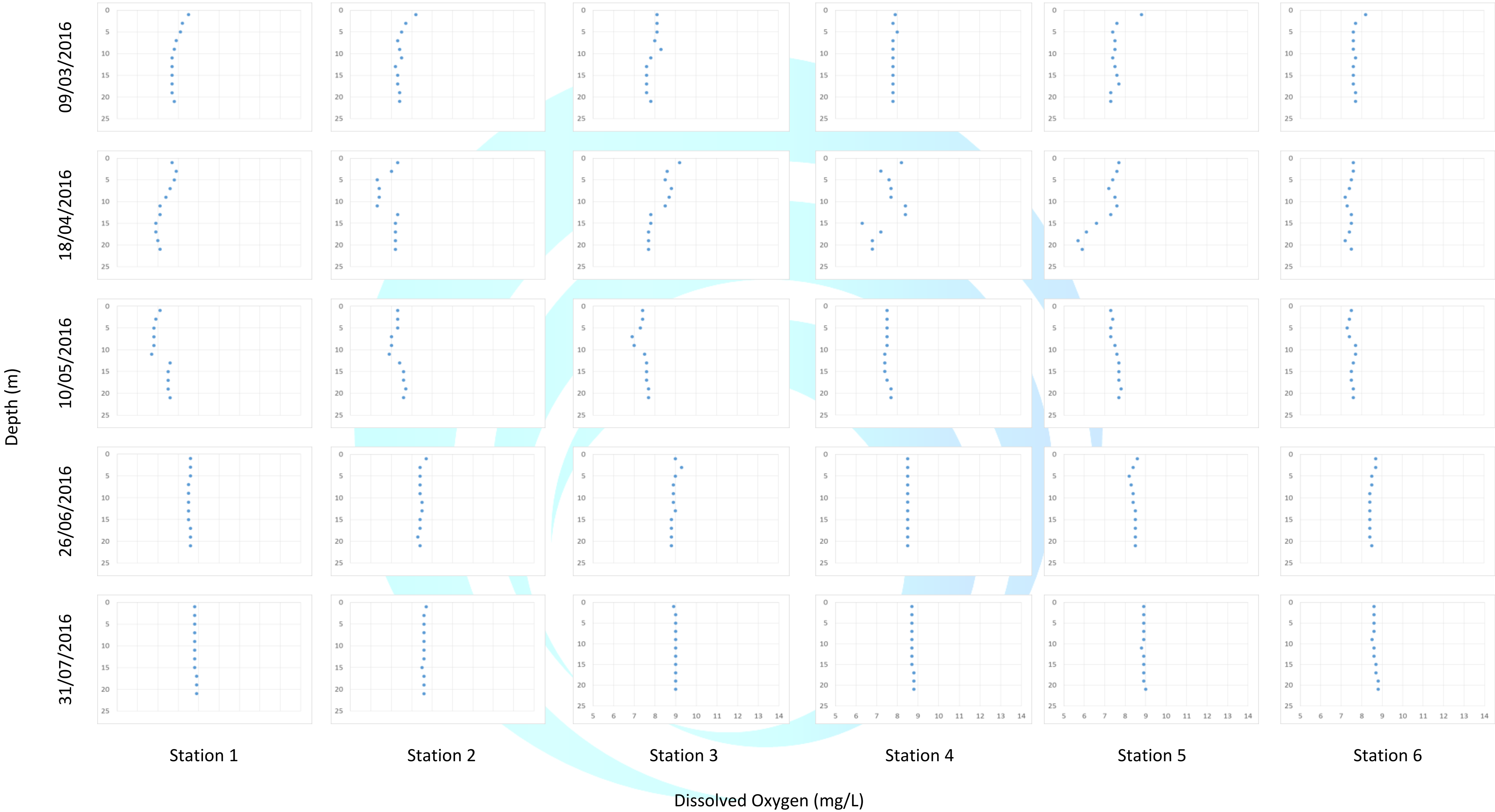


Figure 10 Changes in dissolved oxygen (mg/L) from 1 m below the surface to 21 m depth each month at each station (1 to 6) in Big Glory Bay from March 2016 to July 2016

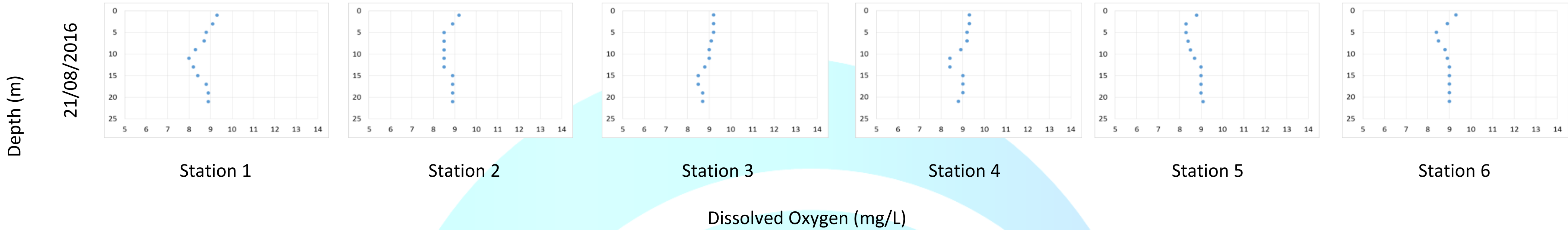


Figure 11 Changes in dissolved oxygen (mg/L) from 1 m below the surface to 21 m depth each month at each station (1 to 6) in Big Glory Bay on August 2016.

4.3 CHLOROPHYLL-A CONCENTRATIONS

Chl-*a* was collected during July 2015, August 2015 and from February 2016 to August 2016 with concentrations across the 6 sites varying considerably, even within sampling periods. The most extreme variation was observed in February 2016, where a high of 5.1 µg/L was observed at Site 3 while a low of less than 0.6 µg/L was detected at site 2 (Figure 12 & Figure 13).

Mean concentrations at each station (n=9 months) ranged between 0.45 µg/L to 2.18 µg/L (Figure 14). There was no sample analyzed for station 1 in May 2016 as the sample was lost in transit. No samples were taken from September 2015 to January 2016.

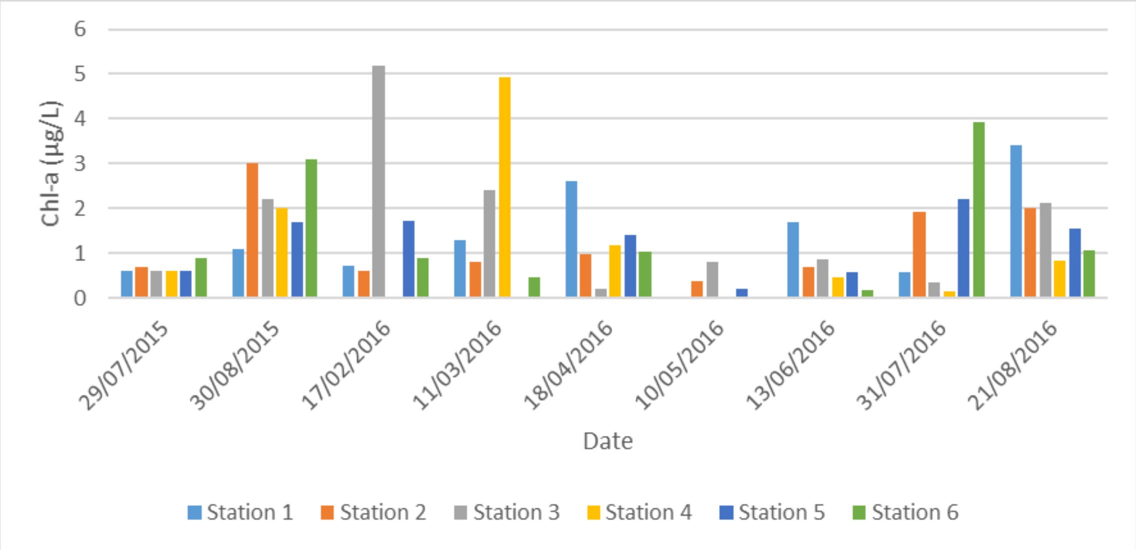


Figure 12 Monthly Chl-a levels (µg/L) at each water quality station in Big Glory Bay.

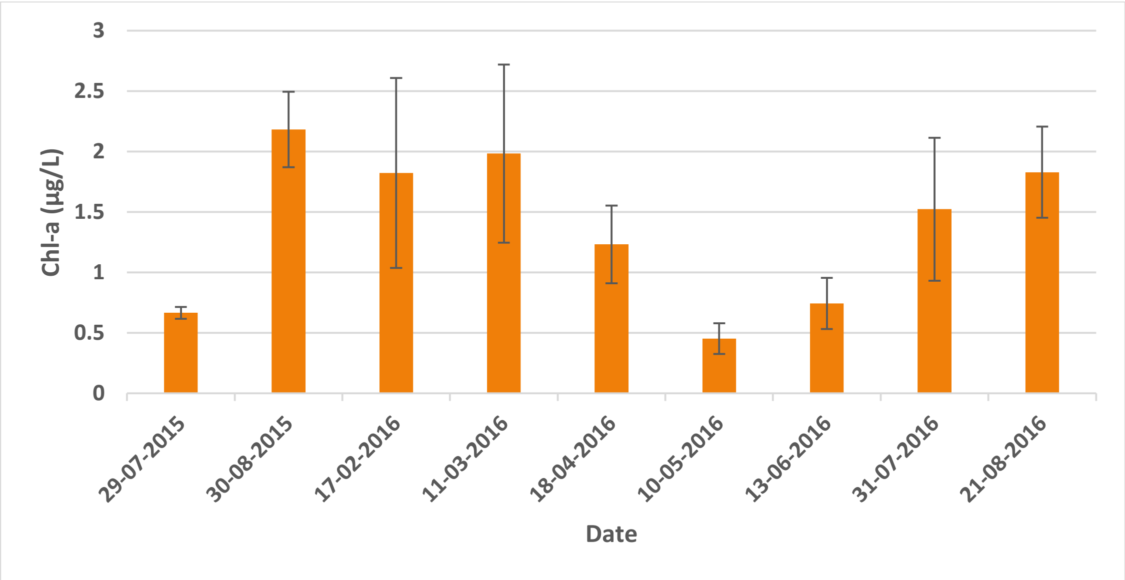


Figure 13 Mean (±1 SE, n=6) monthly chlorophyll-a concentrations (µg/L) in Big Glory Bay based on all six water quality sample stations.

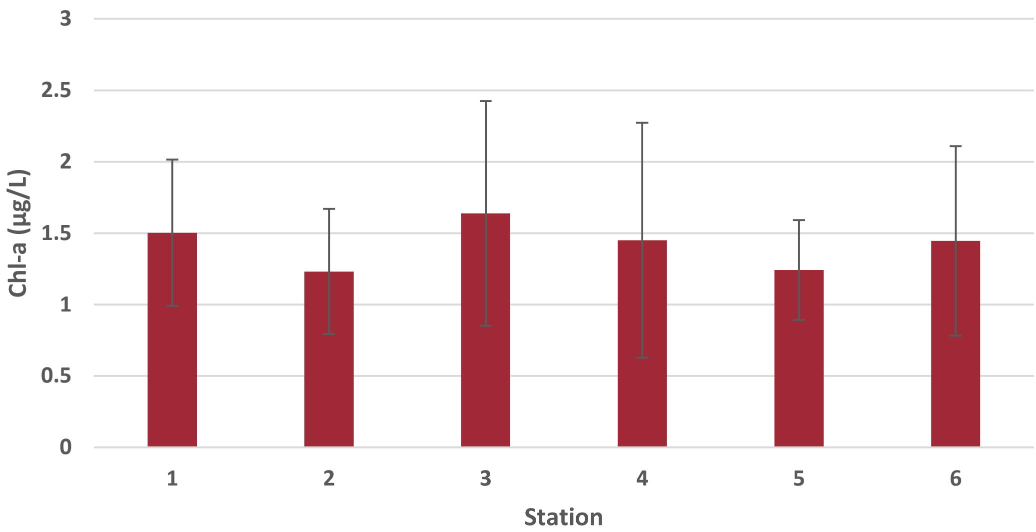


Figure 14 Monthly mean (±1 SE, n=9) Chl-a concentration (µg/L) for each water quality station in Big Glory Bay from July 2015 to August 2016. No samples were taken from September 2015 to January 2016.

4.4 Other Water Parameters Results

Sanford collected additional water samples at stations 3 and 4 from February to August 2016 as part of an internal monitoring program (Figure 2). The results of which are presented below. Water samples have been tested for the following: dissolved reactive phosphorus, ammoniacal nitrogen, nitrate nitrogen, suspended solids, volatile suspended solids, particulate carbon and particulate nitrogen.

4.4.1 Dissolved Reactive Phosphorus

Dissolved reactive phosphorus concentrations ranged from a low of 0.009 mg/L at station 3 in February 2016 and a high of 0.026mg/L at station 4 in July 2016 (Figure 15). Mean dissolved reactive phosphorus concentrations were also at their highest in July 2016 compared to other months of sampling (Figure 16). Mean concentrations for each station (n=7 months) ranged between 0.017 ppm to 0.019 ppm (Figure 17).

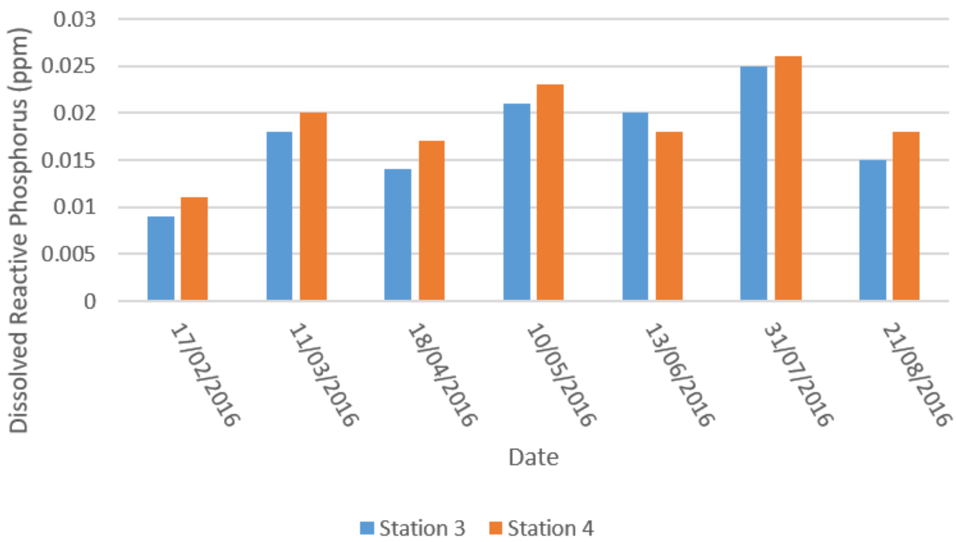


Figure 15 Dissolved reactive phosphorus (ppm) at station 3 and station 4 Big Glory Bay.

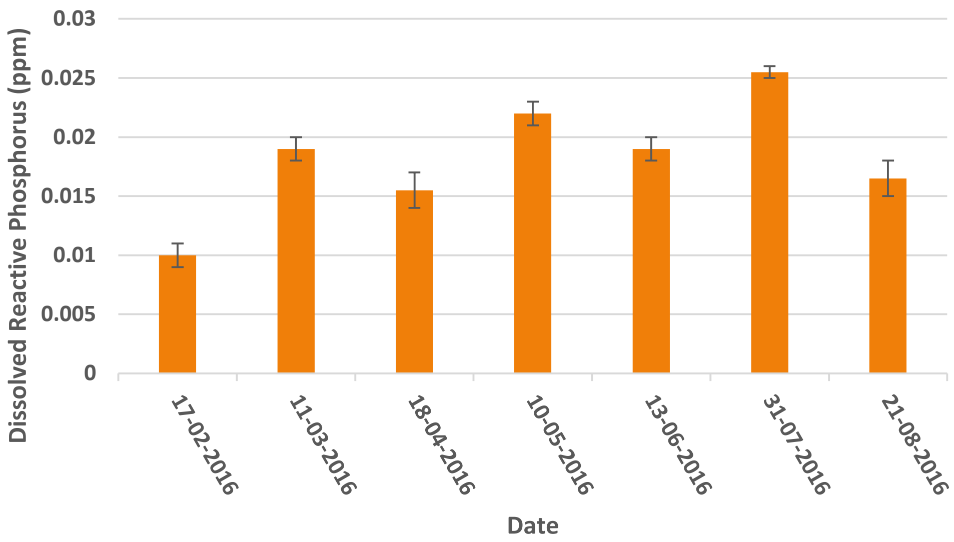


Figure 16 Mean (±1 SE, n=2) monthly dissolved reactive phosphorus concentrations (ppm) in Big Glory Bay based on station3 *and* station *4 water quality samples.*

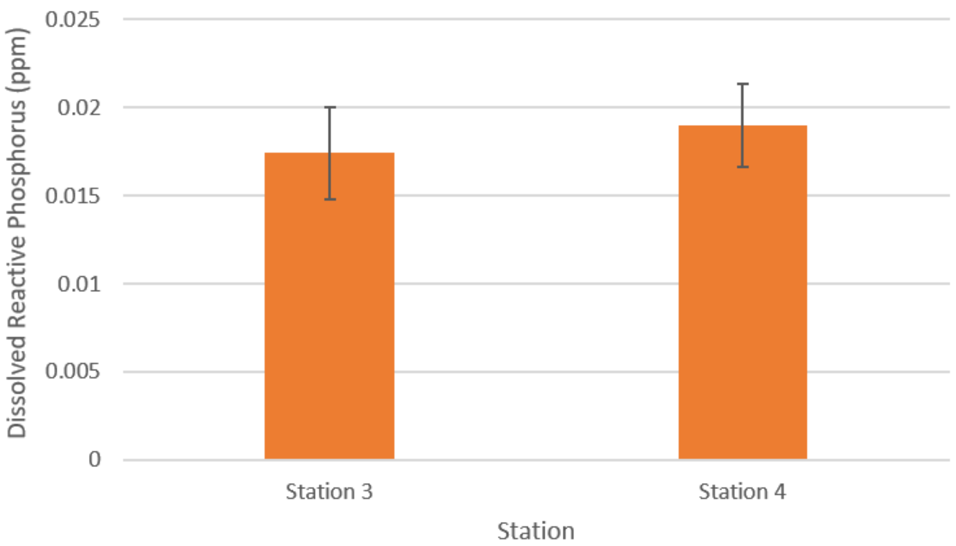


Figure 17 Monthly mean (±1 SE, n=7) dissolved reactive phosphorus concentrations (ppm) at station *3 and* station *4 from February 2016 to August 2016.*

4.4.2 Ammoniacal Nitrogen

Ammoniacal nitrogen had the highest concentrations recorded in May 2016 and the lowest in August 2016, both at station 3 (Figure 18 and Figure 19). Mean concentrations for each station (n=7 months) ranged between 0.026 ppm to 0.081 ppm (Figure 20).

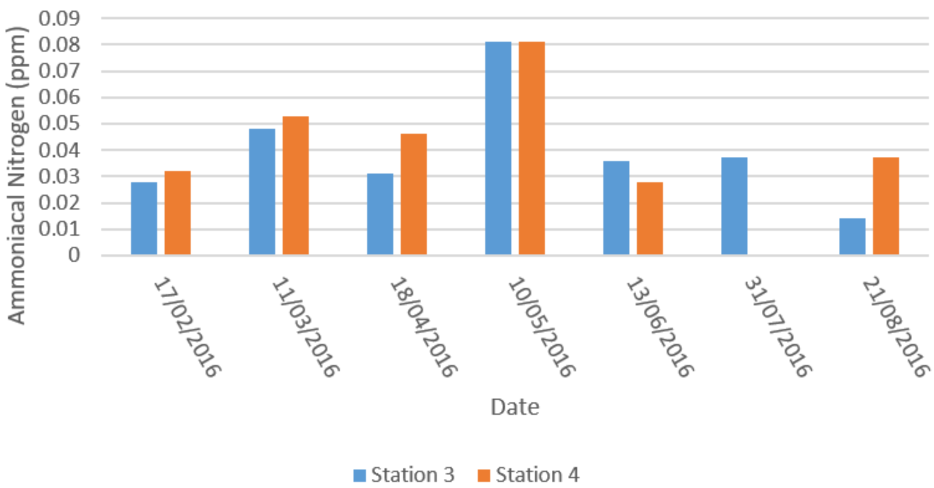


Figure 18 Ammoniacal nitrogen (ppm) at station 3 and station 4 during the February to August 2016 sampling period.

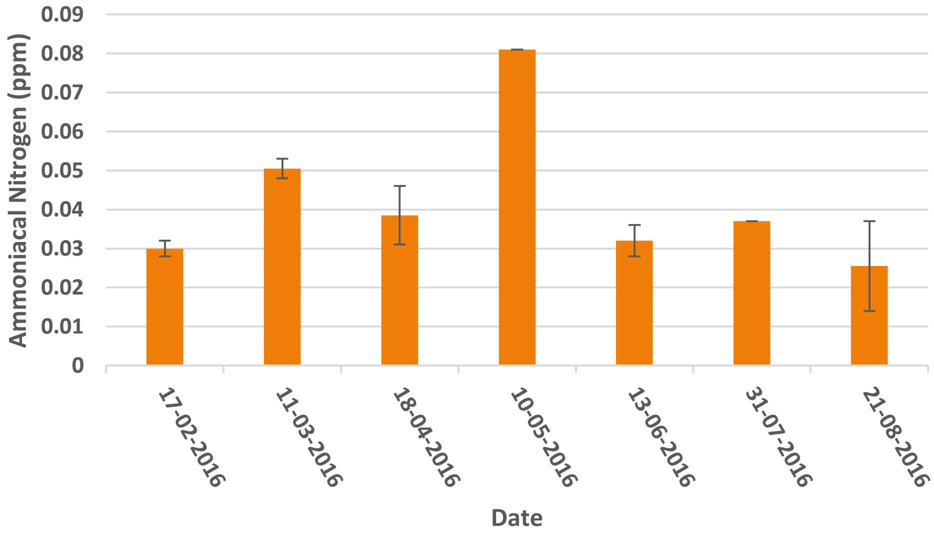


Figure 19 Mean (±1 SE, n=2) monthly ammoniacal nitrogen concentrations (ppm) in Big Glory Bay based on station 3 and station 4 water quality samples.

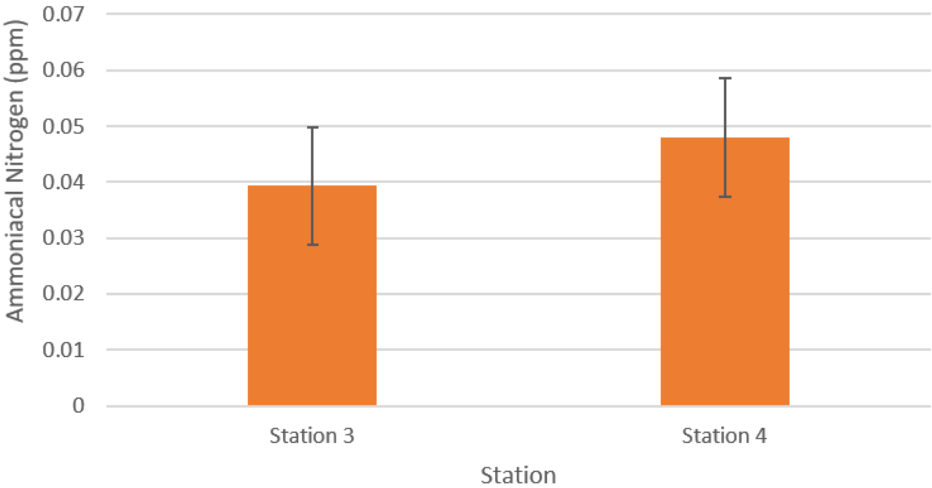


Figure 20 Monthly mean (±1 SE, n=7) ammoniacal nitrogen concentration (ppm) at station 3 and station 4.

Nitrate nitrogen was not tested in February 2016 however it was tested from March to August 2016. Nitrate nitrogen was at its highest in July 2016 with concentrations of 0.09 mg/L recorded at station 4 and a low of 0.02 mg/l recorded in March 2016 at station 3 (Figure 21). Mean concentrations for each station (n=6 months) were both 0.043 mg/l (Figure 22).

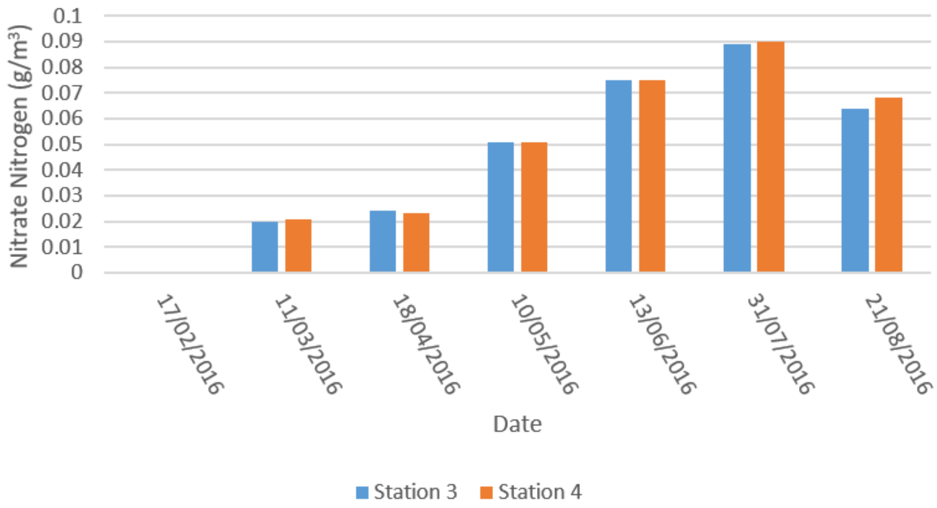


Figure 21 Nitrate nitrogen (mg/l) at station 3 and station 4 during the February to May 2016 sampling period.

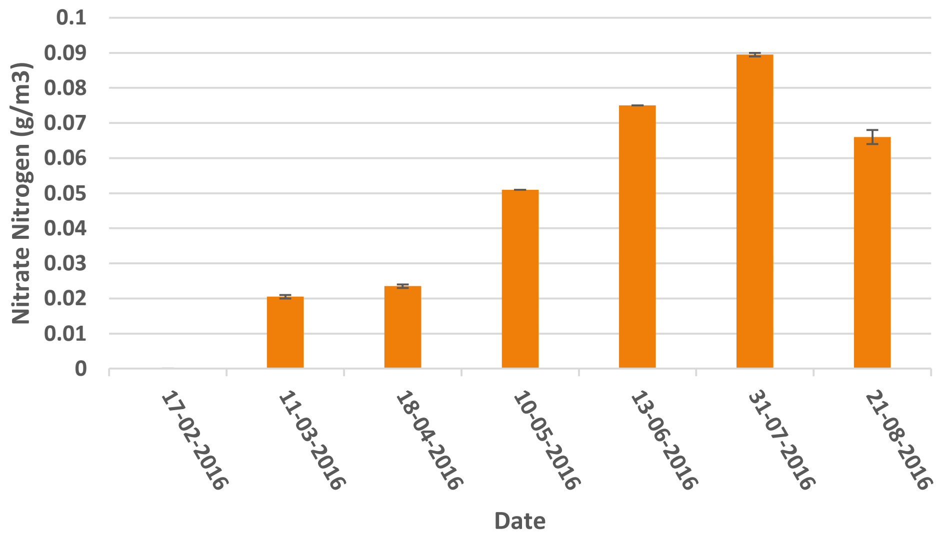


Figure 22 Mean (±1 SE, n=6) monthly nitrate nitrogen concentrations (gm/l) at station 3 and station 4.

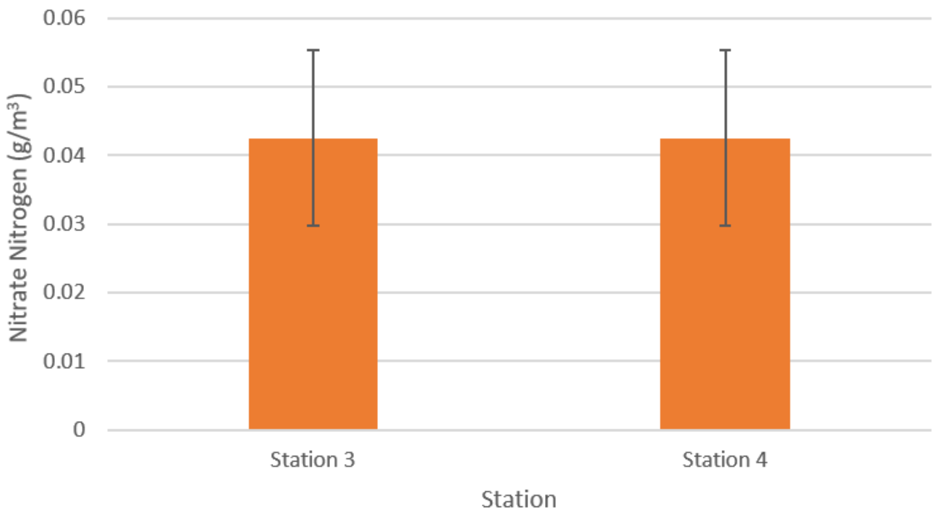


Figure 23 Monthly mean (±1 SE, n=6) nitrate nitrogen concentrations (mg/l) at station 3 and station 4.

4.4.3 Suspended Solids (HFR/TSS)

Suspended solids were at their highest in February 2016 (Figure 24 and Figure 25). Mean concentrations for each station across all months sampled (n=7 months) were (21 g/m^3) at station 4 and 20.4 g/m^3 at station 3 (Figure 26).

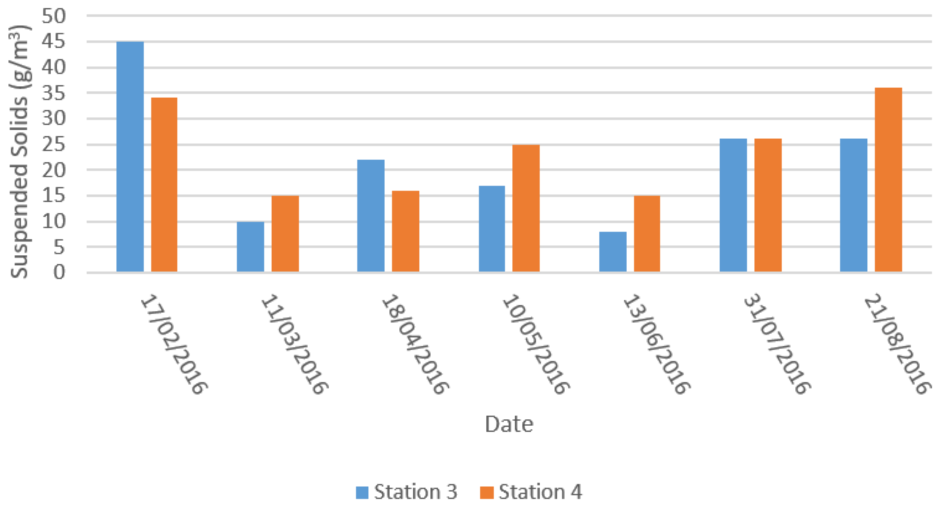


Figure 24 Suspended solids (g/m³) at station 3 and station 4 during the February to August 2016 sampling period.

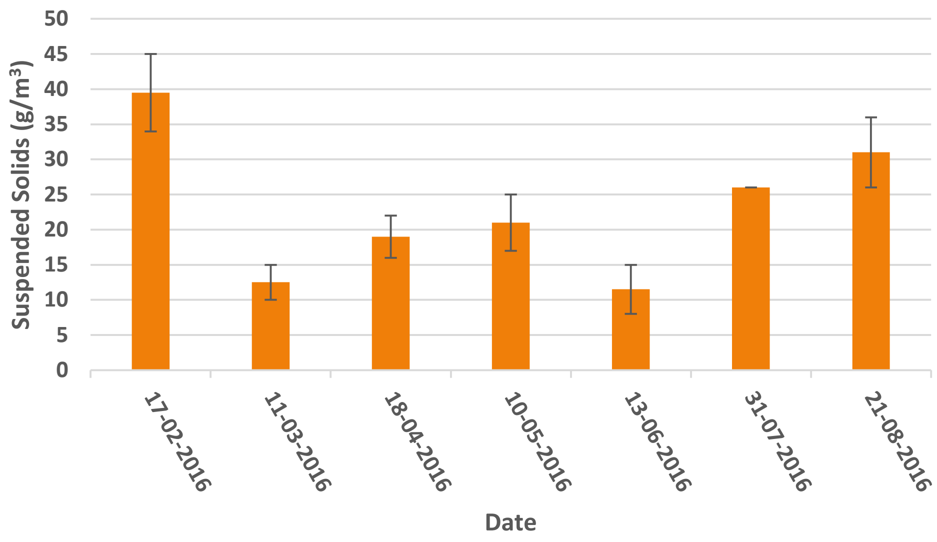


Figure 25 Mean (±1 SE, n=2) monthly suspended solids concentrations (g/m³) station 3 and station 4.

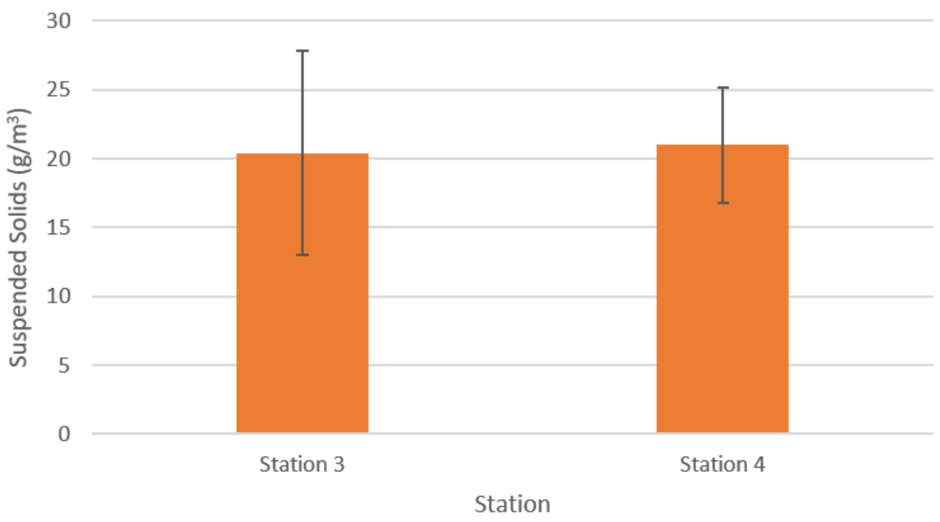


Figure 26 Monthly mean (±1 SE, n=7) suspended solids concentrations (g/m³) at station 3 and station 4.

4.4.4 Volatile Suspended Solids

Volatile suspended solids were highest at station 3 during the February sampling (Figure 27). Oddly the volatile suspended solid concentration at station 4 during February was below the detection level of the laboratory (ADS have no explanation for this difference, having asked for the lab to re-run the sample with the same result). Mean concentrations were only detected in station 3 during February 2016 sampling as all the other sites at all months are below the detection level of the laboratory (Figure 28 and Figure 29).

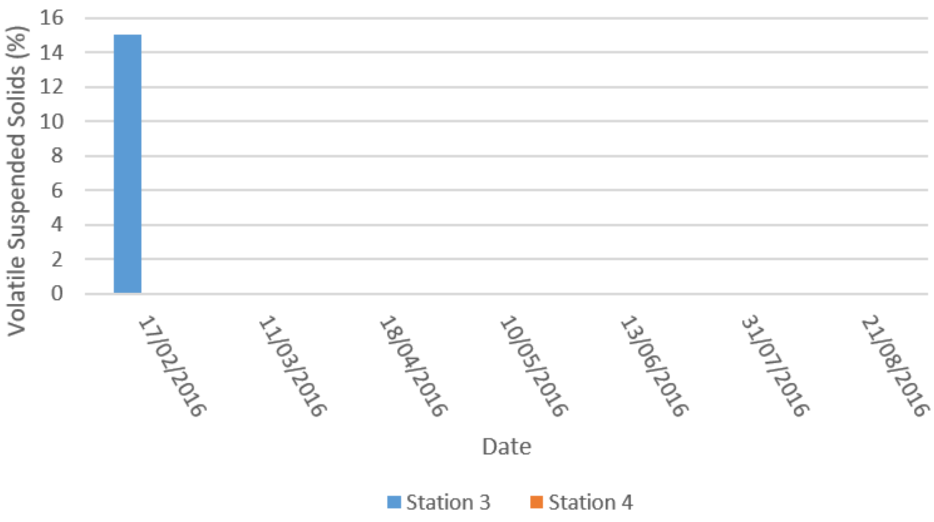


Figure 27 Volatile suspended solids (%) at station 3 and station 4 during the February to August 2016 sampling period.

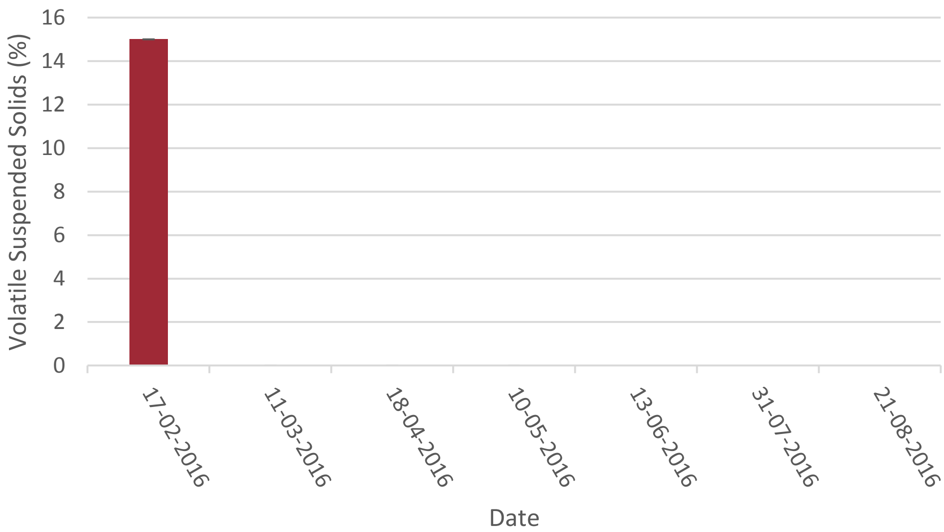


Figure 28 Mean (±1 SE, n=2) monthly volatile suspended solids concentrations (%) based on station 3 and station 4 water quality samples.

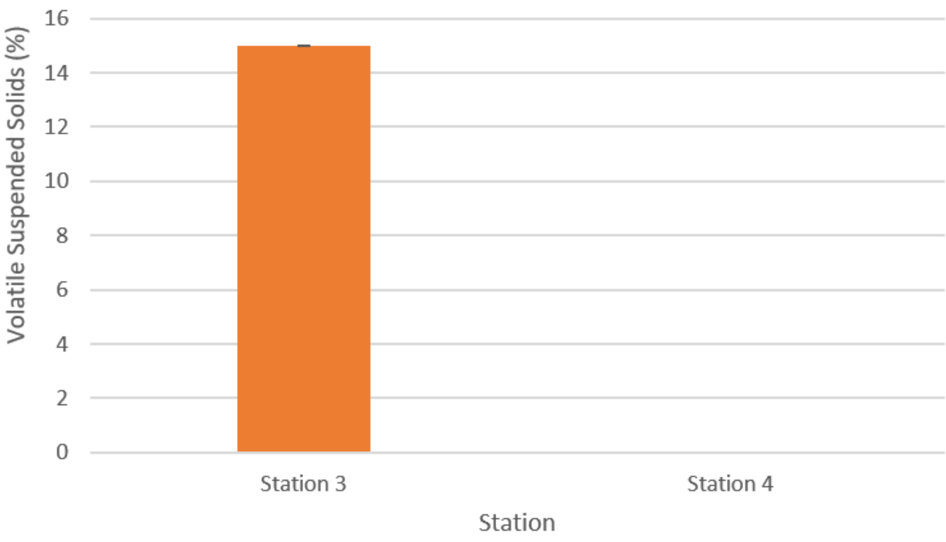


Figure 29 Monthly mean (±1 SE, n=7) volatile suspended solids concentrations (%) at station 3 and station 4.

4.4.5 Particulate Carbon

Particulate carbon concentrations were very low during the February and March 2016 sampling period, but increased markedly in April before reducing again in May 2016 (Figure 30). In April 2016, mean particulate carbon concentrations were the highest compared to other months sampled (Figure 31). Mean concentrations for each station (n=7 months) are presented in (Figure 32).

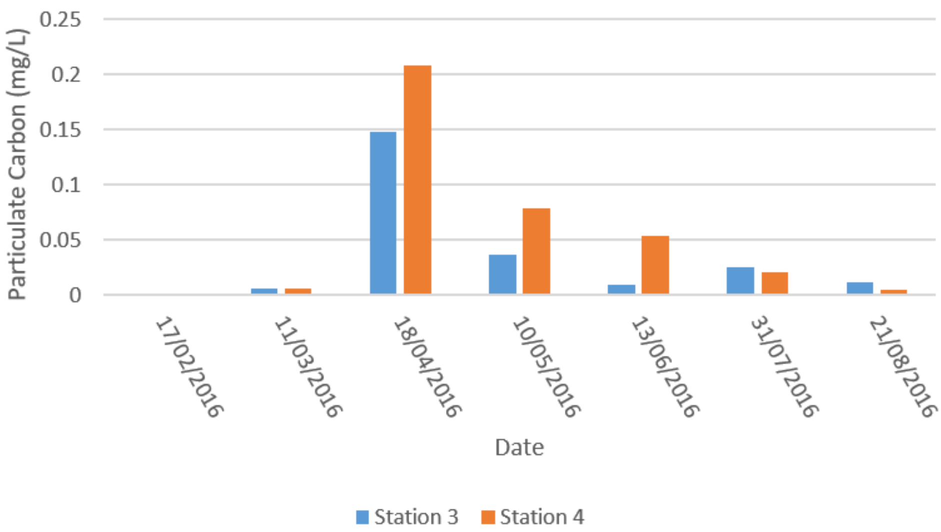


Figure 30 Particulate carbon (mg/L) at station 3 and station 4 during the February to August 2016 sampling period.

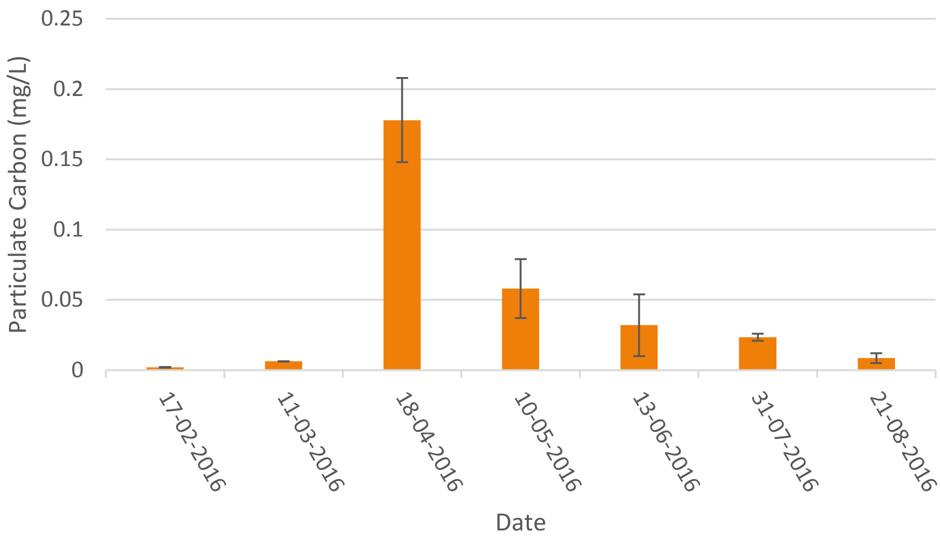


Figure 31 Mean (±1 SE, n=2) monthly particulate carbon (mg/L) in Big Glory Bay based on station 3 and station 4 water quality samples.

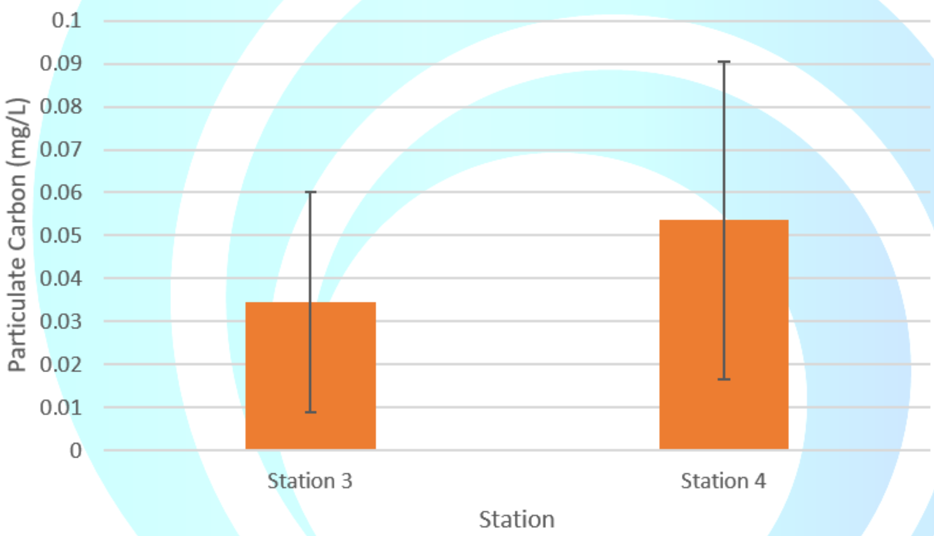


Figure 32 Monthly mean (±1 SE, n=7) particulate carbon (mg/L) at station 3 and station 4

4.4.6 Particulate Nitrogen

Particulate nitrogen concentrations were found to be highest during the April 2016 sampling and much lower in February and March 2016 (Figure 33 & Figure 34). Mean concentrations for each station (n=7 months) ranged between 0.0051 mg/L and 0.0085 mg/L (Figure 35). Only one station was sampled during the June to August 2016 sampling periods.

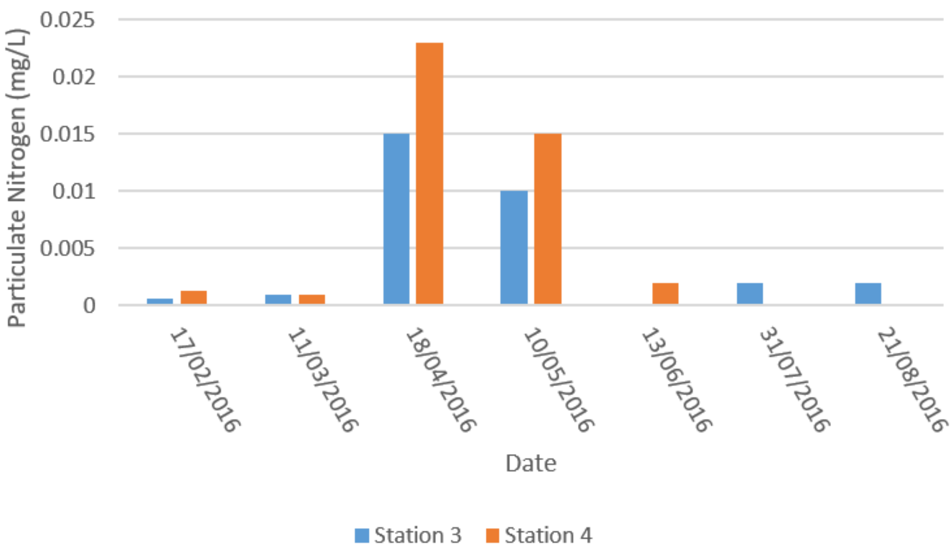


Figure 33 Particulate nitrogen (mg/L) at station 3 and station 4 during the February to August 2016 sampling period.

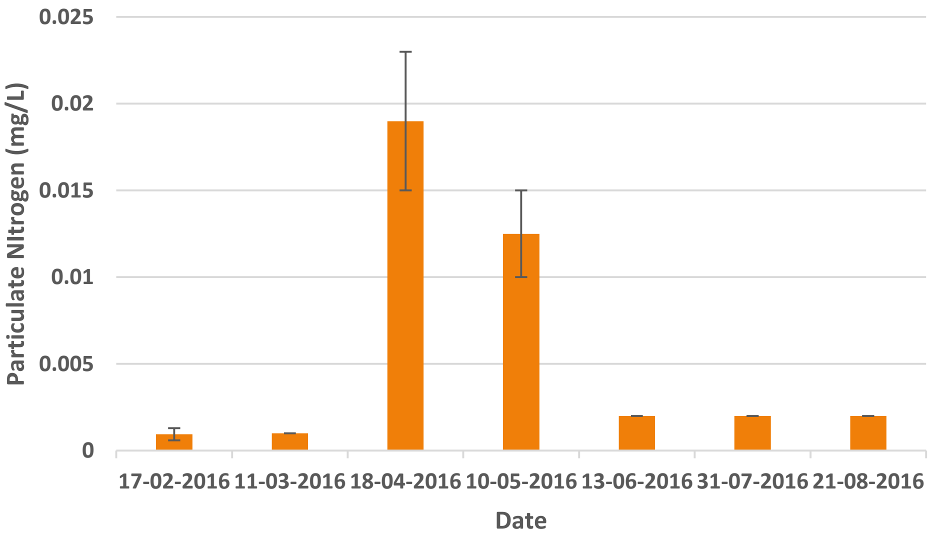


Figure 34 Mean (±1 SE, n=2) monthly particulate nitrogen (mg/L) in Big Glory Bay based on station 3 and station 4 water quality samples.

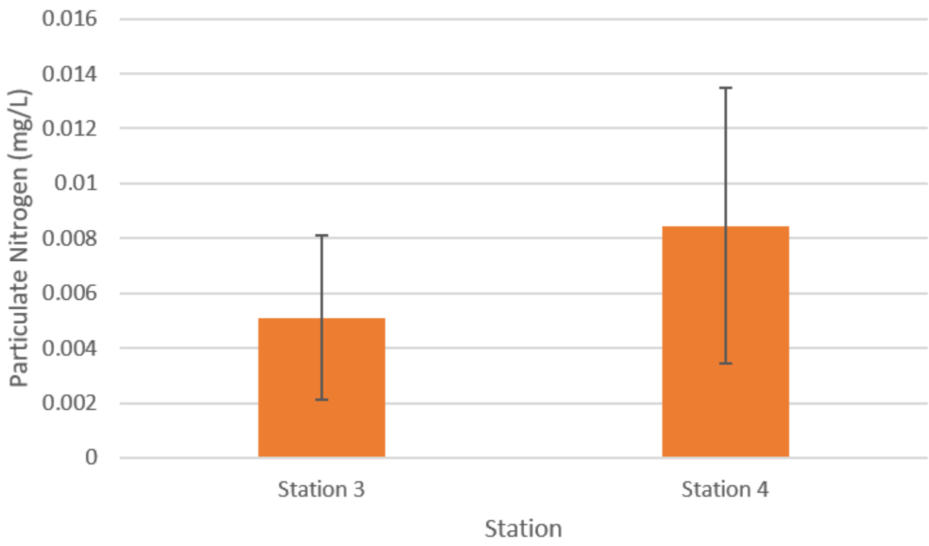


Figure 35 Monthly mean (±1 SE, n=7) particulate nitrogen (mg/L) at station 3 and station 4.

4.5 Benthic Environment

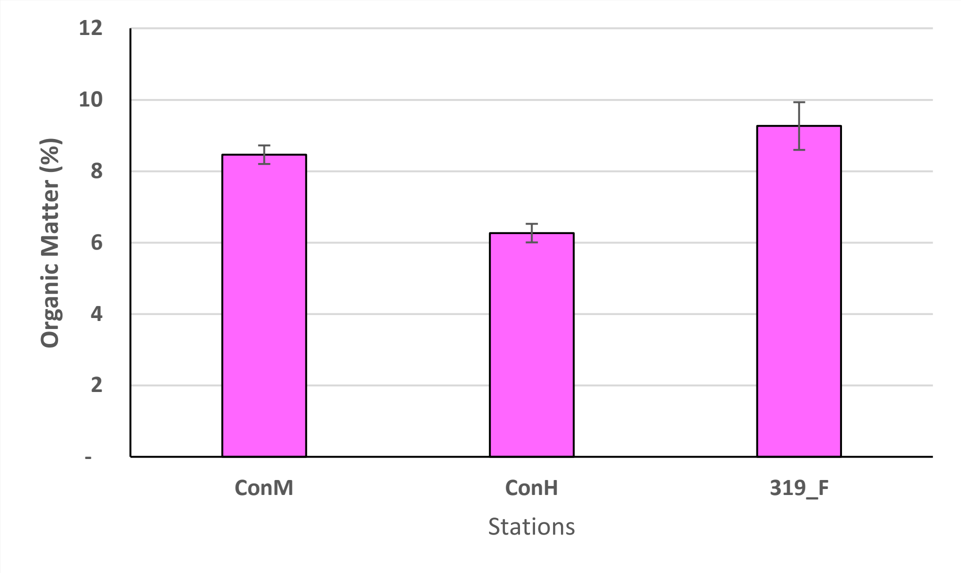
All benthic and sediment environmental data are provided in Appendix C (physical properties of sediments), Appendix D (sediment core profiles), Appendix E (statistical analyses of sediment data), Appendix F (epibenthic photographs) and Appendix G (benthic infauna).

4.5.1 Physical Properties of Sediments

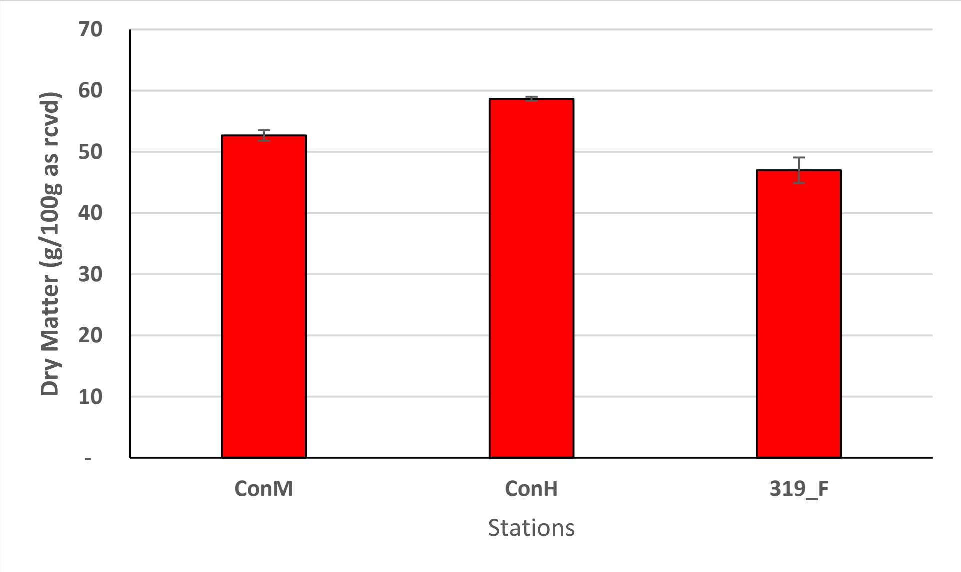
In this section the physical properties of the sediments from the 14 sites sampled are presented, which includes: organic matter, dry matter, % mud, % sand, % very fine gravel, total organic carbon, total recoverable copper and total recoverable zinc content. Mussel and salmon farm site results are presented separately but are compared against the two control stations. Non-quantitative characteristics (i.e. presence or absence of *Beggiatoa* spp) are also provided in Appendix C.

4.5.1.1 Mussel Farms

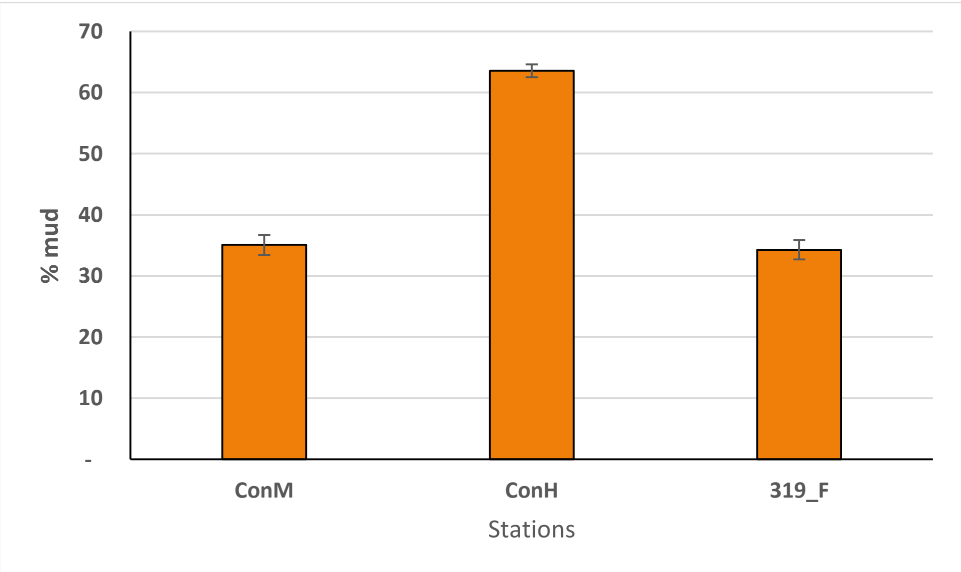
Sediments beneath mussel farm 319_F during the 2016 sampling period were compromised of 34% mud, 58% sand and 8% very fine gravel. Sediments were organically enriched particularly when compared with ConH, though only slightly higher levels of enrichment were observed when compared to ConM (Figure 36). There was no distinct redox layer in the cores and a sulphide odour emanated from the sediments (Appendices C and D).



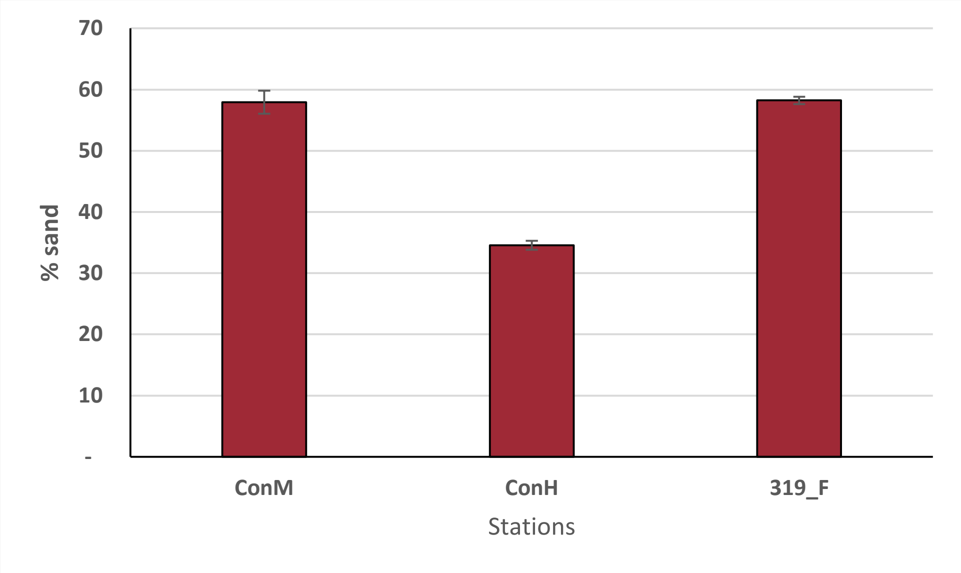
Organic Matter (%)
12
10
8
6
4
2
-
ConM
ConH
319_F
Stations



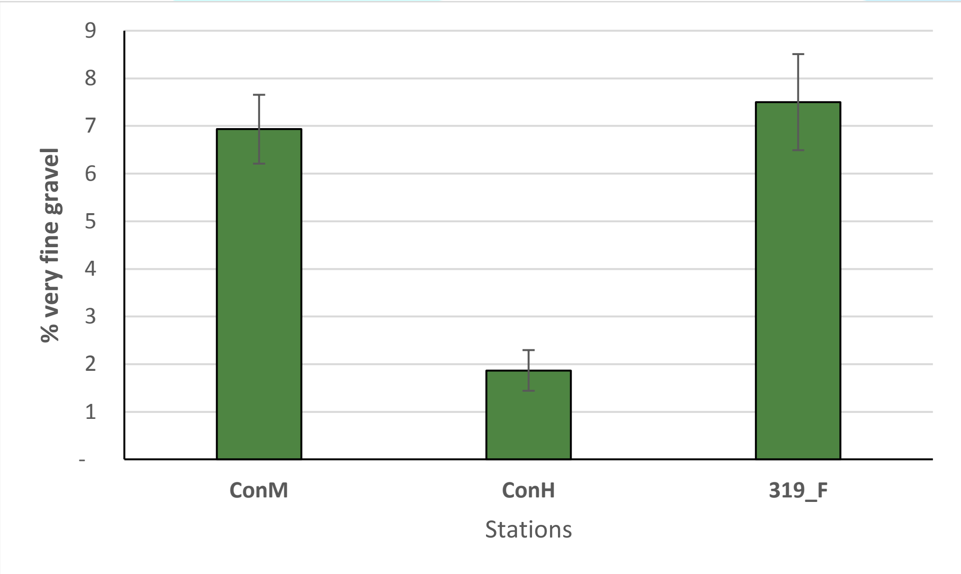
Dry Matter (g/100g as rcvd)
70
60
50
40
30
20
10
-
ConM
ConH
319_F
Stations



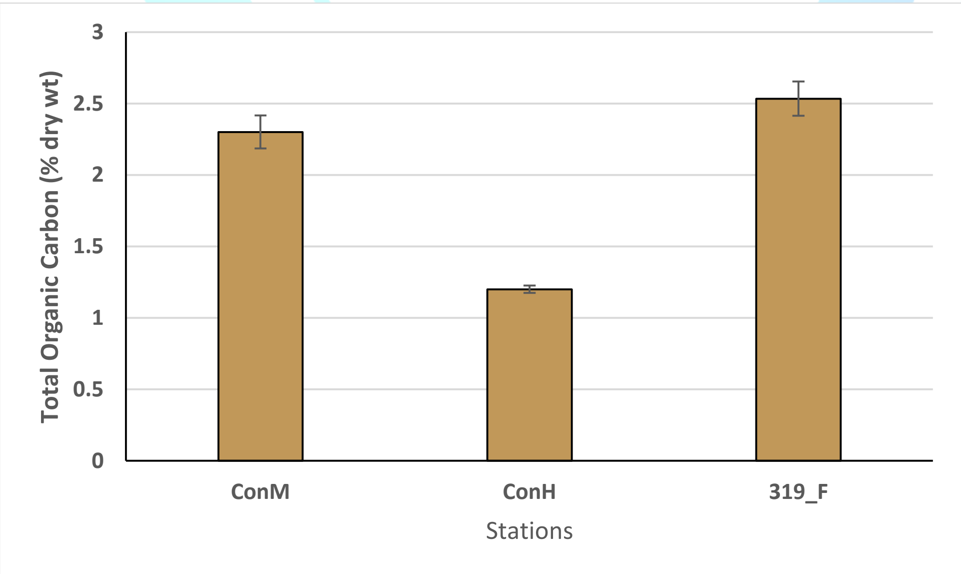
% mud
70
60
50
40
30
20
10
-
ConM
ConH
319_F
Stations



70
60
50
40
30
20
10
-
% sand
ConM
ConH
319_F
Stations



9
8
7
6
5
4
3
2
1
-
% very fine gravel
ConM
ConH
319_F
Stations

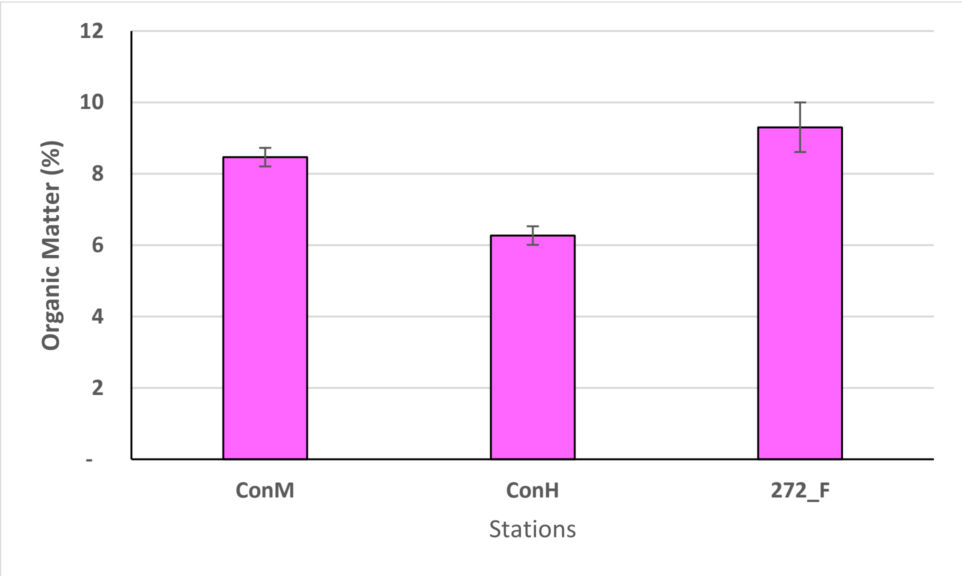


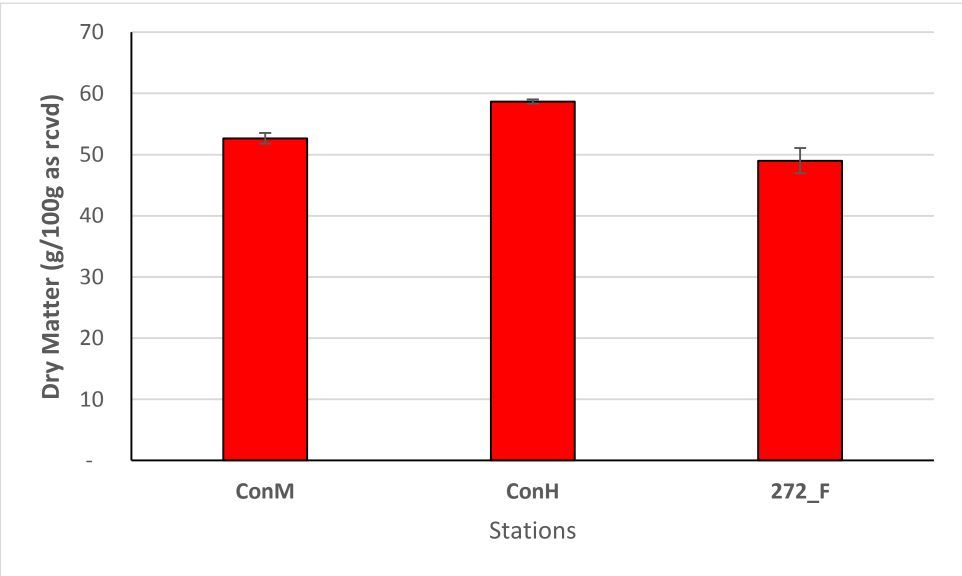
3
2.5
2
1.5
1
0.5
0
Total Organic Carbon (% dry wt)
ConM
ConH
319_F
Stations

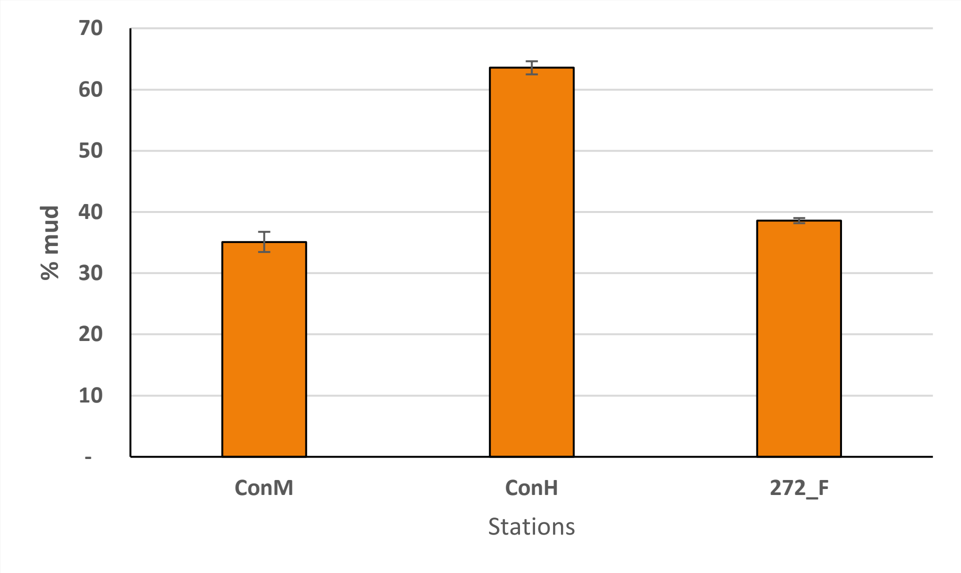
Figure 36 Sediment properties (organic matter, dry matter, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by mussel station 319_F and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

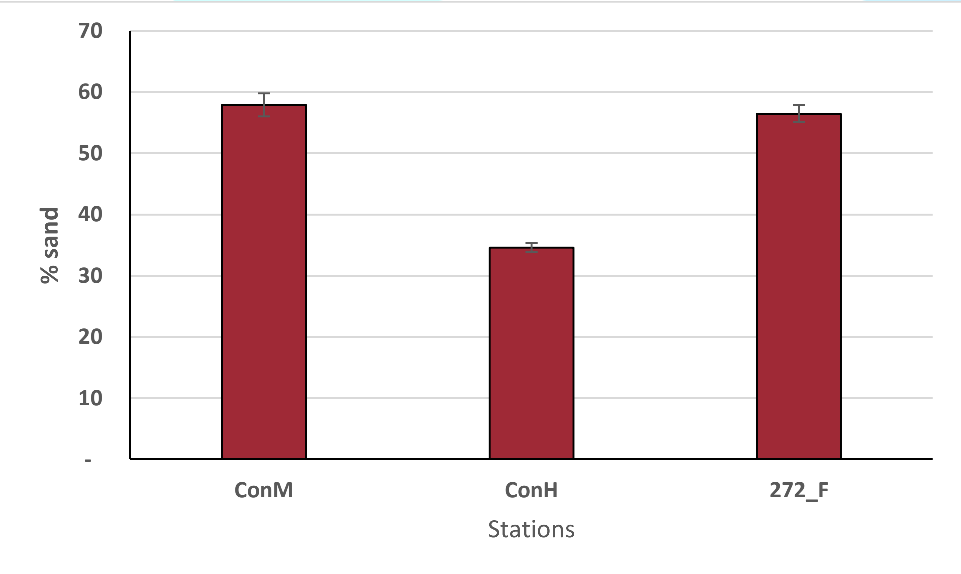
Sediments beneath mussel farm 272_F were compromised 39% of mud, 56% sand and 5% very fine gravel. Compared to ConH, sediments were organically enriched though had similar organic content (about 8-9% organic matter content) as Con M (Figure 41).

