An Bord Achomharc Um Cheadúnais Dobharshaothraithe
Aquaculture Licences Appeals Board

AP 6 /2 /2018

Appellant Name: Victor & Lynda Morgan

Site Ref: T05-590A

Appeal

Cúirt Choill Mhinsí, Bóthar Bhaile Átha Cliath, Port Laoise, Contae Laoise, R32 DTW5
Kilminchy Court, Dublin Road, Portlaoise, County Laois, R32 DTW5

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NOTICE OF APPEAL UNDER SECTION 40(1) OF FISHERIES (AMENDMENT) ACT 1997 (NO. 23)

Name and address of appellant:

Victor & Lynda Morgan,

Mobile Tel: E-mail address:

Subject matter of the appeal:
Aquaculture license decision notice, published in The Southern Star , dated April 21 2018, File Ref T05/590A

Site Reference Number:-
(as allocated by the Department of Agriculture Fisheries & Food) **T05/590A**

Appellant's particular interest
in the outcome of the appeal:

I am a Local Resident, with a background in Maths and Maths physics – Science graduate , UCC. Our eldest son races Laser Radial sailing boats and has competed successfully in Ireland and Europe. We study tides and currents carefully before each race and have a good understanding of Hydrodynamics in bays throughout the country.

Outline the grounds of appeal (and, if necessary, on additional page(s) give full grounds of the appeal and the reasons, considerations and arguments on which they are based):

1. **Proposed site remains unsuitable due to Insufficient Flushing Rate and proximity to coastline.**
2. **Proposed Development will destroy local Bathing Area.**
3. **SAC / Habitats Directive requirement not fulfilled.**
4. **Odour Elimination has not been addressed .**
5. **Concerns about the observations made in reports submitted by the Applicants.**

1. Insufficient Flushing Rate and proximity to the coastline:

The proposed site is in a **sheltered location**. It is bounded on three sides by Land : Carbery Island and Furze Island to the West, Dunmanus Bay Shoreline to the South, and Drishane Harbour to the East. The river that flows into the mouth of the harbour in Durrus does not have the capacity to assist flushing, and the proposed location relies on the ebb and flow of the tide.

There is clear evidence of the sheltered nature of the site - a **large seal colony** resides there permanently , and there are two sand and shingle bathing areas which have been formed by sand , crushed shell deposits, and small stoney deposits which have settled there over time – evidence of a poor Flushing Rate.

Admiralty Chart No 2552-0 (Dunmanus Bay) states : **No perceptible Tidal Stream** (enclosed) .

The Cronin Millar report submitted in the Application for this license, section 9.1.2 , works with depths -15m to -30m, and observed sea velocities between 0.09m/sec and 0.20 m/sec at the site.

The Velocity and Current readings were taken over a 10 hour period, on one single day, in October 2012, 3 days after a New Moon – when tides run strong. On 16 August 2012, the worst storm in 26 years slammed into the cork Coastline.

There was a spike in current readings during a one hour period (hour 12.05) which affected the average readings.

These results were then used to determine calculations for waste dispersal for the entire year. Recordings taken over a single 10 hour period are not a fair reflection of the annual current velocities in the bay, and should not have been used.

The report states that the concentration of waste deposits produced by the farm will settle between 150m and 600m laterally from the source - from calculations based on water depths of between -15m to -30m.These lateral extensions are marked out on the attached Admiralty Chart. They represent the area surrounding and including the site , into which sediment is expected to deposit.

Their calculations would be accurate if the sea bed in this catchment area was fairly level, symmetrical, and was between -15m and -30m throughout the entire zone.

In fact, the depth according to Admiralty Charts varies between -29m and 0m in the catchment area The surface of the sea bed at the location is not symmetrical – verified in the Bathymetric Survey submitted by Cronin Millar. Onshore winds, currents and tides, will, with certainty, drive settling waste into shallow water.

Shallow water is marked on Admiralty Charts (shaded in Blue) as water less than 10 metres deep. We estimate there is approximately 80,000 m^2 of shallow water within the catchment area, where waste is most likely to deposit. It is possible that deposits there will be in the region of 992,000kg/year / 80,000m^2 = 9.92kg/m^2/year = 34gm/m^2/day.

This is more than double the 15gms/m^2/day threshold that the report (section 9.1.3) recommends, and it will have an unacceptable ecological impact on the sea bed locally (Weise et al).

It should also be noted that the concentration of waste deposits is likely to be even higher, because we expect a more extensive Current Velocity Survey would reveal much weaker velocities over a longer time. The waste will continue to be deposited daily, while shallow tidal waters will trap it and expose it to the air.

The proximity of the site to the shallow grounds of the Foreshore renders the proposed development unsuitable.

2. Damage to Local Bathing Area

The proposed site extends left and right of - effectively surrounds - the only local bathing and amenity area, which I have marked on the attached map. The excrement and pollution from a mussel farm would totally destroy this amenity and render it unsuitable for Bathing. The proposal is in direct conflict with EC Council Directive 76/160/EEC concerning the quality of Bathing Water, which declares on page 2 : **"in order to protect the environment and public health, it is necessary to reduce the pollution of bathing areas, and to protect such water against further deterioration"**

This beach is used by all the locals and their children , and is a social focal point for most of the year. It's the most popular bathing area in Dunmanus Bay. It has a small parking area and is used for swimming, snorkling, kayaking, sailing, canoeing, and diving. In the Summer , annual visitors to the Cashelane holiday homes use it every day. Last Summer Canadians, English, French, Germans, Italians and Irish people swam there, including Saoirse Ronan, actress, and David Davin-Power, RTE. The beach is a big factor in the enjoyment of their Tourist Holiday in Ireland, where families interact and meet up with locals and friends in a safe and healthy environment.

This Bathing Area falls inside the Lateral Area marked out for waste faecal deposition by the Applicants. Waste will settle daily in the location due to the proximity of the mussel farm and the sheltered nature of the bay.

The location is not a Designated Bathing Area, but this is not a requirement. It is a popular and well known Bathing Area, listed for "leisure Usage"in Cork County Council's "Marine Leisure Infrastructure Strategyfor West Cork" 2008 . Putting a mussel farm in the proposed location would create an unacceptable waste biodeposit problem there , unpleasant to swim in, smelly, and slippery to access.

These structures should never be placed in areas where there is shallow tidal water – which will lead to exposure of the settled waste twice every day, and should never be placed near bathing areas.

Mussel faecal material is easily suspended in water due to it's low density, and has been found to settle extremely slowly (Saurel, Gascoigne et al 2004) . The majority of filtered and biodeposited material is resuspended immediately (Smaarl et al 1986) . Mussel beds increase sediment flux both from water column to bed and from the bed back to the water column, and mussel biodeposits may contribute significantly to the total suspended load in estuarine and costal environments (Kautsky and Evans, 1987).

The proposed site cannot be picked because mussel faecal material will be carried in the bathing water for a long time before being deposited . To uphold the EU Directive, this appeal should be upheld.

3. SAC / Habitats Directive Requirement not fulfilled

Dunmanus Bay is a well known **Nursery Bay**. The best Scallop spawning ground in the South West lies here. It is a breeding ground for Prawn, Shrimp Velvet Crab and Lobster. A seal colony and otters reside near the proposed location. They crawl up onto the smooth rocks of a small Island here, and their habitat must be protected.
The nearest Natura 2000 site is approx. 2km away from the proposed site, but only about 1.4km away from the predicted waste dispersal zone . We feel that the opinion of the general public should have been obtained , before any decision was reached, in accordance with Article 6(3) of the Habitats Directive.
Fishermen have spoken of the sighting of Sea Grass and Coral in the immediate area, but they were not aware any screening report was being carried out.

There is a harbour seal haulout approx. 200m from the site, but within the expected waste deposition zone. We feel this must surely have an impact on the seal habitat – and we feel this was not considered properly.
There is an otter habitat about 600m away from the site, but bordering the waste deposition zone. We feel this was not considered properly.

We have contacted Seal Rescue Ireland and they have advised that there should be proper assessment before the development is allowed. Harbour seals are afforded protection under Annex II of the EU Habitats Directive.

Ireland is legally mandated to implement MSP – Marine Spatial Planning – which should **proactively** seek to engage stakeholders early.
\The Applicant began work in 2013 and had 5 years to prepare their application. We have 4 weeks from seeing a notice in a newspaper to prepare an objection. This is not balanced or fair – and more time is needed to fully flesh out the facts.
We received no notification from the Department about their decision , despite including email and postal addresses with our comprehensive objection.

More time and public engagement was needed to properly prepare and consider Screening Reports before a decision was made – no Licence should be granted until this is addressed properly.

4. Odour Elimination has not been addressed

The nearest aquaculture farm is about 8km away, close to Durrus village. It is situated close to tidal coastline, similar to the model proposed in this application. At low tides there is a terrible smell locally. The odours from the existing aquaculture farm at Low Water , and especially Low Water Spring Tide is indicative of the difficulty of odour control when a farm is close to shore.

Low tide water happens twice a day, the water level sinks even further at Spring Tides – every two weeks. It is a certainty that waste will settle in shallow waters, and this waste will be exposed to the air as the tide retreats twice every day.

This Application does not demonstrate how odours will be eliminated at LWST.

5. Concerns about observations and caclulations made in reports submitted by the Applicants :

We have a number of concerns about figures used to determine the flushing rate and associated waste footprint.

A figure of 10mm/sec was used as the biodeposit settling rate at Dunmanus Bay. This is about twice the 5mm/sec rate observed by Chamberlain (2002), and Hartstein and Stevens (2005) reported settling speeds over 30 mm/sec. Settling rates vary depending on local conditions and faecal pellet size. The report does not carry out calculations based on these higher and lower recorded velocities and makes no reference to pellet size.

The Pseudofaeces Settling velocity in Table 4 (2mm/sec) has been ignored in their calculations, and no footprint is given for Pseudofaeces waste .

The biodeposit rate per metre has been interpolated linearly from Table 4. However there is no evidence that the relationship between biodeposits and mussel line length is Linear and not exponential. There is recorded and published work to show that benthic environments respond to biodeposition in a *non linear* manner. Therefore the wrong conclusions may be drawn.

Their calculations are based on Low Water depth -15m to -30m. However the waste dispersal area has several areas of tidal coastline where water level is 0m. Their calculations are therefore inaccurate.

The seabed in the immediate area is extremely uneven and waste will not settle or disperse evenly. It will be carried into areas which are shallow, and no account is taken of this.

No account is taken of mussel density on differing line lengths used in calculations.No account is taken of the age or size of the mussels.

The report finds that the acceptable threshold for benthic survival is between 15 to 30gms/m^2/day. This is misleading – it suggests a scale of 15 to 30. The widely accepted level at which the benthic environment is damaged permanently is 15gm/m^2/day (Weise et al) , so the scale is 0 to 15. Many other researchers claim the figure is between3.25 and 10gm/day, or between 4.4 and 8.8 gm/m^2/day. These were not considered .

Section 9.4 of the report , Impact on Foreshore : "None Anticipated". Yet the Foreshore contains much shallow waters, and lies within the Lateral Area for waste deposit. We anticipate there will be a significant impact here from waste deposition.

Current velocities for the entire year are extrapolated from readings taken over a 10 hour period which enjoyed a 2 hour spike which affected the results.

Two people carry out an exploratory dive in the littoral zone in 2013 – the area of the bay that is close to the shore. I cannot find any coordinates for the area they surveyed, and a large portion of the bay is close to the shore. Fishermen have recently reported findings of Coral and Sea Grass in the zone marked out for waste deposition, so maybe these were missed ? The 2013 report could be flawed or simply out of date.
I am willing to commission a new report, and ask that time is given to properly assess the Habitat.

Conclusion :

Everything important was calculated from abstracted material. Table 4 indicated that Biodeposit and faecal settling rates in Dunmanus Bay are "Unknown", but Biodeposit and faecal settling velocities in the bay are already measurable at the Applicant's current location less than 8km away in Dunmanus Bay – these should have been recorded, submitted and used in their calculations instead.

Their analysis of the flushing rate in the proposed location is flawed and incomplete, and does not support the evidence on the ground. The flushing rate is simply too poor in this area to support aquaculture farms. There is no perceptible tidal stream – and it's confirmed clearly on the Admiralty Chart .

We believe the reasons and considerations for the Minister's determination to grant the licence, by accepting at face value the calculations and statements within the Applicant's reports, was surprising and erroneous. We believe they were not examined carefully enough, and the calculations contained within were not scrutinised enough.

The ALAB were correct in their reversal of the decision last time due to concerns over poor flushing rates, and this aspect together with deposits on local tidal foreshore and bathing area still remain.

His reasons for granting (a, b, f, g, and i) are unsound.

The Minister's determination was therefore unsound, and our appeal should be upheld in light of proper analysis of the reports submitted.

Documentation, fees and maps are attached.

Please Note :
Visual Aids, Scientific Paper References and appropriate fees are attached with this application. We are available for any enquiries. We are also available for an Hearing if it will help. Fees for both are attached.

Fee enclosed: € 228.55

(payable to the Aquaculture :Licences Appeals Board in accordance with the Aquaculture Licensing Appeals (Fees) Regulations, 1998 (S.I. No. 449 of 1998))(See Note 2)

Signed by appellant:

Victor Morgan

Lynda Morgan Lynda Morgan

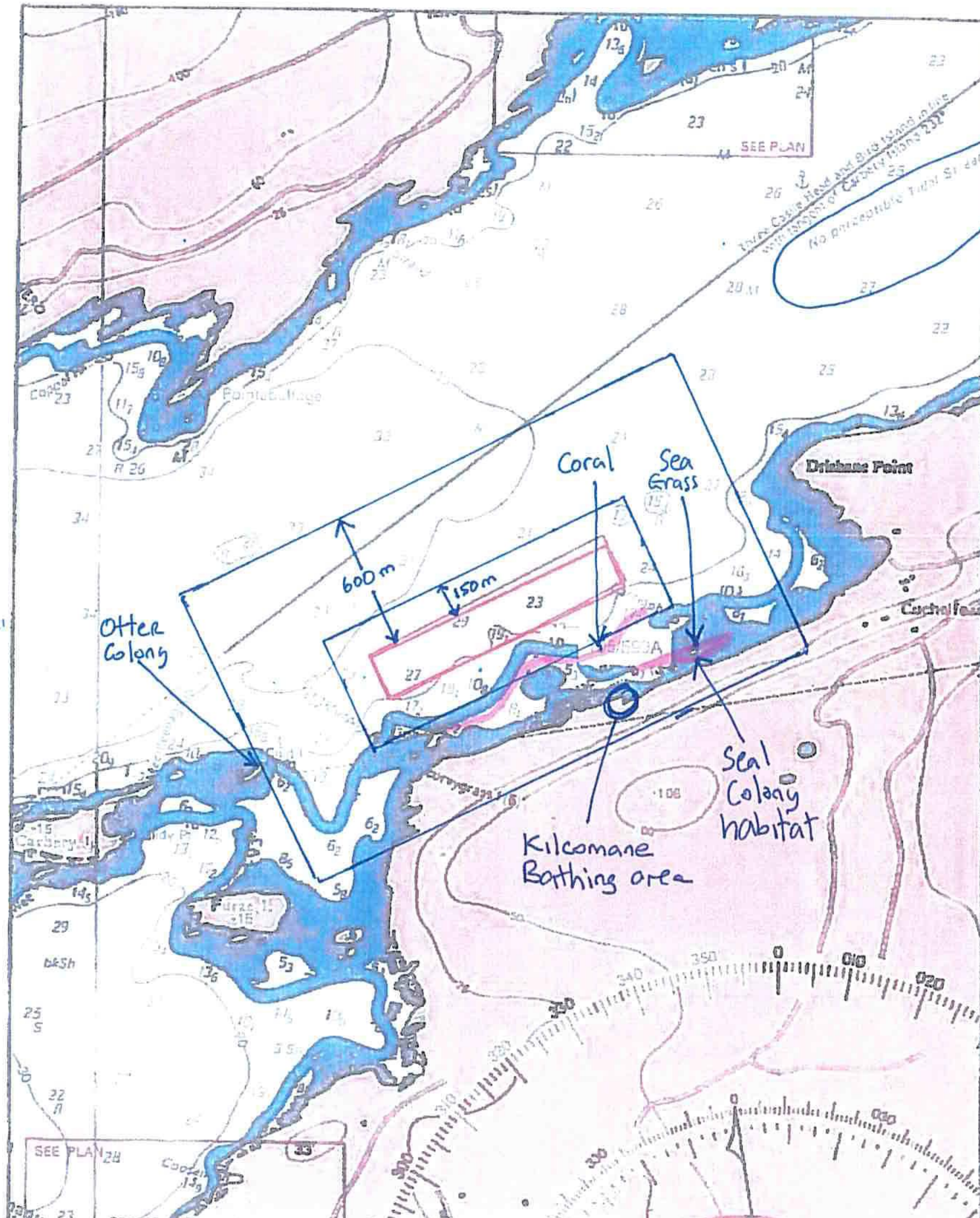
Date: 16th. May. '18.

Note 1: This notice should be completed under each heading and duly signed by the appellant and be accompanied by such documents, particulars or information relating to the appeal as the appellant considers necessary or appropriate and specifies in the Notice.

Note 2: The fees payable are as follows:

Appeal by licence applicant	€380.92
Appeal by any other individual or organisation	€152.37
Request for an Oral Hearing (fee payable in addition to appeal fee)	€76.18

In the event that the Board decides not to hold an Oral Hearing the fee will not be refunded.



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Sites highlighted in red denotes Application

Part of Admiralty Chart No 2552-0

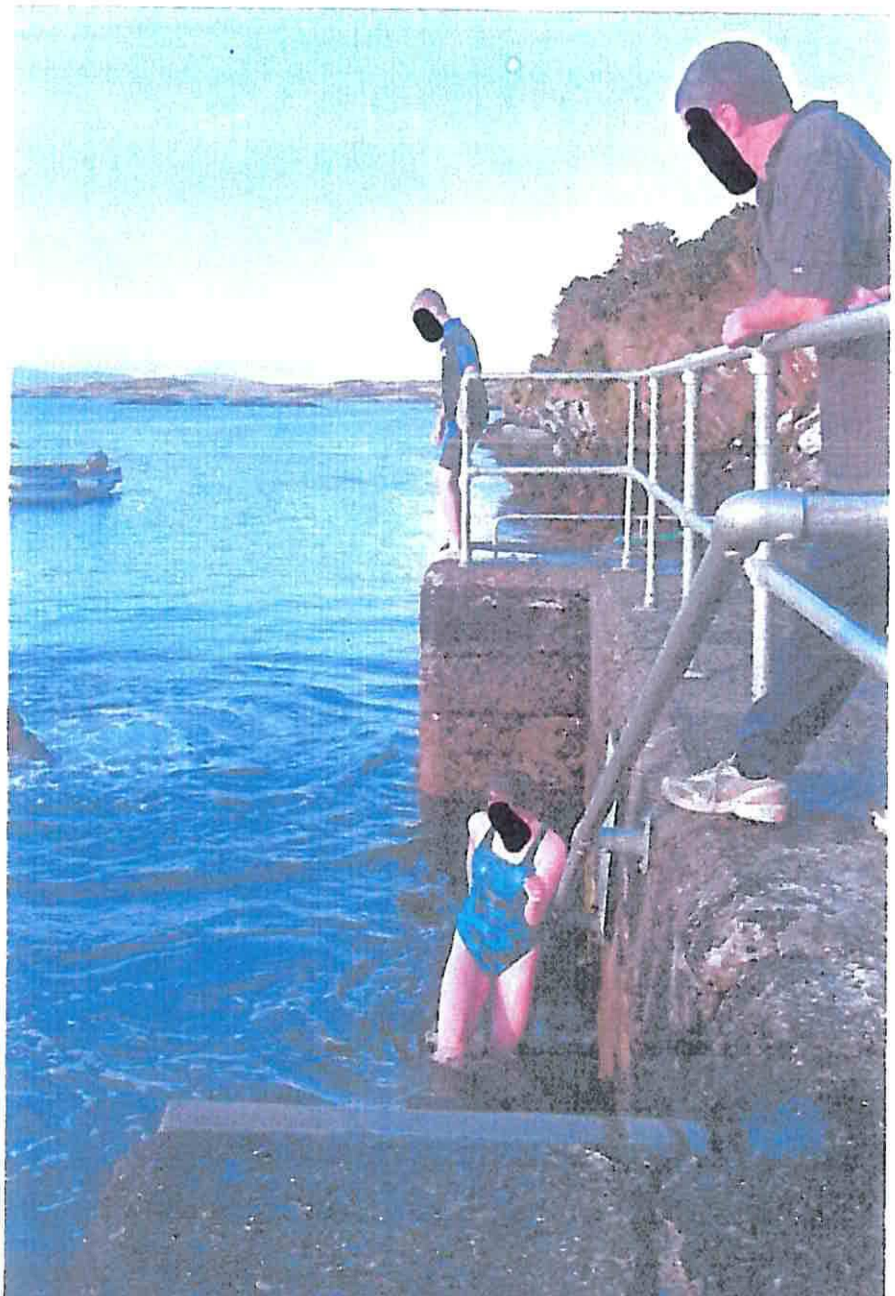
Not to be used for Navigation

Agriculture, Food and the Marine
Talmhaíochta, Bia agus Mara

(scale)
600 m ÷ 24,000 = 25mm
150 m ÷ 24,000 = 6mm

Sailing in Dunmanus Bay 2017 - At the proposed site

Bathing Area, Kilcomane,
Dunmanus Bay.
- Marked on Attached
Admiralty Chart.



Swimming in Bathing Area,
Kilcomane, Dunmanus Bay.

Bathing Area, Kilcomane,
Dunmanus Bay

"*Determination of Aquaculture/Foreshore Licensing Application – T05/590*

Dunmanus Bay Mussels Ltd has applied for an Aquaculture Licence and a Foreshore Licence for the cultivation of mussels on Site T05/590A, totalling 26.25 hectares on the foreshore between Carbery Island and Drishane Point at outer Dunmanus Bay, Co. Cork.

The Minister for Agriculture, Food and the Marine has determined that it is in the public interest to grant the Aquaculture and Foreshore Licences sought. In making his determination, the Minister considered those matters which by virtue of the Fisheries (Amendment) Act 1997 and other relevant legislation, he was required to have regard. Such matters include any submissions and observations received in accordance with statutory provisions. The following are the reasons and considerations for the Minister's determination to grant the licences sought:-

a) *Technical advice is to the effect that the waters are a suitable location for the operation of a suspended rope mussel culture facility with adequate flushing rates;*

b) *There is no significant impact anticipated on existing beneficial usages of the local shore area;*

c) *In general, views of the mussel longline site are obscured and limited from the adjacent scenic routes;*

d) *The landscape character will not be dramatically altered as the development will integrate with the existing bay;*

e) *The aquaculture activity should have a positive effect on the economy of the local area;*

f) *The Minister has already determined that the aquaculture activity is not likely to have a significant effect on the environment and that an Environmental Impact Statement is not required for this project. The reasons and considerations for the Minister's determination are available on the Department's website;*

g) *The site is not located in a Natura 2000 area but is adjacent to the Dunbeacon Shingle Special Area of Conservation (SAC) and there are a number of other Natura 2000 sites in the vicinity, namely the Sheeps Head SAC, the Sheeps Head to Toe Head Special Protection Area, Reen Point Shingle SAC and the Farranamanagh Lough SAC. The proposed aquaculture activity does not spatially overlap with the Natura 2000 sites and there will be no significant effects posed by the culture of shellfish at this current level, on any of the qualifying interests of the Natura 2000 sites (The Screening Matrix for Aquaculture Activities in Dunmanus Bay is available on the Department's website);*

h) Taking account of recommendations requiring full implementation of the measures set out in the draft Marine Aquaculture Code of Practice prepared by Invasive Species Ireland;

i) All issues raised during the public and statutory consultation phases;

j) The updated and enhanced Aquaculture and Foreshore Licences contain terms and conditions which reflect the environmental protection required under EU and National law."

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Dose-dependent response of a benthic system to biodeposition from suspended blue mussel (*Mytilus edulis*) culture

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ARTICLE INFO

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Dose-dependent response
Biodeposition
Biogeochemical fluxes
Benthic community
Threshold effect

ABSTRACT

This study reports the results of a field experiment using benthic mesocosms that examined dose-dependent effects of mussel biodeposition on the benthic environment. Mesocosms were placed in the natural sea bottom and subjected to one of eight levels of biodeposition (from 0 to 1400 mussels m^{-2}). Most analyses indicated non-linear (i.e., threshold) effects. Sediment characteristics changed significantly between 200 and 400 mussels m^{-2} as did multivariate community structure. Community structure effects were characterised by changes in abundances of species that are very sensitive or tolerant to organic loading. The multivariate AZTI Marine Biotic Index (M-AMBI) indicated that the benthic status changed from *High* to *Good* in all mesocosms receiving biodeposits. Sediments acted as a sink for oxygen (O_2), but results suggest O_2 sediment demand was not sensitive enough to evaluate organic loading impacts. Results from this and improved experiments can be used to determine the environmental carrying capacity of sites for bivalve culture.

1. Introduction

The influence of biodeposition from farmed bivalves on infaunal macrofauna communities (e.g., Christensen et al., 2003; Callier et al., 2008), turbidity (e.g., Black, 2001), nutrient cycles (e.g., Kaspar et al., 1985; Mazouni et al., 1998; Richard et al., 2006; Thouzeau et al., 2007), primary production (Wong and Levinton, 2004; Peterson et al., 2008), and other benthic–pelagic parameters (e.g., Hargrave et al., 2008; Forrest et al., 2009) has been well studied around the world. The observed level of culture-related impacts on the benthic environment varies greatly between studies, ranging from little (Callier et al., 2007) to great (e.g., Christensen et al., 2003), the level of impact observed depending on hydrodynamic conditions, depth, culture structures, and other site-specific or seasonal factors (Grant et al., 2007; McKindsey et al., 2011; Jansen et al., 2012). The general consensus is that impacts are largely restricted to sheltered areas with weak hydrodynamics and high densities of cultured bivalves (Black, 2001), as is most common for long-line mussel farms (NRC, 2010).

Suspension-feeding bivalves influence the flux of nutrients and organic matter between pelagic and benthic systems via their great filtration capacity and their release of organic matter to the bottom (Dame, 1996). Only a portion of the food ingested by bivalves is assimilated for respiration, growth, and reproduction, the other portion being released as faeces and undigested deposits (pseudofaeces) (Navarro and Thompson, 1997). This material – collectively known as biodeposits – is organically rich and settles to the bottom and, depending on local hydrodynamic conditions and the density of bivalves, may lead to organic matter accumulation under and in the general vicinity of farms that can exceed the capacity of an area to remineralise the sedimented biodeposits (Giles et al., 2006; Callier et al., 2006). The decomposition of this organic matter may lead to increased sediment oxygen demand and potentially to sulfidic and anoxic conditions near the sediment–water interface (SWI) (Mazouni et al., 1996; Thouzeau et al., 2007; Valdemarsen et al., 2009), and to changes in pore-water chemistry (Gehlen et al., 1997; Froelich et al., 1979) and biogeochemical fluxes at the SWI (Newell, 2004).

