

ECASA Study Site Report

Site name: Vidlin

Country: Scotland

ECASA Partners: SAMS

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List of abbreviations and acronyms

ADCP	Acoustic Doppler Current Profiler
CHN	Carbon Hydrogen Nitrogen
EAP	Envelop of Acceptable Precision
ECASA	Ecosystem Approach for Sustainable Aquaculture
EU	European Union
GPS	Geographical Positioning System
ITI	Infaunal Trophic Index
LOI	Loss on Ignition
OM	Organic Matter
PSA	Particle Size Analysis
SAC	Special Area of Conservation
SAMS	Scottish Association for Marine Science
SEPA	Scottish Environmental Protection Agency
SOTEAG	Shetland Oil Terminal Environmental Advisory Group
SSMEI	Scottish Sustainable Marine Environment Initiative
SSSI	Site of Special Scientific Interest
ZCC	Zetland Country Council

Non- Technical Summary of the ECASA Environmental Impact Assessment and Study Site Report on the Impacts Relating to the Farming Activities of Johnsons Sustainable Seafoods in Vidlin Voe, Shetland.

1. Johnson's Sustainable Seafoods began cod farming at the site in Vidlin Voe, Shetland in 2003. The farm is the largest cod farm in Europe and is run according to the principles of organic farming. Cod is the only species farmed in the Voe. The farm consists of 15 cages, 32 m in diameter, 15 m deep. The cages are spaced 5 m apart in a rectangular layout running southwest to northeast.
2. Vidlin Voe is 3 km long, has a maximum depth of 40 m and runs southwest to northeast. Conditions are extremely exposed at the mouth of the Voe but the location of the cages is sheltered. The tidal range is a moderate 1.8 m.
3. The cages are located in depths ranging from 16 m to 30 m, over a substrate of muddy sand.
4. The farm has been subject to three benthic surveys, in 2004, 2005 and again in 2006. The 2005 survey was carried out by personnel from the Scottish Association for Marine Science, the second by personnel from the Scottish Association for Marine Science and personnel from the University of Kiel.
5. Seven sampling stations were used running in two transects; northeast and southwest. Stations were located at the cage edge, 1 m, 2 m, 25 m and 50 m distant from the cages.
6. Sediment sampling was via a 0.1m² van Veen grab. Redox measurements were taken and macro-fauna were collected via a 1 mm sieve. Sediments were analysed for LOI, PSA and CHN.
7. Examination of the taxa present in the benthic surveys suggests that the northern transect is wave dominated, sand/gravel biotope subjected to strong water movement and not especially enriched with organic matter. However the abundance of *Capitella* sp. would indicate that the benthic community is undergoing change.
8. Examination of taxa from the southern transect showed classic evidence of enrichment.
9. Surficial CHN levels were very low and uniform along both transects.
10. There was no strong gradient of organic matter content of sediment, as determined by LOI, along the transects, away from the source of enrichment (the cage group).
11. Two models were used to predict benthic faunal impacts at the site; DEPOMOD and CODMOD. CODMOD was used to predict the flux and benthic impact for three different periods; May 2004, August 2005 and July 2006, to coincide with the times of the surveys. The predictions were then

compared with the observed ITI. Feed input data was provided by the farmer for the time of the surveys.

12. CODMOD predicted the impact at the stations adequately for 2004 and 2005, but it underperformed for 2006, under-predicting the impacts in the stations to the southern end of the transect.
13. It is difficult for models to accommodate cage rotation which was occurring at the southern end of the farm site. Rotation creates cage shadowing and causes a reduction in current speed. Sensitivity of the model to reduced currents was tested.
14. When cage rotation effects and reduced current were modelled, values for predicted and observed ITI improved. This sensitivity analysis demonstrates the importance of cage rotation and representative hydrographic data in both modelling and locating sampling station transects.

1 Introduction to the aquaculture operation

1.1 Introductory background statement

The developer is Johnson Sustainable Seafoods Ltd. The farm (Vidlin North/Vidlin Outer) is Europe's largest cod farm, and the only organic one. Johnson Sustainable Seafoods Ltd (as Johnson Brothers) started farming salmon in the mid 1980s, but in 2003 began farming cod at the Vidlin site. A management buyout took place in 2005, and haddock, trout and mussels are now grown by the company (but not in Vidlin Voe, where only cod are farmed).

This survey was carried out by researchers from the Scottish Association for Marine Science, (SAMS) and the University of Kiel, Germany, (IFM-GEOMAR). The first survey was during the period 2-3/08/2005 and the second during 25-26/07/2006. Neil Duncan (Facilities Manager) has been the major source of information, both when conducting site visits and when phoning/emailing for information. Methods used in the survey can be found in the ECASA Book of Protocols www.ecasa.org.uk.

1.2 Summary statement of key site specific environmental issues

Aquaculture has been practiced in Vidlin Voe for over 20 years at the time of writing. The fish farm in the voe is one of many aquaculture activities in the area. Although the fishing industry is of major importance to Shetland, there is only a small local fishery in the area. The fish farm is economically important for the local economy, which is primarily agricultural/rural crofting land.

The Vidlin Voe site is close to Yell Sound Coast Special Area of Conservation (SAC). Sea otters and common seals are an important constituent of the SAC. A major oil pipeline comes on to the mainland at Lunna.

The voe is open, with no definable sill or basins *sensu*, Edwards and Sharples, (1986). Flushing time is calculated at 5 days.

Bathymetry at the site varies from 16-17 m in the south to ca 30 at the northern edge of the cage group. The substrate is a muddy sand, becoming more coarse towards the mouth of the voe. To the northeast of the cage group is a wave dominated, sand/gravel biotope subjected to strong water movement and not especially enriched. However, the presence of the opportunistic polychaete *Capitella* sp. as the second most numerically dominant species at the northeastern cage edge would indicate that this community was also undergoing a change in conditions. The sediments to the southwest of the cage group (towards the head of the voe) show classic evidence of enrichment in the dominance of its taxa by Nematoda spp., *Capitella* sp. and *Malacoceros fuliginosus*, although surficial CHN and organic matter levels show, contrary to expectations, no strong gradient of organic matter away from the source of enrichment.

The Marine Nature Conservation Review showed a dense area of seapens, which is a Biodiversity Action Plan habitat (which is uncommon in Shetland) in the mouth of the voe. Vidlin Voe and the surrounding area is important for otters, with a significant year-round population. Cetaceans (mostly harbour porpoises) are regularly recorded. Seals are also present year-round and while they do not have sensitive haul-outs in the immediate area, haul out on the skerries off Lunna Ness and Lunna Holm and at the

Skerry of Lunning. There are significant numbers of eider ducks *Somateria mollissima* (a distinct Shetland population that is in decline) and shags *Phalacrocorax aristotelis* in the area. Herring gulls *Larus argentatus* are the most common avian predators at this site, and special high visibility, small mesh netting is used to deter them.

Seabirds such as gannets *Morus bassanus*, common guillemots *Uria aalge*, razorbills *Alca torda*, kittiwakes *Rissa tridactyla* and puffins *Fratercula arctica* are all common. Migrants e.g. pied wagtails *Motacilla alba*, waxwings *Bombycilla garrulus*, redwings *Turdus iliacus* and greylag geese *Anser anser* frequent the area in autumn and spring. The song thrush *Turdus philomelos*, a Red List species, is common locally.

The current aquaculture activities at Vidlin Voe are not considered to impact on the resident or migratory bird populations.

1.3 Information of farmer's environmental strategy:

Johnson Sustainable Seafoods Ltd has an Environmental Policy, which is attached in Appendix 1. The company has to comply with the environmental policies demanded by the Organic Food Federation, to remain in compliance with its organic status¹, and the company also follows the Code of Good Practice for Scottish Finfish Aquaculture, produced by the Scottish Salmon Producers' Organisation².

1.4 Overview of Regulatory Controls, consents and monitoring requirements.

The Aquaculture industry in the UK is primarily located in Scotland, along the West Coast and in Orkney and Shetland. Scotland produces 90 % of the UK finfish market.

In the UK, EC Directive 85/337 (the EIA Directive) is implemented through over 40 different secondary regulations, in response to this Scotland (which has a separate legal system from the rest of the UK) developed three acts:

Part II of the Environmental Assessment (Scotland) Regulations 1988 (Statutory Instrument (SI) 1221)

Town and Country Planning (General Development Procedure) (Scotland) Order 1992 (SI 224)

Environment Assessment (Scotland) Amendment Regulations 1994 (SI 20212)

In respect to salmon farming the regulations were reviewed in 1999 pending the transfer of responsibility for authorisation of marine aquaculture from the Crown Estate to local authorities in 2006. This review resulted in the implementation of the main legislative act now applying to marine fish farming:

Statutory Instrument No. 367: The Environmental Impact Assessment (Fish Farming in Marine Waters) Regulations 1999.

¹ <http://www.orgfoodfed.com/OFF%20Standards.htm>

² <http://www.scottishsalmon.co.uk/dlDocs/CoGp.pdf>

The main actors with responsibility for regulating salmon farming in Scotland are outlined in Box 2.2.1:

Box 2.2.1. Key Regulatory Bodies of Scottish Aquaculture (Berry and Davison, 2001).

The Crown Estate - the owner of the sea bed and currently regulates the aquaculture industry through the issuing of sea bed leases. EIA is a requirement of the lease under Environmental Impact Assessment (Fish farming in marine waters) Regulations 1999.

Scottish Environment Protection Agency, (SEPA) - a government agency responsible for safeguarding the cleanliness of Scotland's tidal waters and protecting aquatic fauna and flora. SEPA regulates the aquaculture industry through the issuing of discharge consents under the Water Environment (Controlled Activities) (Scotland) Regulations (2005).

Scottish Natural Heritage (SNH) - responsible for conserving the Scottish environment and it is consulted on the environmental impacts of aquaculture by the Crown Estate on EIA and SEPA on discharge consents.

Local Authorities - advises Crown Estate on lease conditions – has replaced the Crown Estate as the statutory planning authority for aquaculture.

Scottish Executive Environment and Rural Affairs Department (SEERAD) - has responsibility for the protection of fish, fisheries and the wider marine environment. All fish farms must register with it for the control of fish diseases

The 1999 regulations specify criteria which determine whether a proposed new aquaculture development or modification to an existing development requires an EIA. These are:

- All proposals in 'sensitive areas' as defined in the regulations
- All new proposals with a designed biomass ≥ 100 tonnes or cage surface area $\geq 1000\text{m}^2$
- Any modifications with a designed biomass ≥ 100 tonnes or cage surface area $\geq 1000\text{m}^2$

The new legislation¹ (Environmental Assessment [Scotland] 2005 Act), regarding EIA came into force in Scotland in February 2006. This Act transfers authority to Scottish local authorities who now have the responsibility for formally determining whether an EIA is required which previously rested with the Crown Estate. In the Scottish Islands of Shetland and Orkney, local councils have been awarded that authority since 1974, under the Zetland County Council Act (1974).

A review of current practice and decision making process that applies to salmon farming is currently underway².

Salmon farming is regulated and monitored through a dual licensing system, based on a policy of self-monitoring with audits. All farms must apply for a lease to develop

¹ <http://www.opsi.gov.uk/legislation/scotland/acts2005/20050015.htm>

² <http://www.sarf.org.uk/SARF024.htm>

operations on the sea bed to the Crown Estate, and apply to SEPA for 'Consent to Discharge'. Basically the Crown Estate regulates the logistics and infrastructure of the farm, e.g. moorings, navigational interests, and SEPA regulate and monitor the benthic and water column environmental impacts of the farms activities. In Orkney and Shetland an additional licence is required. Salmon farms must also apply for a Marine Works Licence from the Islands Council, and applications may require an EIA. The Island Councils assume the responsibility of the Crown Estate in relation to granting these licences and sea bed leases.

The SEPA 'Consent to Discharge' sets conditions and restrictions on the salmon farm to achieve a balance between site productivity and environmental impact. The main legislative instrument, the Control of Pollution Act (1974), upon which 'Consents' were set was replaced by the Water Environment (Controlled Activities) (Scotland) Regulations 2005 on 1 April 2006. These regulations, referred to as the 'CAR' regulations, contain a pre-application discussion process between the farmer and SEPA which establishes the information that will be required to be included in an Environmental Statement (ES)¹. 'Consent' conditions are drawn up on a site by site basis and include cage position and quantity, species farmed and biomass limits based on the carrying capacity of the receiving environment. 'Consent(s) to discharge' are time limited and usually remain in place for a minimum of four years.

The main legislative instrument relating to salmon farming has been reviewed and this has led to the Aquaculture and Fisheries (Scotland) Bill (2006) being approved. On its implementation this Bill will make sea lice management and monitoring a statutory process, and address the environmental impact of escaped fish².

There is no formal zoning system for fish farming in Scotland but the government has produced Locational Guidelines³ that delineate coastal areas⁴ according to their suitability for development on the basis of nutrient modelling and sensitive habitat assessment:

Category 1 where the development of new or the expansion of existing marine fish farms will only be acceptable in exceptional circumstances. These are only likely to arise where it can be demonstrated conclusively, by the applicant, that the development will not have a significant adverse effect on the environmental qualities of the area.

Category 2 where the prospects for further substantial developments are likely to be limited although there may be potential for modifications of existing operations or limited expansion of existing sites particularly where proposals will result in an overall reduction in environmental effect, so enhancing the qualities of the area and hydrological conditions.

Category 3 where there appear to be better prospects of satisfying environmental requirements, although the detailed circumstances will always need to be examined carefully.

For each category the EIA approach is the same.

¹ http://www.sepa.org.uk/pdf/wfd/regimes/car_practical_guide.pdf

² <http://www.scottish.parliament.uk/business/bills/67aquaFish/index.htm>

³ <http://govdocs.aquake.org/cgi/reprint/2004/524/5240210.pdf>

⁴ http://www.marlab.ac.uk/Delivery/Information_Resources/information_resources_view_document.aspx?contentid=1416

Voluntary systems

The recently published Code of Good Practice for Scottish Aquaculture¹ is the main self-regulatory instrument and contains monitoring practices for sea lice control, and environmental monitoring policies. The large majority of farms in Scotland are signatories to this code, which includes annual, independently accredited audits.

2 Site specific regulatory and management background

2.1 The regulatory status of proposed location with respect to fish farming developments.

The site is Category 1 under Location Guidelines For Authorisation Of Marine Fish Farms In Scottish Waters (Anon., 2004a). The site has no designations under EU directives.

The closest designated areas are Yell Sound Coast SAC (otters and common seals), Yell Sound Coast Site of Special Scientific Interest (SSSI) (which includes the western coast of Lunna), the area around Lunna House which is classified under ‘Gardens and Designated Landscapes’ and is also a Local Protection Area, selected to protect important local landscapes; the area around Vidlin Harbour has been put forward as a potential Conservation Area (built heritage), although the Local Council is currently reviewing this. The surrounding land is covered by ESA or the equivalent.

A local Marine Framework is being developed as part of the SSMEI² pilot project. As with rest of Shetland the area is covered by various policies relating to the ZZC (1974) Act, in particular policies relating to aquaculture. Johnson Sustainable Seafoods and the rest of the aquaculture industry have been looking at strategic spatial plans for aquaculture.