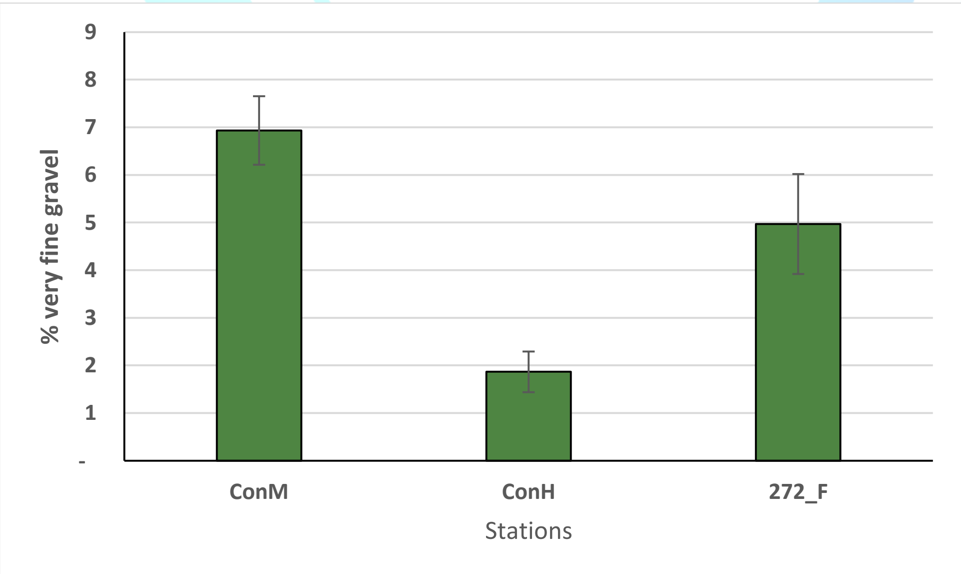
There was approximately a 1 mm redox layer in the cores and a sulphide odour emanated from the sediments (Appendices C and D).






70
60
50
40
30
20
10
-
% mud
ConM
ConH
272_F
Stations


70
60
50
40
30
20
10
-
% sand
ConM
ConH
272_F
Stations


9
8
7
6
5
4
3
2
1
-
% very fine gravel
ConM
ConH
272_F
Stations

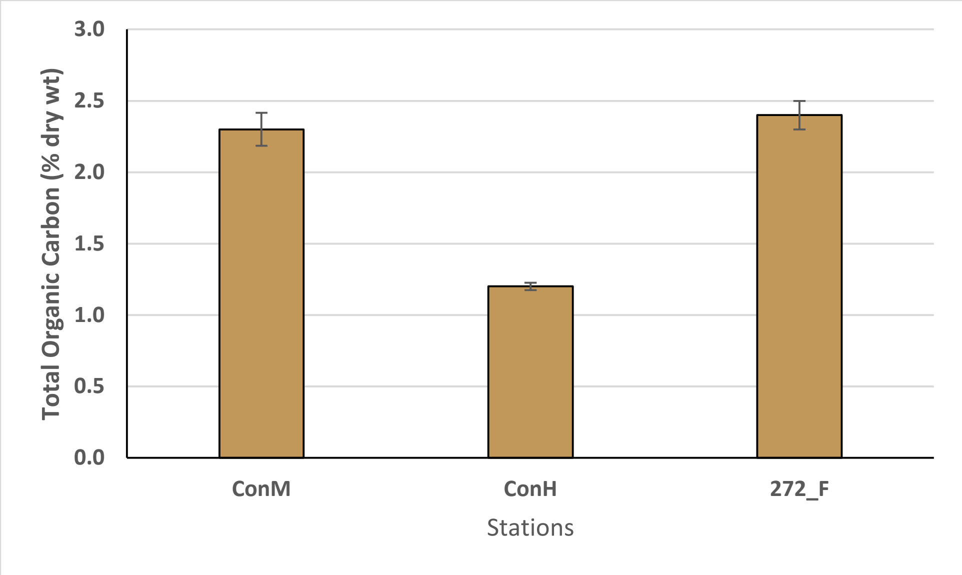
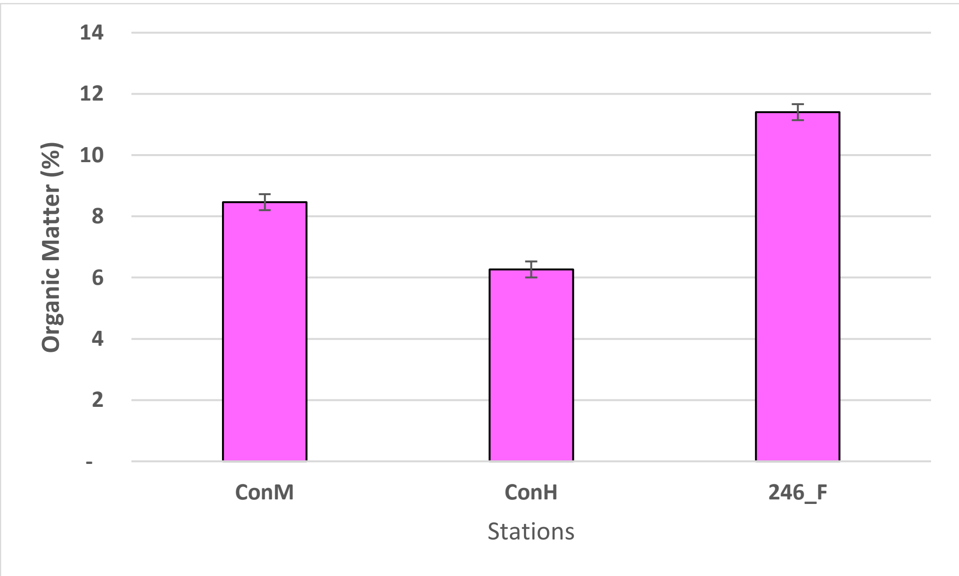


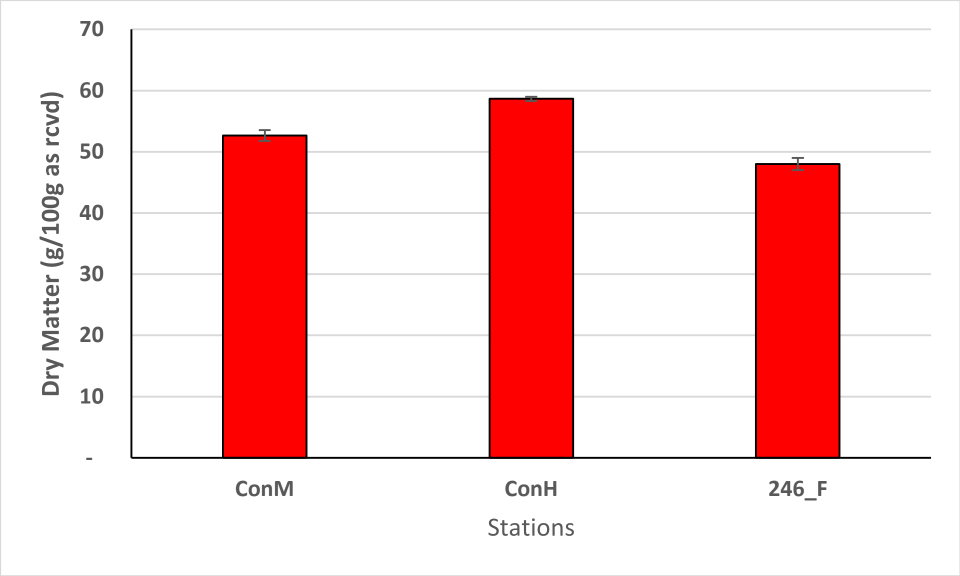
Figure 37 Sediment properties (organic matter, dry matter, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by mussel site 272_F and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

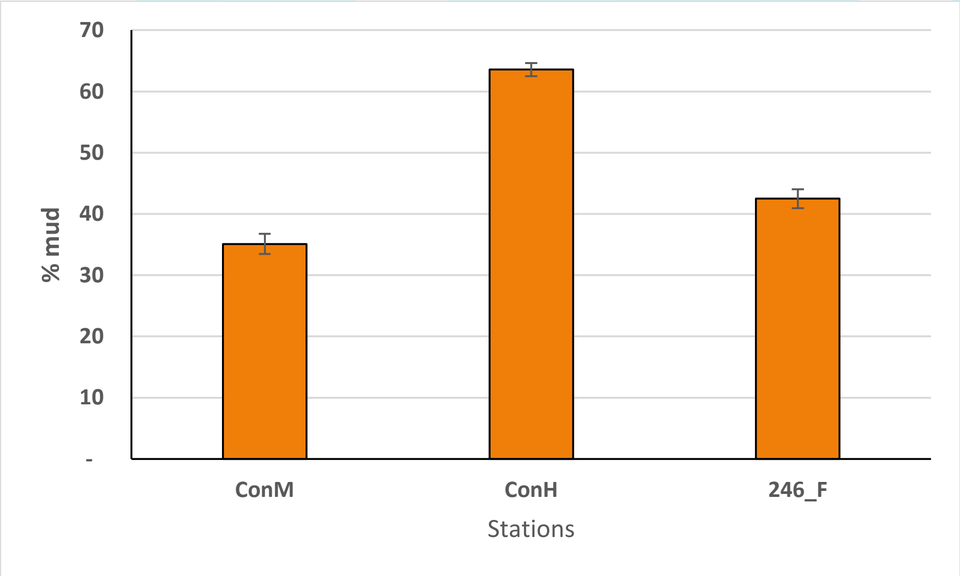
4.5.1.2 Salmon Farms

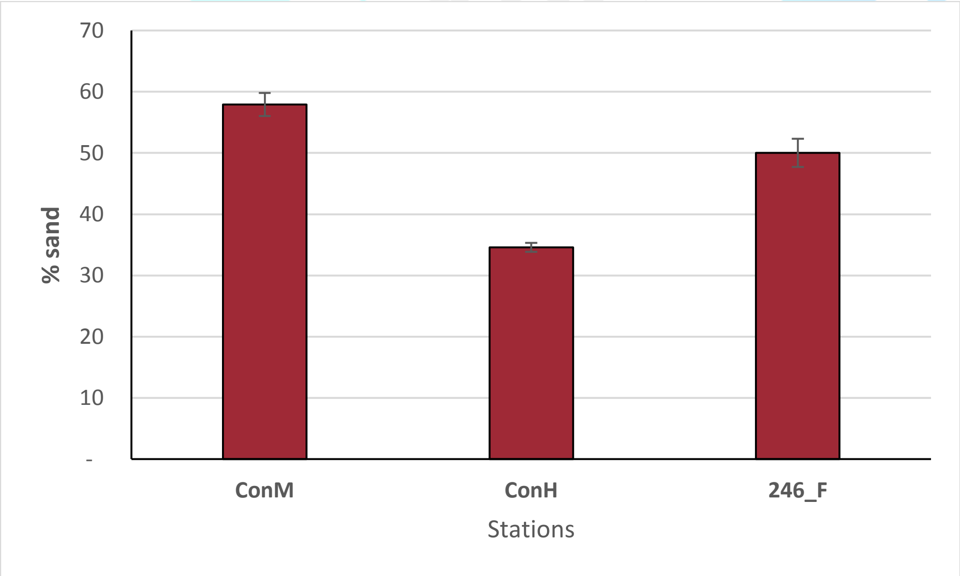
Sediment texture beneath salmon farm station 246_F is comprised of 42% of mud, 50% sand and 8% very fine gravel. Sediments beneath the salmon farm station are organically enriched with organic matter comprising more than 11% of the entire sample compared to just over 6 and 8% at the two control stations (Figure 38). Somewhat surprisingly, total organic carbon content was similar to that observed at ConM. In a study observing benthic infauna species richness and TOC content of sediments from several systems throughout the world, Hyland *et al* (2005) suggested that potential losses to species richness were greatest when TOC in sediments was greater than 3.5% and lowest when TOC was lower than 1%. All stations are well below 3.5%.

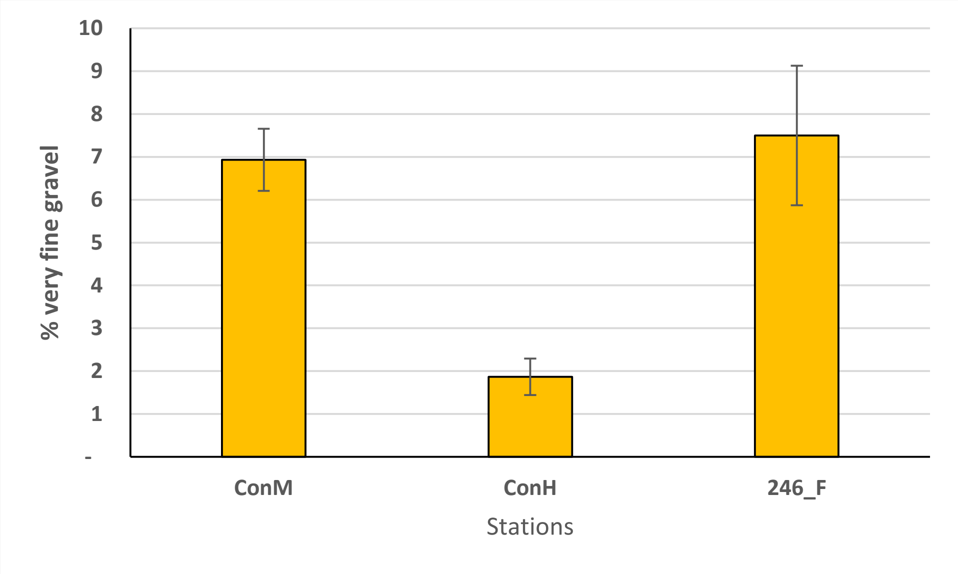
There was 1 mm redox layer in the cores and a sulphide odour emanated from the sediments (Appendices C and D).




70
60
50
40
30
20
10
-
Dry Matter (g/100g as rcvd)
ConM
ConH
246_F
Stations


70
60
50
40
30
20
10
-
% mud
ConM
ConH
246_F
Stations


70
60
50
40
30
20
10
-
% sand
ConM
ConH
246_F
Stations



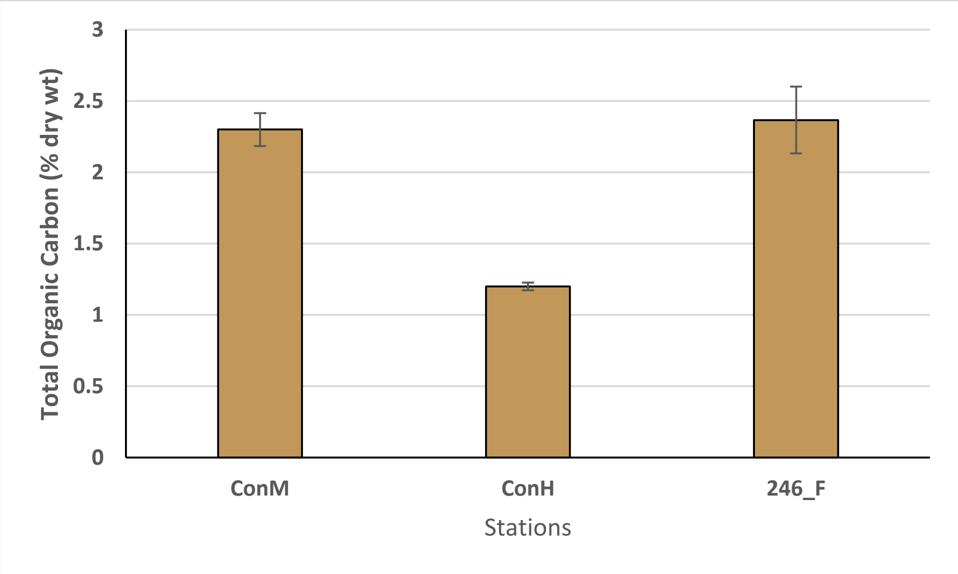


Figure 38 Sediment properties (organic matter, dry matter, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by salmon station 246_F and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

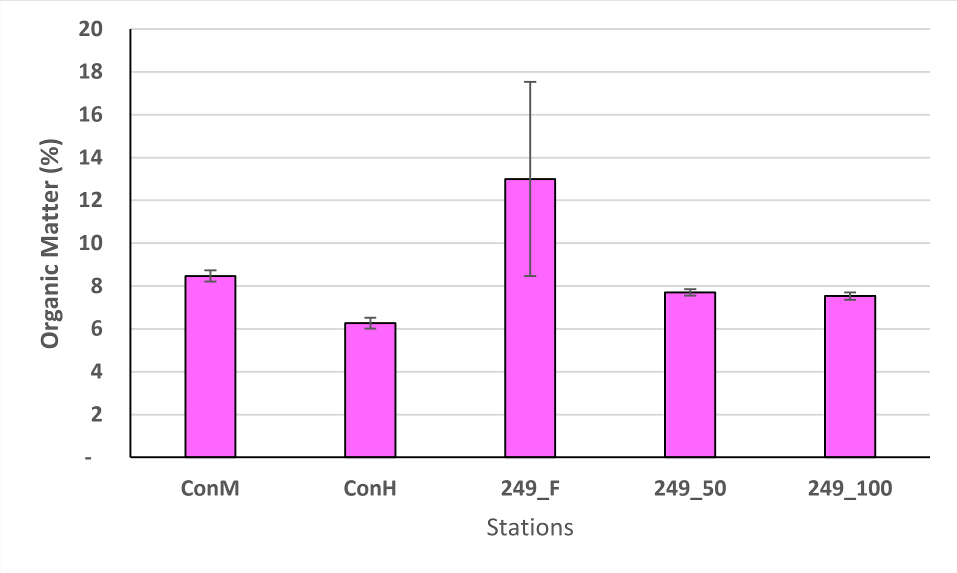
249

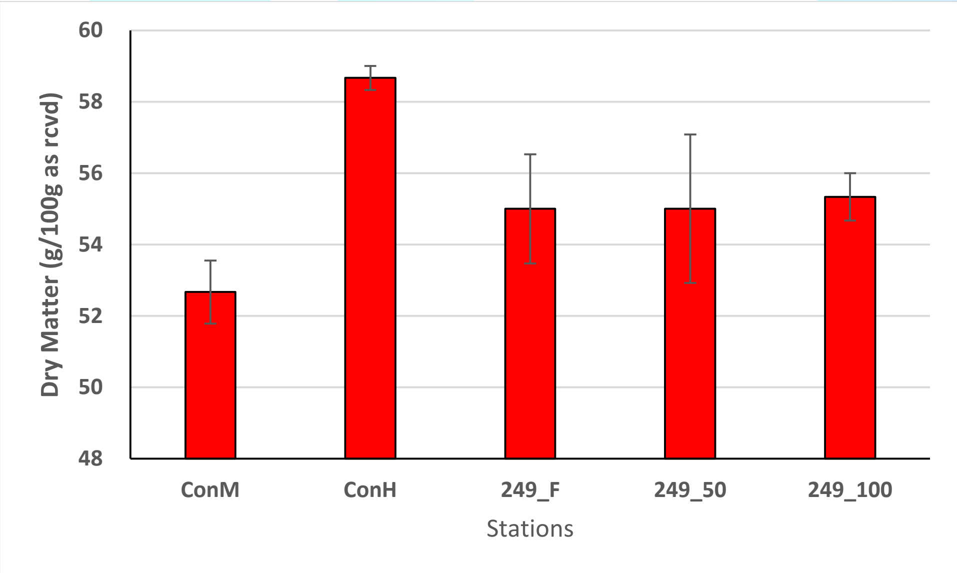
Sediment texture (%mud, % sand and % very fine gravel) varied considerably between the two control and three farming sampling stations sampled in and around the 249 site (Figure 39). Such textural differences are thought to be related to the natural characteristics of each of the five stations sampled. ConM for instance is located towards the mouth of the bay where there are stronger current flows and hence the sediments are coarser in nature (i.e. more sand and gravel), compared to lower energy sites in the center of the bay.

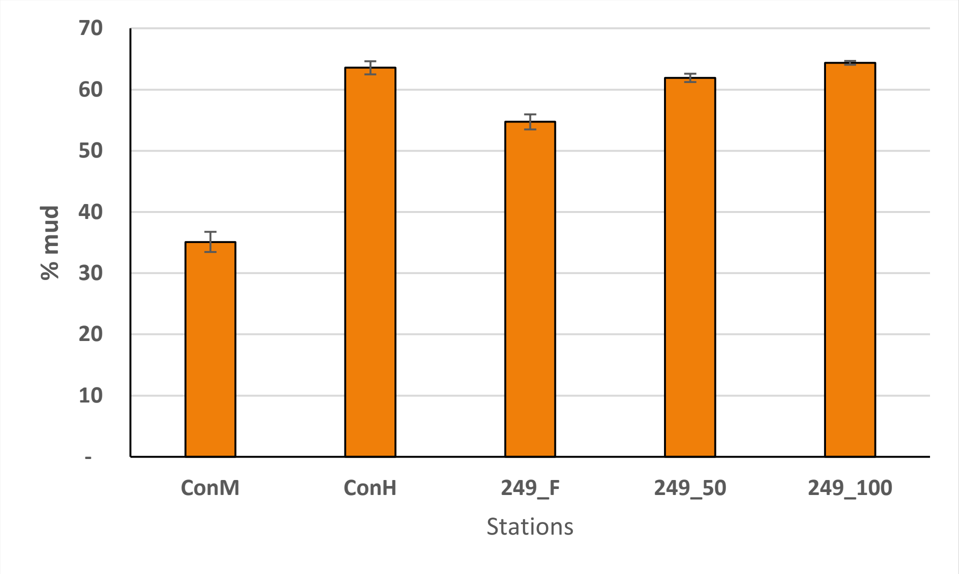
Total organic matter was observed to be higher under the farm (13 %) compared to the less than 8 % observed 50 and 100 meter from the farm sampling station.

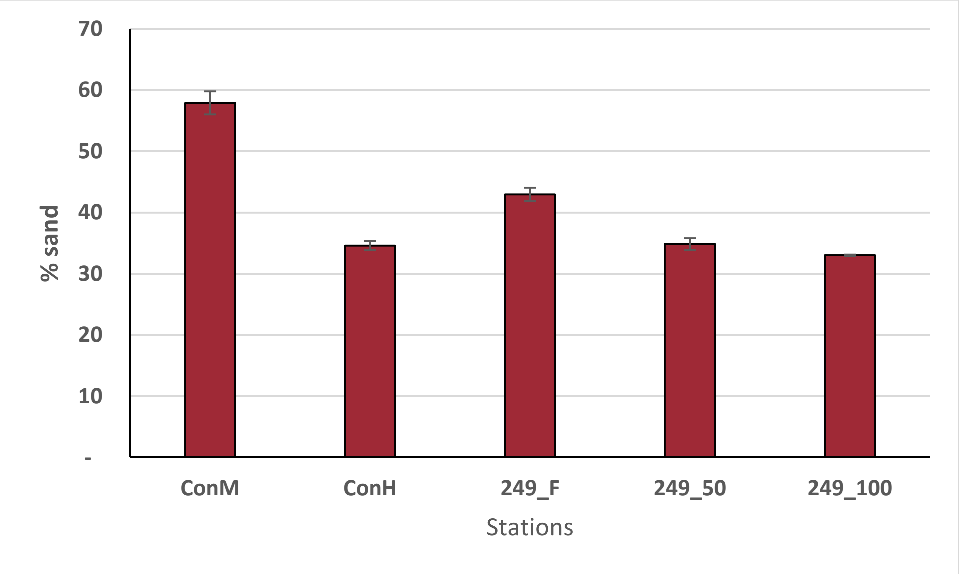
A sulphide odour was detected at 249_F and 249_50 and no odour was detected at 249_100. No redox layer was observed at station 249_F as the anoxic layer appeared very close to the surface, while a

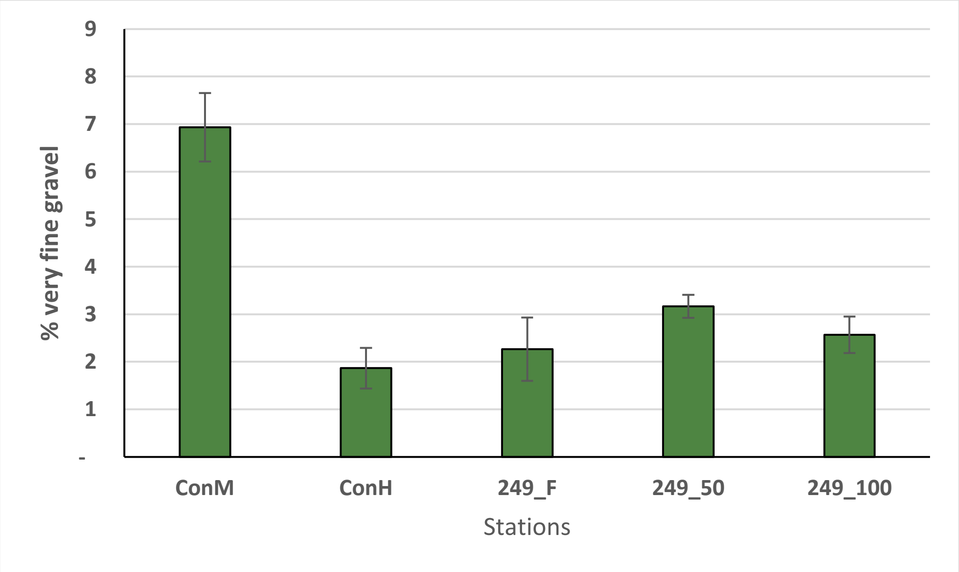
3mm redox layer was observed at 249_50 and 2mm redox layer observed at the samples collected 100 m from the edge of the lease (Appendices C and D).






70
60
50
40
30
20
10
-
% mud
ConM
ConH
249_F
249_50
249_100
Stations


70
60
50
40
30
20
10
-
% sand
ConM
ConH
249_F
249_50
249_100
Stations


9
8
7
6
5
4
3
2
1
-
% very fine gravel
ConM
ConH
249_F
249_50
249_100
Stations

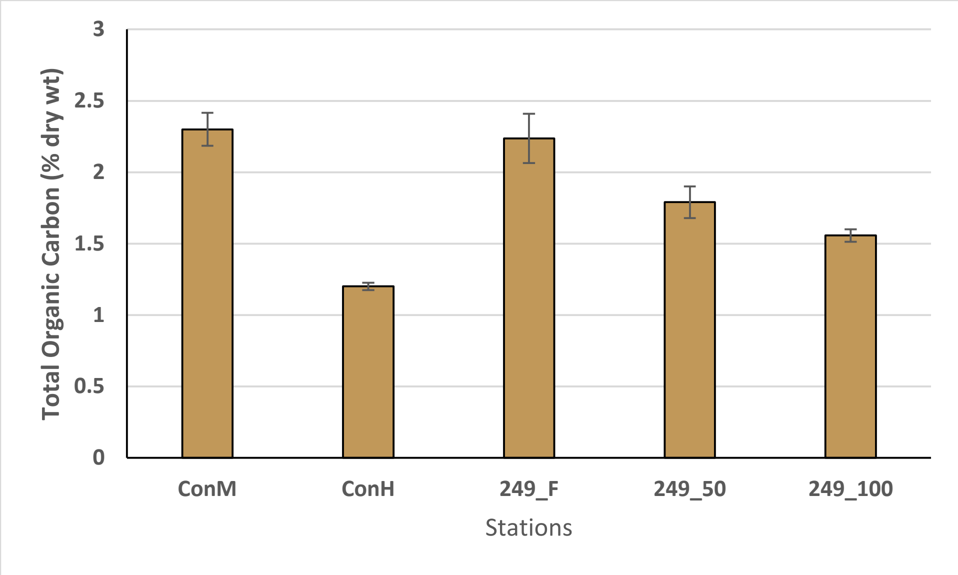


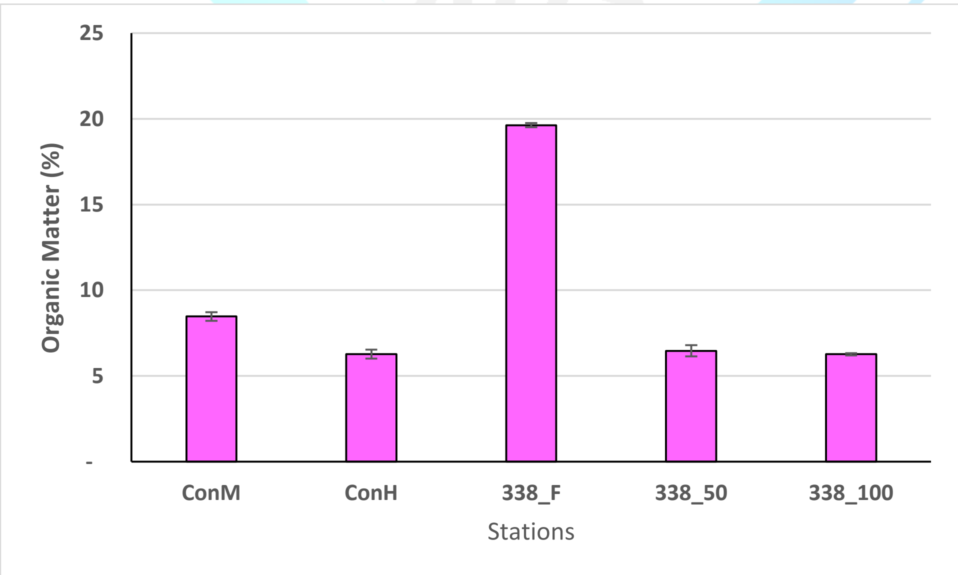
Figure 39 Sediment properties (organic matter, dry matter, ash, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by salmon stations 249_F, 249_50 and 249_100 and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

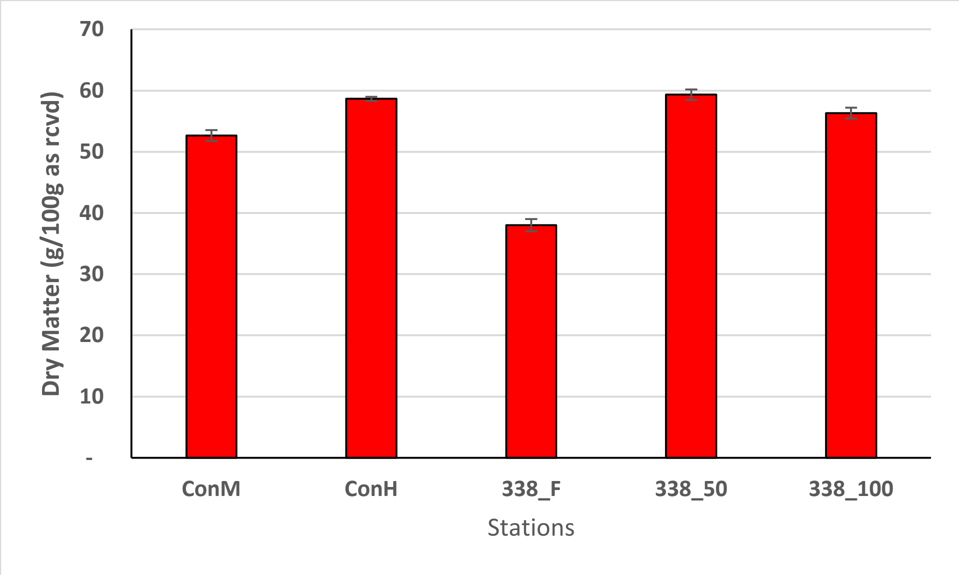
338

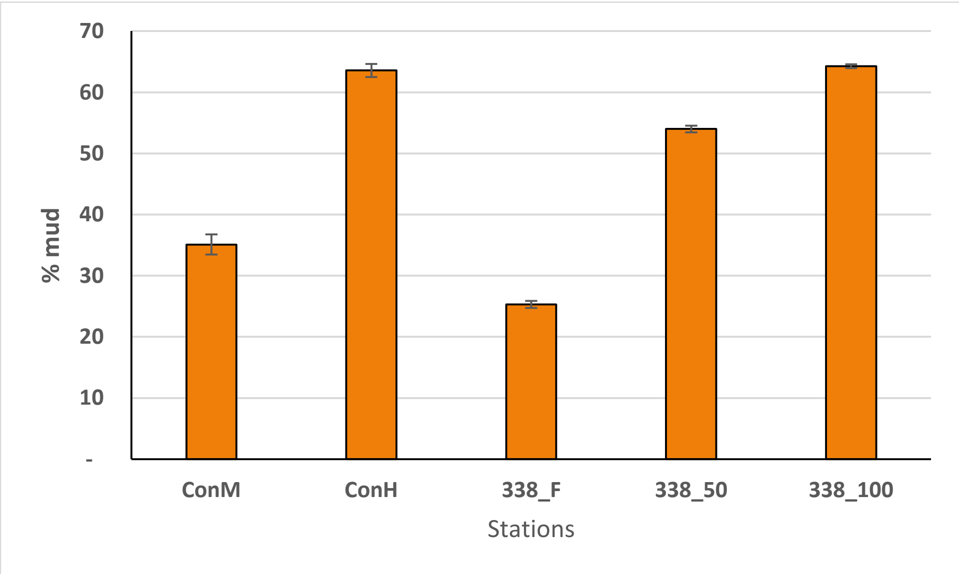
Again, sediment texture (%mud, % sand and % very fine gravel) was significantly different between the controls and the salmon farm 338_F, 50 and 100 m sampling stations (Figure 40). Such differences relate to specific characteristics of the site and aren't thought to be related to farming (i.e. high sand content under the cages).

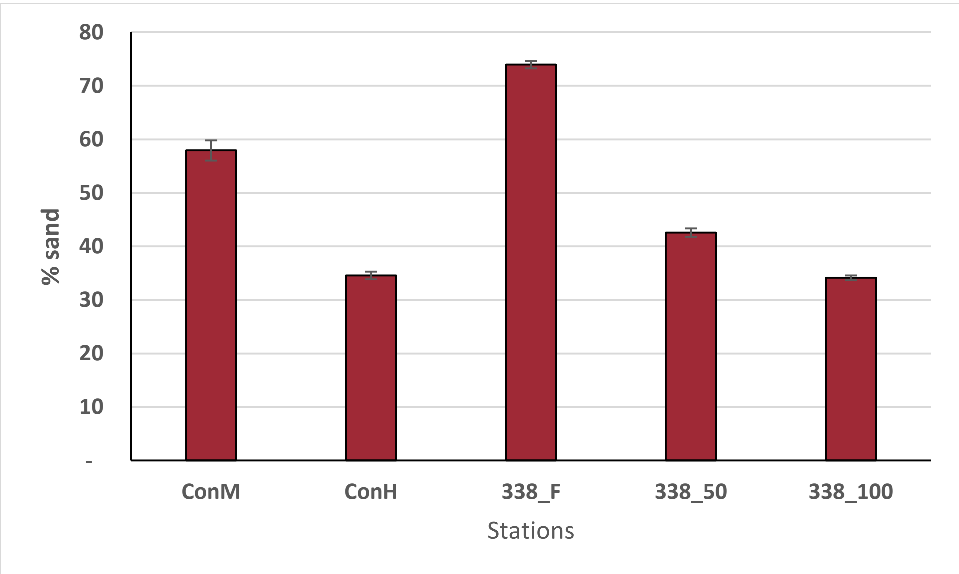
The sample taken under the farm cage at station 338_F is organically enriched with total organic matter exceeding 16 % and total organic carbon content of more than 8 %, which is more than 2x higher than either the control stations or samples collected 50 and 100m from the site boundary.

A sulphide odour was detected emanating from stations 338_F and 338_50, while no odour was detected in the 338_100 sample. There was no redox layer observed at 338_F, while a 1mm redox layer was observed 50 m and 100 m away from the site boundary (Appendices C and D).




70
60
50
40
30
20
10
-
Dry Matter (g/100g as rcvd)
ConM
ConH
338_F
338_50
338_100
Stations


70
60
50
40
30
20
10
-
% mud
ConM
ConH
338_F
338_50
338_100
Stations


80
70
60
50
40
30
20
10
-
% sand
ConM
ConH
338_F
338_50
338_100
Stations

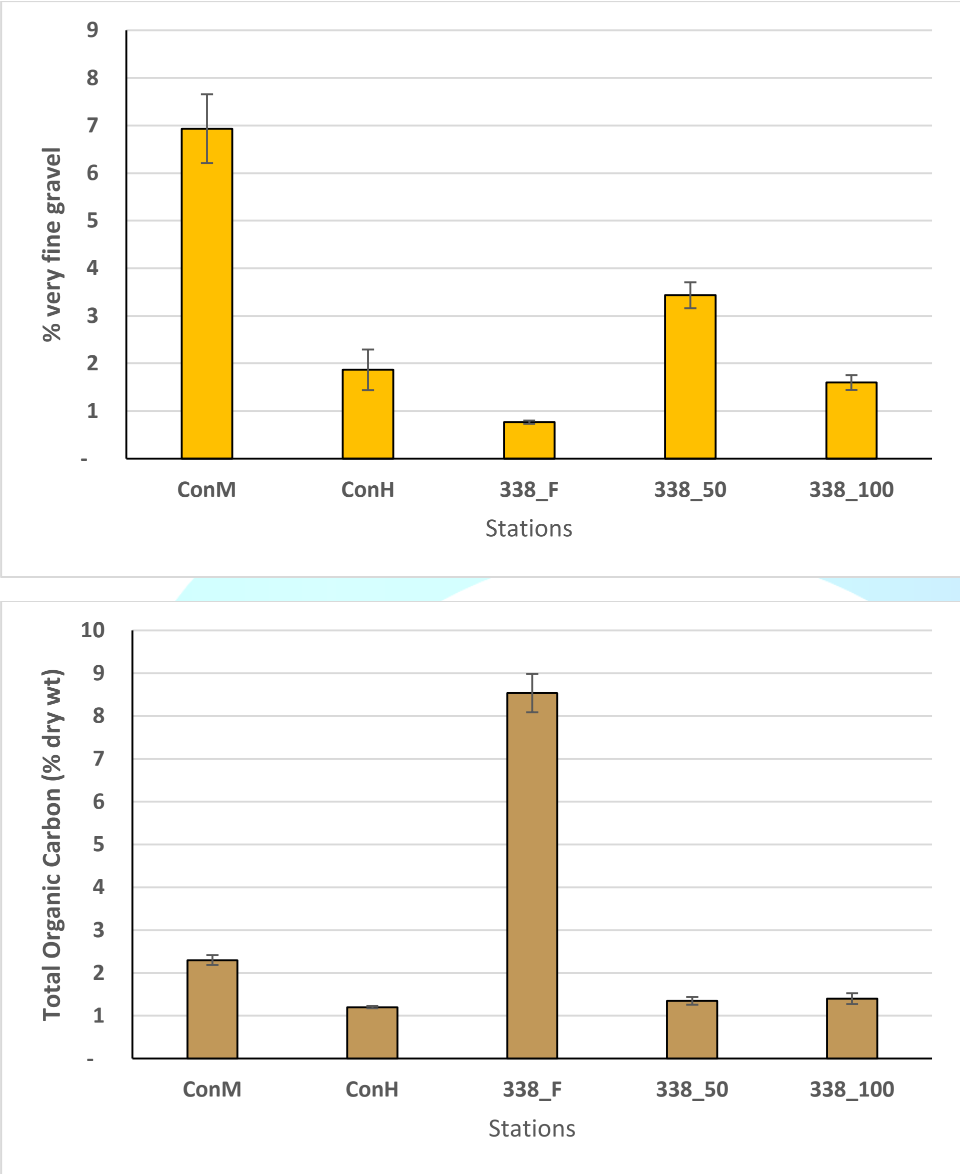


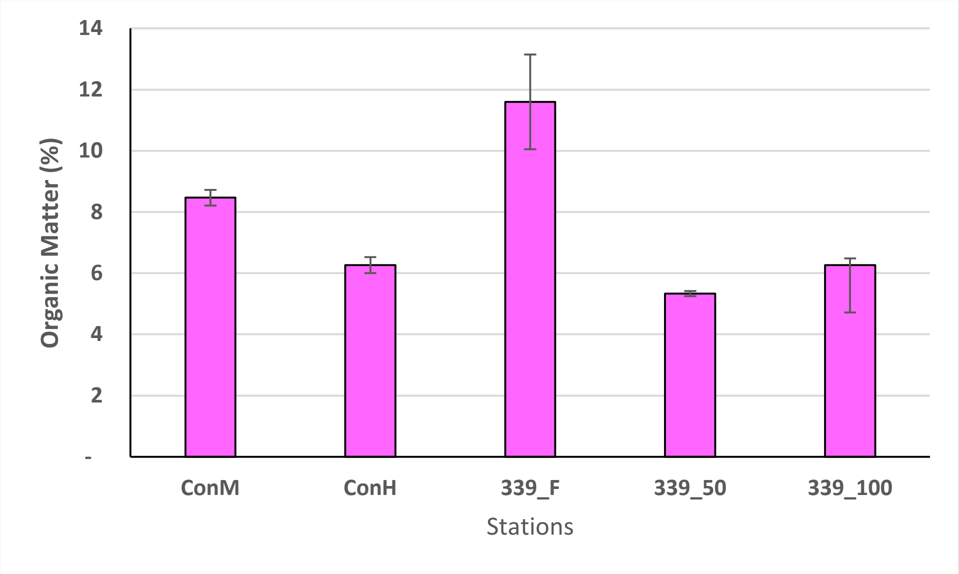
Figure 40 Sediment properties (organic matter, dry matter, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by salmon stations 338_F, 338_50 and 338_100 and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

339

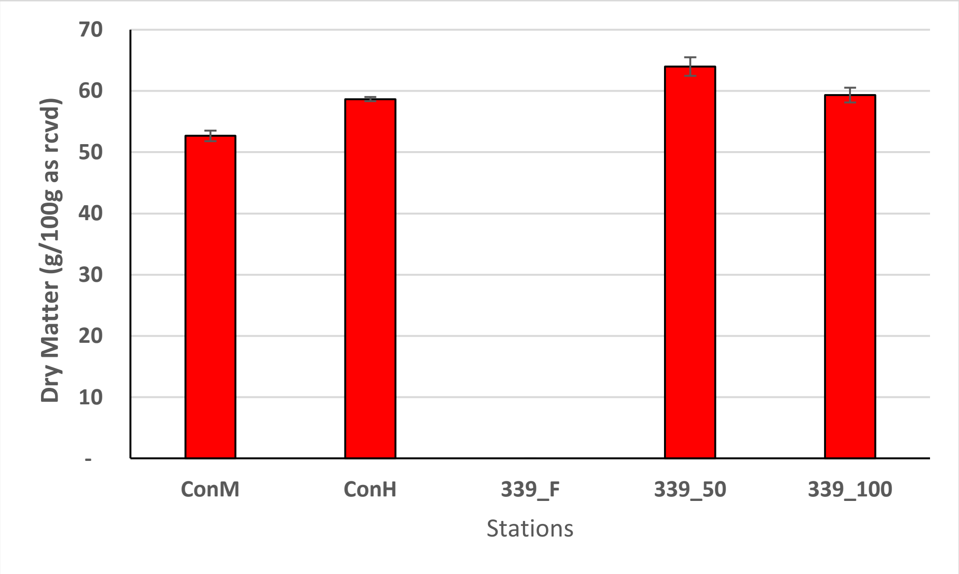
Only a small volume of sediment was collected at 339_F as the sample was predominately mussel shells (Figure 41). Due to the small volume and composition no grain size analysis was undertaken, though there was enough material for organic content analysis and heavy metal testing. Sufficient sediments were collected at stations 339_50 and 339_100 to conduct grainsize analysis.

The sample taken under the farm cage at 339_F was organically enriched with mean total organic matter just less than 12 % and total organic carbon 5 %, which is significantly higher than both the control and 50/100 meter sample locations.

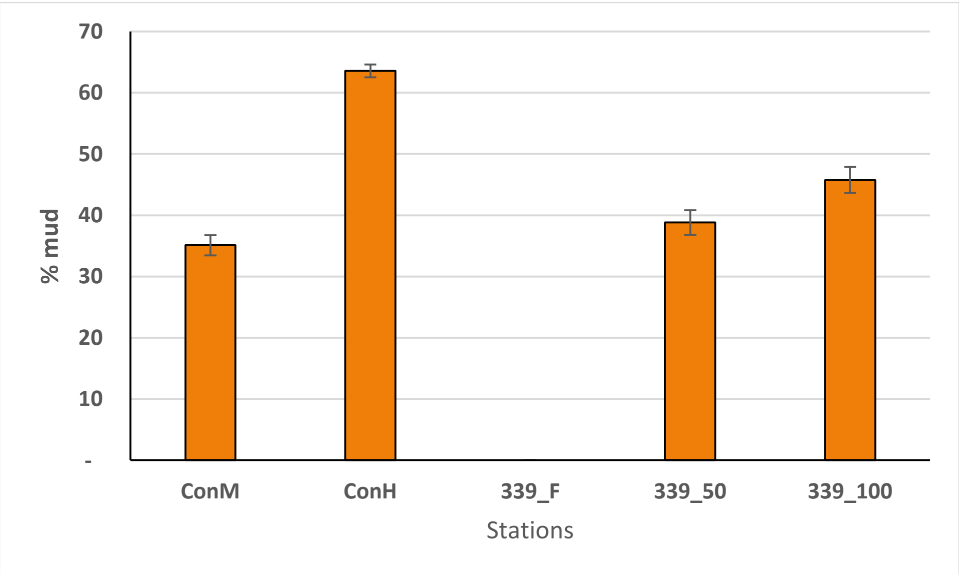
There was strong sulphide odour emanating from 339_F and a faint sulphide odour was detected at sample station 339_50, while no odour was detected at 339_100. There was no redox layer observed at 339_F, while 2mm redox layer was observed 50 m and 100 m away from cage (Appendices C and D).



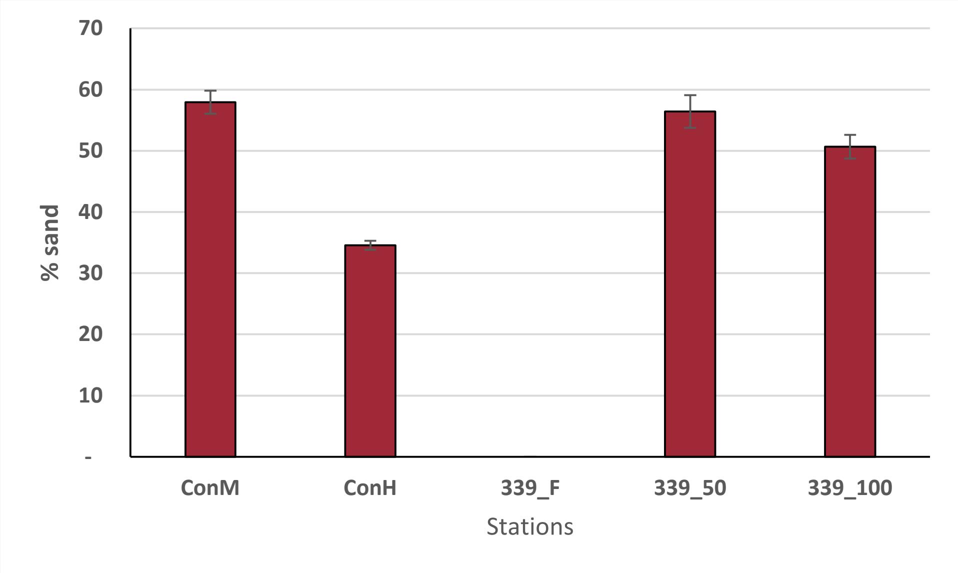
Organic Matter (%)
14
12
10
8
6
4
2
-
ConM
ConH
339_F
339_50
339_100
Stations



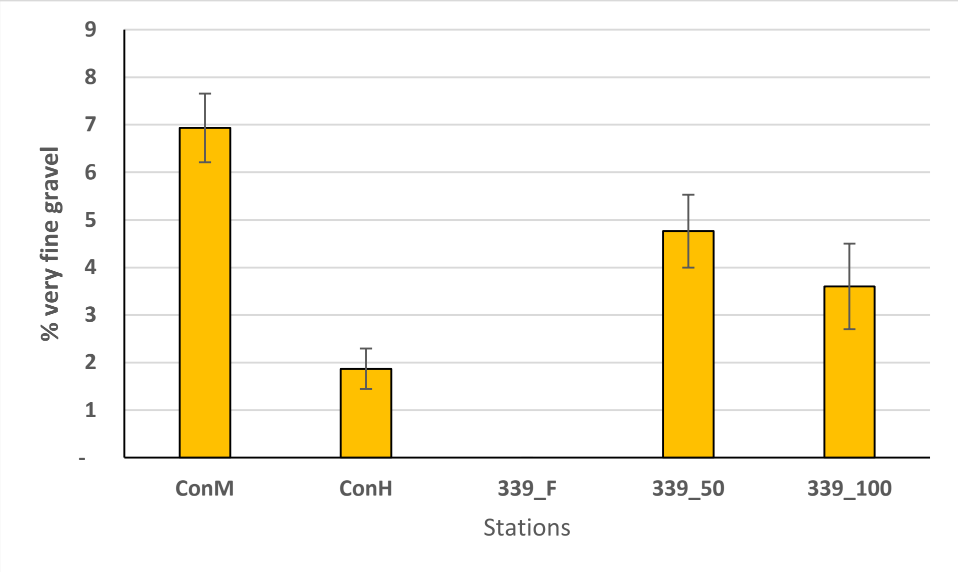
Dry Matter (g/100g as rcvd)
70
60
50
40
30
20
10
-
ConM
ConH
339_F
339_50
339_100
Stations



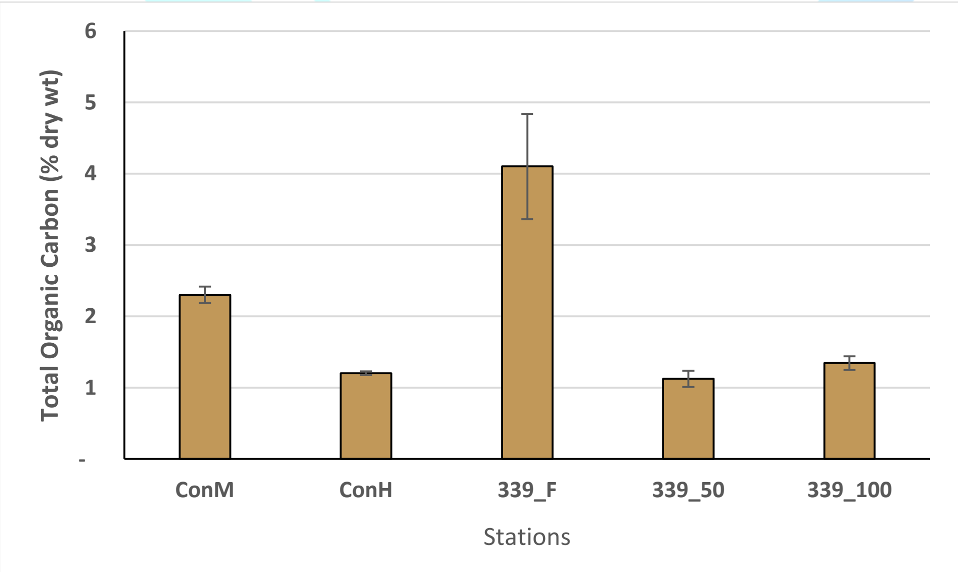
% mud
70
60
50
40
30
20
10
-
ConM
ConH
339_F
339_50
339_100
Stations



70
60
50
40
30
20
10
-
% sand
ConM
ConH
339_F
339_50
339_100
Stations



9
8
7
6
5
4
3
2
1
-
% very fine gravel
ConM
ConH
339_F
339_50
339_100
Stations



6
5
4
3
2
1
-
Total Organic Carbon (% dry wt)
ConM
ConH
339_F
339_50
339_100
Stations

Figure 41 Sediment properties (organic matter, dry matter, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by salmon stations 339_F, 339_50 and 339_100 and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

All control and salmon farming stations have been tested for Copper and Zinc content. Copper is used as anti-fouling agent in paint that is applied to fish nets while zinc is an ingredient in salmon feed.

Table 4 shows the data (means and standard deviations (n=3) relative to the ISQG-Low and High thresholds for these metals (ANZECC 2000).

At the 249_F station, the mean copper concentration was 238.7 mg/kg and is hence above the ISQG-Low threshold of 65 mg/kg. 50 m to 100 m away from the site boundary, concentrations were well below the ISQG-Low threshold (16.0 mg/kg and 12.7 mg/kg, respectively). The mean zinc concentrations were all lower than the low threshold of 200 mg/kg.

At 338_F the mean copper concentration was 893.3 mg/kg, which is higher than the ISQG high range of 270 mg/kg. Again, copper concentrations were lower 50 m (42.0 mg/kg) and 100 m (15.0 mg/kg) away from the farm leases. The mean zinc concentrations were highest under the cage at this station compared to all other sampling stations at 946.7 mg/kg (> 410 mg/kg – High threshold). 50 m away from the site boundary the concentration was an order of magnitude lower at 77.7 mg/kg (below the ISQG – Low threshold). 100 m away from the site boundary the mean zinc concentration was 46.0 mg/kg well is below the 200 mg/kg- Low threshold.

The mean copper concentration measured under the cage at 339_F was the highest (1,040 mg/kg) observed across the entire study area. However, copper concentrations were lower than the Low threshold 50 m (11.0 mg/kg) and 100 m (12.0 mg/kg) from the site boundary. Mean zinc was 290.7 mg/kg under the cage (less than the 410 mg/kg – High threshold), while low zinc concentrations were detected 50 m (35 mg/kg) and 100 m (37.3 mg/kg) from the site (see table 4).

Table 4 Mean and standard deviation of copper and zinc concentrations (mg/kg) at all the sampling stations. These data are listed in accordance with the ISQG-Low and ISQG-High thresholds for both metals (ANZECC 2000). Green = below ISQG-Low thresholds, Orange= between ISQG-Low and High thresholds, and Red= above ISQG- High thresholds

Station	Copper (mg/kg) dry wt						Zinc (mg/kg) dry wt					
	< Low 65		< High 270		> High 270		< Low 200		< High 410		> High 270	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ConM	7.3	0.6					37.0	3.6				
ConH	9.3	0.6					35.0	1.0				
319_F	23.0	-					58.0	-				
272_F	-	-					-	-				
246_F	11.0	1.0					39.0	3.6				
249_F			238.7	175.3			108.7	41.0				
249_50	16.0	5.3					44.0	6.9				
249_100	12.7	0.6					37.7	3.5				
338_F					893.3	35.1					946.7	63.5
338_50	42.0	22.6					77.7	27.3				
338_100	15.0	2.6					46.0	7.0				
339_F					1040.0	910.0			290.7	219.7		
339_50	11.0	4.4					35.0	4.4				
339_100	12.0	1.7					37.3	3.2				

4.5.2 Benthic Seabed Features and Epifauna

4.5.2.1 Introduction

Two days before the seabed benthic survey, a storm passed through BGB bringing with it wind speeds of more than 120km and damaging some of the equipment situated at farm site 249. The strong winds also appeared to have created flow near the seabed and or an influx of fine material from catchments adjacent to Big Glory Bay as near-bed visibility was poor. On each splash camera dive marine snow was observed 1-2 meters from the seabed at all sampling stations other than ConM.

Despite the relatively poor visibility of the bottom environment, a total of 19 conspicuous seabed features were identified and recorded from photo quadrats, including 15 different seabed-dwelling organisms (this included invertebrates and benthic algae) (Table 5, Appendix F). Nine epifauna taxa were observed at both control sites.

A few specific observations include:

At mussel farm station 272_F, seven epifaunal species were observed and only one epifaunal species was observed at station 319_F due to the poor visibility (marine snow).

A large number of mussel shells were observed in the sediments at the new 246_F salmon farm station supporting that indeed this site was previously used for mussel farming. At ConM several species were identified that weren't observed at any of the other sampling stations. These species are likely present due to the location of the stations (closer to the mouth of the bay), where numerical modelling indicates that there are stronger currents than other areas of the bay (resulting in coarser sediments, though there was a high level of organic material which is surprising.).

Beggiatoa were observed only at stations 272_F, 249_50 and 249_100 indicating possible anoxic conditions in the sediments and hydrogen sulphide production beneath the farm and extending some distance from the 249 site boundary. As far as ADS is aware cages on this farm are being moved to the 246 lease and the 249 lease will be fallowed.

Statistical analyses indicate that the control stations, mussel farms, salmon farms and their 50 and 100 m stations clustered (using Bray-Curtis similarities) into three main groups (Figure 42) based on presence-absence of seabed features and epibiota (Table 5). Replicates for Control Station H (ConH) were grouped together along with samples collected 100m from the edge of the farm lease at 339_100. Somewhat surprisingly replicates for Control Station M (ConM) were grouped together with those from 338_100. There is some variability in samples collected in and around the salmon and mussel farms.

Another method of grouping replicates from these stations (MDS or multiple Dimensional Scaling) (Figure 43) essentially replicated the groupings identified in the cluster analysis (Figure 42). Stations 246_F, 249_F and 339_F do not have similarity between other clusters. In an MDS plot the further the dots (presenting sample stations) are apart the less similar the sample is.

Table 5 Conspicuous seabed features and epibenthos seen in photo-quadrats. 0 = absent, 1 = present

Stations	**246_F**			**249_F**			**249_50**			**249_100**			**272_F**			**319_F**			**338_F**			**338_50**			**338_100**			**339_F**			**339_50**			**339_100**			**ConH**			**ConM**		
Replicate	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Small holes/burrows	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0
Worm tubes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	1	1	0	0	0
Mussel shell	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shell hash	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1
Yellow sponge	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solitary ascidian	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Greenlip mussels	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycymeris shells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pecten novaezelandiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Ophiopsammus maculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Patiriella regularis	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Notolabrus celidotus	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Small finfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Beggiatoa* sp.**	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coralline algae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Red algae	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
Green algae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Shark	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bryozoans	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1

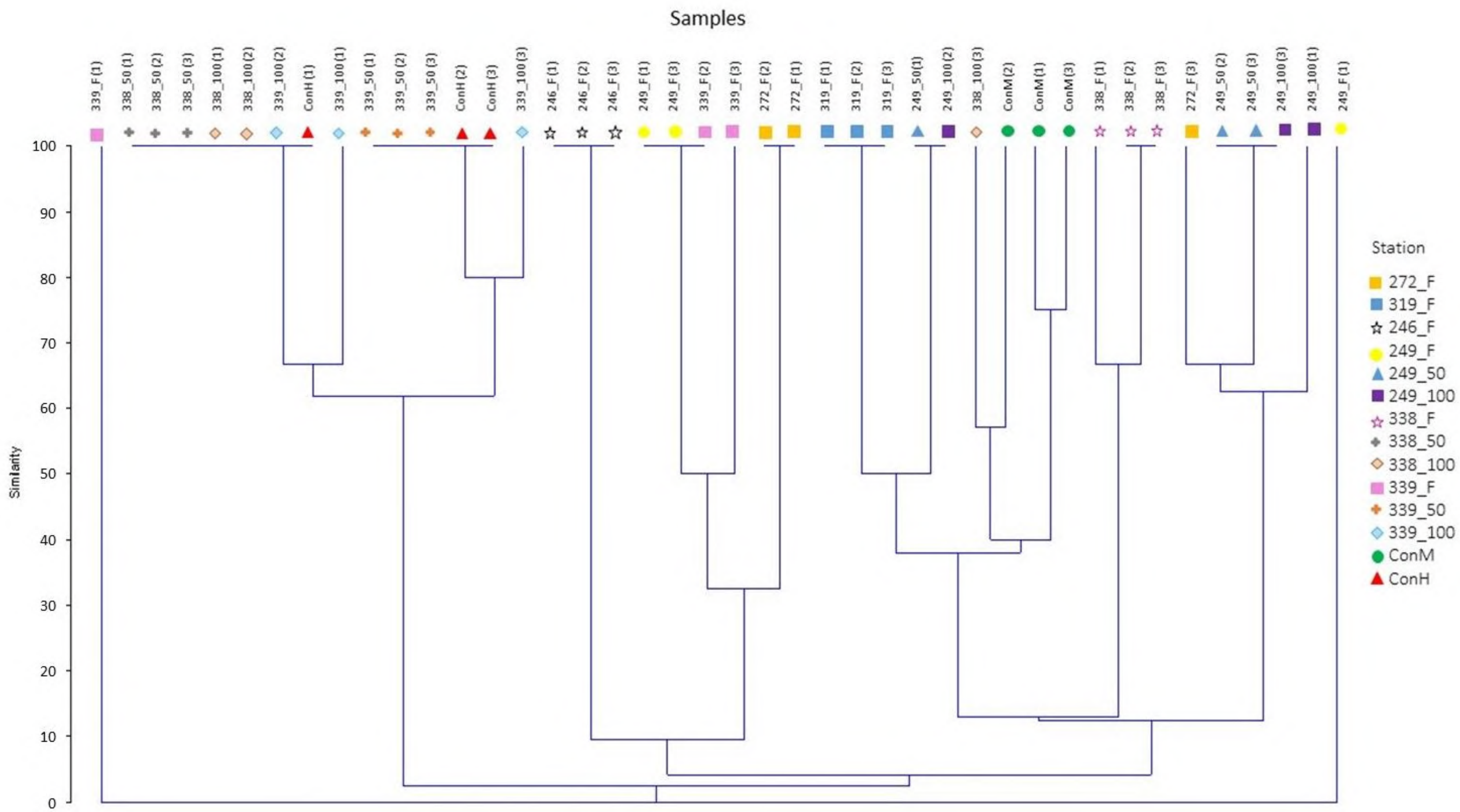


Figure 42 Cluster analysis (Bray Curtis similarities) of Big Glory Bay replicate samples and stations based on the epibenthic features.

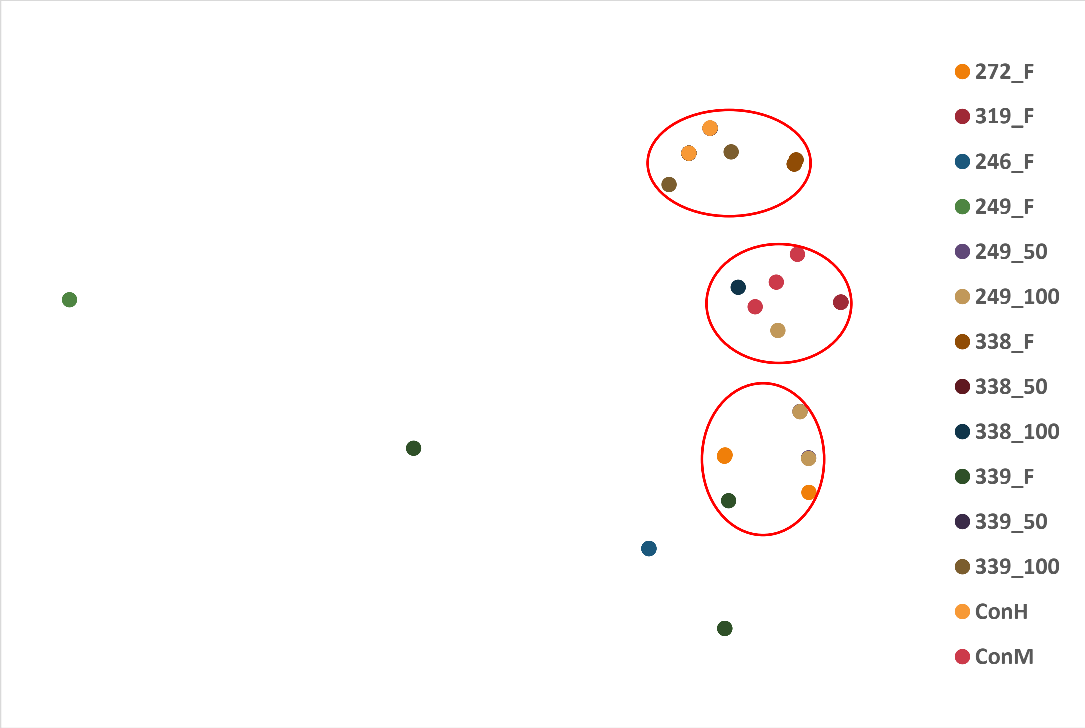


Figure 43 Multidimensional scaling plot of relationships between control, mussel and salmon stations in Big Glory Bay based on epibenthic features and epifauna

4.5.3 Benthic Infauna

A list of the infauna species and their densities per station and replicate is given in Appendix G.

4.5.3.1 Infauna structure

4.5.3.1.1 Number of species (S)

Sampling station 339_100 (salmon station) had the highest number of species (15) found during this sampling period. Two stations, 272_F (mussel station) and 246_F (salmon station) contained 13 species. The mean number of species (S) in the grabs at ConM was 11 and 10 at ConH (Figure 44). Samples collected beneath the cage at farm station 339_F contained the lowest number of species (4).

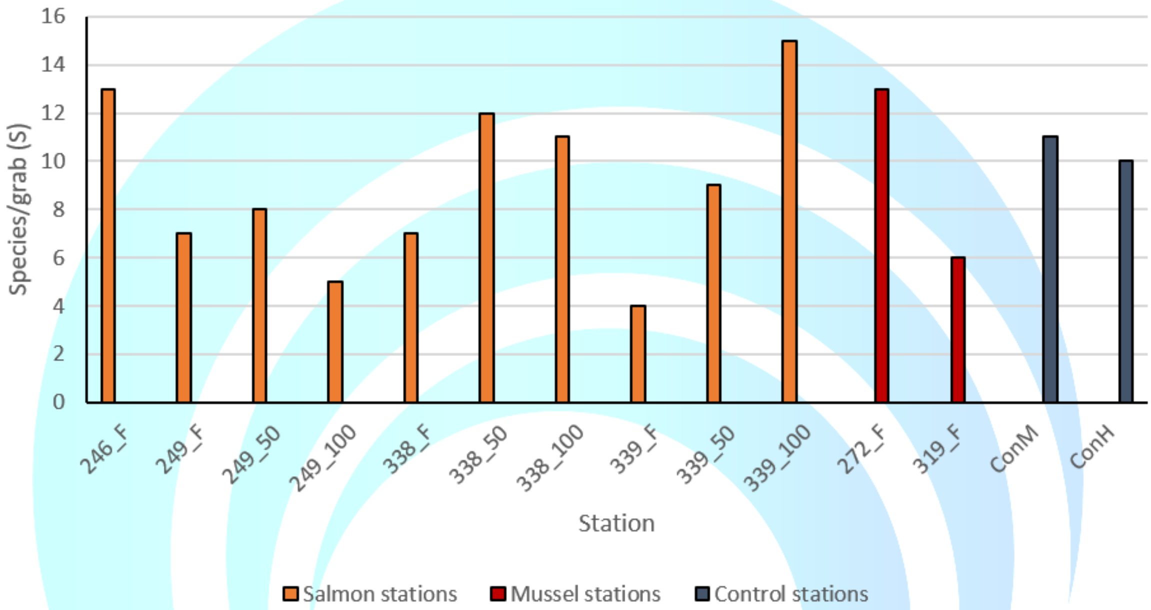


Figure 44 Mean number of species/core (S) from sediments at all sampling stations

4.5.3.1.2 Densities (N)

Mean infauna densities or abundance (N, individuals/grab) at the control stations were 21 at ConM and 12 at ConH. Mean densities at the salmon stations 339_50 and 246_F were 25 respectively.