Changes in sediment biogeochemical state may, in turn, alter benthic (Kaspar et al., 1985; Callier et al., 2007) and planktonic (Dame, 1996; Newell, 2004) communities. Pearson and Rosenberg (1978) showed that benthic macrofaunal communities are altered when subjected to organic loading. As benthic species vary in their tolerance to organic enrichment, information on their relative tolerances and abundances may be combined and used as indicators of environmental quality (Borja et al., 2000). Species such as

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Capitella spp. are often found in great abundances in disturbed sediments (Tsutsumi, 1990) whereas pollution-sensitive ones, such as the gastropod *Acteocina* sp., may disappear from these sites (Callier et al., 2007). The influence of benthic species diversity and abiotic variables on ecosystem processes remains poorly understood and requires further study (Godbold and Solan, 2009).

Although impacts of increased biodeposition due to farmed bivalves on benthic communities and biogeochemical fluxes have been well studied, little attention has focused on dose (flux of sedimented matter) –. response (effects) relationships (McKindsey et al., 2006). Knowledge of this relationship is needed to develop models to predict benthic responses due to bivalve culture. Callier et al. (2009) did an experimental field mesocosm study to evaluate the effects of varying rates of biodeposition from mussels on benthic conditions. Although nutrient flux intensities were expected to change with increasing biodeposition, only silicate showed a clear response while ammonium, nitrite, nitrate, phosphate fluxes and oxygen consumption (i.e., respiration) either did not vary or else varied randomly with biodeposition rates. A possible explanation for these results was that the physical structure of the mesocosms used limited macrofaunal recruitment and migration to and from the mesocosm. In addition, the relatively small size of the mesocosms used (10 cm diameter) may also have reduced water exchange with the surrounding ecosystem which may have exacerbated impacts due to mussel biodeposition. In contrast, clear trends were observed for benthic communities within mesocosms and suggested that there is a threshold below which communities are only slightly impacted but beyond which benthic loading has a dramatic effect. Thus this type of field or "*in situ*" manipulative study can provide important information on dose–response relationships to aid in the development of carrying capacity models that integrate benthic ecosystem processes.

The present study evaluates dose–response relationships for bivalve culture and the benthic environment. Here, *dose* is the mussel biodeposition rate to the bottom and *response* is its effect on sediment characteristics, nutrient and oxygen fluxes at the SWI, and benthic infaunal community structure. We used a field experiment as we wished to extrapolate the findings to predict the ecological carrying capacity of the natural benthic environment for biodeposition in the study site. Indeed, Michaud et al. (2010) showed that the use of laboratory-based experimental conditions may alter biogeochemical responses and suggest maintaining experimental conditions as close to natural conditions as possible. The field experiment was designed to address some of the issues identified by Callier et al. (2009) in their work by using larger mesocosms, evaluating a greater range of organic loading, and running the experiment over a longer period (60 days instead of 50). The general hypothesis evaluated is that increasing biodeposition influences benthic conditions only slightly up to a threshold (tipping point), beyond which they change markedly. It is anticipated that this type of experiments will provide information needed to develop models for benthic *ecological carrying capacity* (Inglis et al., 2000). A marked carrying capacity threshold would provide key tools for sustainable aquaculture management (McKindsey et al., 2006).

2. Materials and methods

2.1. Experimental site

The study was done in Havre-aux-Maisons Lagoon (HAML), îles-de-la-Madeleine, eastern Canada (Fig. 1). The lagoon is located in the centre of the archipelago (47°26′N, 61°50′W) and is open to the Gulf of St. Lawrence by a channel to the southeast and connected to Grande-Entrée Lagoon to the northeast. Water mixing is mostly due to persistent winds, which mix the entire water column of the shallow (ca. 6 m maximum depth, Souchu and Mayzaud, 1991) lagoons and the tidal amplitude is limited (mean 0.58 m) (Koutitonsky et al., 2002). The experimental site was 500 m from mussel farms that have been present since 1989 and in an area where bivalves have never been cultured. As Callier et al. (2008) showed that the benthic communities 300 m away from the HAML mussel farm where characteristic of less disturbed conditions, this site was judged to be sufficiently distant from farms to limit their influence.

2.2. Field experimental design

A series of 40 benthic mesocosms was installed within a 20 m × 40 m area on a 5 × 9 grid with each mesocosm being separated from its nearest neighbour by 5 m to avoid one mesocosm influencing another. Mesocosms were made of 50 cm high × 60 cm diameter plastic cylinders and inserted into bottom sediments by scuba divers applying downward pressure while rotating the cylinders back and forth using a weighted wooden bar for torque. The mesocosms were inserted 30 cm into the sediments to avoid intrusions by lobsters (Lawton and Lavalli, 1995). Mesh cages of the same diameter as mesocosms and 20 cm high (sides of 1.25 cm weld wire and top and bottom of 1 cm Vexar) were placed on and attached to the top of each mesocosm. Each cage received one of 8 pre-defined densities of mussels with density treatments randomly placed within the grid. Different mussel densities were assumed to provide a given rate of biodeposition to each mesocosm.

Mussel (mean length: 58.5 ± 6.0 mm) densities used were 0, 200, 400, 600, 800, 1000, 1200 and 1400 mussels m^{-2}. Callier et al. (2009) showed that biodeposition rates are significantly correlated to mussel density such that biodeposition averages 0.022 g day^{-1} $mussel^{-1}$ for this size of mussel. Based on this, the given treatments were subjected to biodepositional loading at rates of ca. 0, 4.4, 8.8, 13.2, 17.6, 22, 26.4, 30.8 g day^{-1} m^{-2}. Each treatment level was replicated five times and five locations were left undisturbed as references. Cages with mussels were left in place for ca. 60 days, from June 5 to August 7 2009. This period of time was chosen based on the generational time of the opportunist polychaete *Capitella* spp. that Grassle and Grassle (1976) estimated to be between 37 to 50 days at 15 °C. Further, as Callier et al. (2009) found little difference in biogeochemical fluxes in their 50 days mesocosm experiment, the present experiment was planned to last for 60 days to create a stronger signal. After this time, cages were removed from mesocosm bases and incubations done to measure biogeochemical fluxes and sediment cores taken to evaluate sediment characteristics and macrofaunal communities.

2.3. Experimental chambers

Removed cages were replaced by incubation chambers that contained water from the surrounding environment (see incubation system in Richard et al. (2007)). Incubation chambers fit precisely on mesocosms to create a water-tight seal. The chambers, associated tubing and multi-parameter probe (YSI 6600) were made of opaque plastic to avoid photosynthetic activity. A submersible pump created a 2 L min^{-1} circulation (verified by a flowmeter) within the mesocosms, a rate that Thouzeau et al. (2007) found to be sufficient to obtain stable measurements using probes but low enough to avoid resuspension of particulate matter within mesocosms. The probe measured oxygen levels (measured as mg O_2 m^{-2} h^{-1}) and physico-chemical measurements such as temperature (°C ±0.01) and salinity (±0.01) every minute. Incubations were done over 40 min. This incubation time was determined based on trials done using sediments receiving biodeposits from

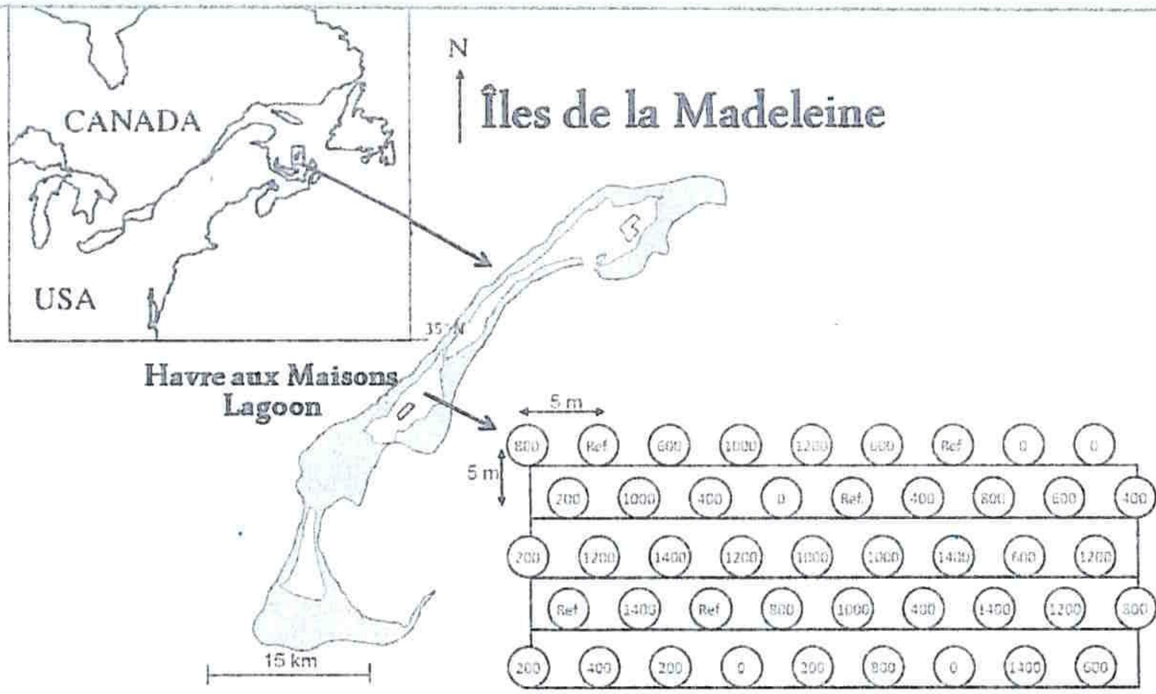

Fig. 1. Location of study site in Havre-aux-Maisons Lagoon, Îles de la Madeleine, eastern Canada. The polygons in the lagoons represent the position of existing mussel farms. Layout of experimental grid in Havre-aux-Maisons Lagoon: numbers represent mussel density m^{-2}. "Ref." represents reference locations that where sampled but not occupied by mesocosms or modified in any other way.

1400 mussels m^{-2} to ensure that the trials ended with $\geq$80% O_2 remaining to avoid artefacts from hypoxic conditions (Mazouni et al., 1998) and was used for all treatment levels. That period of time was presumed to maintain a final concentration within the region of linear oxygen decrease (Grenz et al., 2003).

2.4. Sample collection and processing

2.4.1. Sediment characteristics

Following oxygen and flux measurements, sediment characteristics were sampled by collecting two sediment cores with 10 mL cut-off syringes in each mesocosm and reference location which were frozen (−20 °C) until analysed. One core from each mesocosm was split and part used to determine organic matter (%OM) and water (%Water) content and the other part for grain size analysis. For %OM and %Water, samples were weighed, dried for 48 h at 60 °C and then reweighed. %Water is calculated as the difference between initial and dry weight of the sediment. Dry samples were ashed for 6 h at 450 °C and reweighed to determine ash free dry weight (AFDW). Organic matter content is calculated as the difference between sediment AFDW and dry weight according to Byers et al. (1978). Sediment grain size was measured with a Beckman Coulter LS13320 ALM laser diffraction particle size analyser after preparing the sample with a Calgon solution to remove the >1 mm fraction and disperse the particles (McCave et al., 1986). The second sediment core was used to evaluate total nitrogen content (%N_{Tot}) and sediment C_{Tot}/N_{Tot} ratios (C/N). Sediment %N_{Tot} and C/N ratio were measured with a Costech 4010 elemental analyser after being dried at 60 °C for 48 h (Byers et al., 1978).

2.4.2. Macrofaunal communities

Macrofaunal communities were sampled by collecting two, 10 cm deep and 10 cm diameter circular cores and washing their content through a sieve with 500 µm mesh. The retained material was stored in a 4% buffered formaldehyde solution until being sorted. Identifications were done to the lowest taxonomic level possible. Samples were characterised in terms of total abundance (N), abundance of dominant species, number of species (S; species richness), Shannon–Weiner diversity (H′), and Pielou's evenness index (J′). Species were classified into ecological groups based on their tolerance to organic enrichment: I – very sensitive to organic enrichment, II – indifferent to organic enrichment, III – tolerant to excess organic enrichment, IV – second-order opportunistic species, and V – first-order opportunistic species, to calculate an index of biotic integrity based on the relative abundance of these different groups (AZTI Marine Biotic Index – AMBI; Borja et al., 2000) and a related multivariate index that also considers species richness and diversity (M-AMBI; Muxika et al., 2007).

2.4.3. Biogeochemical fluxes

Samples were taken three times during the 40 min incubations (T0 – immediately after setting up the chamber, T20 and T40) with triplicate 60 mL syringes that fitted precisely into ports on top of the incubation chambers. The sampled volume was replaced by ambient water through an adjacent port. The volume of added ambient water was negligible compared to the total volume of the chamber (ca. 72 L) and was not included in nutrient flux calculations. Ammonium levels were determined using the OPA (orthophtaldialdhehyde) method of Holmes et al. (1999) immediately following sampling using a 10-AU Turner Designs fluorometer. The remaining water samples were filtered on 0.8 µm GF/F syringe filters and frozen (−80 °C) in three Falcon tubes. Analyses for dissolved total nitrate ($\sum NO_3$) and phosphates (PO_4) were done on a Bran-Luebbe AutoAnalyser 3 following Tréguer and Le Corre (1975). Measured nutrients were given as concentrations and benthic fluxes (*F*) were then calculated from the slopes of linear regression between concentrations and incubation time as follows:

$$F = \left[\frac{(Cf - Ci)}{(Tf - Ti)}\right] \times \frac{V}{A}$$

where *Ci* and *Cf* are the initial and final concentrations, *Ti* and *Tf* correspond to the initial and the final incubation times, *V* is the volume of water enclosed in the chamber and *A* is the surface area of sediment covered by the incubation chamber. Differences between *Cf* and *Ci* determine the direction of the gradient. A positive (+) flux indicates a transfer from benthic sediments to the water column while a negative (−) flux indicates a transfer from the water column to the sediment.

2.5. Statistical analysis

Variation in univariate metrics due to treatment levels was evaluated using an hierarchical model and analysed using a Permutational Multivariate Analysis of Variance (PERMANOVA) using Plymouth Routines in Multivariate Research (PRIMER) v.6 (Clarke and Gorley, 2001) with PERMANOVA+ (Anderson, 2005) as the permutation-based method makes no assumptions about the normality of the data (Anderson, 2001). Homogeneity of multivariate dispersion was evaluated using the Permutational analysis of multivariate dispersions (PERMDISP) routine (Anderson et al., 2008) and demonstrated homogeneous dispersion in most analyses. When correlations between independent variables were great (i.e., $0.8 \leqslant |r| \leqslant 1$), environmental variables were log-transformed to reduce interaction effects in multivariate analyses and simplify the data for further analyses (Quinn and Keough, 2002). Multivariate community structure was compared among treatment levels using PERMANOVA. Benthic community data for univariate metrics was analysed using raw data for each core where the source of variation was Treatment (9 levels of mussels density; fixed) and Mesocosm nested with Treatment (5 mesocosms per treatment; random). Multivariate analyses were done using a one-way PERMANOVA (Treatment with 9 levels of mussel density; fixed) from the pooled data from replicate cores taken from the same mesocosm. Pair-wise multiple comparison tests were used to identify differences among treatment levels using PERMANOVA. Variation in multivariate macrofaunal community structure is shown graphically using non-metric multidimensional scaling (MDS). Dominant species were determined according to their tolerance to organic enrichment, combined with a similarity percentages analysis (SIMPER) (Clarke, 1993) to determine the contribution of species to similarity/dissimilarities among treatment levels.

The relationship between multivariate community structure and environmental variables was examined using the distance-based multivariate analysis for linear models (DISTLM) routine (Anderson, 2001; McArdle and Anderson, 2001). The model was built using a forward selection procedure and adjusted r^2 selection criteria for the environmental variables (Anderson et al., 2008). Results are presented in a distance-based redundancy analysis ordination (dbRDA; McArdle and Anderson, 2001).

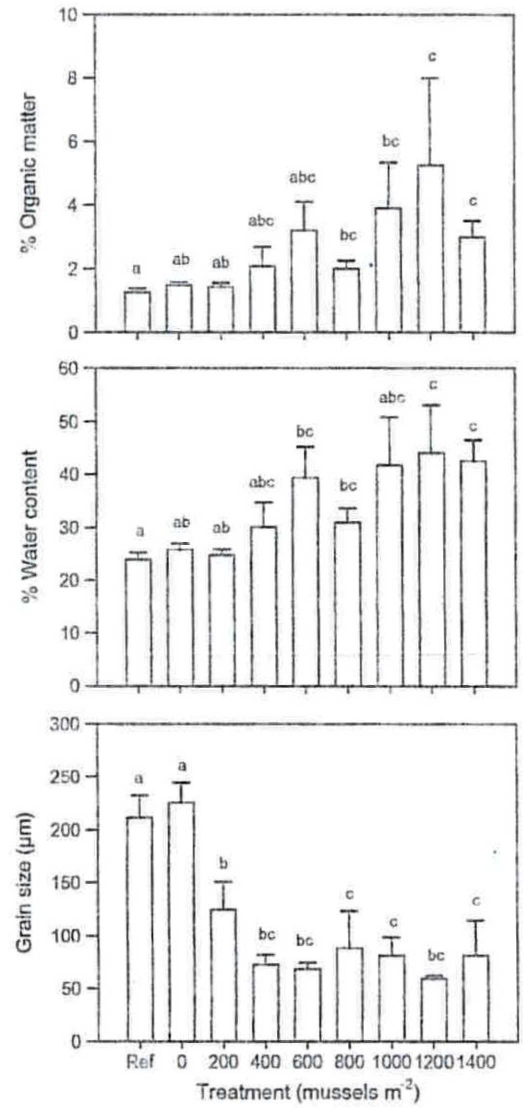

Fig. 2. Mean organic matter content (% ±SE, $n = 5$), water content (% ±SE, $n = 5$) and grain size (µm ±SE, $n = 5$) in the top 2 cm of sediments from reference sites (Ref) and mesocosms receiving biodeposits from 8 mussel densities (0–1400 mussels m^{-2}). Different letters indicate significant differences between treatment levels based on *a posteriori* pair-wise tests.

Table 1
Results of the PERMANOVAs evaluating the effect of mussel biodeposition from various treatment levels (TR: Ref, 0, 200, 400, 600, 800, 1000, 1200, 1400; $n = 9$) on sediment characteristics: % organic matter, % water content, grain size (µm), nitrogen content (mg; N) and carbon to nitrogen ratio (C/N). Significant effects ($p < 0.05$) are indicated in bold.

Variable	Source	df	MS	F	P(perm)
% Organic matter[a]	TR	8	0.692[a]	2.18	0.0540
	Error	35	0.318		
% Water content	TR	8	0.037	2.45	**0.0297**
	Error	36	0.037		
Grain size	TR	8	19873	8.39	**0.0001**
	Error	36	2367.5		
N	TR	8	0.0367	0.82	0.5958
	Error	36	0.0449		
C/N	TR	8	2.2963	1.64	0.1479
	Error	36	1.4019		

[a] log(x + 1).

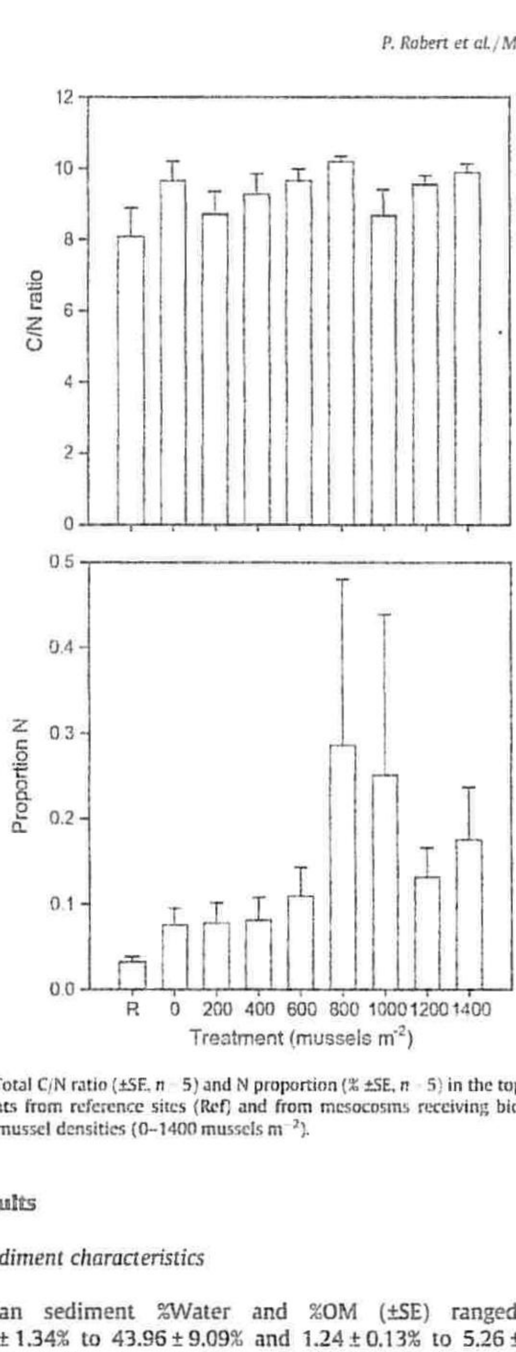

Fig. 3. Total C/N ratio (±SE, $n = 5$) and N proportion (% ±SE, $n = 5$) in the top 2 cm of sediments from reference sites (Ref) and from mesocosms receiving biodeposits from 8 mussel densities (0–1400 mussels m^{-2}).

Table 2
Results of the permutational ANOVAs (PERMANOVAs) testing the effect of mussel biodeposition from various treatment levels (TR: Ref, 0, 200, 400, 600, 800, 1000, 1200, 1400; $n = 9$) and Mesocosm (ME; $n = 5$) on macrofaunal abundance (N), number of species (S), Shannon–Weiner diversity (H′), Pielou's eveness (J′) and the abundance of different species. Significant effects ($p < 0.05$) are indicated in bold.

Variable	Source	df	MS	F	P (perm)
N	TR	8	326.74	4.25	**0.0015**
	ME(TR)	36	76.87	1.31	0.1808
	Error	45	58.63		
S	TR	8	29.65	5.92	**<0.001**
	ME(TR)	36	5.011	1.27	0.2254
	Error	45	3.956		
H′	TR	8	1.298	3.53	**0.0047**
	ME(TR)	36	0.3681	1.52	0.0864
	Error	45	0.2416		
J′	TR	8	0.2476	1.61	0.1545
	ME(TR)	36	0.1538	1.36	0.1704
	Error	45	0.1135		
Abundance					
Angulus agilis	TR	8	2985.9	3.62	**0.0022**
	ME(TR)	36	825.67	1.63	**0.0216**
	Error	45	507.42		
Capitella spp.	TR	8	1375.2	1.69	0.1055
	ME(TR)	36	815.65	2.22	**<0.001**
	Error	45	367.86		
Polydora cornuta	TR	8	2002.4	5.87	**0.0001**
	ME(TR)	36	340.96	0.75	0.7462
	Error	45	456.95		
Pectinaria gouldii	TR	8	334.68	3.67	**0.0077**
	ME(TR)	36	91.204	0.87	0.6709
	Error	45	104.94		
Acteocina canaliculata	TR	8	1367.7	2.53	**0.0066**
	ME(TR)	36	543.38	1.86	**0.0047**
	Error	45	291.88		

3. Results

3.1. Sediment characteristics

Mean sediment %Water and %OM (±SE) ranged from 23.92 ± 1.34% to 43.96 ± 9.09% and 1.24 ± 0.13% to 5.26 ± 2.74%, respectively (Fig. 2). Both variables differed significantly among mussel densities (Table 1) and generally increased with mussel density. Values from reference sites (1.24 ± 0.13 %OM, 23.92 ± 1.34 %Water) were similar to those from mesocosms with densities of 0 (1.47 ± 0.10 %OM, 25.77 ± 1.09 %Water) to 200 (1.42 ± 0.12 %OM, 24.73 ± 1.09 %Water) mussels m^{-2} and increased thereafter with increasing densities of mussels. Sediment %OM was significantly correlated with %Water content ($r = 0.906$, $p < 0.0001$). Mean sediment grain size (±SE) ranged from 58.99 ± 2.86 to 225.67
± 18.72 μm (Fig. 2) and differed significantly among mussel density treatments (Table 1) such that it was similar in reference sites and mesocosms with 0 mussels and significantly smaller in other mesocosms. Grain size was not significantly correlated with either %OM ($r = -0.408$) or %Water ($r = -0.461$). Sediment total carbon:nitrogen ratios (C/N ± SE) varied from 8.08 ± 0.81 (reference sites) to 10.19 ± 0.15 (mussel density 800) and sediment total nitrogen content (%N_{Tot} ± SE) from 0.03 ± 0.01% (reference sites) to 0.29 ± 0.19% (mussel density 800). Although C/N and %N_{Tot} did not differ significantly among mussel density treatments, there was a trend for the latter variable to be lowest in reference areas and increase with increasing biodeposition (Fig. 3).