¹ <http://www.scottishsalmon.co.uk/aboutus/codes.asp>

² <http://www.scottish-marine-sustainability.co.uk>

2.2 Site description

There is open coastline leading to the entrance of Vidlin Voe, which has a maximum depth of 40 m. At 3.0 km long, the voe trends southwest to northeast and, while extremely exposed at the mouth near Lunna Ness, the voe becomes very sheltered at the head. A narrow sand/shingle bar at the head separates a freshwater lochan from the voe. Tidal range is a moderate 1.8 m, and there are considered to be no basins or sills in the voe (Edwards & Sharples, 1986).

The seabed surrounding the cod farm in Vidlin Voe is muddy sand, while the sediment towards the mouth of the voe becomes more gravelly and shelly. The substrate in the outer voe has the characteristics of wave dominated, current swept conditions, while the inner voe is more typical of sheltered conditions.

In her report on the sublittoral fauna of Shetland, Foula and Fair Isle, Howson (1988) placed Vidlin Voe into two separate habitats on the basis of two sample stations. The following is taken from her report:

“Habitat 35. Coarse muddy shell gravel at the entrance to Vidlin Voe moderately exposed to wave action. Site 154. This shell gravel slope was surveyed from 18 to 33 m; bedrock shallower than 18 m was not inspected, and the sediment continued deeper than 33 m. The site is treated alone because the community recorded was not found elsewhere during the diving surveys, although its individual elements have certainly been recorded either by diving or the remote sampling of other workers. A dense bed of *Virgularia mirabilis* covers the shallower parts of the slope, with scattered *Pennatula phosphorea* and *Peachia cylindrica*. With increasing depth, the *V. mirabilis* thins and *P. phosphorea* becomes more numerous. *Pecten maximus* and *Ophiura albida* are Common, *Astropecten irregularis* Occasional and *Aequipecten opercularis* and *Atelecyclus rotundatus* both Rare. Scattered shell debris is colonised by *Clavelina lepadiformis*, *Corella parallelogramma* and *Asciidiella aspersa*. This is considered to be a potential site for *Funiculina quadrangularis* or large cerianthid anemones, both of which often occur in deeper water associated with *P. phosphorea* and *V. mirabilis*. Time, however, limited the depth of survey.”

Figure 1, (Fig. 7 in Howson, 1988) shows the location of the two Vidlin survey sites, Sites 154 and 156.

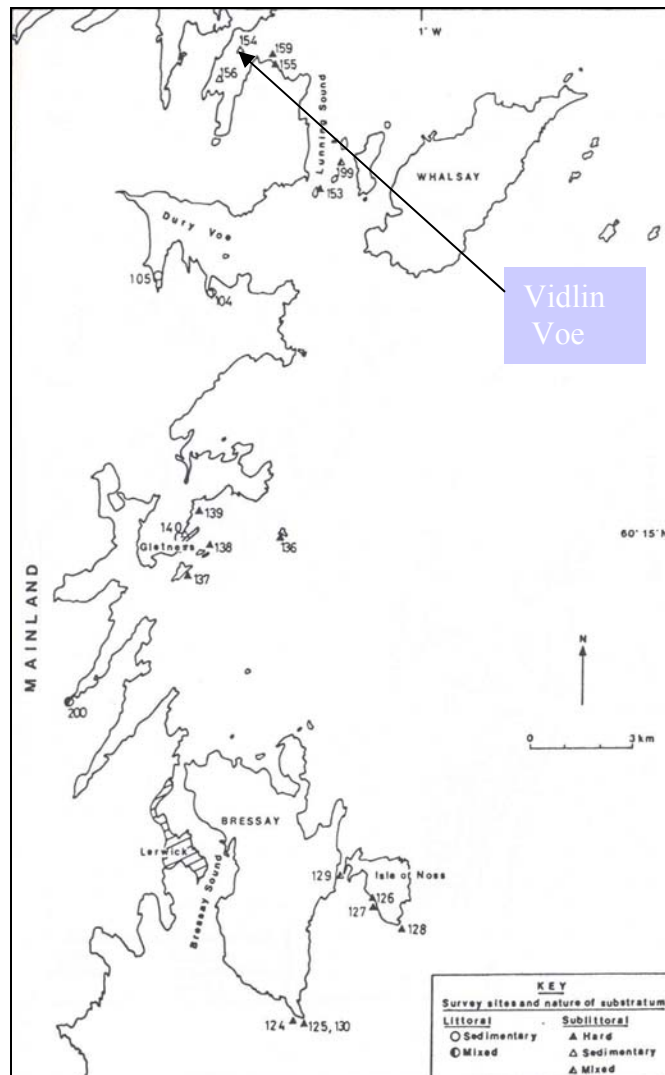


Figure 1. Map of Shetland sublittoral stations on east mainland, from Fig. 7 in Howson (1988), showing Vidlin Voe stations 154 and 156.

Howson (1988) gives more detail on the other habitat described in Vidlin Voe:

“Habitat 36. Sediment slopes sheltered from wave action Sites 67 68, 69, 70, 98, 116, 117, 143,144, 151 **156** (Hiscock habitats 7, 10.) A variety of sediments occur in the shelter of the voes; at the sites visited these range from muddy sand to shell gravel. However, all except Sonso Ness (67) have beds of *Modiolus modiolus* and an associated community, and so have been included in one category. One of the group, Silver Skerry (151) is semi-exposed but is not sufficiently different to the sheltered sites to warrant separation. Sediment communities as described here are certainly widespread throughout the voes, and the study of more sites would no doubt enable further subdivision of habitats. Although there were few hard substrata other than shell debris and rock in shallow water at the sites grouped here, this category appears to be the equivalent of Hiscock’s Habitats 7 and 10.”

“*M. modiolus* forms beds varying in density centred in a band around the 20 m depth mark. The precise depth varies from site to site, but tends to rise with shelter and drop deeper with increased exposure. The brittle stars *Ophiothrix fragilis* and *Ophiocomina nigra* and other mobile species are often associated with the mussels, which provide shelter. Other species colonise the shells, including ascidians such as *Ascidiella scabra*, *Ascidia mentula*, *Ciona intestinalis* and *Botryllus schlosseri* and the hydroids *Kirchenpaueria pinnata* and *Nemertesia antennina*. Other molluscs frequent in the beds are *Pecten maximus*,

Aequipecten opercularis (often with *Suberites domuncula* or *Mycale* sp. on its shell), *Buccinum undatum*, *Colus gracilis* and *Neptunea antiqua*. *Cucumaria frondosa* is frequently present in this habitat. In shallower depths, foliose algae find a refuge on the shells from extensive grazing, and several small species are found, including *Callophyllis cristata*. *Phycodrys rubens* is often one of the most abundant species.”

“Vidlin Voe has a shell gravel slope at the entrance with *Virgularia mirabilis*, *Pennatula phosphorea*, *Peachia cylindrica* and *Atelecyclus rotundatus*. Deeper sediment at this site would merit investigation. Further into the voe there is slightly muddy sand with relatively few species although these include *Pecten maximus*, *G. magus*, *S. turgida* and *Asperococcus turneri* and an accumulation of decaying algae at 26 m.”

In her area summaries for the Marine Nature Conservation Review, Howson (1999) identified several other sublittoral surveys, displayed below (Figure 7.1 in Howson, 1999):

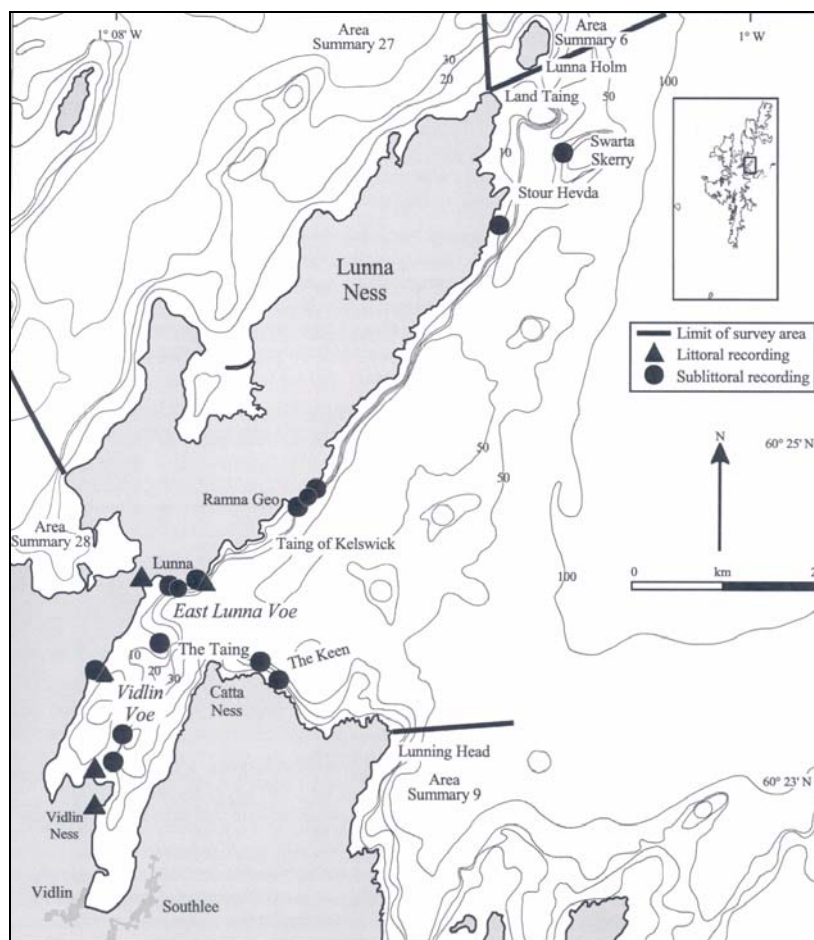


Figure 2. Review of Vidlin Voe sublittoral survey sites, from Fig. 7.1 in Howson, 1999.

A total of 9 sublittoral survey sites are given by Howson (1999) within Vidlin Voe. Although they are described as recording surveys, none utilised quantitative infaunal methods. Surprisingly, Howson does not mention the survey reported by Dixon (1986), in which 2 dives in the inner voe are described (Sites 21 and 22, which are south of Johnson Sustainable Seafoods shore base, and which roughly bracket to north and south the previous salmon farm cage group in the inner voe) (Figure 9):

“3. Infralittoral mud, including sandy mud, in the shelter of voes (c.f. Habitat 10, Hiscock 1986). Covered by kelp, mostly loose-lying, and sometimes with a high percentage cover of other algae; especially ‘*Trailliella intricata*’ and *Phyllophora crispa*. Brown diatoms in large patches over sediment between lugworm burrows. The loose-lying kelp was often showing signs of decay, with small patches of white bacterial film (provisionally identified as *Beggiatoa* sp.) extending over the fronds and onto the surrounding sediment surface. Fauna basically similar to that found in the sandier habitats but often included, in addition, the burrowing anemone *Cerianthus lloydii* (Sites 1, 5 to 9, and 11 to 33).”

Several of Howson’s survey sites are shared with an earlier survey by Hiscock (1986), while one survey by Moss & Ackers (1987) is unpublished and no data have been found on their stations 32 A&B, 33 A&B and 34 (Figure 9). Earll (1982) describes the results of one survey from 1974 (Institute of Terrestrial Ecology, 1974), in which one dive was performed at Lunna (Station 16, Figure 9) and another on the western shore of the voe a little north of the present cage group (Station 27, Figure 9).

From her 1999 review, Howson updates the information on habitats within the voe:

“Steep bedrock and boulder slopes continue into the sublittoral to a depth of about 30-36 m along Lunna Ness and around Catta Ness, at which depth a sediment slope begins, although there is a cobble plain at 37 m depth off the Keen at Catta Ness. The rock-sediment boundary becomes gradually shallower southwards along Lunna Ness towards the head of Vidlin Voe; it is 12 m at Vidlin Ness and is shallower in the inner arm of the voe. Sediments grade from very coarse shell-gravel, consisting predominantly of broken tubes of the keel worm *Pomatoceros triqueter*, at the tip of Lunna Ness to muddy sand in the inner parts of the voe.

The upper infralittoral zone is dominated by a kelp forest of *Laminaria hyperborea* which extends to a depth of 12-18 m on the open coast (Lhyp.Ft; LhypGz.Ft). This is followed by a lower infralittoral kelp park, either of *Laminaria saccharina* or a mixture of the two kelp species, which reaches 19-20 m (LhypGz.Pk; XKScrR). Occasional kelp plants are found as deep as 33 m, which indicates that water clarity would enable the kelp forest to extend deeper. However, both the upper and lower infralittoral zones are heavily grazed by the urchin *Echinus esculentus* with few foliose algae on either the rock surface or the kelp stipes, and at most sites there is a very sharp boundary between the infralittoral and the circalittoral. Coralline crusts are common and there are several animal species in crevices, including the brittlestar *Ophiopholis aculeata*, the holothurian *Pawsonia saxicola* and ascidians such as *Ciona intestinalis*. At the tip of Lunna Ness, where tidal streams are strongest, there are a few more red algal species, such as *Phycodrys rubens* and *Cryptopleura ramosa* amongst the kelp.

The influence of heavy grazing is also apparent on circalittoral rock which is dominated by *E. esculentus*, grazing-tolerant encrusting species such as *P. triqueter*, coralline algae and the bryozoan *Parasmittina trispinosa*, and mobile species such as the cushion star *Porania pulvillus* and brittlestars *Ophiocomina nigra* and *Ophiothrix fragilis* (FaAIC). At some sites, particularly in the lower circalittoral, these brittlestars form dense beds which have a similar effect to the grazing activities of the urchins (Oph). At other sites there are dense aggregations of the featherstar *Antedon bifida*, often concentrated along edges of rock (Ant). The associated fauna is similar in all these situations. Crevices in the rock and boulder interstices support a wider range of species, similar to those found in the infralittoral. These include, in addition to those species mentioned above, the ascidians *Ascidia mentula* and *Ascidia virginea* and terebellid worms. Encrusting species, particularly coralline algae and *P. triqueter*, also dominate the deep cobble plain off Catta Ness.

The coarse shelly sediments off Lunna Ness in depths of 20-36 m support scallops *Pecten maximus* and occasional horse mussels *Modiolus modiolus* with the brittlestar *Ophiura albida* and the northern whelk species *Colus islandicus* (IGS). Sediment becomes sandier from Ramna Geo towards Vidlin Voe, with species such as *P. maximus*, razor clams *Ensis* sp., the swimming crab *Liocarcinus depurator*, the pelican’s foot shell *Aporrhais pespelecani* and the

ascidian *Molgula oculata*. At the entrance to Vidlin Voe, a steep muddy shell-gravel slope has a dense bed of the sea-pens *Virgularia mirabilis* and *Pennatula phosphorea* with *P. maximus*, small numbers of the burrowing anemone *Peachia cylindrica* and the crab *Atelecyclus rotundatus* (VirOph). The sediments are muddier within Vidlin Voe, with the sediment slope beginning in a depth of about 12 m. There are *L. saccharina* plants attached to the cobbles, pebbles and shell debris lying on the sediment surface, and scattered plants reach a depth of 20 m (LsacX). There are few other algal species present including the brown algae *Chorda filum* and *Asperococcus fistulosus* and the red *Ceramium* spp. *C. intestinalis* is frequent on shells and stones whilst the sediment has casts of lugworm *Arenicola marina*, the topshell *Gibbula magus*, *P. maximus*, *M. oculata* and the starfish *Asterias rubens*.”