The mean density at 249_F was 16 and this decreased with distance from the site boundary (6 individuals 50m away and 5 individuals 100m away). A similar trend was also observed at the salmon farm station338, where a mean of 22 individuals were collected under the cage edge, followed by 15 at 50 meters away and 13, 100 meters away from the site boundary (Figure 45). Observing higher density numbers beneath farm sites is common at anthropogenically disturbed sites (Peterson and Rosenberg 1976, Hartstein and Rowden 2004 and many others).

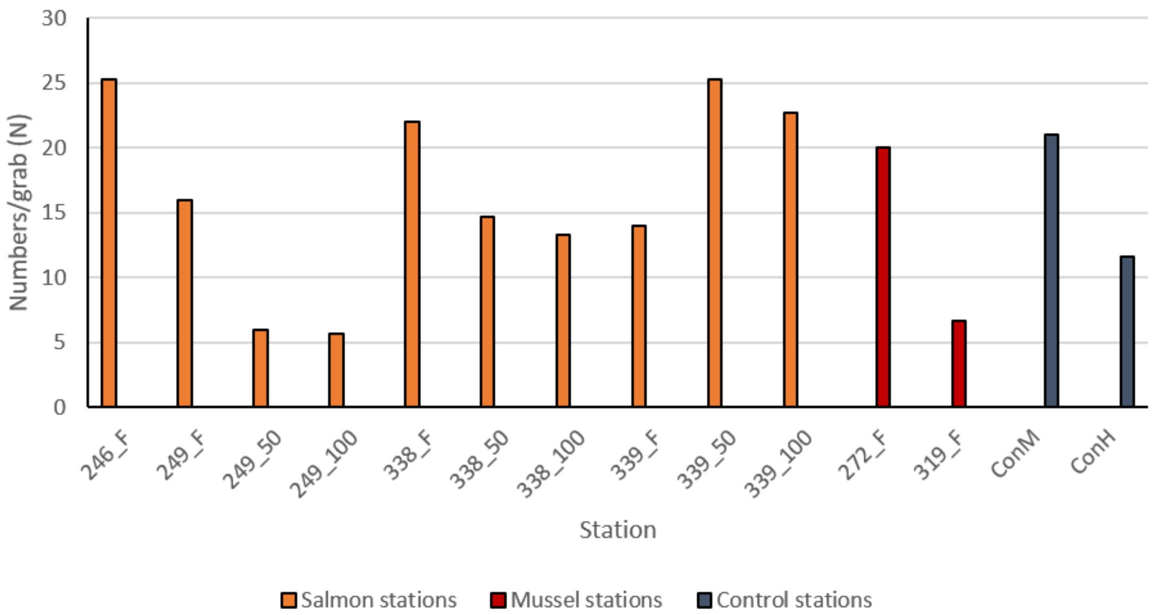


Figure 45 Mean density of individuals/grab (N) from sediments at all sampling stations

4.5.3.1.3 Species richness (d)

The species richness index (Margalef's, *d*) varied widely between stations and little if any trends can be observed other than perhaps at farm site 339 where species richness appears to have increased with distance from the site boundary (Figure 46).

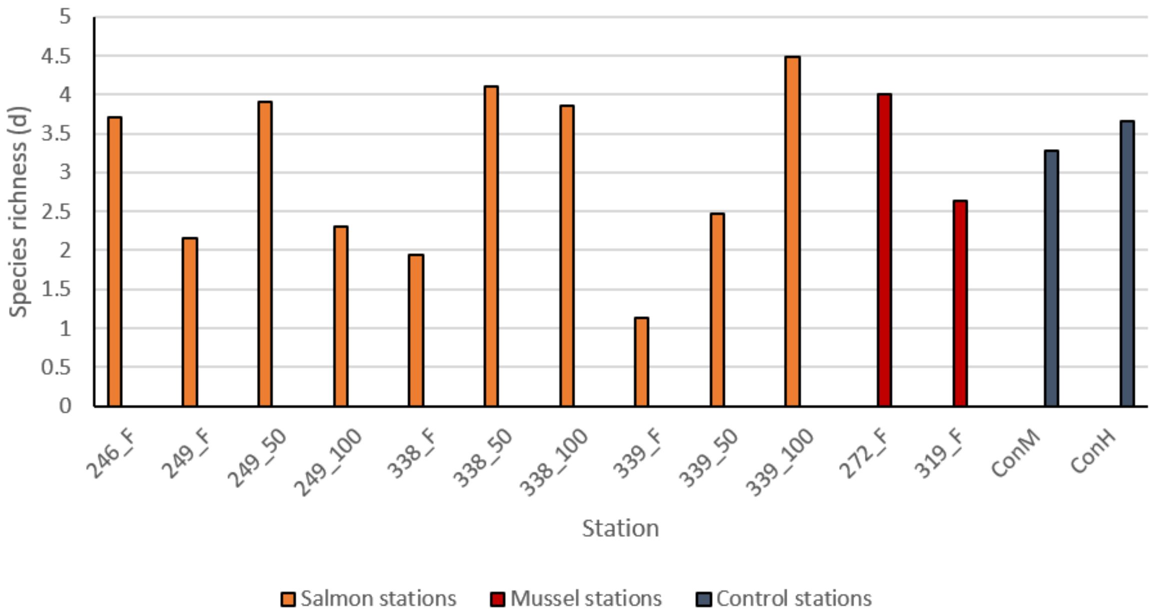


Figure 46: Mean number of species richness index (Margalef's d) from sediments at all sampling stations

4.5.3.1.4 Infauna community composition

4.5.3.1.4.1 Mussel farms

Figure 47 shows the composition matrix comparing two mussel farm stations (272_F and 319_F) with control stations (ConM and ConH).

Polychaetes were found at both mussel farms stations (272_F; 9 species, 319_F; three species). *Dorvilleid sp.* and *Lumbrinerid sp.* were found at both stations, while *Maldanid sp., Eunicid sp., Glycerid sp., Goniadid sp., Nephtyid sp., Cirratulid sp., and Ampharetid sp.* were only found at 272_F. *Orbiniid sp.* was only found in 319_F. The additional polychaete species observed within the mussel farm stations are likely attracted to the organic rich mussel farm faeces deposition.

For bivalves, *Thracia vegrandis* and *Veneridae sp.* were found at all stations, while *Nucula nitidula* was only found at 272_F.

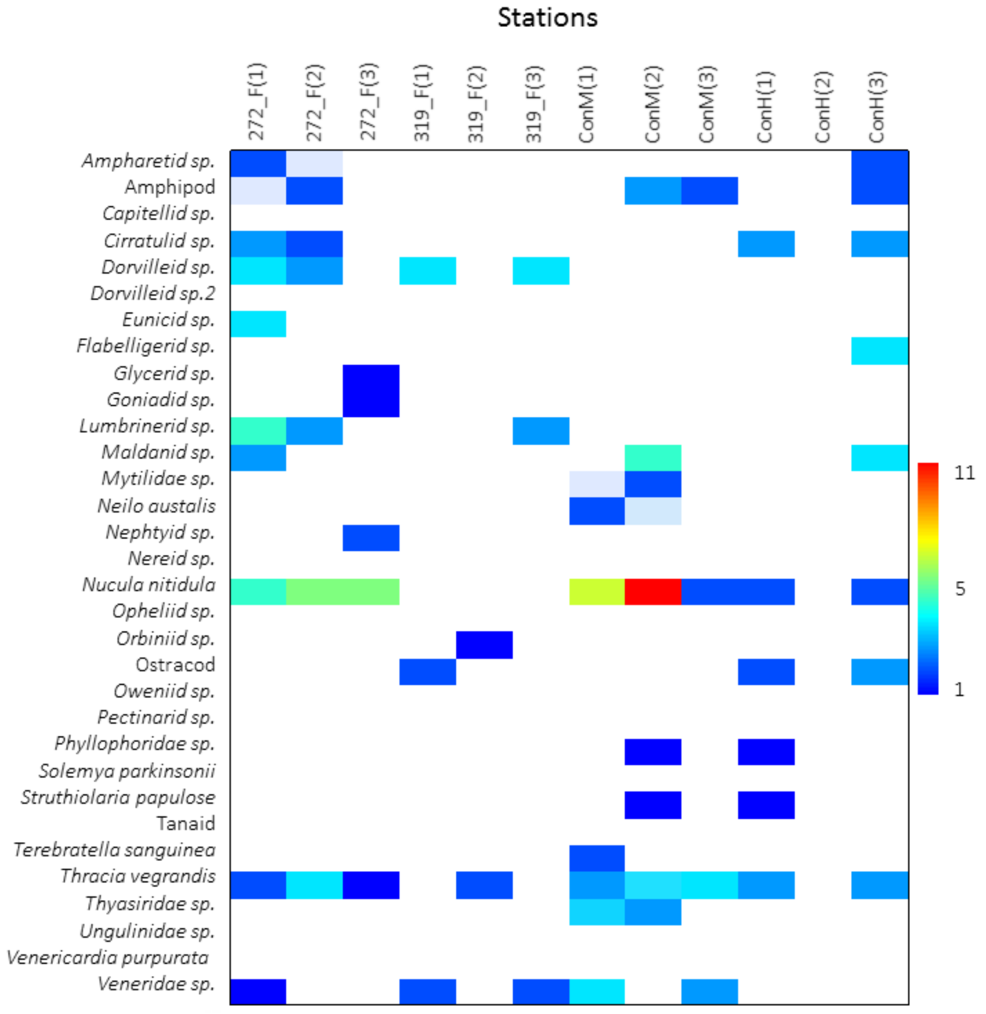


Figure 47 Abundance matrix of infauna species at control and mussel stations. The vertical colour bar indicates numbers/grab

Figure 48 indicates that the infauna differed for each farm site, between farms and controls stations. Some similarity (40-50%) was observed between the controls and farming stations.

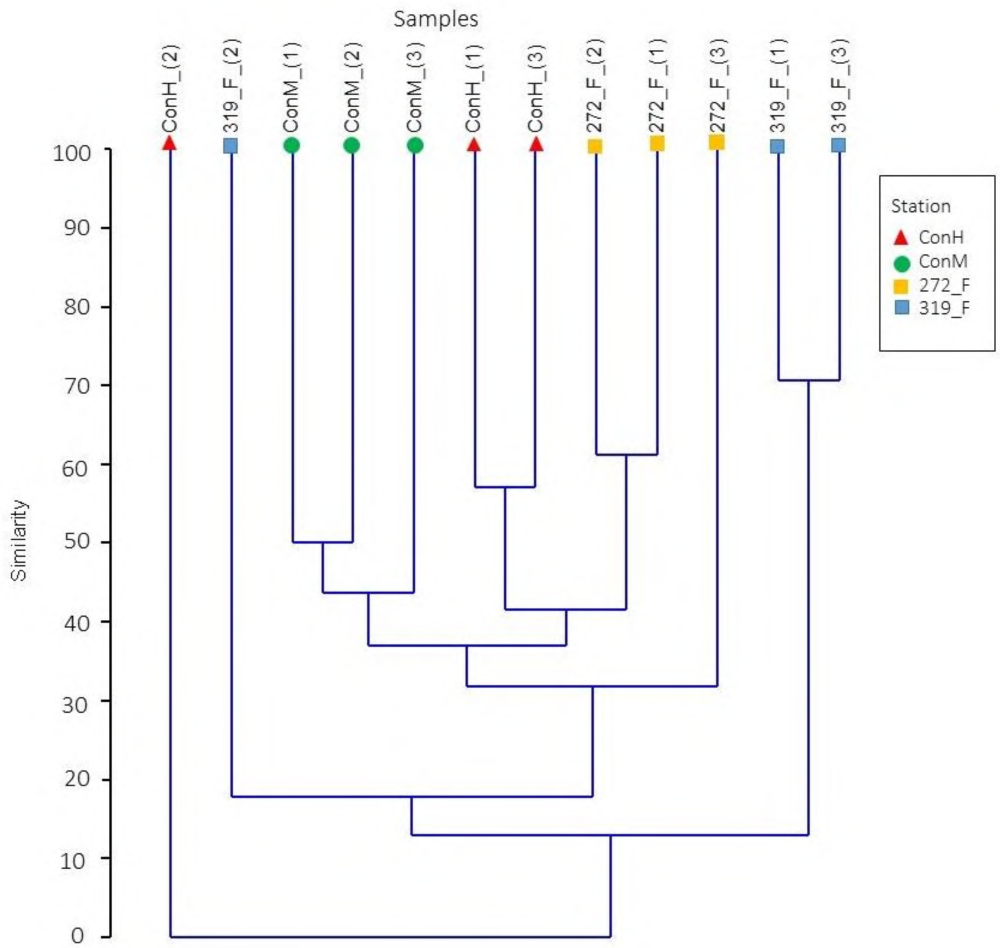


Figure 48 Dendrogram showing cluster analysis (Bray-Curtis similarities) results for infauna at mussel farms 272_F and 319_F and control stations. (1), (2) and (3) are three replicates samples per station.

These differences between stations were statistically significant overall (one way ANOSIM/analysis of similarity; R=0.321 p= 0.0122).

The above analysis indicates that the mussel stations still retained a moderately high species richness and diversity. A wide range of polychaete species were observed (Maldanid sp., Dorvilleid sp., Eunicid sp., Lumbrinerid sp., Orbiniid sp., Glycerid sp., Goniadid sp., Nephtyid sp., Cirratulid sp. and Ampharetid sp.). Filter feeding bivalves (*Nucula nitidula, Thracia vegrandis* and Veneridae sp.) were also found in the mussel sampling stations. Amphipod and Ostracods were also collected beneath the mussel farm stations, though in low abundance (Figure 43 & Appendix G).

4.5.3.1.4.2 Salmon farms

The salmon stations still retained a moderately high species richness and diversity. A wide range of polychaetes were found at these sites (Capitellid sp., Maldanid sp., Dorvilleid sp., Eunicid sp., Lumbrinerid sp., Flabelligerid sp., Opheliid sp., Oweniid sp., Orbiniid sp., Glycerid sp., Goniadid sp., Nephtyid sp., Nereid sp., Cirratulid sp., Pectinarid sp. and Ampharetid sp.) and filter feeding bivalves were common (Nucula nitidula, Thracia vegrandis, Ungulinidae, Solemya parkinsonii and Veneridae sp. See Appendix F for full species counts).

Some basic statistical analysis was undertaken examine the relationship between farm sites and control stations. Similarities (Bray-Curtis similarity index) between salmon farm stations and controls based on infauna were used to group or cluster replicates and stations (Figure 49).

There was generally little similarity between salmon stations and control stations, all stations were variously inter-mixed except for ConM (2) which had no species found and 249_100 (3) which was clustered on its own at c. 5% similarity to all other stations.

An MDS (Multiple Dimensional Scaling) plot confirmed this lack of similarity (Figure 50).

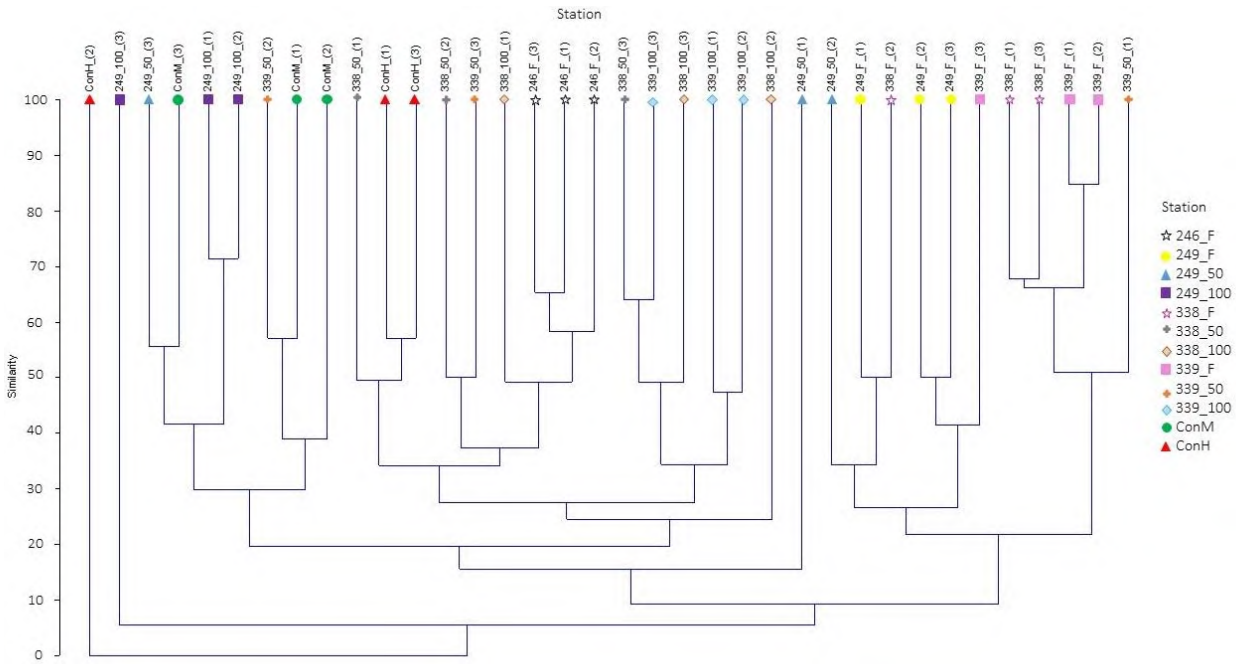


Figure 49 Cluster analysis dendrogram based on Bray-Curtis similarities between infauna composition at control and salmon farm stations.

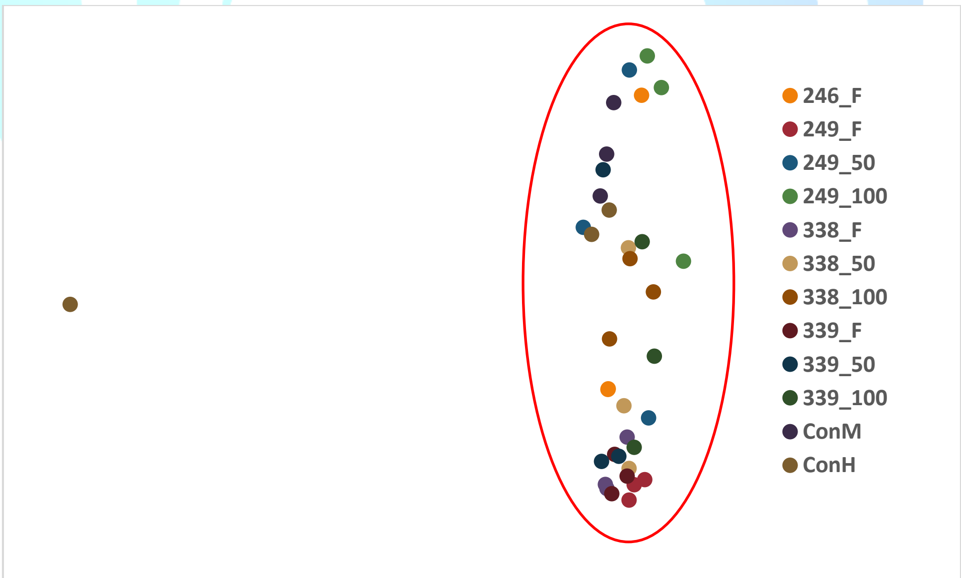


Figure 50 MDS (Multiple Dimensional Scaling) analysis plot of control and salmon farm stations based on Bray-Curtis similarities between infauna composition at control and salmon farm stations.

A SIMPER analysis was undertaken to examine the similarity between farm stations sampled and individual species within each stations vs each of the two control stations. *Dorvilleid* sp. had the highest percentage similarity and were found in all stations except 249_100 and ConM. *Opheliid* sp. and Nereid sp. had the lowest percentage similarity when compare to ConH (Figure 51). Dorvilleid species are often opportunists and are attracted to sites where there is organic enrichment such as under mussel and salmon farms (Hartstein and Rowden 2004, Keeley 2012.).

Nucula nitidula had the highest percentage similarity and were found in all sampling stations when compared to ConM, again this species is common in soft bottom communities associated in and around aquaculture production areas (Figure 52).

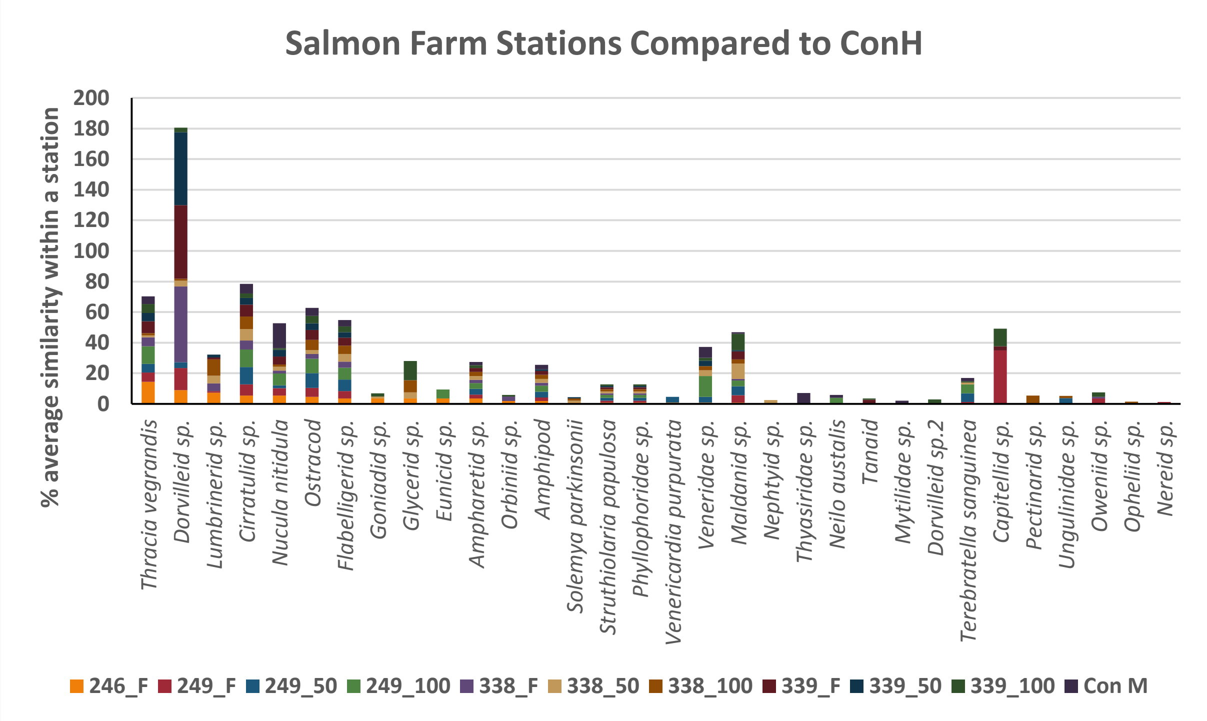


Figure 51 Species contributing to the percentage similarity between the three replicates at each station compare to ConH based on SIMPER (Similarity percentage) analysis

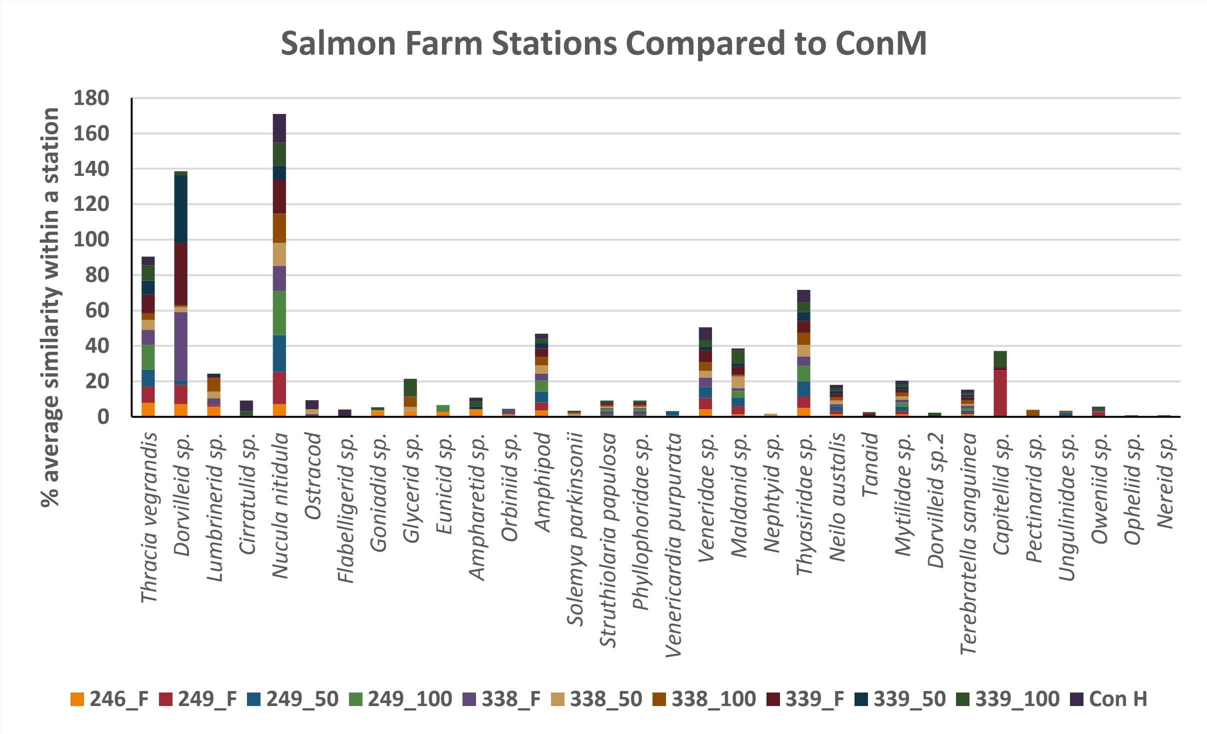


Figure 52 Species contributing to the percentage similarity between the three replicates at each station compare to ConM based on SIMPER (Similarity percentage) analysis

Based on the results presented above it appears that the community structure at control sites is diverse due to the wide range of species types identified i.e. filter feeders, predators, etc.

5 CONCLUSIONS

Water sampling using both a multi parameter sonde and a Van Dorn (to collect water for laboratory analysis) was undertaken at six sampling stations within Big Glory Bay. *In-situ* samples collected included oxygen, salinity, water visibility and temperature. Results indicate that the oxygen levels within the Bay were above 6mg/l during all sampling periods and at all depths. There is no indication that fish or mussel farming activities are having any adverse impacts on oxygen levels within the bay. Generally, levels would need to fall below 5.5mg/l or lower for extended periods of time to have an adverse impact on fish growth and performance (US EPA 2012).

Temperature data indicates a slight thermal stratification during summer periods. Sonde casts indicate that the surface waters of Big Glory Bay can be approximately 1 degree warmer than water that is 5m deep. Such heating is purely related to climatic forcing and isn't related to farming activities.

Unfortunately water quality sampling was not undertaken every month and some samples were also lost in transit (when being sent to the laboratory) and hence, there are gaps in the data. Future sampling will ensure that additional samples are stored on site to avoid a similar situation happening again.

The Chl-*a* and nutrient data that were collected indicate that there is variability between nutrient uptake and phytoplankton. Higher Chl-*a* levels were observed in late summer and corresponded to lower levels of soluble and particulate nutrients. In Autumn Chl-*a* levels were lower while both soluble and particulate nutrient concentrations increased (perhaps as a result of die off and cooler temperatures). Other seasonal patterns are impossible to assess due to the lack of data. Previous modelling and wide scale water quality monitoring (DHI 2012 & Key, 2001), indicates that large changes in nutrient dynamics occur due to regional changes outside of the bay (i.e. influx of nutrient rich water into the bay).

Other water quality parameters indicate no detectable adverse water quality conditions within the bay.

Results of the seabed sampling and analysis indicate that the seabed in an around the mussel and finfish farm sites is typical of that observed in several marine aquaculture impact studies including those undertaken in the Marlborough Sounds during the early 2000's (Hartstein 2003).

Organic enrichment (when compared to the nearby central bay control station ConH) was observed beneath all farming stations (both mussel and fish farm), along with mussel shells (at both mussel farms and one of the salmon farms, which was once a mussel farm). Opportunist polychaetes i.e. *Dorvilleid* were also observed beneath all farming stations and similar species have been observed in and around many farms in the Marlborough Sounds and in Tasmania.

Both the mussel and salmon stations still retained a moderately high species richness and diversity. A wide range of polychaetes were found at these sites including, grazer's, detritus feeders, opportunists and predators. Conditions were generally observed to improve (i.e. organic matter content decreased away from the site boundaries) with distance from the salmon farms i.e. at distances of 50 and 100m from the site boundary. Ostracods were also observed at several stations.

There were however two surprises in that *Beggiatoa* matting was observed both beneath farm stations 249_50 and 249_100. In addition, patchy *Beggiatoa* was also observed (via the underwater video camera) beneath mussel farm site 272. As far as ADS is aware the 249 site has been farmed for a significant period of time and is about to be fallowed with the cages moving east across the bay to farm site 246.

Overall the sediment quality in Big Glory Bay does not appear to be badly impacted given that there are a large number (more than 30) farms scattered across the entire bay. Both control stations one situated in the middle of the bay while the second is toward the mouth appear to be un-impacted by farm debris.

6 REFERENCES

ANZECC. (2000) Australia and New Zealand guidelines for fresh and marine water quality 2000 Volume 1. National Water Quality Management Strategy Paper No.4. Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Black, K.D., Hansen, P.K., Holmer, M. (2008) Salmon Aquaculture Dialogue: Working Group Report on Benthic Impacts and Farm Siting. 54 p.

Clarke, K.R., Warwick, R.M. (1994) *Changes in marine communities: An approach to statistical analysis and interpretation*. Plymounth Marine Laboratory, Plymouth, United Kingdom.

Clarke, D., Taylor, D., Keeley, N., Dunmore, R., Forrest, R., Goodwin, E. (2011) Assessment of effects of farming salmon at Ruaomoko, Queen Charlotte Sound: deposition and benthic effects. Prepared for The New Zealand King Salmon Company Limited. *Cawthron Report* No. 1992. 52 p.

Cromey, C.J., Nickell, T.D., Black, K.D. (2002) DePOMOD – modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214: 211-239.

DHI, 2012. Appendix A, Hydrodynamic modelling. 56.

Hargrave, B.T., Holmer, M., Newcombe, C.P. (2008) Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. *Marine Pollution Bulletin* 56: 810-824.

Hartstein, N.D. and Stevens, C.L. 2005. Deposition beneath longline mussel farms. Aquacul-ture Engineering. 33 (3) 191-213

Hartstein, N.D. 2005. Acoustic Characterisation of Substrates in and Around Sheltered and Open-Ocean Mussel Aquaculture Sites and its bearing on the Dispersal of Mussel Debris. IEEE Journal of Oceanic Engineering. Vol 30, 85-94.

Hartstein, N.D and Rowden, A.A. 2004 “Effect of Biodeposits from Mussel Culture on Mac-robenthic Assemblages at Sites of Different Hydrodynamic Regime” Marine Environmental Research. Vol 57, 339-357.

Hopkins, G. (2008) Advice on the development of appropriate monitoring conditions for marine farm sites in Southland. Prepared for Environment Southland. *Cawthron Report* no. 1514. 18p.

Hyland, J., Balthis, L., Karakassis, I., Magni, P., Petrov, A., Shine, J., Vestergaard, O. and Warwick, R., 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. *Marine Ecology Progress Series*, *295*, pp.91-103.Keeley, N.B. (2012) Statement of Evidence in Relation To Benthic Effects. For The New Zealand King Salmon Company Limited – June 2012.

J. Key. 2001. Growth and condition of the greenshell mussel Perna canaliculus, in Big Glory Bay, Stewart Island: relationships with environmental parameters. MSc thesis Otago Univeristy.

Keeley N.B. 2012. Statement of evidence in relation to benthic effects. For the New Zealand King Salmon Company limited.

Kruskal, J.B., Wish, M. (1978) *Multidimensional scaling. Beverly Hills, California*. Sage Publications.

NIWA 2016, Assessment of water column and benthic environments of Big Glory Bay June 2014 to June 2015.

Pearson, T.H. and Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review, 16, 229-311.

Ren, J., Stenton-Dozey, J.M.E., Roulston, H., Grant, B. (2013) Benthic capacity of three proposed fish farm sites at Steward Island. Prepared for Sanford Ltd. May 2013. Client report CHC2013-051, Project no. SFL12502, 30p.

USEPA. 2012. 5.2 Dissolved Oxygen and Biochemical Oxygen Demand. http://water.epa.gov/type/rsl/monitoring/vms52.cfm Accessed 2/08/2012

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7 APPENDIX

7.1 APPENDIX A BIG GLORY BAY MONITORING PROGRAMME

APPENDIX 1
Big Glory Bay Monitoring Programme

1. The consent holder shall monitor the effects of the marine farming activities on the seabed, as follows:

(a) (i) except for LI339, LI340, MF249, MF250, MF271, MF272 and MF365, monitoring of the seabed at representative locations under the marine farm site shall be undertaken at least once prior to 1 January 2025.

Note: The Programme shall monitor at least two marine farm sites per year within the bay from the following marine farm sites LI149, LI315, LI316, LI317, LI318, LI319, LI320, LI321, LI322, LI324, LI325, LI337, LI338, LI342, LI366, LI418, LI461, LI474, LI475, MF244, MF245, MF246, MF247, MF248, MF273, MF274, MF275 and MF326 so each site is monitored at least once prior to 1 January 2025.

(ii) an exception to Clause 1(a)(i) is if the marine farm site is actively farming salmon at the site, then monitoring of the seabed shall be undertaken at the following locations on an annual basis:
(1) under the salmon cage as close as possible;
(2) 50 metres from the site boundary identified in Appendix 2; and
(3) 100 metres from the site boundary identified in Appendix 2.

(iii) when the marine farm site is fallowed, monitoring of the seabed within the site boundary identified in Appendix 2, at the location previously occupied by salmon cages, shall be undertaken annually. If the marine farm site is reactivated to farm salmon then the annual monitoring regime in Condition 1(a)(ii) recommences and replaces this following monitoring regime.

(iv) within three months of the granting of this consent, monitoring of the seabed at the furthest point from the pen edge but within the site boundary of MF246.

(v) in addition to Clause 1(a)(i), monitoring of the seabed at two control sites identified in the Programme and approved, in writing, by the Consent Authority. The monitoring shall occur every year for the first three years from the granting of this consent, then once every three years thereafter.

(b) the samples will be analysed for the following to assess the sediment quality:

- a sediment profile detailing the features of the sediment sample;
- colour photographs of the sediment sample;
- depth of the oxygenated layer below the sediment surface;
- occurrence of hydrogen sulphide;
- sediment texture and grain size;
- total organic carbon content;
- infaunal and epifauna community composition; and
- zinc and copper trace metal levels.

2. The consent holder shall monitor the effects of the marine farming activities on the water quality, as follows:

(a) (i) monitoring of the water column shall be undertaken monthly for the first two years, commencing from 1 July 2011, by taking samples at four sites within Big Glory Bay and two control sites inside the bay, at a depth of 5 metres, as identified in the Programme and approved, in writing, by the Consent Authority.

(ii) after the first two years outlined in Clause 2(a)(i), monitoring of the water column shall be undertaken three times during the period of 1 November to 30 June each year and once during the period of 1 July to 31 October each year at four sites within Big Glory Bay and two control sites inside the bay, at a depth of 5 metres, as identified in the Programme and approved, in writing, by the Consent Authority.

(b) the water quality samples will be analysed for the following:

- water temperature;
- chlorophyll *a;*
- vertical secchi depth; and
- dissolved oxygen.

7.2 Appendix B Monthly In-Situ Water Column Parameters

Appendix Ba: Monthly water column parameters from 14/07/2015 to 21/08/2016: Secchi depth (m) (an indication of water clarity) and water temperature (°C) and dissolved oxygen (mg/L) at 2 meter depth intervals from 1 meter below the surface until 21 meters. There were no data collected from November 2015 January 2016.

Station	Date Collected	Secchi depth (m)	Water temperature ° C (depth from surface (m)											Dissolved oxygen mg/L (depth from surface (m)										
			1	3	5	7	9	11	13	15	17	19	21	1	3	5	7	9	11	13	15	17	19	21
1	14/7/2015	14.0	8.4	8.4	8.4	8.4	8.4	8.4	8.6	8.8	8.8	8.8	8.7	11.0	11.0	11.6	11.7	11.7	11.7	11.9	11.9	11.9	11.9	11.9
2	14/7/2015	12.5	8.4	8.4	8.4	8.5	8.5	8.6	8.6	8.6	8.6	8.7	8.7	10.8	10.9	10.9	11.0	11.0	11.8	11.9	11.8	11.8	11.9	11.9
3	14/7/2015	16.0	8.5	8.5	8.5	8.5	8.6	8.6	8.6	8.6	8.6	8.6	8.6	11.8	11.8	11.8	11.8	11.9	11.9	11.9	11.9	11.9	12.0	12.0
4	14/7/2015	16.0	8.5	8.5	8.5	8.5	8.5	8.5	8.6	8.9	9.0	9.0	9.0	11.5	11.6	11.6	11.8	11.8	11.8	11.8	11.9	12.1	12.1	12.2
5	14/7/2015	16.0	8.5	8.5	8.5	8.5	8.5	8.6	8.9	9.0	9.0	9.0	9.0	11.5	11.6	11.6	11.7	11.7	11.6	11.6	11.6	11.6	11.8	11.9
6	14/7/2015	16.0	8.6	8.6	9.1	9.2	9.2	9.2	9.2	9.2	9.1	9.0	9.0	10.7	12.3	12.0	12.0	12.4	12.4	12.4	12.4	12.3	12.4	12.7
1	30/8/2015	13.0	8.8	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.6	7.8	7.8	7.7	7.6	7.5	7.7	7.8	7.7	7.7	7.7	7.9
2	30/8/2015	11.0	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.5	8.3	8.1	8.2	8.1	8.1	8.3	8.2	7.9	7.6	7.9
3	30/8/2015	12.0	8.9	8.9	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	7.5	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6	7.5
4	30/8/2015	12.0	8.8	8.8	8.8	8.8	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.2	8.2	8.2	8.1	8.0	8.1	8.1	8.1	8.1	8.1	8.1
5	30/8/2015	13.0	8.9	8.9	8.9	8.9	8.9	9.0	9.0	9.0	9.0	9.0	9.0	7.2	7.2	7.2	7.2	7.2	7.3	7.5	7.5	7.5	7.5	7.6
6	30/8/2015	10.0	8.8	8.8	8.8	8.8	8.8	8.8	8.9	8.9	8.9	8.9	9.0	8.1	8.1	8.1	8.1	8.0	7.7	7.8	7.4	7.3	7.0	7.0
1	23/9/2015	10.0	11.9	11.9	11.9	12.0	12.0	12.1	12.5	12.5	12.5	12.5	12.5	9.1	9.0	8.3	8.5	8.6	8.7	8.9	8.9	8.9	9.1	9.1
2	23/9/2015	9.0	11.7	11.7	11.7	11.9	11.9	12.0	12.0	12.0	12.0	12.1	12.2	8.3	8.3	8.2	8.5	8.3	8.3	8.3	8.4	8.6	8.5	8.5
3	23/9/2015	9.0	11.9	11.9	11.9	12.0	12.0	12.3	12.5	12.5	12.5	12.5	12.5	9.1	9.1	8.6	8.7	8.7	8.9	8.9	8.9	9.0	9.0	9.0
4	23/9/2015	9.0	11.8	11.9	12.0	12.0	12.0	12.0	12.0	12.5	12.5	12.5	12.5	8.2	8.2	8.2	8.5	8.9	9.0	9.0	9.0	9.1	9.2	9.3
5	23/9/2015	9.0	11.8	11.8	11.8	11.8	11.8	11.8	11.9	12.0	12.0	12.0	12.0	8.3	8.3	8.3	8.3	8.3	8.3	9.0	8.5	8.5	9.0	9.0
6	23/9/2015	10.0	11.7	11.7	11.7	11.7	11.7	11.7	11.6	11.6	11.7	11.7	11.8	8.1	8.1	8.1	8.1	8.1	8.2	8.2	8.2	8.2	8.2	8.2
1	29/10/2015	8.5	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	7.6	7.5	7.3	7.1	6.9	6.5	6.3	6.3	6.3	6.4	6.3
2	29/10/2015	8.5	11.9	11.9	11.9	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	8.1	8.1	7.6	7.8	8.1	7.9	7.9	7.9	7.9	7.9	7.9

Station	Date Collected	Secchi depth (m)	Water temperature ° C (depth from surface (m)											Dissolved oxygen mg/L (depth from surface (m)										
			1	3	5	7	9	11	13	15	17	19	21	1	3	5	7	9	11	13	15	17	19	21
3	29/10/2015	8.5	11.8	11.8	11.8	11.8	11.8	11.9	11.9	11.9	11.9	11.9	11.9	8.2	8.2	8.2	8.2	8.1	8.3	8.1	8.2	8.2	8.1	8.1
4	29/10/2015	8.5	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.1	7.5	7.5	7.5	7.5	7.4	7.4	7.4	7.4	7.4	7.3	7.0
5	29/10/2015	8.5	12.0	12.0	12.0	12.0	12.1	12.1	12.1	12.1	12.1	12.2	12.2	7.3	6.9	6.6	6.6	6.6	6.8	6.6	6.6	6.8	7.4	7.4
6	29/10/2015	8.5	11.1	11.8	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	7.2	7.2	7.1	7.5	7.0	6.7	6.7	6.6	6.8	7.4	7.1
1	7/2/2016	8.0	16.2	16.1	15.4	14.7	14.6	14.5	14.5	14.4	14.4	14.5	14.5	8.3	8.0	7.7	7.3	7.2	7.2	7.4	7.4	7.3	7.0	7.9
2	7/2/2016	9.5	16.4	16.2	15.4	14.6	14.5	14.4	14.3	14.3	14.3	14.1	14.2	7.9	7.8	7.3	5.8	5.8	7.5	7.7	7.7	7.5	7.0	6.5
3	7/2/2016	7.0	16.3	16.1	15.6	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.1	8.9	8.6	8.3	9.1	9.0	9.0	8.8	8.7	8.7	8.7	8.7
4	7/2/2016	7.5	16.4	15.7	15.1	14.9	14.8	14.8	14.8	14.8	14.8	14.9	15.1	8.8	8.5	8.5	8.8	8.2	8.1	7.9	7.6	7.4	7.4	7.0
5	7/2/2016	8.0	16.1	15.2	15.2	14.9	14.8	14.8	14.8	14.7	14.7	14.7	14.7	8.9	8.6	8.3	8.0	8.1	7.8	7.6	7.4	7.1	6.5	6.3
6	7/2/2016	9.0	15.8	15.1	14.7	14.6	14.6	14.5	14.5	14.5	14.5	14.4	14.4	8.7	8.6	9.1	9.5	8.8	8.8	8.5	8.1	7.7	7.1	7.0
1	9/3/2016	8.0	14.5	14.4	14.4	14.4	14.4	14.4	14.3	14.3	14.3	14.3	14.3	8.5	8.2	8.1	7.9	7.8	7.7	7.7	7.7	7.7	7.7	7.8
2	9/3/2016	8.5	14.6	14.6	14.6	14.6	14.6	14.5	14.5	14.5	14.5	14.5	14.5	8.2	7.7	7.5	7.3	7.4	7.5	7.2	7.3	7.3	7.4	7.4
3	9/3/2016	8.0	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.5	14.5	14.5	8.1	8.1	8.1	8.0	8.3	7.8	7.6	7.6	7.6	7.6	7.8
4	9/3/2016	8.0	14.5	14.5	14.5	14.5	14.5	14.4	14.4	14.4	14.3	14.3	14.2	7.9	7.8	8.0	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
5	9/3/2016	8.0	14.6	14.6	14.6	14.5	14.5	14.5	14.5	14.4	14.4	14.4	14.3	8.8	7.6	7.4	7.5	7.5	7.4	7.5	7.6	7.7	7.3	7.3
6	9/3/2016	6.0	14.5	14.5	14.5	14.4	14.4	14.4	14.3	14.3	14.3	14.3	14.3	8.2	7.7	7.6	7.6	7.6	7.7	7.6	7.6	7.6	7.7	7.7
1	18/4/2016	7.0	13.5	13.5	13.5	13.6	13.6	13.7	13.7	13.7	13.7	13.6	13.6	7.7	7.9	7.8	7.6	7.4	7.1	7.1	6.9	6.9	7.0	7.1
2	18/4/2016	7.0	13.5	13.6	13.3	13.6	13.6	13.6	13.5	13.5	13.5	13.5	13.5	7.3	7.0	6.3	6.4	6.4	6.3	7.3	7.2	7.2	7.2	7.2
3	18/4/2016	8.0	13.4	13.5	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.2	9.2	8.6	8.5	8.8	8.7	8.5	7.8	7.8	7.7	7.7	7.7
4	18/4/2016	8.0	13.6	13.5	13.6	13.6	13.5	13.5	13.7	13.6	13.7	13.6	13.6	8.2	7.2	7.6	7.7	7.7	8.4	8.4	6.3	7.2	6.8	6.8
5	18/4/2016	8.0	13.5	13.5	13.6	13.6	13.6	13.5	13.5	13.5	13.5	13.4	13.3	7.7	7.6	7.4	7.2	7.5	7.6	7.3	6.6	6.1	5.7	5.9
6	18/4/2016	8.5	13.5	13.4	13.5	13.6	13.5	13.5	13.4	13.4	13.4	13.4	13.4	7.6	7.6	7.5	7.4	7.2	7.3	7.5	7.5	7.4	7.2	7.5

Station	Date Collected	Secchi depth (m)	Water temperature ° C (depth from surface (m)											Dissolved oxygen mg/L (depth from surface (m)										
			1	3	5	7	9	11	13	15	17	19	21	1	3	5	7	9	11	13	15	17	19	21
1	10/5/2016	11.5	13.0	13.1	13.2	13.2	13.2	13.1	13.1	13.1	13.1	13.1	13.0	7.1	6.9	6.8	6.8	6.8	6.7	7.6	7.5	7.5	7.5	7.6
2	10/5/2016	12.0	13.1	13.0	13.1	13.1	13.1	13.2	13.2	13.2	13.1	13.2	13.0	7.3	7.3	7.3	7.0	7.0	6.9	7.4	7.6	7.6	7.7	7.6
3	10/5/2016	12.0	13.1	13.1	13.1	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	7.4	7.4	7.3	6.9	7.0	7.5	7.6	7.6	7.6	7.7	7.7
4	10/5/2016	9.0	13.1	13.1	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.1	7.5	7.5	7.5	7.5	7.5	7.4	7.4	7.4	7.5	7.7	7.7
5	10/5/2016	12.0	13.2	13.2	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.2	7.3	7.4	7.3	7.3	7.5	7.6	7.7	7.7	7.7	7.8	7.7
6	10/5/2016	8.0	13.2	13.2	13.3	13.4	13.5	13.5	13.6	13.6	13.6	13.6	13.6	7.5	7.4	7.3	7.4	7.7	7.7	7.6	7.5	7.5	7.6	7.6
1	26/6/2016	15.0	8.7	8.7	8.8	8.8	8.8	8.8	8.8	8.7	8.7	8.7	8.7	8.6	8.6	8.6	8.5	8.5	8.5	8.5	8.5	8.6	8.6	8.6
2	26/6/2016	13.0	8.6	8.9	8.9	8.9	8.9	8.9	8.8	8.8	8.8	8.8	8.8	8.7	8.4	8.4	8.4	8.4	8.5	8.5	8.4	8.4	8.3	8.4
3	26/6/2016	12.0	9.1	9.1	9.0	9.0	9.0	9.0	9.0	8.9	8.9	8.8	8.9	9.0	9.3	9.0	8.9	8.9	8.9	9.0	8.8	8.8	8.8	8.8
4	26/6/2016	14.0	9.0	9.0	8.9	8.9	8.9	8.9	8.9	8.8	8.8	8.8	8.7	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
5	26/6/2016	11.0	8.9	9.0	9.0	9.0	8.9	8.8	8.8	8.7	8.7	8.6	8.6	8.6	8.4	8.2	8.3	8.4	8.4	8.5	8.5	8.5	8.5	8.5
6	26/6/2016	14.0	9.0	9.0	9.0	9.0	9.0	9.0	8.9	8.9	8.9	8.9	8.9	8.7	8.7	8.5	8.5	8.4	8.4	8.4	8.4	8.4	8.4	8.5
1	31/7/2016	10.5	8.4	8.4	8.4	8.4	8.4	8.4	8.3	8.3	8.2	8.1	8.0	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.9	8.9	8.9
2	31/7/2016	9.0	8.7	8.7	8.8	8.8	8.8	8.8	8.8	9.1	9.1	9.2	9.2	8.7	8.6	8.6	8.6	8.6	8.6	8.6	8.5	8.6	8.6	8.6
3	31/7/2016	9.0	8.4	8.4	8.4	8.3	8.3	8.3	8.2	8.2	8.1	8.1	8.1	8.9	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
4	31/7/2016	11.0	8.4	8.4	8.4	8.3	8.3	8.3	8.2	8.1	8.0	7.9	7.9	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.8	8.8	8.8
5	31/7/2016	9.5	8.7	8.7	8.6	8.6	8.6	8.6	8.5	8.5	8.4	8.4	8.3	8.9	8.9	8.9	8.9	8.9	8.8	8.9	8.9	8.9	8.9	9.0
6	31/7/2016	11.0	8.7	8.7	8.6	8.6	8.6	8.6	8.5	8.6	8.5	8.5	8.5	8.6	8.6	8.6	8.6	8.5	8.6	8.6	8.7	8.7	8.8	8.8
1	21/8/2016	13.0	9.0	9.2	9.2	9.3	9.3	9.4	9.4	9.4	9.4	9.4	9.4	9.3	9.1	8.8	8.7	8.3	8.0	8.2	8.4	8.8	8.9	8.9
2	21/8/2016	10.5	9.2	9.3	9.3	9.3	9.4	9.4	9.5	9.5	9.5	9.5	9.5	9.2	8.9	8.5	8.5	8.5	8.5	8.5	8.9	8.9	8.9	8.9
3	21/8/2016	8.5	9.1	9.1	9.1	9.1	9.2	9.2	9.1	9.2	9.3	9.3	9.2	9.2	9.2	9.2	9.1	9.0	9.0	8.8	8.5	8.5	8.7	8.7
4	21/8/2016	10.5	9.4	9.1	9.1	9.1	9.2	9.2	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.2	9.2	8.9	8.4	8.4	9.0	9.0	9.0	8.8
5	21/8/2016	11.0	9.3	9.5	9.5	9.6	9.6	9.6	9.5	9.5	9.5	9.5	9.5	8.8	8.3	8.3	8.4	8.5	8.7	9.0	9.0	9.0	9.0	9.1
6	21/8/2016	14.0	9.2	9.3	9.3	9.3	9.4	9.4	9.4	9.5	9.5	9.6	9.6	9.3	8.9	8.4	8.5	8.8	8.9	9.0	9.0	9.0	9.0	9.0

7.3 Appendix C Physical characteristics of benthic sediments

Physical characteristics of benthic sediments in Big Glory Bay, Steward Island. Sampling stations are abbreviated as ConM = Control Mouth, ConH = Control Head. Note: Depth of the oxygenated layer below the sediment surface corresponds to the redox depth in (mm.

Latitude/Longitude	Station	Grab	Core	Sample	Site Depth (m)	% mud	% sand	% very fine gravel	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
46° 58.15204' S 168° 07.97891' E	ConM	1	a	ConM_1a	22.3	32.8	59.3	7.8				4	9	No	No	No
		1	b	ConM_1b	22.3				2.1			4	8	No	No	No
		1	c	ConM_1c	22.3					7	33	4	7	No	No	No
		2	a	ConM_2a	22.3	38.3	54.2	7.5				4	6	No	No	No
		2	b	ConM_2b	22.3				2.3			4	7	No	No	No
		2	c	ConM_2c	22.3					8	40	4	8	No	No	No
		3	a	ConM_3a	22.3	34.2	60.3	5.5				4	7	No	No	No
		3	b	ConM_3b	22.3				2.5			4	4	No	No	No
		3	c	ConM_3c	22.3					7	38	4	6	No	No	No
46° 58.98857' S 168° 07.06492' E	ConH	1	a	ConH_1a	22.4	61.6	35.7	2.7				3	7	No	No	No
		1	b	ConH_1b	22.4				1.25			3	7	No	No	No
		1	c	ConH_1c	22.4					9	35	3	7	No	No	No
		2	a	ConH_2a	22.4	63.9	34.8	1.3				3	6	No	No	No
		2	b	ConH_2b	22.4				1.19			3	9	No	No	No
		2	c	ConH_2c	22.4					10	34	3	7	No	No	No
		3	a	ConH_3a	22.4	65.2	33.2	1.6				3	6	No	No	No
		3	b	ConH_3b	22.4				1.16			3	8.5	No	No	No
		3	c	ConH_3c	22.4					9	36	3	7	No	No	No

Latitude/Longitude	Station	Grab	Core	Sample	Site Depth (m)	%mud	% sand	% very fine gravel	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
46° 58.29318' S 168° 06.82449' E	319_F	1	a	319_F_1a	21.6	37.5	57.0	5.5				Indistinct	5	No	Mild	No
		1	b	319_F_1b	21.6				2.7			Indistinct	3	No	Mild	No
		1	c	319_F_1c	21.6					23	58	Indistinct	4	No	Mild	No
		2	a	319_F_2a	21.6	32.8	58.9	8.3				Indistinct	9	No	Mild	No
		2	b	319_F_2b	21.6				2.3			Indistinct	7	No	Mild	No
		2	c	319_F_2c	21.6					-	-	Indistinct	5	No	Mild	No
		3	a	319_F_3a	21.6	32.6	58.8	8.7				Indistinct	11	No	Mild	No
		3	b	319_F_3b	21.6				2.6			Indistinct	10	No	Mild	No
		3	c	319_F_3c	21.6					-	-	Indistinct	7	No	Mild	No
46° 59.02909' S 168° 07.87438' E	272_F	1	a	272_F_1a	22.7	38.1	57.5	4.4				Indistinct	12	Yes	Moderate	No
		1	b	272_F_1b	22.7				2.5			Indistinct	8	Yes	Moderate	No
Lots of mussel debris		1	c	272_F_1c	22.7					-	-	Indistinct	9	Yes	Moderate	No
		2	a	272_F_2a	22.7	38.3	58.2	3.5				Indistinct	9	Yes	Moderate	No
		2	b	272_F_2b	22.7				2.2			Indistinct	10	Yes	Moderate	No
		2	c	272_F_2c	22.7					-	-	Indistinct	12	Yes	Moderate	No
		3	a	272_F_3a	22.7	39.4	53.7	7.0				Indistinct	10	Yes	Moderate	No
		3	b	272_F_3b	22.7				2.5			Indistinct	7	Yes	Moderate	No
		3	c	272_F_3c	22.7					-	-	Indistinct	-	Yes	Moderate	No

Latitude/Longitude	Station	Grab	Core	Sample	Site Depth (m)	% mud	% sand	% very fine gravel	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
46° 58.58209' S 168° 08.05062' E	246_F	1	a	246_F_1a	23.1	45.3	48.3	6.4				2	6	No	Mild	No
		1	b	246_F_1b	23.1				2.8			2	8	No	Mild	No
		1	c	246_F_1c	23.1					12	40	2	7	No	Mild	No
		2	a	246_F_2a	23.1	40.0	54.6	5.4				2	8	No	Mild	No
		2	b	246_F_2b	23.1				2.3			2	7	No	Mild	No
		2	c	246_F_2c	23.1					10	35	2	5	No	Mild	No
		3	a	246_F_3a	23.1	42.2	47.2	10.7				2	8	No	Mild	No
		3	b	246_F_3b	23.1				2.0			2	8	No	Mild	No
		3	c	246_F_3c	23.1					11	42	2	7	No	Mild	No
46° 58.746065' S 168° 06.673647' E **Lots of shell debris mixed with terrestrial organic matter (leaves and twigs)**	249_F	1	a	249_F_1a	26.9	54.9	44.0	1.1				No	10	No	Mild	No
		1	b	249_F_1b	26.9				2.3			No	9	No	Mild	No
		1	c	249_F_1c	26.9					120	87	No	8	No	Mild	No
		2	a	249_F_2a	26.9	56.8	40.8	2.3				No	9	No	Mild	No
		2	b	249_F_2b	26.9				1.91			No	9	No	Mild	No
		2	c	249_F_2c	26.9					156	83	No	-	No	Mild	No
		3	a	249_F_3a	26.9	52.5	44.1	3.4				No	10	No	Mild	No
		3	b	249_F_3b	26.9				2.5			No	7	No	Mild	No
		3	c	249_F_3c	26.9					440	156	No	-	No	Mild	No

Latitude/Longitude	Station	Grab	Core	Sample	Site Depth (m)	% mud	% sand	% very fine gravel	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
46° 58.845805' S 168° 06.507737' E	249_50	1	a	249_50_1a	26.9	60.6	36.7	2.7				3	6	Yes	Mild	No
		1	b	249_50_1b	26.9				2.0			3	8	Yes	Mild	No
		1	c	249_50_1c	26.9					22	52	3	10	Yes	Mild	No
		2	a	249_50_2a	26.9	62.4	34.3	3.3				3	11	Yes	Mild	No
		2	b	249_50_2b	26.9				1.75			3	10	Yes	Mild	No
		2	c	249_50_2c	26.9					14	40	3	12	Yes	Mild	No
		3	a	249_50_3a	26.9	62.8	33.6	3.5				3	9	Yes	Mild	No
		3	b	249_50_3b	26.9				1.62			3	9	Yes	Mild	No
		3	c	249_50_3c	26.9					12	40	3	9	Yes	Mild	No
46° 58.872365' S 168° 06.509371' E **Sand and mix mixture**	249_100	1	a	249_100_1a	26.9	65.0	33.2	1.8				2	9	Yes	No	No
		1	b	249_100_1b	26.9				1.49			2	11	Yes	No	No
		1	c	249_100_1c	26.9					13	38	2	10	Yes	No	No
		2	a	249_100_2a	26.9	64.0	33.0	2.9				2	10	Yes	No	No
		2	b	249_100_2b	26.9				1.64			2	10	Yes	No	No
		2	c	249_100_2c	26.9					12	34	2	7	Yes	No	No
		3	a	249_100_3a	26.9	64.1	32.8	3.0				2	9	Yes	No	No
		3	b	249_100_3b	26.9				1.54			2	9	Yes	No	No
		3	c	249_100_3c	26.9					13	41	2	10	Yes	No	No

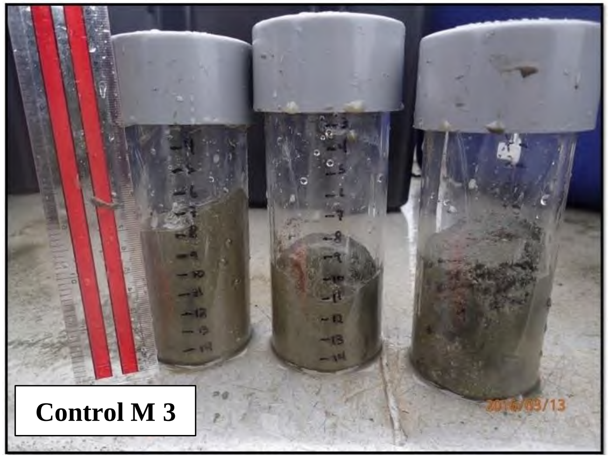
Latitude/Longitude	Station	Grab	Core	Sample	Site Depth (m)	%mud	% sand	% very fine gravel	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
46° 59.355892' S 168° 06.632339' E	338_F	1	a	338_F_1a	25.3	25.1	74.1	0.8				1	9	No	Moderate	No
		1	b	338_F_1b	25.3				9.4			1	8	No	Moderate	No
		1	c	338_F_1c	25.3					860	910	1	8	No	Moderate	No
		2	a	338_F_2a	25.3	26.4	72.7	0.8				1	6	No	Moderate	No
		2	b	338_F_2b	25.3				7.9			1	9	No	Moderate	No
		2	c	338_F_2c	25.3					890	1020	1	6	No	Moderate	No
		3	a	338_F_3a	25.3	24.4	75.0	0.7				1	7	No	Moderate	No
		3	b	338_F_3b	25.3				8.3			1	8	No	Moderate	No
		3	c	338_F_3c	25.3					930	910	1	6	No	Moderate	No
46° 59.194826' S 168° 06.633739' E	338_50	1	a	338_50_1a	25.4	54.1	42.1	3.8				1	9	No	Mild	No
		1	b	338_50_1b	25.4				1.19			1	9	No	Mild	No
		1	c	338_50_1c	25.4					36	65	1	12	No	Mild	No
		2	a	338_50_2a	25.4	53.0	44.1	2.9				1	9	No	Mild	No
		2	b	338_50_2b	25.4				1.51			1	8	No	Mild	No
		2	c	338_50_2c	25.4					67	109	1	8	No	Mild	No
		3	a	338_50_3a	25.4	54.9	41.5	3.6				1	8	No	Mild	No
		3	b	338_50_3b	25.4				1.34			1	10	No	Mild	No
		3	c	338_50_3c	25.4					23	59	1	9	No	Mild	No

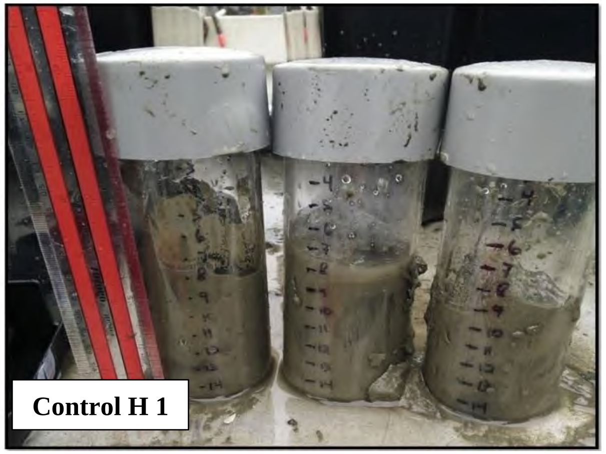
Latitude/Longitude	Station	Grab	Core	Sample	Site Depth (m)	% mud	% sand	% very fine gravel	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
46° 59.167791' S 168° 06.633726' E	338_100	1	a	338_100_1a	25.6	63.9	34.8	1.3				1	11	No	No	No
		1	b	338_100_1b	25.6				1.63			1	9	No	No	No
		1	c	338_100_1c	25.6					18	54	1	9	No	No	No
		2	a	338_100_2a	25.6	64.9	33.4	1.8				1	9	No	No	No
		2	b	338_100_2b	25.6				1.18			1	10	No	No	No
		2	c	338_100_2c	25.6					13	43	1	11	No	No	No
		3	a	338_100_3a	25.6	64.0	34.3	1.7				1	12	No	No	No
		3	b	338_100_3b	25.6				1.39			1	9	No	No	No
		3	c	338_100_3c	25.6					14	41	1	7	No	No	No
46° 59.100' S 168° 07.634' E	339_F	1	a	339_F_1a	26.2	-	-	-				No	-	No	Strong	No
		1	b	339_F_1b	26.2				3.8			No	-	No	Strong	No
Lots of mussel shell debris mix with sand and lots of feed waste present		1	c	339_F_1c	26.2					930	270	No	-	No	Strong	No
		2	a	339_F_2a	26.2	-	-	-				No	5	No	Strong	No
		2	b	339_F_2b	26.2				5.5			No	-	No	Strong	No
		2	c	339_F_2c	26.2					2000	520	No	-	No	Strong	No
		3	a	339_F_3a	26.2	-	-	-				No	-	No	Strong	No
		3	b	339_F_3b	26.2				3			No	-	No	Strong	No
		3	c	339_F_3c	26.2					190	82	No	-	No	Strong	No

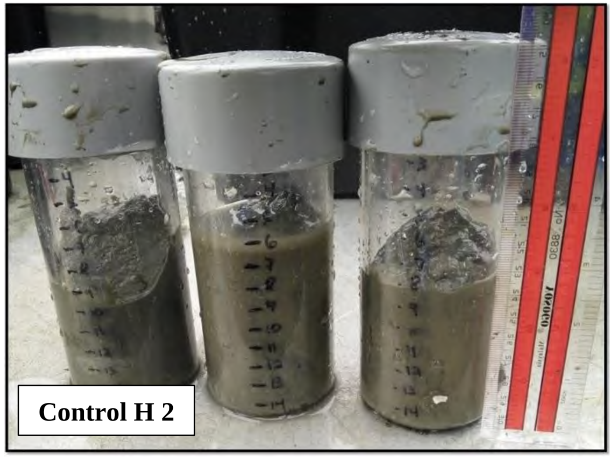
Latitude/Longitude	Station	Grab	Core	Sample	Site Depth (m)	%mud	% sand	% very fine gravel	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (m)	Bacterial mat	Sulphide Odour	Nepheloid layer
46° 59.078603' S 168° 07.576170' E	339_50	1	a	339_50_1a	26.2	35.1	60.9	4				2	9	No	Moderate	No
		1	b	339_50_1b	26.2				0.98			2	9	No	Moderate	No
		1	c	339_50_1c	26.2					9	37	2	9	No	Moderate	No
		2	a	339_50_2a	26.2	39.3	56.7	4				2	10	No	Moderate	No
		2	b	339_50_2b	26.2				1.04			2	12	No	Moderate	No
		2	c	339_50_2c	26.2					8	30	2	10	No	Moderate	No
		3	a	339_50_3a	26.2	42.0	51.7	6.3				2	9	No	Moderate	No
		3	b	339_50_3b	26.2				1.35			2	8	No	Moderate	No
		3	c	339_50_3c	26.2					16	38	2	9	No	Moderate	No
46° 59.058054' S 168° 07.549513' E	339_100	1	a	339_100_1a	26.2	47.0	51.1	1.8				2	7	No	No	No
		1	b	339_100_1b	26.2				1.44			2	10	No	No	No
		1	c	339_100_1c	26.2					13	36	2	10	No	No	No
		2	a	339_100_2a	26.2	41.6	53.8	4.6				2	10	No	No	No
		2	b	339_100_2b	26.2				1.15			2	12	No	No	No
		2	c	339_100_2c	26.2					10	35	2	10	No	No	No
		3	a	339_100_3a	26.2	48.6	47.1	4.4				2	8	No	No	No
		3	b	339_100_3b	26.2				1.44			2	8	No	No	No
		3	c	339_100_3c	26.2					13	41	2	10	No	No	No

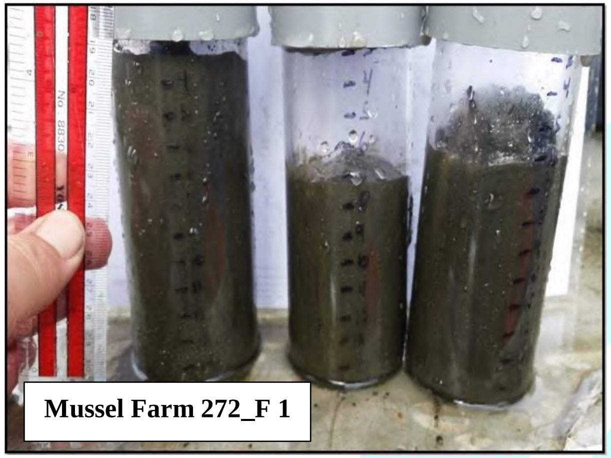
7.4 APPENDIX D SEDIMENTS CORE PROFILES

Sediment core profiles for control (reference) stations in Big Glory Bay, Steward Island. Cores extracted from separated Van Veen grabs (1-3)