3.2. Macrofaunal communities

Mean (±SE) benthic macrofauna abundance, species richness, and Shannon–Weiner diversity varied in similar ways among treatment levels such that each was greatest in reference sites (abundance: 18.9 ± 5.0 ind. core^{-1}; species: 6.5 ± 0.9 core^{-1}; diversity: 1.5 ± 0.2), followed by mesocosms with 0 and 200 mussels and then decreased significantly in mesocosms receiving biodeposition from greater densities of mussels (Table 2, Fig. 4). Pielou's evenness did not vary among treatment levels or show any trends related to deposition rate (Table 2). Multivariate community structure varied significantly among treatment levels ($F_{(8:36)} = 1.704$, $P(\text{perm}) = 0.0004$) such that communities in reference sites and those from mesocosms with 0 mussels differed from mesocosms with 200 and 400 mussels and all of which differed from all other treatments (Fig. 5). Multivariate variation among treatments was largely due to variation in the abundance of a small number of dominant species. Dominant species were defined as contributing greatly to differences among treatment levels, measured by a SIMPER analysis. For example, *Acteocina canaliculata* was responsible for >20% of the dissimilarity between reference and control mesocosms and all other mesocosms. *Angulus agilis* accounted for 10–27% of the total dissimilarity between mesocosms with 0–400 mussel m^{-2} and higher treatment levels, while *Polydora*

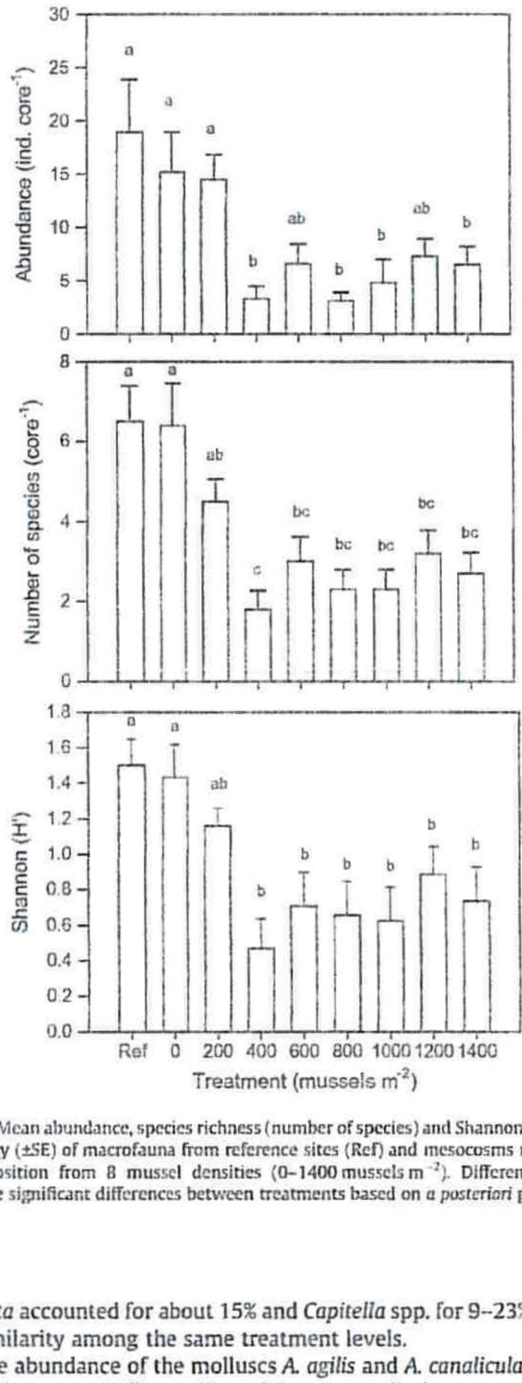

Fig. 4. Mean abundance, species richness (number of species) and Shannon–Weiner diversity (±SE) of macrofauna from reference sites (Ref) and mesocosms receiving biodeposition from 8 mussel densities (0–1400 mussels m^{-2}). Different letters indicate significant differences between treatments based on *a posteriori* pair-wise tests.

cornuta accounted for about 15% and *Capitella* spp. for 9–23% of the dissimilarity among the same treatment levels.

The abundance of the molluscs *A. agilis* and *A. canaliculata* (formally known as *Tellina agilis* and *Retusa canaliculata*, respectively, and classified as being very sensitive to organic enrichment; WORMS, 2010; Borja et al., 2000) decreased greatly in mesocosms exposed to biodeposits from greater than 400 mussels m^{-2} (Fig. 6). Likewise, the abundance of polychaetes *Pectinaria gouldii* (very sensitive) and *P. cornuta* (second-order opportunistic) were also less abundant in mesocosms with greater densities of mussels. The abundance of *Capitella* spp., a first-order opportunistic species, showed an increasing trend with increasing biodeposition although this effect was not statistically significant (Fig. 6). The relatively great mean abundance of this species in mesocosms with 200 mussels m^{-2} was largely due to one replicate core containing 10 individuals (the mean of all other cores was 0.55 individual core^{-1}). Although Fig. 7 shows a trend for an increasing proportion of opportunistic species and decreasing proportion of sensitive species from reference sites through the greatest density of mussels in mesocosms, only the proportion of communities belonging to group III, those defined as being tolerant to excess organic enrichment, differed significantly among treatments ($F_{(8;36)}$ = 2.987, P = 0.0113). While community condition estimated using AMBI did not differ among treatment levels (not shown), variation in M-AMBI scores (Fig. 8) indicated a shift between a *High* (reference sites and mussel density 0) to a *Good* (mussel density: 200–1400) ecological status in treatments in which mesocosms received biodeposits.

3.3. Biogeochemical fluxes at the SWI

All O_2 fluxes were directed from the water column to the sediment. Values of O_2 consumption (±SE) ranged from 57 ± 8 (mussel density: 0) to 111 ± 12 (mussel density 1200) mg m^{-2} h^{-1} but did not differ significantly among treatment levels (Table 3) and no trends were apparent (Fig. 9). In contrast, the flux of ammonium (NH_4) showed a net efflux from benthic sediments to the water column. NH_4 fluxes differed significantly between mussel densities (Table 3), ranging from a low of 54 ± 40 μmol m^{-2} h^{-1} at reference sites to a high of 619 ± 49 μmol m^{-2} h^{-1} in mesocosms with a mussel density of 1000 m^{-2}. Fluxes of $\sum NO_3$ and PO_4 evaluated at the SWI (Fig. 9) were directed out of and into bottom sediments, respectively for reference sites and the first treatment levels (0 and 200 mussel m^{-2}). At intermediate mussel density levels (between 200 and 400 mussels m^{-2}), the direction of the fluxes changed for both nutrients. Mussel density had no significant effect (Table 3) on the mean flux values but there were trends in their general directions.

3.4. Relationship between community structure and environmental variables

As log(%OM) was highly correlated with %Water (r = 0.906), the latter was removed from the DISTLM analysis. Together, all measured environmental variables accounted for only 19.3% of the total variation in macrofauna community structure (Table 4). Grain size accounted for 6.9% of the total variation while %N, $Si(OH)_4$ flux, O_2 consumption, and water temperature accounted for 3.7%, 3.8%, 2.6%, and 2.3% respectively. Changes in benthic community structure between reference sites and mesocosms with mussel densities ranging from 0 to 200 m^{-2} were mostly correlated with changes in grain size whereas community structure from samples from mesocosms receiving biodeposits from greater densities of mussels varied only slightly along this axis (Fig. 10).

4. Discussion

This study showed a clear dose–response relationship between biodeposition rates from the blue mussel (*Mytilus edulis*) and the condition of the benthic environment. The benthic response follows a non-linear pattern for some sediment characteristics and macrofaunal variables with a tipping point at a biodeposition rate between 200 and 400 mussels m^{-2} or 4.4 and 8.8 g of biodeposits m^{-2} day^{-1}. In addition, the direction of the flux of several nutrients also tended to change at this intermediate treatment level, suggesting that the sediments shifted from nutrient sinks to nutrient sources around this level of enrichment.

4.1. Effects of experimental design on sediment characteristics

This experiment successfully enhanced organic loading to the sediment surface in a manner similar to how mussel farms in that area do. For example, the greatest mean %OM observed, 5.26%

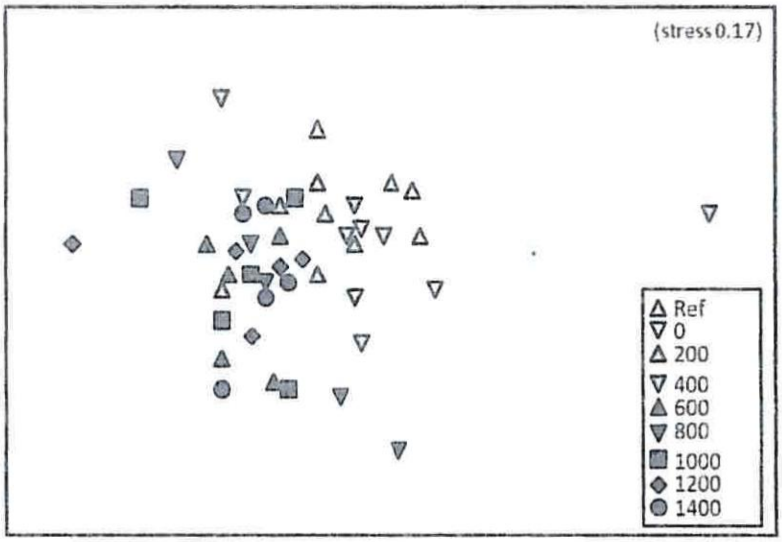

Fig. 5. Multi-dimensional scaling of assemblages of benthic fauna in mesocosms (n = 5). Pair-wise tests *a posteriori* defined three groups that differed significantly, as defined by different symbol fill types (empty, grey, and black). Data for the 2 cores from each mesocosm were pooled.

(mussel density: 1200), is similar to values observed under mussel lines in previous studies in the area (Callier et al., 2007; Richard et al., 2007), showing that the experiment well represented local conditions. Benthic species tolerant to high organic matter content, such as *Capitella* spp., showed enrichment-related responses similar to those that were expected based on other studies done in the region (Callier et al., 2007). Similar responses between reference samples and mesocosms without mussels (mussel density: 0) for most of measured variables (e.g., %OM, %Water, and sediment grain size) shows the limited effect of the physical structure of the mesocosms.

4.2. Evidence for a tipping point

4.2.1. Sediment characteristics

Mussel aquaculture has often been suggested to enhance sedimentation rates to the bottom and lead to organic enrichment (e.g., Kaspar et al., 1985; Stenton-Dozey et al., 2001; Richard et al., 2006). That %OM increased with mussel densities suggests that the benthic system received a higher level of biodeposition than it could mineralise in the short term. Sediment grain size also varied among treatment levels with a clear threshold between 200 and 400 mussels m^{-2}, beyond which sediment grain size was reduced. Callier et al. (2008) observed under HAML mussel lines relative to that in reference locations. We expected C/N ratios in the upper 2 cm of sediments to increase with increasing deposition due to differential degradation rates for N-and C-rich compounds in biodeposits (Dahlbäck and Gunnarsson, 1981; Christensen et al., 2003; Giles et al., 2006) but this effect was not observed. The observed C/N ratios (means between 8.08 and 10.19) are typical of freshly deposited marine organic matter (Rullkötter, 2006).

4.2.2. Macrofaunal communities

With the exception of Pielou's eveness, all univariate measures of macrofaunal community structure showed a clear threshold between 200 and 400 mussels m^{-2}. Several other studies done on organic loading have also shown decreased macrofaunal abundance or biomass beyond a certain level of organic loading, as predicted by Pearson and Rosenberg (1978) (e.g. Rosenberg, 2001; Christensen et al., 2003; Richard et al., 2007; Callier et al., 2009). Previous studies on shellfish farms have suggested there is a threshold of ca. 15 g of biodeposits m^{-2} day^{-1} (Hargrave et al., 2008; Weise et al., 2009), corresponding to about 680 mussels m^{-2}, below which benthic macrofaunal communities are not significantly impacted.

Multivariate benthic community structure varied between treatment levels such that 3 community types were apparent with a clear difference between the group formed by reference sites and control benthocosms with 0 mussels and benthocosms receiving biodeposits from 600 or more mussels m^{-2} and an overlap for communities in benthocosms subjected to intermediate levels of biodeposition. Changes in macrofauna community structure were mainly driven by several key species that are either sensitive or tolerant to organic loading. Although the abundance of the deposit feeding bivalve *A. agilis* was relatively low in this study compared to previous observations in HAML and the adjacent lagoon (Bourget and Messier, 1982; Callier et al., 2008), its abundance was a function of treatment level and decreased significantly. Callier et al. (2009) observed a similar threshold such that the species' abundance was reduced in treatments receiving biodeposits from greater than 255 mussels m^{-2}. The gastropod *A. canaliculata* and the polychaete *P. gouldii* are also classified as very sensitive species (Borja et al., 2000) and they too had lower abundances in mesocosms impacted by mussel biodeposition.

Some species may also benefit from biodeposition as it provides a food source for some organisms which may increase in abundance in enriched zones (Giles et al., 2006). This was predicted for the polychaetes *P. cornuta* (second-order opportunistic species) and *Capitella* spp. (first-order opportunistic species) (Borja et al., 2000), as has been observed in other studies (e.g. Tsutsumi, 1990; Christensen et al., 2003). However, this effect was not clear in the present study, although *Capitella* spp. was not recorded from reference sites and its abundance tended to increase with increasing biodeposition. That the effect was not greater may be due to the level of organic loading in mesocosms being greater than that which these species can support or the solid mesocosm walls may have restricted the recruitment of these and perhaps other species.

AMBI and M-AMBI are widely used to assess benthic conditions (e.g., Borja and Tunberg, 2011). While AMBI values did not vary among treatment levels (*Slightly disturbed*), M-AMBI values shifted from *High* (reference sites and control mesocosms) to *Good* status in mesocosms receiving mussel biodeposits, suggesting that the

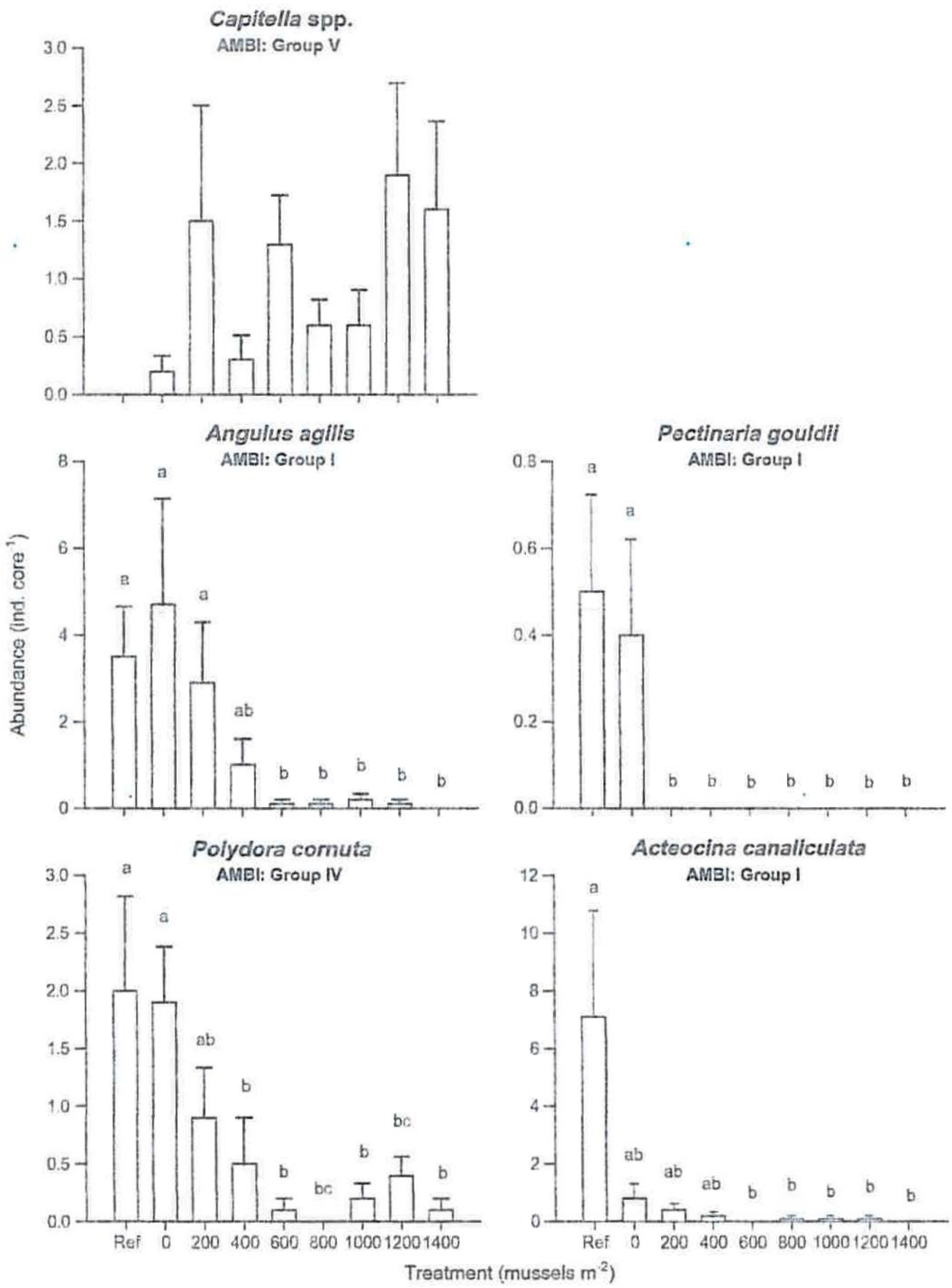

Fig. 6. Mean abundance (±SE, $n = 10$) of selected species (as chosen *a priori* for their tolerance to organic loading and indicated *a posteriori* by SIMPER analysis as contributing greatly to differences among treatments) from reference sites (Ref) and from mesocosms receiving biodeposits from 8 mussel densities (0–1400 mussels m^{-2}). Different letters indicate significant differences between treatments based on *a posteriori* pair-wise tests.

latter index may be more suitable for assessing benthic infaunal communities responses to increasing biodeposition. The change in ecological status within mesocosms subjected to biodeposition was mostly due a greater proportion of first-order opportunistic species in those mesocosms and suggests that very low levels of biodeposition influence benthic communities.

4.2.3. Benthic respiration and biogeochemical fluxes

Benthic respiration and nutrient regeneration are linked to sediment OM content (Grenz et al., 1991; Hatcher et al., 1994) and thus biodeposition may enhance sediment oxygen demand and benthic fluxes at the SWI (Hargrave et al., 1993; Mazouni et al., 1996; Richard et al., 2007). Most theoretical ecological and geochemical models assume a linear relationship between organic flux and the rates of O_2 and nutrient exchanges at the SWI (Cai and Sayles, 1996; Berelson et al., 2005; Jiang and Gibbs, 2005; Godbold and Solan, 2009). However, this assumption does not consider the various feedback loops that develop between biotic and abiotic processes as organic loading increases.

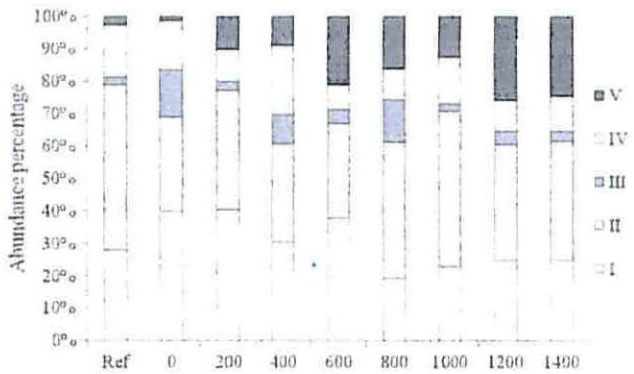

Fig. 7. Proportion (%) of the abundance of macrofauna classified as belonging to different ecological groups as defined by Borja et al. (2000) in reference sites (Ref) and from mesocosms exposed to biodeposition from 8 mussel densities (0–1400 mussels m^{-2}). The ecological groups correspond to I, species very sensitive to organic enrichment; II, species indifferent to organic enrichment; III, species tolerant to organic enrichment; IV, second-order opportunistic species; V, first-order opportunistic species.

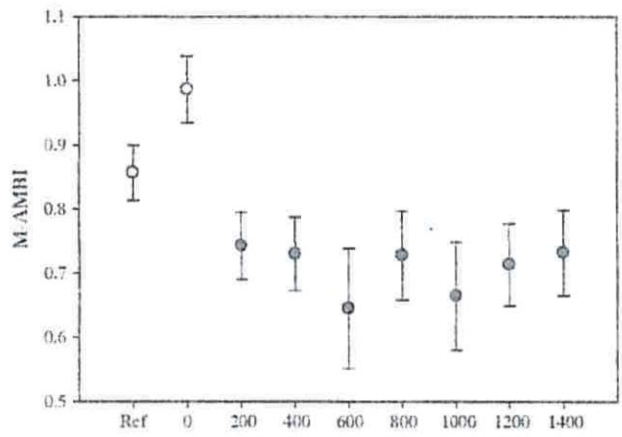

Fig. 8. Multivariate biotic index (M-AMBI) calculated for each treatment level (0–1400 mussels m^{-2}) and reference sites (Ref) (±SE). The empty symbols correspond to High ecological status and filled symbols to Good ecological status.

Table 3
Results of PERMANOVAs testing the effect of mussel biodeposition from various treatment levels (TR: Ref, 0, 200, 400, 600, 800, 1000, 1200, and 1400 mussels m^{-2}; n = 9) on biogeochemical fluxes (NH_4: ammonium; PO_4: phosphates; $\sum NO_3$: nitrogen oxides; $Si(OH)_4$: silicates; O_2 consumption: oxygen consumption). Significant effects ($p < 0.05$) are indicated in bold.

Variable	Source	df	MS	F	P (perm)
Fluxes					
NH_4	TR	8	94524	3.0649	**0.0142**
	Error	36	30841		
PO_4	TR	8	5238.1	1.4777	0.1918
	Error	36	3544.9		
$\sum NO_3$	TR	8	4804	0.6432	0.8237
	Error	36	7468.9		
$Si(OH)_4$	TR	8	1.4989E5	0.70274	0.6734
	Error	36	2.1329E5		
O_2 consumption	TR	8	10.49.4	1.0331	0.423
	Error	36	1015.7		

Sediment oxygen demand represents an integrated measurement of multiple processes and large volume incubation chambers, as used in the current study, integrate multiple variables that may influence it. In the present study, benthic sediments were a sink for O_2. The precise mechanisms that created this were not evaluated but include aerobic OM remineralisation processes mediated through various groups of organisms (e.g., infaunal macroinvertebrates, meiofauna, bacteria, microphytobenthos, etc.) and metabolic processes (Glud, 2008). Oxygen fluxes, however, did not vary significantly among treatment levels.

That O_2 uptake did not increase with biodeposition may be due to O_2 concentrations at the SWI being reduced in mesocosms receiving greater biodeposition prior to the initiation of incubations. Reduced oxygen levels may have a variety of effects on O_2 flux, such as decreasing the O_2 gradient at the SWI and diffusive flux, as has been shown by Rasmussen and Jørgense (1992). It may also decrease the depth of the oxic layer and thus reduce the population of aerobic micro-organisms which could consume O_2 and aerobic macrofaunal activity which modifies bioirrigation processes (Rasmussen and Jørgense, 1992). At a longer time scale, anaerobic respiration may dominate the system and result in the accumulation of reduced chemical species such as sulphides (S, FeS, FeS_2) at the SWI which would require O_2 to be re-oxidised. The accumulation of such chemical species seems to have occurred, particularly in higher treatment levels where evidence of sediment anoxia (black sediment colour and the presence of sulphide-oxidising *Beggiatoa* bacterial mats) was observed by the scuba divers taking samples. These findings support the idea that sediment oxygen demand may not be sensitive enough to evaluate the impact of organic loading from mussel culture because of increased activity of the sulphur cycle (Holmer and Kristensen, 1992).

Nutrient concentrations in shallow coastal waters are largely a function of nutrient regeneration and fluxes from benthic sediments (Soetaert et al., 2000). The present study showed that whether sediments acted as sinks for or sources of nutrients to the water column was a function of biodeposition rate. Faeces and pseudofaeces are known to be a rich source of N and P (Navarro and Thompson, 1997; Richard et al., 2006) and many studies have shown increased NH_4 fluxes with increasing sediment OM content (Aller and Yingst, 1980; Christensen et al., 2003; Giles and Pilditch, 2006 Callier et al., 2009; Guyondet et al., 2010). Sediments were a source of NH_4^+ to the water column in all treatments.

Although the predicted increases in nutrient fluxes with increasing OM loading were not statistically significant, there was a clear shift in the direction of fluxes that is consistent with a change in pore-water nutrient concentration gradients with increasing OM content. Nitrate release from sediments in mesocosms receiving biodeposits from less than 400 mussels m^{-2} suggests the development of a nitrification zone near the SWI, probably where oxygen diffusion oxidises reduced metabolites such as ammonia. In mesocosms subject to greater biodeposition, nitrate uptake and denitrification processes occur at the sediment surface, which is typical of sediments receiving excess organic matter (Hyacinthe et al., 2001; Chang and Devol, 2009; Hulth et al., 2005). Change in macrofaunal communities may also alter benthic nitrogen cycles and the direction of nitrate exchanges at the SWI. Release of $\sum NO_3$ may be enhanced by macrofaunal bioturbation that stimulates oxygen diffusion in suboxic and anoxic sediments and enhances nitrification (Pearson and Rosenberg, 1978; Jenkins and Kemp, 1984). Thus the low positive and negative $\sum NO_3$ fluxes observed in some replicates in the present study may be due to low macrofaunal abundance and activity. For example, *Capitella* spp. is smaller than key bioturbating species and thus cannot compensate for the loss of the larger species that are largely responsible for reworking benthic sediments and removing deeper reduced metabolites and organic matter (Michaud et al., 2005; Godbold and Solan, 2009).

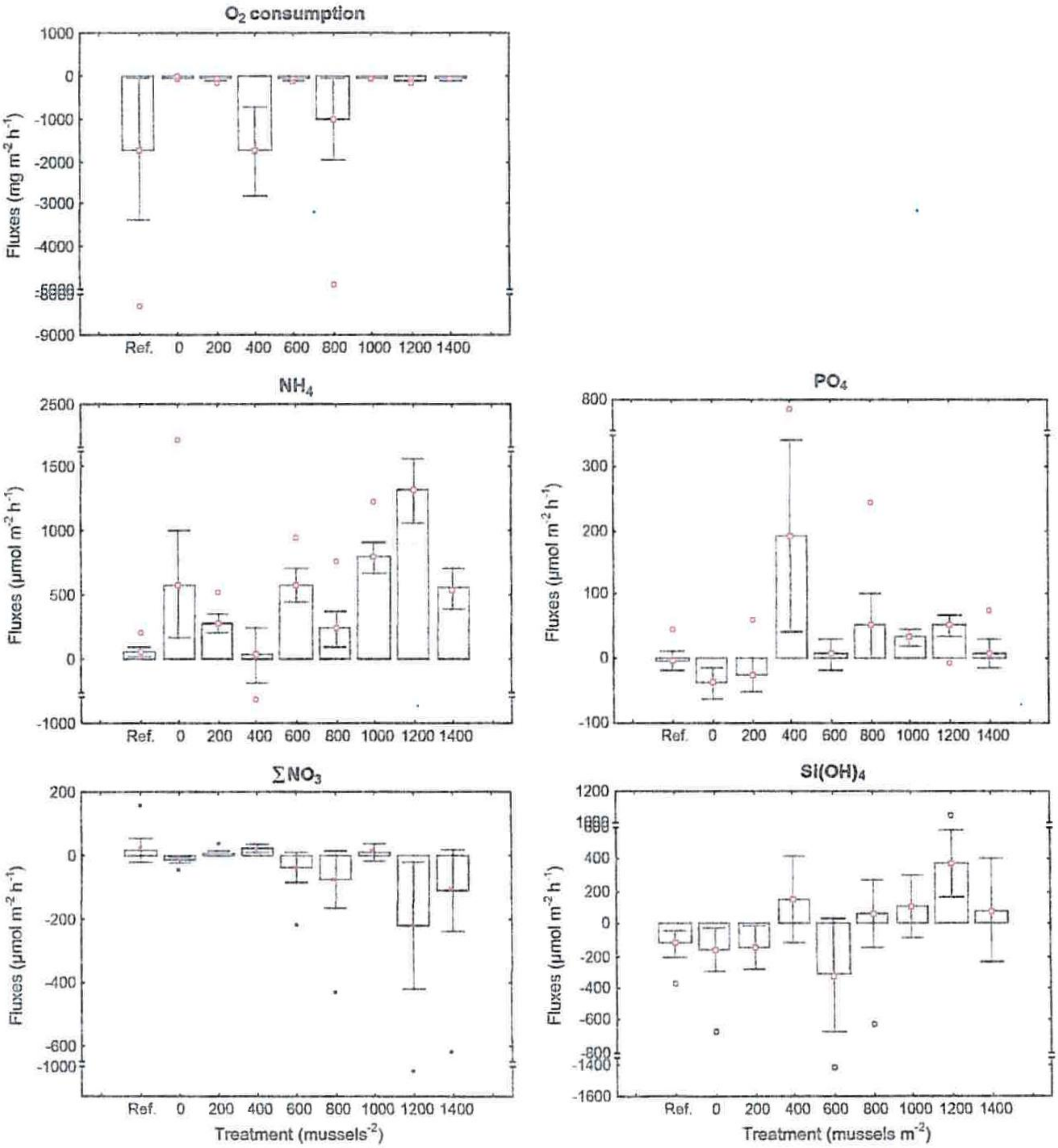

Fig. 9. Mean oxygen consumption and nutrient fluxes (NH_4, ammonium; PO_4, phosphates; $\sum NO_3$, nitrogen oxides; $Si(OH)_4$, silicates) (±SE, $n = 5$) measured at the water–sediment interface in reference sites (Ref) and mesocosms exposed to biodeposition from 8 mussel densities (0–1400 mussels m^{-2}).