Habitats listed by coded abbreviation above in Howson (1999) are explained fully below:

Lhyp.Ft = *Laminaria hyperborea* forest and foliose red seaweeds on moderately exposed upper infralittoral rock

LhypGz.Ft = Grazed *Laminaria hyperborea* forest with coralline crusts on upper infralittoral rock

LhypGz.Pk = Grazed *Laminaria hyperborea* park with coralline crusts on lower infralittoral rock

XKScrR = Infralittoral rock with mixed kelps and scour-tolerant algae

FaAIC = Faunal and algal crusts on exposed to moderately wave-exposed circalittoral rock

IGS = Infralittoral gravels and sands

Oph = Circalittoral rock or mixed substrata with dense brittlestars

VirOph = Circalittoral sandy or shelly mud with ascidians

LsacX = *Laminaria saccharina*, *Chorda filum* and filamentous red seaweeds on sheltered infralittoral sediment

These geographical extent of these habitats is displayed in Fig. 7.2 in Howson (1999), which is reproduced in Figure 3.

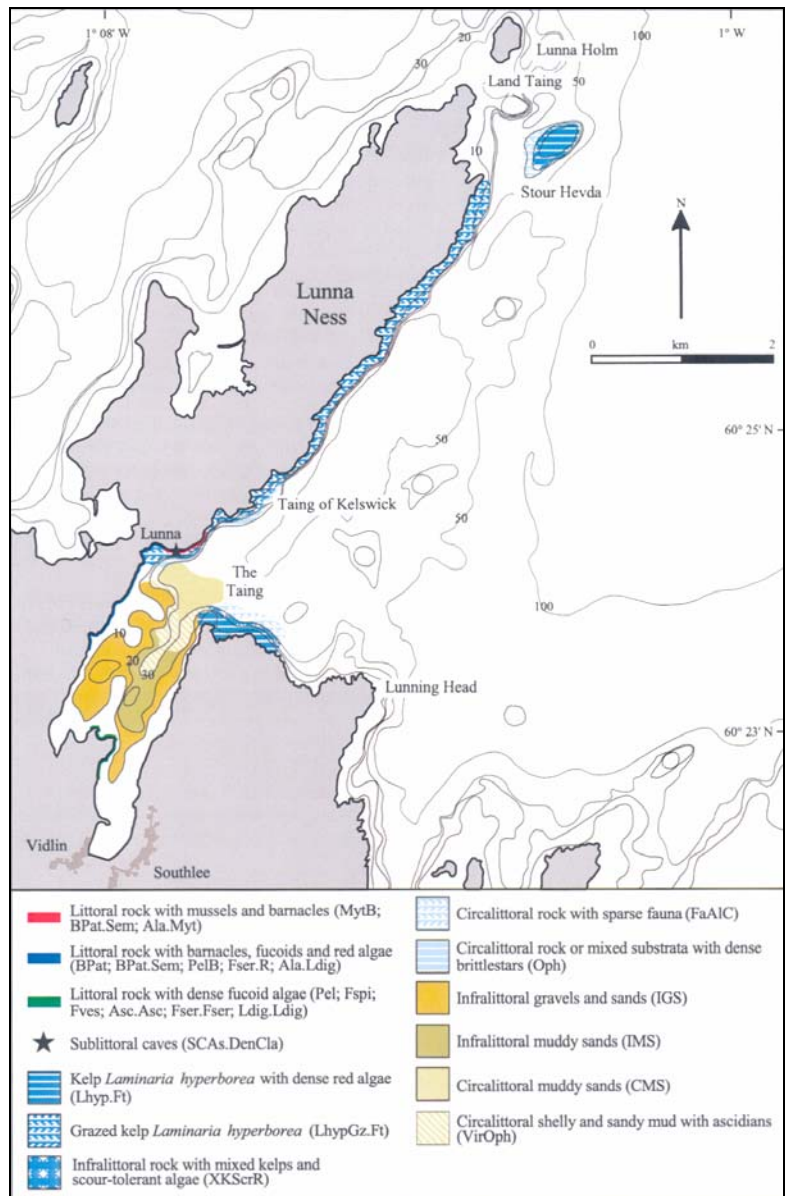


Figure 3. Vidlin Voe biotopes identified by Howson (1999, Fig. 7.2).

2.3 Detailed description of the farm

Johnson Sustainable Seafoods run their cod farming operation split into 5 sections: the farm sites, hatchery, processing unit, accounts, and marketing, all of which employ a total of 106 people. The Vidlin area contains the shore base (25 employees) and the office (10 employees). The shore base is equipped with a modern canteen where the food is provided by the employer, toilets, and a drying room with heated flooring. Waste disposal is in accordance with Shetland Island Council recycling policy.

2.4 Proposed management strategy: biomass, medicines, chemicals, cycle, feed inputs, growth measurements.

The production cycle of cod at Vidlin is based on fish arriving from the hatchery and entering the nursery area near the head of the voe following which they are transported to the on-growing area (Vidlin North/Outer). Juveniles are deliberately sourced from 3 separate Scottish hatcheries to ensure supply: Johnson's own Shetland

hatchery, Stirling IoA at Machrahanish and Viking at Ardtoe. The fish are on site for a total of 13 months. The feed inputs are not regulated by SEPA, and the strategy is based on maximising FCR. Certified organic feeds from fish offcuts intended for human consumption are used. There is photoperiod manipulation of fish from midsummer to the end of the growth cycle.

Maximum consented biomass for the whole voe is 2190 t, although this biomass has not been achieved due to limitations in juvenile supply. Expected FCR is 1.3:1, although in this early stage of cod farming this ideal may not be achieved.

Stocking density is set according to organic standard, $< 15 \text{ kg m}^{-3}$. The production biomass is the consented biomass, 2190 t, over the maximum farm area 50000 m^2 , giving 43.8 kg m^{-2} of seafloor.

Previously (up to 2005), the antibiotic oxytetracycline (as Aquatet and Oxytet) was used by prescription at Vidlin to treat cod for *Vibrio* spp., in line with organic policy of only 3 treatments in any growth cycle; since the development of a vaccine, however, no medicines or chemicals have been used in cod production at Vidlin.

2.5 Physical farm logistics, including type of gear used (Cages, long lines, rafts...), moorings, access, lighting and anti-predator measures (use maps, and diagrams).

There are 17 Polar Cirkel cages (100 m circumference) on site, moored by a total of 42 anchors (750-1000 kg each). All site access is *via* boat from the shore base. The only lighting is on the feed barge, with no surface lighting on the cages. Navigational hazard lighting and marking is mandated by the Northern Lighthouse Board (NLB); the farm position is licensed to be in a safe place by the Shetlands Islands Council (Marine Operations Dept.), the Scottish Executive and the NLB. The NLB notify the Admiralty (official Notice To Mariners) as to the navigational hazard posed by the farm subject to the Coast Protection Act 1949, periodically surveying the site to maintain compliance. This license is renewed every 5 years.

Surface anti-predator (avian) nets are small-mesh, in high visibility yellow (Figure 7). Anti-seal netting sub-surface is in the form of tension double-netting. No audible seal scarers are employed.

2.6 Production and Processing

Fish are removed for slaughtering by herding and netting, not by suction, in accordance with SSPCA recommendations for animal welfare. The fish are loaded onto boats stunned and then killed on board. The fish are then placed in bins, transported to shore and loaded onto trucks for road transport to Scalloway for processing. The processing unit is owned and operated by Johnson's, where waste products are disposed of in accordance with UK and local law. The waste product disposal is inspected by the Council Environmental Health officer to ensure compliance; all liquid waste is controlled by discharge consent from SEPA.

Airborne emissions from the farm are minimal. The only smoke arises from the diesel generator on board the feed barge. All emissions are regulated by the Control of Pollution Act 1989. There are no liquid emissions from the farm; mortalities are removed by divers, and transported to Lerwick where Shetlands Islands Council dispose of them by incineration. Heat generated from this process is used to heat houses and public buildings in Lerwick.



3 Description of the site and quantification of effects on the environment – existing information only, not collected by ECASA.

3.1 Land use, landscape and visual quality (use maps and photographs)

Fish farming has taken place in Vidlin Voe since the early 1980's, although the farm site within the voe has altered in that time. The village of Vidlin is the only substantial population centre in the area around the voe, which is in the Nesting and Lunnasting Community Council area, although there are numerous hamlets of several dwelling houses scattered along the roads (Figure 6). The latest census data show ca. 208 households in the Council area (Anon., 2004b).

There are numerous other aquaculture sites within the area; the community council lists farms at Cat Firth, Wadbister Voe, Grunna Voe, Dury Voe, Gletness, Lax Firth, Swining Voe, Setter, Lunna Voe and Culness (Anon., 2004b), although not all of these would appear to be active at this time (Neil Duncan, Johnson Sustainable Seafoods, pers. comm.). All active sites in the vicinity at the time of writing are presented below in Figure 4. No other farms are present in Vidlin Voe itself (certainly not at Grunna Voe; the site at Taing of Kelswick at the mouth of Vidlin Voe is owned by Johnson Seafarms but not active). Distance to the nearest farm depends largely on which ones are active; these data are not certain at this time. The nearest site listed is in Grunna Voe, a small embayment within Vidlin Voe which is only 642 m from the present Vidlin North cage group, but this site is not active at present. The nearest active cages are probably to the west in Swining Voe, which are 2195 m in a straight line, although 14084 m by sea.



Figure 4. Shetland aquaculture sites in the Vidlin Voe area.  = fish farms,  = mussel farms. Image © Digital Globe 2007.

There is some fishing locally, with boats mainly targeting scallops, lobster and crab.

Surrounding land class (urban, rural etc give maps).

The area surrounding Vidlin Voe is largely moorland which is used primarily for crofting, the major occupation (Figure 6).



Figure 5. Setting of Johnsons Sustainable Seafoods cod farm in Vidlin Voe. High visibility yellow anti-predator net visible on right.



Figure 6. Ordnance Survey map of area surrounding Vidlin Voe study site (© Crown Copyright).

Visual pollution and reduction in wilderness amenity.

The site is located in an area that has been associated with fish farming for over 20 years. There are numerous other fish farms located nearby. As a result fish farming sites are a characteristic element in the contemporary landscape. The site area has no conservation status.

The following image represents the visual impact of the cages. The anti-predator nets are a response to repeated attacks by sea birds as the previously used, but less visually intrusive nets, were not preventing sea bird attacks.



Figure 7. Cod farm in Vidlin Voe, showing high visibility small mesh anti-predator nets (photo © Neil Duncan).

Proximity to Marine Protected Areas.

The farm site is close to Yell Sound Coast Special Area of Conservation (SAC) - otters and common seals will move into the farm area from the SAC. In addition, a major oil pipeline comes on to the mainland at Lunna, around which an exclusion zone applies. One of the SOTEAG survey sites used to be in Vidlin Voe.

3.2 Hydrography and water quality

Vidlin Voe does not have a sill or any basins. Deep water isolation does not occur due to absence of these features and the short flushing time of 5 days calculated for zone B by Edwards & Sharples (1986) [compare Loch Etive which has isolated water and a theoretical flushing time of 14 days calculated by the same method (note - flushing time is much longer in the isolated basins)].

Seasonal stratification due to salinity is unlikely, due to the low flow of freshwater into the head of the voe and the regular exchange with the open sea. Summer sea surface temperatures are around 13 °C, no profiles of temperature through different seasons are available. Temperature stratification is not expected to be significant, again partly related to the absence of freshwater.

Physical data for the site – are wider scale models available? How is the site rated in terms of dispersiveness?

Wider scale models of the area around Shetland exist in the form of shelf seas models. Given the scale of these models, very few nodes are likely to exist around the entrance to the voe.

Hydrographic data measured at the site indicated current residuals were to the north east mid-water and near-bed (seaward), with a particularly strong residual at the sea bed (Table 1, Figure 24 - Figure 27) (Anon. 2001). Surface residual was to the south west (landward) and near-bed current was unusually stronger than surface current.

Table 1. Summary statistics for surface (4.3 m), mid-water (16.3 m) and near-bed (25.3 m) current measured using a Nortek 500 kHz ADCP (Anon., 2001) (length 15 days: 31/10/01-15/11/01).

Instrument depth	Max Speed (cm s ⁻¹)	Mean Speed (cm s ⁻¹)	Residual Direction (°True)	Residual Speed (cm s ⁻¹)
Surface	17.7	4.7	220	2.4
Mid-water	21.4	5.2	50	1.0
Near-bed	20.0	6.9	44	3.4

Flushing and potential for nutrient enrichment: What is the flushing rate for the system? Have calculations on Equilibrium Concentration Enhancements for nutrients been done?

Calculations of Equilibrium Concentration Enhancements for nutrients have been taken from Locational Guidelines which established guidelines for nutrient enhancement for each sea loch in Scotland (FRS, 2006). This box model calculates the nutrient input to a water body using information on flushing rate of the system and annual discharge of nitrogen from the farm. The calculated input can then be categorised to determine whether this imposes a risk of nutrient enhancement.

As the nutrient output per tonne of cod produced is known, it is necessary to use annual production rather than peak biomass. However, following FRS (2006) annual production was assumed to equal peak biomass.

Table 2. Calculation of nutrient concentration in Vidlin Voe using the ECE model (FRS, 2006).

Symbol	Value	Units	Description	Source
ALW	2.6	km ²	LW Area	Edwards & Sharples (1986)
AHW	2.8	km ²	HW area	Edwards & Sharples (1986)
DepthLW	11.4	m	Mean depth at LW	Edwards & Sharples (1986)
VLW	2.96E+07	m ³	LW vol	Calculated ^a
R	1.8	m	Tidal range	Edwards & Sharples (1986)
Tf	4.5	days	Flushing time	Calculated ^b
Q	75.7	m ³ s ⁻¹	Flushing rate	Calculated ^c
Q(yr)	2.4E+09	m ³ y ⁻¹		Calculated ^d
M	1390	tonnes kg N / tonne fish produced	Combined peak biomass Vidlin Outer and North 2006	Johnson Sea Farms FRS (2006)
S	72.3		Equilibrium Concentration	Calculated ^e
ECE	4.21E-05	kg N m ⁻³	Enhancement	
	4.21E-05	g l ⁻¹		
	4.21E+01	µg l ⁻¹		
	3.00	µmol l ⁻¹		Calculated

Notes

^a VLW = ALW*1E+06 * DepthLW;

^b Tf = (0.52*VLW)/(0.5*(ALW+AHW)*1E+06*R*0.7)

^c Q = VLW / (Tf*24*3600) ^d Q(yr) = Q * 365.25*24*3600

^e ECE = S * M / Q(yr) ^f 1 µmol l⁻¹ = 14 µg l⁻¹

A value of 3.0 µmol l⁻¹ results in a nutrient enhancement index of borderline 3 and 4, which is moderate enhancement of the nutrients in the voe (Table 3). This calculation is useful as it can be compared with calculations from other water bodies, as 28 % of sea lochs fall into category 3. The model is based on tidal excursion, and therefore does not consider local effects such as wind driven surface flows. The data used for nutrient output from cod is an estimate from FRS (2006), based partly on the difference between cod and salmon diets. Recent research undertaken by the Institute of Stirling will reveal the nutrient output from cod farming and allow a more accurate calculation.