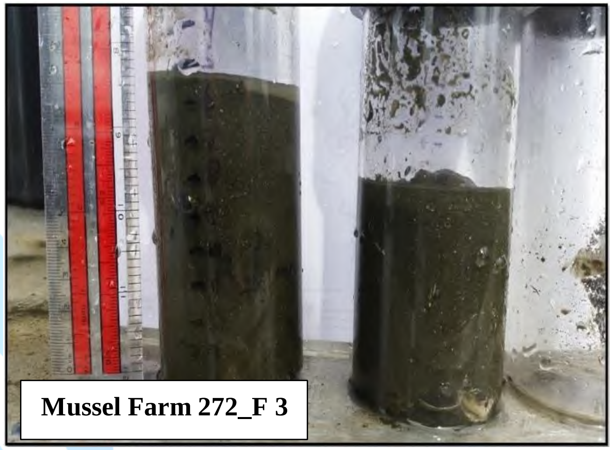






Mussel Farm 272_F 1

Mussel Farm 272_F 2



Mussel Farm 272_F 3

Mussel Farm 319_F 1

Mussel Farm 319_F 2

Mussel Farm 319_F 3

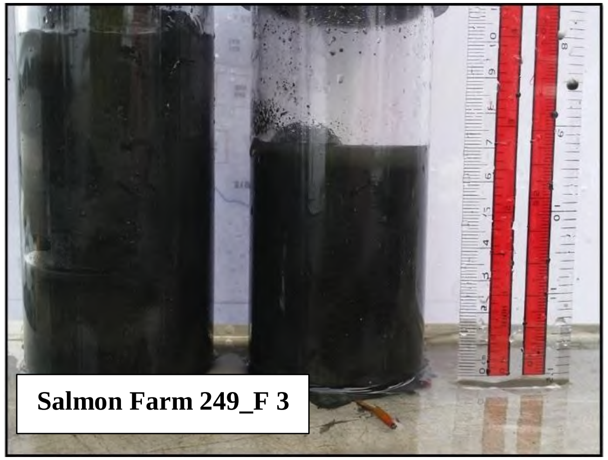

Salmon Farm 246_F 1


Salmon Farm 246_F 2

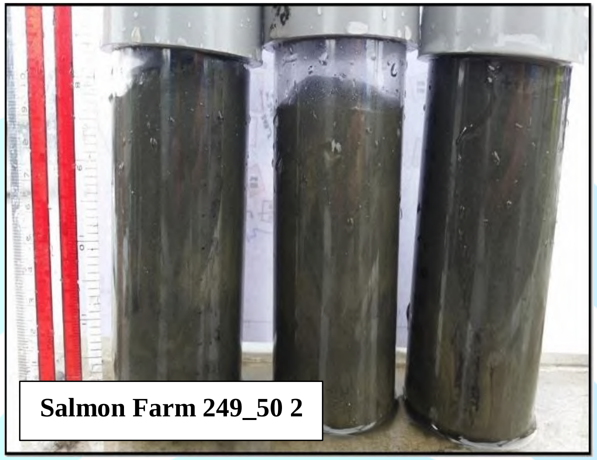

Salmon Farm 246_F 3


Salmon Farm 249_F 1


Salmon Farm 249_F 2


Salmon Farm 249_F 3

Salmon Farm 249_50 1



Salmon Farm 249_50 2

Salmon Farm 249_50 3

Salmon Farm 249_100 1

Salmon Farm 249_100 2

Salmon Farm 249_100 3


Salmon Farm 338_F 1


Salmon Farm 338_F 2


Salmon Farm 338_F 3


Salmon Farm 338_50 1


Salmon Farm 338_50 2


Salmon Farm 338_50 3


Salmon Farm 338_100 1

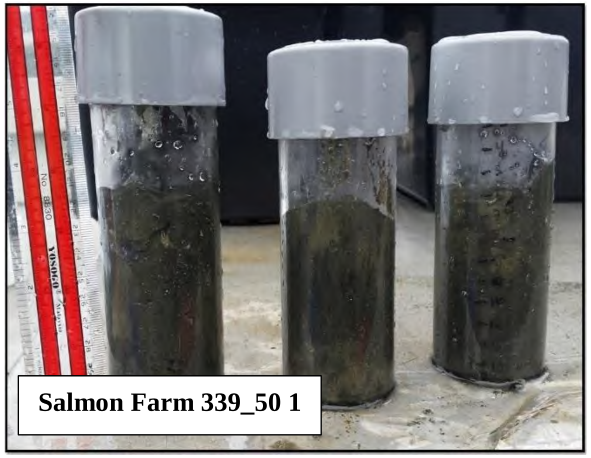

Salmon Farm 338_100 2


Salmon Farm 338_100 3

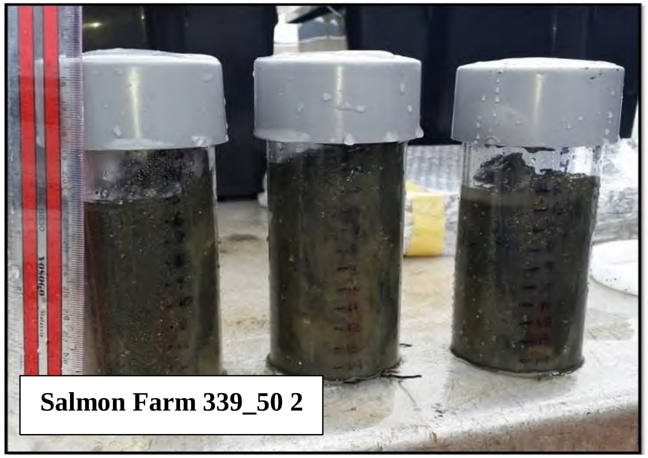
Salmon Farm 339_F 1

Salmon Farm 339_F 2

Salmon Farm 339_F 3

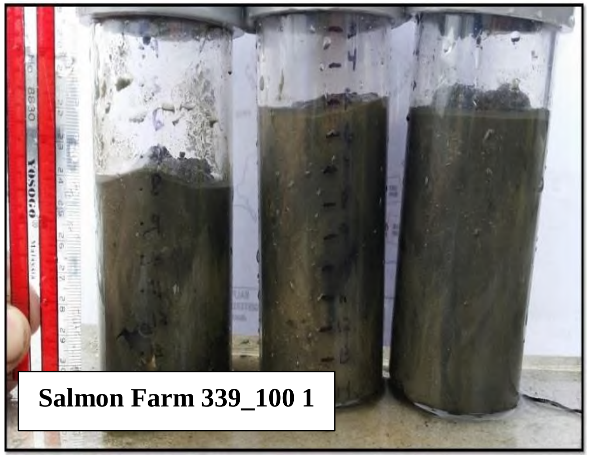


Salmon Farm 339_50 1

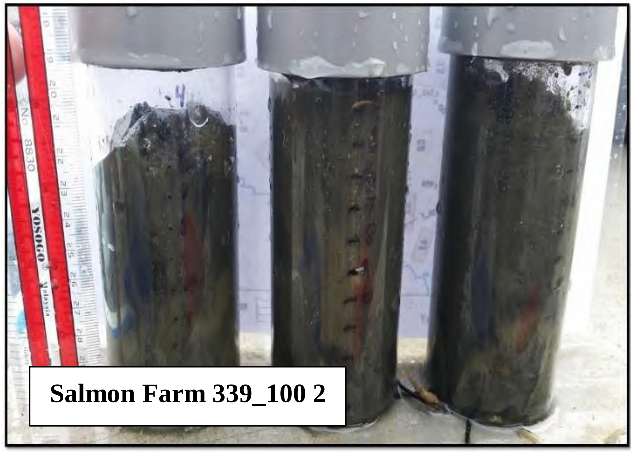


Salmon Farm 339_50 2

Salmon Farm 339_50 3



Salmon Farm 339_100 1



Salmon Farm 339_100 2

Salmon Farm 339_100 3

7.5 APPENDIX E STATISTICAL ANALYSES OF BENTHIC SEDIMENT DATA

Appendix E. 1a. 319_F (mussel farm) Summary statistics: Mean and standard deviation for sediment properties at the mussel station 319_F two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% mud			% sand		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	8.467	0.451	3	52.667	1.528	3	91.333	0.577	3	35.100	2.858	3	57.933	3.272	3
ConH	6.267	0.451	3	58.667	0.577	3	93.667	0.577	3	63.567	1.823	3	34.567	1.266	3
319_F	9.267	1.159	3	47.000	3.606	3	90.667	1.528	3	34.300	2.773	3	58.233	1.069	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	6.933	1.250	3	2.300	0.200	3	7.333	0.577	3	37.000	3.606	3
ConH	1.867	0.737	3	1.200	0.046	3	9.333	0.577	3	35.000	1.000	3
319_F	7.500	1.744	3	2.533	0.208	3	23.000	-	3	58.000	-	3

Appendix E.1b. 319_F: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 2

	SS	MS	F	P-value
Organic Matter	14.480	7.240	12.411	0.007
Dry matter	204.222	102.111	19.553	0.002
Ash	14.889	7.444	7.444	0.024
% silt/mud	1667.529	833.764	130.389	0.000011
% sand	1106.202	553.101	123.368	0.000
% very fine gravel	57.727	28.863	16.824	0.003
% Total organic carbon	3.042	1.521	53.414	0.000
Cu mg/kg dry wt	6.889	3.444	0.058	0.944
Zn mg/kg dry wt	561.556	280.778	0.742	0.515

Appendix E. 1c 319_F ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)			Dry Matter (g/100gd)			Ash (g/100g)			%mud			% sand		
	ConM	*ConH*	*319_F*	*ConM*	*ConH*	*319_F*	*ConM*	*ConH*	*319_F*	*ConM*	*ConH*	*319_F*	*ConM*	*ConH*	*319_F*
ConM		0.028	0.4539		0.041	0.052		0.06	0.70		0.0002	0.9217		0.002	0.98
ConH	4.98		0.007	4.548		0.002	4.041		0.024	19.5		0.0002	19.11		0.0002
319_F	1.814	6.803		4.295	8.843		1.155	5.196		0.548	20.05		0.24	19.36	

	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	ConM	*ConH*	*319_F*	*ConM*	*ConH*	*319_F*	*ConM*	*ConH*	*319_F*	*ConM*	*ConH*	*319_F*
ConM		0.007	0.8601		0.0006	0.28		0.9461	0.9985		0.99	0.54
ConH	6.7		0.0046	11.29		0.0003	0.451		0.9622	0.17		0.61
319_F	0.74	7.449		2.395	13.69		0.075	0.37		1.573	1.395	

Appendix E. 2a. 272_F (mussel farm) Summary statistics: Mean and standard deviation for sediment properties at the mussel station 272_F two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% mud			% sand		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	8.467	0.451	3	52.667	1.528	3	91.333	0.577	3	35.100	2.858	3	57.933	3.272	3
ConH	6.267	0.451	3	58.667	0.577	3	93.667	0.577	3	63.567	1.823	3	34.567	1.266	3
272_F	9.300	1.200	3	49.000	3.606	3	90.667	1.528	3	38.600	0.700	3	56.467	2.421	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	6.933	1.250	3	2.300	0.200	3	7.333	0.577	3	37.000	3.606	3
ConH	1.867	0.737	3	1.200	0.046	3	9.333	0.577	3	35.000	1.000	3
272_F	4.967	1.818	3	2.400	0.173	3	-	-	3	0.000	-	3

Appendix E.2b. 272_F: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 2

	SS	MS	F	P-value
%Organic Matter	14.736	7.368	11.969	0.008
Dry matter	142.889	71.444	13.681	0.006
Ash	14.889	7.444	7.444	0.024
% silt/mud	1445.936	722.968	180.993	0.000004
% sand	1027.762	513.881	84.846	0.000
% very fine gravel	39.149	19.574	10.855	0.010
%Total organic carbon	2.660	1.330	55.340	0.000
Cu mg/kg dry wt	144.889	72.444	326.000	0.000
Zn mg/kg dry wt	2598.000	1299.000	278.357	0.000

Appendix E. 1c 272_F ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)			Dry Matter (g/100gd)			Ash (g/100g)			% mud			% sand		
	ConM	*ConH*	*272_F*	*ConM*	*ConH*	*272_F*	*ConM*	*ConH*	*272_F*	*ConM*	*ConH*	*272_F*	*ConM*	*ConH*	*272_F*
ConM		0.032	0.44		0.041	0.20		0.065	0.7075		0.0002	0.1607		0.0002	0.75
ConH	4.857		0.007	4.548		0.005	4.041		0.024	24.67		0.0002	16.45		0.0002
272_F	1.84	6.696		2.779	7.327		1.155	5.196		3.033	21.64		1.032	15.41	

	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	ConM	*ConH*	*272_F*	*ConM*	*ConH*	*272_F*	*ConM*	*ConH*	*272_F*	*ConM*	*ConH*	*272_F*
ConM		0.008	0.24		0.0005	0.72		0.013	0		0.40	0
ConH	6.535		0.067	12.29		0.0003	6		0	1.309		0
272_F	2.537	3.998		1.117	13.41		0	0		0	0	

Appendix E. 3a. 246_F (salmon farm) Summary statistics: Mean and standard deviation for sediment properties at the salmon site 246_F two control stations (ConM and ConH).

Station	**Organic Matter (%)**			**Dry Matter (g/100g)**			**Ash (g/100g)**			**% mud**			**% sand**		
	Mean	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**
ConM	8.467	0.451	3	52.667	1.528	3	91.333	0.577	3	35.100	2.858	3	57.933	3.272	3
ConH	6.267	0.451	3	58.667	0.577	3	93.667	0.577	3	63.567	1.823	3	34.567	1.266	3
246_F	11.400	0.458	3	48.000	1.732	3	88.333	0.577	3	42.500	2.663	3	50.033	3.993	3

Station	**% very fine gravel**			**Total Organic Carbon (%)**			**Copper (mg/kg)**			**Zinc (mg/kg)**		
	Mean	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**
ConM	6.933	1.250	3	2.300	0.200	3	7.333	0.577	3	37.000	3.606	3
ConH	1.867	0.737	3	1.200	0.046	3	9.333	0.577	3	35.000	1.000	3
246_F	7.500	2.816	3	2.367	0.404	3	11.000	1.000	3	39.000	3.606	3

Appendix E.3b. 246_F: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 2

	SS	**MS**	**F**	**P-value**
% Organic Matter	39.796	19.898	96.800	0.00003
Dry matter	171.556	85.778	45.412	0.00024
Ash	42.889	21.444	64.333	0.00009
% silt/mud	1308.916	654.458	105.652	0.000021
% sand	847.629	423.814	45.007	0.0002
% very fine gravel	57.727	28.863	8.627	0.017
% Total organic carbon	2.576	1.288	18.806	0.003
Cu mg/kg dry wt	20.222	10.111	18.200	0.003
Zn mg/kg dry wt	24.000	12.000	1.333	0.332

Appendix E. 3c 246_F ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)			Dry Matter (g/100gd)			Ash (g/100g)			% mud			% sand		
	ConM	*ConH*	*246_F*	*ConM*	*ConH*	*246_F*	*ConM*	*ConH*	*246_F*	*ConM*	*ConH*	*246_F*	*ConM*	*ConH*	*246_F*
ConM		0.002	0.0007		0.004	0.01		0.006	0.001		0.0002	0.02		0.0004	0.04
ConH	8.405		0.0002	7.562		0.0003	7		0.0002	19.81		0.0003	13.19		0.002
246_F	11.21	19.61		5.881	13.44		9	16		5.15	14.66		4.459	8.73	

	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	ConM	*ConH*	*246_F*	*ConM*	*ConH*	*246_F*	*ConM*	*ConH*	*246_F*	*ConM*	*ConH*	*246_F*
ConM		0.03	0.92		0.005	0.9483		0.03	0.0024		0.70	0.7
ConH	4.798		0.02	7.281		0.003	4.648		0.07	1.155		0.3
246_F	0.5366	5.334		0.4413	7.722		8.521	3.873		1.155	2.309	

Appendix E. 4a. 249_F, 249_50 and 249_100 (salmon farm) Summary statistics: Mean and standard deviation for sediment properties at the salmon station with two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% mud			% sand		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	8.467	0.451	3	52.667	1.528	3	91.333	0.577	3	35.100	2.858	3	57.933	3.272	3
ConH	6.267	0.451	3	58.667	0.577	3	93.667	0.577	3	63.567	1.823	3	34.567	1.266	3
249_F	13.000	7.846	3	55.000	2.646	3	87.000	7.810	3	54.733	2.155	3	42.967	1.877	3
249_50	7.700	0.265	3	55.000	3.606	3	92.333	0.577	3	61.933	1.172	3	34.867	1.626	3
249_100	7.533	0.306	3	55.333	1.155	3	92.333	0.577	3	64.367	0.551	3	33.000	0.200	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	6.933	1.250	3	2.300	0.200	3	7.333	0.577	3	37.000	3.606	3
ConH	1.867	0.737	3	1.200	0.046	3	9.333	0.577	3	35.000	1.000	3
249_F	2.267	1.150	3	2.237	0.300	3	238.667	175.286	3	108.667	41.041	3
249_50	3.167	0.416	3	1.790	0.193	3	16.000	5.292	3	44.000	6.928	3
249_100	2.567	0.666	3	1.557	0.076	3	12.667	0.577	3	37.667	3.512	3

Appendix E.4b. 249_F, 249_50 and 249_100: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 4

	SS	MS	F	P-value
% Organic Matter	80.309	20.077	1.616	0.245
Dry matter	55.333	13.833	2.882	0.080
Ash	78.667	19.667	1.578	0.254
% mud	1802.56933	450.64233	126.4902	0.00000002
% sand	1299.167	324.792	87.718	0.00000010
% very fine gravel	50.583	12.646	15.625	0.00026513
% Total organic carbon	2.576	0.644	18.371	0.00013320
Cu mg/kg dry wt	124163.733	31040.933	5.047	0.017
Zn mg/kg dry wt	11980.400	2995.100	8.515	0.003

Appendix E. 4c 249_F, 249_50 and 249_100 ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)					**Dry Matter (g/100gd)**					**Ash (g/100g)**				
	ConM	***ConH***	***249_F***	***249_50***	***249_100***	***ConM***	***ConH***	***249_F***	***249_50***	***249_100***	***ConM***	***ConH***	***249_F***	***249_50***	***249_100***
ConM		0.9353	0.5427	0.9987	0.9973		0.04544	0.6949	0.6949	0.5899		0.9219	0.5829	0.9964	0.9964
ConH	1.081		0.2097	0.9858	0.991	4.743		0.3111	0.3111	0.3932	1.145		0.2178	0.9892	0.9892
249_F	2.227	3.308		0.4037	0.3763	1.845	2.899		1	0.9997	2.126	3.27		0.3996	0.3996
249_50	0.3767	0.7043	2.604		1	1.845	2.899	0		0.9997	0.4906	0.6541	2.616		1
249_100	0.4586	0.6224	2.686	0.08189		2.108	2.635	0.2635	0.2635		0.4906	0.6541	2.616	0	

	% mud					**% sand**					**% very fine gravel**				
	ConM	***ConH***	***249_F***	***249_50***	***249_100***	***ConM***	***ConH***	***249_F***	***249_50***	***249_100***	***ConM***	***ConH***	***249_F***	***249_50***	***249_100***
ConM		0.0001	0.000176	0.0001	0.0001		0.0001	0.00018	0.00017	0.00017		0.0004	0.00073	0.003	0.001
ConH	26.12		0.001507	0.8224	0.9834	21.03		0.002	0.9997	0.851	9.755		0.9802	0.4391	0.8697
249_F	18.02	8.106		0.0062	0.0008	13.47	7.561		0.003	0.0007	8.985	0.7701		0.7383	0.9933
249_50	24.62	1.499	6.607		0.5406	20.76	0.27	7.291		0.7581	7.252	2.503	1.733		0.9195
249_100	26.86	0.7341	8.84	2.233		22.44	1.41	8.971	1.68		8.407	1.348	0.5776	1.155	

	Total Organic Carbon (%)					**Copper (mg/kg)**					**Zinc (mg/kg)**				
	ConM	***ConH***	***249_F***	***249_50***	***249_100***	***ConM***	***ConH***	***249_F***	***249_50***	***249_100***	***ConM***	***ConH***	***249_F***	***249_50***	***249_100***
ConM		0.0003	0.9929	0.04672	0.004		1	0.03046	0.9999	1		0.9999	0.006144	0.9897	1
ConH	10.18		0.000488	0.02083	0.2116	0.04417		0.03197	1	1	0.1847		0.005087	0.974	0.9998
249_F	0.5859	9.59		0.0885	0.008	5.109	5.065		0.03	0.03	6.619	6.803		0.01	0.006
249_50	4.718	5.458	4.132		0.5699	0.1914	0.1472	4.918		1	0.6465	0.8312	5.972		0.99
249_100	6.877	3.3	6.291	2.159		0.1178	0.07362	4.991	0.07		0.06157	0.2463	6.557	0.5849	

Appendix E. 5a. 338_F, 338_50 and 338_100 (salmon farm) Summary statistics: Mean and standard deviation for sediment properties at the salmon station with two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% mud			% sand		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	8.467	0.451	3	52.667	1.528	3	91.333	0.577	3	35.100	2.858	3	57.933	3.272	3
ConH	6.267	0.451	3	58.667	0.577	3	93.667	0.577	3	63.567	1.823	3	34.567	1.266	3
338_F	19.633	0.208	3	38.000	1.732	3	80.333	0.577	3	25.300	1.014889	3	73.933	1.159	3
338_50	6.467	0.569	3	59.333	1.528	3	93.667	0.577	3	54.000	0.953939	3	42.567	1.361	3
338_100	6.267	0.115	3	56.333	1.528	3	94.000	0.000	3	64.267	0.550757	3	34.167	0.709	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	6.933	1.250	3	2.300	0.200	3	7.333	0.577	3	37.000	3.606	3
ConH	1.867	0.737	3	1.200	0.046	3	9.333	0.577	3	35.000	1.000	3
338_F	0.767	0.058	3	8.533	0.777	3	893.333	35.119	3	946.667	63.509	3
338_50	3.433	0.473	3	1.347	0.160	3	42.000	22.605	3	77.667	27.301	3
338_100	1.600	0.265	3	1.400	0.225	3	15.000	2.646	3	46.000	7.000	3

Appendix E.5b. 338_F, 338_50 and 338_100: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 4

	SS	MS	F	P-value
% Organic Matter	401.491	100.373	637.962	0.00
Dry matter	925.333	231.333	111.935	0.0000000293
Ash	408.933	102.233	383.375	0.0000000001
% silt/mud	3670.884	917.721	334.0406455	0.0000000001
% sand	3511.620	877.905	274.231	0.0000000004
% very fine gravel	71.577	17.894	37.228	0.00000561
% Total organic carbon	118.895	29.724	205.909	0.0000000015
Cu mg/kg dry wt	1839469.600	459867.400	1312.407	0.00
Zn mg/kg dry wt	1937804.400	484451.100	500.294	0.00

Appendix E. 5c 338_F, 338_50 and 338_100 ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)					**Dry Matter (g/100gd)**					**Ash (g/100g)**				
	ConM	***ConH***	***338_F***	***338_50***	***338_100***	***ConM***	***ConH***	***338_F***	***338_50***	***338_100***	***ConM***	***ConH***	***338_F***	***338_50***	***338_100***
ConM		0.0004	0.0001	0.0008	0.0004		0.003	0.0001	0.001	0.06489		0.005	0.0002	0.005	0
ConH	9.607		0.0001	0.9689	1	7.229		0.0001	0.977	0.3369	7		0.0002	1	0
338_F	48.76	58.37		0.0001	0.0001	17.67	24.9		0.0001	0.0001	33	40		0.0002	0
338_50	8.733	0.8733	57.49		0.9689	8.032	0.8032	25.7		0.1535	7	0	40		0
338_100	9.607	0	58.37	0.8733		4.418	2.811	22.09	3.614		0	0	0	0	

	% mud					**% sand**					**% very fine gravel**				
	ConM	***ConH***	***338_F***	***338_50***	***338_100***	***ConM***	***ConH***	***338_F***	***338_50***	***338_100***	***ConM***	***ConH***	***338_F***	***338_50***	***338_100***
ConM		0.0001	0.0003	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0008	0.0001
ConH	29.75		0.0001	0.0003	0.9836	22.62		0.0001	0.002	0.9986	12.66		0.3564	0.1119	0.9884
338_F	10.24	39.99		0.0001	0.0001	15.49	38.11		0.0001	0.0001	15.41	2.748		0.005	0.6004
338_50	19.75	9.997	29.99		0.0002	14.88	7.744	30.36		0.001	8.744	3.914	6.662		0.05433
338_100	30.48	0.7315	40.72	10.73		23.01	0.3872	38.5	8.132		13.32	0.6662	2.082	4.58	

	Total Organic Carbon (%)					**Copper (mg/kg)**					**Zinc (mg/kg)**				
	ConM	***ConH***	***338_F***	***338_50***	***338_100***	***ConM***	***ConH***	***338_F***	***338_50***	***338_100***	***ConM***	***ConH***	***338_F***	***338_50***	***338_100***
ConM		0.03	0.0001	0.070	0.09134		0.9999	0.0001	0.2317	0.9854		1	0.0001	0.5287	0.9961
ConH	5.015		0.0001	0.98	0.9638	0.1851		0.0001	0.2772	0.9953	0.1113		0.0001	0.4862	0.9916
338_F	28.42	33.43		0.0001	0.0001	81.98	81.8		0.0001	0.0001	50.63	50.74		0.0001	0.0001
338_50	4.346	0.6686	32.76		0.9998	3.208	3.023	78.77		0.4407	2.264	2.375	48.37		0.7269
338_100	4.103	0.9118	32.52	0.2431		0.7094	0.5243	81.27	2.498		0.5009	0.6123	50.13	1.763	

Appendix E. 6a. 339_F, 339_50 and 339_100 (salmon farm) Summary statistics: Mean and standard deviation for sediment properties at the salmon station with two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% silt/mud			% sand		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	8.467	0.451	3	52.667	1.528	3	91.333	0.577	3	35.100	2.858	3	57.933	3.272	3
ConH	6.267	0.451	3	58.667	0.577	3	93.667	0.577	3	63.567	1.823	3	34.567	1.266	3
339_F	11.600	2.685	3	-	-	3	88.333	2.887	3	-	-	3	-	-	3
339_50	5.333	0.153	3	64.000	2.646	3	95.000	0.000	3	38.800	3.477	3	56.433	4.606	3
339_100	6.267	0.379	3	59.333	2.082	3	93.667	0.577	3	45.733	3.668	3	50.667	3.371	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	6.933	1.250	3	2.300	0.200	3	7.333	0.577	3	37.000	3.606	3
ConH	1.867	0.737	3	1.200	0.046	3	9.333	0.577	3	35.000	1.000	3
339_F	-	-	3	4.100	1.277	3	1040.000	910.000	3	290.667	219.730	3
339_50	4.767	1.328	3	1.123	0.199	3	11.000	4.359	3	35.000	4.359	3
339_100	3.600	1.562	3	1.343	0.167	3	12.000	1.732	3	37.333	3.215	3

Appendix E.6b. 339_F, 339_50 and 339_100: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 4

	SS	MS	F	P-value
% Organic Matter	76.33067	19.08267	12.25867	0.000719
Dry matter	8454.933	2113.733	754.9048	0.0000000000023
Ash	82.93333	20.73333	11.10714	0.001064
% silt/mud	6471.783	1617.946	218.4248	0.001
% sand	7004.777	1751.194	195.0829	0.0000000019
% very fine gravel	84.89333	21.22333	16.81722	0.000194
% Total organic carbon	19.0166	4.75415	13.66475	0.000462
Cu mg/kg dry wt	2546610	636652.4	3.84395	0.038297
Zn mg/kg dry wt	155564.7	38891.17	4.023946	0.033747

Appendix E. 6c 339_F, 339_50 and 339_100 ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)					**Dry Matter (g/100gd)**					**Ash (g/100g)**				
	ConM	***ConH***	***339_F***	***339_50***	***339_100***	***ConM***	***ConH***	***339_F***	***339_50***	***339_100***	***ConM***	***ConH***	***339_F***	***339_50***	***339_100***
ConM		0.2689	0.06988	0.06988	0.2689		0.01	0	0.0005	0.01		0.3113	0.1534	0	0.311
ConH	3.054		0.0028	0.8844	1	5.555		0	0.03	0.9705	2.646		0.011	0	1
339_F	4.35	7.404		0.0009	0.002	0	0		0	0	3.402	6.047		0	0.01
339_50	4.35	1.296	8.7		0.8844	10.49	4.938	0		0.06163	0	0	0		0
339_100	3.054	0	7.404	1.296		6.172	0.6172	0	4.32		2.646	0	6.047	0	

	% mud					**% sand**					**% very fine gravel**				
	ConM	***ConH***	***339_F***	***339_50***	***339_100***	***ConM***	***ConH***	***339_F***	***339_50***	***339_100***	***ConM***	***ConH***	***339_F***	***339_50***	***339_100***
ConM		0.000234	0	0.4858	0.01162		0.000324	0	0.9445	0.108		0.005099	0	0.2279	0.04684
ConH	16.2		0	0.00025	0.000609	12.08		0	0.000391	0.001801	6.987		0	0.08491	0.3876
339_F	0	0		0	0	0	0		0	0	0	0		0	0
339_50	2.106	14.1	0		0.08948	0.7756	11.31	0		0.2292	2.988	3.999	0		0.6786
339_100	6.053	10.15	0	3.947		3.757	8.325	0	2.982		4.597	2.39	0	1.609	

	Total Organic Carbon (%)					**Copper (mg/kg)**					**Zinc (mg/kg)**				
	ConM	***ConH***	***339_F***	***339_50***	***339_100***	***ConM***	***ConH***	***339_F***	***339_50***	***339_100***	***ConM***	***ConH***	***339_F***	***339_50***	***339_100***
ConM		0.2267	0.02512	0.1808	0.3375		1	0.06652	1	1		1	0.06134	1	1
ConH	3.23		0.001068	0.9998	0.998	0.008512		0.06714	1	1	0.03524		0.05903	1	1
339_F	5.286	8.516		0.000882	0.001521	4.395	4.386		0.06766	0.06797	4.469	4.504		0.05903	0.06174
339_50	3.455	0.2251	8.741		0.9897	0.01561	0.007093	4.379		1	0.03524	0	4.504		1
339_100	2.809	0.4209	8.095	0.646		0.01986	0.01135	4.375	0.004256		0.005873	0.04111	4.463	0.04111	

7.6 Appendix F Drop-camera photos of sediment surface

Drop-camera photos in triplicate (1-3) of sediment surface at control (reference), mussel and salmon stations.

Control M (1)

Control M (2)

Control M (3)

Control H (1)

Control H (2)

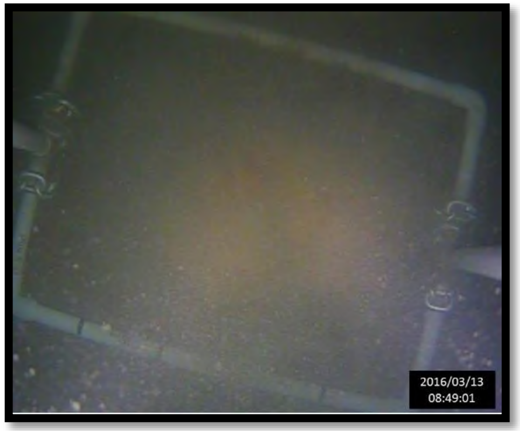
Control H (3)

Mussel 272_F (1)

Mussel 272_F (2)

Mussel 272_F (3)

Mussel 319_F (1)



Mussel 319_F (2)

Mussel 319_F (3)

Salmon 246_F (1)

Salmon 246_F (2)

Salmon 246_F (3)

Salmon 249_F (1)

Salmon 249_F (2)

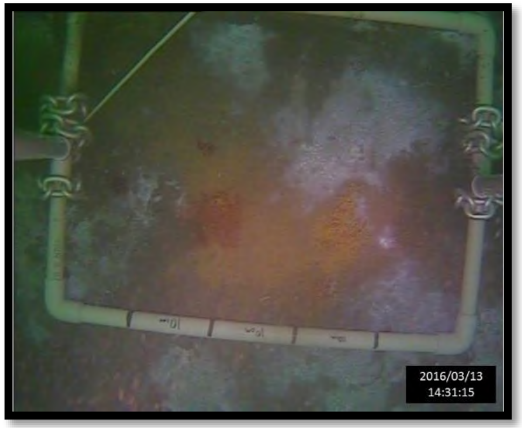
Salmon 249_F (3)

Salmon 249_50 (1)

Salmon 249_50 (2)

Salmon 249_50 (3)

Salmon 249_100 (1)



Salmon 249_100 (2)

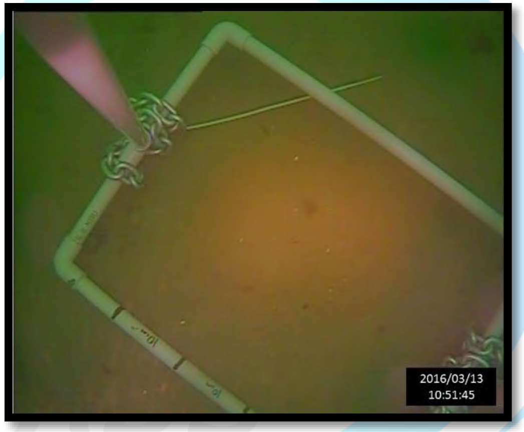
Salmon 249_100 (3)

Salmon 338_F (1)

Salmon 338_F (2)

Salmon 338_F (3)

Salmon 338_50 (1)

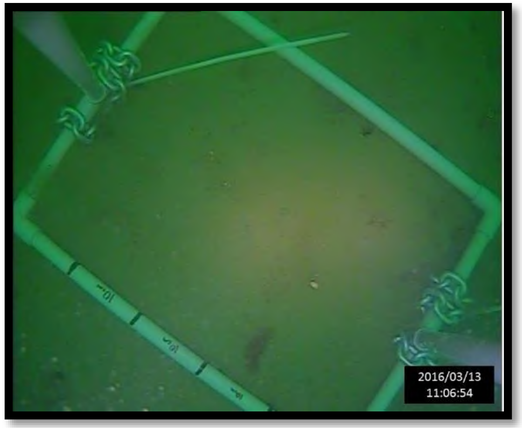


Salmon 338_50 (2)

Salmon 338_50 (3)

Salmon 338_100 (1)

Salmon 338_100 (2)



Salmon 338_100 (3)

Salmon 339_F (1)

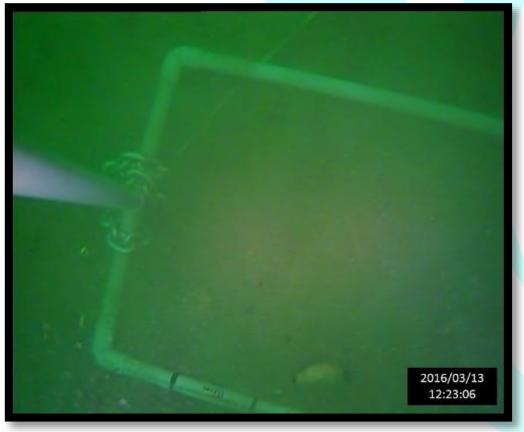
Salmon 339_F (2)

Salmon 339_F (3)

Salmon 339_50 (1)

Salmon 339_50 (2)

Salmon 339_50 (3)



Salmon 339_100 (1)

Salmon 339_100 (2)

Salmon 339_100 (3)

7.7 Appendix G Benthic Infauna Taxa and Abundance

Appendix Ga: Benthic infauna taxa and abundance at control and mussel stations. Triplicate grab samples R1-R3 were collected at each station. ConH = Control H, ConM = Control M

TAXA					Mussel Station						Control Station					
					272_F			319_F			Con M			Con H		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Annelida	Polychaeta	Capitellida	Capitellidae	*Capitellid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Capitellida	Maldanidae	*Maldanid sp.*	3	0	0	0	0	0	0	5	0	0	0	4
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.*	4	3	0	4	0	4	0	0	0	0	0	0
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.2*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Eunicida	Eunicidae	*Eunicid sp.*	4	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Eunicida	Lumbrineridae	*Lumbrinerid sp.*	5	3	0	0	0	3	0	0	0	0	0	0
Annelida	Polychaeta	Flabelligerida	Flabelligeridae	*Flabelligerid sp.*	0	0	0	0	0	0	0	0	0	0	0	4
Annelida	Polychaeta	Opheliida	Opheliidae	*Opheliid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Orbiniida	Orbiniidae	*Orbiniid sp.*	0	0	0	0	1	0	0	0	0	0	0	0
Annelida	Polychaeta	Oweniida	Oweniidae	*Oweniid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycerid sp.*	0	0	1	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Phyllodocida	Goniadidae	*Goniadid sp.*	0	0	1	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Nephtyid sp.*	0	0	2	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Phyllodocida	Nereidae	*Nereid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Spionida	Cirratulidae	*Cirratulid sp.*	3	2	0	0	0	0	0	0	0	3	0	3
Annelida	Polychaeta	Terebellida	Pectinaridae	*Pectinarid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Terebellida	Ampharetidae	*Ampharetid sp.*	2	0	0	0	0	0	0	0	0	0	0	2
Brachiopoda	Rhynchonellata	Terrebratulida	Terebratellidae	*Terebratella sanguinea*	0	0	0	0	0	0	2	0	0	0	0	0
Crustacea	Malacostraca	Amphipoda		Amphipod	0	2	0	0	0	0	0	3	2	0	0	2
Crustacea	Malacostraca	Tanaidacea		Tanaid	0	0	0	0	0	0	0	0	0	0	0	0
Crustacea	Ostracoda			Ostracod	0	0	0	2	0	0	0	0	0	2	0	3

TAXA					Mussel Station						Control Station					
					272_F			319_F			Con M			Con H		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Echinodermata	Holothuroidea	Dendronchirotida	Phyllophoridae	Phyllophoridae sp.	0	0	0	0	0	0	0	1	0	1	0	0
Mollusca	Bivalvia	Mytiloida	Mytilidae	Mytilidae sp.	0	0	0	0	0	0	0	2	0	0	0	0
Mollusca	Bivalvia	Mytiloida	Nuculidae	*Nucula nitidula*	5	6	6	0	0	0	7	11	2	2	0	2
Mollusca	Bivalvia	Nuculoida	Malletiidae	*Neilo austalis*	0	0	0	0	0	0	2	0	0	0	0	0
Mollusca	Bivalvia	Pholadomyoida	Thraciidae	*Thracia vegrandis*	2	4	1	0	2	0	3	4	4	3		3
Mollusca	Bivalvia	Solemyoidae	Solemyidae	*Solemya parkinsonii*	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Veneroida	Ungulinidae	Ungulinidae sp.	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Veneroida	Thyasiridae	Thyasiridae sp.	0	0	0	0	0	0	4	3	0	0	0	0
Mollusca	Bivalvia	Veneroida	Veneridae	*Venericardia purpurata*	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Veneroida	Veneridae	Veneridae sp.	1	0	0	2	0	2	4	0	3	0	0	0
Mollusca	Gastropoda	Stromboidea	Struthiolariidae	*Struthiolaria papulosa*	0	0	0	0	0	0	0	1	0	1	0	0

Appendix Gb: Benthic infauna taxa and abundance at salmon sites. Triplicate grab samples R1-R3 were collected at each station. 50 and 100 refer to sample stations 50 and 100 m from the salmon pens.

TAXA					Salmon Station											
					246_F			249_F			249_50			249_100		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Annelida	Polychaeta	Capitellida	Capitellidae	*Capitellid sp.*	0	0	0	0	8	21	0	0	0	0	0	0
Annelida	Polychaeta	Capitellida	Maldanidae	*Maldanid sp.*	0	3	0	0	0	0	0	1	0	1	0	1
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.*	3	3	4	3	2	7	0	2	0	0	0	0
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.2*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Eunicida	Eunicidae	*Eunicid sp.*	0	1	3	0	0	0	0	0	0	1	2	0
Annelida	Polychaeta	Eunicida	Lumbrineridae	*Lumbrinerid sp.*	3	2	3	0	0	1	0	0	0	0	0	0
Annelida	Polychaeta	Flabelligerida	Flabelligeridae	*Flabelligerid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Opheliida	Opheliidae	*Opheliid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Orbiniida	Orbiniidae	*Orbiniid sp.*	0	2	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Oweniida	Oweniidae	*Oweniid sp.*	0	0	0	3	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycerid sp.*	0	0	4	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Phyllodocida	Goniadidae	*Goniadid sp.*	1	0	3	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Nephtyid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Phyllodocida	Nereidae	*Nereid sp.*	0	0	0	1	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Spionida	Cirratulidae	*Cirratulid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Terebellida	Pectinaridae	*Pectinarid sp.*	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Terebellida	Ampharetidae	*Ampharetid sp.*	2	0	4	0	0	0	0	0	0	0	0	0
Brachiopoda	Rhynchonellata	Terrebratulida	Terebratellidae	*Terebratella sanguinea*	0	0	0	0	0	1	0	1	2	2	1	0
Crustacea	Malacostraca	Amphipoda		Amphipod	0	0	0	0	0	0	0	0	0	0	0	0
Crustacea	Malacostraca	Tanaidacea		Tanaid	0	0	0	0	0	0	0	0	0	0	0	0
Crustacea	Ostracoda			Ostracod	0	0	0	0	0	0	0	0	0	0	0	0
Echinodermata	Holothuroidea	Dendronchirotida	Phyllophoridae	Phyllophoridae sp.	0	0	0	0	0	0	0	0	0	0	0	0

TAXA					Salmon Station											
					246_F			249_F			249_50			249_100		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Mollusca	Bivalvia	Mytiloida	Mytilidae	Mytilidae sp.	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Mytiloida	Nuculidae	*Nucula nitidula*	2	3	5	0	0	0	3	0	0	0	0	0
Mollusca	Bivalvia	Nuculoida	Malletiidae	*Neilo austalis*	0	0	0	0	0	0	0	0	0	0	0	2
Mollusca	Bivalvia	Pholadomyoida	Thraciidae	*Thracia vegrandis*	6	9	7	1	0	0	0	0	3	0	0	0
Mollusca	Bivalvia	Solemyoidae	Solemyidae	*Solemya parkinsonii*	1	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Veneroida	Ungulinidae	Ungulinidae sp.	0	0	0	0	0	0	0	2	0	0	0	0
Mollusca	Bivalvia	Veneroida	Thyasiridae	Thyasiridae sp.	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Veneroida	Veneridae	*Venericardia purpurata*	0	1	0	0	0	0	2	0	0	0	0	0
Mollusca	Bivalvia	Veneroida	Veneridae	Veneridae sp.	1	0	0	0	0	0	0	0	2	3	4	0
Mollusca	Gastropoda	Stromboidea	Struthiolariidae	*Struthiolaria papulosa*	0	0	0	0	0	0	0	0	0	0	0	0

TAXA					Salmon Station																	
					338_F			338_50			338_100			339_F			339_50			339_100		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Annelida	Polychaeta	Capitellida	Capitellidae	*Capitellid sp.*	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	5	3	4
Annelida	Polychaeta	Capitellida	Maldanidae	*Maldanid sp.*	0	0	3	2	3	7	0	2	4	0	0	0	0	0	3	3	3	9
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.*	27	3	20	0	3	0	1	0	0	14	17	6	50	0	3	3	0	0
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Annelida	Polychaeta	Eunicida	Eunicidae	*Eunicid sp.*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Eunicida	Lumbrineridae	*Lumbrinerid sp.*	0	1	4	1	0	3	3	2	3	1	0	0	0	2	0	0	0	0
Annelida	Polychaeta	Flabelligerida	Flabelligeridae	*Flabelligerid sp.*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Opheliida	Opheliidae	*Opheliid sp.*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Orbiniida	Orbiniidae	*Orbiniid sp.*	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Annelida	Polychaeta	Oweniida	Oweniidae	*Oweniid sp.*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycerid sp.*	0	0	0	0	0	3	3	0	3	0	0	0	0	0	0	3	3	7
Annelida	Polychaeta	Phyllodocida	Goniadidae	*Goniadid sp.*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Nephtyid sp.*	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Phyllodocida	Nereidae	*Nereid sp.*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Spionida	Cirratulidae	*Cirratulid sp.*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0
Annelida	Polychaeta	Terebellida	Pectinaridae	*Pectinarid sp.*	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0
Annelida	Polychaeta	Terebellida	Ampharetidae	*Ampharetid sp.*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	4	0	0
Brachiopoda	Rhynchonellata	Terrebratulida	Terebratellidae	*Terebratella sanguinea*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Crustacea	Malacostraca	Amphipoda		Amphipod	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1
Crustacea	Malacostraca	Tanaidacea		Tanaid	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0
Crustacea	Ostracoda			Ostracod	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Echinodermata	Holothuroidea	Dendronchirotida	Phyllophoridae	Phyllophoridae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Mytiloida	Mytilidae	Mytilidae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Mytiloida	Nuculidae	*Nucula nitidula*	0	0	2	3	0	3	3	0	0	0	0	0	0	6	3	0	0	3
Mollusca	Bivalvia	Nuculoida	Malletiidae	*Neilo austalis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TAXA					Salmon Station																	
					338_F			338_50			338_100			339_F			339_50			339_100		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Mollusca	Bivalvia	Pholadomyoida	Thraciidae	*Thracia vegrandis*	0	0	0	3	2	0	2	1	4	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Solemyoidae	Solemyidae	*Solemya parkinsonii*	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0
Mollusca	Bivalvia	Veneroida	Ungulinidae	Ungulinidae sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Veneroida	Thyasiridae	Thyasiridae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Veneroida	Veneridae	*Venericardia purpurata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Bivalvia	Veneroida	Veneridae	Veneridae sp.	0	0	0	1	0	2	0	0	2	0	0	0	0	4	0	0	0	2
Mollusca	Gastropoda	Stromboidea	Struthiolariidae	*Struthiolaria papulosa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

F

Big Glory Bay Benthic and Water Quality Sampling 2016/2017, Aquadynamic Solutions Sdn Bhd, May 2017.

CONFIDENTIAL FINAL REPORT

Aquadynamic Solutions Sdn Bhd

FINAL – Big Glory Bay Benthic and Water Quality Sampling 2016/2017

May 2017

Report prepared for Sanford Limited by Aquadynamic Solutions Sdn Bhd.

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1 SUMMARY

The 2017 Big Glory Bay (BGB) seabed benthic monitoring survey was conducted on the 18th and 19th of February 2017 on a Sanford crewed vessel. This monitoring program focussed on three salmon farm sites, two mussel farm sites and two control stations. Sediment samples were taken from stations at each site and analysed for sediment grain size, percentage total organic matter (TOM), particulate organic carbon (POC), zinc (Zn) and copper (Cu) concentrations. Seabed samples were also collected and analysed for microbenthic invertebrate assemblages and epifauna (using a splash camera). Additional samples were also collected 50 and 100m away from each of the three fish farm sites.

Organic enrichment was observed at several of the mussel farm and fin fish sites. Mussel shells were also observed at both mussel farms and one of the salmon farms (which was once a mussel farm). Opportunist polychaetes (*i.e. Dorvilleid*) were also observed beneath most farming stations (other than the new salmon farm at lease 246) and similar species have been observed in and around many farms in the Marlborough Sounds. Seabed Visibility was poor at several of the farming sites (and 50 & 100m from the edge of the lease). This poor visibility is attributed to a storm that passed through just before the survey period.

A wide range of polychaetes were observed at most sites including, grazer's, detritus feeders, opportunists and predators. Several stations had many amphipods (more than 40 per sample), which were not observed during the previous (2016) sampling period. Unlike the previous 2016 survey, *no Beggiatoa* matting was observed at any station during the 2017 survey period. In general, seabed conditions look to have improved across the bay compared to 2016.

In addition to the benthic survey, water sampling has been conducted monthly, from April 2016 to April 2017, by Sanford personal at six sampling stations within Big Glory Bay.

In-situ oxygen, salinity, water visibility and temperature profiles were collected with a multi parameter sonde. Results indicate that the oxygen levels within the bay were above 6mg/l during all sampling periods and at all depths. There is no indication that the fish farming activities are having any adverse impacts on oxygen levels within the bay. Temperature data indicate slight thermal stratification of the water column during summer periods (of approximately 1 degree). Such heating is purely related to natural variation and isn't related to farming activities. Similar observations were made during the 2015/2016 sampling period.

In addition to the *in-situ* sonde profiles, water samples were collected every month and sent to the laboratory for analysis. Samples were analysed for nutrients including phosphorus, ammoniacal nitrogen, nitrate nitrogen, suspended solids, volatile suspended solids, particulate carbon, particulate nitrogen, and chlorophyll-*a*.

The chlorophyll-*a* and nutrient data that were collected do indicate that there is variability between nutrient uptake and phytoplankton abundance. Higher chlorophyll-*a* levels were observed in spring (spring bloom) and late summer and corresponded to lower levels of soluble and particulate nutrients. In Autumn, chlorophyll-*a* levels were lower while both soluble and particulate nutrient concentrations increased (perhaps as a result of die off and cooler temperatures). Other seasonal patterns are impossible to assess due to the lack of data.

As per the 2016 survey the 2017 water quality survey indicates there are no detectable adverse water quality issues within Big Glory Bay.

2 INTRODUCTION

Big Glory Bay (BGB) has been used for the sea cage rearing of King Salmon (*Oncorhynchus tshawytscha*) since the early 1980’s (and was one of the pioneer fin-fish aquaculture production areas within New Zealand), while Green Shell Mussel culture (*Perna canaliculus*) has been farmed in the bay since 1987 (Environmental Southland 2011).

In 2011, Environment Southland reviewed the existing monitoring conditions outlined in Hopkins (2008) and developed a new bay-wide monitoring programme that would encompass all farming activities in the bay, looking at both the ***seabed*** and the ***water column***. This new monitoring programme would be conducted once per year. A slight amendment to this review was conducted in January 2016 and these amendments have been undertaken in this year’s (2016) monitoring. The new monitoring program specifics can be found in Appendix 7.1.

The seabed monitoring program is designed to assess all marine farms within BGB for a period of 13 years. All fish farms within the bay are monitored yearly along-side two mussel farms. The mussel farms monitored at any given year are chosen on a rotational 13 year cycle (*i.e*. two different mussel farms are sampled each year. Two control stations at fixed locations in the middle of the bay and at the mouth of the bay are also monitored each sampling period (see Section 3.3 below).

Several farm sites within BGB have had varying uses, alternating from salmon culture to mussel culture and *vice versa*. Historically site 339 was a salmon farm that was converted into a mussel farm, and now recently has been converted back into a salmon farm. Site 246 was a mussel farm that has been converted into a salmon farm site. Site 338 has been a salmon farm for much of its history, but was a mussel farm for a brief period. Previous farming on these sites can result in changes to seabed sediment composition beneath the farms (*e.g.* mussel shells were observed in sediment grab samples collected under the 246 fin-fish farm site in 2016).

The 2017 benthic survey reported here was conducted on the 18th and 19th of February 2017 on a Sanford Ltd, crewed vessel. Weather was clear with a light breeze and a similar weather pattern were observed on the day before the sampling campaign. During the week leading up to the sampling there was an unseasonal summer storm.

In addition to the seabed sampling, water quality samples are collected each month by Sanford Ltd staff along with *in-situ* measurements collected by a hand held YSI Sonde. ADS have presented the water quality data collected over the last year in Section 4 below.

3 METHODS

3.1 COMPLIANCE REQUIREMENTS

Consent compliance requirements for marine farming in BGB involve assessment of the water column and the seabed benthic environment (Environment Southland (ES) 2016, Appendix 7.1).

Monthly water column monitoring was initially required for a period of two years starting in July 2011. Although this two-year period has expired, Sanford Ltd and other resource users within the Bay have decided to continue the monthly water quality monitoring as part of their sustainability program.

As stated in Section 2, benthic monitoring occurs at every salmon farm site every year along with two mussel farm sites. The two mussel farm sites sampled each year are different and chosen on a rotational basis. This report includes benthic assessments for three salmon and two mussel farm sites and presents water column data collected over the last 12 months (April 2016 to April 2017). Several additional water column water quality parameters are also reported and listed below (beyond those required for compliance requirements). Statistical analyses were also undertaken looking at the variability of seabed community composition between fish farm stations, controls and mussel farm stations (see Appendix 7.5).

3.2 MONITORING INDICATORS

Several environmental indicators were used in BGB to assess the potential impacts on water quality. These indicators are temperature, chlorophyll-*a* (chl-*a*) as a proxy to phytoplankton, water transparency and dissolved oxygen (DO) (see Sections 4.1, 4.2, and 4.3). Sanford Ltd also collects and analyses additional samples for the following water quality parameters: dissolved reactive phosphorus, ammoniacal nitrogen, nitrate nitrogen, suspended solids (HFR/TSS), volatile suspended solids, particulate carbon and particulate nitrogen which are also presented in section 4.4 of this report.

The status of the physical and biogeochemical quality of the sediments within BGB is determined by examining the sediment grain size, % total organic matter (TOM), particulate organic carbon (POC), zinc (Zn) and copper (Cu) concentrations, presence of sulphide, depth of the oxygenated layer and presence or absence of bacterial mats on the surface of BGB sediments. An increase in the proportion of the sediments comprising mud sized particles, % organic matter, sulphide odour, and/or presence of bacterial matting are indicators that the sediments are experiencing increased organic matter loading and may be harmful to benthic fauna. A change in grain size may also indicate a shift in the physical forcings of the system such as a flood or storm events or seasonal changes in sediment depositional patterns.

The ecological quality of seabed sediments is also assessed by examining the invertebrate taxa present, their abundance, and diversity (and sometimes flora, though camera footage during the presented survey suffered from poor visibility due to a high volume of suspended sediments in the lower few meters of the water column) on the seabed surface and within seabed sediments.

A summary of these indicators is provided in Table 1 and has been modified from the descriptions provided in (NIWA, 2016).

Figure 1 presents a schematic of the enrichment gradient extending from an aquaculture production site (Modified after Pearson and Rosenberg 1976, Hartstein 2003, Black 2008). As discussed in previous BGB reports, the concept of an allowable zone of effect can be utilized in BGB. This concept represents an area around a farm where some deterioration is acceptable by the managing authority. This concept has been adapted by the World Wildlife Foundation (WWF) and is used by aquaculture consenting authorities in Australia and Canada. In New Zealand, these zones have been customized to suit site specific criteria (*i.e*. Hopkins *et al.* 2008) or are based on model results using such tools as DEPOMOD, MIKE or Delft (Cromey *et al.* 2002, Hartstein and Stevens 2005, DHI, 2012).

Table 1 Water and benthic quality indicators for the environment monitoring of marine farms in Big Glory Bay as stipulated by the Southland Regional Council (Modified from NIWA 2016).

WATER QUALITY	INDICATOR RATIONALE
Temperature	Indicates physical process affecting the system (*e.g.* oceanic intrusions/upwelling, river flow, thermal stratification). General following a seasonal pattern
Transparency	Water clarity
Phytoplankton (Chl-*a*)	Used for obtaining an indication of phytoplankton abundance
Dissolved oxygen (DO)	Dissolved oxygen (DO) levels can be impacted by temperature and the addition of organic material from the farms (increases biological oxygen demand). Additional oxygen can be consumed by biological oxygen demand in the seabed and through the conversion of ammonium released by the fish to nitrate. Low levels of oxygen can cause stress to fish and benthic faunal communities. Oxygen is also consumed directly by the fish themselves with higher consumption usually occurring during and directly after feeding
BENTHIC QUALITY	**INDICTOR RATIONALE**
Sediment grain size	Percentage of silt/clay (also known as mud) to sand and gravels in sediments beneath marine farms. Can provide some indication of organic enrichment if the mud content increases, or other changes due to physical forcings *i.e.* floods or seasonal forcings
Total Organic Matter content (TOM)	All organic matter including the organic carbon fraction. Buildup of total organic matter can lead to losses in biodiversity and abundance due to the depletion of oxygen and release of toxic metabolic waste products associated with the breakdown of this organic matter.
Particulate Organic Carbon content (POC)	A good indicator of the presence of organic-rich material originating from marine farming. It reflects the accumulated and more stable fraction of total organic matter buried in marine sediments.
Copper and zinc	Copper from anti-fouling paints and zinc from fish products can be a major environmentally significant metal contaminants within New Zealand finfish stations.
Appearance of sulphide depth and general colour of sediment	Depth of RPD (Redox Potential Discontinuity) layer: usually represents where sediments are no longer oxygenated. As the level of organic enrichment increases, the biological oxygen demand in the

	sediments increases, and they become increasingly anoxic, the RPD moves closer towards the sediment surface.
Sulphide odour	Presence indicates predominance of sulphate reduction (oxygen has already been consumed in the sediments and organic matter is processed using sulphate instead).
Depth of oxygenated layer below the sediment surface	ADS proposes to use the depth of the redox layer to determine how deep sediments are oxygenated. Normally this is only a few mm in nearshore environments, where there is an abundance of organic material.
Mat-forming. Filamentous bacteria	Their presence provides an indication that the sediments are highly anaerobic and sulphide-rich at the sediment surface, but that the overlying water column still contains some oxygen (Pearson and Rosenberg 1976, Sayama 2001).
Epifauna	These are organisms that live on the surface of the sediment. Their presence/absence, species diversity and abundance collectively provide an indication of the biological quality of the seabed.
Infauna	Infauna are animals living within the sediment. For the purpose of this assessment these are animals greater than >0.5 mm (called macrofauna). Their presence/absence, species diversity and abundance collectively provide an indication of biological quality of the seabed and the surrounding environmental forcings. There is usually a strong link between the volume of organic deposition and the corresponding benthic community structure (Pearson and Rosenberg 1976, Hartstein and Rowden 2004 and many others).

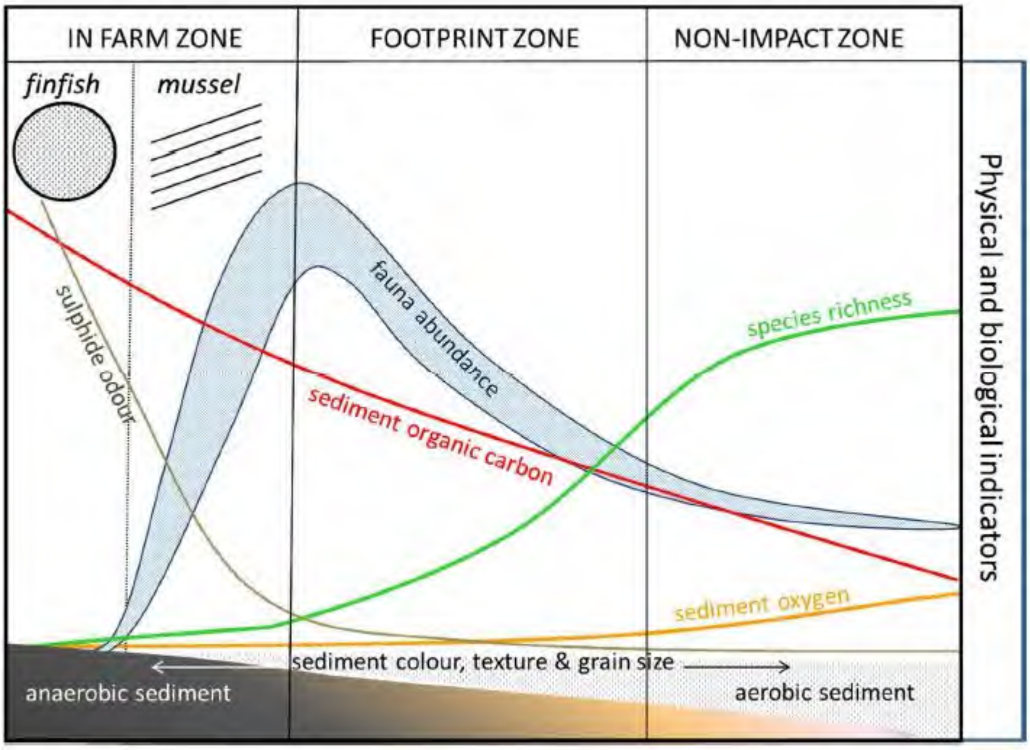


Figure 1 Schematic representation of physical and biological indicator responses to a decreasing enrichment gradient from within farms to beyond the farm footprint. The lines refer to the expected indicator. (Adapted from Pearson and Rosenberg 1976, Hartstein 2003, Hartstein and Rowden 2004, Black et al. 2008, Hopkins 2008, and Hargrave et al. 2008)

3.3 Monitoring Stations

Environmental monitoring in BGB has been divided into water and benthic sampling, and as stated above, all water quality monitoring is undertaken by Sanford Ltd staff. The results from that monitoring program have been passed to ADS to present in this report. A total of six water quality stations were sampled in the bay on a monthly basis with their locations shown in Table 2 and Figure 2.

Thirteen benthic sampling stations were also sampled (Figure 3). Of these stations two were located beneath leases 244 and 340 (mussel farms) while 9 more are located across three fish farm leases (246, 338 & 339). At each of the fish farm leases, samples were collected under the farm/edge of the cage (F), 50 m and 100 m from the site boundary (Table 2 and Figure 3). Also included are two control stations, one at the mouth of the bay (ConM) and the other in the middle (ConH) of the bay (see Figure 2 & Figure 3).

Table 2 Co-ordinates for the water quality and benthic sampling stations (NZMG) in Big Glory Bay. Co-ordinates are in WGS 84 datum and given as easting and northings, and latitude in degrees and decimal minutes.

Stations	Name	New Zealand Map Grid		World Geodetic System 1984	
		Northing	Easting	Latitude (S)	Longitude (E)
Water sampling					
WS1	WS1	5348527	2138255	-46° 58.29485’	168° 07.05104’
WS2	WS2	5347816	2137279	-46° 58.64655’	168° 06.24941’
WS3	WS3	5348861	2139414	-46° 58.15204’	168° 07.97891’
WS4	WS4	5347245	2138349	-46° 58.98857’	168° 07.06492’

WS5	WS5	5347224	2139516	-46° 59.03728'	168° 07.98269'
WS6	WS6	5346826	2137577	-46° 59.18951'	168° 06.43746'
Benthic sampling					
Control stations					
ConM	ConM	5348861	2139414	-46° 58.15204'	168° 07.97891'
ConH	ConH	5347245	2138349	-46° 58.98857'	168° 07.06492'
Mussel sites					
Centre of site 244 (no metals)	244_F	5347652	2137201	-46° 58.7234'	168° 06.1803'
Centre of site 340 (no metals)	340_F	5346839	2138937	-46° 59.2256'	168° 07.5093'
Salmon sites					
Site 246					
Pen edge, on transect line, record	246_F	5348065	2139552	-46° 58.584'	168° 08.048'
50m out from south site boundary	246_50	5348021	2139295	-46° 58.600806'	168° 07.845976'
100m out from south site boundary	246_100	5348011	2139246	-46° 58.604625'	168° 07.806936'
Site 338					
Pen edge, on transect line, record	338_F	5346527	2137842	-46° 59.358'	168° 06.630'
50m out from north site boundary	338_50	5346831	2137826	-46° 59.194826'	168° 06.633739'
100m out from north site boundary	338_100	5346881	2137823	-46° 59.167791'	168° 06.633726'
Site 339					
Pen edge, on transect line, record	339_F	5347137	2139070	-46° 59.069'	168° 07.626'
50m out from W-N site boundary	339_50	5347117	2139006	-46° 59.078603'	168° 07.576170'
100m out from W-N site boundary	339_100	5347153	2138970	-46° 59.058054'	168° 07.549513'

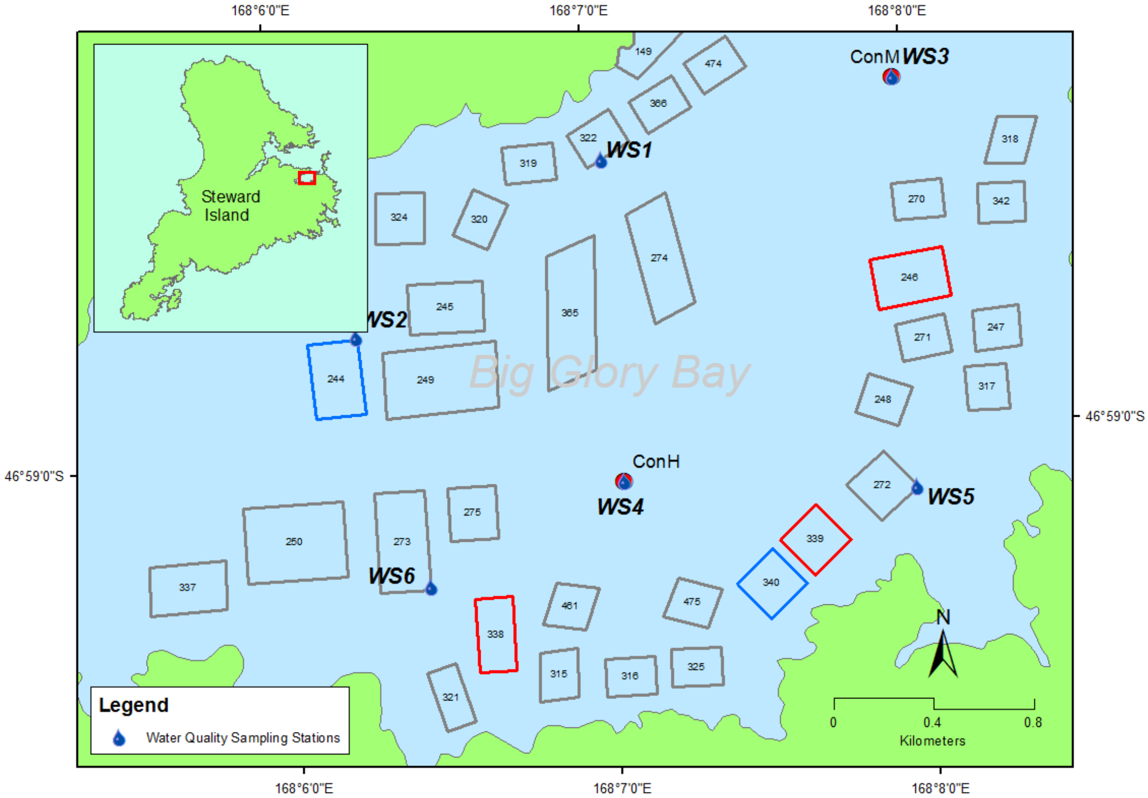


Figure 2 Marine farms in Big Glory Bay (supplied by Stanford Ltd). The three salmon farms (red rectangles: 246, 338 and 339), two mussel farms (blue rectangles: 244 and 340) and two control stations (red circles), one near the bay mouth (Control Mouth: ConM) and the other in the middle of the bay (Control Head: ConH)

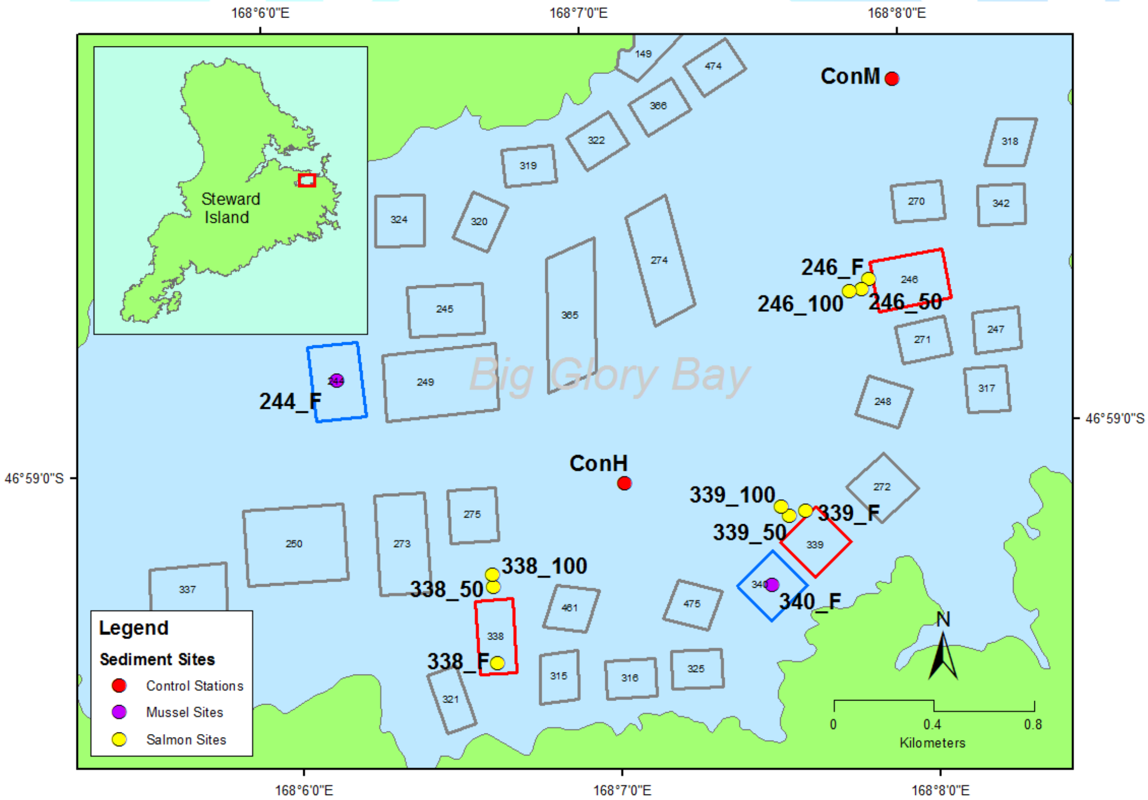


Figure 3 Marine farms in Big Glory Bay (supplied by Stanford Ltd). Location of the benthic sampling stations associated with the salmon farms (246, 338 and 339) and the mussel farms (244 and 340) in Big Glory Bay. The three salmon farms (red

rectangles: 246, 338 and 339), two mussel farms (blue rectangles: 244 and 340) and two control stations (red circles), one near the bay mouth (Control Mouth: ConM) and the other in the middle of the bay (Control Head: ConH)

3.4 Sampling Methodology

3.4.1 Water Quality Sampling

Monthly water quality sampling has been conducted at 6 stations. Temperature and dissolved oxygen levels (mg O_2/L) were measured every 2 meters from the sea surface to the seabed with a water quality probe/sonde, while a Secchi disc was used to measure water transparency/turbidity.