Table 4
Relationship between multivariate macrofaunal community structure and environmental variables as evaluated with DISTLM.

Variable	Prop (cumulative)	SS (Trace)	*F*	*P*
Grain size	0.0693	9636.3	3.201	<0.001
% N_{Tot}	0.106	5105.5	1.724	0.0657
$Si(OH)_4$	0.144	5346.9	1.842	0.0409
O_2 consumption	0.170	3613.6	1.253	0.2447
Temperature	0.193	3185.3	1.107	0.3408

Increased biodeposition tended to alter the direction of PO_4 fluxes, which were, on average, negative in reference sites and in mesocosms with densities of 0–200 mussels m^{-2} and became positive under higher mussel densities. Phosphate may be regenerated and bound to iron ions in sediments, thereby reducing its release (Sundby et al., 1992). This process seemed to be dominant in reference sites and mesocosms with 0 and 200 mussels m^{-2} where influxes of PO_4 were measured. PO_4 efflux is enhanced when sediments become anoxic (Krom and Berner, 1980; Sundby et al., 1992) and Graca et al. (2006) observed higher NH_4 and PO_4 concentrations in the pore water of zones affected by long-term anoxia. Anoxia and the presence of hydrogen sulphide may reduce the

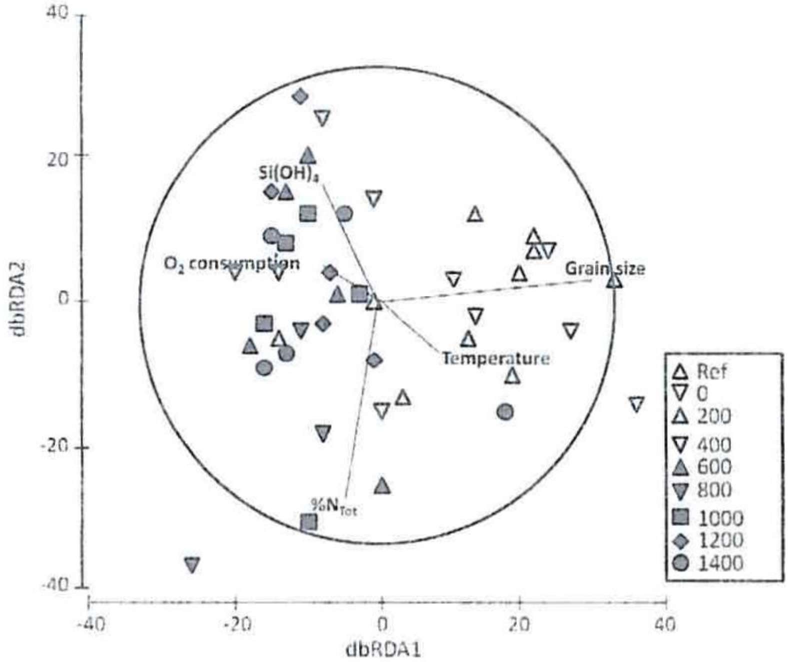

Fig. 10. Relationships between measured environmental variables and variation in benthic communities. Plot represents results of a distance-based redundancy analysis (dbRDA) ordination of benthic community with environmental variables plotted as vectors. The X and Y axes account for 41.2% and 30% of the fitted variation, respectively.

absorption capacity of sediments for phosphorus and result in the removal of PO_4 in bottom waters (Graca et al., 2006). In the present study, the sediment surface was black, and presumably anoxic, in mesocosms subjected to biodeposition by the highest mussel densities, indicating reduced sediments and the presence of sulphides, thus supporting the hypothesis that reduced or anoxic sediments boosted PO_4 release.

The flux of $Si(OH)_4$ may be influenced by mussel feeding and biodeposition as siliceous diatom frustules may be present in mussel faeces and pseudofaeces (Navarro and Thompson, 1997). Silicate fluxes were not significantly affected by mussel density, although there was a trend for increased efflux of $Si(OH)_4$ with increasing mussel density, as was expected based on numerous studies done in mussel culture sites (see review in McKindsey et al., 2011), and were lower than values observed in previous studies done in the same lagoon (Richard et al., 2007) and in the mesocosm study by Callier et al. (2009) in the adjacent lagoon. Thus, although Callier et al. (2009) suggested that silicate fluxes would be a useful indicator of organic loading due to biodeposition, the present study gives only weak support for this suggestion.

4.3. Relationship between community structure and environmental variables

Sediment grain size was the best predictor of community structure. Given that grain size is reduced with increasing biodeposition, this indicates the important role of mussel biodeposits in driving the biological changes identified by the univariate and multivariate analysis. However, although sediment grain size explained the largest portion of the variation in community structure of all the variables examined, it explained only 6.9% of the total variation in community structure and only 19.3% of the variation in community structure was explained by all the variables considered. That the majority of the total variation in community structure was not explained by the model suggests that other variables are also likely important in structuring benthic communities.

5. Conclusions

This study shows that the described *in situ* field experiment is an effective tool to integrate experimentally manipulated treatments and the natural variability and conditions of a system to better understand dose-dependent processes. The large variability in the observed results likely reflects the natural variability of the benthic environment but clear trends are evident.

The benthic environment responded to increased organic loading due to biodeposition by mussels in a non-linear manner, with a break in the area of 200–400 mussels m^{-2} – roughly equivalent to 4.4–8.8 g of biodeposits day^{-1} m^{-2}. Most physical sediment variables and macrofaunal community metrics changed when mesocosms were subject to biodeposition from between 200 and 400 mussels m^{-2}. Although O_2 consumption did not vary significantly among treatment levels, NH_4 increased with mussel density treatment levels and other biogeochemical fluxes showed the same trend, some shifting from influxes to effluxes at ca. 200 to 400 mussels m^{-2}. Of the variation in multivariate community structure explained by the various physical variables measured, that in reference sites and mesocosms with 0–400 mussels m^{-2} was largely due to variation in sediment grain size but was more related to other variables – mostly O_2 consumption and N and $Si(OH)_4$ efflux – at greater mussel densities. These results may be useful to define the ecological carrying capacity of sites for bivalve culture and incorporated into models to promote sustainable bivalve culture.

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International Council for the Exploration of the Sea
Theme H: Ecological Carrying Capacity in shellfish Culture

ICES CM 2008/H:16

Farmed mussel biodeposit production and dose-dependent influence on benthic communities

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Abstract. Much work has examined the influence of benthic loading from suspended bivalve culture on benthic infaunal communities. However, little effort has been directed at determining the production of biodeposits and dose-dependent effects of biodeposition on such communities. A study was done to determine the mussel size-dependent production of biodeposits in situ and characterize biodeposit sedimentation dynamics. Based on the results of this study, an in situ manipulative experiment was done to evaluate the dose-dependent response of biodeposition on sandy benthic infaunal community structure. Benthic communities sampled with sediment cores were used to create mesocosms which were exposed over 50 days to 7 different levels of mussel biodeposition by varying the densities of mussels (0, 1, 2, 3, 4, 5, 6 mussels, equivalent to 0, 127, 255, 382, 510, 637 and 764 mussels m-2). Benthic communities responded as would be predicted from the Pearson & Rosenberg (1978) model of organic enrichment. The abundance and biomass of opportunistic species (Capitella sp.) were observed to increase in the mesocosms exposed to the highest mussel density. Sensitive species such as Tellina agilis and Pherusa plumosa tended to decrease in abundance and biomass with increasing mussel density. These results are discussed with respect to their importance to predictive ecological modelling for bivalve aquaculture.

Keywords: mussel aquaculture, biodeposit production, organic enrichment, benthic effects, mesocosm, AMBI

Highlights related to the theme objective:
- Mussel biodeposit production and settlement dynamics determined for dispersal estimates
- Evaluation of dose-response effects of farmed mussel biodeposition on benthic communities

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Introduction

Bivalve aquaculture production is growing worldwide and concerns about its impact on the environment are increasing. Environmental influences of bivalve aquaculture are mainly related to the filtration of the plankton and seston (Dame, 1996) and the production of organically-rich faeces and pseudofaeces by the bivalves that may accumulate on the bottom (e.g., Mattsson and Lindén, 1983). Although numerous models have been developed to determine production carrying capacity (i.e., maximizing production) (e.g., Campbell and Newell, 1998), less effort has been directed at modelling effects of bivalve biodeposition on the benthos. There is thus a need to determine the benthic environmental carrying capacity of sites for bivalve aquaculture, i.e., "the maximum level of production which is possible without having an unacceptable ecological impact" (see review by McKindsey et al., 2006).

The extent and intensity of benthic effects depend on many factors, including the age and size of culture operations, species being cultivated, bivalve density, local hydrodynamic conditions and topography, which vary considerably between sites, making general conclusions about the influence of bivalve culture on the benthic environment difficult to establish. The accumulation and decomposition of biodeposits from bivalve culture may affect the abundance, biomass and diversity of benthic communities, generally according to the Pearson and Rosenberg (1978) model of organic enrichment. However, there are critical information gaps with respect to the etiology of bivalve aquaculture benthic effects. At the basic level, there is little information available on the production of biodeposits by bivalves in culture. Dose-response relationships for bivalve aquaculture, where "dose" is the flux of biodeposition to the bottom and the "response" is chemical, physical or biological in nature, are also lacking (McKindsey et al., 2006). Such empirical studies are needed to better predict benthic changes and to help guide managers in setting density limits to maintain a given benthic condition.

The aim of this study was to investigate i) the size-specific production and sedimentation dynamics of biodeposits produced by mussels (*Mytilus edulis*) in suspended aquaculture and ii) examine the effects of short-term mussel biodeposition on sandy benthic community characteristics using *in situ* mesocosms. Biodeposit production and sedimentation were evaluated in 2 sites. Benthic communities and related parameters within mesocosms were examined following exposure to 7 mussel biodeposition rates for 50 days that simulate conditions in Quebec mussel aquaculture sites in a single location.

Methods

Biodeposit production and sedimentation rates

Biodeposition by different mussel cohorts was evaluated *in situ* by placing a fixed number of mussels within cylindrical vexar cages fitted into the top of sediment traps made of PVC tubing (10.2 cm diameter, 76.2 cm height). The number of mussels used ensured that ca. 2/3 of the cage area was covered by a layer of mussels. Sediment traps containing dead mussels were used as controls to measure background sedimentation rates. Shell treatments were used because sedimentation rates may be altered by the mussel shells physically blocking a part of the trap area and modifying the hydrodynamics at the trap entrance. Traps were retrieved following 24 h periods and the contents filtered through pre-burned and pre-weighed glassfiber filters (Whatman GF/F, 0.7 μm). Filters were rinsed with ammonium formate, dried to constant weight, and weighed. Biodeposition was calculated as the amount of material collected in the sediment traps with mussels less the average sedimentation obtained in the corresponding shell controls, and expressed as biodeposit production per individual mussel.

Each treatment had three replicates in each experimental location on each trial date. Rates were evaluated on three trial dates in Great Entry Lagoon, Magdalen Islands (GE), in 2003 and on two trial dates in Cascapedia Bay, baie-des-Chaleurs (CAS), in 2005. The sediment traps were deployed on the bottom 800 m outside of the mussel farm in GE and hung on empty backlines in CAS. Experimental cages in GE each contained 6 mussels measuring 4.0 to 5.2 cm in length or 3 mussels measuring 6.7 to 6.9 cm for 0+ and 1+ mussels, respectively. Experimental cages in CAS each contained 6 mussels measuring 5.5 to 5.7 cm in length or 3 mussels measuring 6.6 to 6.7 cm for 1+ and 2+ mussels, respectively. These size ranges were selected based on preliminary field measurements of mussels on mussel lines at that time.

The sinking velocity of biodeposits was evaluated only in GE. Faecal pellets were collected for 5 size classes of mussels

(3, 4, 5, 6 and 7 cm shell length, 3 mussels trap^{-1}) using sediment traps as described above. The sinking speed of randomly chosen faecal pellets collected from the sediment traps was evaluated in a cylindrical glass sedimentation column (45 cm height, 10.5 cm diameter) filled with filtered (0.7 µm) seawater (21 ± 1°C, 28 psu) by measuring the time needed for faecal pellets to pass between 2 marks separated by 10 cm. The dimensions and sinking speed of at least 25 randomly chosen faecal pellets were measured for each mussel size class.

Local biodeposition rates were predicted based on the number and size of mussels on mussel lines in the study locations combined with measured biodeposit production and settlement velocities and local hydrodynamic regime (see Callier et al., 2006).

Benthocosms and benthic community analyses

Thirty five sediment cores (PVC pipes, 78.5 cm^2 cross-section area and 20 cm high, filled with benthic sediments to 17cm) were collected by SCUBA divers from a 5 m deep area with a sandy bottom in GE. Cores were fitted with PVC caps on both the tops and bottoms and transported to experimental racks – iron bars fitted with plastic caps secured at 40 cm intervals open end up to act as holders for the sediment cores - "benthocosms" (Fig. 1). Biodeposition was modified experimentally by placing 0, 1, 2, 3, 4, 5, or 6 mussels within cylindrical vexar cages fitted into the top of cores (5 replicates per mussel density), corresponding to 0 to 764 mussels m^{-2} (equivalent to the density of mussels found in Quebec aquaculture sites) or 0 to 16.8 g dw biodeposits m^{-2} d^{-1}.

The experiment was run for ca. 50 days (June 12 through August 4-6 2004), at which time benthocosms were collected and the macrofauna (> 500 µm) quantified. The period of 50 days was selected based on the turnover rate of one of the indicator species present in the general area, the opportunist polychaete *Capitella* sp. (37 to 50 days at 15 °C, Grassle and Grassle, 1974). The experiment was done > 2 km from the mussel farm in GE and on the far side of a navigation channel and therefore not otherwise under the influence of mussel biodeposition.

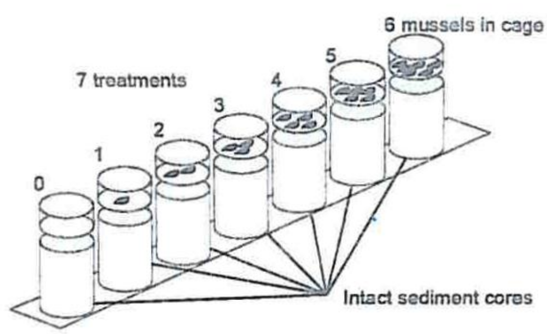

Fig. 1. Benthocosms (78.5 cm^2 sediment cores) exposed to 7 mussel densities (0, 1, 2, 3, 4, 5, 6 mussels. cage^{-1}). Five replicates per mussel density were placed randomly at 40 cm intervals along an iron support (diagram not to scale).

Sites were characterised in terms of total abundance, total biomass and the number of species (species richness). Species were classified into ecological groups based on their sensitivity to organic enrichment to calculate a global index of community status (AMBI – see Borja et al., 2000) using AMBI version 4.0 (http://www.azti.es). The AMBI index was combined with richness and a diversity index (Shannon Wiener) to give a multivariate index (M-AMBI – see Muxika et al., 2007).

Statistical analysis

The relationships between: (i) mussel size and biodeposit production, (ii) mussel size and faecal pellet size, and (iii) faecal pellet size and sinking velocity were evaluated by linear regression. Variations in biodeposit production between dates were evaluated by ANCOVA, with mean mussel mass as the covariate on $\log_{10}$-transformed data. Macrofaunal benthic characteristics (species richness, abundance and biomass) among the mussel densities were compared using analysis of variance (ANOVA). Nonparametric multivariate analyses of community structure (based on counts and biomass), including multi-dimensional scaling (MDS) were done using PRIMER version 5.2.9 (Clarke and Warwick, 1994) and DISTLM (McArdle and Anderson, 2001. Data were √-transformed for all multivariate analyses. Of 35 samples, 2 replicates were lost during the manipulation by divers (one each from the n = 1 and n = 4 mussel treatments). A further replicate (from the n = 5 mussel treatment) was considered as an extreme outlier (with a density of one species - *Tellina agilis* > 10 × greater than the next largest abundance for this species) and was not included in further analyses.

Results

Biodeposit production and sedimentation rates

Summarized results on the relationship between *M. edulis* size and biodeposit production are given in Tables 1 and 2. Both background and biodeposit-related sedimentation rates varied among sampling dates and locations (Table 1). Although larger mussels within a location produced a greater mass of biodeposits relative to that produced by smaller ones, biodeposit production per unit mussel biomass showed the opposite trend (data not shown). This relationship was further elucidated by size-based production and sedimentation evaluations, as outlined in Table 2. Sedimentation rates were best described by faecal pellet width, the two variables being positively correlated.

Benthocosms and benthic community analyses

Total abundance differed significantly among mussel density treatments such that abundance was greatest in control benthocosms and generally decreased thereafter, with the lowest abundance recorded in benthocosm with 3 mussels cage^{-1} (Fig. 2, Table 3). Control benthocosms had the greatest species richness and benthocosms with 3 and 4 mussels cage^{-1} had the smallest species

Table 1. Biodeposit production measured *in situ* for 2 mussel cohorts (0+ and 1+) in Great Entry Lagoon (GE) during 3 trial dates and for 2 mussel cohorts (1+ and 2+) in Cascapedia Bay (CAS) during 2 trial dates. Average mussel shell length (cm), minimum and maximum biodeposit production rates (mg mussel^{-1} d^{-1}) are given for each mussel cohort. Biodeposition was calculated as the amount of material collected in sediment traps with mussels less the average sedimentation obtained in the corresponding shell controls (see text for details). Each treatment had 3 replicates on each trial date.

Site	Trial date	Mussel size (cm)	Biodeposit production (mg mussel^{-1} d^{-1}) (range, mean, ± SE)
GE 0+	Aug 14-15	4.0 ± 1.1	24-32, 29.1 ± 4.8
	Aug 18-19	4.5 ± 0.3	25-75, 51.1 ± 25.2
	Aug 21-22	5.2 ± 0.3	13-21, 17.0 ± 5.7
GE 1+	Aug 14-15	6.9 ± 0.2	32-52, 44.4 ± 10.5
	Aug 18-19	6.7 ± 0.2	65-126, 86.0 ± 34.3
	Aug 21-22	6.7 ± 0.3	17-33, 24.2 ± 7.8
CAS 1+	July 6-7	5.7 ± 0.3	29-58
	July 9-10	5.5 ± 0.3	15-32
CAS 2+	July 6-7	6.7 ± 0.2	45-95
	July 9-10	6.6 ± 0.4	29-39

Table 2. Results of the linear regression analysis of: (i) biodeposit production DW as a function of mussel tissue DW on different sampling dates, and (ii) sinking velocity as a function of faecal pellet size. For all analyses: $y = ax + b$

	Dependent (y)	Independent (x)	a	b	r^2	p	n
(i)	Biodeposit production ($\log_{10}$, mg g^{-1} tissue d^{-1})	Mussel tissue DW ($\log_{10}$, g)					
		14 to 15 August	−0.691	1.625	0.762	0.005	8
		18 to 19 August	−0.809	1.832	0.714	0.001	11
		21 to 22 August	−1.060	1.316	0.656	0.001	7
(ii)	Sinking velocity (cm s^{-1})	Faecal pellet size (mm)					
		Width	0.589	0.328	0.426	0.000	235
		Length	0.037	0.761	0.128	0.000	235
		Area	0.029	0.783	0.193	0.000	235

richness (Fig. 2). The greatest biomass was recorded in benthocosms receiving biodeposits from 1 mussel cage^{-1} (Fig. 2). Overall, abundance and species richness were negatively correlated with mussel density (Table 3).

The abundance and biomass of several dominant species were correlated with mussel density (see Fig. 3 for abundance data; for brevity, results using biomass data are not shown as they show the same general trends). The abundances of the polychaete *Pherusa plumosa* and the bivalve *T. agilis* were greatest in control benthocosms (i.e., no mussel biodeposition) and negatively correlated with mussel density (Fig. 3, Table 3). In contrast, the polychaete *Capitella* sp. was most abundant in benthocosms receiving biodeposition from 6 mussels cage^{-1}, although this trend was not statistically significant (Fig. 3).

Community structure. Community structure differed significantly among

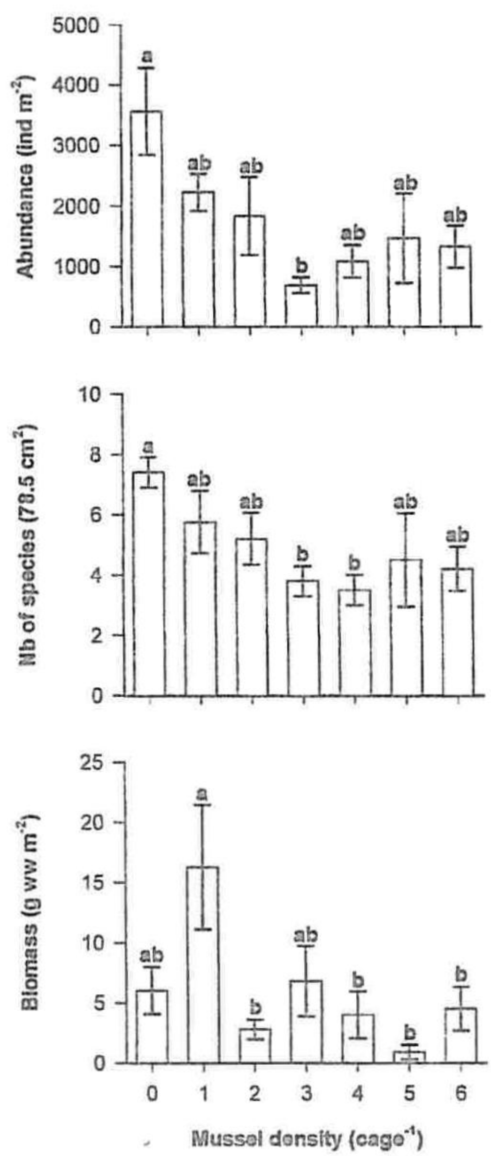

Fig. 2. Mean benthic macrofaunal abundance, species richness, and biomass (± SE, n = 4 to 5) measured in benthocosms exposed to biodeposition from 7 densities of mussels (0, 1, 2, 3, 4, 5, 6 mussels cage^{-1}). Different letters indicate significant differences between treatments. Data are standardized (m^{-2}), except for species richness (reported as number of species per benthocosm). →

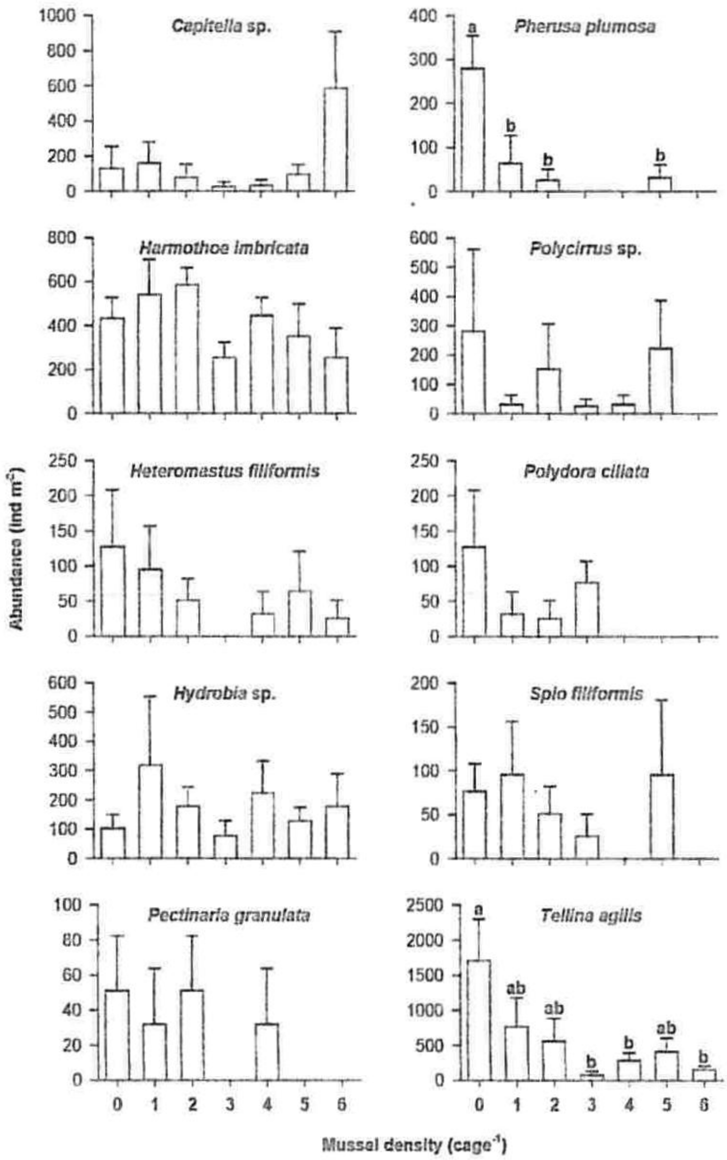

Fig. 3. Mean abundance (average ± SE, n = 4 to 5) of dominant species in benthocosms exposed to biodeposition from 7 densities of mussels (0, 1, 2, 3, 4, 5, 6 mussels cage^{-1}). Different letters indicate significant differences between treatments.

treatments (Fig. 4, p = 0.036). That in control benthocosms (0 mussels) differed from those exposed to biodeposition from 3, 4 and 6 mussels and communities from benthocosms with 2 mussels differed from those with 6 mussels.