Table 3. Nutrient enhancement from aquaculture showing the number of Scottish sea lochs falling into each category (FRS, 2006).

ECE (µmol l ⁻¹)	Nutrient enhancement index	Number of Scottish sea lochs
> 10.0	5	0
3.0 – 10.0	4	6
1.0 – 3.0	3	31
0.3 – 1.0	2	31
< 0.3	1	43

Have calculations on dispersion of dissolved medicines been done? What are the dissolved waste levels and what is the perceived risk of eutrophication?

No medicines whatsoever have been used since 2005. Given the nutrient enhancement index of 3.5, this would imply there is some risk of eutrophication. However, given the wind driven flows present in the voe (which are not included in the model), this perceived risk is low.

Is there background information on pelagos: phytoplankton, zooplankton and wild fish studies?

No data on these parameters have been found.

3.3 Bathymetry, geology and habitats.

Describe the site at Zone A and B scales. Have habitats been mapped? Is there a substratum map?

Bathymetry at the site varies from 16-17 m in the south to ca 30 at the northern edge of the cage group (Figure 8). While the habitats have not been mapped, from benthic surveys performed in 2004-2006 the substrate is a muddy sand, becoming more coarse towards the mouth of the voe. There is no substratum map available, however Howson (1999) has an indicative map drawn from various sources (see Figure 3 above).

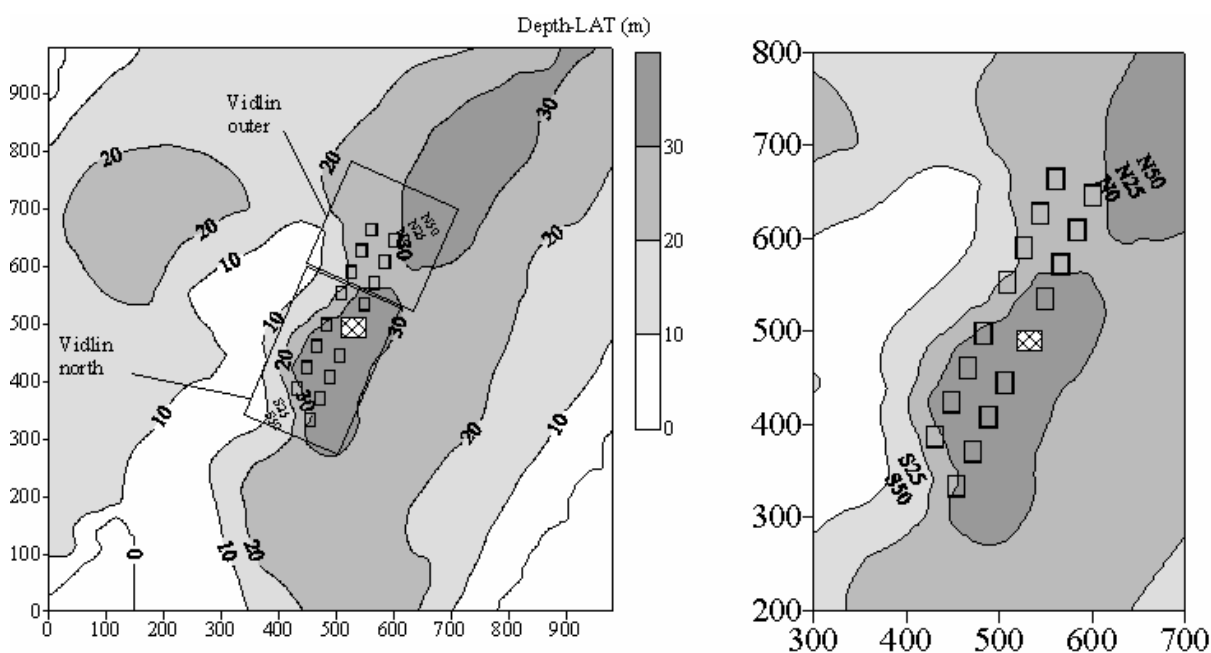


Figure 8. Bathymetry for Vidlin cod farm (squares are cage centres) showing inner sampling stations. All cages are 32 m diameter * 15 m depth. Spacing between cage edges is 9 m.

3.4 Benthos and sediments

Show data (and list meta data) on benthic and sediment measurements at the site. Are there any unusual or rare species?

Examination of the taxa present from benthic surveys during 2004-2006 (Williamson, 2004; Cromey *et al.*, 2007) yields the only quantitative data located on the benthos in Vidlin Voe. The dominance of the venerid bivalve *Moerella pygmaea* at the cage edge on the northern transect would suggest that this is a wave dominated, sand/gravel biotope subjected to strong water movement and not especially enriched with organic matter. However, the presence of the opportunistic polychaete *Capitella* sp. as the second most numerically dominant species would indicate that this community was also undergoing a change in conditions. In contrast, Williamson (2004) found this station dominated by the polychaete *Nephtys hombergi* (24 % total abundance) and the amphipod *Perioculodes longimanus* (16 % total abundance), neither of which are indicative of impacted conditions encountered at other Scottish aquaculture sites (Nickell *et al.*, 1995).

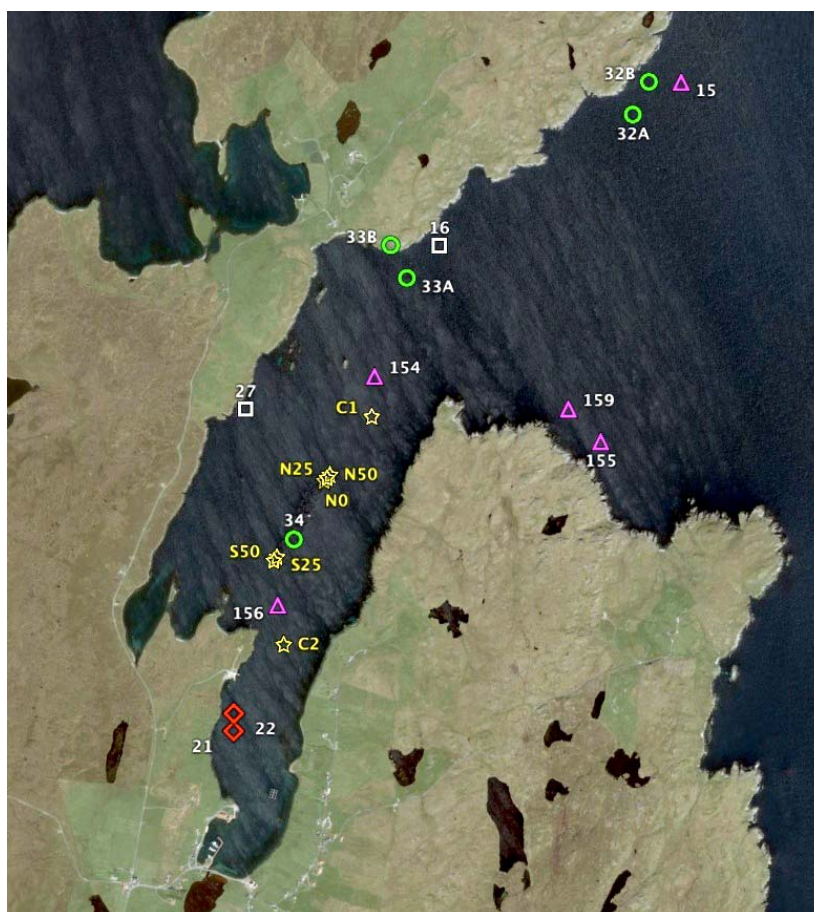


Figure 9. Study area and all known sublittoral survey stations, showing stations not included in Howson, 1999 (image © DigitalGlobe).

Are there protected species in the area?

From the Marine Nature Conservation Review, mapping has taken place within Vidlin Voe. This showed a dense area of seapens, which is a Biodiversity Action Plan habitat (which is uncommon in Shetland) in the mouth of the voe. Otters and cetaceans are all

protected under European Protected Species legislation. Seals (common and grey) are also protected under various legislation.

3.5 Marine mammals; seals, cetaceans, otters

Are these animals abundant in the vicinity – give maps, describe seasonality etc.

Are there any predator deterrents?

Vidlin Voe and the surrounding area is important for otters, with a significant year-round population. Cetaceans (mostly harbour porpoises) are regularly recorded. Seals are also present year-round and while they do not have sensitive haul-outs in the immediate area, haul-out on the skerries off Lunna Ness and Lunna Holm and at the Skerry of Lunning.

Static anti-predator nets are employed at the farm, but no other active devices (e.g. sonic scarers) are used.

3.6 Birds

How much known about birds in the area, are there important or rare species in the area or piscivorous birds that may have specific interactions (ducks, cormorants...)

There are significant numbers of eider ducks *Somateria mollissima* (a distinct Shetland population that is in decline) and shags *Phalacrocorax aristotelis* in the area. Herring gulls *Larus argentatus* are the most common avian predators at this site, and special high visibility, small mesh netting is used to deter them.

Seabirds such as gannets *Morus bassanus*, common guillemots *Uria aalge*, razorbills *Alca torda*, kittiwakes *Rissa tridactyla* and puffins *Fratercula arctica* are all common. Migrants e.g. pied wagtails *Motacilla alba*, waxwings *Bombycilla garrulus*, redwings *Turdus iliacus* and greylag geese *Anser anser* frequent the area in autumn and spring. The song thrush *Turdus philomelos*, a Red List species, is common locally.

The current aquaculture activities at Vidlin Voe are not considered to impact on the resident or migratory bird populations.

3.7 Fisheries and wild fish populations.

Is there a local fishery? What are the interactions?

There is a limited local fishery for scallops, lobsters and crabs. Outwith the immediate area, Shetland is home to a very large whitefish fleet. It is not thought that there will be any interactions between the cod farm and local stocks.

Is there a policy or code on transmission of diseases/parasite and prevention and recapture of escapees? Are there records of escapes?

The policy on disease transmissions is contained in the Scottish Salmon Producers' Organisation's Code Of Good Practice. The company maintains a rigorous biosecurity procedure, with all equipment entering or leaving the farm subject to disinfection. There are no ectoparasite issues with cod farming.

Escape prevention is maintained by a double net system. There is no record of any escapes of farmed cod in Vidlin Voe.

Does the site attract large numbers of wild fish? Are fishing and angling prohibited near the farm?

There is a substantial number of wild fish in the vicinity of the cages, notably pollack (*Pollachius pollachius*). Fishing and angling are permitted near the farm.

3.8 Noise

Activities on site, either within daylight hours, night-time. Proximity of residential areas.

The noise on site is limited to the sound of feed travelling through plastic pipes running from the barge to the cages. There is a generator on the barge, which was responsible for some noise. Following a complaint from a local householder, further soundproofing was employed and the problem seems to have been resolved. This cottage is the nearest residential property, and is ca 700 m due west. Other houses in the area are best described as scattered. The village of Vidlin is ca 1.8 km distant.

All work is done during daylight hours.

3.9 Transport

Deliveries. Staff access. Site access-road quality. Shore bases.

Feed is delivered by boat direct to the barge. All other deliveries to the farm are by road. Staff access is also by road. These are predominantly single track rural roads with passing places. The shore base access road has recently been improved.

3.10 Socio-economic impact

Employment and socio-economic benefits. How many jobs are supported? Do these come from fragile remote communities? Are staff imported into the area? Are there any other socio-economic benefits e.g. retention of school or post office?

The turnover from Johnson Sustainable Seafarms is over £9 million in Shetland. In the Vidlin area, 35 employees are directly supported. These employees are primarily from the Vidlin/Walsay area. These employees' families have aided in the retention of the local school; the post office, however, has recently closed. The local shop is supported by the expenditure of ca £2500 per month by the employees.

4 Results of ECASA field studies: Indicators and Models applied and evaluated.

4.1 Background to field programme: dates, staff, boats, stations sampled, etc.

4.1.1 Benthic surveys

Two benthic surveys of the Vidlin Voe cod farm were carried out. The first was during the period 2-3/08/2005, and the SAMS personnel were Mrs J. Moore, Mrs J. Duncan and Dr T.D. Nickell. The second survey took place during 25-26/07/2006, and the personnel were Miss S. Magill and Dr T.D. Nickell (SAMS), and Dr H. Thetmeyer (IFM-GEOMAR). Station locations are shown below in Table 4, and in relation to the cage group in Figure 10. Stations for the 2005 and 2006 surveys are the same regulatory monitoring stations used by Williamson (2004) in a benthic assessment in 2004. Monitoring stations were located as recommended by SEPA

guidelines (Anon., 2005). At some stations, differences between GPS positions between surveys were apparent when using measured line to mark out distance from the cage group. In these cases, a relative distance approach was adopted (e.g. 0, 25 m, 50 m, etc.) as described by Cromey *et al.* (2000). These locational differences are most likely attributable to cage movement by the site operator.

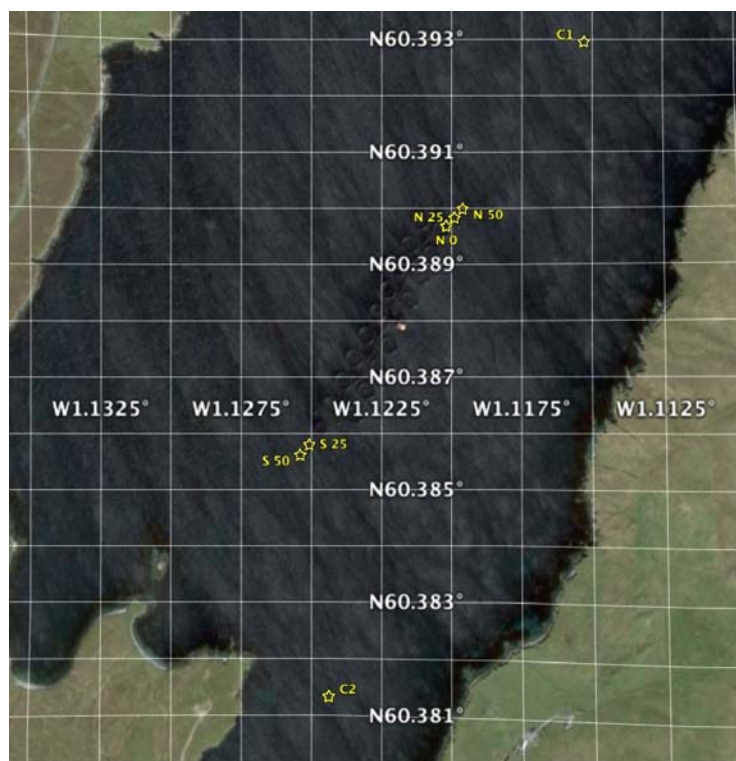


Figure 10. Study area showing cage group and sample station layout (image © DigitalGlobe).

Table 4. Vidlin station locations. N = north, S = south, C = reference, and the number following N or S refers to distance (m) from cage edge.