Monthly samples for the analysis of Chl-*a*, and dissolved nutrients were collected at 5 meters depth using a Van Dorn sampler.

3.4.2 Benthic Sampling

At each benthic station the following sampling methods were employed (further description can be found in Table 3).

- Three drop camera photographs were collected within a 10 m radius to visually assess the seabed and identify epifaunal communities;
- Three Van Veen grabs (bite area ca. 0.1 m^2, max bite depth 16 cm) were collected within a radius of 5 m.
- One core (maximum depth of 12 cm, diameter 15 cm) extracted from each grab sample for analyses of infauna.
- Three sediment cores (depth 12 cm, 6 cm internal diameter) extracted from each grab for sediment analyses including metals and grainsize.

Trace metal concentrations were compared against national sediment quality criteria derived by the Australia and New Zealand Environment and Conservation Council (ANZECC 2000). ANZECC have derived low interim sediment quality guideline (ISQG) values (ISQG-Low) and high interim sediment quality guideline values (ISQG-High) for each trace element and organic compound.

The ISQG-Low threshold is the level below where adverse effects on sediment-dwelling organisms are deemed unlikely and thus, exceedance of these concentrations is not necessarily cause for concern, but indicates the need for further investigation (*i.e.* resampling or a review of recent farm practices/physical forcing's *etc.*). The ISQG-High value is the level at which adverse effects on some animals are known to occur. If sampled concentrations of a particular substance fall between the ISQG-Low value and ISQG-High this indicates the potential for adverse biological effects.

Water quality and sediment differences between farm sampling stations and control stations, along with all infaunal data, were analysed using the statistical analysis software (PAST3). Measures (or indices) of community structure were calculated using the DIVERSITY feature in PAST.

To assess the similarity between infauna assemblages from the different stations, species density data were square-root transformed to de-emphasise the influence of the dominant species and comparisons made using clustering (Bray-Curtis similarities) (Clarke and Warwick 1994) and nonmetric multidimensional scaling ordination (MDS; Kruskal and Wish 1978). Each mussel farm station was compared to the control stations and each salmon farm compared to the sample stations located 50 m and 100 m from the site boundary and the two control stations. Analyses of similarity (ANOSIM) tested the significance of differences between infauna assemblages from different stations. If significant differences were found, then the major species contributing to the similarities within each group and the differences between groups were identified using analysis of similarities (SIMPER; Clarke and Warwick 1994).

Table 3 Methodologies for analyzing sediment samples

Sediment Core for:	**Measure**	**Method**
Grain size	% clay and silt, % sand, % organic matter	Core size (12 cm deep and 6 cm diameter): Oven drying at 100 °C overnight and washing a weighed subsample through stacked 2000 µm and 63 µm sieves. The fraction retained on each sieve was dried and weighed and the weight of material passing the 63 µm sieve obtained by subtraction from the original weight. The amount of organic matter in the sediments was determined by freezing-drying each sample, grinding, combusting in a furnace at 500 °C for 4 hours, and reweighing. The weight of organic matter was determined by subtracting the combusted weight from the original (freeze-dried) weight and expressed as a percentage. Conducted at Hill Laboratories.
Total Organic Matter	% organic content (TOM)	Freeze-drying followed by oven drying 60 °C for 2 hours; combustion at 500 °C for 4 hours to burn off organic matter; TOM content by difference between dry weight and ash weight
Particulate Organic Carbon	% particulate organic carbon (POC)	CHN analyser at Hill Laboratories: this provided POC and PON simultaneously
Copper and zinc	Cu and Zn as mg/kg dry weight sediment from control salmon farm stations only	Hill Laboratories: Air-dried at 35 °C and sieved, <2 mm fraction. Nitric/hydrochloric acid digestion
Appearance of sulphide depth and general colour of sediment	Depth of RPD (Redox Potential Discontinuity layer)	Measurement of RDP layer (black colour demarcation) from surface of sediment in each of 3 cores from each grab sample. Depths are normally in the range of a few millimeters for coastal sediments. These depths were measured in-situ directly from the core itself
Sulphide odour	Presence or absence	Odour detection
Depth of oxygenated layer below the sediment surface	Core measurement in millimeters	Measure the thickness of the oxygenated surface layer (usually only a few millimeters thick in nearshore soft sediments). Again measured *in-situ* directly from the core itself
	Fauna	
Epifauna	Presence/absence on the surface of the sediment Identification of surface features such as burrows and bacterial mats	Three drop camera photo quadrats (35 x 50 cm) per station to describe the presence of conspicuous epifauna. The presence of other seabed features such as burrows and holes made by seabed-dwelling organisms, and shell debris within each quadrat were also recorded

Infauna	Numbers and taxa per core Number per taxon	Core depth 12 cm pushed into the sediment (diameter 15 cm). Sieve sediment core samples though a 0.5 mm mesh. Retained infauna counted and taxa identified

4 RESULTS

4.1 WATER QUALITY

All water quality data are provided in Appendix 7.2.

4.2 WATER CLARITY, TEMPERATURE AND OXYGEN LEVELS

Monthly Secchi depth (m) measurements from April 2016 to April 2017 (averaged across all stations) are between 7 and 13.3 m (Figure 4). The deepest (clearest water) Secchi depth measurements were observed during January 2017. Monthly water temperatures (averaged over all stations and depths) varied seasonally, with a high of 14 °C observed in summer compared to a low of 8.4 °C in winter (Figure 5).

Monthly average DO concentrations varied seasonally with higher values observed in end of winter to early spring and lower values in summer (Figure 5). Measured DO concentrations in Big Glory Bay are above critical levels for sustaining aerobic respiration (<2 mg/L) and for stressing most aerobic organisms (4 mg/L) (USEPA 2012).

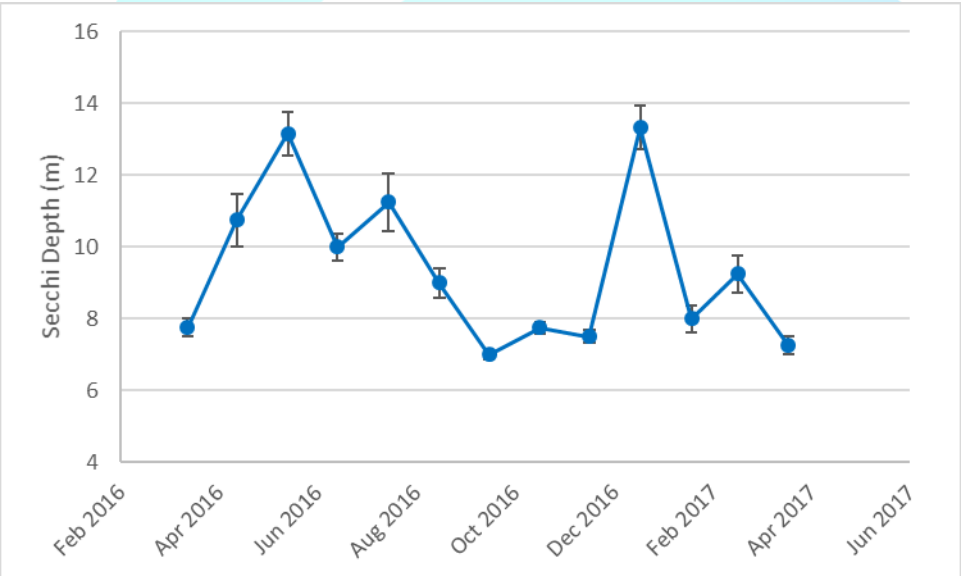


Figure 4 Water clarity (mean Secchi depth) (m) averaged across all six water quality stations in Big Glory Bay. Vertical bars are ±1 SE (n=13).

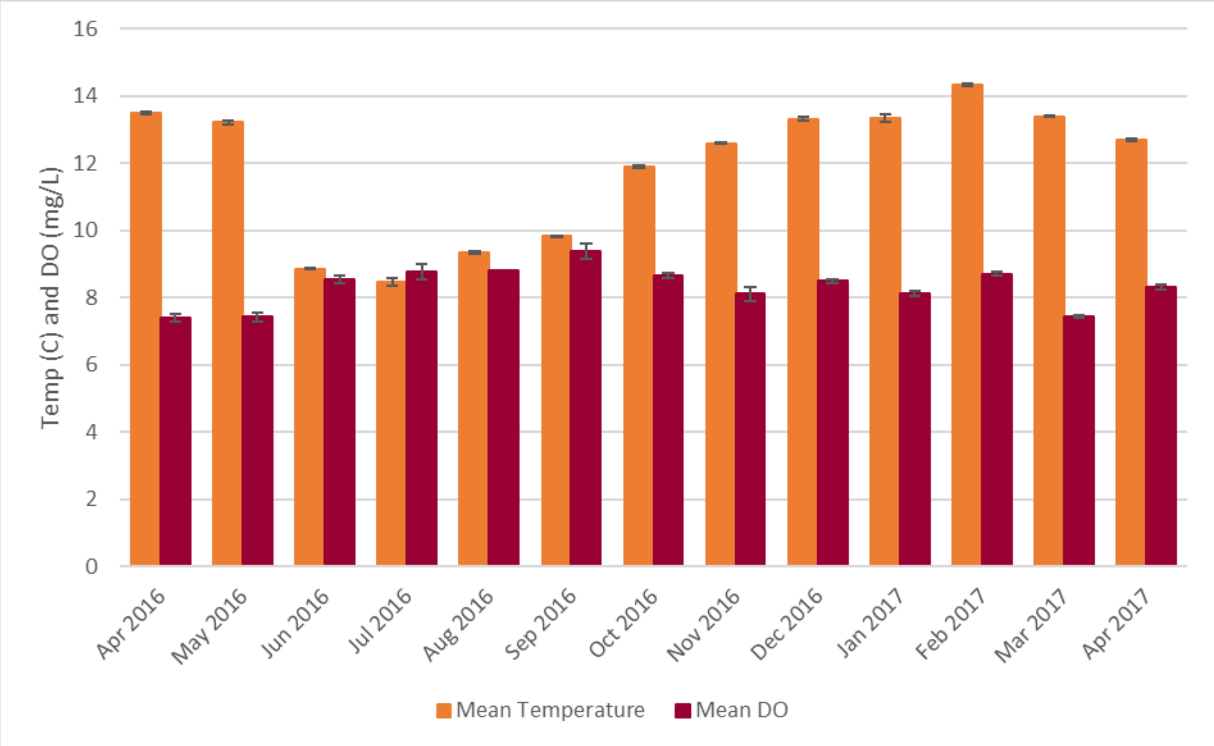


Figure 5 Monthly mean temperature (°C) and mean dissolved oxygen concentrations (mg/L) for all stations and depths. Vertical bars are ±1 SE (n=13).

There was generally little change in water temperature with depth across all stations sampled though there were changes from month to month Figure 6, Figure 7, Figure 8). DO changed little with depth in the summer months, but DO levels increase markedly with depth in autumn and early winter (Figure 9, Figure 10, Figure 11).

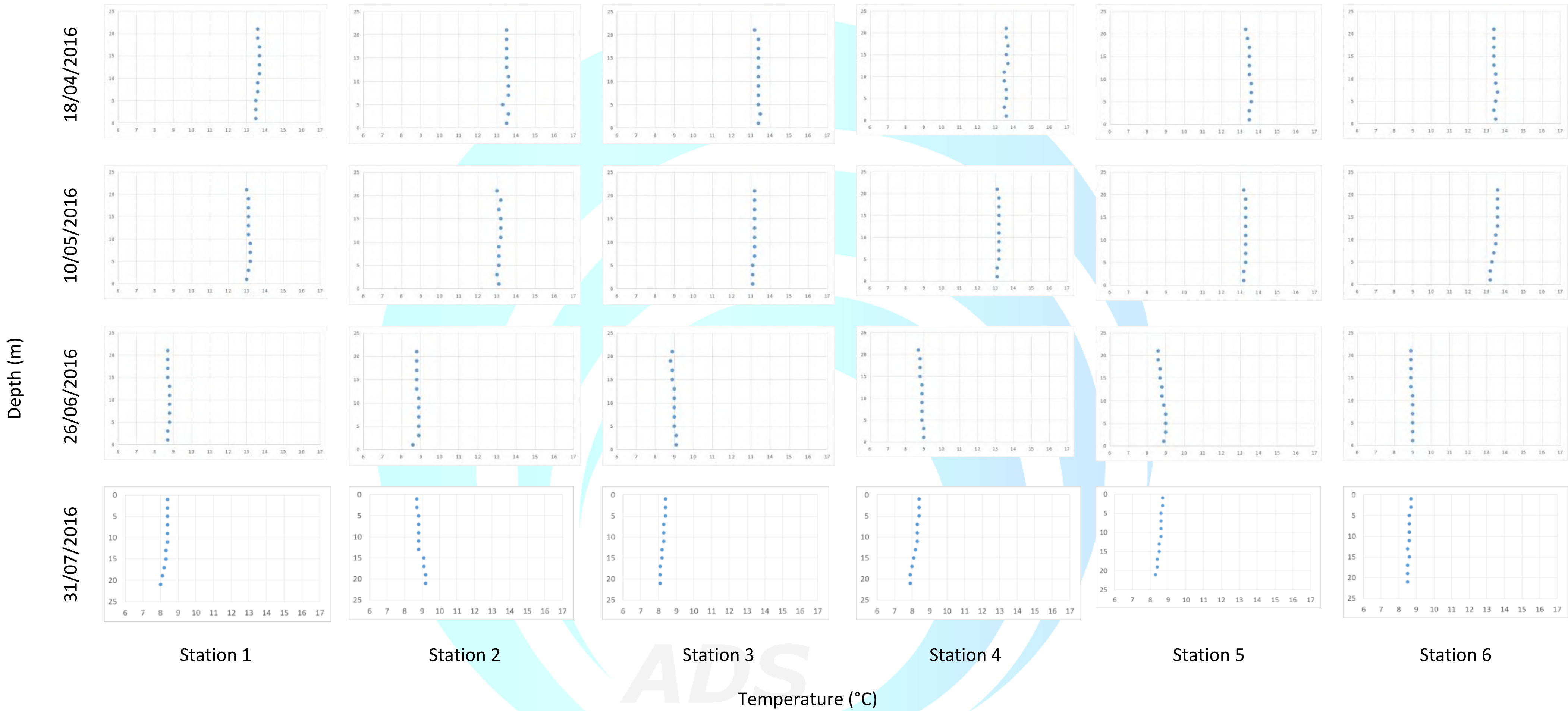


Figure 6: Changes in temperature from 1 m below the surface to 21 m depth in each month at each station (columns 1 to 6) in Big Glory Bay from April 2016 to July 2016.

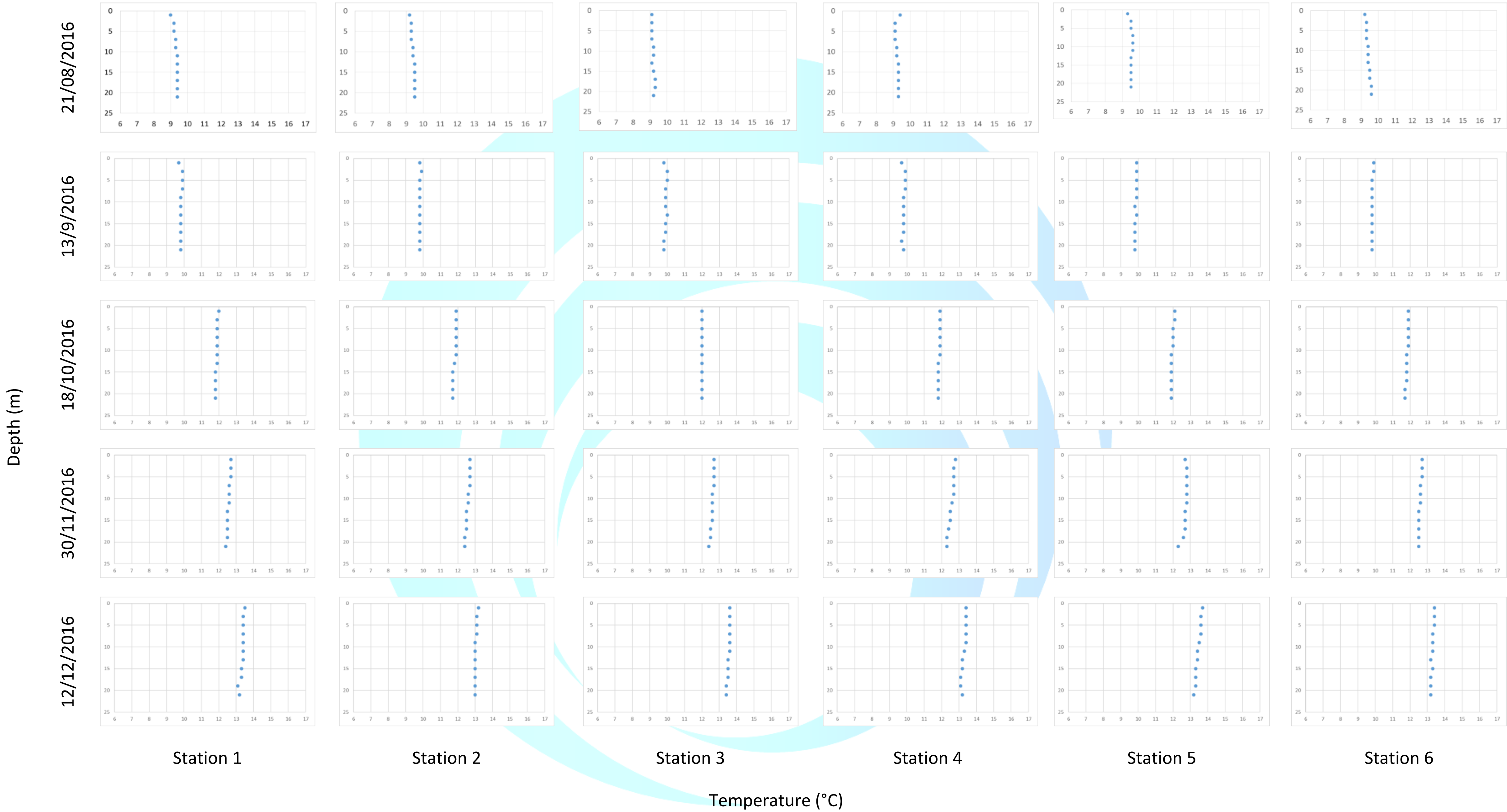


Figure 7: Changes in temperature from 1 m below the surface to 21 m depth in each month at each station (columns 1 to 6) in Big Glory Bay for August to December 2016.

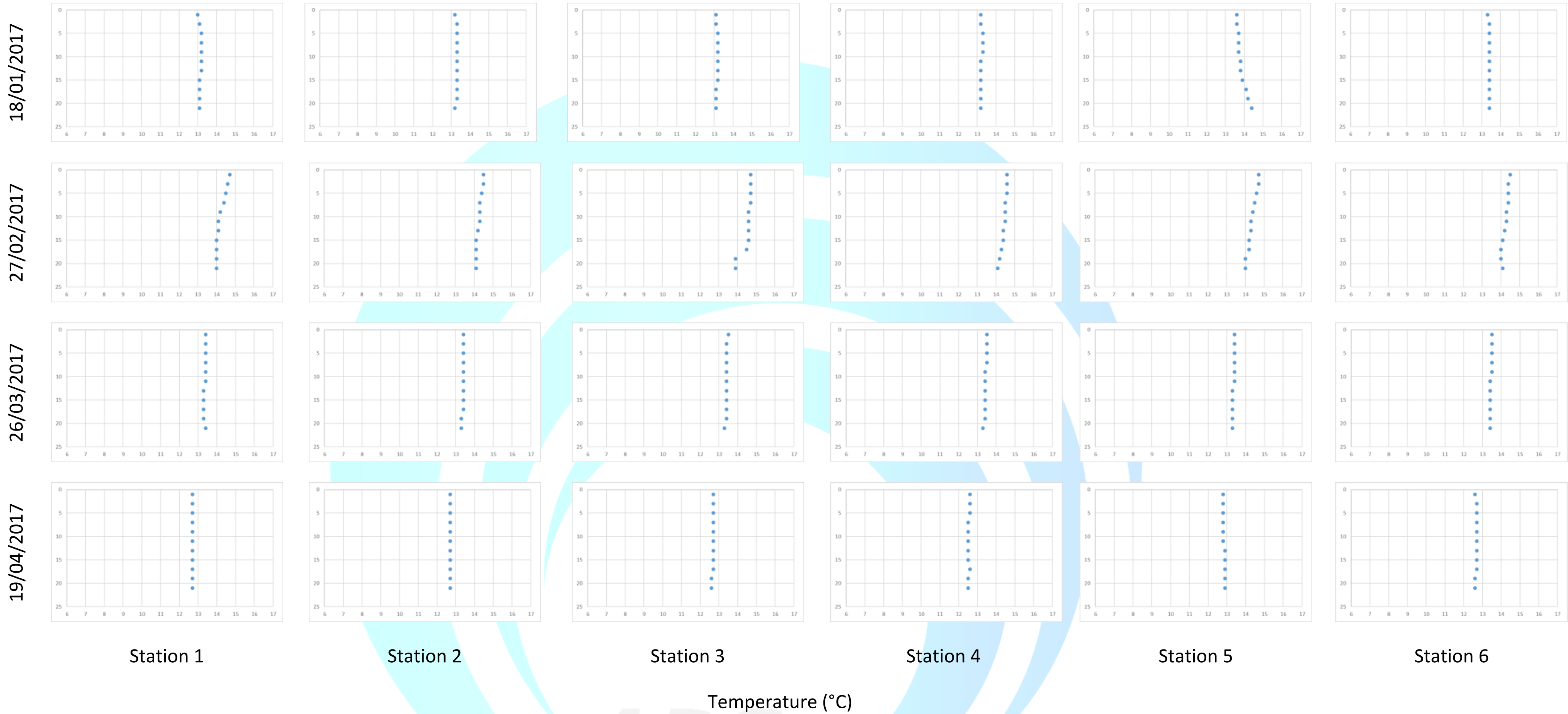


Figure 8: Changes in temperature from 1 m below the surface to 21 m depth in each month at each station (columns 1 to 6) in Big Glory Bay for January to April 2017.

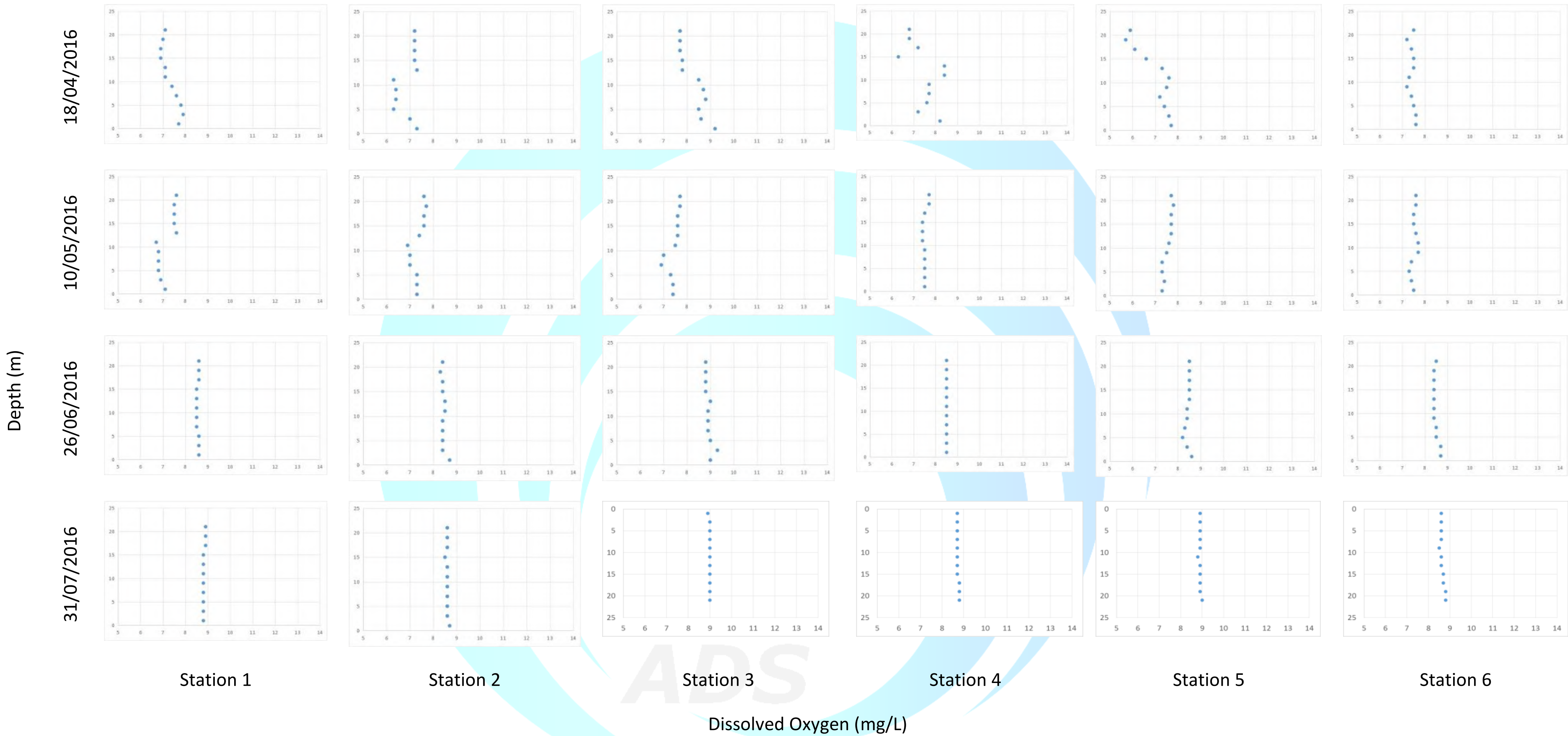


Figure 9: Changes in dissolved oxygen (mg/L) from 1 m below the surface to 21 m depth each month at each station (1 to 6) in Big Glory Bay from April 2016 to July 2016.

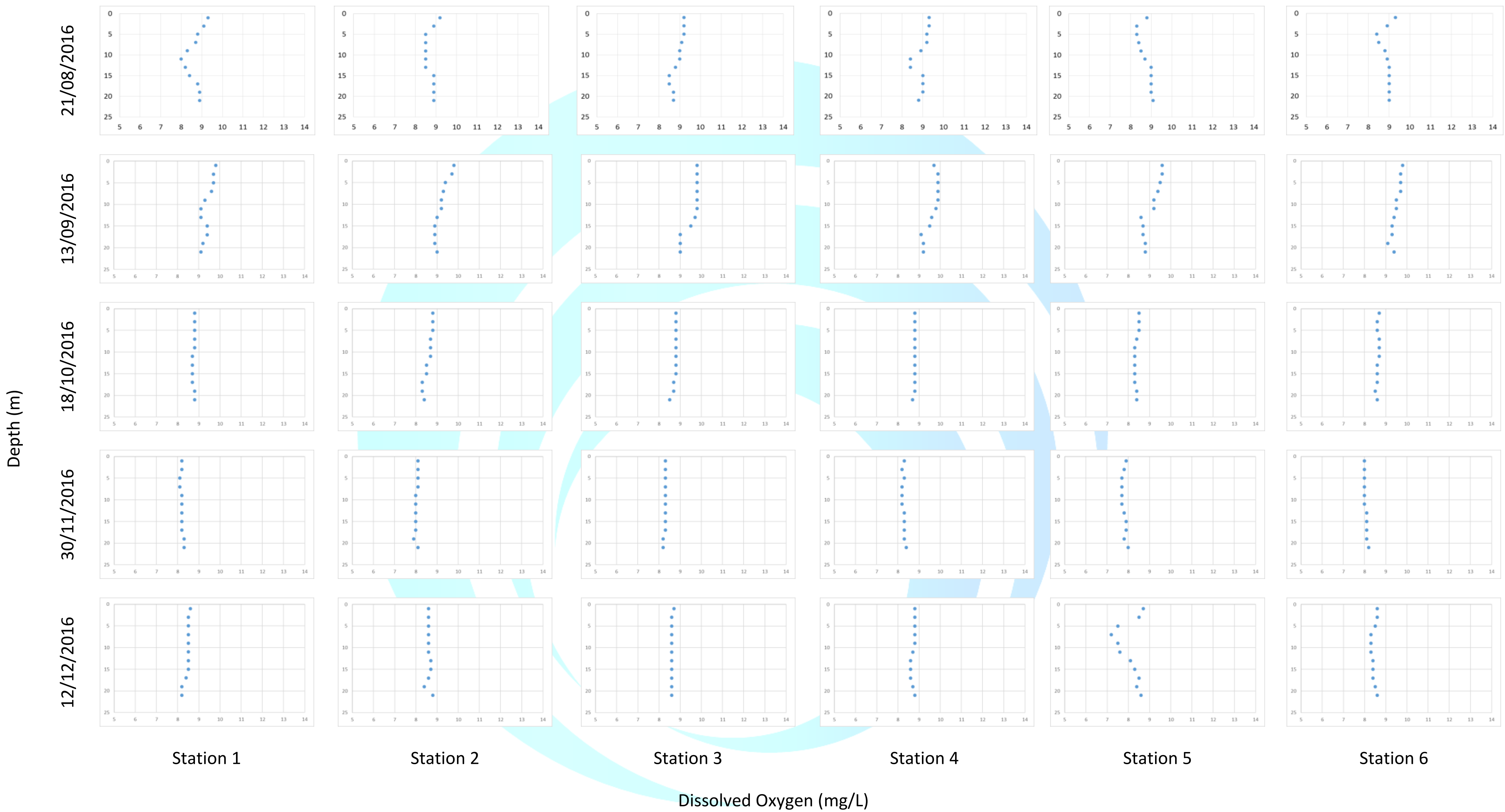


Figure 10: Changes in dissolved oxygen (mg/L) from 1 m below the surface to 21 m depth each month at each station (1 to 6) in Big Glory Bay on August to December 2016.

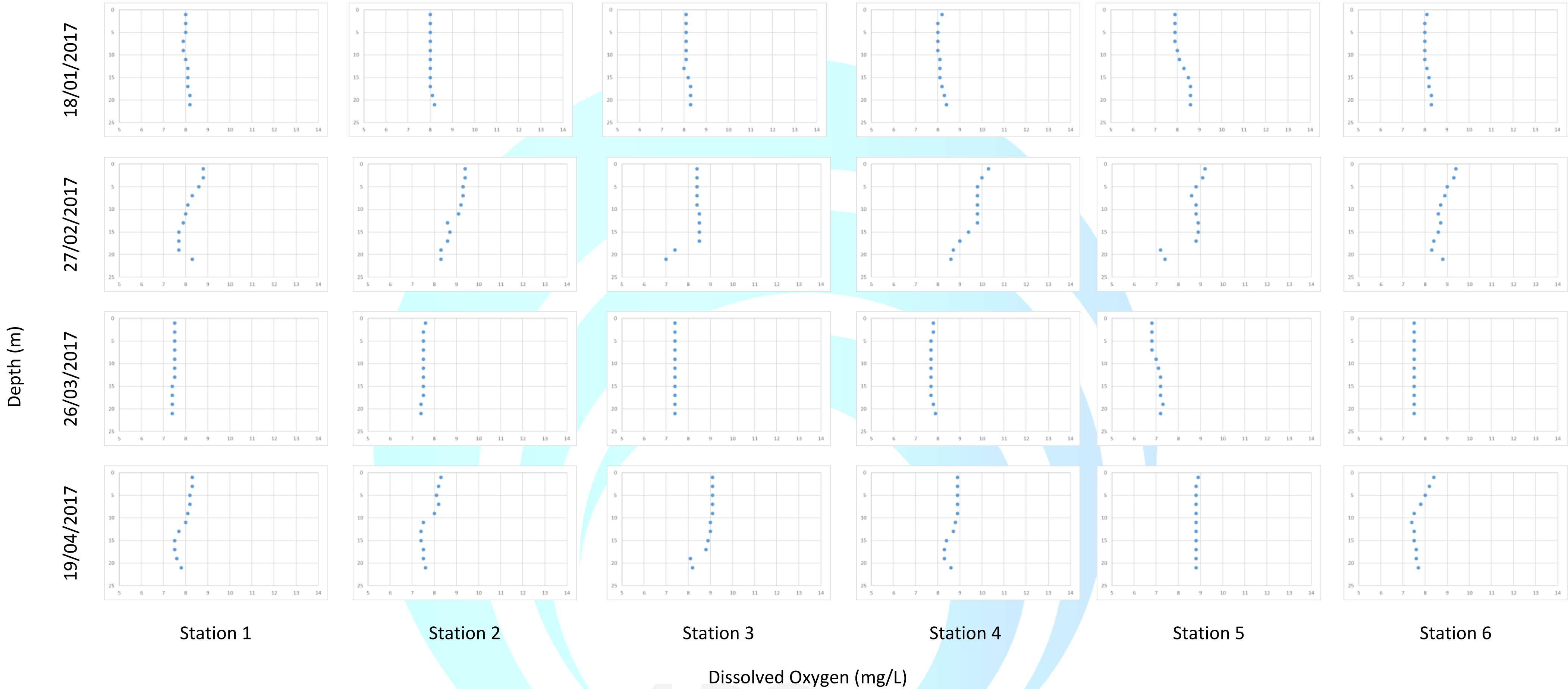


Figure 11: Changes in dissolved oxygen (mg/L) from 1 m below the surface to 21 m depth each month at each station (1 to 6) in Big Glory Bay on January to April 2017.

4.3 Chlorophyll-a Concentrations

Chl-*a* was collected from April 2016 to April 2017 with concentrations across the 6 sites varying considerably, even within sampling periods. The most extreme variation was observed in December 2016, where a high of 4.4 µg/L was observed at Site 3 while a low of less than 0.3 µg/L was detected at site (Figure 12 & Figure 13). Mean concentrations at each station (n=13 months) ranged between 1.15 µg/L to 1.66 µg/L which fall within previously observed observations (Figure 14).

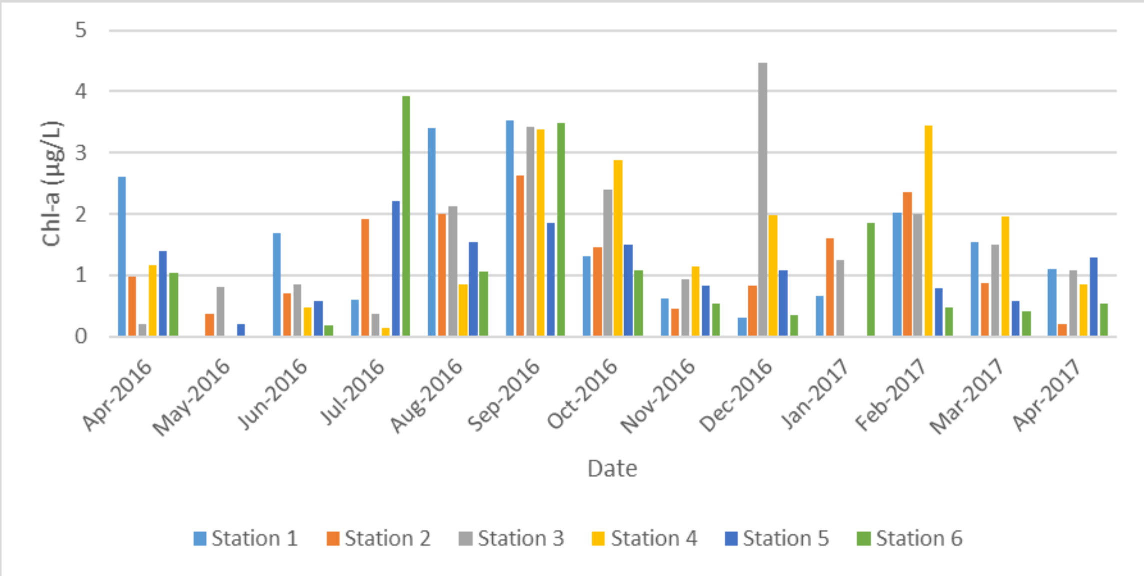


Figure 12 Monthly Chl-a levels (µg/L) at each water quality station in Big Glory Bay.

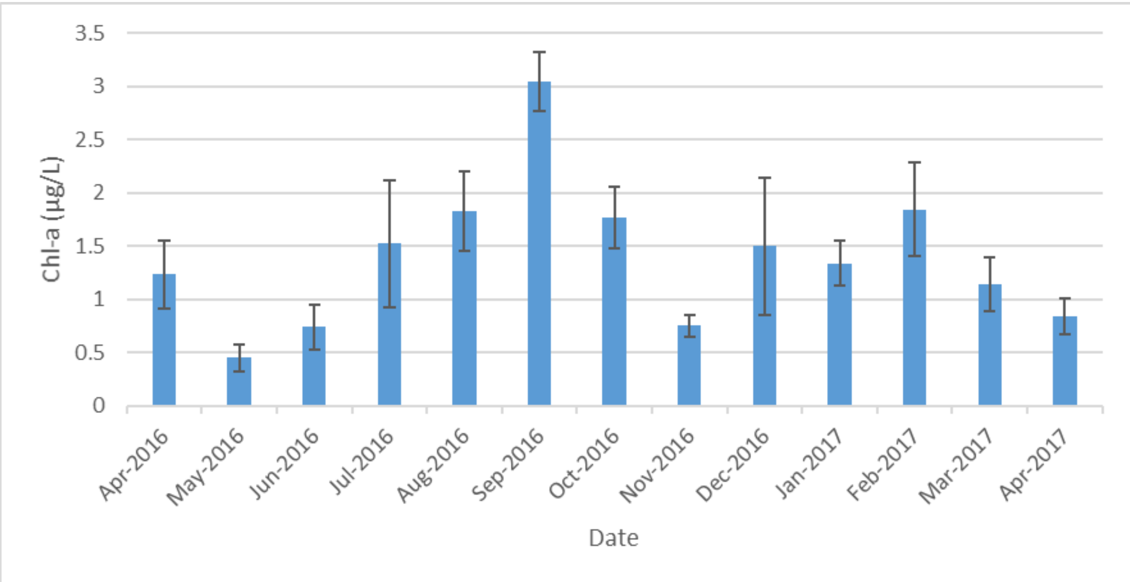


Figure 13: Mean (±1 SE, n=6) monthly chlorophyll-a concentrations (µg/L) in Big Glory Bay based on all six water quality sample stations.

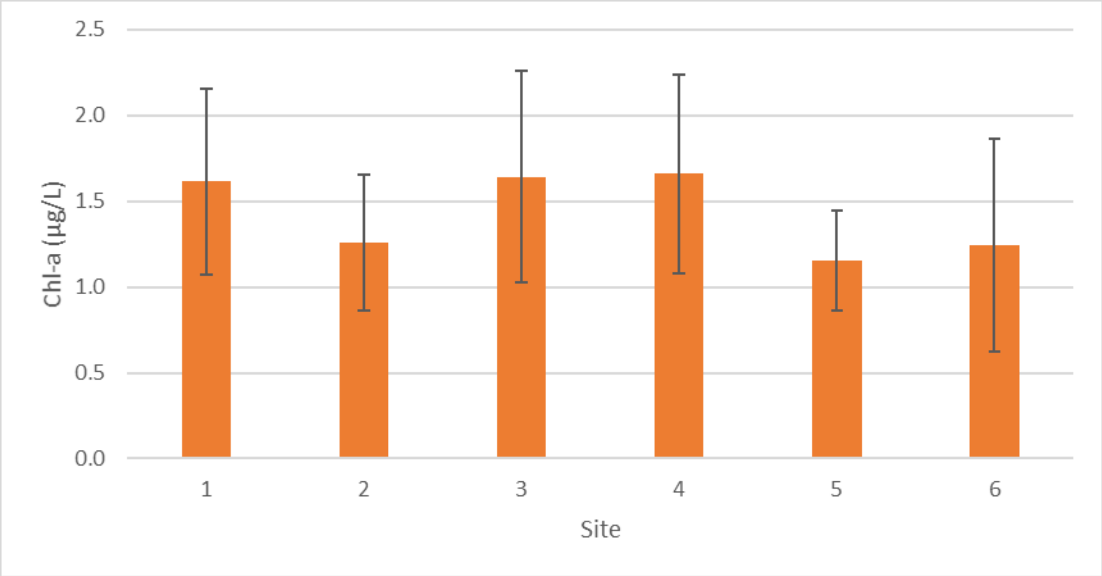


Figure 14: Monthly mean (±1 SE, n=13) Chl-a concentration (µg/L) for each water quality station in Big Glory Bay from April 2016 to April 2017.

4.4 Other Water Parameters Results

Sanford collected additional water samples at stations 3 and 4 from April 2016 to April 2017 as part of an internal monitoring program (see Figure 2). The results of which are presented below. Water samples have been tested for the following: dissolved reactive phosphorus, ammoniacal nitrogen, nitrate nitrogen, suspended solids, volatile suspended solids, particulate carbon and particulate nitrogen.

4.4.1 Dissolved Reactive Phosphorus

Dissolved reactive phosphorus concentrations ranged from a low of 0.004 mg/L at station 3 in April 2017 and a high of 0.026mg/L at station 4 in July 2016 (Figure 15). Mean dissolved reactive phosphorus concentrations were also at their highest in July 2016 compared to other months of sampling (Figure 16). Mean concentrations for each station (n=13 months) ranged between 0.0138 ppm to 0.0143 ppm (Figure 17).

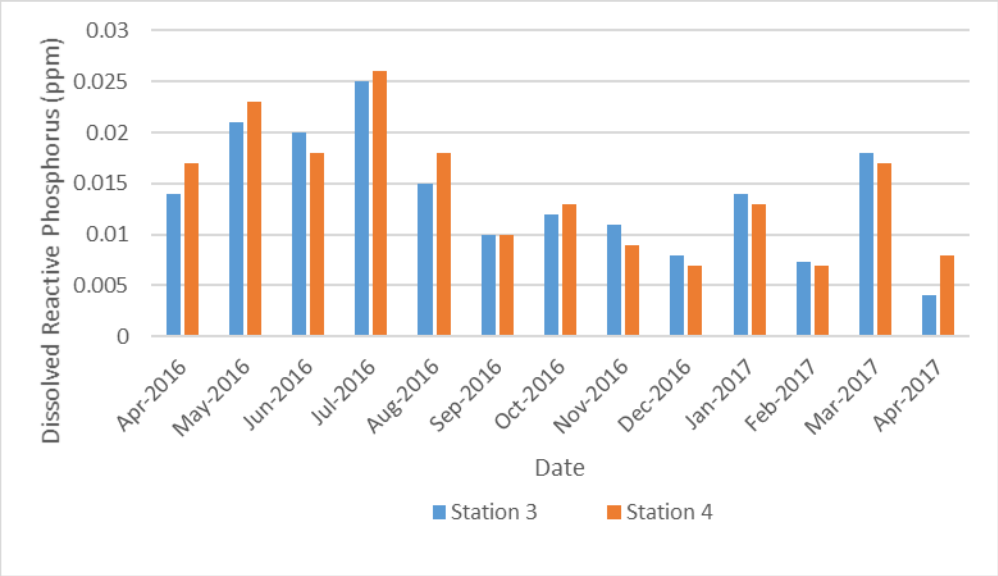


Figure 15: Dissolved reactive phosphorus (ppm) at station 3 and station 4 Big Glory Bay.

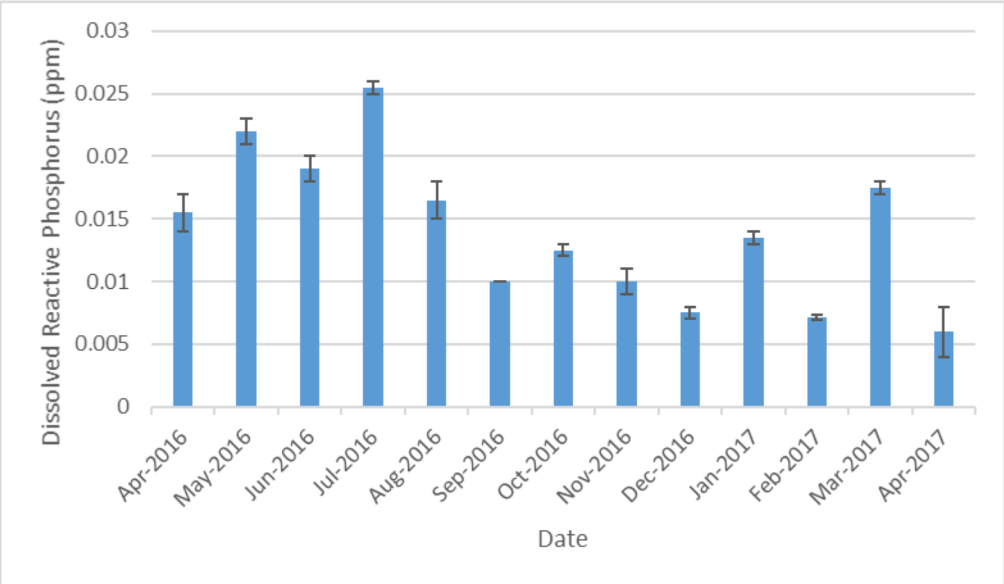


Figure 16: Mean (±1 SE, n=2) monthly dissolved reactive phosphorus concentrations (ppm) in Big Glory Bay based on station 3 and station 4 water quality samples.

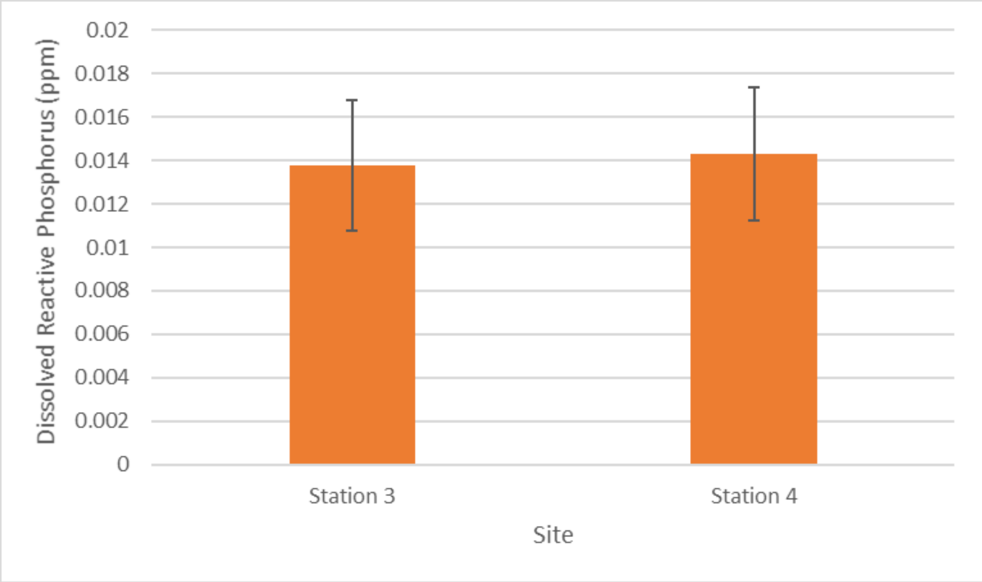


Figure 17: Monthly mean (±1 SE, n=13) dissolved reactive phosphorus concentrations (ppm) at station 3 and station 4 from April 2016 to April 2017.

4.4.2 Ammoniacal Nitrogen

Ammoniacal nitrogen had the highest concentrations recorded in May 2016 and the lowest in April 2017, both at station 3 (Figure 18 and **Error! Reference source not found.**). Mean concentrations for each station (n=13 months) ranged between 0.0341 ppm to 0.0392 ppm (**Error! Reference source not found.**).

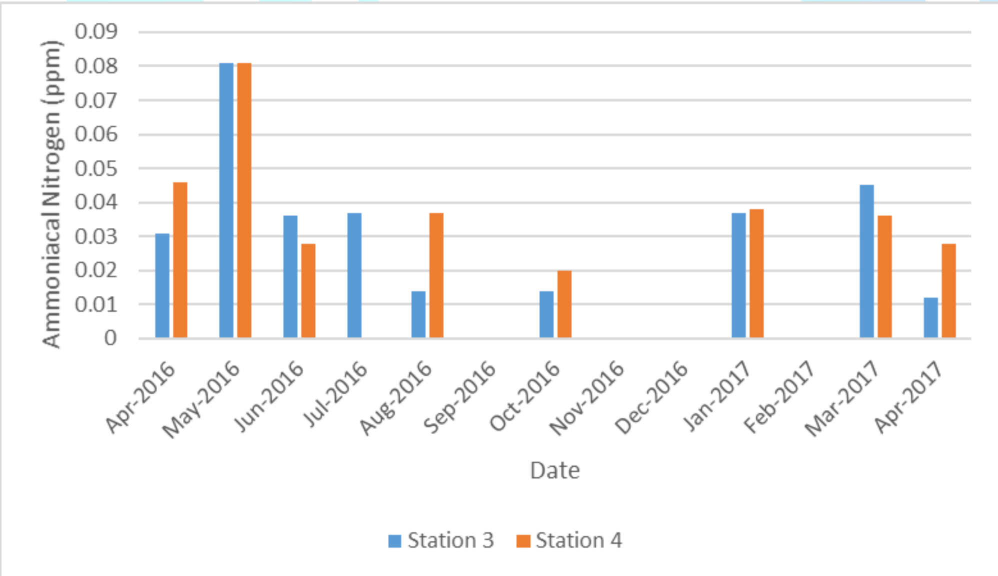


Figure 18: Ammoniacal nitrogen (ppm) at station 3 and station 4 during the April 2016 to April 2017 sampling period.

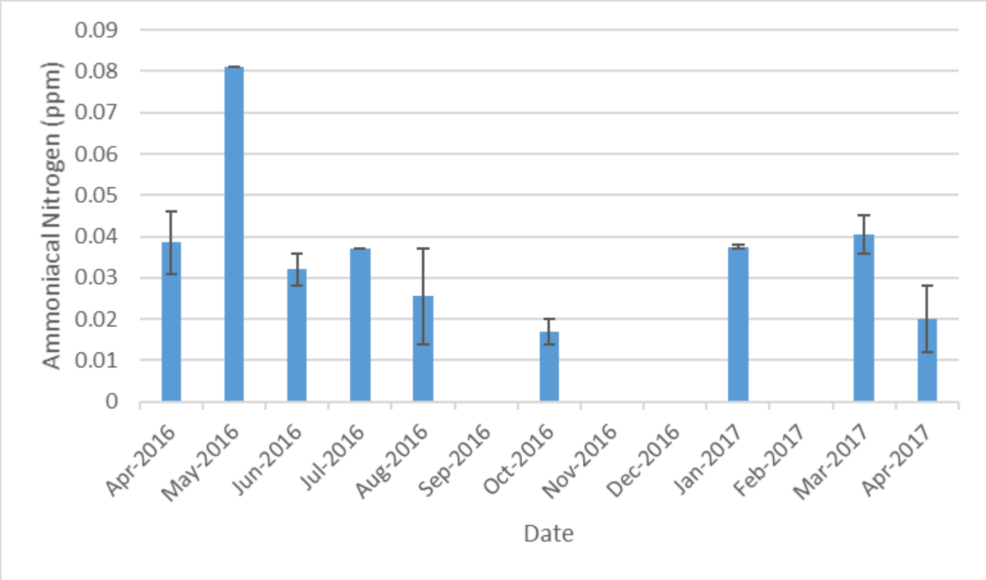


Figure 19: Mean (±1 SE, n=2) monthly ammoniacal nitrogen concentrations (ppm) in Big Glory Bay based on station 3 and station 4 water quality samples.

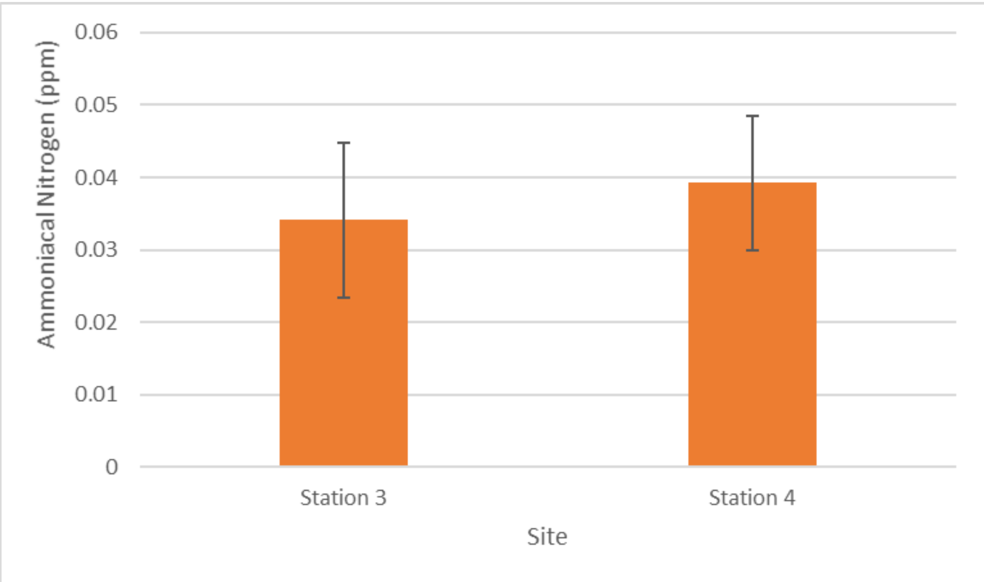


Figure 20: Monthly mean (±1 SE, n=13) ammoniacal nitrogen concentration (ppm) at station 3 and station 4.

Nitrate nitrogen was tested from April 2016 to April 2017. Nitrate nitrogen was at its highest in July 2016 with concentrations of 0.09 mg/L recorded at station 4 and was observed to be below lab detection limits at both stations in December 2016 & February 2017 and Station 3 in April 2017. (**Error! Reference source not found.**& Figure 22). Mean concentrations for each station (n=13) were 0.0359 g/m^3 for Station 3 and 0.0338 g/m^3 for Station 4 (Figure 23).

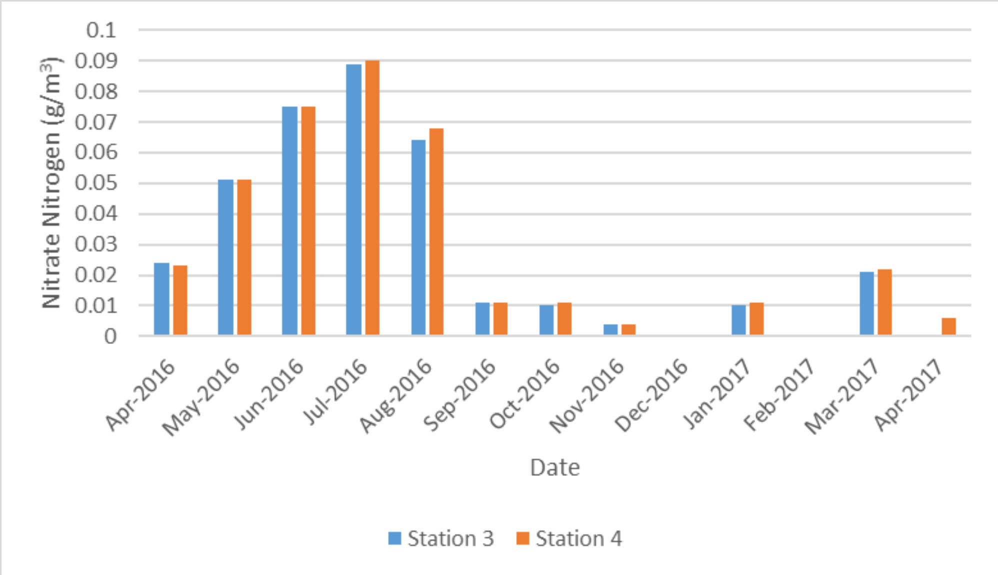


Figure 21: Nitrate nitrogen (mg/l) at station 3 and station 4 during the April 2016 to April 2017 sampling period.

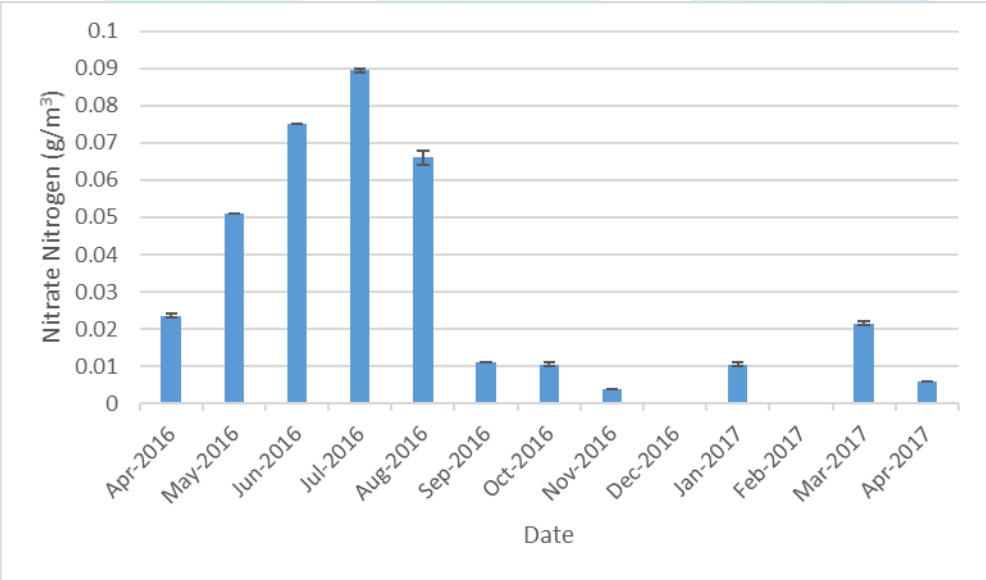


Figure 22: Mean (±1 SE, n=2) monthly nitrate nitrogen concentrations (gm/l) at station 3 and station 4.

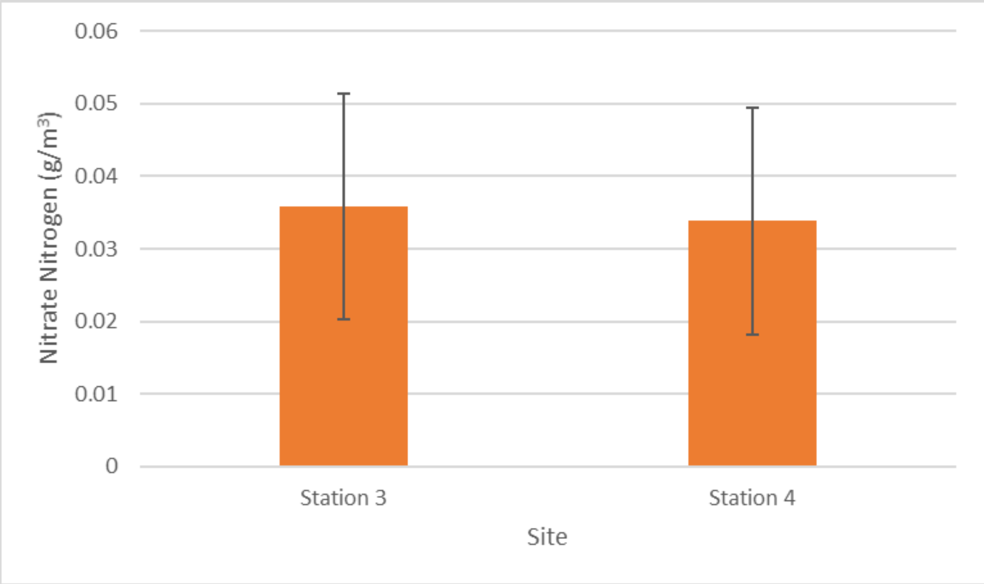


Figure 23: Monthly mean (±1 SE, n=13) nitrate nitrogen concentrations (mg/l) at station 3 and station 4.

4.4.3 Suspended Solids (HFR/TSS)

Suspended solids were observed to be at their highest in February 2016 (59 g/m^3) at Station 4 (**Error! Reference source not found.** and **Error! Reference source not found.**). Mean concentrations for each station across all months sampled (n=13 months) were 26.3 g/m^3 at Station 3 and 28.7 g/m^3 at Station 4 (Figure 26).

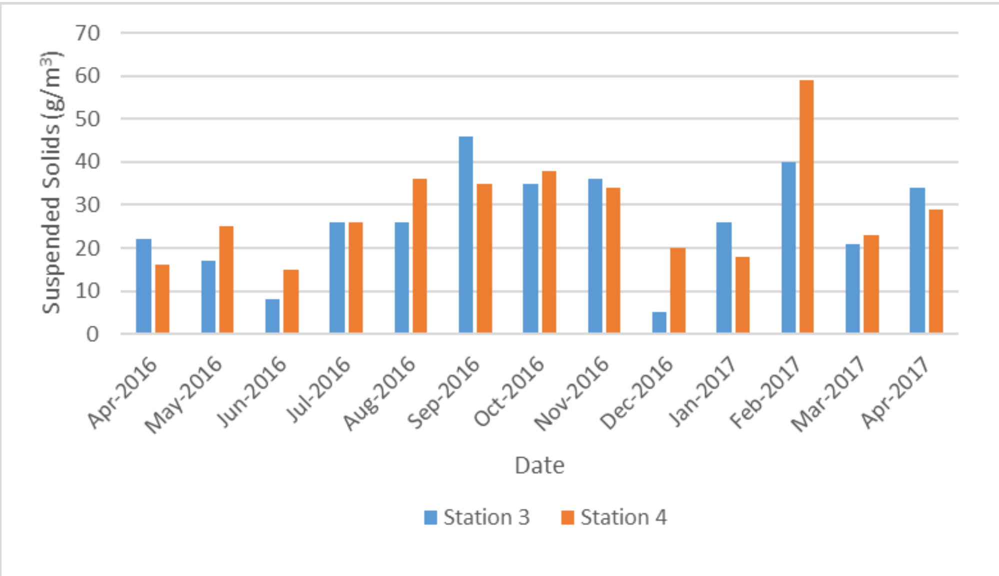


Figure 24: Suspended solids (g/m3) at station 3 and station 4 during the April 2016 to April 2017 sampling period.

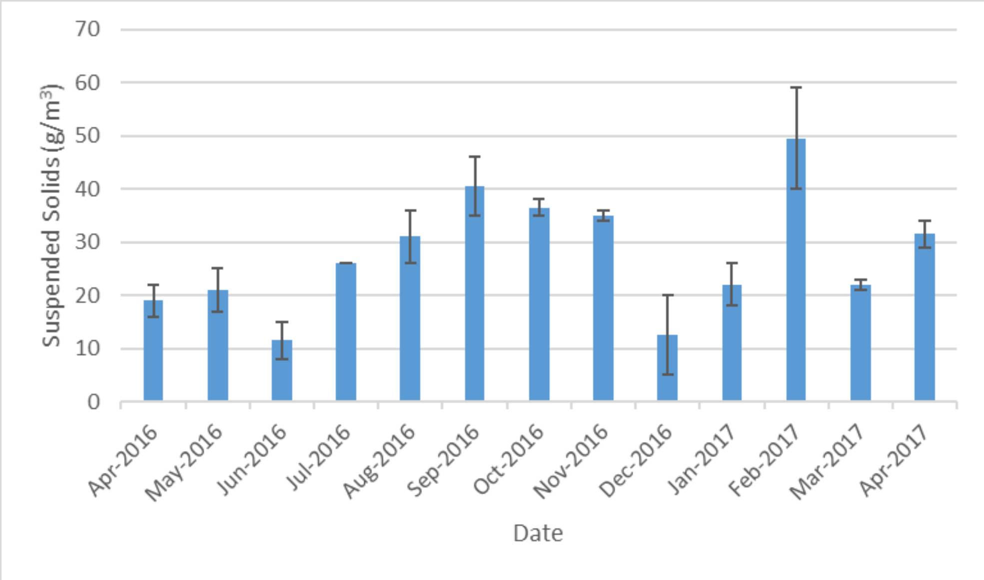


Figure 25: Mean (±1 SE, n=2) monthly suspended solids concentrations (g/m3) station 3 and station 4.

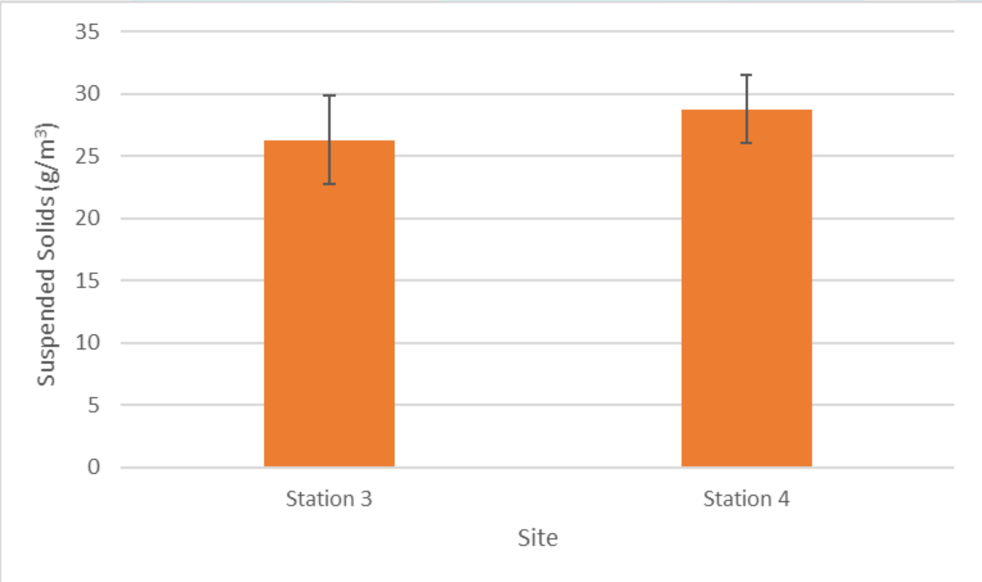


Figure 26: Monthly mean (±1 SE, n=13) suspended solids concentrations (g/m3) at station 3 and station 4.

4.4.4 Volatile Suspended Solids

During April 2016 to April 2017 sampling period volatile suspended solids were found to be below the lab detection limits.

4.4.5 Particulate Carbon

Particulate carbon concentrations were very low during the October 2016 and January 2017 sampling period, but were an order of magnitude higher in both April 2016 and 2017 (**Error! Reference source not found.**). In April 2017, mean particulate carbon concentrations were the highest compared to other months sampled (**Error! Reference source not found.**). Mean concentrations for each station (n=13 months) are presented in (Figure 29).