Ecological groups. Benthocosms receiving the greatest level of biodeposition had the greatest proportion of second-order opportunistic species (data not shown). Accordingly, M-AMBI was significantly negatively correlated to mussel density (Fig. 5) and the disturbance classification indicated a shift between a slightly disturbed to a moderately disturbed community structure at a density of 764 mussels m^{-2} (n = 6 mussels benthocosm^{-1}).

Table 3. Results of the significant relationships between mussel biodeposition rates in benthocosms and various parameters describing the communities within them, including abundance (N) and taxonomic richness (S), and the abundance of individual species.

Variable	r^2	p
N	0.250	0.004
S	0.277	0.002
Abundance		
Tellina agilis	0.268	0.002
Pherusa plumosa	0.322	0.001
Polydora ciliata	0.161	0.023
Pectinaria granulata	0.122	0.050

Discussion

The effect of organic enrichment on benthic marine communities has been well documented (Pearson and Rosenberg, 1978). However, organic enrichment related to bivalve farming does not always follow the general organic enrichment model described by Pearson and Rosenberg (1978) (e.g., Grant et al., 1995). Further, there is a lack of information on the dose-response relationship between bivalve biodeposition rates and benthic variables. The aim of this study was therefore to provide some useful information on the dose-response relationship between mussel biodeposition rates and macrofaunal communities.

Biodeposit production and sedimentation rates

Biodeposit production was shown to be a function of *M. edulis* size with smaller mussels producing more biodeposits per unit body mass than do large mussels. This has been explained by the higher clearance rates of younger mussels compared to older ones (Tsuchiya 1980).

Biodeposit production differed considerably between sampling dates, and this may be related to changes in food quantity and quality, as has been observed in previous studies (Tenore & Dunstan 1973). Although several studies have shown relationships between environmental conditions and mussel metabolism, a field study that measured daily seston availability and several environmental parameters showed that these factors explained only 28% of the variation in daily ingestion rates of mussels (Cranford & Hill 1999) and so this likely cannot explain the variations observed. But his does underline the importance of doing such experiments several times to better understand the natural variation in biodeposit production and, by extension, sedimentation rates.

Although increasing with mussel size, the average sinking velocity of 1.0 ± 0.3 cm s^{-1} for *M. edulis* faecal pellets measured in this study was about twice that observed by Chamberlain (2002) for 4.2 cm *M. edulis* individuals. Our results were within the 0.2 to 4.5 cm s^{-1} range observed for the mussel *Perna canaliculus* measuring 2.7 to 11.4 cm (Giles & Pilditch 2004). De Jong (1994) reported that faecal pellets of *P. canaliculus* settled at a rate of 1.2 ± 0.1 cm s^{-1}, although the size of the mussels studied was not given and Hartstein & Stevens (2005) reported that faecal pellets from 6 cm individuals of the same species settled at 3.0 ± 0.4 cm s^{-1}.

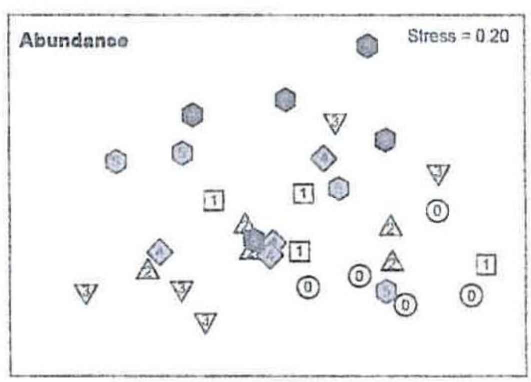

Fig. 4. MDS on abundance data of communities from benthocosms exposed to biodeposition from 7 densities of mussels (0, 1, 2, 3, 4, 5, 6 mussels cage^{-1}).: 0 (○), 1 (□), 2 (△), 3 (▽), 4 (◇), 5 (○) and 6 (●) mussels cage^{-1}.

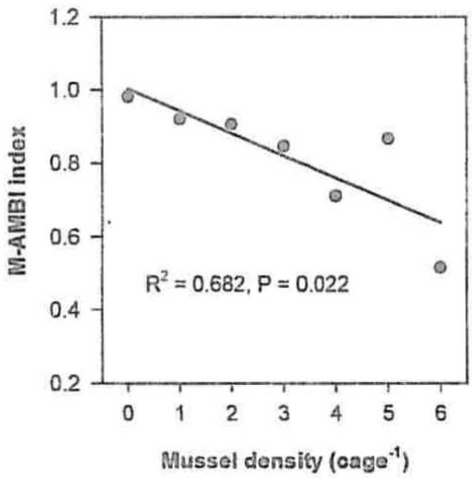

Fig. 5. Linear relationships between the biotic index (AMBI) and mussel density. Data from the 5 replicates at each level were pooled.

Variations in sinking velocity may be due in part to variations in food quality, which has been shown to influence faecal pellet density. For example, faecal pellets from mussels fed on diets with a high silt content sank more rapidly than those from mussels fed on mostly algal diets (Chamberlain 2002, Miller et al. 2002, Giles & Pilditch 2004).

Macrofaunal response

This part of the study was done to simulate biodeposition conditions in bivalve aquaculture farms in eastern Canada. Miron et al. (2005) have, for example, observed mussel densities ranging from 0.16 to 0.70 kg m^{-2} in Prince Edward Island and the mussel density in GE was ca 575 mussels per linear metre of longline (Callier et al., 2006). This range of densities is relatively low as compared to other countries. For example, mussel densities are ca. 24 kg m^{-2} in Sweden (Dahlbäck and Gunnarsson, 1981) and 175 kg m^{-2} in raft culture in South Africa (Stenton-Dozey et al., 1999). However, the different levels of deposition and associated organic loading that were created in experimental benthocosms in the present study were great enough to influence the biological and chemical environments within them.

Overall, abundance and species richness decreased with increasing biodeposition in accordance with the Pearson and Rosenberg (1978) general model of organic enrichment and as observed in other studies (e.g., Mattsson and Lindén, 1983; Chamberlain et al., 2001; Callier et al., 2007).

Only *P. plumosa* and *T. agilis* showed significant (negative) trends with mussel density. Both are classified as being sensitive to pollution. Although not statistically significant, *Capitella* sp. clearly responded to increased biodeposition. The present experiment was run over 50 days, which corresponds to the life span of *Capitella* sp. (37 to 50 days at 15 °C, Grassle & Grassle 1974). That the abundance of this species was not increased substantially except for at the greatest biodeposition rate suggests that there may be a threshold or organic loading below which this species does not react.

Classifying species into ecological groups showed that opportunistic species dominated the benthocosms exposed to the greatest level of deposition. The related biotic index – M-AMBI – responded clearly to increased biodeposition rates and may therefore be a useful tool for assessing the effect of bivalve farming on the benthic environment, thus extending observations by Muxika et al. (2005) as to the generality utility of AMBI for detecting various sources of disturbance, including finfish aquaculture, to include the influence of bivalve aquaculture – even at the relatively low densities farmed in eastern Canada.

Conclusions

The use of cores probably limits the generalisation of the observed effects. Only *Capitella* sp. showed an increase in abundance with increased biodeposition and this perhaps only because its life history allowed it to increase its local (benthocosm-scale) abundance via self recruitment. Trends in abundances for other species were mostly decreases at greater biodeposition levels. This may represent a lack of recruitment from within or outside of the benthocosms. However, relative comparisons between the treatments are valid as all treatments were similar in the way they were manipulated (excepting biodeposition levels). Another experimental design would be needed to allow for the recruitment to the sediments to be better represented within the study.

The results of this manipulative experiment are an important first step towards evaluating the environmental carrying capacity of sites for bivalve aquaculture. Further research is needed to extend the generality of the findings and to the range of biodeposition increase as well as to reduce potential experimental artefacts.

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Abstract

This experimental microcosm study reports the influence of organic enrichments by mussel biodeposits on the metabolic activity and functional diversity of benthic prokaryotic communities. The different biodeposit enrichment regimes created, which mimicked the quantity of faeces and pseudo-faeces potentially deposited below mussel farms, show a clear stimulatory effect of this organic enrichment on prokaryotic metabolic activity. This effect was detected once a certain level of biodeposition was attained with a tipping point estimated between 3.25 and 10 g day-1 m-2. Prokaryotic communities recovered their initial metabolic activity by 11 days after the cessation of biodeposit additions. However, their functional diversity remained greater than prior to the disturbance suggesting that mussel biodeposit enrichment may disturb the functioning and perhaps the role of prokaryotic communities in benthic ecosystems. This manipulative approach provided new information on the influence of mussel biodeposition on benthic prokaryotic communities and dose-response relationships and may support the development of carrying capacity models for bivalve culture.

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Fax: (023) 8821782

Revised 2013

AQUACULTURE AND FORESHORE LICENCE APPLICATION FORM, for purposes of FISHERIES (AMENDMENT) ACT, 1997 and FORESHORE ACT, 1933

NB: The accompanying Guidance Notes should be read before completing this form.

Note: Details provided in Parts 1 and 2 will be made available for public inspection. Details provided in Parts 3 and 4 and any other information supplied will not be released except as may be required by law, including the Freedom of Information Act 1997 as amended

USE BLOCK CAPITALS IN BLACK INK PLEASE

For Office Use

Application Ref No. T5/578

Date of Receipt (Dept. Stamp)

Type of Applicant (tick one)

Sole Trader	
Partnership	
Company	✓
Co-Operative	
Other Please specify-	

PART 1: PRELIMINARY DETAILS

Applicant's Name(s)

1. Dunmanus Bay Mussles Ltd.

Address:

Dromduff West,
Bantry,
Co. Cork

2.

Address:

3.

Address:

4.

Address:

2

Contact in case of enquiries (if different from above)	
Contact Name	Shane McCarthy
Organisation Name (if applicable)	Cronin Millar Consulting Engineers (Agent)
Address	Ivy Fort House 5 Cathedral Place Cobh Co. Cork

PART 1: PRELIMINARY DETAILS

TYPE OF APPLICATION – please indicate relevant type of application.
This Application Form is valid for each type of application – *See Guidance Note 3.1*

(i) Aquaculture Licence	✓
(ii) Trial Licence	
(iii) Foreshore Licence, if Marine Based	
(iv) Review of Aquaculture Licence	
(v) Renewal of Aquaculture Licence	

TYPE OF AQUACULTURE *See Guidance Note 3.2*

Indicate the relevant type of application with a tick.

(i) MARINE-BASED

Finfish			Go to Parts 2.1 and 2.1A
Shellfish	*Subtidal*	✓	Go to Parts 2.2 and 2.2A
	Intertidal		Go to Parts 2.2 and 2.2A
Seaweed/Aquatic Plants/Aquatic Fish Food			Go to Parts 2.3 and 2.3A

(ii) LAND-BASED

Finfish ___ Shellfish ___ Go to Parts 2.4 and 2.4A

Aquatic Plants ___ Aquatic Fish Food ___ Go to Parts 2.3 and 2.3A

(iii) TRIAL LICENCE ___ Go to appropriate Part as above and to Part 2.5

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2.2 MARINE-BASED SHELLFISH AQUACULTURE

When filling out this section refer also to 2.2A and Guidance Note 3.3 for information on Conditions and Documents required with this application type

Proposed Site Location

(i) Bay: Dunmanus Bay

(ii) County Cork

(iii) OS Map No: CK 139

(iv) Co-ordinates of Site: (please specify coordinate reference system used e.g. Irish Grid (IG) or Irish Transverse Mercator (ITM) or Latitude/Longitude [in which case specify whether ETRS89 or WGS84 etc.]

ITM
1) 485,662; 536,503
2) 486,781; 537,062
3) 486,875; 536,874
4) 485,756; 536,315

← 1250 x 210 = 262,500.

(v) Size of Site (hectares): 26.25 hectare

(vi) Species (common and scientific name) and whether native or non-native species (see Guidance Notes 3.3.1)

Mussels (Mytilus Edulis)

(vii) Whether production will be sub-tidal or inter tidal? Sub-Tidal

(viii) Please supply details of (a) source of seed e.g. wild hatchery and location and (b) means of collection and introduction to culture

Natural Spat Collection on stockings

[illegible]

(ix) Method of culture (rope, trestles – intensive; bottom – extensive, other)
Rope

(x) Proposed number of lines/ropes/trestles as per site layout drawing
3 blocks of 6 No. 220m long longlines

(xi) Proposed Production Tonnage

Year 1	0	Year 2	190	Year 3	250	Year 4	250	Year 5	250

(xii) (a) Please outline the reasons for site selection

Sheltered location, close access to Durrus Pier.

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(b) If using trestles please outline the physical characteristics of the site which make it suitable for using trestles

N/A

([illegible]) Is it intended that the product is for direct human consumption or half grown? Please specify

Human Consumption

([illegible]) How will the visual impact issues of the [illegible] devices for the proposed application be addressed?

See Environmental Report appended to application

([illegible]) Is the site located in Designated Shellfish Waters Area? (Refer to Guidance Note [illegible])

Yes ☐ No ✓

If yes give details

If **no** outline the reasons why you believe the site suitable for the proposed aquaculture, notwithstanding its location outside Designated Shellfish Waters Area?

Sheltered location. close access to Durrus Pier, good history of growth in Dunmanus Bay, applicant currently operates site in Inner Dunmanus Harbour, good environmental status.

(xxvi) Has the area been classified under Food Safety Legislation? (For Bivalve Molluscs) What is the current classification of the area for the proposed species applied for?

Yes, Mussels, B (Classified Bivalve Mollusc Production Area in Ireland)

([illegible]) Is the site located in/adjacent to a sensitive area e.g. SPA (Special Protection Area) or SAC (Special Area of Conservation) i.e. a Natura 2000 site? (Refer to Guidance Note [illegible] Natura 2000 sites)

No

([illegible]) Are there known sources of pollution in the vicinity e.g. sewage outfall? Yes No
If yes please give full details

No

([illegible]) Methods used to harvest the shellfish and details of any subsequent processing of shellfish

See Environmental Report appended. No processing will occur.

([illegible]) Describe any proposed purification facilities to be used

N/A

([illegible]) What are the main predators of the species to be cultivated?

Asterias Vulgaris (sea stars), Nucella lapillus (dog whelk), jellyfish, fish larvae.

([illegible]) Describe the methods which will be used to control them

Active monitoring, bottom of roes (droppers) will be an adequate distance from the sea bed

See Part 2.2A for details of documentation to be included with this application type

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2.2A DOCUMENTATION REQUIRED FOR MARINE-BASED SHELLFISH AQUACULTURE

(to be included separately with a Licence Application for a new site or for a renewal or review of an existing Licence)

1. **An appropriate Ordnance Survey Map (recommendation is a map to the Scale of 1:10,000/1:10,560, i.e. equivalent to a six inch map).** Note: The proposed access route to the site from the public road across tidal fore-hore must also be shown on the map.

2. **Scale drawing of the structures to be used and the layout of the farm.** The proposed site drawings must illustrate all site structures above and below the water including mooring blocks. (recommended scales normally 1:100 for structures and 1:200 for layout) (See Guidance Note 3.3.2)

3. **The prescribed application fee (See Guidance Note Section 4)**

4. **If the applicant is a limited Company within the meaning of the Companies Act 1963, as amended, the Certificate of Incorporation and Memorandum and Articles of Association**

5. **If the applicant is a Co-operative, the Certificate of Incorporation and Rules of the Co-operative Society**

6. **Environmental Impact Statement (if required) in certain cases- See Guidance Notes Section 3.3.1**

starfish? 7. **Alien Species dossier (where required) - See Guidance Notes Section 3.3.1**

NOW COMPLETE PARTS 2.6, 3, 4 AND 5 PLEASE

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2.6 Employment, Qualifications, Experience, etc
TO BE FILLED IN BY ALL AQUACULTURE APPLICANTS

(i) Please provide details of experience, qualifications of the applicant and any key personnel which are relevant to the aquaculture now proposed

Dunmanus Bay Mussels have been in operation for 9 years.
Applicants operate similar sites in Inner Dunmanus Bay and Bantry Bay.
Directors have over 20 years' experience operating in aquaculture development and management.

(ii) If a new application please provide details of projected employment creation during first two years of the proposed aquaculture project.
(iii) In the case of a renewal please provide current and future details.

The proposed development will create 3 jobs during the five week construction phase.

Employment levels will vary during the operational phase. Greatest employment will be created during thinning and harvesting phases.

FULLTIME JOBS

Year 1	1	Year 2	1	Year 3	1	Year 4	1

PART TIME JOBS

Year 1	1	Year 2	2	Year 3	2	Year 4	2

PART 5: DECLARATION AND SIGNING

NB: Refer to Guidance Note Section 3.5 and Section 4 - Guidance on Declaration and Signing and Annual Aquaculture and Foreshore Licence Fees

If this is a renewal review have you met all licence conditions of the existing aquaculture licence? If applicable, explain why you have not complied with all conditions

I We hereby declare the information provided in Parts 1, 2, 3 and 4 above to be true to the best of my our knowledge. I We enclose an application fee* of €95.23 with this application

Signature(s) of Applicant(s)
(Please state capacity of persons signing on behalf of a Company Co-op)

Brian Murnane,
Director, Dunmanus Bay Mussels Ltd.

Date 28 November 2013

NB All persons named on this licence application must sign and date this application form. Only the existing licence holder(s) can apply for the renewal/review of an Aquaculture Licence.

*Preferred method of payment is by cheque or bank draft. The fee should be made payable to the Department of Agriculture, Food and the Marine.

Refer to Guidance Note Section 4 - Guidance on Aquaculture and Foreshore Licence Fees

The application form should be forwarded, with the required documents and application fee, to

Aquaculture Licensing
Aquaculture & Foreshore Management Division
Department of Agriculture, Food and the Marine
National Seafood Centre
Clonakilty
Co. Cork

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PART 5: APPLICATION DOCUMENTATION

The following documents are enclosed with this application:
NB: Refer to Guidance Note Section 3.3 – Guidance on Application Documentation

No.	DOCUMENTATION	YES	NO	N/A
1	An appropriate Ordnance Survey Map (recommendation is a map to the scale of 1:10,000/10:10,560, i.e., equivalent to a six inch map)	✓		
2	Scale drawing of the structures to be used and the layout of the farm (recommended scales normally 1:100 for structures and 1:200 for layout)	✓		
3	The prescribed application fee	✓		
4	Environmental Impact Statement (EIS), if required			✓
5	Water Quality Analysis Report, if appropriate			✓
6	Decision of Planning Authority under the Planning Acts, if required			✓
7	Copy of Licence under Section 4 of the Local Government (Water Pollution) Act, 1977 – Effluent Discharge, if required			✓
8	If the applicant is a limited Company within the meaning of the Companies Act 1963, as amended, a copy of the Certificate of Incorporation and Memorandum and Articles of Association.	✓		
9	If the applicant is a Co-operative, a copy of the Certificate of Incorporation and Rules of the Co-operative Society			✓
10	Integrated Pest Management Plan, if required			✓
11	Alien Species documentation, if required.			✓

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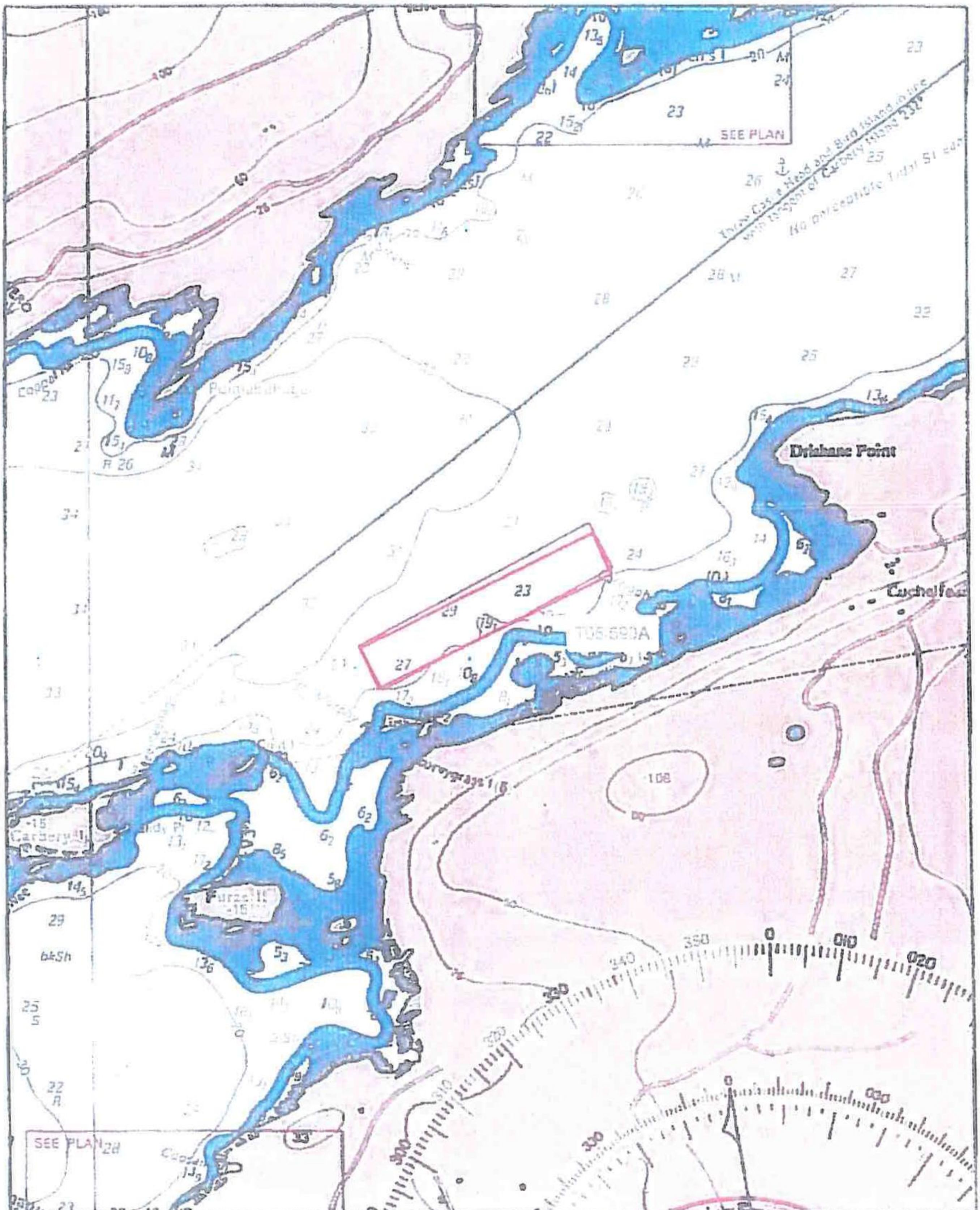
1 NO. SITE AT DUNMANUS BAY CO.CORK

Co-ordinates & Area

Site T05/590A (26.3 Ha)

The area seaward of the high water mark and enclosed by a line drawn from Irish National Grid Reference point

085688, 036433	to Irish National Grid Reference point
086807, 036992	to Irish National Grid Reference point
086901, 036804	to Irish National Grid Reference point
085782, 036245	to the first mentioned point.



1:24,000

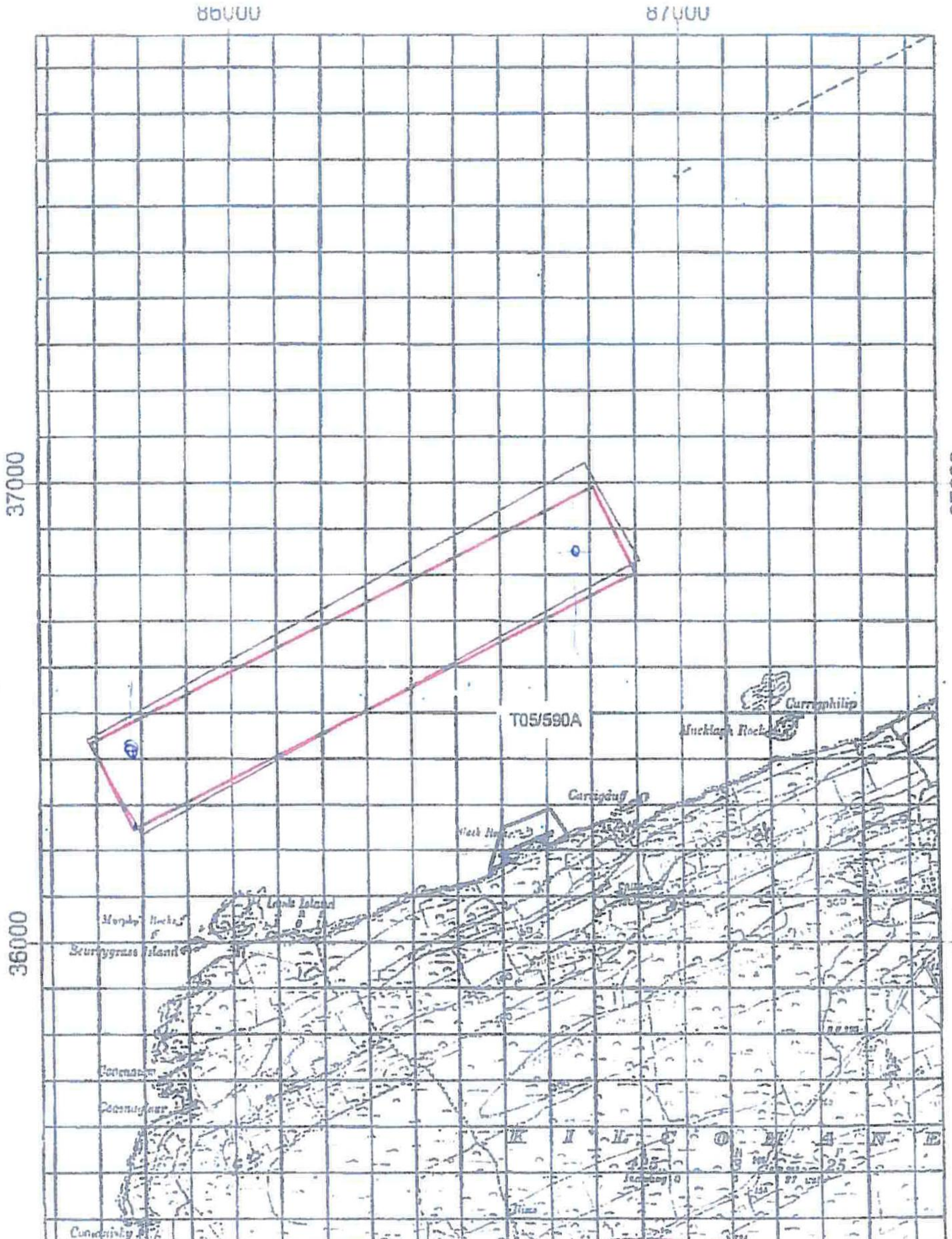
Sites highlighted in red denotes Application

Part of Admiralty Chart No 2552-0

Not to be used for Navigation

Department of Agriculture, Food and the Marine

An Roinn Talmhaíochta, Bia agus Mara



Aqua Culture Sites
<all other values>
Site_Status
Application
Lapsed
Licensed
Refused
Renewal
Revoked
Surrendered
Withdrawn

1:10,560

Sites highlighted in red denotes Application

Ordnance Survey Ireland Licence No. EN 0076413

Aquaculture & Foreshore Man...
6 JUN 2014

Department of
Agriculture, Food and the Marine
An Roinn
Talmhaíochta, Bia agus Mara

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Notes:

Map Sheets: CK 130

Scale: 1 10,560

Site Area: 26.25 Ha

Lease Area Co-Ordinates ITM
1) 495,682; 536,603
2) 496,781; 537,062
3) 496,876; 536,874
4) 495,750; 536,316

T5.590

-8 JAN 2016

Cronin Millar Consulting Engineers
Civil Marine Structural Environmental
Ivy Fort House, 8 Cathedral Place, Cobh, Co. Cork
Ph: 021 [illegible]
email: [illegible]
website: [illegible]

This drawing is to be read in conjunction with all other CMCE drawings and any other relevant information.