Station	2005 and 2006 surveys			2004 survey		
	Lat.	Lon.	Depth (m)	Lat.	Lon.	Depth (m)
N0	60°23.385N	1°07.205W	29	60°23.313N	1°07.247W	30
N25	60°23.398N	1°07.182W	28	60°23.316N	1°07.219W	29
N50	60°23.408N	1°07.165W	25	60°23.322N	1°07.201W	26
S25	60°23.152N	1°07.420W	17	60°23.179N	1°07.535W	18
S50	60°23.123N	1°07.456W	16	60°23.168N	1°07.551W	16
C1	60°23.578N	1°06.917W	32	60°23.577N	1°06.914W	33
C2	60°22.881N	1°07.463W	17	60°22.882N	1°07.462W	17

4.2 Sampling methods and materials, analytical methods. (Refer to the book of protocols for detailed methods)

4.3 Description of methodology employed

Sediment sampling was *via* 0.1 m² van Veen grab (Stubbs *et al.*, 1987) from a Johnson Seafarms fish farm boat on both occasions. Redox measurements (Zobell, 1946; Pearson & Stanley, 1979) were taken from core sub-samples ($\phi = 0.057$ m;

depth = 0.14 m) from van Veen grabs (duplicates at each station; only 1 core per grab to avoid pseudo-replication), and readings taken every 0.5 cm until a sediment depth of 4 cm, after which 1 cm intervals were used. A Palmer stand (Hodgkin, 1938) was used to accurately measure probe depth within sediment, and the probe was recalibrated in Zobell's solution between cores.

Macrofauna were collected from replicate 0.1 m² grabs per station, sieved on board over 1 mm mesh using round mesh sieves and sieve table, and the residue preserved in ca. 10% buffered (with excess borax) formal saline and rose bengal as vital stain.

Samples for Loss On Ignition (LOI), CHN and Particle Size Analysis (PSA) were obtained as sub-cores ($\phi = 0.057$ m; depth = 0.04 m) from replicate 0.1 m² grabs per station. Loss On Ignition follows the method described by Loh (2005), viz. accurately weighing, ashing at 250°C for 16 hours, reweighing and then ashing to 500°C for 16 hours. The weight loss of the sediment at the two temperatures is related to the relative amounts of labile and refractory organic matter, instead of merely giving the more common value for ashing at 500°C alone (see annex).

Particle size analysis was performed on bulk wet sediment (2 g samples). The analyses were obtained using a laser diffraction particle size analyser (Coulter Counter LS230, Beckman Coulter, Inc., Fullerton, CA, USA) (Pye & Blott, 2004). Sodium hexametaphosphate (20 ml) was added to each suspension to inhibit flocculation. Each sample was analysed 3 times, after 5 minutes of ultrasound treatment.

Organic carbon (CHN) samples were frozen, lyophilised, ground and acidified to remove inorganic carbon (Tung and Tanner, 2003) prior to analysis by LECO CHN-900 auto analyser (LECO Corporation, St. Joseph, MI, USA).

4.4 Models used and their parameterization.

4.4.1 Introduction

DEPOMOD is an aquaculture impact model developed and validated for North Atlantic salmon farms (Cromey *et al.*, 2002). The model predicts the benthic faunal impact associated with flux of waste material from marine cages. The MERAMOD model was developed from the DEPOMOD model and validated for sea bass and sea bream farms in the Eastern Mediterranean (MERAMED¹). Figure 11 shows the stages involved in taking an existing model and developing it for a new species and environment and this was used in the development and validation of MERAMOD from DEPOMOD. This involved adaptation of a model primarily designed for macro-tidal North Atlantic salmon farms to an impact model of micro-tidal Eastern Mediterranean sea bass and bream farms.

DEPOMOD was used as the basis for CODMOD. The main effort has focussed on obtaining model input data specific for cod, which were identified as important in the early stages of the project by sensitivity analysis. Measurements on settling rates of cod faeces, feeds and faecal outputs described previously were prioritised.

¹ <http://www.meramed.com>

Validation of DEPOMOD and MERAMOD involved three stages: particle tracking model validation which is dispersion of particles from sea surface to sea bed; resuspension model validation in DEPOMOD which erodes and redeposits bed particles in response to near-bed current speed thresholds (Cromey *et al.*, 2002); and benthic response model validation which relates a benthic response to solids waste flux ($\text{g solids m}^{-2} \text{ yr}^{-1}$). The main validation priority for CODMOD was the benthic module, as validation of the particle tracking components was satisfactorily undertaken with DEPOMOD and MERAMOD. The resuspension model predictions in CODMOD were tested in a sensitivity analysis.

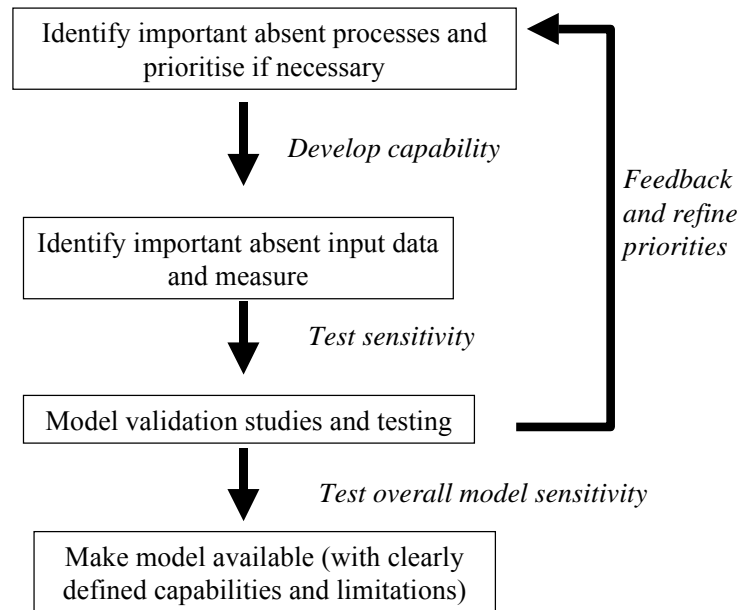


Figure 11. CODMOD development and validation ethos used throughout this project.

4.4.2 Model components

CODMOD is made up of six modules: grid generation, fish bioenergetics, particle tracking, resuspension and benthic faunal response. A grid containing information on depth, cage and sampling station positions for the area of interest is required. Given wastage rates of fish food and faeces from the bioenergetics model and hydrodynamic data and settling velocity of wastes, initial deposition of particles on the sea bed are predicted with the particle tracking component. A resuspension model (Cromey *et al.*, 2002b) then redistributes particles according to near-bed current flow fields to predict net solids accumulated on the sea bed. Finally, some impact assessment (validation) is required and this is undertaken by correlating predictions of a physical aspect of the waste (e.g. solids flux – $\text{g m}^{-2} \text{ yr}^{-1}$) with a benthic faunal indicator of impact.

CODMOD was used to predict the flux and benthic impact at the Vidlin cod farm for three different periods during the growing cycle corresponding with benthic macrofaunal surveys. The model was used to predict flux and benthic impact in May 2004, August 2005 and July 2006, and these were compared with the observed Infaunal Trophic Index (ITI). Model predictions were made for these dates using the

best available information on husbandry data, cage layout and using cod experimental data for food and faecal settling rates and faecal outputs.

No modification was made to the benthic response model in CODMOD as a result of the additional tests. In this approach, we assume that the benthic response to solids flux is primarily dependent on the magnitude of flux and associated modification of sediment chemistry. i.e. the magnitude of flux is important irrespective of whether the source of waste feed and faecal material is from a cod or salmon farm. By undertaking experiments with cod to determine species specific model input data, we assume that the accuracy of flux predictions is much higher than if salmon model input data were used.

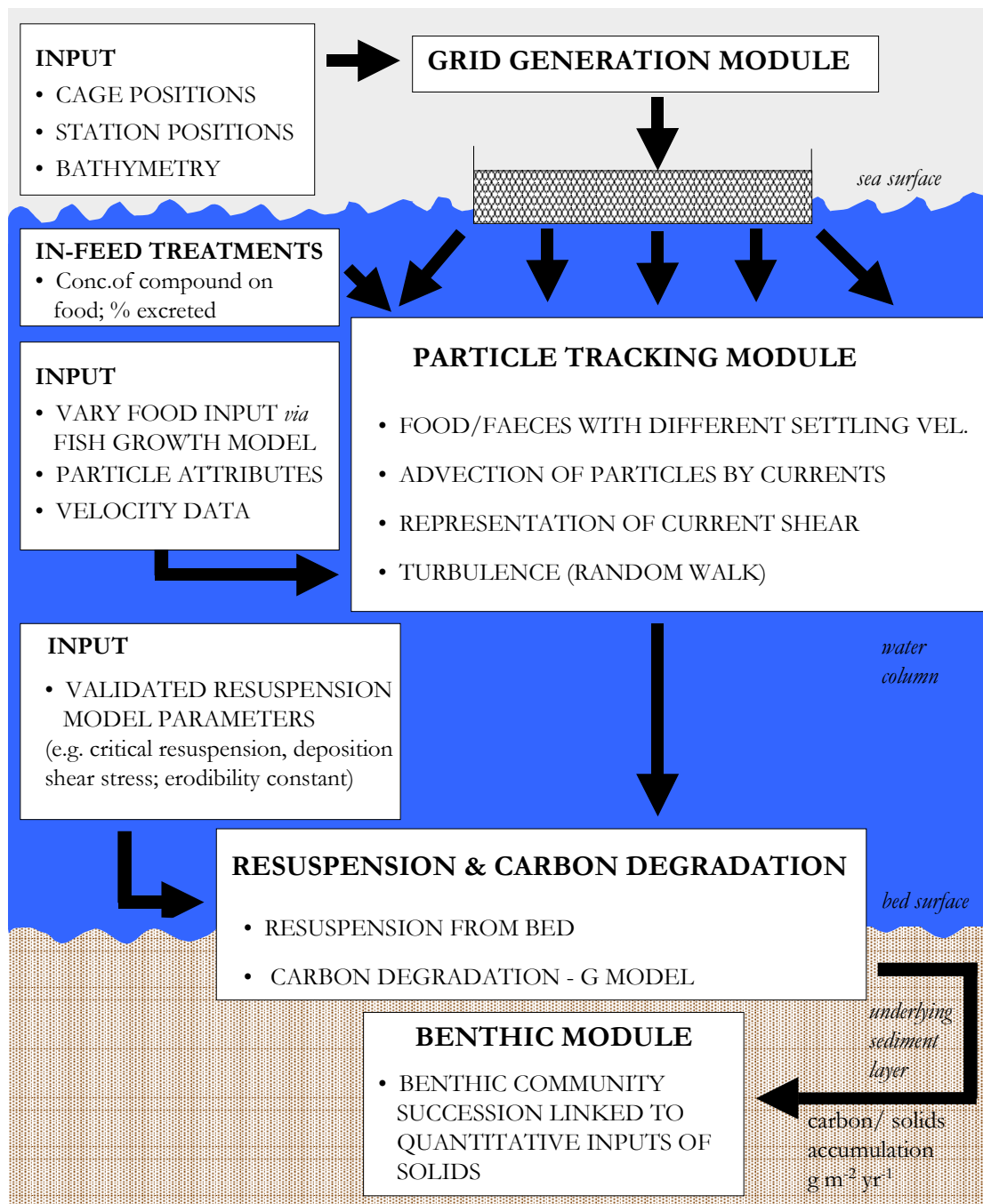


Figure 12. Flow of information through CODMOD based on the DEPOMOD model (Cromey *et al.*, 2002).

4.4.3 Model input data for Vidlin

Bathymetry was taken from Admiralty chart 3282 and cage layout information was provided by the farmer and site surveys. There was some uncertainty on the position and rotation of some of the cages, but as much cage information as possible was confirmed at the time of surveys. The northern 6 cages are Vidlin Outer and the remaining cages are Vidlin North (Figure 8, Figure 14).

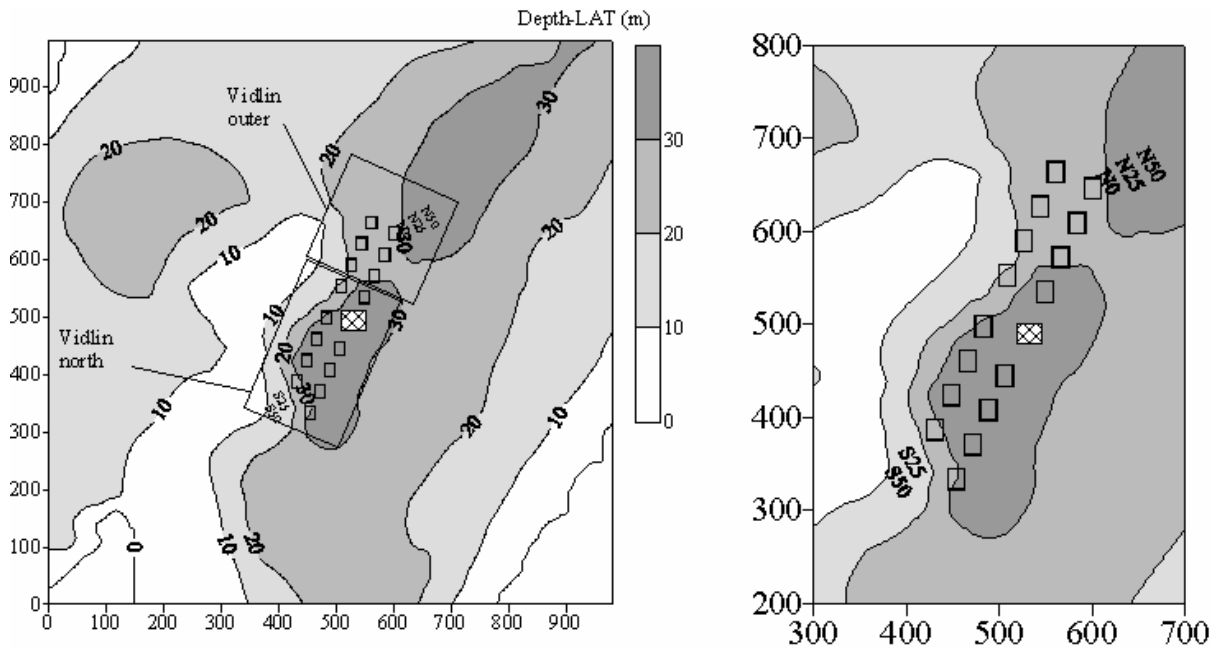


Figure 13. CODMOD model grid for Vidlin cod farm for 2004 and 2005 scenarios (squares are cage centres). All cages are 32 m diameter * 15 m depth. Spacing between cage edges is 9 m.