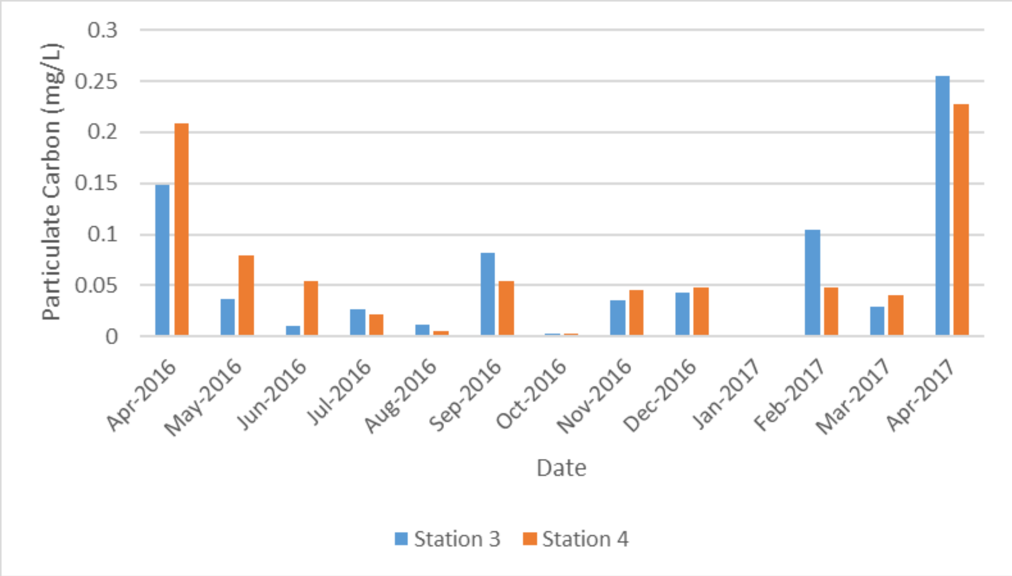


Figure 27: Particulate carbon (mg/L) at station 3 and station 4 during the April 2016 to April 2017 sampling period.

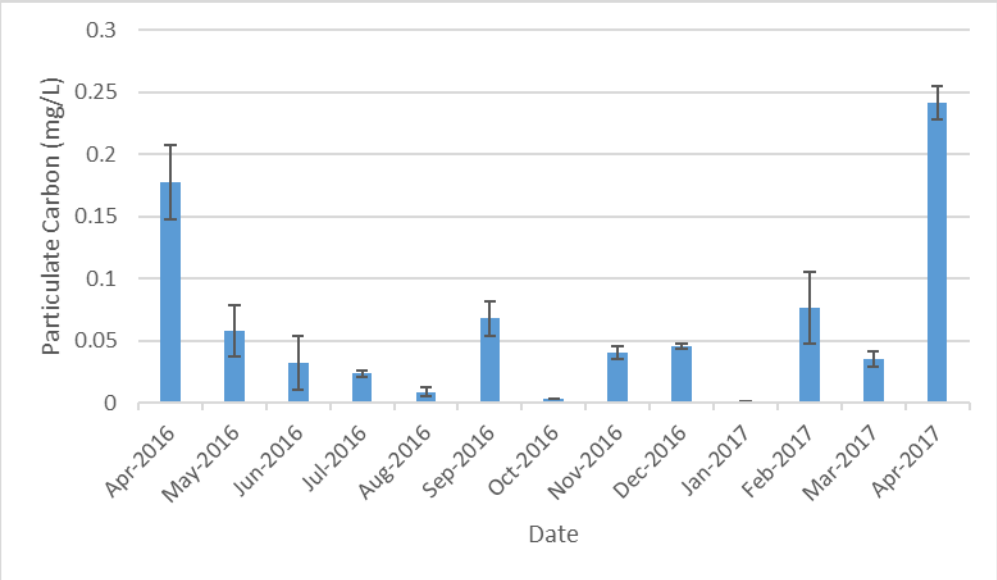


Figure 28: Mean (±1 SE, n=2) monthly particulate carbon (mg/L) in Big Glory Bay based on station 3 and station 4 water quality samples.

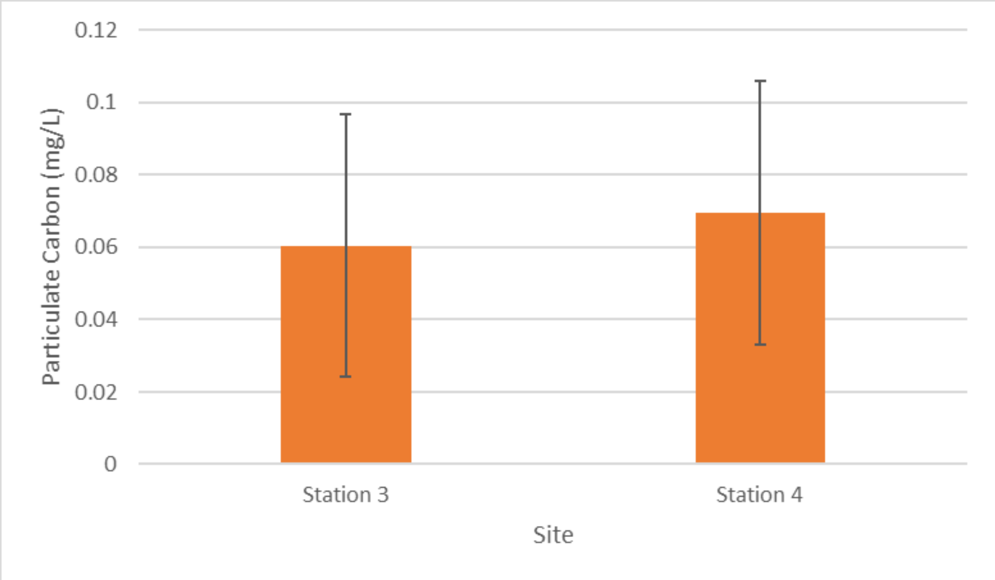


Figure 29: Monthly mean (±1 SE, n=13) particulate carbon (mg/L) at station 3 and station 4.

4.4.6 Particulate Nitrogen

Particulate nitrogen concentrations were found to be highest during the February 2017 sampling period (Site 3) while much lower values were observed between June and August 2016 and January 2017 (Figure 30 & Figure 31). Mean concentrations for each station (n=13 months) ranged between 0.0159 mg/L and 0.0163 mg/L (**Error! Reference source not found.**).

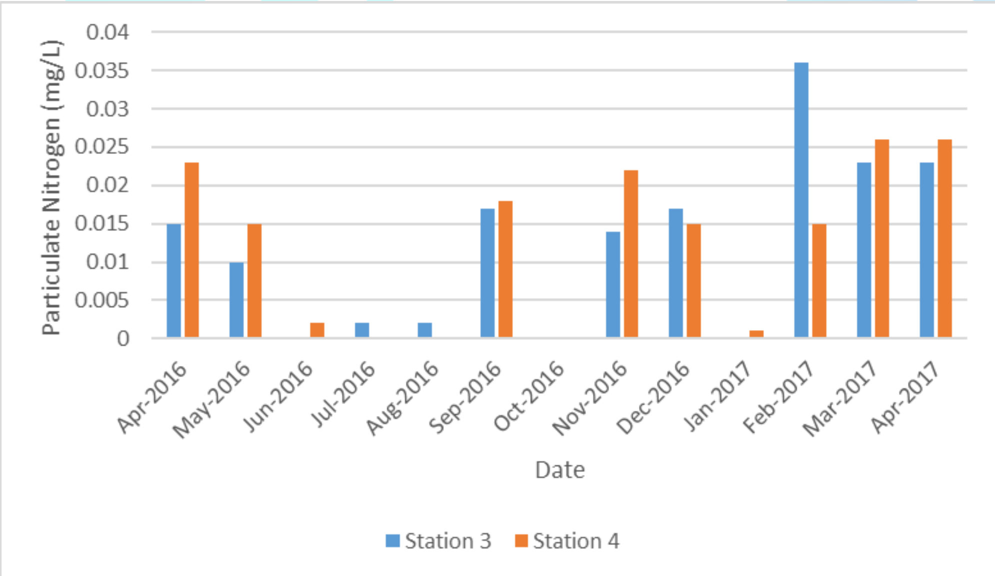


Figure 30: Particulate nitrogen (mg/L) at station 3 and station 4 during the April 2016 to April 2017 sampling period.

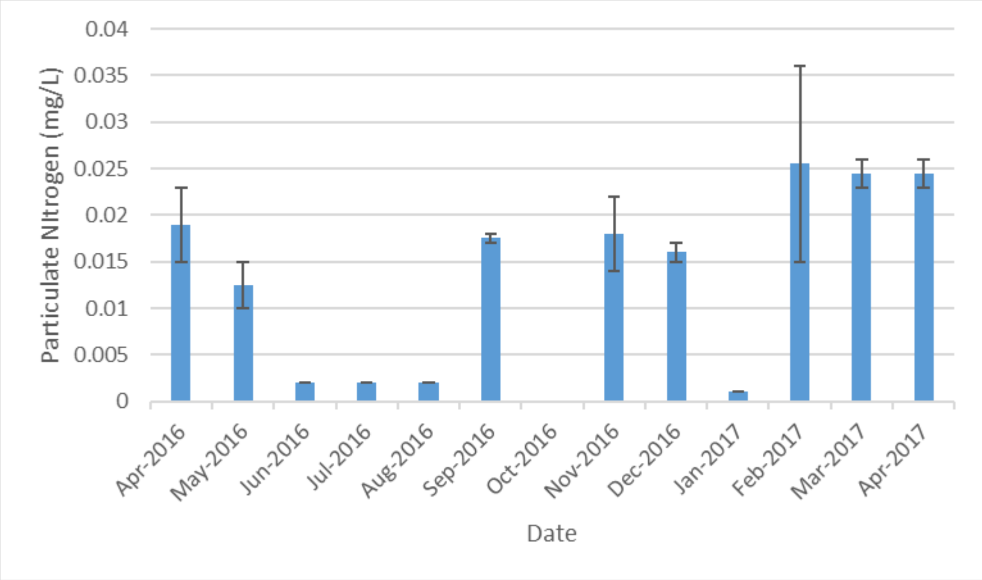


Figure 31: Mean (±1 SE, n=2) monthly particulate nitrogen (mg/L) in Big Glory Bay based on station 3 and station 4 water quality samples.

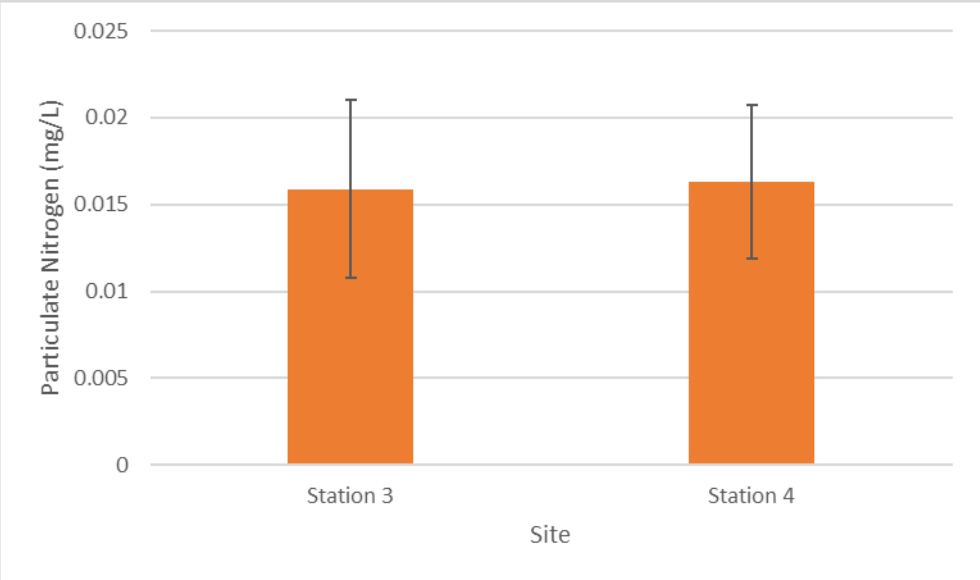


Figure 32: Monthly mean (±1 SE, n=13) particulate nitrogen (mg/L) at station 3 and station 4.

4.5 Benthic Environment

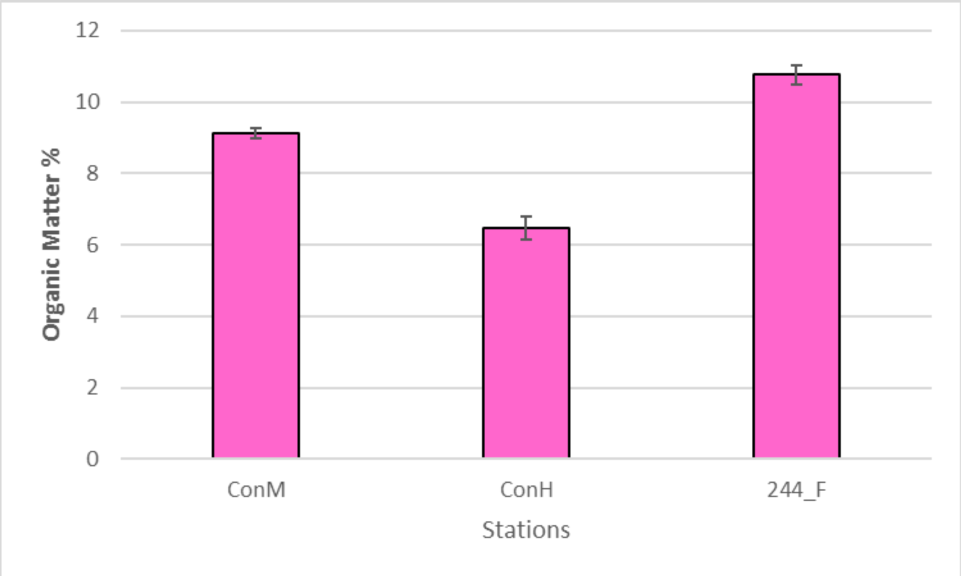
All benthic and sediment environmental data are provided in Appendix 7.3 (physical properties of sediments), Appendix 7.4 (sediment core profiles), Appendix 7.5 (statistical analyses of sediment data), Appendix 7.6 (epibenthic photographs) and Appendix 7.7 (benthic infauna).

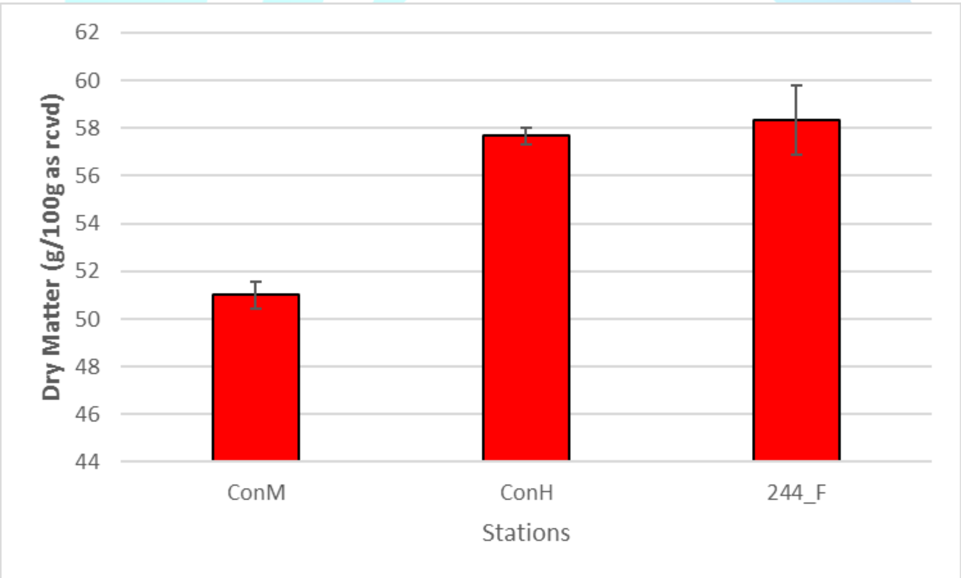
4.5.1 Physical Properties of Sediments

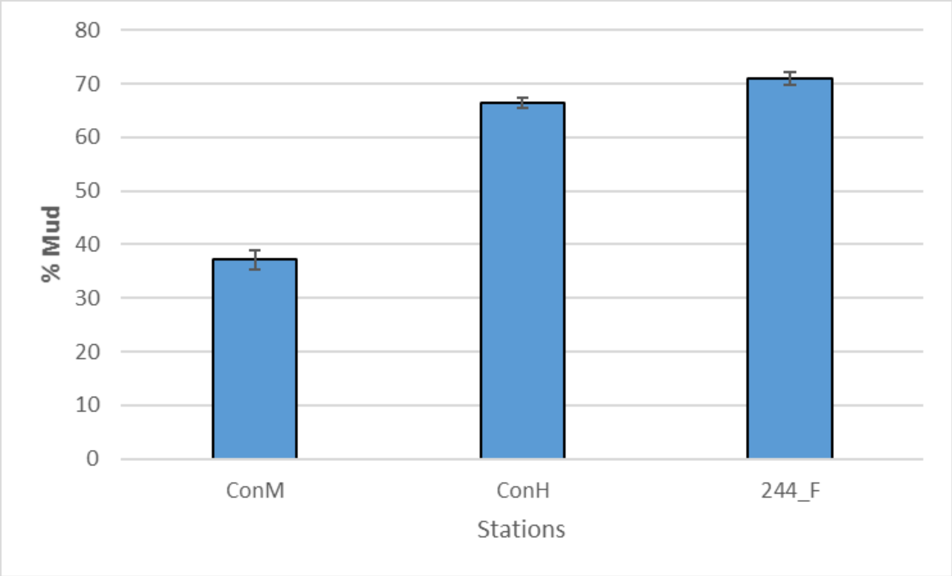
In this section, the physical properties of the sediments from the 13 sites sampled are presented, which includes: organic matter, dry matter, % mud, % sand, % very fine gravel, total organic carbon, total recoverable copper and total recoverable zinc content. Mussel and Salmon farm site results are presented separately but are compared against the two control stations. Non-quantitative characteristics (*i.e.* presence or absence of *Beggiatoa* spp) are also provided in Appendix 7.3.

4.5.1.1 *Mussel Farms*

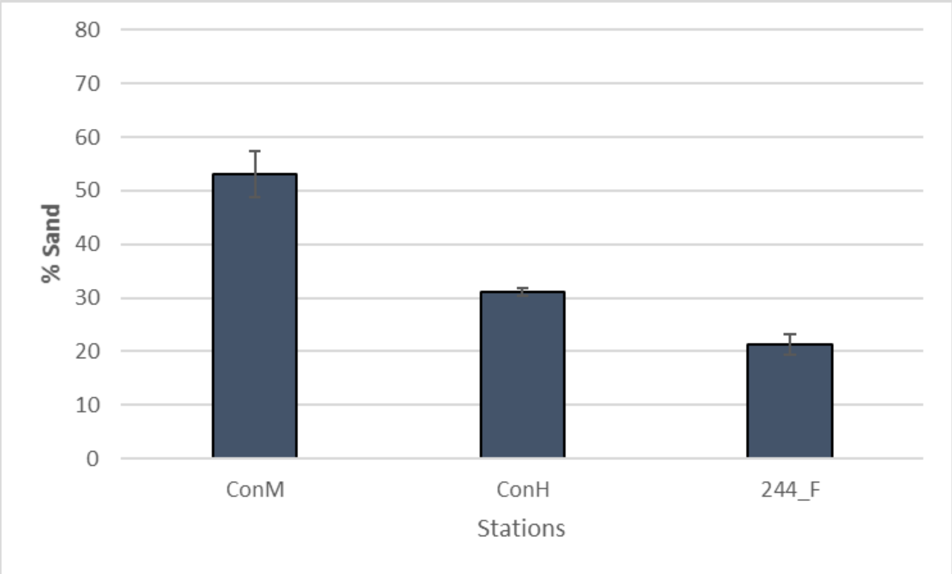
Sediments beneath mussel farm 244_F during the 2017 sampling period were compromised of 71% mud, 21% sand and 7% very fine gravel. Sediments were organically enriched particularly when compared with ConH, though only slightly higher levels of enrichment were observed when compared to ConM (**Error! Reference source not found.**). There was approximately a 1 mm redox layer in the cores and no sulphide odour emanated from the sediments (Appendices 7.3 & 7.4). No organic carbon measurements were conducted as there were too many mussel shells in the sample to obtain a representative sample (Feedback from Hill Laboratories).



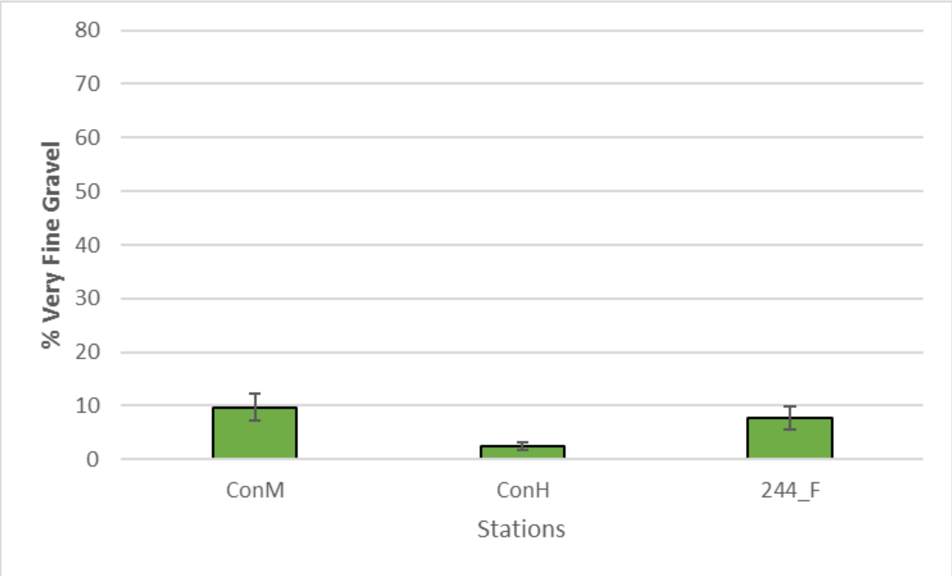




% Mud
80
70
60
50
40
30
20
10
0
ConM
ConH
244_F
Stations



% Sand
80
70
60
50
40
30
20
10
0
ConM
ConH
244_F
Stations



% Very Fine Gravel
80
70
60
50
40
30
20
10
0
ConM
ConH
244_F
Stations

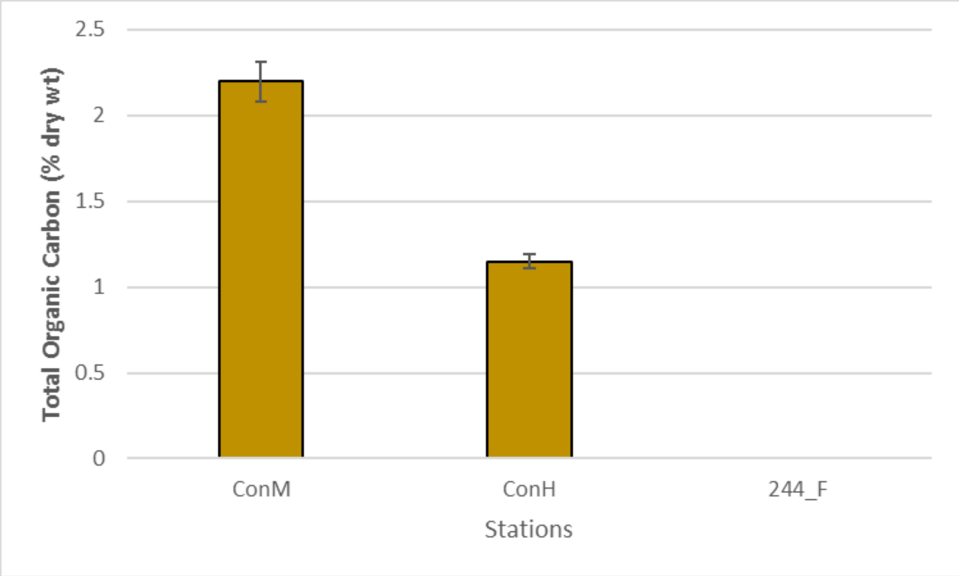
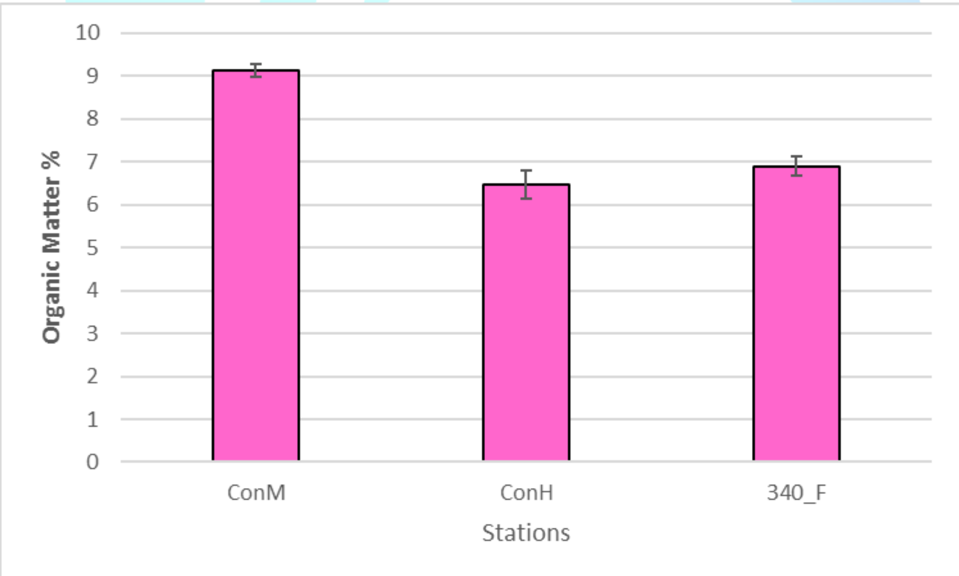
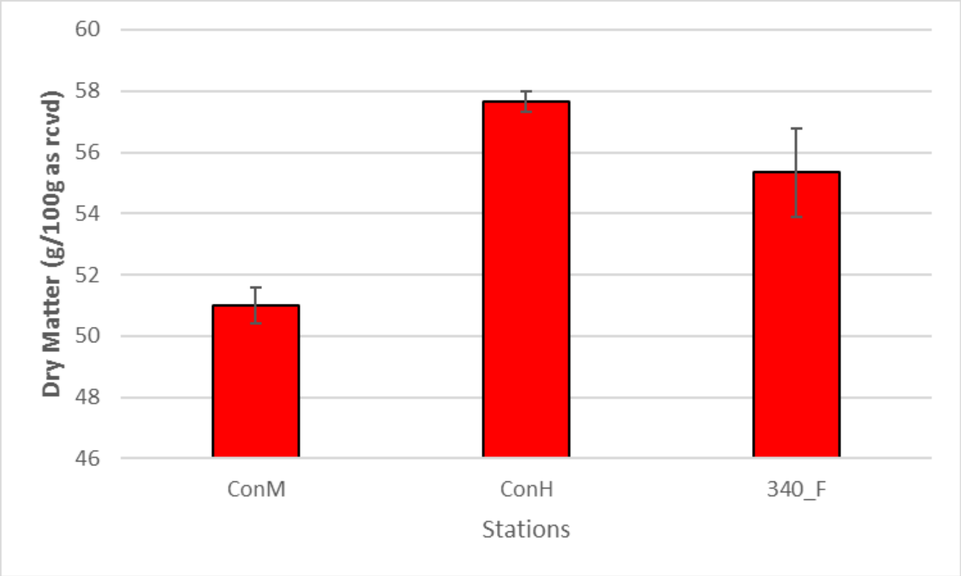


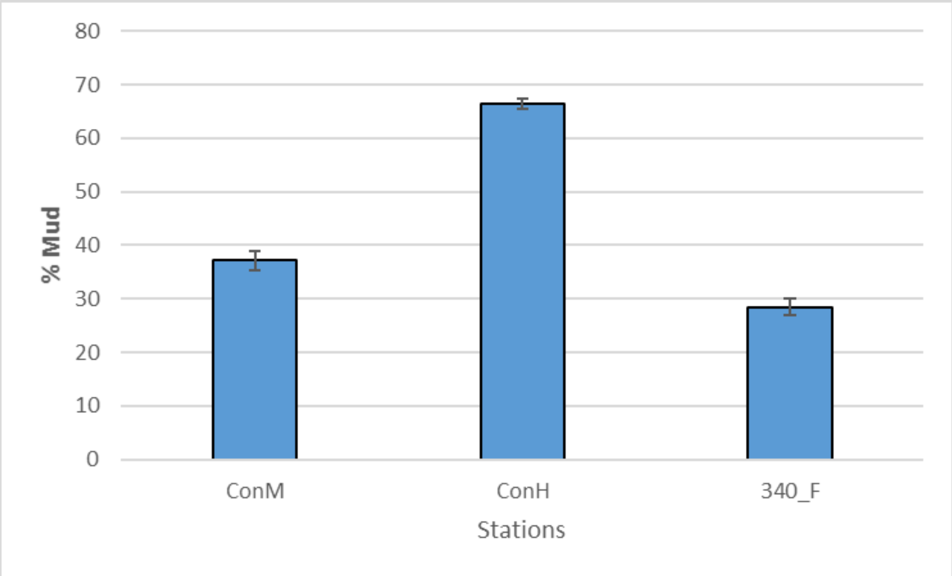
Figure 33: Sediment properties (organic matter, dry matter, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by mussel station 244_F and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

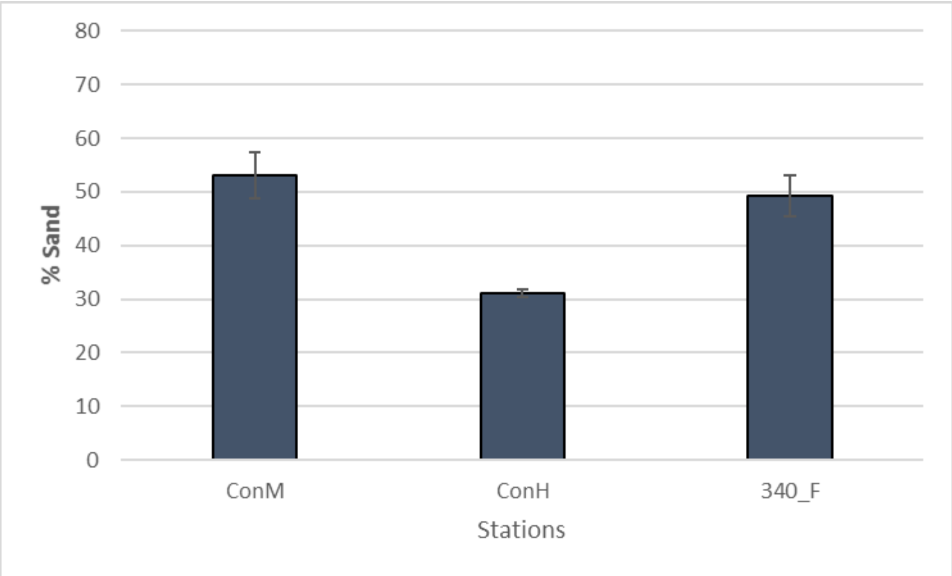
Sediments beneath mussel farm 340_F were compromised 29% of mud, 49% sand and 22% very fine gravel. Organic matter levels are similar or lower than control stations (Figure 34).

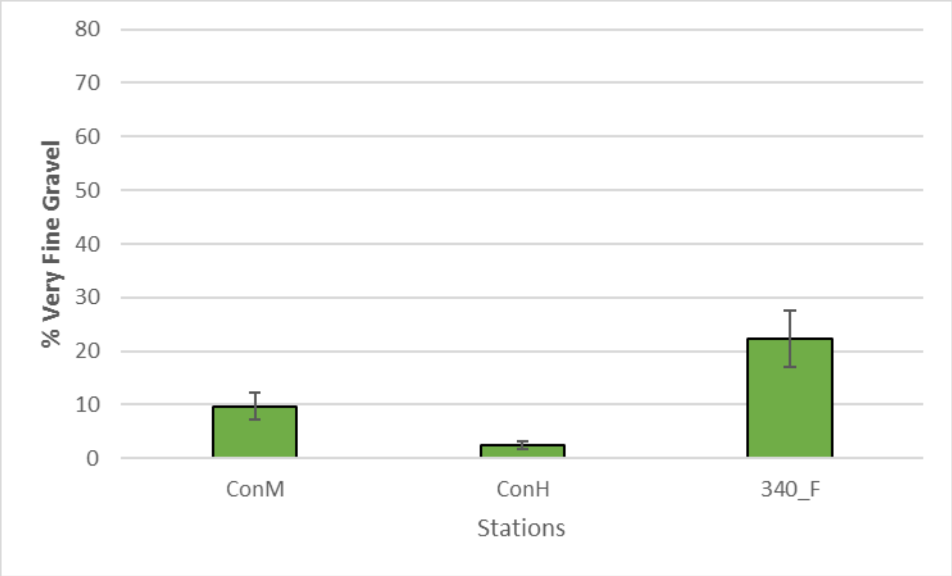
There was approximately a 1 mm redox layer in the cores and there is no sulphide odour emanated from the sediments (Appendices 7.3 and 7.4). Again no organic carbon samples were processed due to the large number of mussel shells in the sample.




60
58
56
54
52
50
48
46
Dry Matter (g/100g as rcvd)
ConM
ConH
340_F
Stations


80
70
60
50
40
30
20
10
0
% Mud
ConM
ConH
340_F
Stations


80
70
60
50
40
30
20
10
0
% Sand
ConM
ConH
340_F
Stations



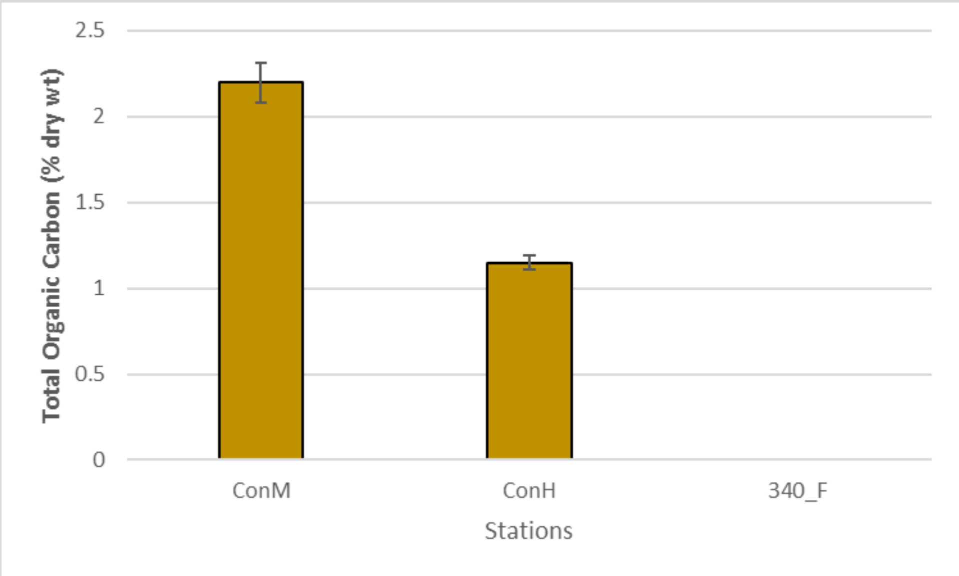


Figure 34: Sediment properties (organic matter, dry matter, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by mussel site 340_F and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

4.5.1.2 Salmon Farms

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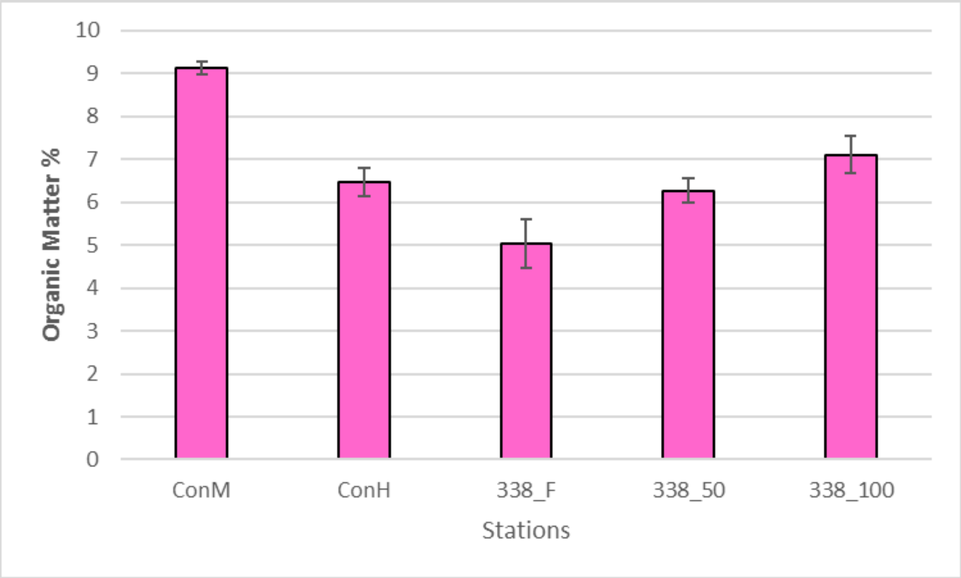
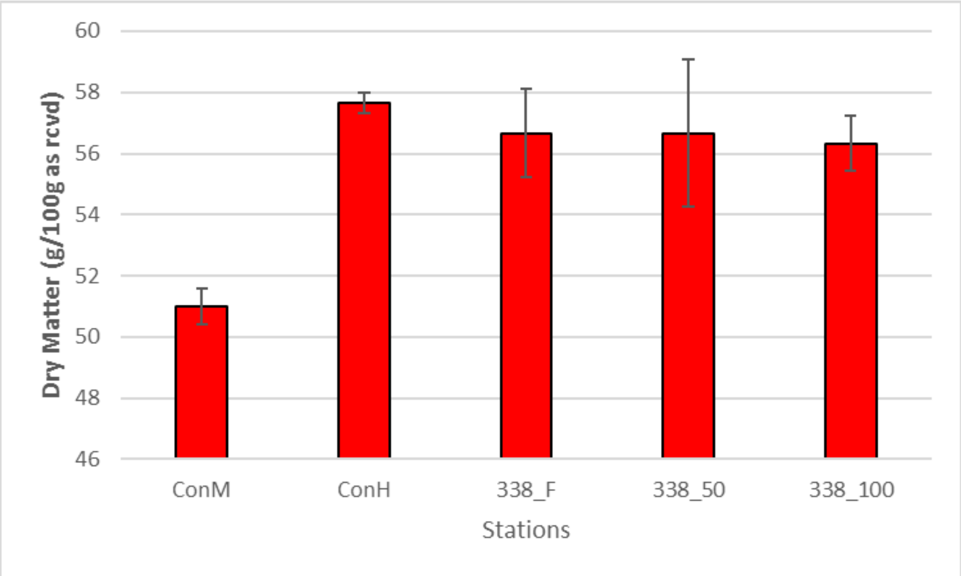
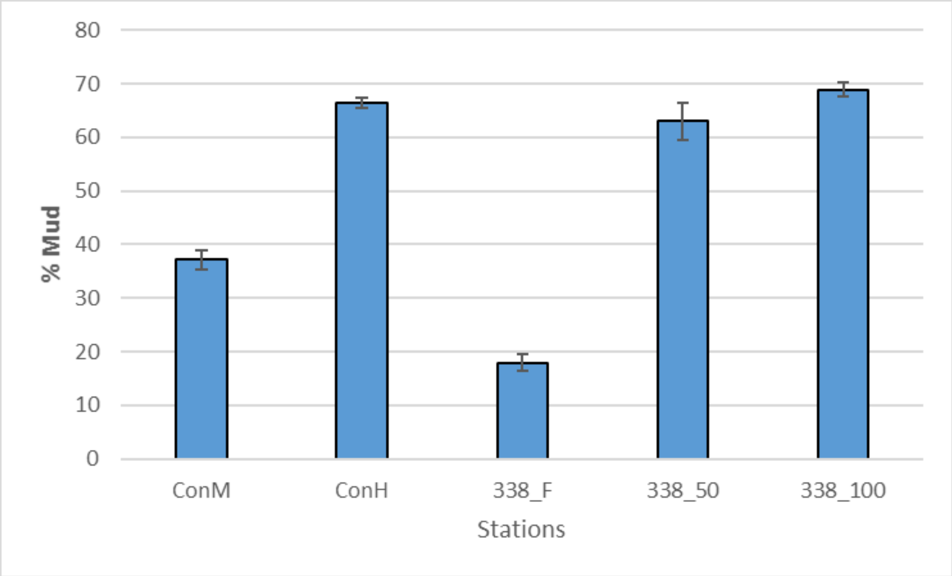
Sediment texture (% mud, % sand and % very fine gravel) varied considerably between the two control and three farming sampling stations sampled in and around site 338_F, 338_50 and 338_100 (Figure 35). Such textural differences are thought to be related to the natural characteristics of each of the five stations sampled. Surprisingly, fish farm 338 sediments appear courser than control station M which is located near the head of the bay where there is higher energy (stronger flows).

In a study observing benthic infauna species richness and TOC content of sediments from several systems throughout the world, Hyland *et al.* (2005) suggested that potential losses to species richness were greatest when TOC in sediments was greater than 3.5% and lowest when TOC was lower than 1%. All stations from this study show TOC well below 3.5%.

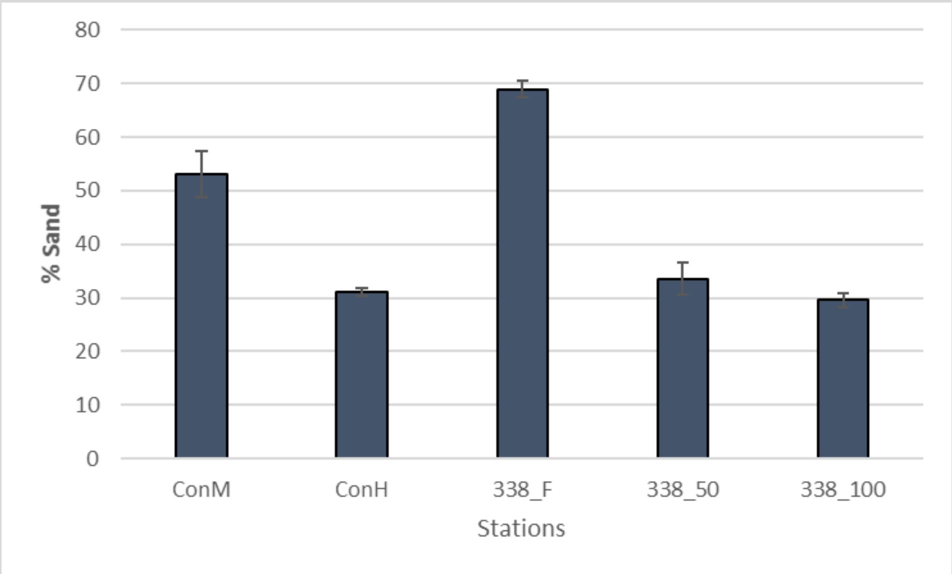
There was 1 mm redox layer in the cores and no sulphide odour emanated from the sediments (Appendices 7.3 and 7.4).



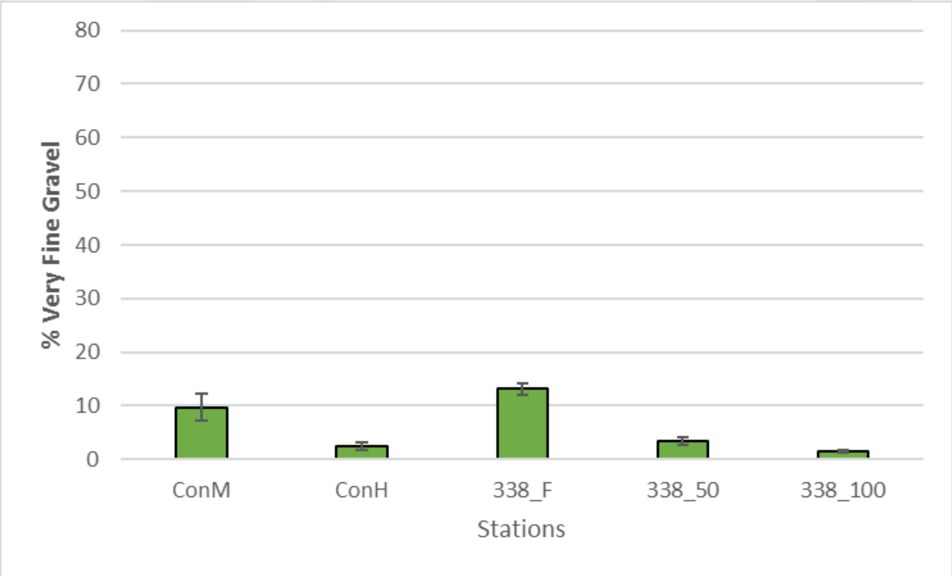




80
70
60
50
40
30
20
10
0
% Mud
ConM
ConH
338_F
338_50
338_100
Stations



80
70
60
50
40
30
20
10
0
% Sand
ConM
ConH
338_F
338_50
338_100
Stations



80
70
60
50
40
30
20
10
0
% Very Fine Gravel
ConM
ConH
338_F
338_50
338_100
Stations

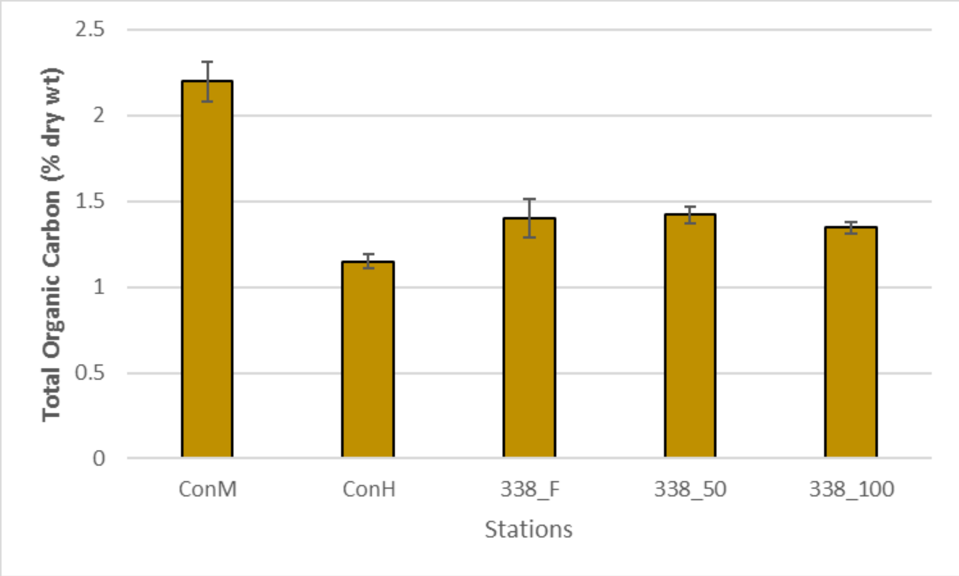


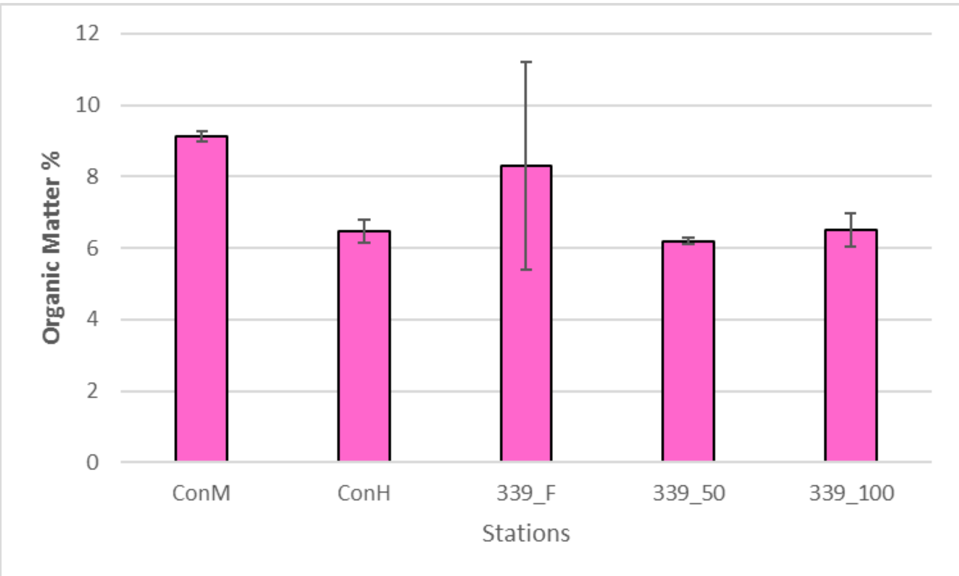
Figure 35: Sediment properties (organic matter, dry matter, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by salmon station 338_F, 338_50, 338_100 and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3..

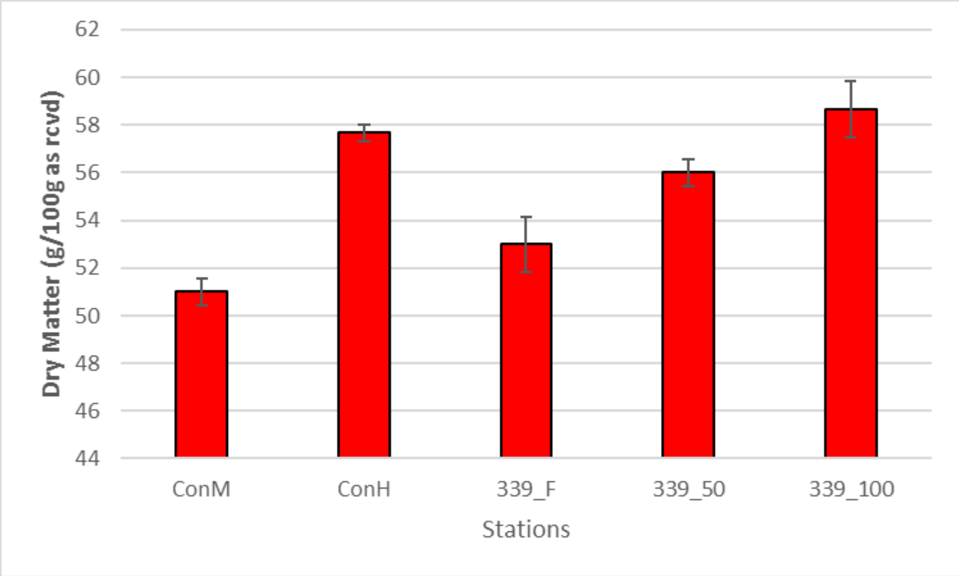
339

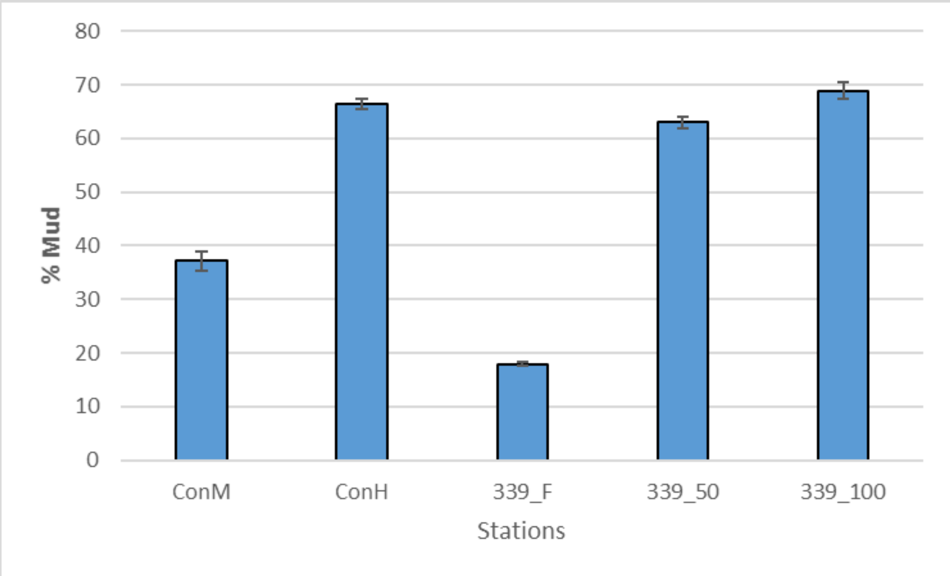
Sediment textures (% mud, % sand and % very fine gravel) very between the controls and the salmon farm 339_F, 339_50 and 339_100 sampling stations (Figure 36). Such differences are believed to relate onto specific characteristics of the site and aren't thought to be related to farming itself.

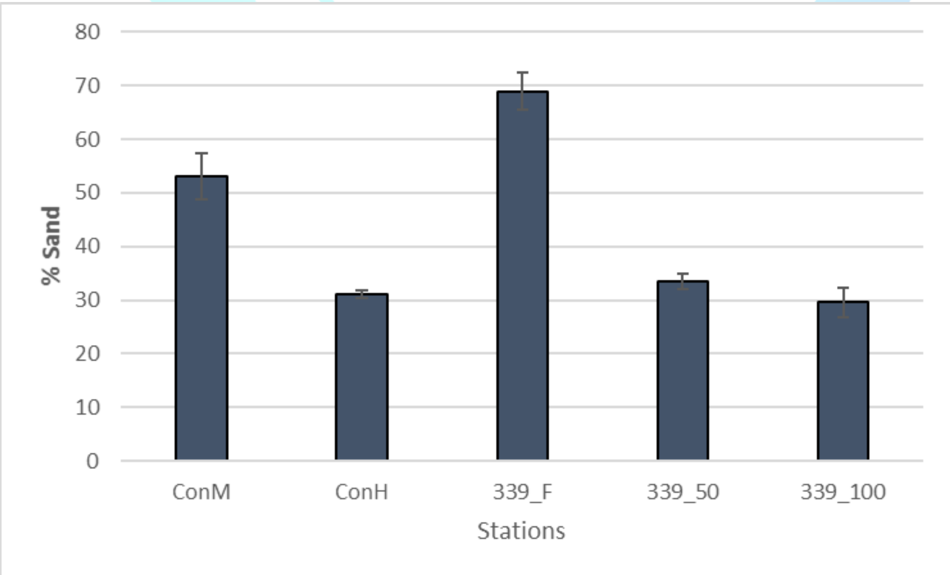
Total organic matter was observed to be higher under the farm (8 %) compared to the 50 and 100 meter sampling stations (less than 6.5 %). Organic carbon levels were high at the farm site, but there was high variability between each sample (hence the wide standard deviation).

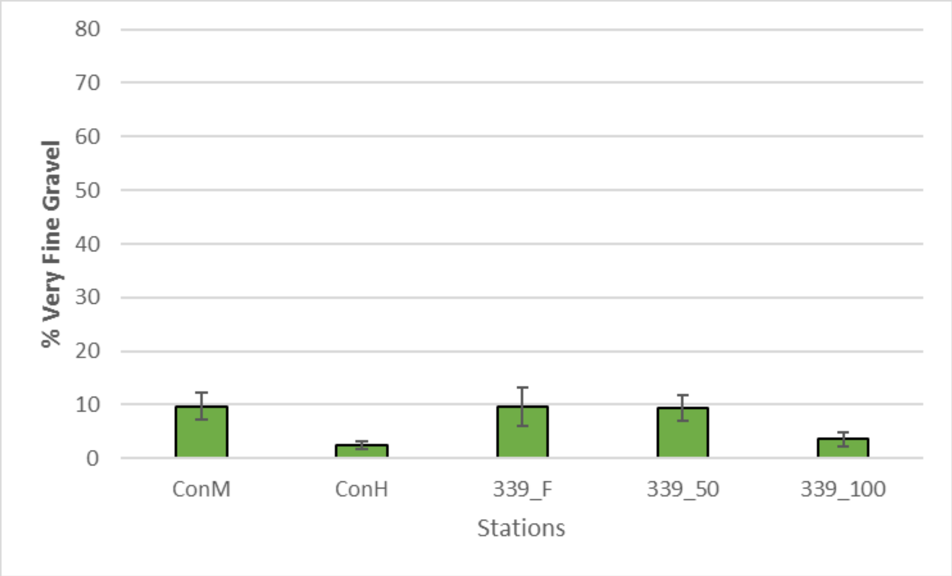
Strong sulphide odour was detected at 339_F, but was reduced to a mild odour at 239_50, and no odour was detected at 339_100. 1mm redox layer was observed at all 3 sample from Site 339. (Appendices 7.3 and 7.4).




Dry Matter (g/100g as rcvd)
62
60
58
56
54
52
50
48
46
44
ConM
ConH
339_F
339_50
339_100
Stations


% Mud
80
70
60
50
40
30
20
10
0
ConM
ConH
339_F
339_50
339_100
Stations


% Sand
80
70
60
50
40
30
20
10
0
ConM
ConH
339_F
339_50
339_100
Stations



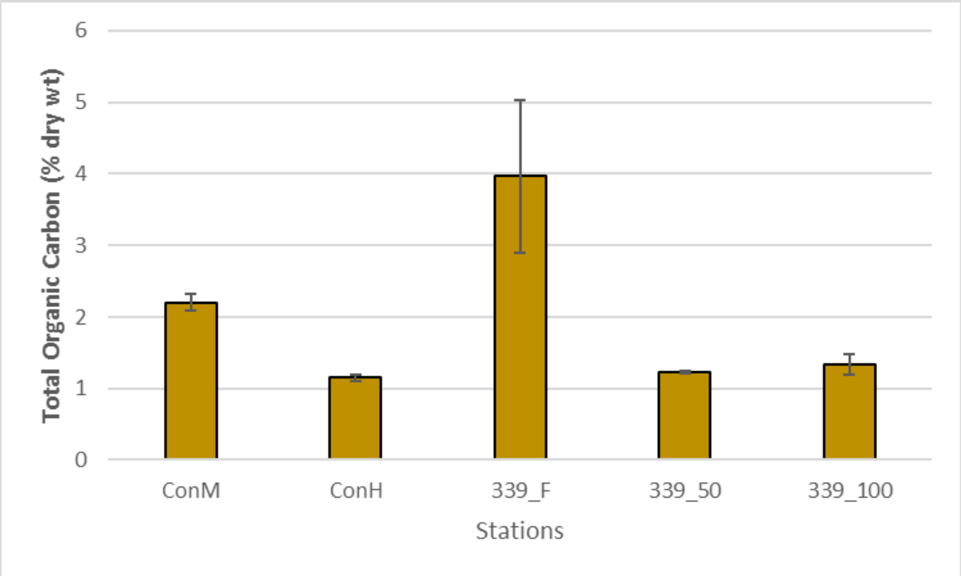


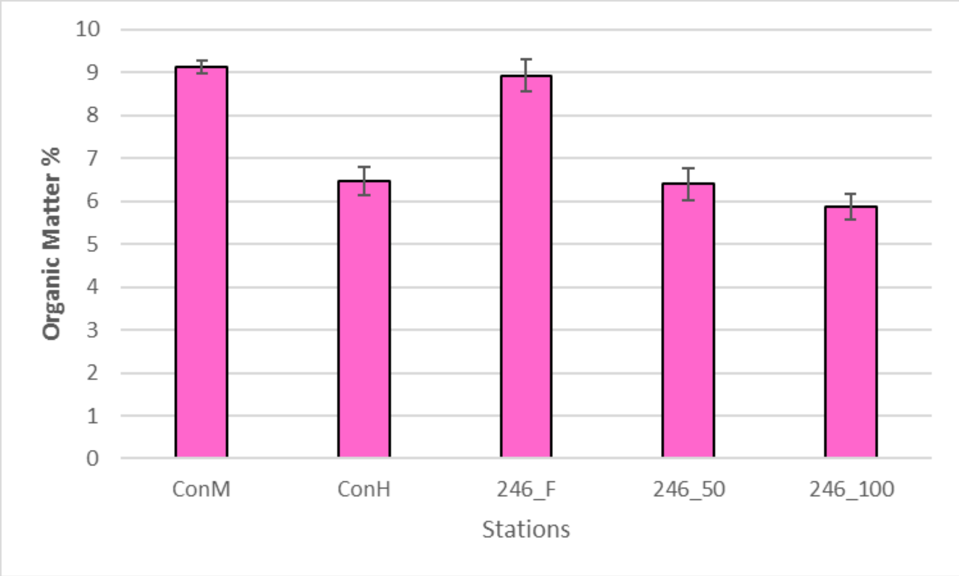
Figure 36: Sediment properties (organic matter, dry matter, ash, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by salmon stations 339_F, 339_50 and 339_100 and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

246

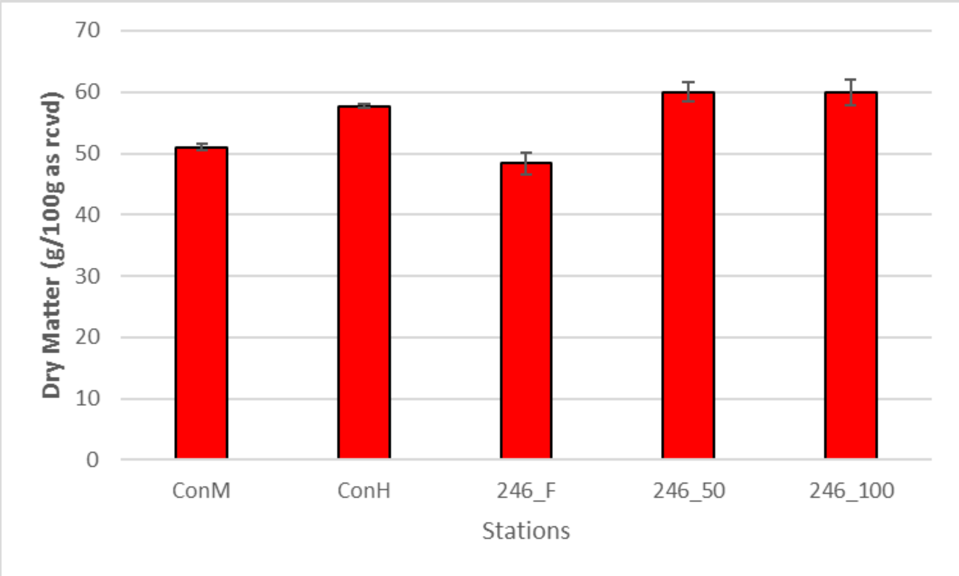
Again, sediment texture (%mud, % sand and % very fine gravel) was significantly different between the controls and the salmon farm 246_F, 50 and 100 m sampling stations (Figure 37). Such differences relate to specific characteristics of the site and aren't thought to be related to farming.

The sample taken under the farm cage at station 246_F showed that it is organically enriched with total organic matter surpassing ConH and coming close to values observed at ConM.

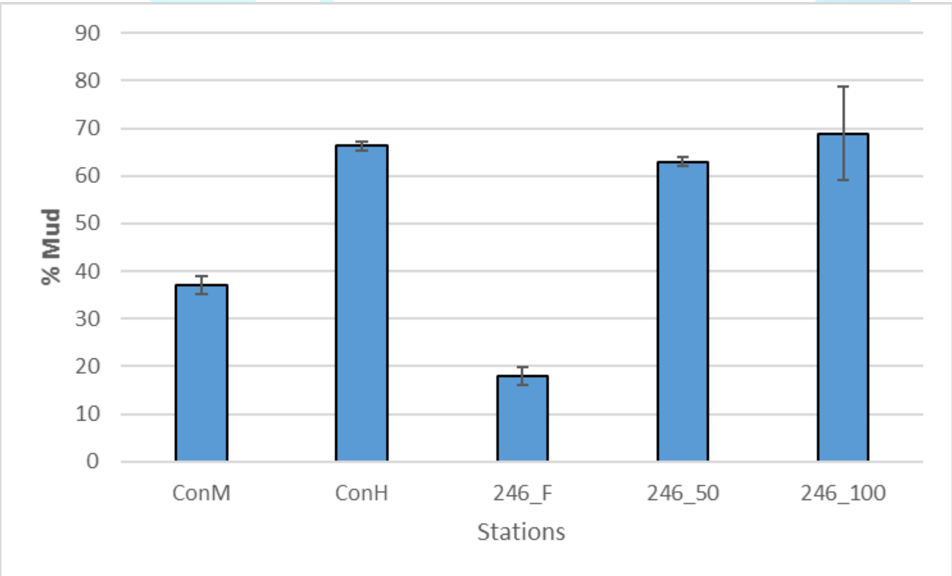
No sulphide odour detected emanating from any samples collected from 246 station. A small (1 mm) redox layer was observed at each farm sample while a thicker layer (3-4 mm) was observed at the 50 and 100m stations.



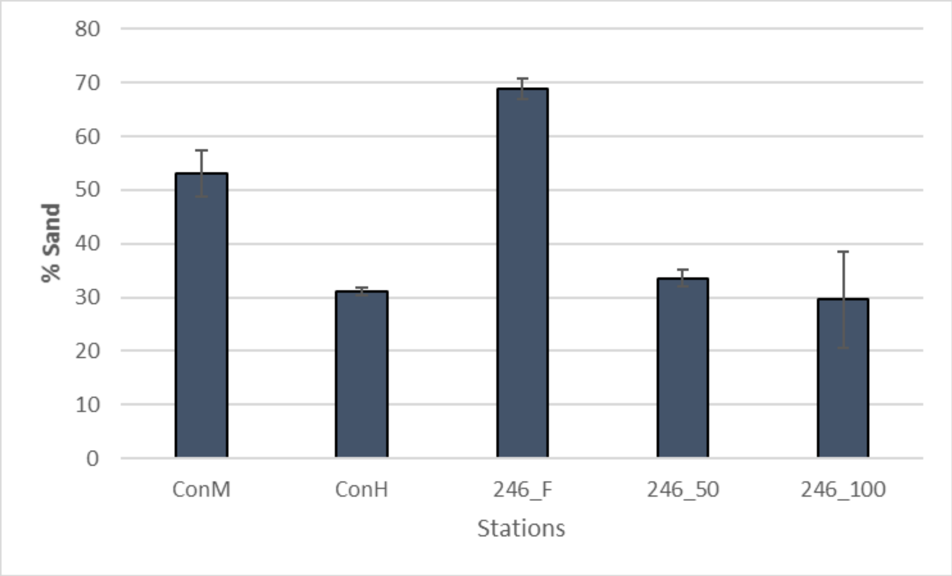
Organic Matter %
10
9
8
7
6
5
4
3
2
1
0
ConM
ConH
246_F
246_50
246_100
Stations

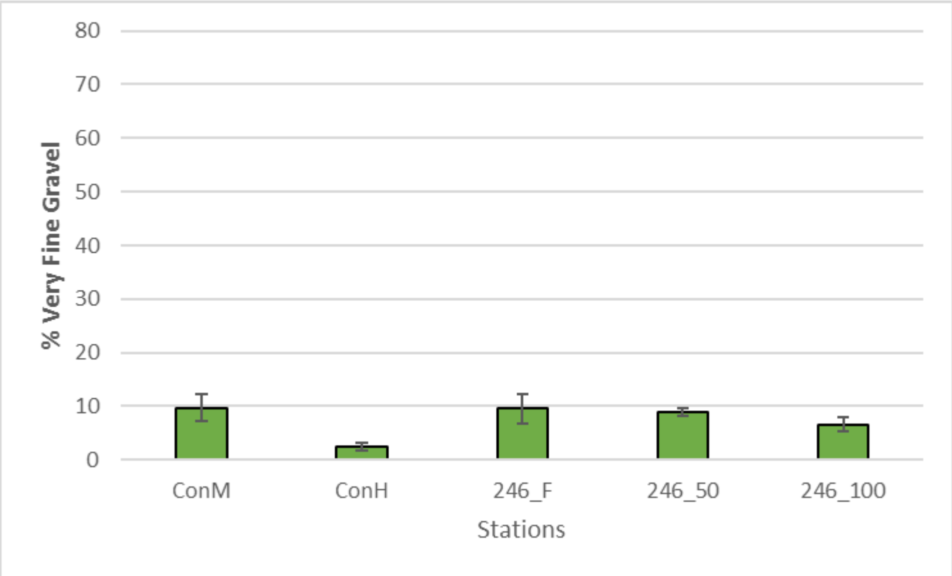


Dry Matter (g/100g as rcvd)
70
60
50
40
30
20
10
0
ConM
ConH
246_F
246_50
246_100
Stations



% Mud
90
80
70
60
50
40
30
20
10
0
ConM
ConH
246_F
246_50
246_100
Stations


% Sand
80
70
60
50
40
30
20
10
0
ConM
ConH
246_F
246_50
246_100
Stations


% Very Fine Gravel
80
70
60
50
40
30
20
10
0
ConM
ConH
246_F
246_50
246_100
Stations

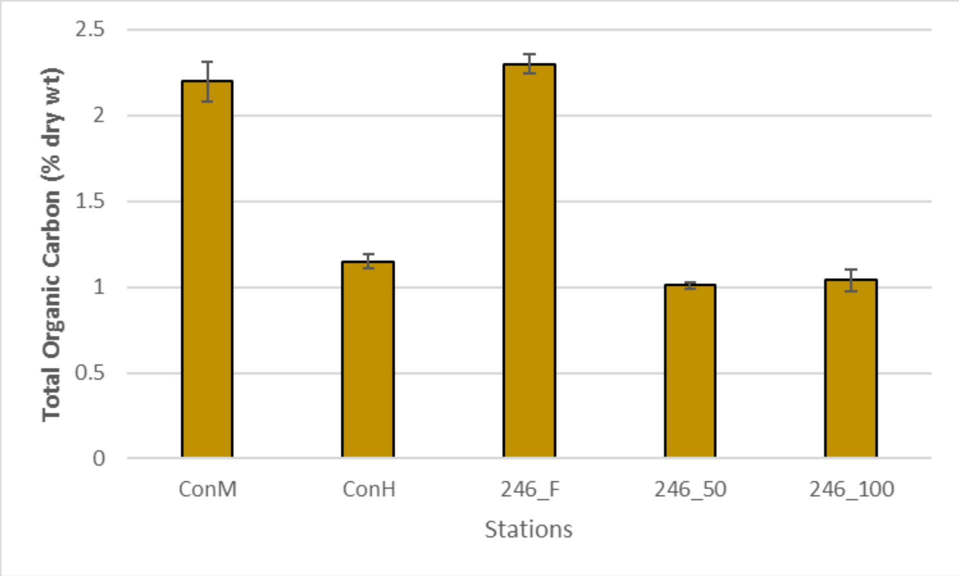


Figure 37: Sediment properties (organic matter, dry matter, % mud, % sand, % very fine gravel and total organic carbon) from the area covered by salmon stations 246_F, 246_50 and 246_100 and at the two control stations. (ConM = Control Mouth and ConH = Control Head) Mean ±1 SE, n=3.