No dimensions are to be scaled from this drawing.

Unless noted otherwise, all dimensions are in millimetres and all levels are in metres from the noted datum.

Rev	Description	Date	Drawn	Checked
A	Aquaculture Licence Application	06/12/13	BMC	AC

Client: Dunmanus Bay Mussels

Project: Mussel Farm Development Aquaculture Application

Title: 1:10,560 Location Map

Scale:	Sheet Size:	Date:
1:10,560	A3	06/12/2013

Drawn By:	Checked By:	Drawing No:	Revision:
BMC	AC	C130/A/1	A

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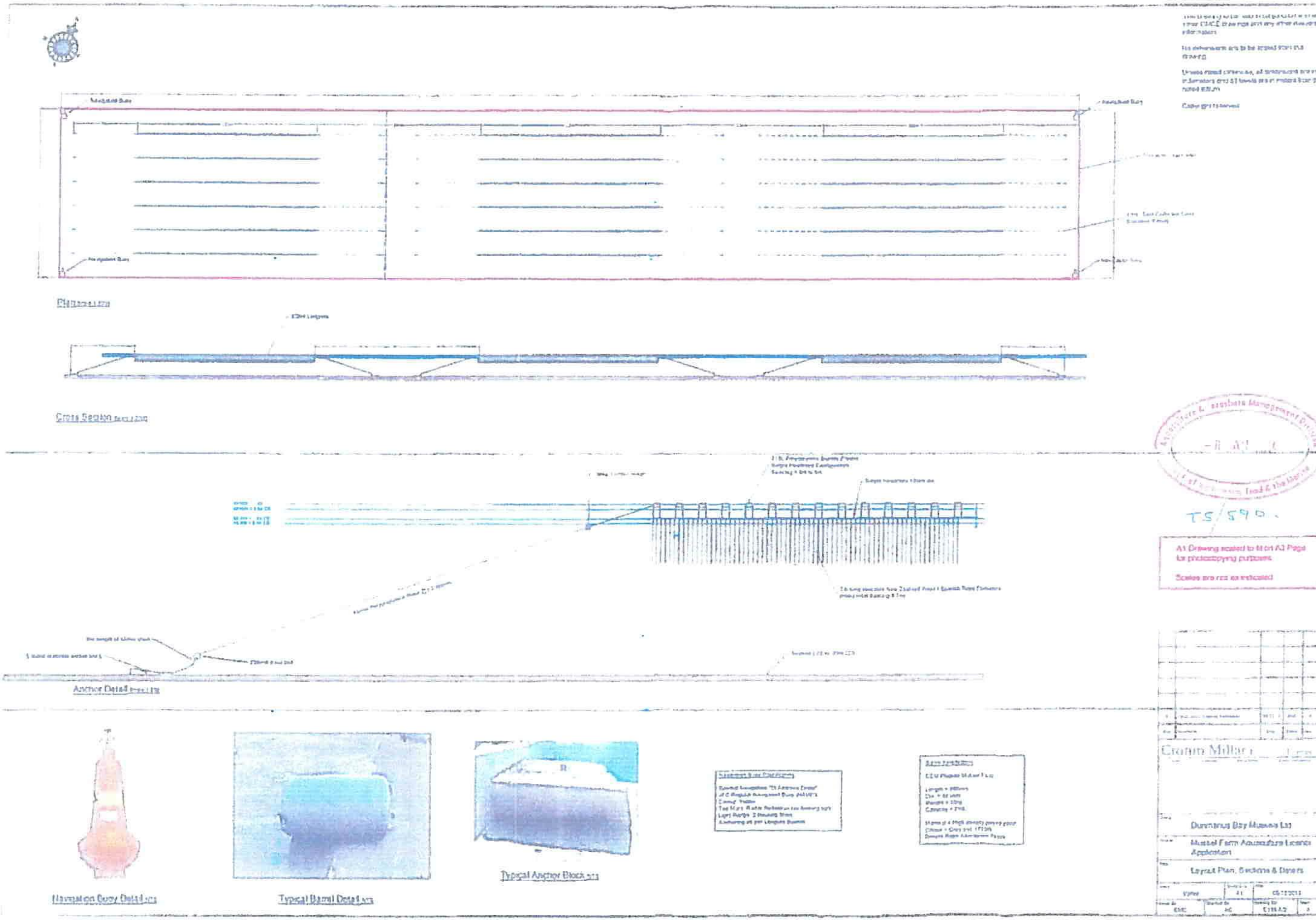

Plan
Cross Section
Anchor Detail
Navigation Buoy Detail
Typical Barrel Detail
Typical Anchor Block
TS/590.
A1 Drawing scaled to fit on A3 Page for photocopying purposes
Scales are not as indicated
Cronin Millar
Dunmanus Bay Mussels Ltd
Mussel Farm Aquaculture Licence Application
Layout Plan, Sections & Details

Dunmanus Bay Mussels Ltd

Aquaculture Licence Application

Supplementary Information and Environmental Report

Date	06 December 2013
Job No	C136
Client	Dunmanus Bay Mussels Ltd

Cronin Millar

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T5/590

Contents

Revision Control Table & Document History Record

Rev.	Date	Description & Reason for Issue	Orig.	Chkd.	App.
1	*06/12/2013*	*Aquaculture Licence Application*	*SMC*	*AC*	*AC*

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1.0 INTRODUCTION

It is Irish Government policy to support the growth and development of aquaculture as a sustainable, reliable food production industry. Food Harvest 2020 sets an ambitious target of increasing aquaculture volume production by 78% by 2020. This is a difficult target to realise due to the current constraints associated with EU Conservation Directives.

Dunmanus Bay Mussels Ltd. proposes to install and operate a mussel farm in Dunmanus Bay, Co. Cork, in the body of water between Carbery Island and Drishane Point. The installation and operation of this farm will require an Aquaculture Licence from the Department of Agriculture, Food and the Marine (DAFM) under the Fisheries Act 1997 and relevant Statutory Instruments. The proposed licenced site will incorporate an area of approximately 26.25 hectares.

1.1 Environmental Impact Assessment

A full Environmental Impact Assessment (EIA) is not required for this development, as it falls below the thresholds as outlined in the relevant planning and fisheries legislation.

It is also very unlikely that the competent authority will require a full EIA due to the fact that the development site does not fall within any sensitive designated areas and is relatively minor in scale.

For the purposes of a more complete aquaculture licence application, this report has been created to provide supplementary environmental information. Various environmental categories are examined, the impacts therein assessed and mitigation measures are proposed where required.

1.2 Application History

Dunmanus Bay Mussels previously applied for an aquaculture licence for this site, for which DAFM issued a Notice of Ministerial Decision to Grant an Aquaculture Licence and Companion Foreshore Licence on 20 December 2011 (Ref. T5/503). This notice was appealed by Third Parties to the Aquaculture Licence Appeals Board (ALAB) and their appeal was upheld by ALAB.

This revised application is for a slightly modified, smaller site. The concerns of the appellants and ALAB's Technical Advisor have been considered in the re-design of the proposed site and the preparation of the application documentation. In particular it is noted that ALAB's Technical Advisor recommended that further investigations were required, with an appropriate extension of time, to consider the decision fully. ALAB refused the licence outright. It's also worth noting that all the DAFM advisors and consultees recommended granting of the licence, including the EIA Pre-Screening Expert Panel.

1.3 Site Selection

In our opinion, supported by relevant technical assessment data, this site is wholly suitable for the location and operation of a suspended rope mussel culture facility. As outlined in this report and relevant application documentation, the operation will not have any significant impact on the environment in Dunmanus Bay. Pre consultations with the relevant statutory bodies have helped to determine the size, location and type of proposed aquaculture operation.

2.0 PHYSICAL ENVIRONMENT

The proposed site is located between Carbery Island and Drishane Point, in Dunmanus Bay, west Cork. The site is located approximately 7 miles south west of the village of Durrus along the southern coastline of the bay.

2.1 Tidal Levels

The tidal levels in Dunmanus Bay are outlined in Table 1 below.

Tide	MLWS	MLWN	MHWN	MHWS
Level (CD)	+3.40m	+2.60m	+1.10m	+0.40m

Table 1 Tidal Levels in Dunmanus Bay

2.2 Sea Bed

The sea bed at the site of the proposed development is rocky with some areas of cobbles and gravels.

A hydrographic survey was carried out at the site of the proposed development. The sea bed level varies between -15m and -30m CD. The survey drawing is enclosed in the Appendix of this report.

2.3 Currents

A study of current flows in Dunmanus Bay was carried out by Hydrographic Surveys Ltd. The result of this analysis is enclosed in the Appendix of this report.

The survey was carried out on 19/10/2012. The predicted tide levels on that date were as outlined in Table 2.

one single day!

Tide	LW	HW	LW	HW
Level (CD)	+0.30m	+3.40m	+0.30m	+3.20m
Time	01:38	07:46	14:04	20:11

Table 2: Tidal Levels in Dunmanus Bay on 19 October 2012

Currents were surveyed at the west and east extremities of the site. In general, current velocities decreased with depth. Table 3 below summarises the results recorded on the day of surveying.

Point	CM 01 (West)	CM 02 (East)
Ebb Tide Average Current	0.13m/s (0.25 knots)	0.20m/s (0.40 knots)
Ebb Tide Average Direction	185° (south)	56° (north east)
Flood Tide Average Current	0.09m/s (0.18 knots)	0.12m/s (0.23 knots)
Flood Tide Average Direction	192° (south)	162° (south)

Table 3 Tidal Levels in Dunmanus Bay on 19 October 2012

It is estimated that the currents at the site may be 50% lower during neap tides.

2.4 Waves

Detailed wave modelling has not been carried out at this site

It is anticipated (based on surveys at similar bays in west Cork) that extreme wave heights in the area could reach up to 3.5m. These waves would originate as offshore swells propagating Dunmanus Bay from west to east. It may be assumed that some local protection is provided by Carbery Island and Furze Island

2.5 Wind

A design wind speed of 25.2m/s (1 hour wind duration, 50 year return period) shall be used. This is based on BS 6399-2

2.6 Foreshore Inspection

The intertidal foreshore adjacent to the proposed site comprises of steep rock outcrops

2.7 Aquaculture Sites

There are a number of other aquaculture sites located in Dunmanus Bay. They are located primarily in the Inner Dunmanus Bay area. The applicant successfully operates a number of these sites

3.0 NATURAL HABITATS

As part of the Habitats Directive Screening Report a literary review and on-site observations were carried out to determine natural habitats that may be affected by the proposed development.

3.1 Birds

It was found that the habitats in the vicinity of the proposed mussel farm were unsuited for nesting for peregrine falcons and chough. The skerries at Carrigphillip and Mucklagh Rocks may be suited for nesting by Artic Terns. Full details of the findings are contained with the relevant report.

3.2 Cetaceans – Harbour Seals (Phoca Vitulina)

According to National Parks and Wildlife Service *"Harbour Seal Population Monitoring 2009-2012 Report No. 1"* a maximum of 34 No. harbour seals were counted in Dunmanus Bay. The principal sites for Harbour seals were found in the inner reaches of the bay at Carraigphillip and Mucklagh Rocks. In recent years 27 and 29 Harbour seals were recorded on 15th Sept 2007 and 18th Sept 2008 respectively. Full details of the findings are contained with the relevant report.

3.3 Otters

There is likely to be considerable otter activity in the general vicinity of the proposed farm, although this activity is likely to occur along the shallower shoreline. The closest otter holt is likely to be on Holt Island, which is approximately 700m from the proposed farm. The mussel farm is unlikely to create any disturbance to the otter community.

3.4 Scallops & Nephrops

The Screening Report identified that the seabed at the site had a poor species community. It identified Nephrops as the dominant species. It is anticipated that the Nephrops will feed on the mussel pseudo faeces.

It is possible that there is some limited scallop fishing in the vicinity of the proposed farm. The applicant is willing to facilitate the continuation of scallop fishing within the boundaries of the proposed licence area, subject to agreement. This accommodation currently exists in inner Dunmanus Harbour, whereby Dunmanus Bay Mussels Ltd. allow, by agreement, local fisherman to fish between the lines of their existing mussel farms.

3.5 Biotoxology

The Marine Institute carries out weekly inspections of toxin levels in various sites around Ireland, including Dunmanus Bay. They monitor toxin levels in waters, to ensure that the levels are below a minimum threshold before shellfish are harvested. This ensures that the aquaculture products are safe for human consumption. It is expected that this practice will be extended to outer Dunmanus Harbour after the farm is established.

4.0 EXISTING RESOURCES

A number of existing natural and manmade resources are found in the location of the proposed development

4.1 Adjacent Land Resources
The site is located immediately north and west of the town lands of Cashelfean and Kilcomane. The land primarily comprises agricultural land and areas of overgrown gorse There are approximately 20 No houses within 1km of the proposed site.

4.2 Road Network
The land south of the proposed development site is accessed via the R591 road from Durrus A number of narrow third class roads are also found in the locality Farm operations will not use these roads Access to the proposed site will be by water from Durrus Pier.

4.3 Adjacent Intertidal Foreshore Resources
The intertidal foreshore comprises primarily rocky outcrops There is a small pier located in Drishane to the south of the proposed site Access to the pier from the water is tidally dependant. The pier is occasionally used by local, small scale inshore fisherman The development will not have any impact on the pier or pier users

Image 1 Pier at Drishane

A small strand is located east of the site, adjacent to the pier This beach may be used for occasional bathing and as an area for the launching and recovery of small boats and dinghies

This area is not listed as a bathing area in the current Cork County Development Plan or the Bantry Local Area Plan Cork County Council's *"Marine Leisure Infrastructure Strategy for West Cork"* (January 2008) states that there is limited leisure usage at Kilcomane It further states that the primary use is for *"fishing"*.

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Image 2 Strand at Cashelfean

4.4 Adjacent Water Resources

Dunmanus Bay is used for small scale fisheries and some leisure boating. Piers at Ahakista and Durrus are used for access to the bay. There are a number of licenced aquaculture sites operational in Dunmanus Bay Inner.

The area occupied by the site of the proposed development is used, on an ad hoc basis, by inshore fishermen. The applicant, Dunmanus Bay Mussels, is willing to accommodate inshore fisherman to continue to fish the area after the farm is installed. This arrangement currently exists and works well between the applicant and inshore fishermen at their sites in Dunmanus Bay Inner.

Angling and inshore fishing activities also take place throughout the bay.

5.0 STATUTORY DESIGNATIONS

A literature review of statutory designations was carried out as part of this report. The results of this are outlined in sections 5.1 to 5.4 below

5.1 Statutory Designations

There are no Natural Heritage Areas (NHA), proposed Natural Heritage Areas (pNHA), Special Areas of Conservation (SAC) or Special Protection Areas (SPA) at the site of the proposed development. The nearest natural designation areas to the site of the proposed development are as follows

- Dunbeacon Shingle SAC is located approximately 6km north east of the site
- Owen's Island pNHA is located approximately 2.5km north of the site
- Sheep's Head to Toe Head SPA is located at the west of the Mizen Peninsula and Dunmanus Peninsula
- Sheep's head pNHA is located on Dunmanus Peninsula to the North

There are no designated bathing areas near the proposed development

5.2 Scenic Routes

The land immediately south of the site is designated as a scenic landscape in the Cork County Development Plan 2009. Scenic route S107 and S106 are located adjacent to the site and Scenic Route S109 is located on Sheeps Head Peninsula to the north

5.3 Water Quality Status

The EPA Water Quality in Ireland 2007-2009 report identifies Dunmanus as a shellfish production area with A and B classification

The site of the proposed development does not fall under the category of a designated bathing area. There is no water quality designation within Dunmanus Bay following reference to EPA Bathing Water Quality 2009. The closest designated Good Water Quality designation in EPA Water Quality in Ireland 2007-2009 is Barley Cove, approximately 15km south west

The EPA does not provide a status for Dunmanus Bay in relation to Transitional and Coastal Waters Ecological Status. Roaringwater Bay to the south has a moderate status

In 2009, the minister for the Environment, Heritage and Local Government signed the Dunmanus Inner Pollution Reduction Programme. This programme was implemented to improve water quality in the designated shellfish growing waters in Dunmanus Bay Inner

5.4 Local Area Plans and County Development Plan

Although planning permission is not required for offshore aquaculture developments, the relevant area plans were reviewed as part of the assessment process. The current Cork County Development Plan (2009) (CDP) and the Bantry Local Area Plan (2011) (LAP) does not include any restrictions in relation to aquaculture development in Dunmanus Bay. The LAP recognises aquaculture as an economic strength of the area and states that the strategy is to promote further growth and development in this sector. The CDP states that the Bantry area is "*an important location for marine and aquaculture industries*". It also states that "*In accordance with Government policy, the Council will support and promote the sustainable development of the aquaculture sector in order to maximize its contribution to jobs and growth*."

6.0 SITE SELECTION

A number of factors contribute to selecting an appropriate site for the development and operation of a longline suspended culture farm.

6.1 Site Suitability

The site has been selected due to the relative shelter provided by Carbery Island and Furze Island. There is adequate site flushing as outlined in section 9.0 of this report

Dunmanus Bay Mussels currently operates a site in the inner harbour (adjacent to Mannion's Island). Access to the new proposed site, availability of plant and machinery and labour resources is therefore conveniently located.

6.2 Access to Site

Dunmanus Bay Mussels operates from Durrus Pier. This pier is approximately 9km or 5 nautical miles north east of the site. There is no pier infrastructure in the vicinity of the proposed site.

6.3 Navigation

Extensive consultations with the Marine Survey Office (MSO) were previously held. The outcome of this consultation assisted in determining a location for the proposed development that would satisfy navigational safety issues.

6.4 Alternative Sites

Alternative sites within Dunmanus Bay were examined. The final site was dictated by the MSO to satisfy navigational safety issues. The applicant already operates sites within the bay.

7.0 PROPOSED WORKS

7.1 Physical Infrastructure

The works will comprise the installation of 18 no. longlines. each of a length of 220m as indicated on the drawings that form part of this application. Each longline will comprise 1 no. 220m long head rope (singlehead rope). Droppers will hang vertically from the longlines at approximately 800mm spacing. The droppers upon which the mussels will grow, will be approximately 6m long and 12mm diameter. Buoyancy to the longline system will be provided by 210Litre polyethylene barrels at spacings of 3m to 4m.

Anchorage to the long lines will be provided by 40mm diameter polypropylene ropes connected to approximately 8m of chain that will in turn be connected to a 5 tonne concrete anchor. Damper weights and trawl balls will be provided to the anchorage system also.

To provide navigation warnings, Floatex 1200PE Light Buoys will be installed in the four corners of the site. The proposed lamp standards will be subject to approval from the Commissioner of Irish Lights (CIL). These buoys will be anchored with 28mm anchor chains connected to a 5 tonne concrete anchor block on the sea bed.

All materials will be brought to the site from Durrus Pier, where the applicant currently operates from.

7.2 Construction Methodology

The site will be installed by the applicant using existing plant and machinery. A crane will be used to drop 5 tonne concrete anchor blocks on the sea bed. The location of the blocks will be confirmed using GPS. Approximately 8m of chain and anchor ropes will be attached to the anchor blocks before deployment.

From a work barge, the anchor ropes will be tied to 1 headrope which will be 220m long. The headropes will then be connected to 210litre polyethylene barrels at 3m to 4m spacing.

The process will be repeated for all the other lines. It is estimated that the installation works will take approximately 1 month.

7.3 Operation Works

The operation works comprise of three distinct stages.

7.3.1 Seed (Spat) Collection

Seeds will be collected via natural spat fall collection. Reusable Spanish spat collector rope will be suspended in late January and early February. This rope is reusable with a circa 25 year lifespan.

7.3.2 Thinning

When the mussels have grown to between 10mm and 13mm the collector rope is hauled into the harvesting vessel and the mussels are stripped from the rope. The rope is washed and stored for reuse the following season. The mussels are sorted through a grading machine and sorted into two sizes. The mussels are then placed on a grow rope (New Zealand) and a biodegradable cotton sock. The rope is hung at 800mm spacing with a 6/7 m drop. This process is repeated in the summer. After approximately 12 months, when the mussels have grown to market size, they are harvested.

7.3.3 Harvesting

When the mussels have grown to market size, the rope is hauled into the harvesting vessel and mussels are removed from the rope and the rope is washed and stored for reuse. The mussels are washed and graded and bagged into 1 tonne bags. The bags are then placed onto pallets for onward transportation. The New Zealand rope also has a lifespan of circa 25 years.

Image 3 MFV Muireann

Image 4 Work Gear

Works will be carried out from MFV Muireann, a 15m long fishing vessel retro-fitted to accommodate mussel harvesting plant.

8.0 LANDSCAPE AND VISUAL ENVIRONMENT

Impacts on landscape and visual are addressed separately.

8.1 Landscape

The Cork County Council Draft Landscape Strategy 2007 identifies the landscape character areas of County Cork. The site of the proposed development falls into Type 4 "*Rugged Ridge Peninsulas*" in the strategy. The site falls into Sheeps Head – Mizen Head Landscape Character area and is identified as being "*indented rugged peninsular ridge*" in the area of the proposed development. It states that the landscape value is "*very high*" the landscape sensitivity as "*very high*" and the landscape importance as "*national*".

The landscape character will not be dramatically altered by the proposal as the development will integrate with the existing bay/harbour. All infrastructure will be installed below, at, or only slightly above water level. The view of the water edge and the bay will not be altered by the presence of the farm.

It is unlikely that the Scenic Landscape Designation or the Scenic Roads designation will change due to the proposed development.

8.2 Visual

The main visual receptors of the proposed development will be residential properties in the locality and users of the small strand east of the development.

8.2.1 Zone of Visual Influence

The area of study (or visual envelope) for a visual assessment may extend to the whole of the area from which the development is visible, however it is generally limited to the distance from the development within which the view is expected to be of interest or concern.

A zone of visual influence is the area within which a proposed development may have an influence or effect on visual amenity. A visual receptor may be a physical landscape resource, special interest or viewer group that will expect an effect.

The Zone of Visual Influence was assessed during a field survey to determine the locations where there are potential impacts on the visual environment. Six locations were assessed in terms of visual impact as per Figure 1.

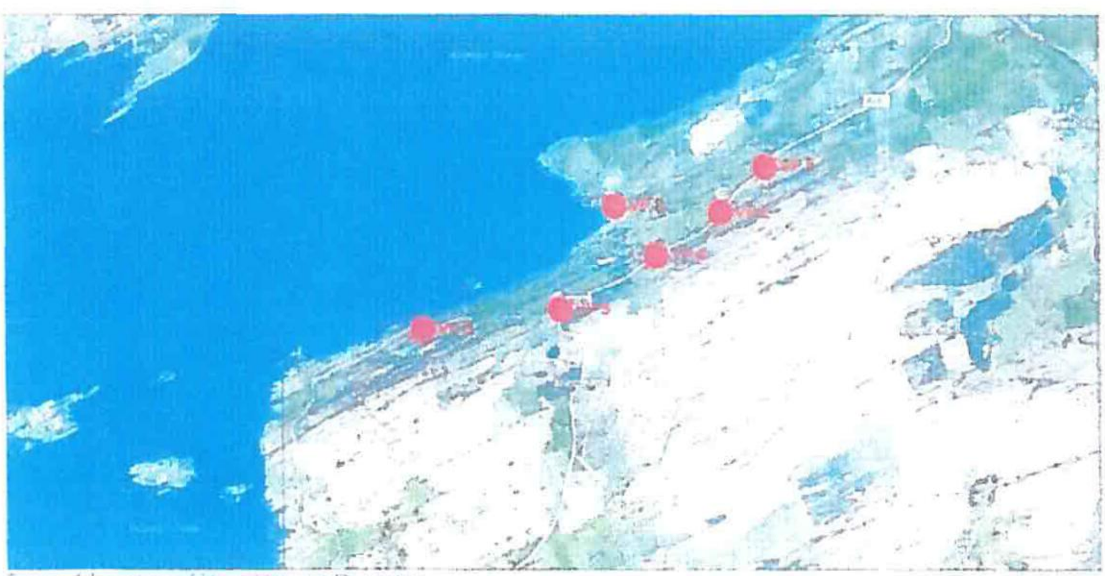

Figure 1 Location of Visual Impact Receptors

8.2.2 Visual Representations

Images 5 to 17 present views from the various viewpoints (as per Figure 1), with visual representations shown thereafter.

Image 5 Viewpoint 1 Pre Development

Image 6 Viewpoint 1 Post Development

Image 7 Viewpoint 2 Pre Development

Image 8 Viewpoint 2 Post Development

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Image 9 Viewpoint 3 Pre Development

Image 10 Viewpoint 3 Post Development


Image 11 Viewpoint 4 Pre Development


Image 12 Viewpoint 4 Post Development

Image 13 Viewpoint 5 Pre Development

Image 14 Viewpoint 5 Post Development

Image 15: Viewpoint 6 Pre Development

Image 15: Viewpoint 6 Post Development

8.2.3 Residential Properties

Less than 20 residential properties are located within 1km of the proposed development. Some of these will have clear views of all or part of the development. The main visual impact will be of vessels berthed at the farm during operations. The view of vessels will not be out of context given the nature of the existing site.

The view of the floats will be more apparent from higher elevations.

8.2.4 Strand

A small strand is located to the east of the proposed development. Here, users will have unobstructed views of the proposed development. The main visual impact will be of vessels berthed at the farm during operations. This view will not be out of context given the nature of the existing site.

The floats will not be highly visible due to the low elevation of the receptor over the development.