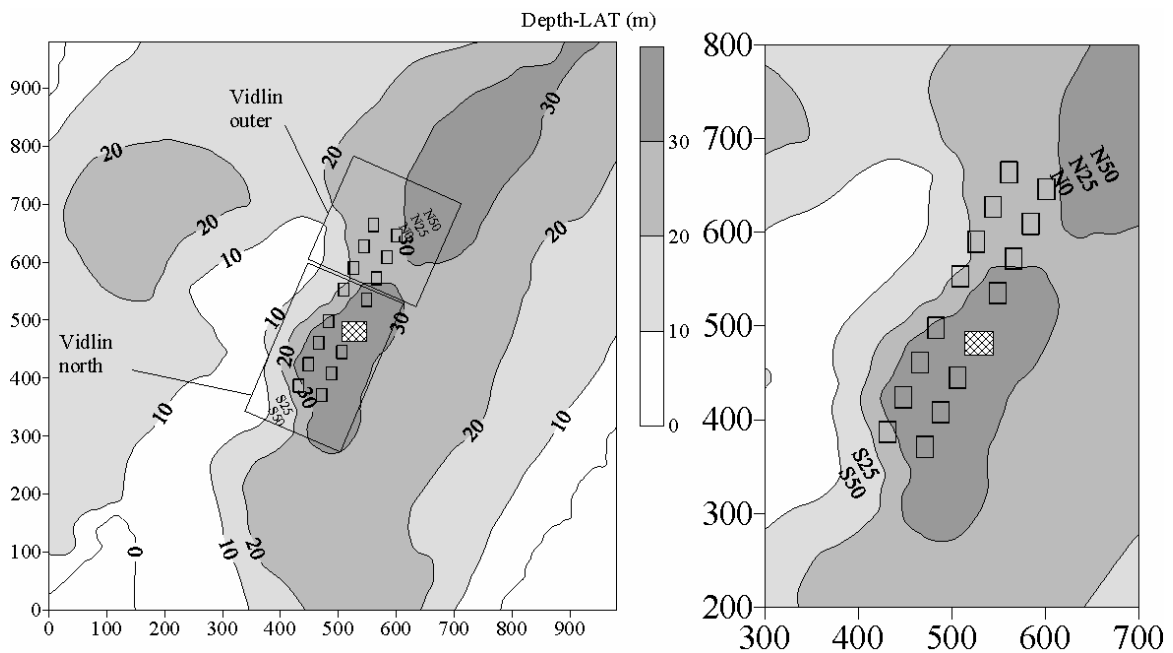


Figure 14. DEPOMOD model grid for Vidlin cod farm for the 2006 scenario (squares are cage centres). All cages are 32 m diameter * 15 m depth. Spacing between cage edges is 9 m.

Feed input data provided by the farmer were used in the model scenarios for each of the survey dates. Data were provided as monthly summaries for both Vidlin Outer and Vidlin North, adjusted to daily rates and distributed evenly across all cages. In assessing these husbandry data, an average value of up to three months is taken depending on the trends in biomass and feed input around the time of benthic survey.

Feed input data are not specified in this report as these data are “commercial in confidence” (Table 5).

A measured faecal output rate of 8.2% of food consumed per day was represented in the model using a digestibility and water content of 91 % and 9 % respectively [= (1-0.91)*0.91 = 0.082].

From husbandry data supplied by the farmer, a settling velocity for the pellet size in use was selected for the 2004 and 2005 scenarios. For the 2006 scenario, 92 % of the feed mass used was made up of 6.5, 9 and 12 mm feeds and so a mean and standard deviation of all these three pellet sizes were used.

As there was some uncertainty in the sampling of the larger particles in the cod experiments, a weighted mean of 3.72 cm s⁻¹ was used, and this is similar to the salmon default value of 3.2 cm s⁻¹. A normal distribution was not used in representing the faecal particles, so all particles had a settling velocity of 3.72 cm s⁻¹.

Modelling scenarios were undertaken with the resuspension model switched on to obtain predictions of waste feed and faecal flux at the sea bed (g solids m⁻² yr⁻¹) and ITI. Predictions were made for each of the sampling stations along the north transect (N0, N25, N50), south transect (S25, S50) and 2 reference stations.

Table 5. Input data used for modelling of Vidlin cod farm for three scenarios.

Input data Scenario	Value			Source
	May 2004	August 2005	July 2006	Admiralty chart
Bathymetry		0 – 35 m		Anon. 2001
Hydrographic survey date		November 2001		Anon. 2001
Instrument type		Nortek 500 kHz ADCP		Anon. 2001
No. of current velocity data sets used		3		Anon. 2001
Height of moorings above sea bed (m); total depth		25.7, 13.7, 4.7; 30		Anon. 2001
Length of current velocity record (days); model time step (mins)		15; 60		Williamson 2004
Sampling stations	0, 25, 50 m (N0, N25, N50)	068°; 25, 50 m (S25, S50)		Williamson 2004 and survey
Months used for FI	May 2004	Jun-Jul 2005	Jun-Aug 2006	
Biomass (tonnes):				Farmer
Vidlin outer (6 cages)	87 in total	181	1390	
Vidlin north (11 cages)		304		
Feed pellet size (mm)	6 mm	9.0 and 12 mm	All	Farmer
Food water content (%)		9		Default – note A
Digestibility (%)		91		Measured – note A
Food wasted as % food fed (%)		5		Default – note B
Food settling velocity (cm s ⁻¹): Mean, sd		9.0, 1.6		Measured
Faecal settling velocity (cm s ⁻¹)		Weighted mean 3.7		Measured
Dispersion coefficients k _x , k _y , k _z (m ² s ⁻¹)		0.1, 0.1, 0.001		Default
Trajectory evaluation accuracy (s)		60		Default
Mean tidal height (m)		1.3		Admiralty tide tables

Notes:

- A. A digestibility and water content of 91 % and 9 % respectively is equivalent to the measured cod faecal output rate of 8.2 % of food consumed per day (= (1-0.91)*0.91 = 0.082).
- B. This is unknown for cod and is the same value as used in regulatory modelling of salmon farms.

Hydrographic data are summarised in section 3.2.

4.5 Results.

4.5.1 Benthic results

4.5.1.1 Benthic survey 2005

Sedimentary conditions next to the cage group on the northern transect, as measured by redox potential, were not extremely reducing in 2005, both in terms of absolute value (mean = -120 mV) at depth or depth of the redox potential discontinuity (RPD), ca 0.5 cm sediment depth (Figure 15). This appears to be a slight deterioration in the conditions relative to those measured by Williamson (2004) (-112.5 mV, 4 cm depth), when 87 t of cod were reported on site. The elevation of the RPD next to the cages was not a significant deterioration, and was similar to redox conditions around Scottish salmon cage sites (Pearson & Black, 2001; Pereira *et al.*, 2004), and is probably due to the increased biomass on the site (484 t in 2005).

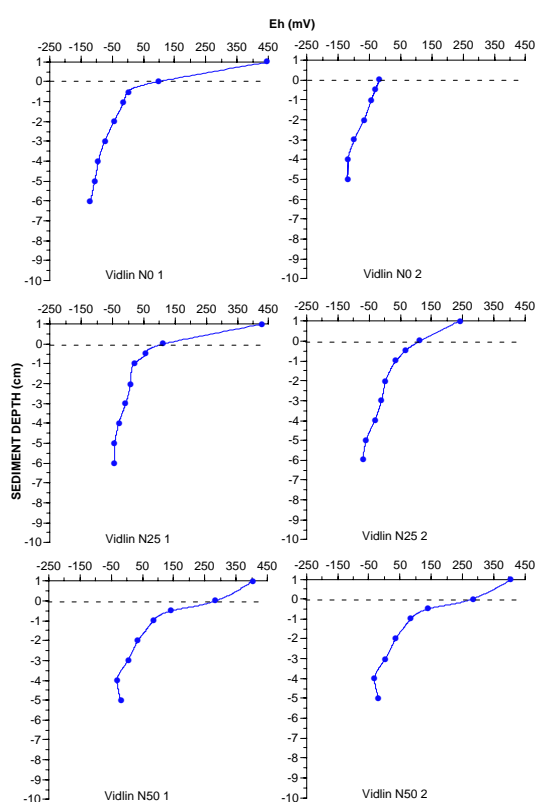


Figure 15. Redox potential profiles (corrected) of the sediment core samples from stations along the northern transect in 2005.

Further along the northern transect, redox conditions at 25 m from the cage edge did change markedly from 2004 – 2005, the RPD remaining ca 3 cm deep, and the minimum value improving. This situation did not extend to 50 m from the cage edge on the northern transect, where the RPD was elevated from 4 cm depth to 2 cm, and the minimum value of -86 mV decreased to -102 mV. As with all redox and physico-chemical measurements obtained from small numbers of grabs and cores, the variance between samples can be large, due to spatial patchiness and lack of heterogeneity. Additionally, these values (redox and RPD depth) are not excessive when compared with sedimentary values at intermediate distance to marine salmon farms (Pereira *et al.*, 2004).

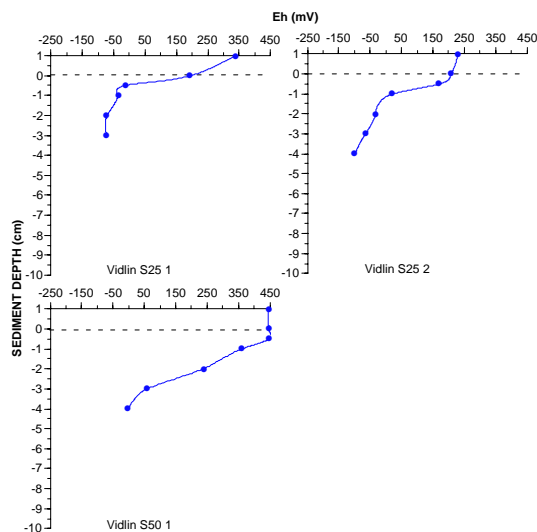


Figure 16. Redox potential profiles (corrected) of the sediment core samples from stations along the southern transect in 2005.

On the southern transect (Figure 16) there was no cage-edge station, in accordance with SEPA guidelines (Anon., 2005). The 25 m station on this transect showed an increase in organic enrichment in 2005, compared to 2004 (min. value = -44 mV, RPD = -5.5 cm in 2004; min. value = -99 mV, RPD = -1.0 cm in 2005). The reference stations (Figure 17) showed little change in redox conditions between 2004 and 2005, remaining positive through nearly the entire sediment core. This would indicate there is no increase in enrichment of the entire voe in this time period.

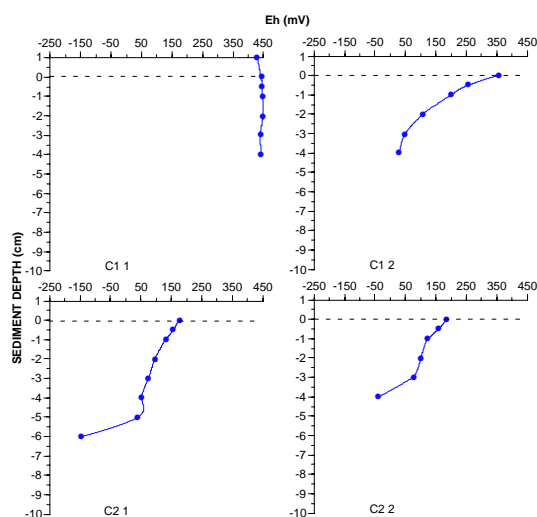


Figure 17. Redox potential profiles (corrected) of the sediment core samples from the reference stations in 2005.

Table 6. The dominant species at each station (% of total abundance and rank) for the 2005 survey

Taxa	N0		N25		N50		S25		S50		C1		C2	
	%	R	%	R	%	R	%	R	%	R	%	R	%	R
<i>Moerella pygmaea</i>	32.6	1	16.0	2	1.2	13	7.2	6	34.0	1	0.1	41	18.6	2
<i>Capitella</i> sp.	21.0	2	1.7	11	3.3	10	14.4	2	5.7	5	6.0	5	0.2	12
<i>Nephtys hombergi</i>	11.6	3	2.4	9	0.4	24	12.0	3	4.7	8	2.1	10	1.5	7
<i>Nephtys longosetosa</i>	7.2	4	1.1	13	0.5	22							1.2	8
<i>Abra alba</i>	5.1	5	1.7	11	2.0	12	6.3	7	4.9	6	0.1	41	0.2	12
<i>Thyasira flexuosa</i>	4.3	6	19.8	1	26.8	1	21.2	1	15.1	2	16.0	1	60.8	1
<i>Chaetozone setosa</i>	2.9	8	7.5	4	6.6	4	1.4	8	1.3	12	1.2	18		
<i>Ophryotrocha hartmanni</i>	2.2	8	5.9	6	5.7	5			0.5	16	0.5	32		
<i>Leitoscoloplos mammosus</i>	1.4	11	4.8	7	5.7	5	11.5	4	7.3	3	4.8	6	2.6	5
<i>Ampelisca tenuicornis</i>	0.7	11	4.0	8	3.6	8	8.7	5	3.1	9	0.1	41	5.5	3
<i>Spio filicornis</i>	0.7	11	0.5	15	1.1	15							0.5	9
<i>Prionospio</i> sp.			14.1	3	11.6	2					1.2	18	3.5	4
<i>Tubificoides benedeni</i>			6.0	5	4.0	7							0.4	9
Oligochaeta spp.			0.3	15	6.7	3								
Sabellidae spp.			0.5	15			1.0	15			10.6	2		
<i>Scalibregma inflatum</i>					0.7	20					6.3	4		
<i>Lumbrineris</i> sp.							0.5	15			7.2	3		
<i>Ampelisca brevicornis</i>									6.5	4				

4.5.1.2 Benthic survey 2006

There were substantial changes in the redox conditions from 2005-2006 at the 0 m station (2005 min value -120 mV, -0.5 cm RPD; 2006 min value -52 mV, -4.0 cm RPD), indicating a reduction in the amount of organic matter reaching the seabed at the northern end of the cage group. The northern transect as a whole experienced reduced organic enrichment as measured by redox potential (Figure 18), with higher minimum values at the 25 and 50 m stations (15 and 8 mV respectively) and no RPD (average values were not negative) compared with 2005 values (see Section 4.5.1.1 above).

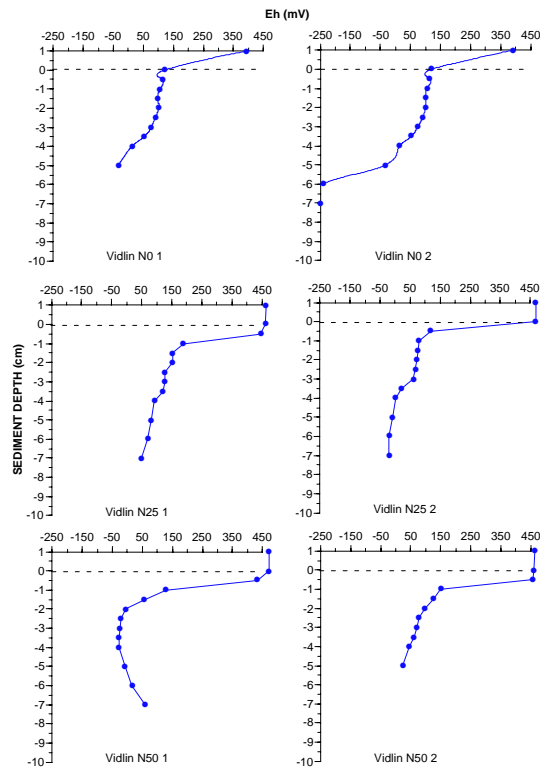


Figure 18. Redox potential profiles (corrected) of the sediment core samples from stations along the northern transect in 2006.