All control and salmon farming stations have been tested for Copper and Zinc content. Copper is used as anti-fouling agent in paint that is applied to fish nets while zinc is an ingredient in salmon feed.

Copper values under the new 246_F site are low as the farm is less than 1 year old.

Table 4 shows the data (means and standard deviations (n=3) relative to the ISQG-Low and High thresholds for these metals (ANZECC 2000).

At the 246_F station, the mean copper concentration was 10.7 mg/kg and is well below the ISQG-Low threshold of 65 mg/kg. Similar low levels of mean copper concentration also detected in 50 m to 100 m (6.7 mg/kg and 5.3 mg/kg, respectively) away from the site boundary. The mean zinc concentrations were all lower than the low threshold of 200 mg/kg.

At 338_F the mean copper concentration was 1383.3mg/kg, the highest observed across the entire study area. Copper concentrations were orders of magnitude lower 50 m (23.7 mg/kg) and 100 m (12.7 mg/kg) away from the farm leases. The mean zinc concentrations were highest under the cage at this station compared to all other sampling stations at 284.7 mg/kg (less than the 410 mg/kg – High threshold). 50 m away from the site boundary the mean zinc concentration was lower at 57.3 mg/kg and 100 m away from the site boundary at 46.0 mg/kg well is below the ISQG – Low threshold (200 mg/kg).

The mean copper concentration measured under the cage at 339_F was 1353.3 mg/kg which is significantly higher than the ISQG high range of 270 mg/kg. However, copper concentrations were lower than the Low threshold 50 m (13.0 mg/kg) and 100 m (11.3 mg/kg) from the site boundary. Mean zinc was 357.7 mg/kg under the cage (less than the 410 mg/kg – High threshold), while low zinc concentrations were detected 50 m (37.3 mg/kg) and 100 m (36.0 mg/kg) from the site (see Table 4).

Copper values under the new 246_F site are low as the farm is less than 1 year old.

Table 4: Mean and standard deviation of copper and zinc concentrations (mg/kg) at all the sampling stations. These data are listed in accordance with the ISQG-Low and ISQG-High thresholds for both metals (ANZECC 2000). Green = below ISQG-Low thresholds, Orange= between ISQG-Low and High thresholds, and Red= above ISQG- High thresholds

Station	Copper (mg/kg) dry wt						Zinc (mg/kg) dry wt					
	< Low 65		< High 270		> High 270		< Low 200		< High 410		> High 410	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ConM	7.7	0.6					32.7	4.5				
ConH	9.3	0.6					31.7	2.5				
244_F	NA						NA					
340_F	NA						NA					
338_F					1383.3	884.4			284.7	153.6		
338_50	23.7	14.2					57.3	19.9				
338_100	12.7	0.6					36.3	2.3				
339_F					1353.3	1158.5			357.7	248.6		
339_50	13.0	3.0					37.3	2.1				
339_100	11.3	1.5					36.0	3.6				
246_F	10.7	1.2					43.7	5.1				
246_50	6.7	1.2					29.3	1.5				
246_100	5.3	1.2					27.3	1.5				

4.5.2 Benthic Seabed Features and Epifauna

4.5.2.1 Introduction

A total of 17 conspicuous seabed features were identified and recorded from photo quadrats, including 13 different seabed-dwelling organisms (this included invertebrates and benthic algae) (Table 5, Appendix 7.6). Six epifauna taxa were observed at both control sites. As in 2016 a summer storm impacted seabed visibility a few days before ADS conducted the survey.

A few specific observations include:

At mussel farm station 244_F and 340_F, only two epifaunal species were observed which are *Notolabrus celidotus* and Green-Lipped Mussels.

Drop camera photos showed the presence of small finfish at stations 244_F, 246_F, 338_F, and 339_F.

A large number of mussel shells were observed in the sediments at the new 246_F salmon farm station supporting that indeed this site was previously used for mussel farming (Appendix 7.6). At ConM there are species that were identified that weren't observed at any of the other sampling stations (coralline algae). These species are likely present due to the location of the stations (closer to the mouth of the bay), where numerical modelling indicates that there are stronger currents than other areas of the bay (resulting in coarser sediments, though there was a high level of organic material which is surprising.).

Statistical analyses indicate that the control stations, mussel farms, salmon farms and their 50 and 100 m stations clustered (using Bray-Curtis similarities) into two main groups (Figure 38) based on presence-absence of seabed features and epibiota (Table 5). Replicates for Control Station H (ConH) were grouped together along with replicates collected 100m from the edge of the farm lease at 338_100. Somewhat surprisingly replicates for Control Station M (ConM) were grouped together with those replicates from 246_50, 246_100 and from 338_100. There is some variability in samples collected in and around the salmon and mussel farms.

Another method of grouping replicates from these stations is to undertake MDS (or multiple Dimensional Scaling) analysis. In the resulting MDS plot the further the dots (presenting sample stations) are apart the less similar the sample is (Figure 39).

Table 5 Conspicuous seabed features and epibenthos seen in photo-quadrats. 0 = absent, 1 = present

Stations	244_F			246_F			246_50			246_100			338_F			338_50			338_100			339_F			339_50			339_100			340_F			ConH			ConM		
Replicate	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Small holes/burrows	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
Worm tubes	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Mussel shell	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0
Shell hash	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Yellow sponge	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	1
Solitary ascidian	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Greenlip mussels	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Glycymeris shells	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pecten novaezelandiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Ophiopsammus maculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Patiriella regularis	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notolabrus celidotus	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small finfish	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Beggiatoa* sp.**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coralline algae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Red algae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Green algae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
Shark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bryozoan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
Anemone	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

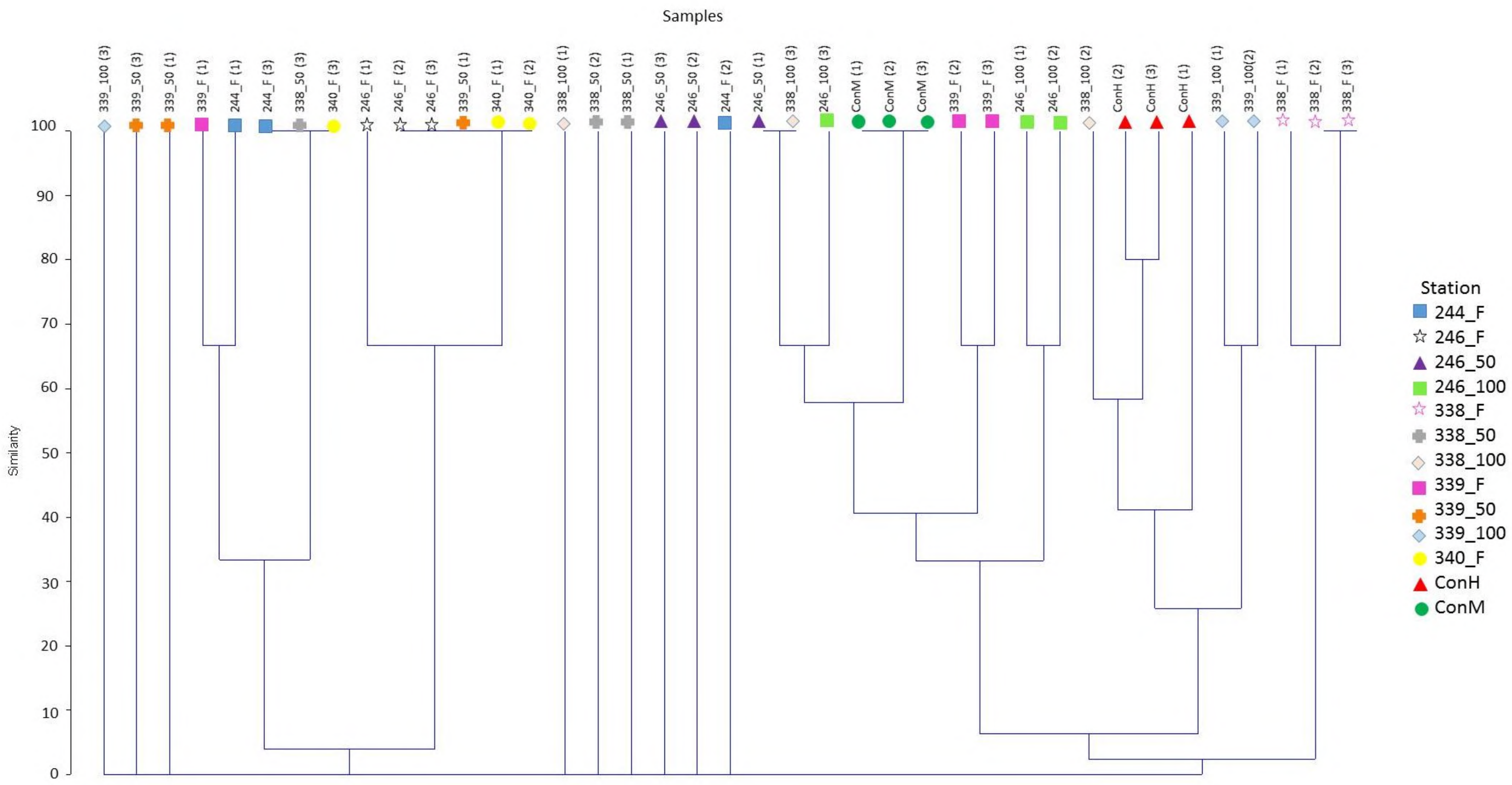


Figure 38: Cluster analysis (Bray Curtis similarities) of Big Glory Bay replicate samples and stations based on the epibenthic features.

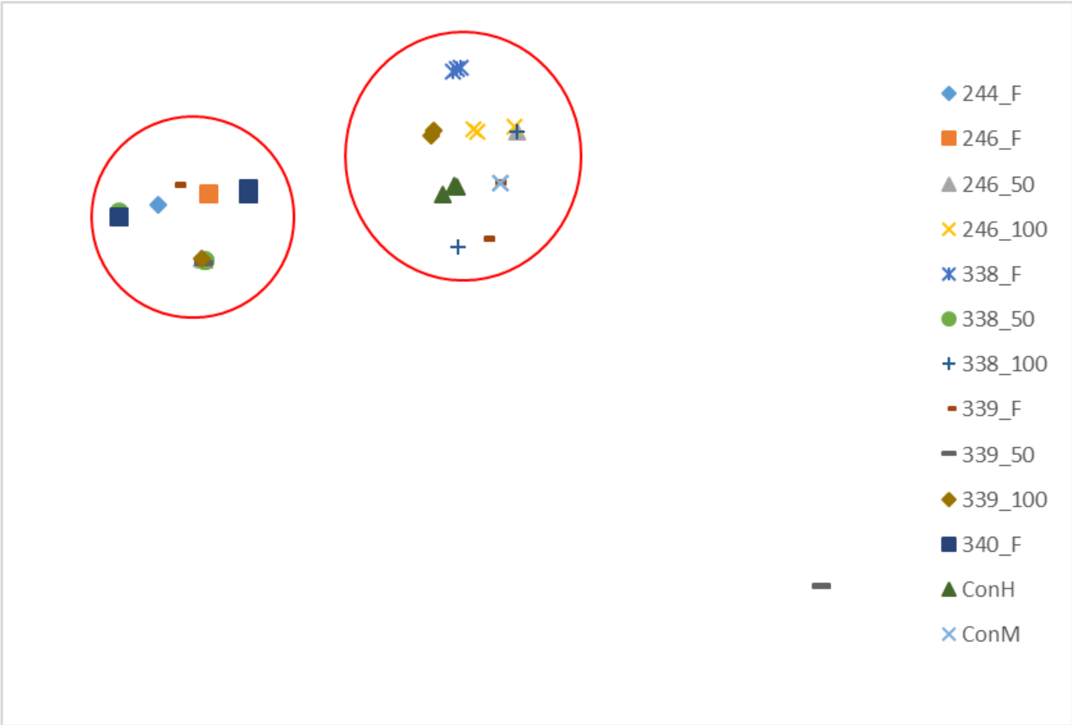


Figure 39: Multidimensional scaling plot of relationships between control, mussel and salmon stations in Big Glory Bay based on epibenthic features and epifauna.

4.5.3 Benthic Infauna

A list of the infauna species and their densities per station and replicate is given in Appendix 7.7.

4.5.3.1 Infauna structure

4.5.3.1.1 Number of species (S)

Sampling station 246_50 (Salmon station) has the highest number of species (14) found during this sampling period (Figure 40). Three stations, 338_100, 339_50 and 339_100 (Salmon station) contained 13 species found. Samples collected beneath the cage at farm station 339_F contained the lowest number of species (2).

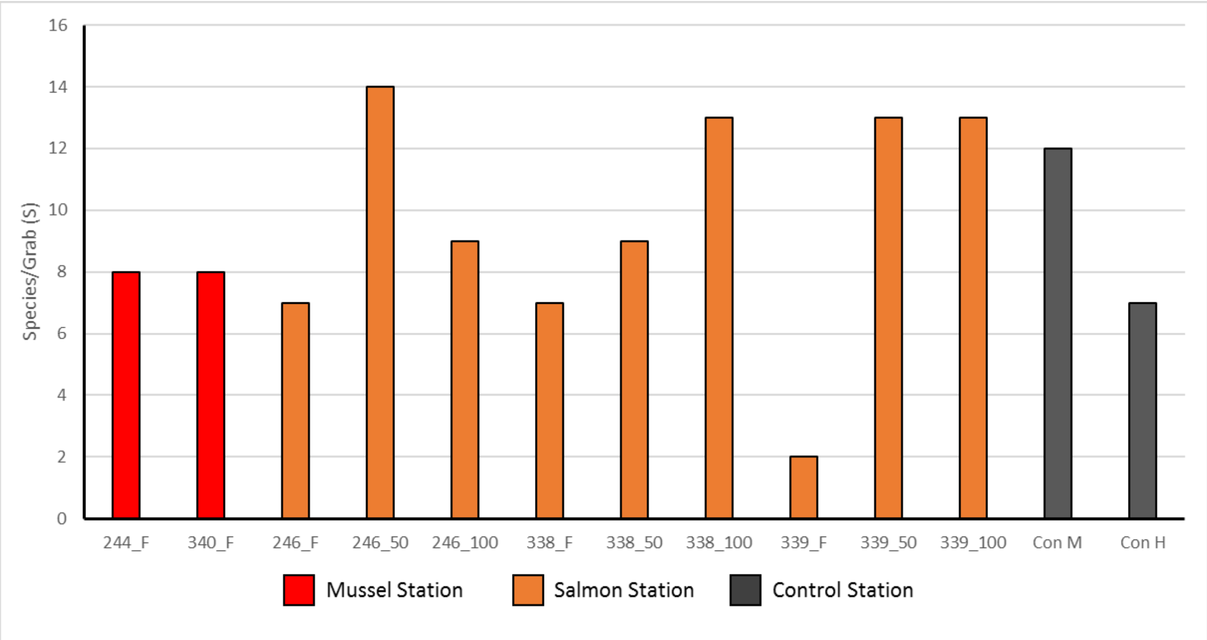


Figure 40: Mean number of species/core (S) from sediments at all sampling stations.

4.5.3.1.2 Densities (N)

Mean infauna densities or abundance (N, individuals/grab) at the control stations were 12 at ConM and 11 at ConH (Figure 41). Highest mean densities were found from samples collected from salmon stations 246_50 (25).

Mean densities varied widely between stations and it can be observed that on farm site 338 and 339 (salmon farm) species density appears to have increased with distance from the site boundary.

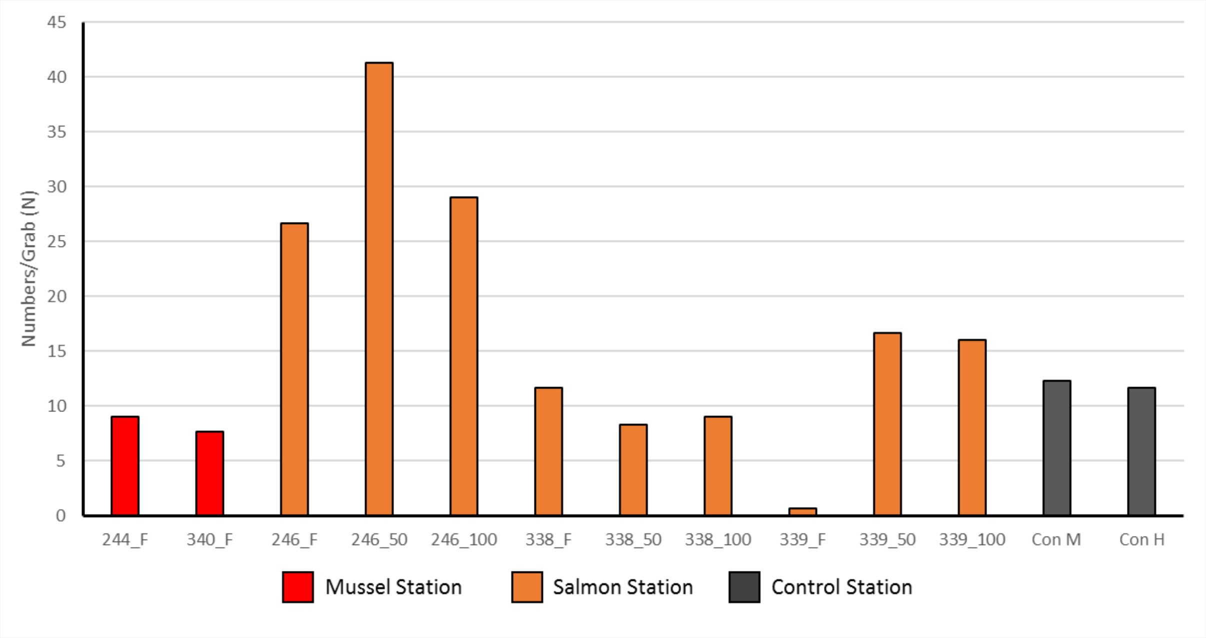


Figure 41: Mean density of individuals/grab (N) from sediments at all sampling stations.

4.5.3.1.3 Species richness (d)

The species richness index (Margalef's, *d*) varied widely between stations and little if any trends can be observed other than perhaps at farm site 338 (salmon farm) where species richness appears to have increased with distance from the site boundary (Figure 42).

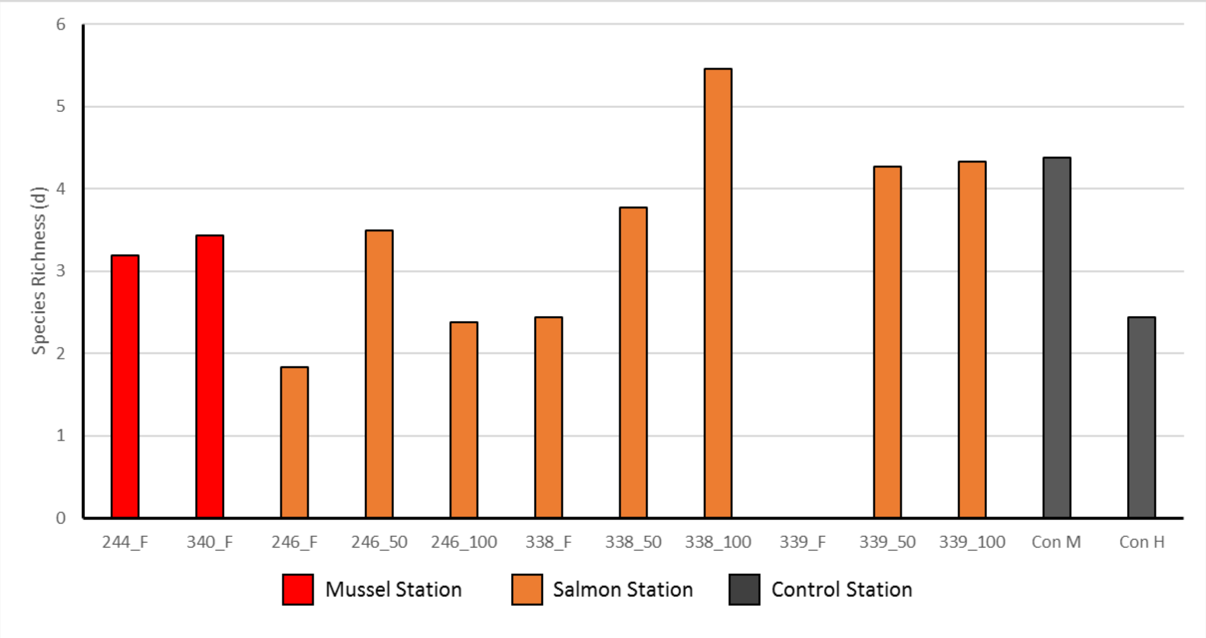


Figure 42: Mean number of species richness index (Margalef's d) from sediments at all sampling stations.

4.5.3.1.4 Infauna community composition

4.5.3.1.4.1 Mussel farms

Figure 43 shows the composition matrix comparing two mussel farm stations (244_F and 340_F) with control stations (ConM and ConH).

Polychaetes were found at both mussel farms stations (244_F; 3 species, 340_F; 2 species). *Dorvilleid sp.* were found at both stations, while *Glycerid sp. & Polychaeta Unidentified sp.* were only found at 244_F and *Capitellid sp.* was only found in 340_F. The additional (*Dorvilleid* and *Capitellid*) polychaete species observed within the mussel farm stations are likely attracted to the organic rich mussel farm faeces deposition.

For bivalves, several individuals were observed across both mussel farm sites.

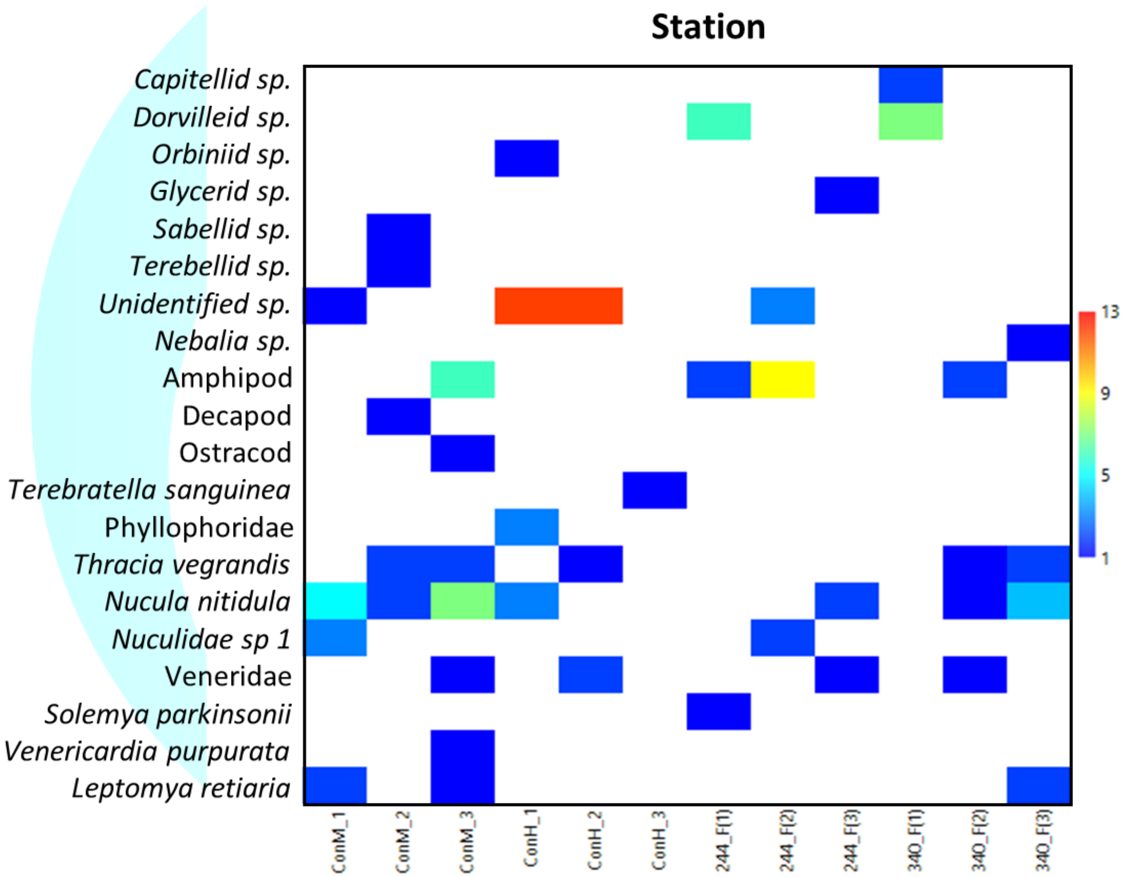


Figure 43: Abundance matrix of infauna species at control and mussel stations. The vertical colour bar indicates numbers/grab.

Figure 44 indicates that the infauna differed for each farm site, between farms and controls stations. Some similarity (50-60%) was observed between the controls and farming stations.

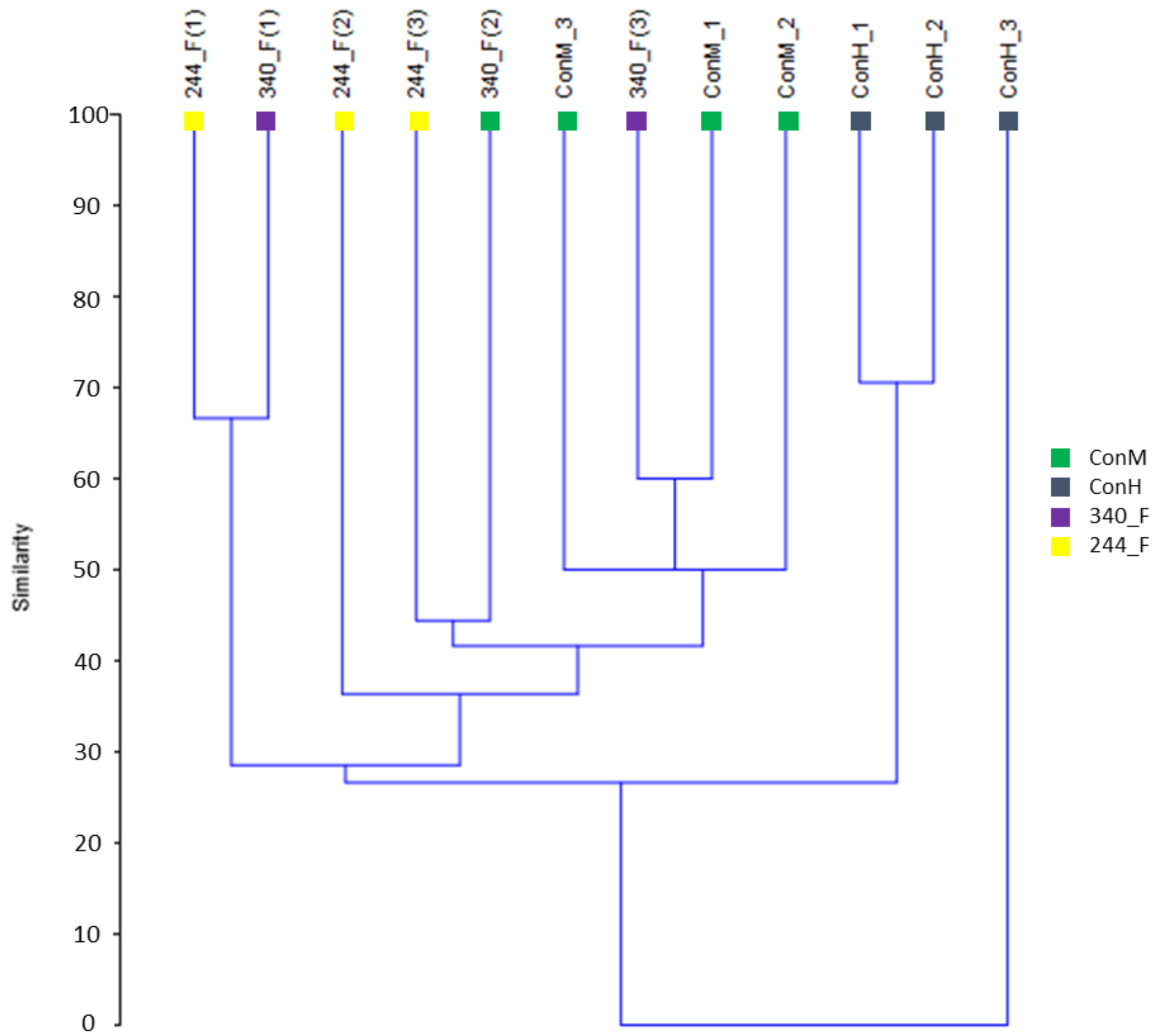


Figure 44: Dendrogram showing cluster analysis (Bray-Curtis similarities) results for infauna at mussel farms 244_F and 340_F and Control Stations. (1), (2) and (3) are three replicates samples per station.

These differences between stations were statistically significant overall (one way ANOSIM/analysis of similarity; R=0.02315 p= 0.4109).

The above analysis indicates that the mussel stations still retained a moderately high species richness and diversity. A wide range of polychaete species were observed (*Dorvilleid sp. Glycerid sp. & Polychaeta Unidentified sp*). Filter feeding bivalves (*Solemya parkinsonii, Nuculidae sp 1, Nucula nitidula, Veneridae, Thracia vegrandis & Leptomya retiariia*) were also found in the mussel sampling stations. Amphipods were also collected beneath the mussel farm station 340, though in low abundance (Appendix 7.7).

4.5.3.1.4.2 Salmon farms

The salmon stations still retained a moderately high species richness and diversity. A wide range of polychaetes were found at these sites (*e.g. Capitellid sp., Maldanid sp., Dorvilleid sp., Lumbrinerid sp., Opheliid sp., Oweniid sp., Orbiniid sp., Glycerid sp., Goniadid sp., Nephtyid sp., Sabellid sp., Terebellid* *sp.* and *Ampharetid sp.*) and filter feeding bivalves were also common (*Nucula nitidula, Thracia vegrandis, Nuculidae sp 1, Leptomya retiaria, Veneridae, Solemya parkinsonii* and *Venericardia purpurata* See Appendix F for full species counts).

A Bray-Curtis Similarity Index was used to investigate the similarity of infauna between salmon farm and control stations (Figure 45)

There was generally "some" similarity between salmon and control stations. At stations 339_F(2), 338_100(2)and 246_100(1) no species were found and ConH (3) was clustered on its own at c. 5% similarity to all other stations.

An MDS (Multiple Dimensional Scaling) plot confirmed this trend of similarity (Figure 46).

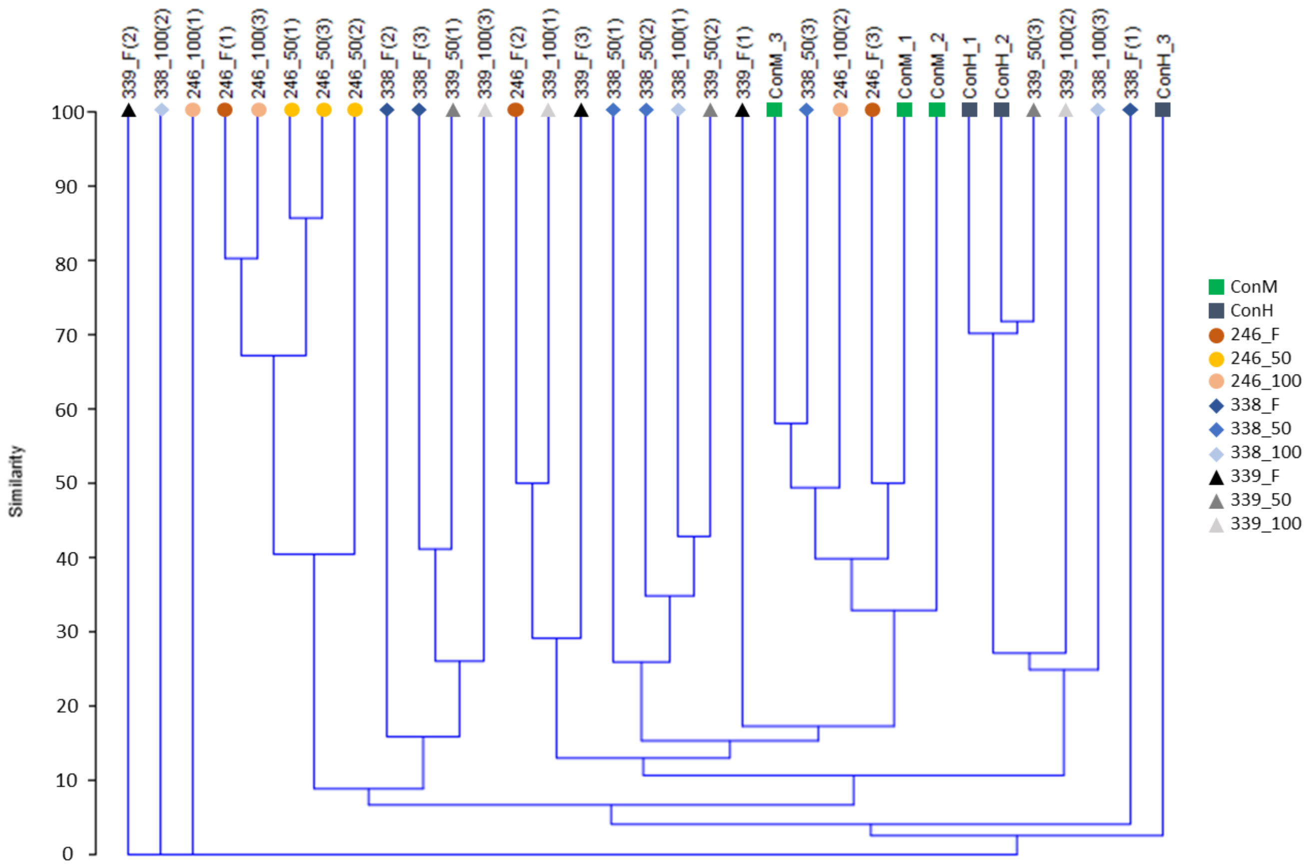


Figure 45: Cluster analysis dendrogram based on Bray-Curtis similarities between infauna composition at control and salmon farm stations.

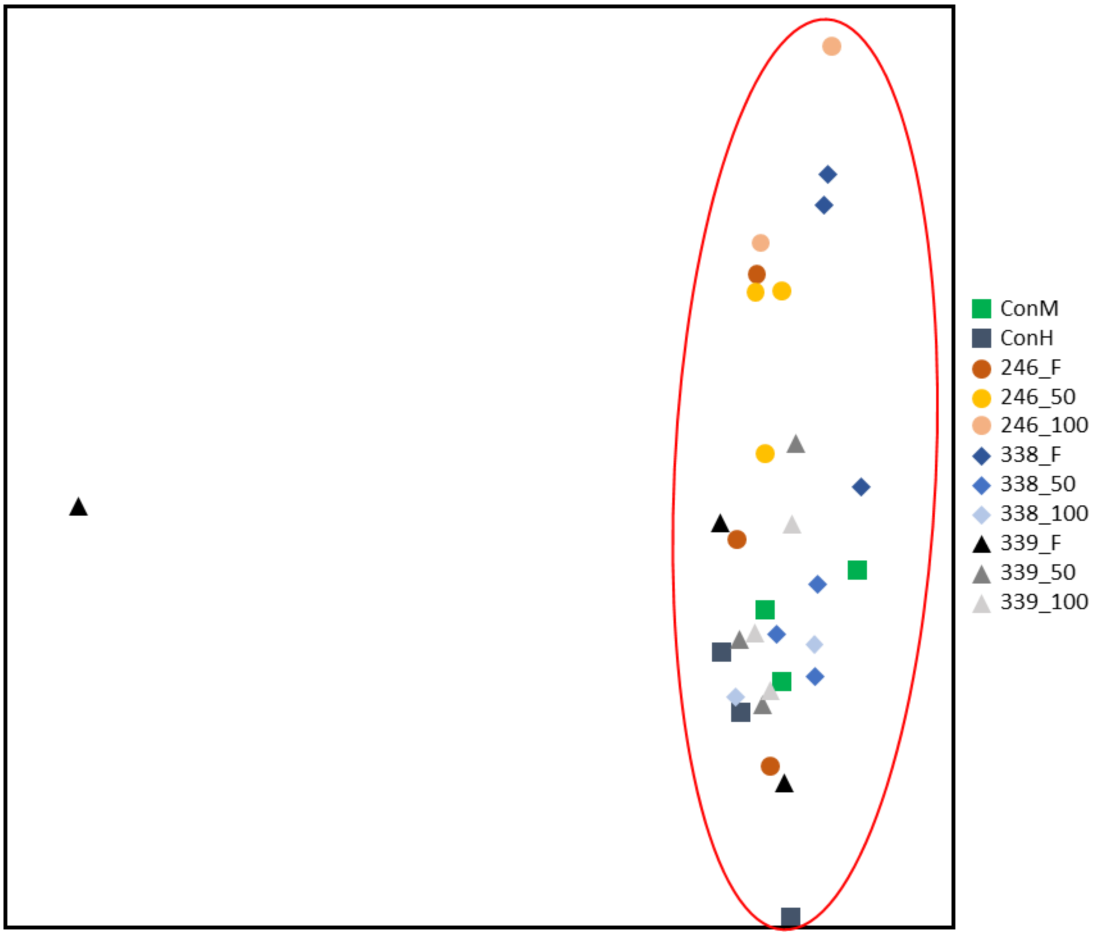


Figure 46: MDS (Multiple Dimensional Scaling) analysis plot of control and salmon farm stations based on Bray-Curtis similarities between infauna composition at control and salmon farm stations.

A SIMPER analysis was used to examine the similarity of infaunal composition between farm stations and individual species within each station vs each of the two control stations. When comparing Control H with the farm site samples *Amphipod sp*. was the most dominate species observed (but only at the farm sites and is the most common/similar between all farm sites sampled), while at Control H a large number of filter feeding polychaetes (unidentifiable as they were damaged in the sampling process) were present. Bivalves were present at both the control and farm site (Figure 47).

In comparison (at control M) *Amphipod*s and bivalves were observed at both the farm and control M sites. (Figure 48) and had the highest similarity.

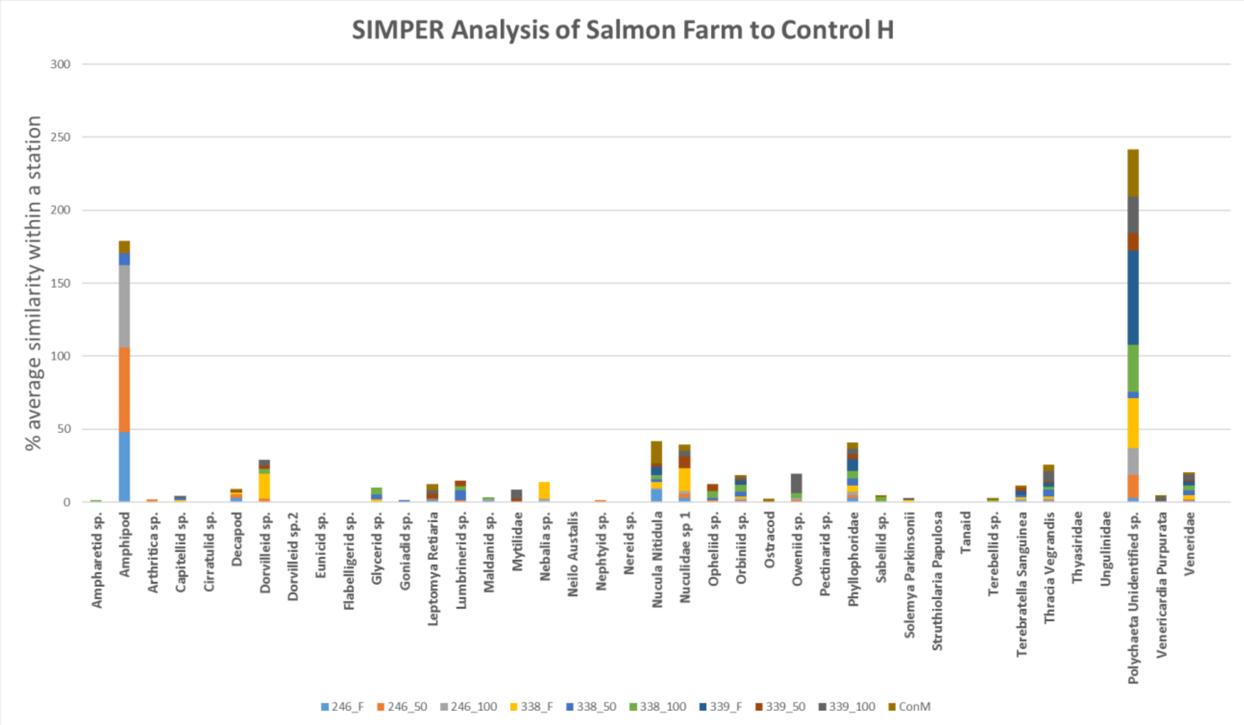


Figure 47: Species contributing to the percentage similarity of infauna composition between the three replicates at each station compared to ConH based on SIMPER (Similarity percentage) analysis.

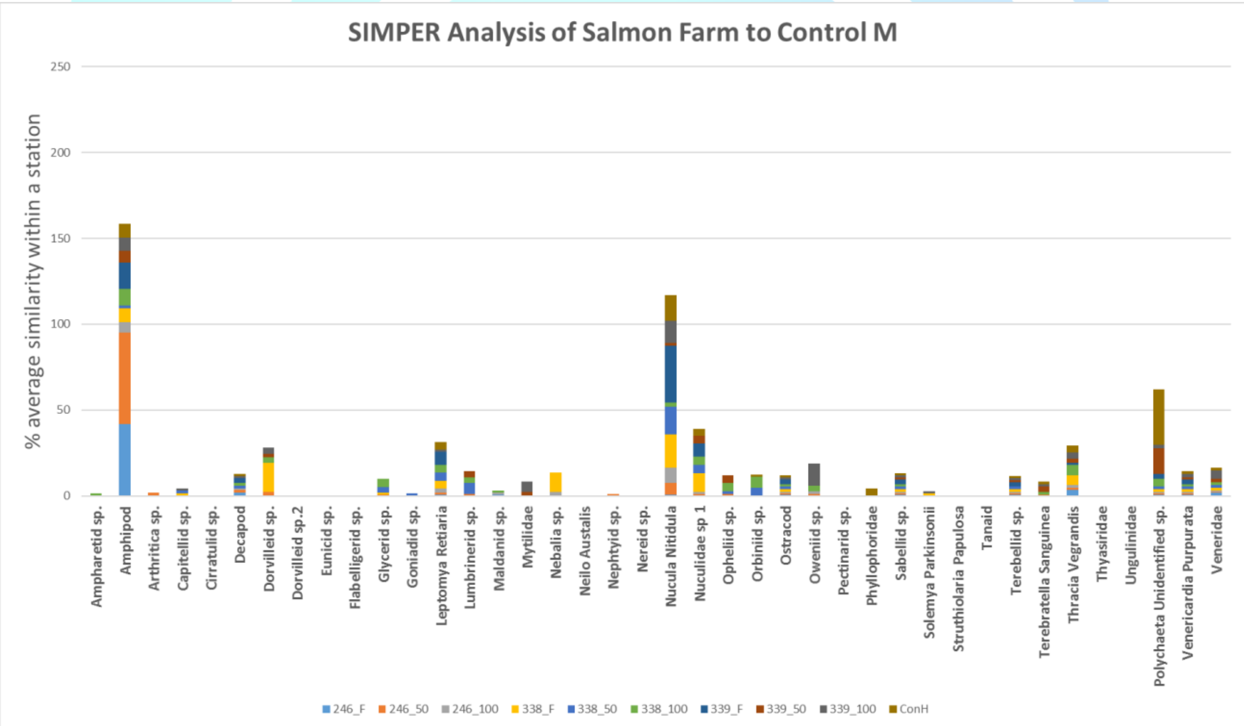


Figure 48: Species contributing to the percentage similarity of infauna composition between the three replicates at each station compare to ConM based on SIMPER (Similarity percentage) analysis.

5 CONCLUSIONS

Water sampling using both a multi-parameter sonde and a Van Dorn sampler (to collect water for laboratory analysis) was undertaken at six sampling stations within Big Glory Bay. The *In-situ* parameters sampled include DO, salinity, water visibility, and temperature. Results indicate that DO levels within the bay were above 6mg/l during all sampling periods and at all depths. There is no indication that fish or mussel farming activities are having any adverse impacts on oxygen levels within the bay. Generally, DO levels need to fall below 5.5mg/l or lower for extended periods of time to have an adverse impact the broader ecological community (US EPA 2012).

Temperature data indicate a slight thermal stratification during summer periods. Sonde casts indicate that the surface waters of Big Glory Bay can be approximately 1 degree warmer than deeper water column, which is related to climatic forcing and not farming activities.

Higher Chl-*a* levels were observed in late summer and spring (we assume there was a spring phytoplankton bloom) and corresponded to lower levels of soluble and particulate nutrients. In Autumn, Chl-*a* levels were lower while both soluble and particulate nutrient concentrations increased (perhaps as a result of die off and cooler temperatures). Previous modelling and wide scale water quality monitoring (DHI 2012 & Key, 2001), indicates that large changes in nutrient dynamics occur due to regional changes outside of the bay (*i.e*. influx of nutrient rich water into the bay).

Other water quality parameters indicate no detectable adverse water quality conditions within the bay.

Results of the seabed sampling and analysis indicate that the seabed in an around the mussel and finfish farm sites is typical of that observed in several marine aquaculture impact studies including those undertaken in the Marlborough Sounds during the early 2000’s (Hartstein, 2003). As with the 2016 survey seabed visibility was poor in places dues to another storm event that occurred a few days before sampling.

Organic enrichment (when compared to the nearby central bay control station ConH) was observed beneath most farming stations (both mussel and fish farm), along with mussel shells (at both mussel farms and one of the salmon farms, which was once a mussel farm). Opportunist polychaetes (*i.e. Dorvilleid*) were also observed beneath both mussel farms and two of the three salmon farms. Similar species have been observed in and around many mussel farms in the Marlborough Sounds. Copper concentrations were observed to be elevated beneath both the 338 and 339 farm leases but copper quickly attenuated to background levels 50m from the edge of lease. At the new 246 salmon farm lease there was no sign of additional copper in the sediments.

Both the mussel and salmon stations still retained a moderately high species richness and diversity. A wide range of polychaetes were found at these sites including grazers, detritivores, opportunists, and predators. Conditions were generally observed to improve (*i.e.* organic matter content decreased away from the site boundaries) with distance from the salmon farms (50 and 100m from the site boundary). The seabed under the new 246_F site looked to be almost un-impacted as there was no increase in metals and few if any opportunistic polychaetes. Currents at this site are also stronger (as it is at the mouth of the bay) and this will likely aid in reducing the impact beneath the farm. A recent storm may also have acted to help clean the seabed of farm related organic material.

During the 2016 survey, *Beggiatoa* matting was observed both beneath farm stations 249_50 and 249_100 and patchy *Beggiatoa* was also observed beneath mussel farm site 272. **During the 2017**

survey *no Beggiatoa* was observed at any of the sites surveyed. Fish farm feed waste was observed under the farm at 339_F, however there was no sign of any feed waste 50 or 100m from the cage edge.

Overall, the sediment quality in Big Glory Bay appears to have improved since the 2016 (no sign of *Beggiatoa*) and does not appear to be badly impacted given that there are a large number (more than 30) farms scattered across the entire bay. Both control stations, one situated in the middle of the bay while the second is toward the mouth, appear to be un-impacted by farm debris.

6 REFERENCES

ANZECC. (2000) Australia and New Zealand guidelines for fresh and marine water quality 2000 Volume 1. National Water Quality Management Strategy Paper No.4. Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Black, K.D., Hansen, P.K., Holmer, M. (2008) Salmon Aquaculture Dialogue: Working Group Report on Benthic Impacts and Farm Siting. 54 p.

Clarke, K.R., Warwick, R.M. (1994) *Changes in marine communities: An approach to statistical analysis and interpretation*. Plymounth Marine Laboratory, Plymouth, United Kingdom.

Clarke, D., Taylor, D., Keeley, N., Dunmore, R., Forrest, R., Goodwin, E. (2011) Assessment of effects of farming salmon at Ruaomoko, Queen Charlotte Sound: deposition and benthic effects. Prepared for The New Zealand King Salmon Company Limited. *Cawthron Report* No. 1992. 52 p.

Cromey, C.J., Nickell, T.D., Black, K.D. (2002) DePOMOD – modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214: 211-239.

DHI, 2012. Appendix A, Hydrodynamic modelling. 56.

Hargrave, B.T., Holmer, M., Newcombe, C.P. (2008) Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. *Marine Pollution Bulletin* 56: 810-824.

Hartstein, N.D. and Stevens, C.L. 2005. Deposition beneath longline mussel farms. Aquacul-ture Engineering. 33 (3) 191-213

Hartstein, N.D. 2005. Acoustic Characterisation of Substrates in and Around Sheltered and Open-Ocean Mussel Aquaculture Sites and its bearing on the Dispersal of Mussel Debris. IEEE Journal of Oceanic Engineering. Vol 30, 85-94.

Hartstein, N.D and Rowden, A.A. 2004 "Effect of Biodeposits from Mussel Culture on Mac-robenthic Assemblages at Sites of Different Hydrodynamic Regime" Marine Environmental Research. Vol 57, 339-357.

Hopkins, G. (2008) Advice on the development of appropriate monitoring conditions for marine farm sites in Southland. Prepared for Environment Southland. *Cawthron Report* no. 1514. 18p.

Hyland, J., Balthis, L., Karakassis, I., Magni, P., Petrov, A., Shine, J., Vestergaard, O. and Warwick, R., 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. *Marine Ecology Progress Series*, *295*, pp.91-103.Keeley, N.B. (2012) Statement of Evidence in Relation To Benthic Effects. For The New Zealand King Salmon Company Limited – June 2012.

J. Key. 2001. Growth and condition of the greenshell mussel Perna canaliculus, in Big Glory Bay, Stewart Island: relationships with environmental parameters. MSc thesis Otago Univeristy.

Keeley N.B. 2012. Statement of evidence in relation to benthic effects. For the New Zealand King Salmon Company limited.

Kruskal, J.B., Wish, M. (1978) *Multidimensional scaling. Beverly Hills, California*. Sage Publications.

NIWA 2016, Assessment of water column and benthic environments of Big Glory Bay June 2014 to June 2015.

Pearson, T.H. and Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review, 16, 229-311.

Ren, J., Stenton-Dozey, J.M.E., Roulston, H., Grant, B. (2013) Benthic capacity of three proposed fish farm sites at Steward Island. Prepared for Sanford Ltd. May 2013. Client report CHC2013-051, Project no. SFL12502, 30p.

USEPA. 2012. 5.2 Dissolved Oxygen and Biochemical Oxygen Demand. http://water.epa.gov/type/rsl/monitoring/vms52.cfm Accessed 2/08/2012

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7 APPENDIX

7.1 APPENDIX A BIG GLORY BAY MONITORING PROGRAMME

APPENDIX 1
Big Glory Bay Monitoring Programme

1. The consent holder shall monitor the effects of the marine farming activities on the seabed, as follows:

   (a) (i) except for LI339, LI340, MF249, MF250, MF271, MF272 and MF365, monitoring of the seabed at representative locations under the marine farm site shall be undertaken at least once prior to 1 January 2025.

   Note: The Programme shall monitor at least two marine farm sites per year within the bay from the following marine farm sites LI149, LI315, LI316, LI317, LI318, LI319, LI320, LI321, LI322, LI324, LI325, LI337, LI338, LI342, LI366, LI418, LI461, LI474, LI475, MF244, MF245, MF246, MF247, MF248, MF273, MF274, MF275 and MF326 so each site is monitored at least once prior to 1 January 2025.

   (ii) an exception to Clause 1(a)(i) is if the marine farm site is actively farming salmon at the site, then monitoring of the seabed shall be undertaken at the following locations on an annual basis:
   (1) under the salmon cage as close as possible;
   (2) 50 metres from the site boundary identified in Appendix 2; and
   (3) 100 metres from the site boundary identified in Appendix 2.

   (iii) when the marine farm site is fallowed, monitoring of the seabed within the site boundary identified in Appendix 2, at the location previously occupied by salmon cages, shall be undertaken annually. If the marine farm site is reactivated to farm salmon then the annual monitoring regime in Condition 1(a)(ii) recommences and replaces this fallowing monitoring regime.

   (iv) within three months of the granting of this consent, monitoring of the seabed at the furthest point from the pen edge but within the site boundary of MF246.

   (v) in addition to Clause 1(a)(i), monitoring of the seabed at two control sites identified in the Programme and approved, in writing, by the Consent Authority. The monitoring shall occur every year for the first three years from the granting of this consent, then once every three years thereafter.

   (b) the samples will be analysed for the following to assess the sediment quality:

   - a sediment profile detailing the features of the sediment sample;
   - colour photographs of the sediment sample;
   - depth of the oxygenated layer below the sediment surface;
   - occurrence of hydrogen sulphide;
   - sediment texture and grain size;
   - total organic carbon content;
   - infaunal and epifauna community composition; and
   - zinc and copper trace metal levels.

2. The consent holder shall monitor the effects of the marine farming activities on the water quality, as follows:

(a) (i) monitoring of the water column shall be undertaken monthly for the first two years, commencing from 1 July 2011, by taking samples at four sites within Big Glory Bay and two control sites inside the bay, at a depth of 5 metres, as identified in the Programme and approved, in writing, by the Consent Authority.

(ii) after the first two years outlined in Clause 2(a)(i), monitoring of the water column shall be undertaken three times during the period of 1 November to 30 June each year and once during the period of 1 July to 31 October each year at four sites within Big Glory Bay and two control sites inside the bay, at a depth of 5 metres, as identified in the Programme and approved, in writing, by the Consent Authority.

(b) the water quality samples will be analysed for the following:

- water temperature;
- chlorophyll *a*;
- vertical secchi depth; and
- dissolved oxygen.

7.2 Appendix B Monthly In-Situ Water Column Parameters

Appendix B: Monthly water column parameters from 18/04/2016 to 19/04/2017: Secchi depth (m) (an indication of water clarity) and water temperature (°C) and dissolved oxygen (mg/L) at 2 meter depth intervals from 1 meter below the surface until 21 meters.

Station	Date Collected	Secchi depth (m)	Water temperature ° C (depth from surface (m)											Dissolved oxygen mg/L (depth from surface (m)										
			1	3	5	7	9	11	13	15	17	19	21	1	3	5	7	9	11	13	15	17	19	21
1	18/4/2016	7.0	13.5	13.5	13.5	13.6	13.6	13.7	13.7	13.7	13.7	13.6	13.6	7.7	7.9	7.8	7.6	7.4	7.1	7.1	6.9	6.9	7.0	7.1
2	18/4/2016	7.0	13.5	13.6	13.3	13.6	13.6	13.6	13.5	13.5	13.5	13.5	13.5	7.3	7.0	6.3	6.4	6.4	6.3	7.3	7.2	7.2	7.2	7.2
3	18/4/2016	8.0	13.4	13.5	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.2	9.2	8.6	8.5	8.8	8.7	8.5	7.8	7.8	7.7	7.7	7.7
4	18/4/2016	8.0	13.6	13.5	13.6	13.6	13.5	13.5	13.7	13.6	13.7	13.6	13.6	8.2	7.2	7.6	7.7	7.7	8.4	8.4	6.3	7.2	6.8	6.8
5	18/4/2016	8.0	13.5	13.5	13.6	13.6	13.6	13.5	13.5	13.5	13.5	13.4	13.3	7.7	7.6	7.4	7.2	7.5	7.6	7.3	6.6	6.1	5.7	5.9
6	18/4/2016	8.5	13.5	13.4	13.5	13.6	13.5	13.5	13.4	13.4	13.4	13.4	13.4	7.6	7.6	7.5	7.4	7.2	7.3	7.5	7.5	7.4	7.2	7.5
1	10/5/2016	11.5	13.0	13.1	13.2	13.2	13.2	13.1	13.1	13.1	13.1	13.1	13.0	7.1	6.9	6.8	6.8	6.8	6.7	7.6	7.5	7.5	7.5	7.6
2	10/5/2016	12.0	13.1	13.0	13.1	13.1	13.1	13.2	13.2	13.2	13.1	13.2	13.0	7.3	7.3	7.3	7.0	7.0	6.9	7.4	7.6	7.6	7.7	7.6
3	10/5/2016	12.0	13.1	13.1	13.1	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	7.4	7.4	7.3	6.9	7.0	7.5	7.6	7.6	7.6	7.7	7.7
4	10/5/2016	9.0	13.1	13.1	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.1	7.5	7.5	7.5	7.5	7.5	7.4	7.4	7.4	7.5	7.7	7.7
5	10/5/2016	12.0	13.2	13.2	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.2	7.3	7.4	7.3	7.3	7.5	7.6	7.7	7.7	7.7	7.8	7.7
6	10/5/2016	8.0	13.2	13.2	13.3	13.4	13.5	13.5	13.6	13.6	13.6	13.6	13.6	7.5	7.4	7.3	7.4	7.7	7.7	7.6	7.5	7.5	7.6	7.6
1	26/6/2016	15.0	8.7	8.7	8.8	8.8	8.8	8.8	8.8	8.7	8.7	8.7	8.7	8.6	8.6	8.6	8.5	8.5	8.5	8.5	8.5	8.6	8.6	8.6
2	26/6/2016	13.0	8.6	8.9	8.9	8.9	8.9	8.9	8.8	8.8	8.8	8.8	8.8	8.7	8.4	8.4	8.4	8.4	8.5	8.5	8.4	8.4	8.3	8.4
3	26/6/2016	12.0	9.1	9.1	9.0	9.0	9.0	9.0	9.0	8.9	8.9	8.8	8.9	9.0	9.3	9.0	8.9	8.9	8.9	9.0	8.8	8.8	8.8	8.8
4	26/6/2016	14.0	9.0	9.0	8.9	8.9	8.9	8.9	8.9	8.8	8.8	8.8	8.7	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
5	26/6/2016	11.0	8.9	9.0	9.0	9.0	8.9	8.8	8.8	8.7	8.7	8.6	8.6	8.6	8.4	8.2	8.3	8.4	8.4	8.5	8.5	8.5	8.5	8.5
6	26/6/2016	14.0	9.0	9.0	9.0	9.0	9.0	9.0	8.9	8.9	8.9	8.9	8.9	8.7	8.7	8.5	8.5	8.4	8.4	8.4	8.4	8.4	8.4	8.5

Station	Date Collected	Secchi depth (m)	Water temperature ° C (depth from surface (m)											Dissolved oxygen mg/L (depth from surface (m)										
			1	3	5	7	9	11	13	15	17	19	21	1	3	5	7	9	11	13	15	17	19	21
1	31/7/2016	10.5	8.4	8.4	8.4	8.4	8.4	8.4	8.3	8.3	8.2	8.1	8.0	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.9	8.9	8.9
2	31/7/2016	9.0	8.7	8.7	8.8	8.8	8.8	8.8	8.8	9.1	9.1	9.2	9.2	8.7	8.6	8.6	8.6	8.6	8.6	8.6	8.5	8.6	8.6	8.6
3	31/7/2016	9.0	8.4	8.4	8.4	8.3	8.3	8.3	8.2	8.2	8.1	8.1	8.1	8.9	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
4	31/7/2016	11.0	8.4	8.4	8.4	8.3	8.3	8.3	8.2	8.1	8.0	7.9	7.9	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.8	8.8	8.8
5	31/7/2016	9.5	8.7	8.7	8.6	8.6	8.6	8.6	8.5	8.5	8.4	8.4	8.3	8.9	8.9	8.9	8.9	8.9	8.8	8.9	8.9	8.9	8.9	9.0
6	31/7/2016	11.0	8.7	8.7	8.6	8.6	8.6	8.6	8.5	8.6	8.5	8.5	8.5	8.6	8.6	8.6	8.6	8.5	8.6	8.6	8.7	8.7	8.8	8.8
1	21/8/2016	13.0	9.0	9.2	9.2	9.3	9.3	9.4	9.4	9.4	9.4	9.4	9.4	9.3	9.1	8.8	8.7	8.3	8.0	8.2	8.4	8.8	8.9	8.9
2	21/8/2016	10.5	9.2	9.3	9.3	9.3	9.4	9.4	9.5	9.5	9.5	9.5	9.5	9.2	8.9	8.5	8.5	8.5	8.5	8.5	8.9	8.9	8.9	8.9
3	21/8/2016	8.5	9.1	9.1	9.1	9.1	9.2	9.2	9.1	9.2	9.3	9.3	9.2	9.2	9.2	9.2	9.1	9.0	9.0	8.8	8.5	8.5	8.7	8.7
4	21/8/2016	10.5	9.4	9.1	9.1	9.1	9.2	9.2	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.2	9.2	8.9	8.4	8.4	9.0	9.0	9.0	8.8
5	21/8/2016	11.0	9.3	9.5	9.5	9.6	9.6	9.6	9.5	9.5	9.5	9.5	9.5	8.8	8.3	8.3	8.4	8.5	8.7	9.0	9.0	9.0	9.0	9.1
6	21/8/2016	14.0	9.2	9.3	9.3	9.3	9.4	9.4	9.4	9.5	9.5	9.6	9.6	9.3	8.9	8.4	8.5	8.8	8.9	9.0	9.0	9.0	9.0	9.0
1	13-09-16	9.5	9.7	9.9	9.9	9.9	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.7	9.7	9.6	9.3	9.1	9.1	9.4	9.4	9.2	9.1
2	13-09-16	8.5	9.8	9.9	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.7	9.4	9.3	9.2	9.2	9	8.9	8.9	8.9	9
3	13-09-16	10.5	9.8	10	10	9.9	9.9	9.9	10	9.9	9.9	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.7	9.5	9	9	9
4	13-09-16	9	9.7	9.9	9.9	9.9	9.8	9.8	9.8	9.8	9.8	9.7	9.8	9.7	9.9	9.9	9.9	9.9	9.8	9.6	9.5	9.1	9.2	9.2
5	13-09-16	9	9.9	9.9	9.9	9.9	9.9	9.8	9.9	9.8	9.8	9.8	9.8	9.6	9.6	9.5	9.4	9.2	9.2	8.6	8.7	8.7	8.8	8.8
6	13-09-16	7.5	9.9	9.9	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.7	9.7	9.7	9.5	9.5	9.4	9.3	9.3	9.1	9.4
1	18-10-16	7	12	11.9	11.9	11.9	11.9	11.9	11.9	11.8	11.8	11.8	11.8	8.8	8.8	8.8	8.8	8.8	8.7	8.7	8.7	8.7	8.8	8.8
2	18-10-16	7	11.9	11.9	11.9	11.9	11.9	11.9	11.8	11.7	11.7	11.7	11.7	8.8	8.8	8.8	8.7	8.7	8.7	8.5	8.5	8.3	8.3	8.4
3	18-10-16	6.5	12	12	12	12	12	12	12	12	12	12	12	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.7	8.7	8.5
4	18-10-16	7	11.9	11.9	11.9	11.9	11.9	11.9	11.8	11.8	11.8	11.8	11.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.7
5	18-10-16	7	12.1	12.1	12	12	12	11.9	11.9	11.9	11.9	11.9	11.9	8.5	8.5	8.5	8.4	8.3	8.3	8.3	8.3	8.3	8.4	8.4
6	18-10-16	7.5	11.9	11.9	11.9	11.9	11.9	11.8	11.8	11.8	11.8	11.7	11.7	8.7	8.6	8.6	8.7	8.7	8.7	8.6	8.6	8.6	8.5	8.6

Station	Date Collected	Secchi depth (m)	Water temperature ° C (depth from surface (m)											Dissolved oxygen mg/L (depth from surface (m)										
			1	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**21**	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**21**
1	30-11-16	7.5	12.7	12.7	12.7	12.6	12.6	12.6	12.5	12.5	12.5	12.5	12.4	8.2	8.2	8.1	8.1	8.2	8.2	8.2	8.2	8.2	8.3	8.3
2	30-11-16	7.5	12.7	12.7	12.7	12.7	12.6	12.6	12.5	12.5	12.5	12.4	12.4	8.1	8.1	8.1	8.1	8	8	8	8	8	7.9	8.1
3	30-11-16	7.5	12.7	12.7	12.7	12.7	12.6	12.6	12.6	12.6	12.5	12.5	12.4	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.2	8.2
4	30-11-16	7.5	12.8	12.7	12.7	12.7	12.7	12.6	12.5	12.5	12.4	12.3	12.3	8.3	8.2	8.3	8.2	8.2	8.2	8.3	8.3	8.3	8.3	8.4
5	30-11-16	8	12.7	12.8	12.8	12.8	12.8	12.8	12.7	12.7	12.7	12.6	12.3	7.9	7.8	7.7	7.7	7.7	7.7	7.8	7.9	7.9	7.8	8
6	30-11-16	8.5	12.7	12.7	12.7	12.6	12.6	12.6	12.5	12.5	12.5	12.5	12.5	8	8	8	8	8	8	8.1	8.1	8.1	8.1	8.2
1	12-12-16	7.5	13.5	13.4	13.4	13.4	13.4	13.4	13.4	13.3	13.3	13.1	13.2	8.6	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.4	8.2	8.2
2	12-12-16	8	13.2	13.1	13.1	13.1	13	13	13	13	13	13	13	8.6	8.6	8.6	8.6	8.6	8.6	8.7	8.7	8.6	8.4	8.8
3	12-12-16	7	13.6	13.6	13.6	13.6	13.6	13.6	13.5	13.5	13.5	13.4	13.4	8.7	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6
4	12-12-16	8	13.4	13.4	13.4	13.4	13.4	13.3	13.2	13.2	13.1	13.1	13.2	8.8	8.8	8.8	8.8	8.8	8.7	8.6	8.6	8.6	8.7	8.8
5	12-12-16	7	13.7	13.6	13.6	13.6	13.5	13.4	13.4	13.3	13.3	13.3	13.2	8.7	8.5	7.5	7.2	7.5	7.6	8.1	8.3	8.5	8.4	8.6
6	12-12-16	7.5	13.4	13.4	13.4	13.3	13.3	13.3	13.2	13.3	13.2	13.2	13.2	8.6	8.6	8.5	8.3	8.3	8.3	8.4	8.4	8.4	8.5	8.6
1	18-01-17	11.5	13	13.1	13.2	13.2	13.2	13.2	13.2	13.1	13.1	13.1	13.1	8	8	8	7.9	7.9	8	8.1	8.1	8.1	8.2	8.2
2	18-01-17	13	13.2	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.2	8	8	8	8	8	8	8	8	8	8.1	8.2
3	18-01-17	13.5	13.1	13.1	13.2	13.2	13.2	13.2	13.2	13.2	13.1	13.1	13.1	8.1	8.1	8.1	8.1	8.1	8.1	8	8.2	8.3	8.3	8.3
4	18-01-17	15	13.2	13.2	13.3	13.3	13.3	13.2	13.2	13.2	13.2	13.2	13.2	8.2	8	8	8	8	8.1	8.1	8.1	8.2	8.3	8.4
5	18-01-17	12	13.6	13.6	13.7	13.7	13.7	13.8	13.8	13.9	14.1	14.2	14.4	7.9	7.9	7.9	7.9	8	8.1	8.3	8.5	8.6	8.6	8.6
6	18-01-17	15	13.3	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	8.1	8	8	8	8	8	8.1	8.2	8.2	8.3	8.3
1	27-02-17	8.5	14.7	14.6	14.5	14.4	14.2	14.1	14.1	14	14	14	14	8.8	8.8	8.6	8.3	8.1	8	7.9	7.7	7.7	7.7	8.3
2	27-02-17	9.5	14.5	14.5	14.4	14.3	14.3	14.3	14.2	14.1	14.1	14.1	14.1	9.4	9.4	9.3	9.3	9.2	9.1	8.6	8.7	8.6	8.3	8.3
3	27-02-17	7.5	14.7	14.7	14.7	14.7	14.6	14.6	14.6	14.6	14.5	13.9	13.9	8.4	8.4	8.4	8.4	8.4	8.5	8.5	8.5	8.5	7.4	7
4	27-02-17	8	14.6	14.6	14.6	14.5	14.5	14.5	14.4	14.4	14.3	14.2	14.1	10.3	10	9.8	9.8	9.8	9.8	9.8	9.4	9	8.7	8.6
5	27-02-17	7	14.7	14.7	14.6	14.5	14.4	14.3	14.3	14.2	14.2	14	14	9.2	9.1	8.8	8.6	8.8	8.8	8.9	8.9	8.8	7.2	7.4
6	27-02-17	7.5	14.5	14.4	14.4	14.4	14.3	14.3	14.2	14.1	14	14	14.1	9.4	9.3	9	8.9	8.7	8.6	8.7	8.6	8.4	8.3	8.8

Station	Date Collected	Secchi depth (m)	Water temperature ° C (depth from surface (m)											Dissolved oxygen mg/L (depth from surface (m)										
			1	3	5	7	9	11	13	15	17	19	21	1	3	5	7	9	11	13	15	17	19	21
1	26-03-17	9	13.4	13.4	13.4	13.4	13.4	13.4	13.3	13.3	13.3	13.3	13.4	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.4	7.4	7.4	7.4
2	26-03-17	8	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.3	13.3	7.6	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.4	7.4
3	26-03-17	9	13.5	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.3	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
4	26-03-17	8	13.5	13.5	13.5	13.5	13.4	13.4	13.4	13.4	13.4	13.4	13.3	7.8	7.8	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.8	7.9
5	26-03-17	11	13.4	13.4	13.4	13.4	13.4	13.4	13.3	13.3	13.3	13.3	13.3	6.8	6.8	6.8	6.8	7	7.1	7.2	7.2	7.2	7.3	7.2
6	26-03-17	10.5	13.5	13.5	13.5	13.5	13.5	13.4	13.4	13.4	13.4	13.4	13.4	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
1	19-04-17	7.5	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	8.3	8.3	8.2	8.2	8.1	8	7.7	7.5	7.5	7.6	7.8
2	19-04-17	6.5	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	8.3	8.2	8.1	8.2	8	7.5	7.4	7.4	7.5	7.5	7.6
3	19-04-17	6.5	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.6	12.6	9.1	9.1	9.1	9.1	9.1	9	9	8.9	8.8	8.1	8.2
4	19-04-17	7.5	12.6	12.6	12.6	12.5	12.5	12.5	12.5	12.5	12.6	12.5	12.5	8.9	8.9	8.9	8.9	8.9	8.8	8.7	8.4	8.3	8.3	8.6
5	19-04-17	7.5	12.8	12.8	12.8	12.8	12.8	12.8	12.9	12.9	12.9	12.9	12.9	8.9	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
6	19-04-17	8	12.6	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.6	12.6	8.4	8.2	8	7.8	7.5	7.4	7.5	7.5	7.6	7.6	7.7

7.3 APPENDIX C PHYSICAL CHARACTERISTICS OF BENTHIC SEDIMENTS

Physical characteristics of benthic sediments in Big Glory Bay, Steward Island. Sampling stations are abbreviated as ConM = Control Mouth, ConH = Control Head. Note: Depth of the oxygenated layer below the sediment surface corresponds to the redox depth in mm.