8.3 Visual and Landscape Impact Mitigation Measures and Design Mitigation Features

In order to reduce any potential impact on visual amenities, the following mitigation measures or design features are proposed:

1) The site will not be located near other farms, which reduces the impact on landscape, in accordance with the Department of Marine and Natural Resources '*Guidelines for Landscape and Visual Assessment of Marine Aquaculture*'.
2) The development will not be located within the central focus of the bay.
3) The longlines as proposed run parallel with the existing coastline, thus reducing fragmentation of the water surface.
4) Simple linear lines are proposed. This suits the elongated nature of the peninsulas.
5) Shore based activities will take place at the existing Durrus Pier and not in the vicinity of this site.
6) Navigation lighting will not be visually negative and will not be out of context within the bay.
7) Floating buoys used will be "battleship grey" in colour, so as to match the existing visual environment. This will mean that they are less visually obtrusive.
8) Care will be made to ensure lines are accurately installed. This will ensure the lines are parallel.
9) Lines will be installed taut, so they do not become misshaped over time. Also, the anchor blocks have been adequately sized so as to avoid drag of the lines.
10) Intermediate anchors will be installed to prevent bowing of the lines, if required.

9.0 PREDICTED IMPACTS & MITIGATION MEASURES

9.1 Biodeposition and Impact on Benthic Community Composition

Shellfish farming results in the bio-deposition of faeces and pseudo faeces on the sea bed. This can affect existing sediment characteristics and benthic community composition.

The volume of bio-sedimentation on the sea bed is very much site specific. It is difficult to accurately forecast sedimentation on a site as it is dependent on existing water quality, farm size, mussel density, currents, wave action, nutrients and other variables. It is considered that shellfish farming has less of an impact on the environment than fin fish farming, as no external feed is added, however they do occupy a larger footprint.

The dynamics of bio-deposition (including faeces and pseudo faces) are not fully understood and not easily modelled. For the purposes of this study, first principles were used to determine the rate of bio-deposition, dispersion, and accumulation of bio-deposits. Reference is made to Weise et al "*Modelling the biodeposition from suspended shellfish aquaculture and assessing benthic effects*", 2009. That study was carried out at shellfish sites in Canada. To date, no similar studies can be sourced in Ireland, so the "worst case scenario" figures from this report are used.

Site	GE 1+ (2003)	CAS (2005)	Dunmanus Bay
Site Size km^2	2.5	1.4	0.26
Longline Dimensions	200 No. longlines 91m long 0.2m diameter 1m dropper length	150 No. longlines 142m long 0.2m diameter 5.5m dropper length	18 No. longlines 220m long 0.04m diameter 7m dropper length
Overall length of Droppers per longline	366m	1100m	1,925m
Depth of Longline below Water Level	1.5m	12m	2m
Biodeposit production (kg/longline.day)	26.4	86.6	Unknown
Faeces Settling Velocity (mm/s)	10.0 ± 3.0	8.0 ± 1.0	Unknown
Pseudofaeces Settling Velocity (mm/s)	2.0 ± 0.2	N/A	Unknown

Table 4 [illegible]

9.1.1 Biodeposition Generation

Upon examination of Table 4, it may be interpolated that approximately 0.079kg of biodeposit per metre of dropper per day may be produced. It can therefore be approximated that 174kg/longline per day of biodeposit may be generated at the proposed site in Dunmanus. This equates to approximately 2,718kg of biodeposit generated daily at the site. This equates to approximately 992Tonnes/year.

9.1.2 Biodeposition Dispersion

Table 4 indicates that faeces settling velocities of approximately 10.0 mm/s have been recorded at previous study sites. For the purposes of this report, we will assume a biodeposit settling velocity at the Dunmanus site of 10.0 mm/s. This yields the following settling times at the Dunmanus site:

Low Water, -15m CD contour, settling time = 1,500s (or 25minutes)
High Water, -30m CD contour, settling time = 3,000s (or 50minutes)

Section 2.3 of this report indicates that current velocities at the site range between 0.09m/s to 0.20m/s. This yields the following potential settling distances from the site:

Minimum:	1,500s x 0.09m/s	= 135m (laterally) from the source
Maximum	3,000s x 0.20m/s	= 600m (laterally) from the source

This equates to an affected footprint of $0.319km^2$ to $0.515km^2$.

The concentration of deposits over the seabed is therefore:

Maximum: 992,070 kg/year / $319,200m^2$ = 3.108 kg/ m^2/year = 8.515 g/m^2/day
Minimum: 992,070 kg/year / $514,500m^2$ = 1.928 kg/ m^2/year = 5.283 g/m^2/day

Allowing for neap tides, the maximum concentration of biodeposition may be in the region of 8.5g/ m^2/day.

These calculations do not take into account wave induced currents and water movements caused by wind effects, which will have a positive impact on biodeposition. The calculations also assume that the site will have 100% harvestable size mussels on the droppers, which will not be the case.

9.1.3 Detectable Impact

Weise et al states that benthic status may become disturbed when biodeposition rates are in the range of circa 15 to 30g/m^2/day. The estimated concentration rates fall well below this criteria. It can therefore be stated that the proposed farm will not have a detrimental impact on the exiting benthic community composition.

9.2 Impact on Human Health

Mytilus edulis are filter feeders and remove toxins and bacteria from the water in which they inhabit. Mussels are not a generator of toxins. They may ingest toxins from the water and convert to biodeposits. The proposed farm will not have an effect on human health due to bathing activities.

Consumption of shellfish containing DSP, PSP and ASP toxins can affect human health. These toxins are caused by enrichment and algal blooms. During occasions when algae blooms are present in the locality, harvesting of mussels is not permitted. A rigorous shellfish monitoring programme is managed by the Sea Fisheries Protection Authority (SFPA).

9.3 Impact on Local Fisheries

The development may have a minor impact on local fisheries. The applicant is willing to accommodate inshore fisherman to continue to fish the area after the farm is installed. This arrangement currently exists and works well between the applicant and inshore fishermen at their sites in Dunmanus Bay Inner

9.4 Impact on Foreshore
None anticipated

9.5 Impact on Land Uses
It is anticipated that the proposed development will have negligible impact on existing land uses as the site does not encroach on the land

9.6 Impact on Employment
The proposed development will have a positive impact on employment as it will help support existing jobs and create new local employment opportunities This will have a positive impact on the local economy as other indirect jobs will be supported

9.7 Impact on Traffic
The site will not have any impact on traffic in the locality adjacent to the development as all works access will be carried out from Durrus Pier via various vessels, as there is no appropriate berthing facility immediately adjacent to the site

9.8 Impact on Navigation
The proposed site will have minimal impact on navigation The propose site lies well to the south of the navigation channel to Dunmanus Inner Local inshore vessels will be able to navigate between the southern side of the site and the shoreline The following additional mitigation measures are proposed

- The applicant will deploy navigation buoys to the satisfaction of the Department of Agriculture Food and Marine the Commissioner of Irish Lights and the Marine Survey Office

- A marine notice will be advertised with the Department of Transport regarding the construction works.

- A public notice will be advertised in a locally read newspaper

- The United Kingdom Hydrographic Office will be notified so amendments can be made to the local navigation charts

9.9 Impact on Statutory Designations
The proposed development will not impact upon or change any statutory designations

9.10 Pollution
Recyclable materials will be used during both the construction and operational phases as far as possible Nylon mesh will not be used for the longline stockings

A hydrocarbon spill clean-up kit will be available on the work boat at all times This will ensure that any potential hydrocarbon spills are contained and appropriately managed

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Appendix A

DUNMANUS BAY MUSSELS

Habitats Directive Screening Report

September 2013

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DUNMANUS BAY MUSSELS
Habitats Directive Screening Report

Contents

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1 INTRODUCTION

This report has been prepared by Paul Murphy of EirEco Environmental Consultants in association with Cronin Millar Consulting Engineers on behalf of Dunmanus Mussels Ltd to determine the potential effects, if any, of the proposed development of a mussel farm in Dunmanus Bay on the Natura 2000 network. The purpose of this assessment is to determine the appropriateness, or otherwise, of the proposed scheme in the context of the conservation status of sites designated under the Natura 2000 network.

1.1 Regulatory Context

The Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora better known as "The Habitats Directive" provides the framework for legal protection for habitats and species of European importance. Articles 3 to 9 provide the legislative means to protect habitats and species of Community interest through the establishment and conservation of an EU-wide network of sites known as Natura 2000. These are Special Areas of Conservation (SACs) designated under the Habitats Directive and Special Protection Areas (SPAs) designated under the Conservation of Wild Birds Directive (79/409/EEC) (better known as "The Birds Directive").

Article 6(3) and 6(4) of the Habitats Directive set out the decision-making tests for plans and projects likely to affect Natura 2000 sites (Annex 1.1). Article 6(3) establishes the requirement for Appropriate Assessment:

"Any plan or project not directly connected with or necessary to the management of the [Natura 2000] site but likely to have a significant effect thereon, either individually or in combination with other plans and projects, shall be subjected to appropriate assessment of its implications for the site in view of the site's conservation objectives. In light of the conclusions of the assessment of the implication for the site and subject to the provisions of paragraph 4, the competent national authorities shall agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the site concerned and, if appropriate, after having obtained the opinion of the general public".

1.2 Stages of Article 6 Assessment

This Screening Report and Natura Impact Statement has been undertaken in accordance with the European Commission Methodological Guidance on the provision of Article 6(3) and 6(4) of the 'Habitats' Directive 92/43/EEC (EC 2001, '*Assessment of plans and projects significantly affecting Natura 2000 site – Methodological guidance on the provisions of Article 6(3) and (4) of the Habitats Directive 92/43/EEC*' and the European Commission Guidance '*Managing Natura 2000 Sites*'. In complying with the obligations under Article 6(3), and following the above Guidelines, this AA has been structured as a stage by stage approach as follows:

Screening

- Description of the proposed project
- Identification of Natura 2000 sites potentially impacted
- Identification and description of individual and cumulative impacts likely to result from the project
- Assessment of the significance of identified impacts on site integrity
- Exclusion of Natura sites from the assessment process where it can be objectively concluded that there will be no significant impacts

Appropriate Assessment

- Description of the Natura 2000 sites that will be considered further in the AA
- Description of significant impacts on the conservation feature of these sites likely to occur from the scheme
- Details of measures to avoid or mitigate any significant impacts
- Assessment of Alternative Solutions (if applicable)
- Examination of alternative solutions (if applicable)
- Assessment where no alternative solutions remain and where adverse impacts remain
- The 'IROPI test' (Imperative Reasons of Over-riding Public Interest) and compensatory measures

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The Habitats Directive promotes a hierarchy of avoidance, mitigation and compensatory measures. Firstly, the proposed scheme should aim to avoid any negative impacts on European sites by identifying possible impacts early in the plan making, and writing the plan in order to avoid such impacts. Secondly, mitigation measures should be developed, if necessary, during the AA process to the point where no adverse impacts on the site(s) remain. Where a proposed scheme is still likely to result in adverse effects and no alternative solutions are identified, if the proposed scheme is required for imperative reasons of overriding public interest (IROPI test) under Article 6 (4) of the Habitats Directive, then compensation measures are required to offset any remaining adverse effect.

As part of this assessment, marine survey was undertaken on the 14th August 2013 using a combination of SCUBA and direct observation during low water within the littoral zone. The survey commenced at 10.00 (mid-tide) and continued through to low tide (HW 06.26 3.9m, LW 12.49 0.8m). Marine habitats were classified according to JNCC Marine Habitat Classification for Britain and Ireland (Version 04.05) and the Heritage Council Classification (Fossitt, 2000).

2. STAGE 1: SCREENING

2.1 Natura Sites Identified

The location of the proposed mussel farm is not within any designated Natura 20000 site, the nearest site being over 2km away. The location of the proposed development relative to designated areas is shown in Figure 1.

Figure 1. Proposed Mussel Farm at Dunmanus Bay in relation to Designated Conservation areas (source: NPWS Mapviewer)

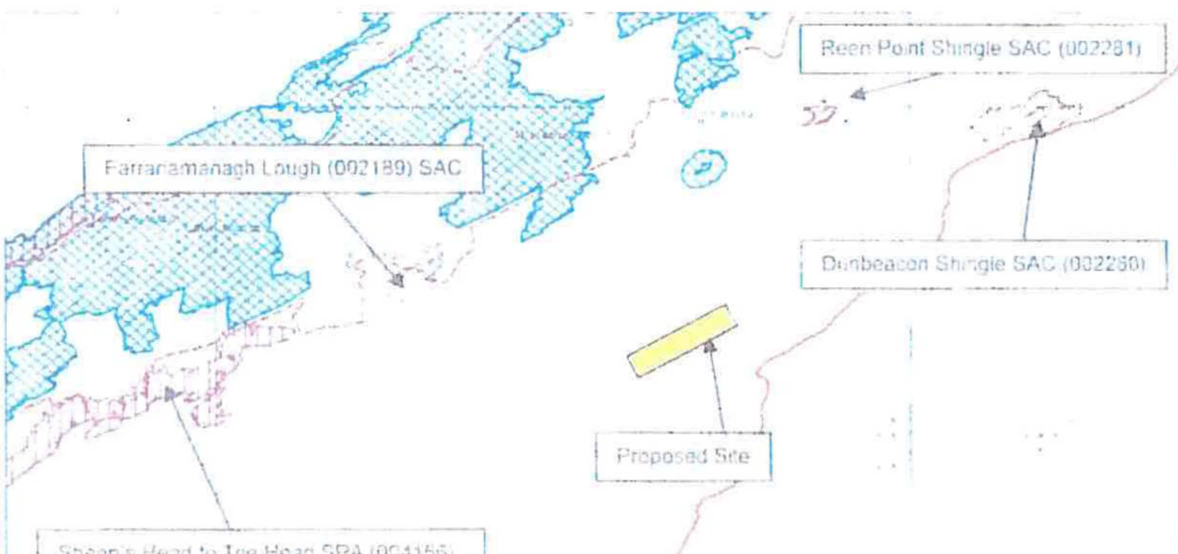

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Table 1 details the Natura 2000 sites that are within the general vicinity of the proposed mussel farm location.

Table 1. Natura 2000 sites in the general vicinity of the proposed Mussel Farm

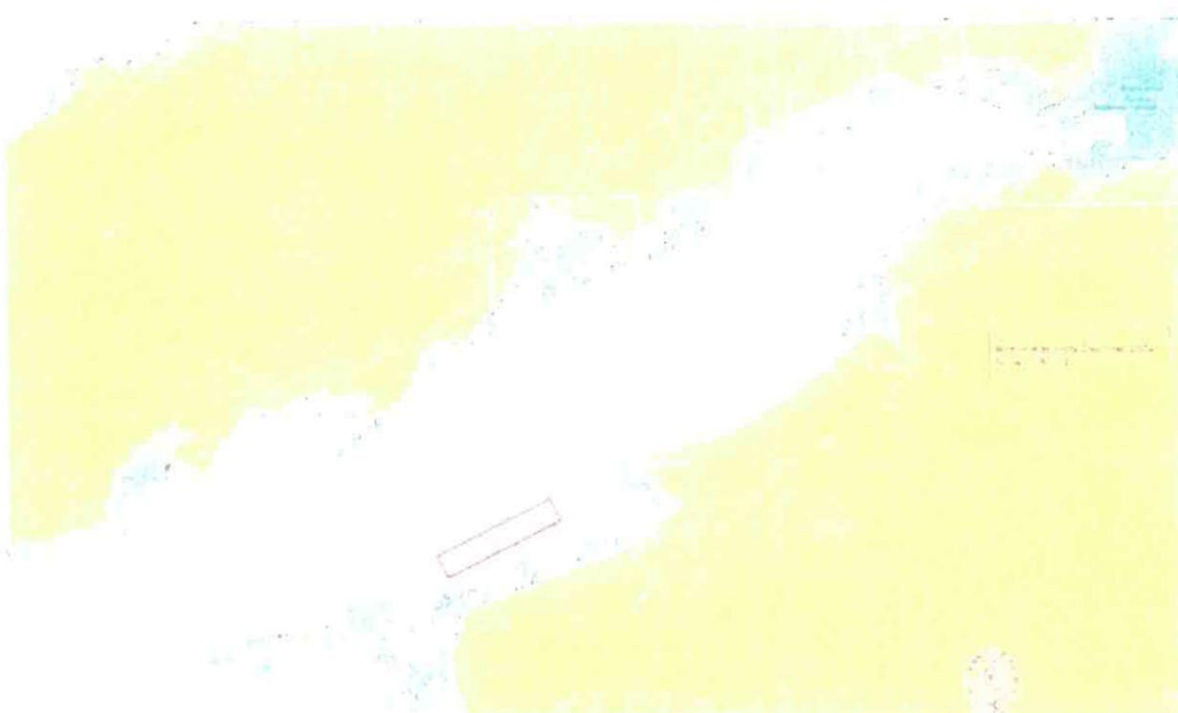
Site Name	Site Code	Designated Status	Principal Interest
Dunbeacon Shingle	002280	SAC	• Perennial vegetation of stony banks • Mediterranean salt meadows (Juncetalia maritimi) • European dry heaths • Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
Reen Point Shingle	002281	SAC	• Coastal lagoons • Perennial vegetation of stony banks • Mediterranean salt meadows (Juncetalia maritimi) • European dry heaths
Farranamanagh Lough	002189	SAC	• Coastal lagoons • Perennial vegetation of stony banks
Sheep's Head to Toe Head	004156	SPA	• Peregrine (*Falco peregrinus*) • Chough (*Pyrrhocorax pyrrhocorax*)

2.2 Description of the Project and Location

2.2.1 Project Location

The project involves the establishment of a mussel long-line farm along the southern shore of Dunmanus Bay (see Figure 2 which shows the location of the proposed mussel farm on the Admiralty Chart).

Figure 2. Aerial view showing proposed Mussel Farm location outlined in red. (Source: CMCE)



2.2.2 *Project Description*

Physical Infrastructure
The works will comprise the installation of 18 No. longlines, each of a length of 220m. Each longline will comprise 1 No. 220m long head rope (single head rope). Droppers will hang vertically from the longlines at approximately 800mm spacing. The droppers, upon which the mussels will grow, will be approximately 6m long with a 12mm diameter. Buoyancy to the longline system will be provided by 210Litre polyethylene barrels at spacing's of 3m to 4m.

Anchorage to the long lines will be provided by 40mm diameter polypropylene ropes connected to approximately 8m of chain that will in turn be connected to a 5 tonne concrete anchor. Damper weights and trawl balls will be provided to the anchorage system also.

To provide navigational warnings, 4 no. Floatex 1200PE Light Buoys will be installed in the four corners of the site. The proposed lamp standards will be subject to approval from the Commissioner of Irish Lights. These buoys will be anchored with 28mm anchor chains connected to a 5 tonne concrete anchor blocks on the sea bed.

All materials will be transported to the site from Durrus Pier, where the applicant currently operates from.

Construction Methodology
The site will be installed by the applicant using their existing plant and machinery. A crane will be used to drop 5 tonne concrete anchor blocks on the sea bed. The location of the blocks will be confirmed using GPS. Approximately 8m of chain and anchor ropes will be attached to the anchor blocks before deployment.

From a work barge, the anchor ropes will be tied to 1 headrope which will be 220m long. The headropes will then be connected to 210litre polyethylene barrels at 3m to 4m spacing.

The process will be repeated for all the other lines. It is estimated that the installation works will take approximately 1 month.

Operation Works
The operation works comprise of three distinct stages as follows.

Seed (Spat) Collection
Seeds will be collected via natural spat fall collection. Reusable Spanish spat collector rope will be suspended in late January and early February. This rope is reusable with a circa 25 year lifespan.

Thinning
When the mussels have grown to between 10mm and 13mm the collector rope is hauled into the harvesting vessel and the mussels are stripped from the rope. The rope is washed and stored for reuse the following season. The mussels are sorted through a grading machine and sorted into two sizes. The mussels are then placed on a grow rope (New Zealand) and a biodegradable cotton sock. The rope is hung at 800mm spacing with a 6/7 m drop. This process is repeated in the summer. After approximately, when the mussels have grown to market size they are harvested.

Harvesting
When the mussels have grown to market size, the rope is hauled into the harvesting vessel and mussels are removed from the rope and the rope is washed and stored for reuse. The mussels are washed and graded and bagged into 1 tonne bags. The bags are then placed onto pallets for onward transportation. The New Zealand rope also has a lifespan of circa 25 years.

2.2.3 *Description of the Existing Marine Environment*

To evaluate and classify the marine environment in the location and vicinity of the proposed mussel farm, a SCUBA survey was carried out by Dr Louise Scally and Paul Murphy on the 14th August 2013. Two separate transects were surveyed running from north to south across the study area at approximately one third intervals. The Biotope Classification assigned to the site is burrowing megafauna and *Maxmuelleria lankesteri* in circalittoral mud (SS.SMU.CFiMu.MegMax) based on Connor et al (2004) which define the biotope as follows:

"*In circalittoral stable mud distinctive populations of megafauna may be found. These typically include* Nephrops norvegicus, Calocaris macandreae *and* Callianassa subterranea. *Large mounds formed by the echiuran* Maxmuelleria lankesteri *are also frequent in this biotope. The seapen* Virgularia mirabilis *may occur occasionally in this biotope but not in the same abundance as SpnMeg to which MegMax is closely allied. Infaunal species may include* Nephtys hystricis, Chaetozone setosa, Amphiura chiajei *and* Abra alba."

The site location is relatively uniform in depth ranging from between approximately 27 to 30 meters (below chart datum). The substrate is undulating mud sediment with no sign of anoxia. The dominant organism is the Dublin Bay prawn *Nephrops norvegicus* with burrows recorded at densities of approximately 8/m² which all appeared to contain live individuals. Otherwise, the site is classified as a relatively species poor community. The nationally rare burrowing anemone *Pachycerianthus multiplicatus* was recorded within Dunmanus Bay in the 1990's (Nick Pfeiffer pers. com) though no evidence of this species was recorded during the current survey. Table 2 presents a list of species recorded and their relative abundance.

Table 2. Species recorded during SCUBA survey at Dunmanus Bay

Species	Abundance	Comment
Nephrops norvegicus	Abundant	Dominant organism
Cerianthus lloydi	Occasional	
Carcinus maenas	Rare	
Pecten maximus	Present	Single individual
Lanice conchilega	Rare	
Anemone viridis	Present	Possibly a drift specimen

The adjacent shoreline in the vicinity of the proposed mussel farm consists of exposed bedrock forming a low-lying shore with occasional skerries and outcropping islets. The site is moderately exposed though some shelter is provided by Carberry Island to the west. The intertidal zone consists primarily of barnacles, limpets, mussels and fucoid seaweeds and is classified as moderately exposed rocky shores (LR2) according to the Heritage Council classification (Fossitt, 2000).

2.2.4 *Description of the Existing Terrestrial Environment*

The adjacent land rises irregularly to the south and has extensive scrub-woodland cover in the eastern half consisting of a mixture of willow (*Salix spp.*), occasional oak (*Quercus robur*) with hawthorn (*Crataegus monogyna*), blackthorn (*Prunus spinosa*) and gorse (*Ulex europaeus*). Further west there are areas of siliceous dry and wet heath (*HH1/3*) with heather (*Calluna vulgaris*) and purple moor-grass (*Molinia caerulea*) on areas of shallow bedrock with patches of dense bracken (*Pteridium aquilinum*) (HD1) and patches of gorse scrub (WS1).

2.2.5 *Marine Mammals*

During the survey carried out in August 2013, a total of 9 harbour seals (*Phoca vitulina*) were hauled out on intertidal skerries to the south of the proposed site known as Carrigphillip and Mucklagh Rocks (see Figure 3). The most recent survey data available from NPWS indicates that a maximum of 34 harbour seals were recorded from Dunmanus Bay in 2009 with the main haulouts located at Carrigphilip and Mucklagh Rocks.

The nearest grey seal haulout to Dunmanus Bay is within Roaringwater Bay which has grey seal listed as one of its Conservation interests as a designated SAC (site code No. 000101). Grey seal would be expected to forage within Dunmanus Bay on a regular basis and a solitary male seal was present off Cold Island during the survey in August 2013. Both harbour and grey seal (*Halichoerus grypus*) are listed under Annex II of the EU Habitats Directive.

Otter (*Lutra lutra*) are reported as being widespread within Dunmanus Bay and there is evidence that Cold Island to the southwest of the proposed site is used as a holt location. The shoreline to the

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south of the proposed site is also well suited for both holt, couch and foraging usage. The site itself is in water too deep to support foraging by otter.

A variety of cetacean species have been recorded in Dunmanus Bay in recent years, with results compiled by the Irish Whale and Dolphin Group presented in Table 3 for the period 2007-2012 (Source, RPS Technical Advisors Report 761363).

Table 3. Cetacean activity recorded from Dunmanus Bay during the period 2007-12.

Date	Species	Number of individuals
June 2012	Common dolphin (Delphinus delphis)	25
August 2011	Whale species	2
August 2011	Medium whale species	1
July 2011	Minke whales (Balaenoptera acutorostrata)	2
August 2010	Minke whales (Balaenoptera acutorostrata)	1
June 2010	Whale species	1
May 2010	Minke whales (Balaenoptera acutorostrata)	1
September 2009	Whale species	1
March 2009	Whale species	1
September 2008	Common dolphin (Delphinus delphis)	100
September 2008	Minke whales (Balaenoptera acutorostrata)	3
September 2008	Minke whales (Balaenoptera acutorostrata)	2
June 2007	Bottlenose dolphin (Tursiops truncatus)	15
September 2007	Common dolphin (Delphinus delphis)	15

On the basis of the data recorded, it can be surmised that periodic occurrence of small to medium sized cetaceans occurs within Dunmanus Bay on an occasional basis primarily during the summer period. Unidentified whale species recorded are likely to be Minke whales, the most widespread of the baleen whales and the species most frequently encountered in inshore environments. The sporadic occurrence of cetaceans within the Bay suggests movements are likely to be primarily associated with movements in pursuit of fish prey. All cetacean species are afforded protection under Annex IV of the EU Habitats Directive.

Figure 3. Harbour seals hauled out on Mucklagh Rocks during site survey.

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2.2.6 Birds

A number of bird species listed under Annex I of the EU Birds Directive are reported from the Dunmanus Bay area including peregrine falcon *Falco peregrinus*, chough (*Pyrrhocorax pyrrhocorax*) and various tern species including Arctic tern (*Sterna paradisea*). The habitats in the vicinity of the proposed mussel farm are unsuited for nesting by peregrine falcon and chough, though the skerries of Carrigphilip and Mucklagh Rocks may be suited for nesting by Arctic tern. Cormorants (*Phalacrocorax phalacrocorax*) were observed using Carrigphilip and Mucklagh Rocks as a temporary roost site during the site survey while further offshore within the open part of the bay Manx shearwaters (*Puffinus puffinus*) were observed in flight along with smaller numbers of gannets (*Morus bassanus*). Both species are confined to offshore islands for breeding.