Changes in redox conditions along the southern transect (Figure 19) were mixed in 2006, with minimum values (-12 mV min., -7.0 cm RPD at S25; -56 mV min., -1.0 cm RPD at S50). Given that the biomass of cod on site had roughly tripled in this period from 484 t to 1390 t with attendant increases in food and faeces to the seabed, a large deterioration in sediment redox would have been expected. Interestingly, it would appear from the similar redox conditions at the N0 and S50 stations that the main deposition from the cages to the seabed is to the southwest, and not northeast as the residual current would lead one to expect.

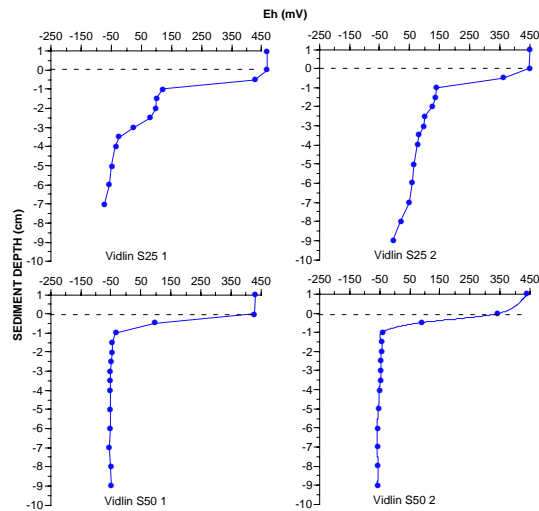


Figure 19. Redox potential profiles (corrected) of the sediment core samples from stations along the southern transect in 2006.

Some indication of a general enrichment of the voe since the 2005 survey can be seen in the redox values from reference stations C1 and C2 in 2006 (Figure 20), which both showed a decrease in RPD depth.

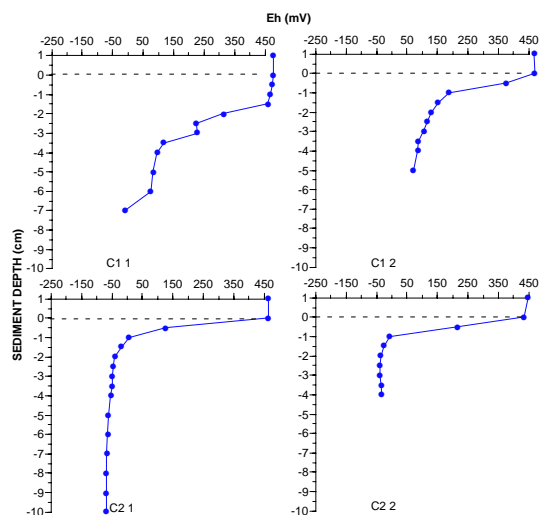


Figure 20. Redox potential profiles (corrected) of the sediment core samples from the reference stations in 2006.

At the N25 station in 2005 the macrofaunal community was dominated by the bivalves *Thyasira flexuosa* and *M. pygmaea*, followed by the polychaete *Prionospio* sp. *Thyasira flexuosa* is commonly found in lightly enriched conditions around salmon farms, while *Prionospio* sp. is typical of moderately enriched conditions (Nickell *et al.*, 1995), which would again indicate that this near-field station was undergoing change. In 2004, the bivalve *Abra alba* was dominant (23 %), followed by *P. longimanus* (16 %) (Williamson, 2004), indicating that this station was only slightly impacted in 2004. Station N50 showed little change in dominant species at the 25 m station in 2005 (Cromeey *et al.*, 2007), as was the case in the 2004 survey (Williamson, 2004).

The two stations on the southern transect, S25 and S50, displayed similar dominant species in 2005 (Cromeey *et al.*, 2007), *T. flexuosa* ranked 2 at 25 m and 1 at 50 m. The other dominant species at these two stations were characteristic of either moderately or lightly enriched conditions (Nickell *et al.*, 1995). The dominant species at these stations in 2004 was the bivalve *Mysella bidentata*, which is not generally indicative of enriched conditions, preferring more sandy/gravelly habitats. Additionally, even though some of the species listed as dominants along both the southern and northern transects in 2005 may be characteristic of organically enriched sediments, they were not dominated by polychaete taxa, which are strong indicators of enrichment.

Examination of the dominant taxa from the 2006 survey (Cromeey *et al.*, 2007) shows the community along the northern transect to be dominated by the opportunistic polychaete *Capitella* sp., ranking 1 at each station, although decreasing in relative abundance from ca 91 % to ca 37 % with distance from the cage edge. The enrichment of station N0 is further displayed by the high rank of *Malacoceros fuliginosus* and Nematoda sp., both of which are indicative of highly enriched sediments (Nickell *et al.*, 1995). The deterioration in station N50 noted above is reinforced by the dominance of *Capitella* sp., as well as the presence of taxa indicative of moderately enriched sediments (*Prionospio fallax*, *Chaetozone setosa*, *Abra alba*, Cirratulidae sp.) (Nickell *et al.*, 1995).

Table 7. The dominant species at each station (% of total abundance and rank R) in 2006.

Taxa	N0		N25		N50		S25		S50		C1		C2	
	%	R	%	R	%	R	%	R	%	R	%	R	%	R
<i>Capitella</i> sp.	91.34	1	84.32	1	36.75	1	10.64	2	61.34	1			3.92	3
<i>Malacoceros fuliginosus</i>	4.87	2	0.86	7			0.19	3	3.35	6			0.98	7
<i>Nematoda</i> sp.	0.97	3	1.51	4			89.17	1	12.27	2			0.98	7
<i>Nemertea</i> sp.	0.92	4			1.2	10								
<i>Nephtys hombergi</i>	0.34	5	2.92	3	12.65	3			3.35	5			13.73	2
<i>Caprella ciliata</i>	0.19	6	0.43	10										
<i>Anaitides mucosa</i>	0.1	7												
<i>Balanus</i> sp.	0.1	7												
<i>Ophryotrocha hartmanni</i>	0.1	7												
<i>Pholoe inornata</i>	0.1	7												
<i>Abra alba</i>			0.86	8	3.01	8			7.81	3				
<i>Ampelisca brevicornis</i>					3.61	7							1.96	5
<i>Chaetozone setosa</i>					4.82	5					2.73	7		
<i>Cirratulidae</i> sp.					2.41	9			1.12	8				
<i>Jasmineira caudata</i>											2.42	9		
<i>Leitoscoloplos mammosus</i>											4.55	4		
<i>Lumbrineris</i> sp.											3.03	6		
<i>Moerella pygmaea</i>													2.94	4
<i>Nephtys assimilis</i>			0.54	9										
<i>Paradonais lyra</i>											8.18	2		
<i>Pectinaria belgica</i>									1.12	9			0.98	7
<i>Phaxas pellucidus</i>					4.22	6			2.6	7				
<i>Prionospio fallax</i>					7.23	4					2.73	7	0.98	10
<i>Protodorvillea kefersteini</i>			0.86	6										
<i>Sabellidae</i> sp.											5.76	3		
<i>Scoloplos armiger</i>											3.33	5		
<i>Spiophanes bombyx</i>													1.96	5
<i>Thyasira</i> sp.			1.19	5	15.66	2			4.83	4	20.61	1	69.61	1
<i>Trichobranchus glacialis</i>									0.37	10	2.12	10		
<i>Tubificoides benedeni</i>			3.57	2										

The southern transect station S25 showed classic evidence of enrichment in the dominance of its taxa by *Nematoda* spp., *Capitella* sp. and *Malacoceros fuliginosus* (Cromeey *et al.*, 2007), although somewhat surprisingly *Capitella* sp. was ranked second in 2006, not first. At the next station away from the cages, S50, *Capitella* sp. had become the dominant species and *Nematoda* spp. second most numerically dominant, with the other taxa in the population largely indicative of enriched conditions. Interestingly, the two reference stations, even though widely separated and in different water depths (Cromeey *et al.*, 2007) were numerically dominated in 2006 by the bivalve *Thyasira* sp.

Table 8. Benthic indicators (mean values) from Vidlin Voe, 2005 SAMS survey.

Parameter	Station							
	N0	N25	N50	N75	S25	S50	C1	C2
ITI	42.73	40.6	39.17	46.31	43.2	57.08	56.46	45.46
No. species S	14	25	47	36	17	20	57	20
Abundance N	69	161	379	365	104	193	373	428
Margalef's d	2.98	4.72	7.64	5.85	3.34	3.61	9.45	3.13
Pielou's J'	0.76	0.72	0.72	0.63	0.77	0.73	0.82	0.46
Brillouin	1.72	2.11	2.58	2.09	1.93	2.03	3.07	1.31
Shannon H' log _e	1.98	2.32	2.75	2.23	2.15	2.18	3.29	1.38
Simpson's 1-λ	0.79	0.83	0.89	0.81	0.83	0.83	0.94	0.58
AMBI	2.47	3.54	3.34	3.29	2.8	1.69	2.43	2.27
Redox _{-2cm}	-56	4.5	-20.5	89	-52	241	277	98.5
% Carbon	1.2	1.2	1.2		1.5	1	0.9	1.1
% Nitrogen	0.14	0.15	0.15		0.15	0.13	0.12	0.13
Distance (m)	0	25	50	75	25	50	500	500
Depth	29	28	25	26	17	16	32	17

Table 9. Benthic indicators (mean values) from Vidlin Voe, 2006 SAMS survey.

Indicator	Station							
	N0	N25	N50	S25	S50	C1	C2	
ITI	1.89	3.63		40.18	0.01	14.1	55.55	37.46
No. species S	16	18		16	3	12	46	8
Abundance N	1031	458		83	6907	136	159	51
Margalef's d	2.09	2.69		3.28	0.23	2.14	8.78	1.65
Pielou's J'	0.18	0.25		0.75	0.38	0.58	0.86	0.57
Brillouin's	0.48	0.66		1.78	0.42	1.31	2.9	0.97
Shannon H' log _e	0.72	1.03		2.99	0.6	2.05	4.73	1.66
Simpson's 1-λ	0.19	0.25		0.81	0.26	0.61	0.94	0.52
RPD	-4				-7	-1	-7	-1
Redox _{-2cm}	61.5	112.5		46.5	112.5	-45.5	221.5	-38.5
% Carbon	1.04	1.09		1.11	3.79	1.97	1.32	1.11
% Nitrogen	0.16	0.15		0.13	0.41	0.23	0.18	0.16
mean labile OM	3.65	4.26		4.035	10.2	5.735	5.52	4.67
Rp	0.0812	0.1494		0.0525	0.0489	0.0998	0.1416	0.0887
TOP	0.05	0.07		0.03	0.20	0.12	0.04	0.03
Distance (m)	0	25		50	25	50	500	500
Depth (m)	29	28		25	17	16	32	17

Surficial CHN levels were very low and uniform along both transects for 2005 (Cromeey *et al.*, 2007).

Table 10. Vidlin Voe sedimentary organic carbon and nitrogen (% dry weight) in the top 40 mm (2005 values).

Station	% Carbon	% Nitrogen
N0	1.2	0.14
N25	1.2	0.15
N50	1.2	0.15
S25	1.5	0.15
S50	1.0	0.13
C1	0.9	0.12
C2	1.1	0.13

Organic matter content along the 2006 survey transects, as determined by LOI, is presented in Table 11. These data show, contrary to expectations, no strong gradient of organic matter away from the source of enrichment (the cage group), rather an elevated level of enrichment with a pronounced peak at the S25 station. Not surprisingly apart from the reference station C1, most of the organic material is labile in nature, suggesting (but not establishing) fish farm origin, while the C1 station is perhaps more enriched with refractory plant material.

Table 11. Organic matter values determined by LOI for 2006.

Sample	% labile OM	% refractory OM	% total OM = labile OM + refractory OM	Mean % total OM	Mean Rp
N0 1	3.76	0.43	4.19	3.98	0.081186383
N0 2	3.54	0.22	3.77		
N25 1	4.92	0.97	5.89	5.02	0.149428847
N25 2	3.60	0.56	4.16		
N50 1	4.16	0.25	4.42	4.26	0.052527654
N50 2	3.91	0.19	4.10		
S25 1	8.10	0.64	8.74	10.67	0.048856804
S25 2	12.30	0.31	12.61		
S50 1	6.39	0.33	6.72	6.35	0.099757668
S50 2	5.08	0.90	5.98		
C1 1	5.67	1.05	6.73	6.44	0.141628408
C1 2	5.37	0.78	6.15		
C2 1	5.27	0.64	5.90	5.14	0.088657385
C2 2	4.07	0.30	4.37		

Organic carbon values were also measured, and follow roughly the same trends observed for OM in 2006 (Table 12):

Table 12. Organic carbon determined by CHN in 2006.

Station	% Carbon	% Nitrogen
N0	1.04	0.16
N25	1.09	0.15
N50	1.11	0.13
S25	3.79	0.41
S50	1.97	0.23
C1	1.32	0.18
C2	1.11	0.16

4.6 Evaluation of Indicator Performance

Discuss and evaluate (statistically as appropriate) the validity etc of the Indicators under test.

Table 13. Correlation matrix (Pearson's product-moment correlation coefficient r) for all univariate indicators tested in 2005. Data are transformed (N , S , $Redox_{-2cm}$, $Distance = \log(x+1)$; $Pielou$'s, $Brillouin$'s, $Shannon$, $Simpson$'s, $AMBI$, TOC & $TON = \sqrt{x}$) where appropriate.

	<i>ITI</i>	<i>S</i>	<i>N</i>	<i>Margalef</i>	<i>Pielou</i>	<i>Brillouin</i>	<i>Shannon</i>	<i>Simpson</i>	<i>AMBI</i>	<i>Redox_{-2cm}</i>	<i>TOC</i>	<i>TON</i>	<i>Distance</i>	<i>Depth</i>
<i>ITI</i>	1													
<i>S</i>	0.204	1												
<i>N</i>	0.237	0.747	1											
<i>Margalef</i>	0.236	0.971	0.597	1										
<i>Pielou</i>	0.183	0.182	-0.476	0.366	1									
<i>Brillouin</i>	0.301	0.824	0.282	0.904	0.702	1								
<i>Shannon</i>	0.269	0.768	0.181	0.869	0.768	0.994	1							
<i>Simpson</i>	0.196	0.536	-0.109	0.653	0.907	0.904	0.935	1						
<i>AMBI</i>	-0.742	0.355	0.087	0.311	0.063	0.246	0.256	0.249	1					
<i>Redox_{-2cm}</i>	-0.734	0.358	0.093	0.308	0.065	0.251	0.260	0.259	0.999	1				
<i>TOC</i>	-0.151	-0.345	-0.411	-0.227	0.237	-0.086	-0.047	-0.024	-0.251	-0.257	1			
<i>TON</i>	-0.095	-0.277	-0.352	-0.160	0.246	-0.027	0.007	0.009	-0.273	-0.276	0.992	1		
<i>Distance</i>	-0.177	-0.295	-0.386	-0.182	0.255	-0.038	-0.001	0.020	-0.200	-0.202	0.993	0.995	1	
<i>Depth</i>	-0.084	0.513	0.012	0.623	0.446	0.583	0.618	0.520	0.460	0.448	-0.207	-0.154	-0.158	1

$p > 0.05$

$p < 0.05$

$p < 0.01$

Table 14. Correlation matrix (Pearson's product-moment correlation coefficient r) for all univariate indicators tested in 2006. RPD = redox potential discontinuity; Rp = index of refractory OM/labile OM; TOP = organic phosphorous. Data are transformed ($ITI, S, N, Margalef, Redox_{2cm}, Distance = \log(x+1), Pielou, RPD, TON, Rp, OP = \sqrt{x}$) where appropriate.