Latitude/Longitude	Station	Sample	Site Depth (m)	% Very Fine Gravel	% Sand	% Mud	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
-46° 58.15204' S 168° 07.97891' E	ConM	ConM 1_1	21.5	10.6	53.7	35.7	2.4	8	33	**5-10**	8	No	No	No
		ConM 1_2									9			
		ConM 1_3									10			
		ConM 2_1		5	60.1	34.9	2	8	37		10			
		ConM 2_2									11			
		ConM 2 _3									12			
		ConM 3_1		13.6	45.5	40.8	2.2	7	28		6			
		ConM 3_1									8			
		ConM 3_1									7			
-46° 58.98857' S 168° 07.06492' E	ConH	ConH 1_1	25.8	3.8	31.1	65.1	1.18	9	34	4	9	No	No	No
		ConH 1_2									12			
		ConH 1_3									10			
		ConH 2_1		1.7	30	68.2	1.07	9	29		8			
		ConH 2_2									7			
		ConH 2_3									12			
		ConH 3_1		2	32.4	65.6	1.2	10	32		11			
		ConH 3_2									11			
		ConH 3_3									11			

Latitude/Longitude	Station	Sample	Site Depth (m)	% Very Fine Gravel	% Sand	% Mud	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
-46° 58.7234' S 168° 06.1803' E	244_F	244_F 1_1	25.4	8.6	18.5	72.9	-	-	-	1	12	No	No	No
		244_F 1_2									12			
		244_F 1_3									7			
		244_F 2_1		3.8	25.1	71.1	-	-	-		8			
		244_F 2_2									9			
		244_F 2_3									7			
		244_F 3_1		10.8	20.2	69	-	-	-		12			
		244_F 3_2									9			
		244_F 3_3									8			
-46° 59.2256' S 168° 07.5093' E **Lots of mussel debris on 340_F R2 and R3**	340_F	340_F 1_1	24.8	26.1	46.8	27	-	-	-	1	6	No	No	No
		340_F 1_2									12			
		340_F 1_3									4			
		340_F 2_1		29	44.2	26.7	-	-	-		See Appendix D			
		340_F 2_2												
		340_F 2_3												
		340_F 3_1		11.8	56.6	31.6	-	-	-					
		340_F 3_2												
		340_F 3_3												
-46° 59.358' S 168° 06.630' E	338_F	338_F 1_1	25.0	11.5	71.9	16.6	1.2	370	124	1	5	No	No	No
		338_F 1_2									6			
		338_F 1_3									3			
		338_F 2_1		12.5	66.4	21.2	1.42	1780	300		5			
		338_F 2_2									4			
		338_F 2_3									4			

Latitude/Longitude	Station	Sample	Site Depth (m)	% Very Fine Gravel	% Sand	% Mud	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
-46° 59.358' S 168° 06.630' E	338_F	338_F 3_1	25.0	15.3	68.6	16.1	1.58	2000	430	1	8	No	No	No
		338_F 3_2									5			
		338_F 3_3									7			
-46° 59.194826' S 168° 06.633739' E	338_50	338_50 1_1	27.3	4.5	39.6	55.9	1.5	40	80	1	12	No	No	No
		338_50 1_1									11			
		338_50 1_1									9			
		338_50 2_1		2.3	30.9	66.7	1.34	14	43		11			
		338_50 2_2									12			
		338_50 2_3									8			
		338_50 3_1		3.5	30.2	66.3	1.42	17	49		8			
		338_50 3_2									10			
		338_50 3_3									9			
-46° 59.167791' S 168° 06.633726' E	338_100	338_100 1_1	24.2	1.8	27.6	70.6	1.38	13	35	1	12	No	No	No
		338_100 1_2									9			
		338_100 1_3									12			
		338_100 2_1		1.2	29.1	69.7	1.38	12	35		12			
		338_100 2_2									10			
		338_100 2_3									11			
		338_100 3_1		1.6	32	66.4	1.28	13	39		8			
		338_100 3_1									9			
		338_100 3_1									11			

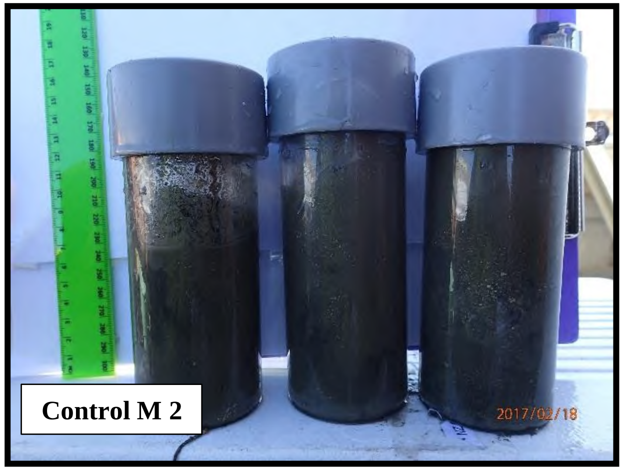
Latitude/Longitude	Station	Sample	Site Depth (m)	% Very Fine Gravel	% Sand	% Mud	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
-46° 59.069' S 168° 07.626' E	339_F	339_F 1_1	25.2	7.9	74.9	17.2	3.8	1150	350	1	12	No	Strong	No
		339_F 1_1									12			
		339_F 1_1									12			
		339_F 2_1		16.6	66.9	16.4	5.9	2600	610		6			
		339_F 2_2									4			
		339_F 2_3									7			
		339_F 3_1		4.3	78.4	17.3	2.2	310	113		See Appendix D			
		339_F 3_2												
		339_F 3_3												
-46° 59.078603' S 168° 07.576170' E	339_50	339_50 1_1	25.0	4.5	45.3	50.2	1.23	16	38	1	7	No	Mild	No
		339_50 1_2									10			
		339_50 1_3									7			
		339_50 2_1		12.1	41.1	46.8	1.27	13	39		12			
		339_50 2_2									10			
		339_50 2_3									11			
		339_50 3_1		11.4	40.8	47.8	1.21	10	35		10			
		339_50 3_2									13			
		339_50 3_3									8			
-46° 59.058054' S 168° 07.549513' E	339_100	339_100 1_1	25.0	2.3	55.2	42.4	1.05	10	32	1	10	No	No	No
		339_100 1_2									12			
		339_100 1_3									11			

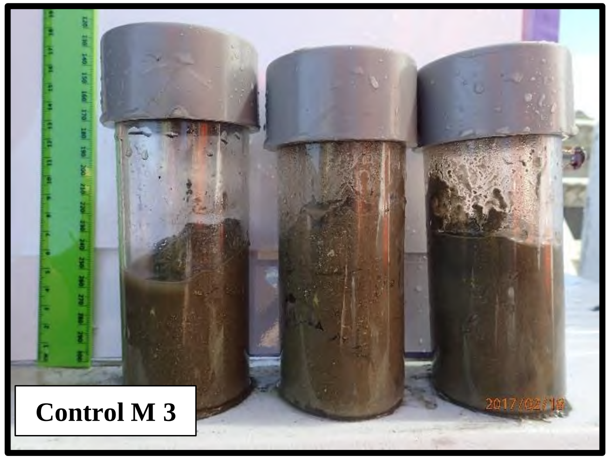
Latitude/Longitude	Station	Sample	Site Depth (m)	% Very Fine Gravel	% Sand	% Mud	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
-46° 59.058054' S 168° 07.549513' E	339_100	339_100 2_1	25.0	2.1	54.5	43.5	1.5	13	37	1	11	No	No	No
		339_100 2_2									8			
		339_100 2_3									11			
		339_100 3_1		6.2	46.4	47.4	1.46	11	39		6			
		339_100 3_2									9			
		339_100 3_3									12			
-46° 58.584' S 168° 08.048' E	246_F	246_F 1_1	25.0	14.8	52.2	33	2.2	10	45	1	12	No	No	No
		246_F 1_2									11			
		246_F 1_3									12			
		246_F 2_1		7.9	52.5	39.5	2.3	12	48		11			
		246_F 2_2									12			
		246_F 2_3									12			
		246_F 3_1		5.9	58.1	36.1	2.4	10	38		12			
		246_F 3_2									9			
		246_F 3_3									9			
-46° 58.600806' S 168° 07.845976' E	246_50	246_50 1_1	24.8	8.3	56.8	34.9	1.03	6	31	3	6	No	No	No
		246_50 1_2									10			
		246_50 1_3									12			
		246_50 2_1		10.3	54.5	35.2	0.97	6	29		8			
		246_50 2_2									6			
		246_50 2_3									6			

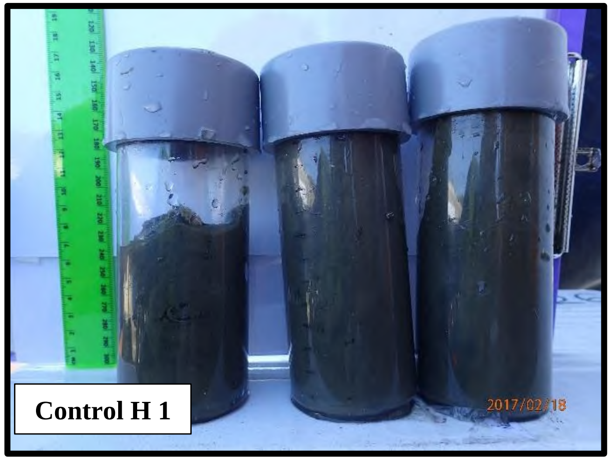
Latitude/Longitude	Station	Sample	Site Depth (m)	% Very Fine Gravel	% Sand	% Mud	% Total organic carbon	Cu mg/kg dry wt	Zn mg/kg dry wt	Redox Depth (mm)	Core Depth (cm)	Bacterial mat	Sulphide Odour	Nepheloid layer
-46° 58.600806' S 168° 07.845976' E	246_50	246_50 3_1	24.8	8	59.9	32.1	1.03	8	28	3	11	No	No	No
		246_50 3_2									10			
		246_50 3_3									11			
-46° 58.604625' S 168° 07.806936' E	246_100	246_100 1_1	24.6	6.8	74	19.3	1.17	6	26	3 - 4	9	No	No	No
		246_100 1_2									10			
		246_100 1_3									8			
		246_100 2_1		8.8	61.7	29.5	0.98	6	27		11			
		246_100 2_2									7			
		246_100 2_3									9			
		246_100 3_1		4.3	43.4	52.4	0.97	4	29		5			
		246_100 3_2									5			
		246_100 3_3									7			

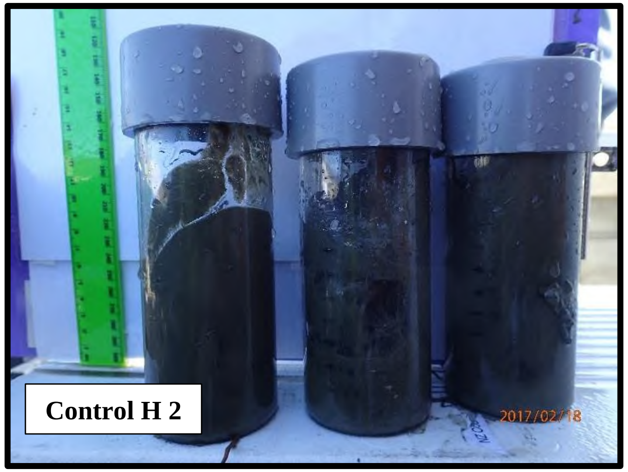
7.4 APPENDIX D SEDIMENTS CORE PROFILES

Sediment core profiles for control (reference) stations in Big Glory Bay, Steward Island. Cores extracted from separated Van Veen grabs (1-3)



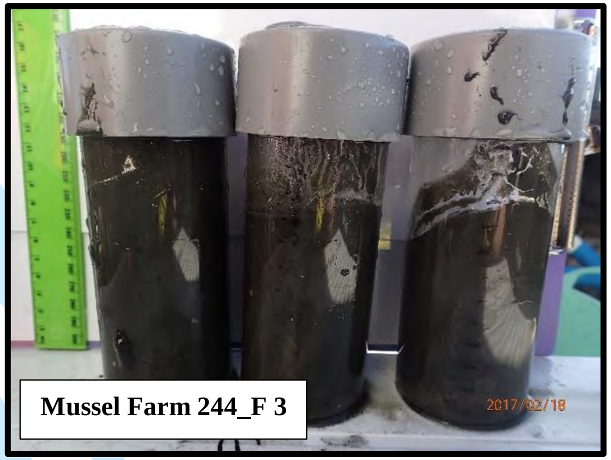






Mussel Farm 244_F 1

Mussel Farm 244_F 2



Mussel Farm 244_F 3

Mussel Farm 340_F 1

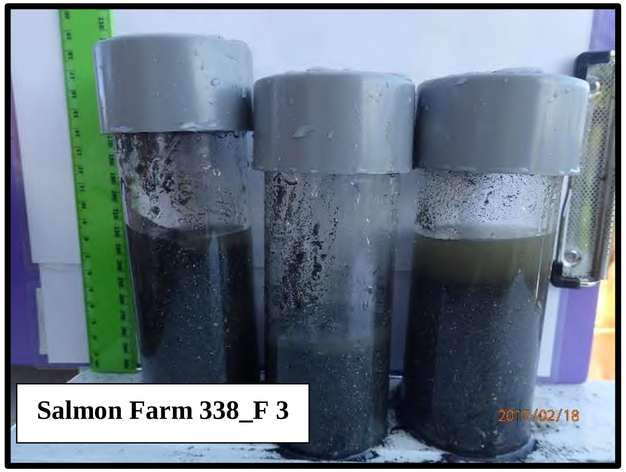
Mussel Farm 340_F 2

Mussel Farm 340_F 3

.

Salmon Farm 338_F 1

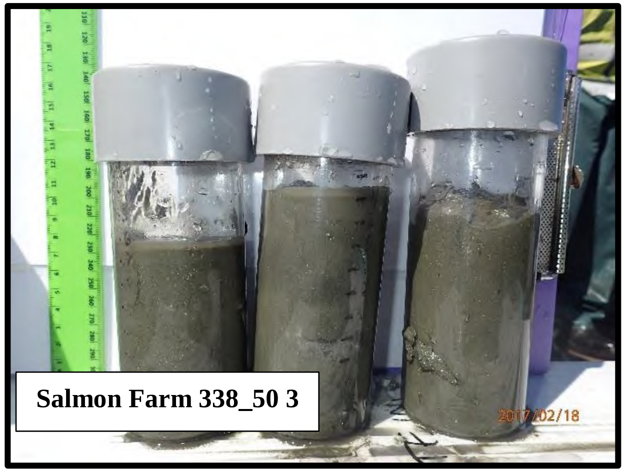
Salmon Farm 338_F 2



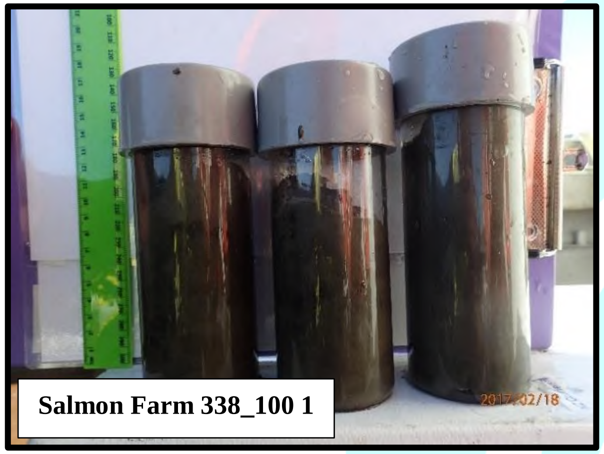
Salmon Farm 338_F 3

Salmon Farm 338_50 1

Salmon Farm 338_50 2



Salmon Farm 338_50 3



Salmon Farm 338_100 1

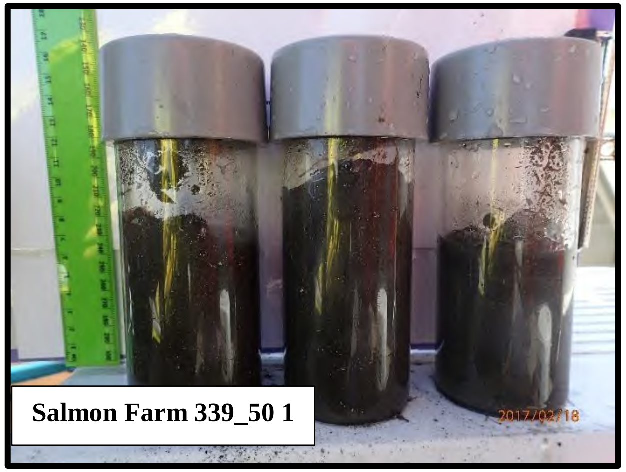
Salmon Farm 338_100 2

Salmon Farm 338_100 3

Salmon Farm 339_F 1

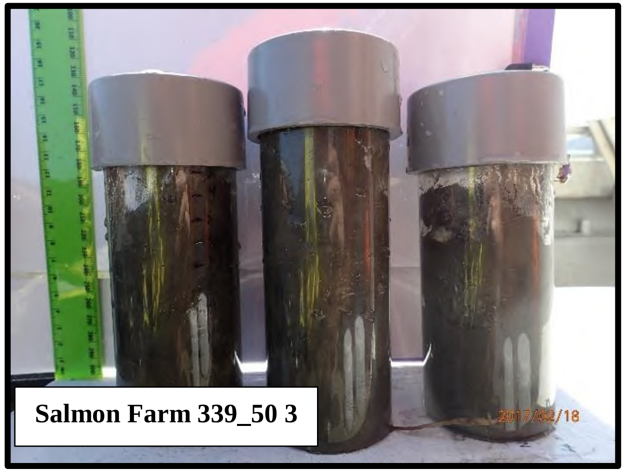
Salmon Farm 339_F 2

Salmon Farm 339_F 3

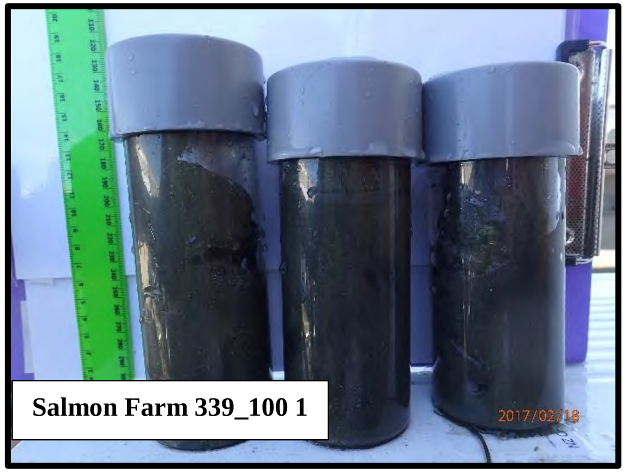


Salmon Farm 339_50 1

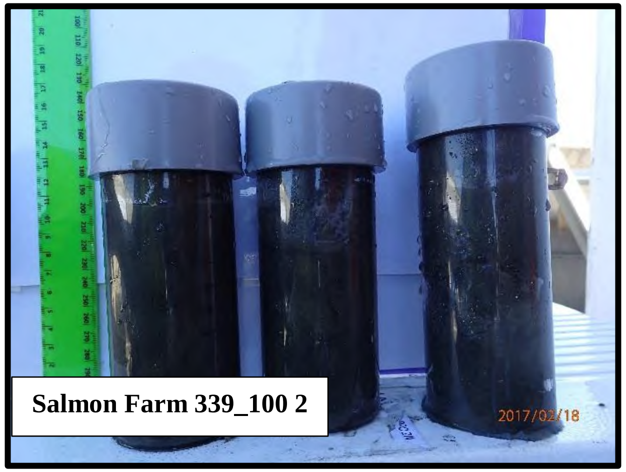
Salmon Farm 339_50 2



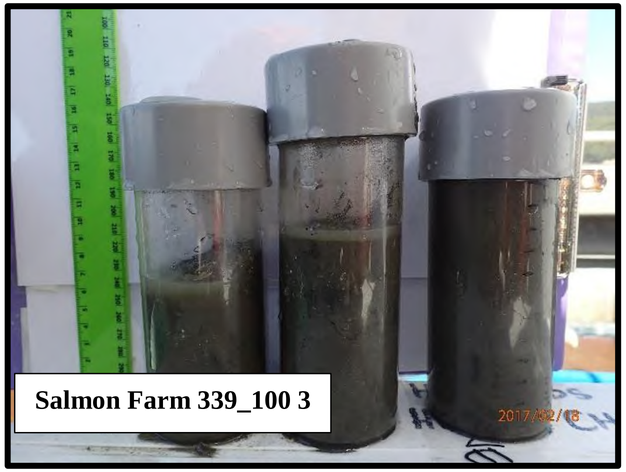
Salmon Farm 339_50 3



Salmon Farm 339_100 1

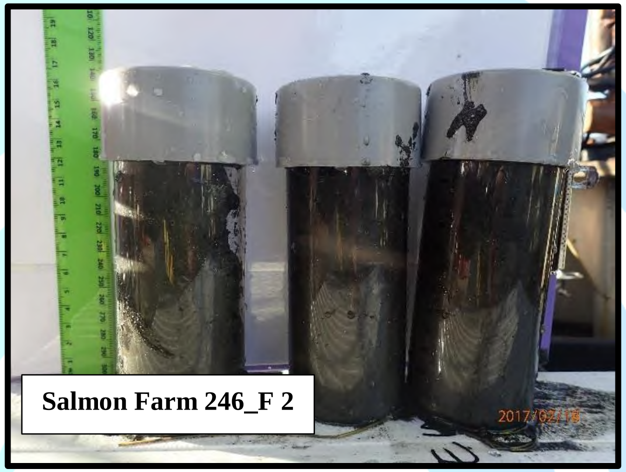


Salmon Farm 339_100 2



Salmon Farm 339_100 3


Salmon Farm 246_F 1

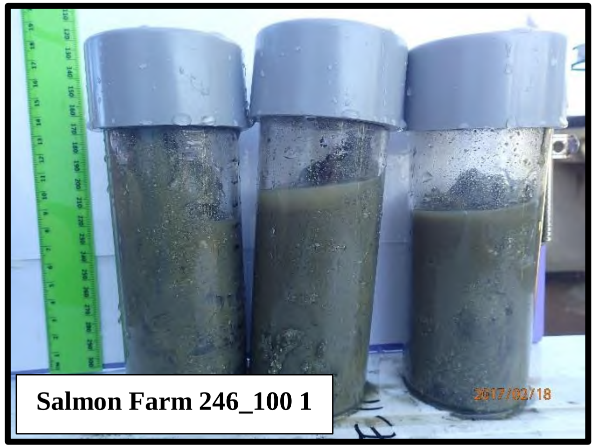

Salmon Farm 246_F 2


Salmon Farm 246_F 3

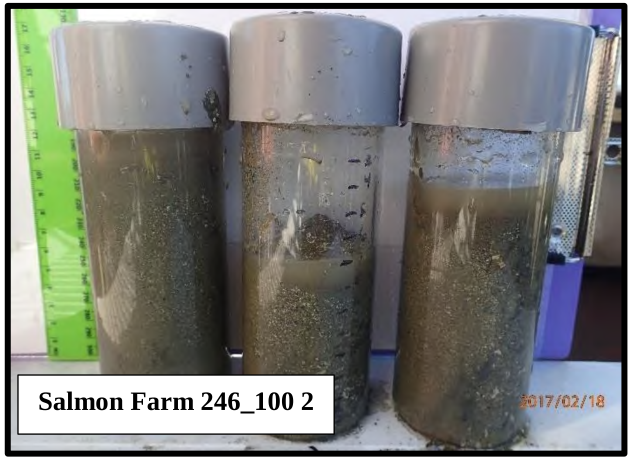

Salmon Farm 246_50 1


Salmon Farm 246_50 2

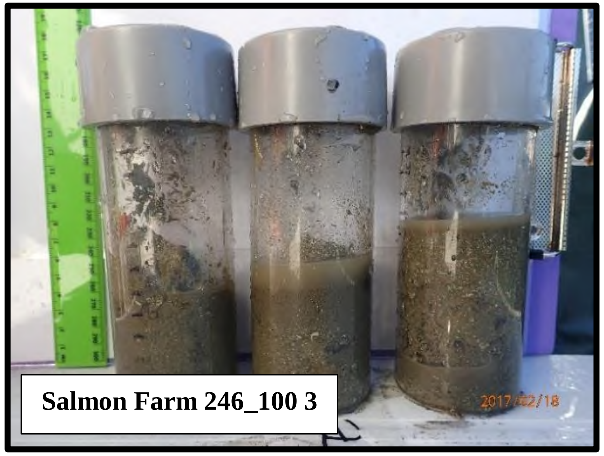

Salmon Farm 246_50 3



Salmon Farm 246_100 1



Salmon Farm 246_100 2



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7.5 APPENDIX E STATISTICAL ANALYSES OF BENTHIC SEDIMENT DATA

Appendix E. 1a. 244_F (mussel farm) Summary statistics: Mean and standard deviation for sediment properties at the mussel station 244_F two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% mud			% sand		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	9.133	0.252	3	51.000	1.000	3	91.000	0.000	3	37.133	3.201	3	53.100	7.318	3
ConH	6.467	0.577	3	57.667	0.577	3	93.333	0.577	3	66.300	1.664	3	31.167	1.201	3
244_F	10.767	0.451	3	58.333	2.517	3	89.333	0.577	3	71.000	1.952	3	21.267	3.427	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	9.733	4.365	3	2.200	0.200	3	7.667	0.577	3	32.667	4.509	3
ConH	2.500	1.136	3	1.150	0.070	3	9.333	0.577	3	31.667	2.517	3
319_F	7.733	3.580	3	-	-	3	-	-	3	-	-	3

Appendix E.1b. 244_F: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 2

	SS	MS	F	P-value
Organic Matter	28.268	14.134	70.672	0.000068
Dry matter	98.666	49.333	19.304	0.002433297
Ash	24.222	12.111	54.5	0.000142024
% silt/mud	2019.736	1009.868	180.083	0.0000044
% sand	1592.442	796.221	35.787	0.000462706
% very fine gravel	83.708	41.854	3.786	0.086364606
% Total organic carbon	-	-	-	-
Cu mg/kg dry wt	-	-	-	-
Zn mg/kg dry wt	-	-	-	-

Appendix E. 1c 244_F ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)			Dry Matter (g/100gd)			Ash (g/100g)			%mud			% sand		
	ConM	**ConH**	**244_F**	**ConM**	**ConH**	**244_F**	**ConM**	**ConH**	**244_F**	**ConM**	**ConH**	**244_F**	**ConM**	**ConH**	**244_F**
ConM		0.001	0.01		0.005	0.0034		0.003	0.0674		0.0002	0.0002		0.0032	0.0005
ConH	10.33		0.000254	7.223		0.8691	8		0.0005	21.33		0.1116	8.054		0.0934
340_F	6.326	16.65		7.945	0.722		4	12		24.77	3.438		11.69	3.635	

	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	ConM	**ConH**	**244_F**	**ConM**	**ConH**	**244_F**	**ConM**	**ConH**	**244_F**	**ConM**	**ConH**	**244_F**
ConM		0.0829	0.7522		-	-		-	-		-	-
ConH	3.769		0.2114	-		-	-		-	-		-
340_F	1.042	2.727		-	-		-	-		-	-	

Appendix E. 2a. 340_F (mussel farm) Summary statistics: Mean and standard deviation for sediment properties at the mussel station 340_F two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% mud			% sand		
	Mean	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**
ConM	9.133	0.252	3	51.000	1.000	3	91.000	0.000	3	37.133	3.201	3	53.100	7.318	3
ConH	6.467	0.577	3	57.667	0.577	3	93.333	0.577	3	66.300	1.664	3	31.167	1.201	3
340_F	6.900	0.400	3	55.333	2.517	3	93.000	0.000	3	28.433	2.747	3	49.200	6.539	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**
ConM	9.733	4.365	3	2.200	0.200	3	7.667	0.577	3	32.667	4.509	3
ConH	2.500	1.136	3	1.150	0.070	3	9.333	0.577	3	31.667	2.517	3
340_F	22.300	9.208	3	-	-	3	-	-	3	0.000	-	3

Appendix E.2b. 340_F: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 2

	SS	MS	F	P-value
%Organic Matter	12.286	6.143	33.107	0.000573537
Dry matter	68.666	34.333	13.434	0.006082357
Ash	9.555	4.777	43	0.00027739
% silt/mud	2360.269	1180.134	172.2265	0.000005
% sand	821.482	410.741	12.604	0.007106303
% very fine gravel	602.282	301.141	8.593	0.017328572
%Total organic carbon	-	-	-	-
Cu mg/kg dry wt	-	-	-	-
Zn mg/kg dry wt	-	-	-	-

Appendix E. 1c 340_F ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)			Dry Matter (g/100gd)			Ash (g/100g)			% mud			% sand		
	ConM	**ConH**	**340_F**	**ConM**	**ConH**	**340_F**	**ConM**	**ConH**	**340_F**	**ConM**	**ConH**	**340_F**	**ConM**	**ConH**	**340_F**
ConM		0.000851	0.0019		0.0054	0.0369		0.0033	0.0033		0.0002	0.0156		0.00803	0.696
ConH	10.72		0.4792	7.223		0.2517	8		1	19.3		0.00022	6.655		0.0195
340_F	8.98	1.742		4.695	2.528		8	0		5.757	25.06		1.183	5.472	

	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	ConM	**ConH**	**340_F**	**ConM**	**ConH**	**340_F**	**ConM**	**ConH**	**340_F**	**ConM**	**ConH**	**340_F**
ConM		0.357	0.09		-	-		-	-		-	-
ConH	2.116		0.0151	-		-	-		-	-		-
340_F	3.677	5.793		-	-		-	-		-	-	

Appendix E. 3a. 246_F, 246_50 and 246_100 (salmon farm) Summary statistics: Mean and standard deviation for sediment properties at the salmon station with two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% mud			% sand		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	9.133	0.252	3	51.000	1.000	3	91.000	0.000	3	37.133	3.201	3	53.100	7.318	3
ConH	6.467	0.577	3	57.667	0.577	3	93.333	0.577	3	66.300	1.664	3	31.167	1.201	3
246_F	8.933	0.666	3	48.333	3.055	3	95.000	1.000	3	36.200	3.251	3	54.267	3.323	3
246_50	6.400	0.656	3	60.000	2.646	3	93.333	0.577	3	34.067	1.710	3	57.067	2.710	3
246_100	5.867	0.503	3	60.000	3.606	3	93.000	1.000	3	33.733	16.951	3	59.700	15.398	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	9.733	4.365	3	2.200	0.200	3	7.667	0.577	3	32.667	4.509	3
ConH	2.500	1.136	3	1.150	0.070	3	9.333	0.577	3	31.667	2.517	3
246_F	9.533	4.669	3	2.300	0.100	3	11.333	1.155	3	43.667	5.132	3
246_50	8.867	1.250	3	1.010	0.035	3	10.667	1.155	3	29.333	1.528	3
246_100	6.633	2.255	3	1.040	0.113	3	6.667	1.155	3	27.333	1.528	3

Appendix E.3b. 246_F, 246_50 and 246_100: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 4

	SS	MS	F	P-value
% Organic Matter	28.7093	7.177	23.557	0.000573537
Dry matter	350.266	87.566	14.277	0.006082357
Ash	24.666	23.125	0.000049	0.00027739
% mud	2333.317	583.329	9.293	0.000005
% sand	1562.756	390.689	6.291	0.007106303
% very fine gravel	110.190	27.547	2.822	0.017328572
% Total organic carbon	5.088	1.272	92.452	0.000573537
Cu mg/kg dry wt	53.6	13.4	14.357	0.006082357
Zn mg/kg dry wt	483.6	120.9	10.482	0.00027739

Appendix E. 3c 246_F, 246_50 and 246_100 ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)					Dry Matter (g/100gd)					Ash (g/100g)				
	ConM	**ConH**	**246_F**	**246_50**	**246_100**	**ConM**	**ConH**	**246_F**	**246_50**	**246_100**	**ConM**	**ConH**	**246_F**	**246_50**	**246_100**
ConM		0.0012	0.9908	0.001	0.0003		0.0496	0.6869	0.0085	0.0085		0.00164	0.6332	0.0016	0.0002
ConH	8.368		0.002	0.9999	0.6799	4.663		0.0067	0.7759	0.7759	8		0.0116	1	0.2831
246_F	0.6276	7.74		0.00172	0.0004	1.865	6.528		0.0014	0.0014	2	6		0.011	0.0007
246_50	8.577	0.2092	7.95		0.7605	6.294	1.632	8.159		1	8	0	6		0.2831
246_100	10.25	1.883	9.623	1.674		6.294	1.632	8.159	0		11	3	9	3	

	% mud					% sand					% very fine gravel				
	ConM	**ConH**	**246_F**	**246_50**	**246_100**	**ConM**	**ConH**	**246_F**	**246_50**	**246_100**	**ConM**	**ConH**	**246_F**	**246_50**	**246_100**
ConM		0.0078	0.9999	0.9882	0.9826		0.0417	0.9997	0.9691	0.8382		0.1009	1	0.9967	0.7436
ConH	6.376		0.0063	0.0039	0.0037	4.821		0.0315	0.0161	0.0087	4.011		0.1136	0.1675	0.5178
246_F	0.204	6.58		0.9971	0.9948	0.2564	5.077		0.9914	0.9105	0.1109	3.9		0.9988	0.7845
246_50	0.6704	7.047	0.4664		1	0.8719	5.693	0.6154		0.9932	0.4805	3.53	0.3696		0.8996
246_100	0.7433	7.12	0.5393	0.072		1.451	6.272	1.194	0.5788		1.719	2.292	1.608	1.238	

	Total Organic Carbon (%)					Copper (mg/kg)					Zinc (mg/kg)				
	ConM	**ConH**	**246_F**	**246_50**	**246_100**	**ConM**	**ConH**	**246_F**	**246_50**	**246_100**	**ConM**	**ConH**	**246_F**	**246_50**	**246_100**
ConM		0.00018	0.8298	0.00018	0.00018		0.2863	0.0227	0.7152	0.0837		0.9958	0.0177	0.7507	0.3653
ConH	15.5		0.00018	0.6063	0.7787	2.988		0.4803	0.0436	0.0035	0.51		0.0103	0.9115	0.5496
246_F	1.477	16.98		0.00018	0.00018	5.379	2.39		0.0035	0.0005	5.61	6.12		0.0031	0.0012
246_50	17.57	2.067	19.05		0.9976	1.793	4.781	7.171		0.4803	1.7	1.19	7.31		0.9468
246_100	17.13	1.624	18.6	0.443		4.183	7.171	9.562	2.39		2.72	2.21	8.33	1.02	

Appendix E. 4a. 338_F, 338_50 and 338_100 (salmon farm) Summary statistics: Mean and standard deviation for sediment properties at the salmon station with two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% mud			% sand		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	9.133	0.252	3	51.000	1.000	3	91.000	0.000	3	37.133	3.201	3	53.100	7.318	3
ConH	6.467	0.577	3	57.667	0.577	3	93.333	0.577	3	66.300	1.664	3	31.167	1.201	3
338_F	5.033	0.971	3	56.667	2.517	3	92.000	5.292	3	17.967	2.811	3	68.967	2.768	3
338_50	6.267	0.493	3	56.667	4.163	3	94.000	0.000	3	62.967	6.123	3	33.567	5.237	3
338_100	7.100	0.755	3	56.333	1.528	3	93.333	0.577	3	68.900	2.211	3	29.567	2.237	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	9.733	4.365	3	2.200	0.200	3	7.667	0.577	3	32.667	4.509	3
ConH	2.500	1.136	3	1.150	0.070	3	9.333	0.577	3	31.667	2.517	3
338_F	13.100	1.970	3	1.400	0.191	3	1383.333	884.440	3	284.667	153.575	3
338_50	3.433	1.102	3	1.420	0.080	3	23.667	14.224	3	57.333	19.858	3
338_100	1.533	0.306	3	1.347	0.058	3	12.667	0.577	3	36.333	2.309	3

Appendix E.4b. 338_F, 338_50 and 338_100: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 4

	SS	MS	F	P-value
% Organic Matter	27.153	6.788	15.762	0.00025554
Dry matter	84.667	21.167	3.8719	0.037543434
Ash	24.4	6.1	11.436	0.000947574
% silt/mud	5941.757	1485.439	117.333	0.000000023
% sand	3556.123	889.031	46.745	0.0000019
% very fine gravel	309.356	77.339	15.146	0.000301978
% Total organic carbon	1.9571	0.4892	26.872	0.000025
Cu mg/kg dry wt	4505026	1126256.50	7.20	0.01
Zn mg/kg dry wt	145564.4	36391.1	7.578	0.004471439

Appendix E. 4c 338_F, 338_50 and 338_100 ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)					Dry Matter (g/100gd)					Ash (g/100g)				
	ConM	**ConH**	**338_F**	**338_50**	**338_100**	**ConM**	**ConH**	**338_F**	**338_50**	**338_100**	**ConM**	**ConH**	**338_F**	**338_50**	**338_100**
ConM		0.00403	0.0003	0.0024	0.023		0.0367	0.0824	0.0824	0.1076		0.0121	0.0005	0.0121	0.0271
ConH	7.038		0.1286	0.9952	0.7613	4.939		0.9828	0.9828	0.9523	5.963		0.1364	1	0.9825
338_F	10.82	3.783		0.2211	0.0209	4.198	0.7408		1	0.9998	9.69	3.727		0.1364	0.0611
338_50	7.566	0.5279	3.255		0.5537	4.198	0.7408	0		0.9998	5.963	0	3.727		0.9825
338_100	5.367	1.672	5.455	2.199		3.951	0.9877	0.2469	0.2469		5.217	0.7454	4.472	0.7454	

	% mud					% sand					% very fine gravel				
	ConM	**ConH**	**338_F**	**338_50**	**338_100**	**ConM**	**ConH**	**338_F**	**338_50**	**338_100**	**ConM**	**ConH**	**338_F**	**338_50**	**338_100**
ConM		0.00017	0.00058	0.00019	0.00017		0.0009	0.0085	0.002	0.00057		0.0189	0.4118	0.0414	0.0086
ConH	14.2		0.00018	0.7792	0.8925	8.711		0.00017	0.9578	0.9903	5.544		0.0015	0.9849	0.9828
338_F	9.33	23.53		0.00017	0.00018	6.302	15.01		0.00018	0.00018	2.581	8.125		0.0028	0.0008
338_50	12.58	1.623	21.91		0.3141	7.758	0.9532	14.06		0.7914	4.829	0.7154	7.41		0.8363
338_100	15.46	1.266	24.79	2.888		9.347	0.6355	15.65	1.589		6.285	0.741	8.866	1.456	

	Total Organic Carbon (%)					Copper (mg/kg)					Zinc (mg/kg)				
	ConM	**ConH**	**338_F**	**338_50**	**338_100**	**ConM**	**ConH**	**338_F**	**338_50**	**338_100**	**ConM**	**ConH**	**338_F**	**338_50**	**338_100**
ConM		0.000183	0.000336	0.00038	0.000258		1	0.01138	1	1		1	0.008526	0.9914	1
ConH	13.48		0.2314	0.1789	0.4314	0.007297		0.01146	1	1	0.02499		0.008308	0.99	1
338_F	10.27	3.209		0.9997	0.9872	6.023	6.016		0.01225	0.01164	6.298	6.323		0.01637	0.00938
338_50	10.01	3.466	0.2567		0.9596	0.07006	0.06276	5.953		1	0.6165	0.6415	5.682		0.9953
338_100	10.95	2.525	0.6846	0.9413		0.02189	0.01459	6.001	0.04816		0.09164	0.1166	6.207	0.5249	

Appendix E. 5a. 339_F, 339_50 and 339_100 (salmon farm) Summary statistics: Mean and standard deviation for sediment properties at the salmon station with two control stations (ConM and ConH).

Station	Organic Matter (%)			Dry Matter (g/100g)			Ash (g/100g)			% silt/mud			% sand		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	9.133	0.252	3	51.000	1.000	3	91.000	0.000	3	37.133	3.201	3	53.100	7.318	3
ConH	6.467	0.577	3	57.667	0.577	3	93.333	0.577	3	66.300	1.664	3	31.167	1.201	3
339_F	8.300	5.027	3	53.000	2.000	3	91.333	0.577	3	16.967	0.493	3	73.400	5.895	3
339_50	6.200	0.173	3	56.000	1.000	3	93.333	0.577	3	48.267	1.747	3	42.400	2.516	3
339_100	6.500	0.819	3	58.667	2.082	3	94.333	0.577	3	44.433	2.627	3	52.033	4.891	3

Station	% very fine gravel			Total Organic Carbon (%)			Copper (mg/kg)			Zinc (mg/kg)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
ConM	9.733	4.365	3	2.200	0.200	3	7.667	0.577	3	32.667	4.509	3
ConH	2.500	1.136	3	1.150	0.070	3	9.333	0.577	3	31.667	2.517	3
339_F	9.600	6.324	3	3.967	1.856	3	1353.333	1158.462	3	357.667	248.589	3
339_50	9.333	4.200	3	1.237	0.031	3	13	3	3	37.333	2.082	3
339_100	3.533	2.312	3	1.337	0.249	3	11.333	1.528	3	36.000	3.606	3

Appendix E.5b. 339_F, 339_50 and 339_100: One-way ANOVA analysis p<0.05: Shows significant differences (red) between stations for all sediment indicators: df = 4

	SS	MS	F	P-value
% Organic Matter	20.710	5.177	0.9818	0.459891004
Dry matter	123.6	30.9	14.484	0.000363723
Ash	17.6	4.4	0.7674	0.570158483
% silt/mud	3852.337	963.084	207.442	0.0000000014
% sand	2918.631	729.658	30.401	0.000014
% very fine gravel	155.776	38.944	2.3371	0.125979776
% Total organic carbon	16.952	4.238	5.967	0.010152552
Cu mg/kg dry wt	4328806	1082201.567	4.032	0.033560684
Zn mg/kg dry wt	250842.267	62710.567	5.07	0.017080038

Appendix E. 5c 339_F, 339_50 and 339_100 ad hoc paired tests Tukey HDS. Marked differences (red) are significant at p<0.05.

	Organic Matter (%)					Dry Matter (g/100gd)					Ash (g/100g)				
	ConM	**ConH**	**339_F**	**339_50**	**339_100**	**ConM**	**ConH**	**339_F**	**339_50**	**339_100**	**ConM**	**ConH**	**339_F**	**339_50**	**339_100**
ConM		0.6286	0.9907	0.5486	0.6387		0.0018	0.4873	0.0126	0.00068		0.6703	0.9578	0.5751	0.6703
ConH	2.011		0.8593	0.9999	1	7.906		0.0192	0.6426	0.9124	1.907		0.9578	0.9998	1
339_F	0.6285	1.383		0.7931	0.8668	2.372	5.534		0.1628	0.0055	0.9535	0.9535		0.911	0.9578
339_50	2.212	0.2011	1.584		0.9998	5.929	1.976	3.558		0.2423	2.145	0.2384	1.192		0.9998
339_100	1.986	0.0251	1.358	0.2263		9.092	1.186	6.72	3.162		1.907	0	0.9535	0.2384	

	% mud					% sand					% very fine gravel				
	ConM	**ConH**	**339_F**	**339_50**	**339_100**	**ConM**	**ConH**	**339_F**	**339_50**	**339_100**	**ConM**	**ConH**	**339_F**	**339_50**	**339_100**
ConM		0.00018	0.00018	0.00075	0.0134		0.00205	0.0035	0.1286	0.9987		0.2651	1	0.9999	0.3947
ConH	23.45		0.00018	0.00018	0.00018	7.754		0.00018	0.1052	0.0029	3.069		0.2798	0.311	0.9977
339_F	16.21	39.66		0.00018	0.00018	7.177	14.93		0.00025	0.0025	0.0566	3.013		1	0.414
339_50	8.95	14.5	25.16		0.262	3.783	3.971	10.96		0.1901	0.1697	2.899	0.1131		0.4543
339_100	5.868	17.58	22.08	3.081		0.3771	7.377	7.554	3.406		2.631	0.4384	2.574	2.461	

	Total Organic Carbon (%)					Copper (mg/kg)					Zinc (mg/kg)				
	ConM	**ConH**	**339_F**	**339_50**	**339_100**	**ConM**	**ConH**	**339_F**	**339_50**	**339_100**	**ConM**	**ConH**	**339_F**	**339_50**	**339_100**
ConM		0.5701	0.1509	0.6412	0.7223		1	0.0594	1	1		1	0.0321	1	1
ConH	2.158		0.0146	0.9999	0.9986	0.0056		0.0598	1	1	0.0156		0.0315	1	1
339_F	3.631	5.789		0.0177	0.0221	4.499	4.493		0.0606	0.0602	5.062	5.077		0.0347	0.0339
339_50	1.98	0.1781	5.611		0.9999	0.0178	0.0123	4.481		1	0.0727	0.0883	4.989		1
339_100	1.774	0.3836	5.405	0.2055		0.0123	0.0067	4.487	0.0056		0.0519	0.0675	5.01	0.0208	

7.6 APPENDIX F DROP-CAMERA PHOTOS OF SEDIMENT SURFACE

Drop-camera photos in triplicate (1-3) of sediment surface at control (reference), mussel and salmon stations.

Control M (1)

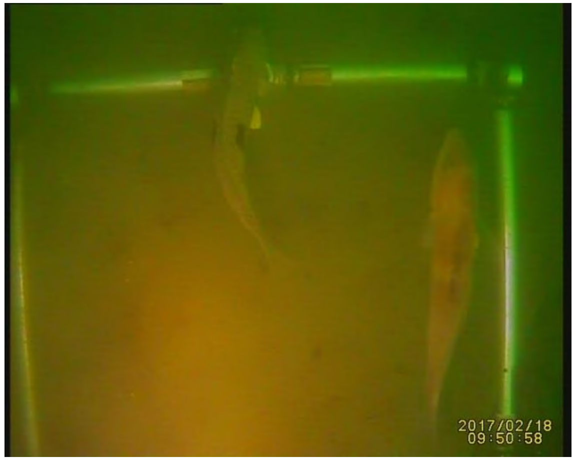
Control M (2)

Control M (3)

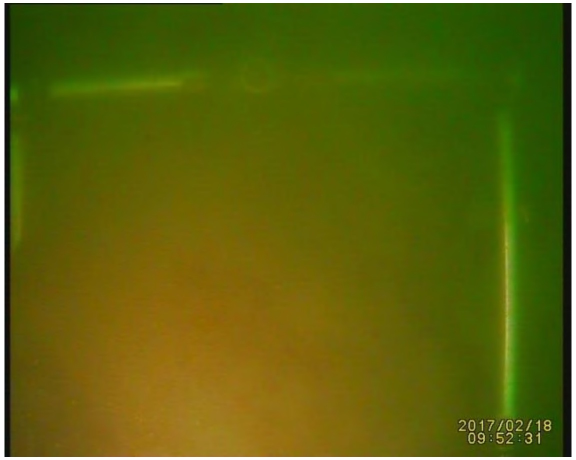
Control H (1)

Control H (2)

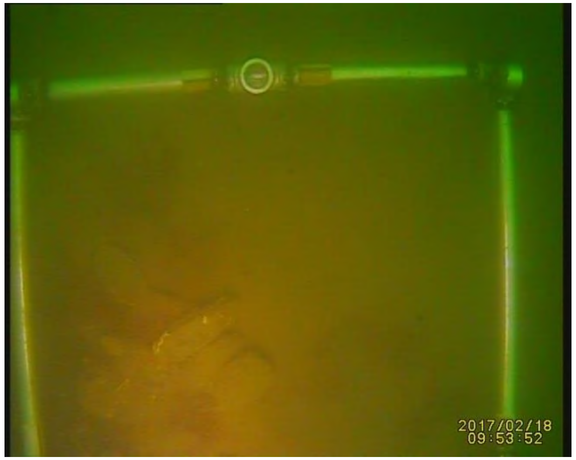
Control H (3)



Mussel 244_F (1)

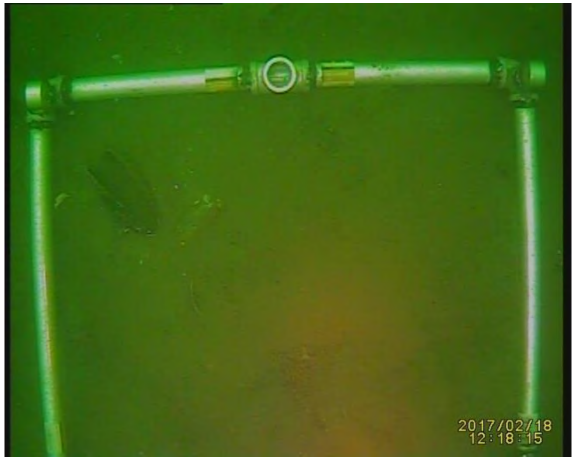


Mussel 244_F (2)



Mussel 244_F (3)

Mussel 340_F (1)



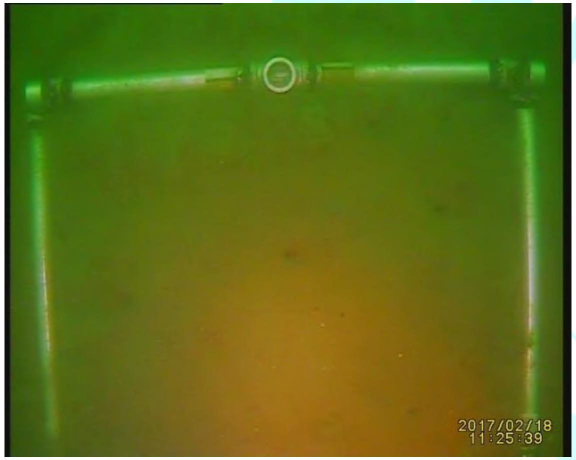
Mussel 340_F (2)

Mussel 340_F (3)

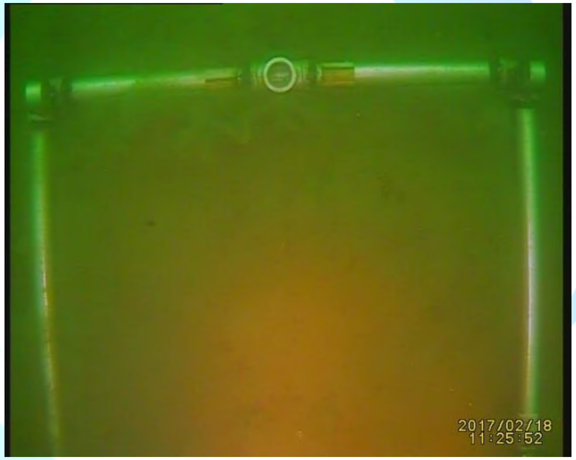
Salmon 338_F (1)

Salmon 338_F (2)

Salmon 338_F (3)

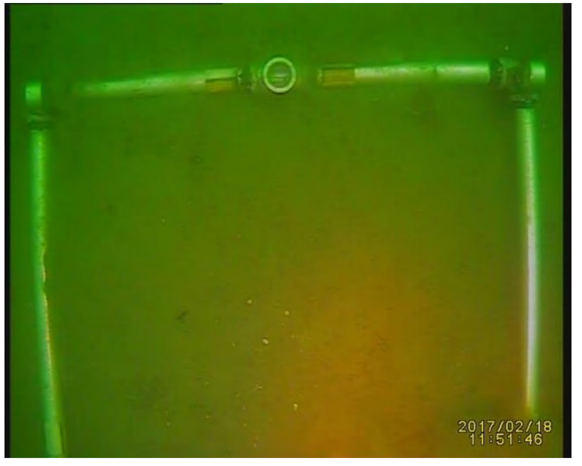


Salmon 338_50 (1)

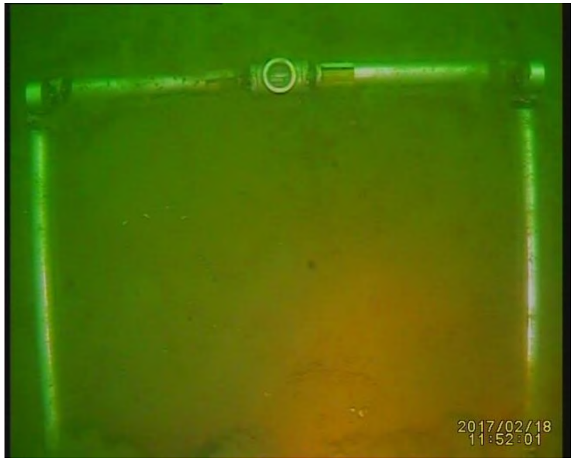


Salmon 338_50 (2)

Salmon 338_50 (3)



Salmon 338_100 (1)



Salmon 338_100 (2)

Salmon 338_100 (3)

Salmon 339_F (1)

Salmon 339_F (2)

Salmon 339_F (3)

Salmon 339_50 (1)

Salmon 339_50 (2)

Salmon 339_50 (3)

Salmon 339_100 (1)

Salmon 339_100 (2)

Salmon 339_100 (3)

Salmon 246_F (1)

Salmon 246_F (2)

Salmon 246_F (3)

Salmon 246_50 (1)

Salmon 246_50 (2)

Salmon 246_50 (3)

Salmon 246_100 (1)

Salmon 246_100 (2)

Salmon 246_100 (3)

7.7 Appendix G Benthic Infauna Taxa and Abundance

Appendix Ga: Benthic infauna taxa and abundance at control and mussel stations. Triplicate grab samples R1-R3 were collected at each station. ConH = Control H, ConM = Control M

TAXA					Mussel Station						Control Station					
					244_F			340_F			ConM			ConH		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Annelida	Polychaeta	Capitellida	Capitellidae	*Capitellid sp.*	-	-	-	2	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Capitellida	Maldanidae	*Maldanid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.*	6	-	-	7	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.2*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Eunicidae	*Eunicid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Lumbrineridae	*Lumbrinerid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Flabelligerida	Flabelligeridae	*Flabelligerid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Opheliida	Opheliidae	*Opheliid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Orbiniida	Orbiniidae	*Orbiniid sp.*	-	-	-	-	-	-	-	-	-	1	-	-
Annelida	Polychaeta	Oweniida	Oweniidae	*Oweniid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycerid sp.*	-	-	1	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Goniadidae	*Goniadid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Nephtyid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Nereidae	*Nereid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Spionida	Cirratulidae	*Cirratulid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Canalipalpata	Sabellidae	*Sabellid sp.*	-	-	-	-	-	-	-	1	-	-	-	-
Annelida	Polychaeta	Canalipalpata	Terebellidae	*Terebellid sp.*	-	-	-	-	-	-	-	1	-	-	-	-
Annelida	Polychaeta	Terebellida	Pectinaridae	*Pectinarid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Terebellida	Ampharetidae	Ampharetid sp.	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta			Unidentified sp.	-	3	-	-	-	-	1	-	-	12	12	-
Arthropoda	Malacostraca	Leptostraca	Nebaliidae	Nebalia sp.	-	-	-	-	-	1	-	-	-	-	-	-

TAXA					Mussel Station						Control Station					
					244_F			340_F			ConM			ConH		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Arthropoda	Malacostraca	Amphipoda		Amphipod	2	9	-	-	2	-	-	-	6	-	-	1
Arthropoda	Malacostraca	Tanaidacea		Tanaid	-	-	-	-	-	-	-	-	-	-	-	-
Arthropoda	Malacostraca	Decapoda		Decapod	-	-	-	-	-	-	-	1	-	-	-	-
Arthropoda	Ostracoda			Ostracod	-	-	-	-	-	-	-	-	1	-	-	-
Brachiopoda	Rhynchonellata	Terrebratulida	Terebratellidae	*Terebratella sanguinea*	-	-	-	-	-	-	-	-	-	-	-	1
Echinodermata	Holothuroidea	Dendronchirotida	Phyllophoridae		-	-	-	-	-	-	-	-	-	3	-	-
Mollusca	Bivalvia	Pholadomyoida	Thraciidae	*Thracia vegrandis*	-	-	-	-	1	2	-	2	2	-	1	-
Mollusca	Bivalvia	Mytiloida	Mytilidae		-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Mytiloida	Nuculidae	*Nucula nitidula*	-	-	2	-	1	4	5	2	7	3	-	-
			Nuculidae	*Nuculidae sp 1*	-	2	-	-	-	-	3	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Ungulinidae		-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Thyasiridae		-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Veneridae		-	-	1	-	1	-	-	-	1	-	2	-
Mollusca	Bivalvia	Veneroida	Lasaeidae	*Arthritica sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Solemyoidae	Solemyidae	*Solemya parkinsonii*	1	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia		Veneridae	*Venericardia purpurata*	-	-	-	-	-	-	-	-	1	-	-	-
Mollusca	Bivalvia		Malletiidae	*Neilo austalis*	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Semelidae	*Leptomya retiaria*	-	-	-	-	-	2	2	-	1	-	-	-
Mollusca	Gastropoda	Stromboidea	Struthiolariidae	*Struthiolaria papulosa*	-	-	-	-	-	-	-	-	-	-	-	-

Appendix Gb: Benthic infauna taxa and abundance at salmon sites. Triplicate grab samples R1-R3 were collected at each station. 50 and 100 refer to sample stations 50 and 100 m from the salmon pens.

TAXA					**Salmon Station**											
					338_F			**338_50**			**338_100**			**339_F**		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Annelida	Polychaeta	Capitellida	Capitellidae	*Capitellid sp.*	-	1	-	1	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Capitellida	Maldanidae	*Maldanid sp.*	-	-	-	-	-	-	1	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.*	1	-	11	-	-	-	2	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.2*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Eunicidae	*Eunicid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Lumbrineridae	*Lumbrinerid sp.*	-	-	-	1	1	2	2	-	-	-	-	-
Annelida	Polychaeta	Flabelligerida	Flabelligeridae	*Flabelligerid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Opheliida	Opheliidae	*Opheliid sp.*	-	-	-	-	1	-	3	-	-	-	-	-
Annelida	Polychaeta	Orbiniida	Orbiniidae	*Orbiniid sp.*	-	-	-	-	2	1	4	-	-	-	-	-
Annelida	Polychaeta	Oweniida	Oweniidae	*Oweniid sp.*	-	-	-	-	-	-	-	-	2	-	-	-
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycerid sp.*	1	-	-	2	-	-	3	-	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Goniadidae	*Goniadid sp.*	-	-	-	-	1	-	-	-	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Nephtyid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Nereidae	*Nereid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Spionida	Cirratulidae	*Cirratulid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Canalipalpata	Sabellidae	*Sabellid sp.*	-	-	-	-	-	-	-	-	2	-	-	-
Annelida	Polychaeta	Canalipalpata	Terebellidae	*Terebellid sp.*	-	-	-	-	-	-	-	-	1	-	-	-
Annelida	Polychaeta	Terebellida	Pectinaridae	*Pectinarid sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Terebellida	Ampharetidae	Ampharetid sp.	-	-	-	-	-	-	-	-	1	-	-	-
Annelida	Polychaeta			Unidentified sp.	-	-	-	-	-	-	-	-	4	-	-	-
Arthropoda	Malacostraca	Leptostraca	Nebaliidae	Nebalia sp.	-	8	-	-	-	-	-	-	-	-	-	-

TAXA					Salmon Station											
					338_F			338_50			338_100			339_F		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Arthropoda	Malacostraca	Amphipoda		Amphipod	-	-	-	2	-	3	-	-	-	-	-	-
Arthropoda	Malacostraca	Tanaidacea		Tanaid	-	-	-	-	-	-	-	-	-	-	-	-
Arthropoda	Malacostraca	Decapoda		Decapod	1	-	-	-	-	-	-	-	-	-	-	-
Arthropoda	Ostracoda			Ostracod	-	-	-	-	-	-	-	-	-	-	-	-
Brachiopoda	Rhynchonellata	Terrebratulida	Terebratellidae	*Terebratella sanguinea*	-	-	-	-	-	-	-	-	1	-	-	-
Echinodermata	Holothuroidea	Dendronchirotida	Phyllophoridae		-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Pholadomyoida	Thraciidae	*Thracia vegrandis*	-	-	-	1	1	2	-	-	-	-	-	-
Mollusca	Bivalvia	Mytiloida	Mytilidae		-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Mytiloida	Nuculidae	*Nucula nitidula*	-	-	-	-	-	4	1	-	-	1	-	-
			Nuculidae	*Nuculidae sp 1*	-	2	9	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Ungulinidae		-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Thyasiridae		-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Veneridae		-	-	-	-	-	-	-	-	-	-	-	1
Mollusca	Bivalvia	Veneroida	Lasaeidae	*Arthritica sp.*	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Solemyoidae	Solemyidae	*Solemya parkinsonii*	1	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia		Veneridae	*Venericardia purpurata*	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia		Malletiidae	*Neilo austalis*	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Semelidae	*Leptomya retiaria*	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Gastropoda	Stromboidea	Struthiolariidae	*Struthiolaria papulosa*	-	-	-	-	-	-	-	-	-	-	-	-

TAXA					Salmon Station														
					339_50			339_100			246_F			246_50			246_100		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Annelida	Polychaeta	Capitellida	Capitellidae	*Capitellid sp.*	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Capitellida	Maldanidae	*Maldanid sp.*	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.*	-	-	2	-	-	3	-	-	-	-	4	-	-	-	-
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Dorvilleid sp.2*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Eunicidae	*Eunicid sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Eunicida	Lumbrineridae	*Lumbrinerid sp.*	-	3	-	-	-	-	-	-	-	2	-	-	-	-	-
Annelida	Polychaeta	Flabelligerida	Flabelligeridae	*Flabelligerid sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Opheliida	Opheliidae	*Opheliid sp.*	-	4	-	-	-	-	-	-	-	1	-	1	-	-	-
Annelida	Polychaeta	Orbiniida	Orbiniidae	*Orbiniid sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Oweniida	Oweniidae	*Oweniid sp.*	-	-	-	-	-	11	-	-	-	2	-	-	-	2	-
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycerid sp.*	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Goniadidae	*Goniadid sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Nephtyid sp.*	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Annelida	Polychaeta	Phyllodocida	Nereidae	*Nereid sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Spionida	Cirratulidae	*Cirratulid sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Canalipalpata	Sabellidae	*Sabellid sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Canalipalpata	Terebellidae	*Terebellid sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Terebellida	Pectinaridae	*Pectinarid sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta	Terebellida	Ampharetidae	Ampharetid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annelida	Polychaeta			Unidentified sp.	-	-	14	-	3	-	-	-	-	-	-	-	-	-	2
Arthropoda	Malacostraca	Leptostraca	Nebaliidae	Nebalia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3

TAXA					Salmon Station														
					339_50			339_100			246_F			246_50			246_100		
Phylum	**Class**	**Order**	**Family**	**Species**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Arthropoda	Malacostraca	Amphipoda		Amphipod	-	-	-	-	-	-	55	-	-	37	17	38	-	-	69
Arthropoda	Malacostraca	Tanaidacea		Tanaid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arthropoda	Malacostraca	Decapoda		Decapod	1	-	-	-	-	-	3	-	-	-	-	4	-	-	-
Arthropoda	Ostracoda			Ostracod	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Brachiopoda	Rhynchonellata	Terrebratulida	Terebratellidae	*Terebratella sanguinea*	2	1	-	1	-	-	-	-	-	-	-	1	-	-	-
Echinodermata	Holothuroidea	Dendronchirotida	Phyllophoridae		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Pholadomyoida	Thraciidae	*Thracia vegrandis*	1	1	-	2	4	1	-	-	-	-	2	-	-	2	-
Mollusca	Bivalvia	Mytiloida	Mytilidae		-	-	2	-	5	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Mytiloida	Nuculidae	*Nucula nitidula*	-	2	3	1	-	2	4	-	9	1	-	2	-	4	-
			Nuculidae	*Nuculidae sp 1*	7	-	-	-	-	3	3	-	-	-	5	-	-	-	2
Mollusca	Bivalvia	Veneroida	Ungulinidae		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Thyasiridae		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Veneridae		-	1	2	1	4	-	-	3	-	-	-	-	-	2	-
Mollusca	Bivalvia	Veneroida	Lasaeidae	*Arthritica sp.*	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Mollusca	Bivalvia	Solemyoidae	Solemyidae	*Solemya parkinsonii*	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia		Veneridae	*Venericardia purpurata*	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia		Malletiidae	*Neilo austalis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	Bivalvia	Veneroida	Semelidae	*Leptomya retiaria*	3	-	-	2	-	-	-	2	-	1	-	-	-	-	-
Mollusca	Gastropoda	Stromboidea	Struthiolariidae	*Struthiolaria papulosa*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-