2.3 Identification of potential impacts

Only those development features that have the potential to impact on features and conservation objectives of the identified Natura sites are considered. A number of factors were examined at this stage and dismissed or carried forward for appropriate assessment as relevant. The following areas were examined in relation to potential impacts from the proposed development on the Natura 2000 network in the area and are dealt with in detail below.

- Direct and indirect loss of habitats
- Disturbance to habitats
- Disturbance to species
- Water Quality
- Air Quality
- Hydrological changes

A summary of the potential impacts on the Natura 2000 network is presented in Tables 1 to 3.

Table 1. Likely direct, indirect or secondary impacts of the project (either alone or in combination with other plans or projects) on Natura 2000 sites within 10km radius of the site.

Size and scale	The proposed works involve the installation of 18No. Mussel longlines each of a length of 220m with associated anchors and navigational lighting.
Land-take	The works involve the establishment of a floating network of longlines with anchors to the seabed. Existing harbour infrastructure will be utilised for onshore works.
Distance from Natura 2000 sites	The proposed mussel farm is approximately 2km from the nearest designated sites (Reen Point Shingle SAC and Farranamanagh Lough SAC).
Resource requirements (water abstraction, etc.)	The proposed mussel farm will utilise naturally occurring spat-fall with mussels grown to harvestable size over a period of approximately 2 years within longlines. No artificial feeds or other substances will be used in their production. Periodic thinning and final harvesting will take place from a dedicated work vessel operating from the existing pier at Durrus.
Emissions (disposal to land, water or air)	While the mussels feed on naturally occurring food reserves of plankton within the water column, the artificially high concentration of mussels will give rise to increasing loads of pseudofaeces produced by the mussels as they grow to maturity.
Excavation requirements	There are no excavation requirements associated with the development though anchoring of the longline installation and associated navigational lighting will require anchors and chain to moor in position.
Transportation requirements	All works will be carried out from MFV Muireann, a 15m long fishing vessel retro-fitted to accommodate mussel harvesting plant.
Duration of construction, operation, decommissioning, etc.	The entire installation works are expected to be completed within a period of 1 month.

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Reduction of habitat area	There reduction in habitat as a result of the footprint of the mussel farm is considered not significant as it is suspended within the water column with only a small number of anchors on the seabed.

Table 2. Description of likely changes to any Natura 2000 sites within a 10km radius of the site arising as a result of disturbance, fragmentation, etc.

Disturbance to key species	A harbour seal haulout is located at Carrigphillip and Mucklagh Rocks along the southern shoreline of Dunmanus Bay in the vicinity of the proposed Mussel farm. The distance to the mussel farm is approximately 200m at its nearest point. Harbour seals would be expected to habituate to ongoing activities at the mussel farm though may potentially be subject to an initial disturbance phase. Otter activity is unlikely to be affected in any way by the proposed development. Cetacean activity which is sporadic within the Bay is also unlikely to be affected in any way by the proposed farm.
Habitat or species fragmentation	The proposed works will not result in any habitat or species fragmentation effects.
Reduction in species density	The works will not result in any significant reduction in species density.
Changes in key indicators of conservation value (water quality etc.)	The works will not result in any changes to key indicators of conservation value.
Climate change	The works will not give rise to any potential for effects on climate.

Table 3. Description of likely impacts on the Natura 2000 site within a 10km radius of the site as a whole in terms of structure and functions.

Key relationships that define the structure of the sites	The proposed works will not result in any significant impacts on the Natura 2000 network.
Key relationships that define the function of the site	The proposed works will not result in any significant alteration of the functioning of the Natura 2000 network.

2.3.1 *Direct and indirect loss of habitats*

There will be no direct or indirect loss of habitat within the Natura 2000 network as a result of the proposed mussel farm development. The proposed development is sufficiently far removed from any Natura site to avoid any affect in terms of fragmentation.

2.3.2 *Disturbance to habitats*

There is no risk of causing disturbance to habitats within the designated area network during the construction or operation works associated with the mussel farm. The passage of boats to and from the mussel farm from the existing pier at Durrus will not result in any disturbance to habitats in any of the surrounding Natura 2000 sites.

2.3.3 *Disturbance to Marine Mammals*

There is likely to be considerable otter activity in the vicinity of the proposed mussel farm though such activity will be primarily the shallower coastal stretch. Cold Island which is located a short distance (c700m southwest of the proposed farm location) is reported to be regularly used by otter and is likely to contain a holt site. However, the mussel farm is unlikely to result in any disturbance to otters or in any way alter food resources for these Annex II listed species.

A harbour seal haulout occurs on the Carrigphillip and Mucklagh Rocks along the southern shoreline of Dunmanus Bay in the vicinity of the proposed Mussel farm, with up to 34 seals recorded at the location in 2009 by the NPWS. Harbour seals are afforded protection under Annex-II of the EU Habitats Directive. The activities on the farm during the establishment phase are likely to cause some level of disturbance to the seals at the haulout though it is anticipated that the animals will quickly become habituated to the activity on the farm site. Evidence of hauled out harbour seals

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tolerating close human activity exists from numerous locations around the country including within the Kenmare River SAC which has up to 12? Harbour seals recorded.

There are occasional records of a variety of small and medium sized cetaceans from Dunmanus Bay, the majority of which occur over the summer months. There is no regular utilization of the waters in the vicinity of the proposed mussel farm and no impacts are anticipated on any cetacean species as a result of the proposed developments. The infrastructure associated with the mussel farm does not pose a threat of entanglement to any cetaceans.

Given the above, no impacts are anticipated on any marine mammal species from the proposed works.

2.3.4 *Water Quality*

The Biotope Classification assigned to the subtidal element of the proposed mussel farm site is burrowing megafauna and *Maxmuelleria lankesteri* in circalittoral mud (SS.SMU.CFiMu.MegMax). Water depths in the site are in the region of 27 to 30m and the site is classified as moderately exposed. While the farmed mussels will feed on naturally occurring food reserves of plankton within the water column, the artificially high concentration of mussels will give rise to increasing loads of pseudofaeces produced by the mussels as they grow to maturity. This will settle out to some extent on the sea bed though due to the depth of water in combination with tidal movements and wind and wave action, the area of deposition is likely to be greater than the footprint of the proposed mussel farm. The existing community of Nephrops norvegicus is likely to feed to some extent on this food reserve though other species may become more widespread including crabs (*Carcinus maenas* and *Necora puber*). The proposed mussel farm may over time give rise to an alteration of the benthic fauna community within the vicinity.

2.3.5 *Hydrological changes*

There will be no hydrological changes to the area or to any Natura 2000 site as a result of the proposed mussel farm. The structures associated with the operation are primarily floating (with the exception of the anchors) and will not impede or alter flow regimes in any way.

2.4 Conclusion

It can be concluded that there will be no significant impact arising from the proposed mussel farm on the Natura 2000 network.

The harbour seal haulout on the adjacent Carrigphilip and Mucklagh Rocks may suffer temporary disturbance during the initial site set up phase of the mussel farm, though it is anticipated that the seals will rapidly habituate to the activity associated with the farm and continue to utilise the location based on their tolerance to activities at other locations around the country. No impacts are anticipated on any other marine mammal species from the proposed mussel farm including otter and cetaceans.

There will be no impact on birds from the proposed mussel farm.

There is no risk of impacting on water quality within any Natura 2000 site as they are sufficiently distant from the proposed mussel farm location (>2km). Localised build up of pseudofaeces may occur with a resultant localised change in the benthic biotic community though this will not affect any designated conservation areas.

There will be no hydrological changes to the area or to any Natura 2000 site as a result of the proposed mussel farm.

While it can be concluded that there will be no significant impact on any Natura 2000 sites, in deference to the requirement to avoid risks of pollution or unnecessary disturbance within the marine environment, a suite of best practice operating procedures will be adopted during the establishment and operation of the facility.

3. REFERENCES

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Appendix B

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Dunmanus Mussels Ltd

Aquaculture Licence Application

Bathymetric and Current Modelling Data

Date	19th October 2012
Job No	C136
Client	Dunmanus Bay Mussels Ltd
Surveyed by	Hydrographic Surveys Ltd

Cronin Millar

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Project PH 12032
Location Mussel Farm Development Aquaculture Application
Client Gunnamus Bay Mussels
CM01
Date 19th Oct 2012

Location	Wind Sp/Dirn	Time	Tidal State	Depth 1 (1m BWL)		Depth 2 5m BWL		Depth 3 10m BWL		Depth 4 (15m BWL)		Depth 5 20m BWL		Depth 6 25m BWL or 1m above bed	
				Current Sp	Dirn	Current Sp	Dirn	Current Sp	Dirn	Current Sp	Dirn	Current Sp	Dirn	Current Sp	Dirn
	Km/hr *Note 1	(BST)		(m/sec)	deg m	(m/sec)	deg m	(m/sec)	deg m	(m/sec)	deg m	(m/sec)	deg m	(m/sec)	deg m
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Current Meter Locations (ING)

	Easting	Northing
CM01	[illegible]	[illegible]
CM02	[illegible]	[illegible]

HW	07 54 00
LW	14 01 00

[illegible]

Note 1 [illegible]
Note 2 [illegible]

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Project PH 12032
Location Mussel Farm Development Aquaculture Application
Client: Dunmanus Bay Mussels
CM 02
Date: 19th Oct 2012

Location	Wind Sp/dirn	Time	Tidal State	Depth 1 (1m BWL)		Depth 2 5m BWL		Depth 3 10m BWL		Depth 4 (15m BWL)		Depth 5 20m BWL		Depth 6 25m BWL or 1m above bed	
	km/hr *Note 1	(BST)		Current Sp (m/sec)	Dirn deg m	Current Sp (m/sec)	Dirn deg m	Current Sp (m/sec)	Dirn deg m	Current Sp (m/sec)	Dirn deg m	Current Sp (m/sec)	Dirn deg m	Current Sp (m/sec)	Dirn deg m *Note 2
CM2		07:47	HW 07:54 HW	0.23	11	0.17	20	0.18	43	0.159	48.7	0.167	48.5	0.177	44.9
CM2		08:41	HW 07:54 HW+1	0.21	46	0.16	4	0.21	14	0.277	27.6	0.285	40.4	0.25	30
CM2	10 km/hr NE	09:53	HW 07:54 HW+2	0.26	32	0.33	24	0.27	3	0.303	22.9	0.282	29.7	0.291	35.5
CM2		11:06	HW 07:54 HW+3	0.26	55	0.19	13	0.13	25	0.098	0	0.119	2.2	0.162	9.4
CM2	7 km/hr E	12:05	HW 07:54 HW+4	0.25	54	0.40	37	0.35	21	0.396	16.5	0.352	17.6	0.393	20.5
CM2	7 km/hr NE	13:20	HW 07:54 HW+5	0.05	137	0.19	57	0.21	55	0.109	37.8	0.137	29	0.127	88.1
CM2	No notable wind	14:11	LW 14:03 LW	0.07	249	0.08	113	0.06	120	0.083	18.1	0.057	350.7	0.027	324.2
CM2	No notable wind	15:01	LW 14:03 HW-5	0.07	273	0.25	96	0.23	93	0.227	153.7	0.145	91.3	0.133	20
CM2	No notable wind	15:51	LW 14:03 HW-4	0.07	303	0.09	157	0.10	116	0.1	87.9	0.087	87.2	0.147	88.6
CM2		17:00	LW 14:03 HW-3	0.02	108	0.04	6	0.26	195	0.11	252.7	0.045	68.2	0.059	156.2
CM2	5 km/hr NW	18:10	LW 14:03 HW-2	0.16	225	0.20	233	0.26	233	0.260	232.6	0.193	230.5	0.197	229

Current Meter Locations (ING)

	Easting	Northing
CM01	65787	36432
CM02	85795	36850

HW	07:54:00	High Water and Low Water Tides taken from tide gauge readings located at Dunmanus Pier on 19th Oct 2012
LW	14:03:00	

Note 1 Wind direction is reported by the direction from which it originates
Note 2 Current direction is reported in degrees magnetic and refers to the direction in which the current is flowing

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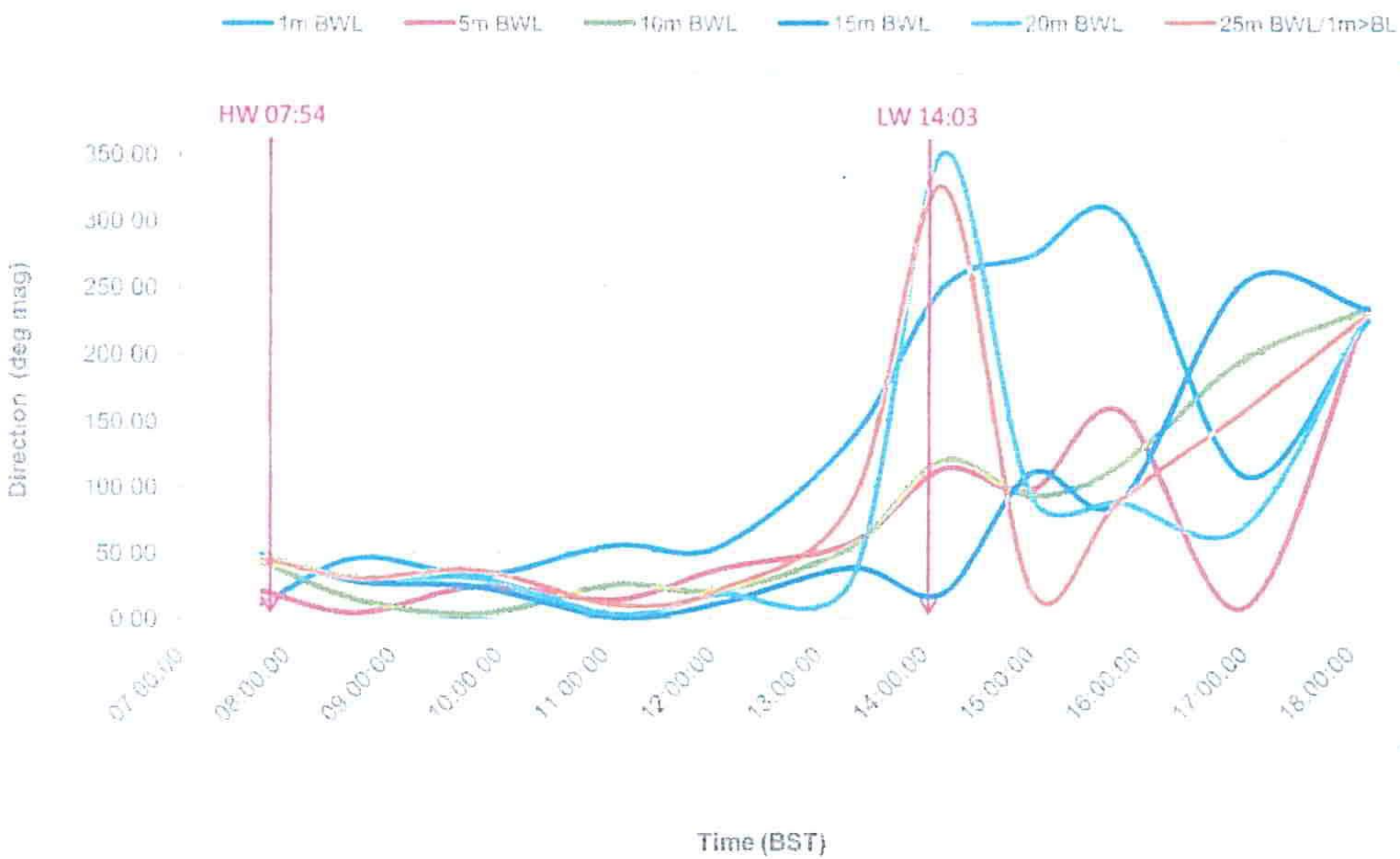
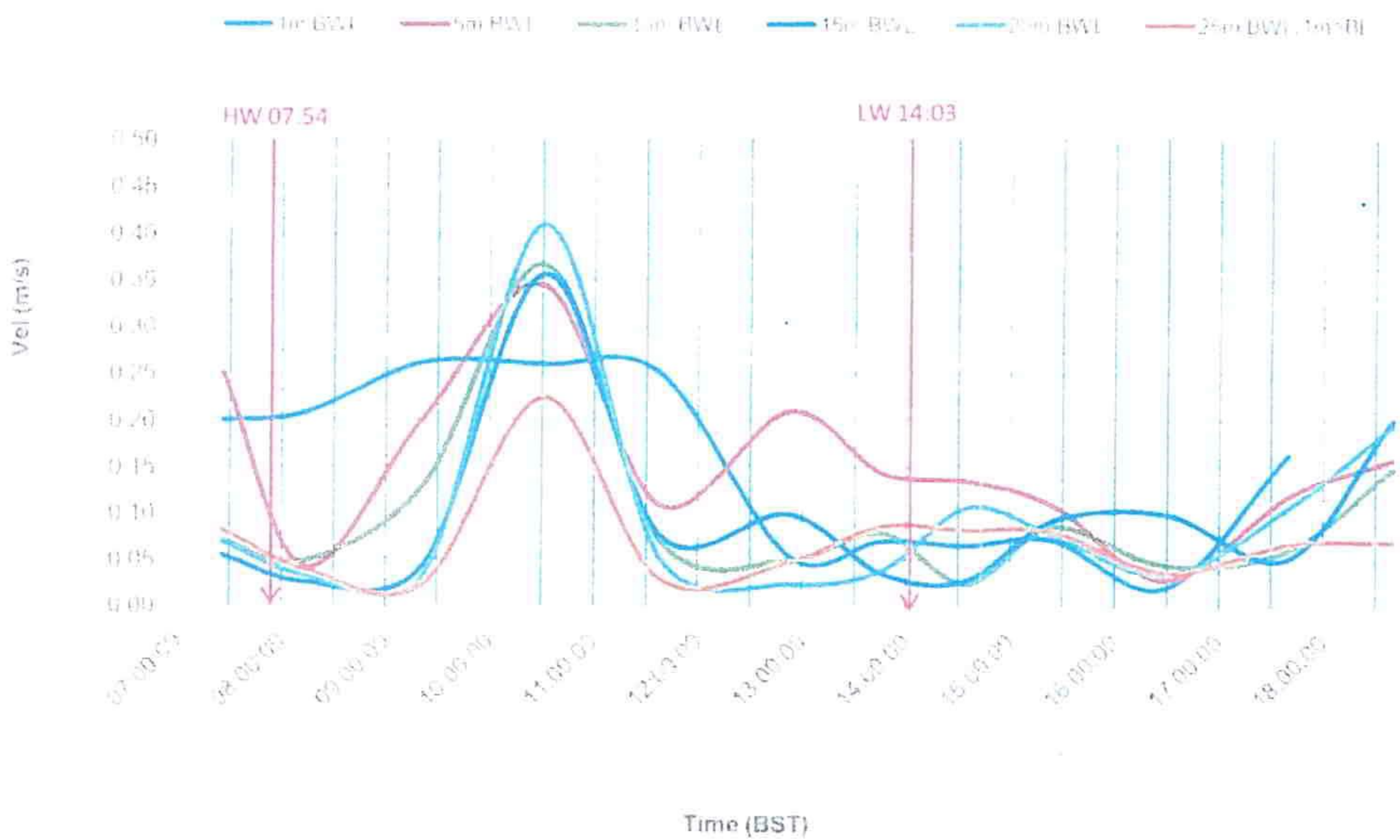
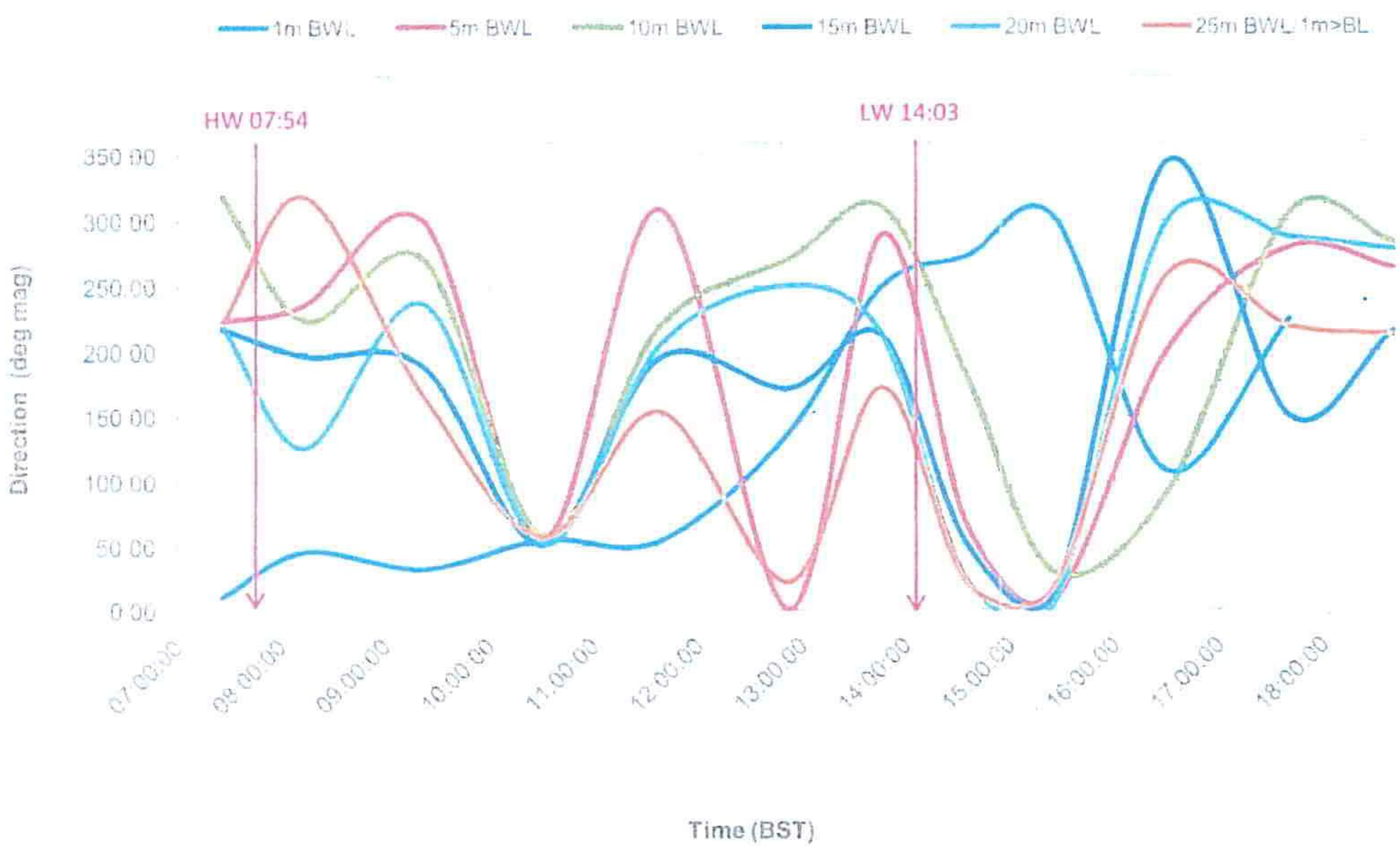
Current Direction Observations
CM 02 19th Oct 2012



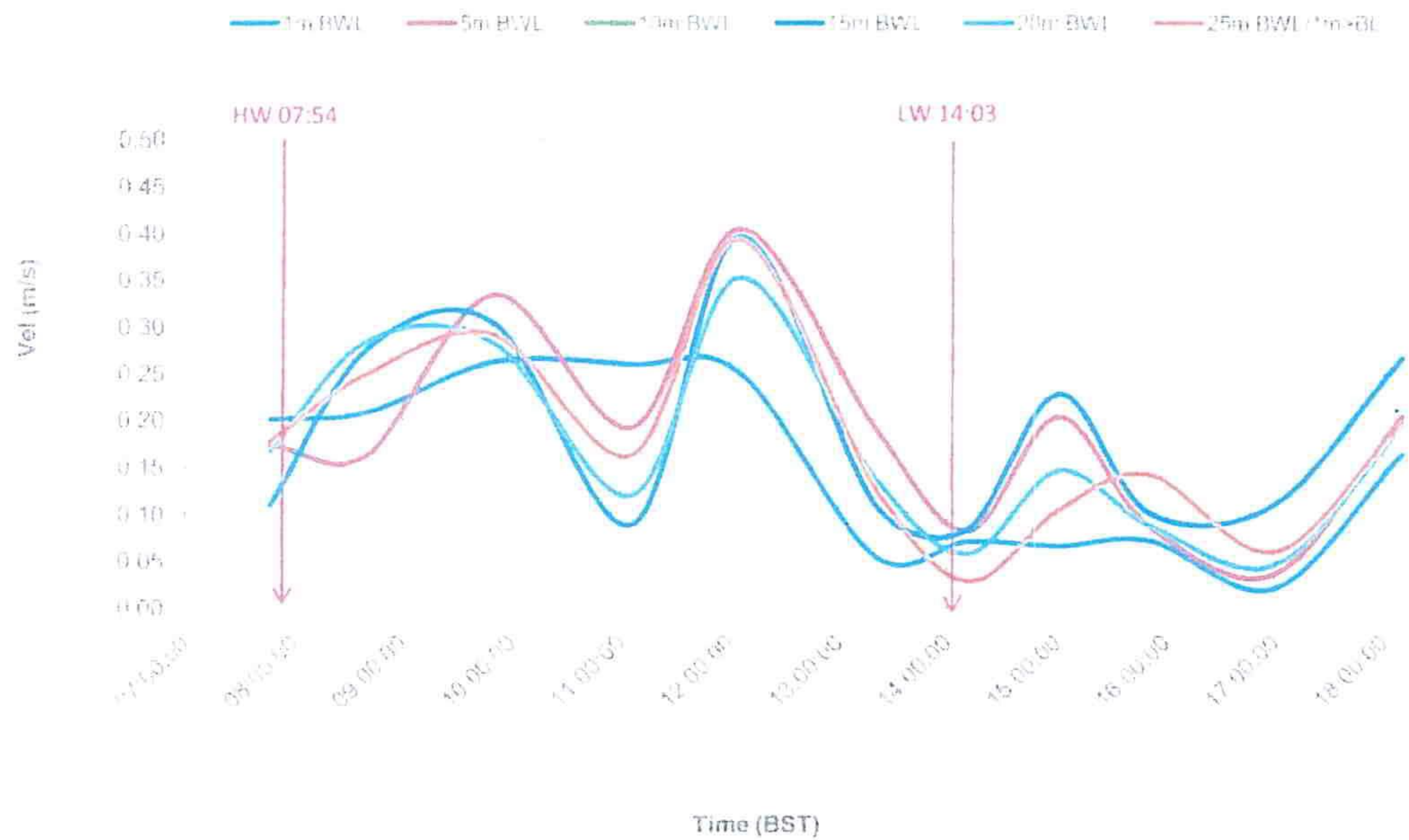
Velocity Observations
CM 01 19th Oct 2012



Current Direction Observations
CM 01 19th Oct 2012



Velocity Observations
CM 02 19th Oct 2012



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