	<i>ITI</i>	<i>S</i>	<i>N</i>	<i>Margalef</i>	<i>Pielou</i>	<i>Brillouin</i>	<i>Shannon</i>	<i>Simpson</i>	<i>RPD</i>	<i>Redox_{2cm}</i>	<i>TOC</i>	<i>TON</i>	<i>labile OM</i>	<i>Rp</i>	<i>TOP</i>	<i>Distance</i>	<i>Depth</i>
ITI	1																
S	0.592	1							p>0.05								
N	-0.933	-0.489	1						p<0.05								
Margalef	0.730	0.976	-0.594	1					p<0.01								
Pielou	0.821	0.320	-0.624	0.513	1												
Brillouin	0.809	0.542	-0.592	0.675	0.858	1											
Shannon	0.822	0.728	-0.586	0.851	0.866	0.897	1										
Simpson	0.879	0.557	-0.683	0.714	0.960	0.923	0.955	1									
RPD	-0.287	-0.082	0.530	-0.076	0.009	0.179	0.096	-0.034	1								
Redox _{2cm}	-0.240	0.234	0.441	0.189	-0.177	-0.044	0.092	-0.101	0.261	1							
TOC	-0.605	-0.718	0.716	-0.679	-0.066	-0.290	-0.327	-0.266	0.515	0.0001	1						
TON	-0.621	-0.686	0.731	-0.659	-0.109	-0.301	-0.337	-0.302	0.608	-0.031	0.986	1					
labile OM	-0.509	-0.647	0.664	-0.585	0.037	-0.212	-0.208	-0.172	0.579	0.070	0.979	0.974	1				
Rp	0.280	0.688	-0.299	0.638	-0.0004	-0.020	0.325	0.133	-0.089	0.017	-0.485	-0.398	-0.392	1			
TOP	-0.727	-0.656	0.737	-0.681	-0.281	-0.508	-0.479	-0.432	0.324	-0.139	0.914	0.909	0.844	-0.305	1		
Distance	0.717	0.173	-0.590	0.364	0.811	0.510	0.645	0.701	-0.026	-0.180	-0.052	-0.057	0.108	0.275	-0.252	1	
Depth	0.156	0.818	-0.024	0.730	-0.069	0.234	0.411	0.169	0.065	0.703	-0.556	-0.540	-0.502	0.488	-0.531	-0.187	1

4.7 Evaluation of Model Performance

4.7.1 Validation of benthic response model

The DEPOMOD benthic response model defines a relationship between flux and ITI and was validated for salmon fish farms. The model has an Envelope of Acceptable Precision, the width of which decreases with increasing impact as natural variability decreases and model performance increases. In the original data set shown in Figure 21, 88 % of stations fell within the EAP. The benthic response curve shown allows prediction of how ITI will change with predicted flux.

Using CODMOD at the Vidlin site, model predictions of flux were obtained for each station and with observed ITI, plotted in Figure 21. Transect stations and reference stations for all three scenarios are shown.

The model predicted impact at the stations for the 2004 and 2005 scenarios adequately (Table 15), but the model underperformed for the 2006 scenario. In summary, 56 % of stations were predicted satisfactorily, excluding the reference stations as these are not stringent tests of the model.

The model under-predicted impact at sampling stations for the 2006 survey, particularly on the southern transect where S25 and S50 were observed to be highly and moderately impacted respectively. These stations are identified as the points below the EAP at $1 \text{ g m}^{-2} \text{ yr}^{-1}$. Later in this section, sensitivity of the model performance is tested with particular reference to this transect, considering the re-suspension model, cage rotation and hydrographic data.

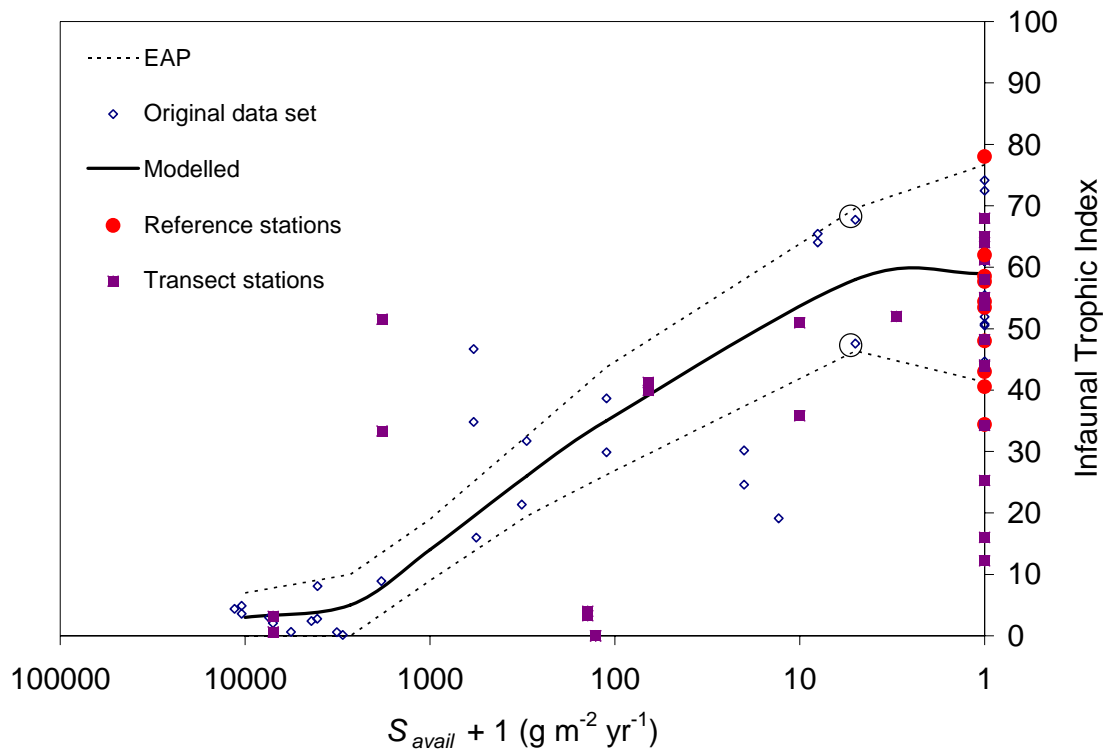


Figure 21. DEPOMOD benthic response curve showing the transect stations and reference stations for Vidlin cod farm predicted using CODMOD. Where the stations fall within the Envelope of Acceptable Precision (EAP), the model has predicted benthic response adequately. Circles give an example of excess variability between 0.1 m² grab duplicates.

Table 15. Predicted and observed ITI for the modelling scenarios (with resuspension model switched on). Sampling station locations are shown in Figure 8 and Figure 14. If an observation falls in the Envelope of Acceptable Precision (EAP), then the model has predicted the situation at the station adequately. Duplicate 0.1 m² data for observed ITI are shown for 2005 and 2006.

Scenario	Station	N0	N25	N50	S25	S50	C1	C2
	Distance from cages	0 m	25 m	50 m	25 m	50 m	>500 m	> 500 m
May 2004	Predicted flux (g m ⁻² yr ⁻¹)	2	0	0	0	0	0	0
	Predicted ITI	58 ± 12	59 ± 18	59 ± 18	59 ± 12	59 ± 18	59 ± 18	59 ± 18
	Observed ITI	52	64	58	65	68	78	62
	In EAP (Y/N)?	Y	Y	Y	Y	Y	(Y)	Y
August 2005	Predicted flux (g m ⁻² yr ⁻¹)	1815	65	0	9	0	0	0
	Predicted ITI	9 ± 5	39 ± 10	59 ± 18	53 ± 13	59 ± 18	59 ± 18	59 ± 18
	Observed ITI	34, 52	41, 40	34, 44	35, 51	61, 53	59, 54	48, 43
	In EAP (Y/N)?	N, N	Y, Y	N, Y	N, Y	Y, Y	Y, Y	Y, Y
July 2006	Predicted flux (g m ⁻² yr ⁻¹)	7046	139	0	126	0	0	0
	Predicted ITI	4 ± 4	17 ± 5	59 ± 18	28 ± 7	59 ± 18	59 ± 18	59 ± 18
	Observed ITI	1, 3	4, 3	55, 25	0, 0	16, 12	58, 53	41, 34
	In EAP (Y/N)?	Y, Y	N, N	Y, N	N, N	N, N	Y, Y	Y, N
14 out of 25 observations (56 %) in EAP (excluding reference stations)								

4.7.2 Sensitivity analysis – the complex problem of hydrographic data and cage rotation

Sensitivity of model predictions to the resuspension model, hydrographic data length and cage movements required evaluation. When modelling a site for regulatory purposes, a 15 day current meter record representative of 1 spring-neap cycle is typically used. Cromey & Black (2005) measured hydrography in a Scottish sea loch over 206 days and determined large differences between 15 day periods. For example, the mean near-bed current speed for the least dispersive 15 day period in Table 16 is 2.0 cm s⁻¹, and this is nearly 5 times lower than the most dispersive period. More importantly, the period of data used in regulation of the site is very different to the 206 day average.

Table 16. Differences in summary statistics of hydrographic data measured at a macro-tidal Scottish fish farm, not Vidlin. The most and least dispersive 15 day periods were selected from the 206 day record. The consent record was used in regulatory procedures for the site and was from a different period (table reproduced from Cromey & Black, 2005).

Portion of data set	Meter location	Speed (cm s ⁻¹)			Residual Direction (°T)	Length (d)
		Mean	Max.	Residual		
Whole	Surface	10.6	48.8	3.2	219	206
	Near bed	5.9	47.0	0.6	207	
Most dispersive	Surface	14.8	48.8	5.4	223	15
	Near bed	9.6	47.0	1.0	241	
Least dispersive	Surface	6.4	19.6	1.8	209	15
	Near bed	2.0	7.1	0.1	74	
Consent record	Surface	2.7	21.8	1.7	72	15
	Near bed	3.8	16.7	0.6	279	

Cage rotation and empty cages within the leased area are common during normal operation of a farm and it is difficult for modelling to take this into account in a detailed way. This is particularly important where benthic sampling transects are located near empty cages or areas of cage rotation. To overcome this, the model is run either assuming all cages are equally stocked, or by approximating biomass distribution between cages using available husbandry information.

In the case of Vidlin, the southern transect for stations S25 and S50 for July 2006 is impacted and the model predicts much less impact than is observed (Table 15). In terms of the biological community and amount of organic matter present in the surficial sediments, S25 was highly enriched in 2006, while S50 was moderately enriched.

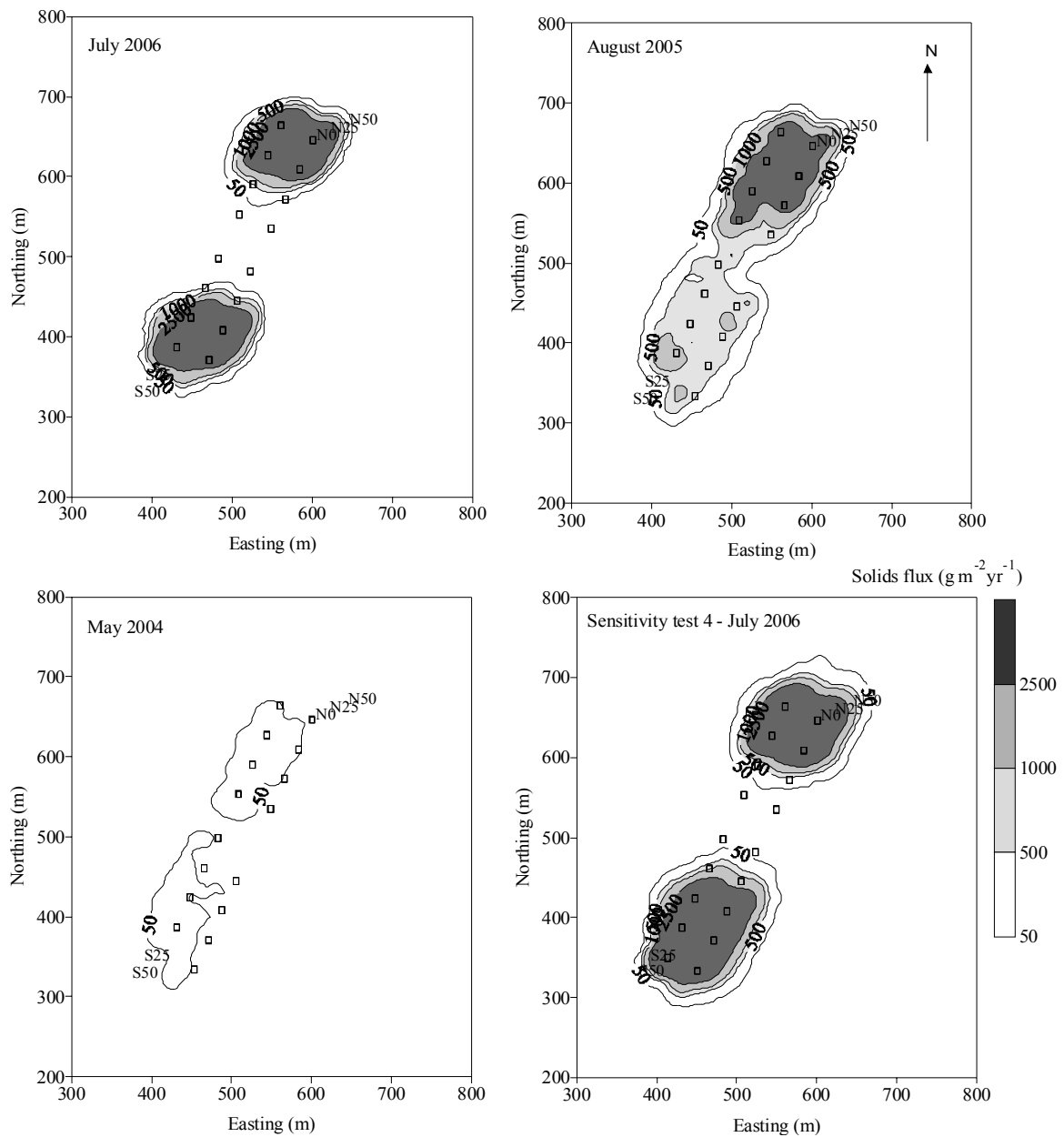


Figure 22. Predicted flux of waste faecal and feed material ($\text{g m}^{-2} \text{yr}^{-1}$) from Vidlin cod farm for the three survey dates 2004 to 2006. A modified scenario is shown for sensitivity test 4, July 2006, showing the effect of additional cages and reduced current speed.

During the 2005 survey, an additional cage was noted at the southern end of the group (Figure 8), indicating this area is subject to cage rotation. This scenario was tested in the model. Hydrographic data used in the model were measured in November 2001 during a period where mean and maximum wind speeds were 17 and 32 knots respectively, which is not especially windy for this area. Stations S25 and S50 are inshore of the cage group position and at the opposite end of the cage group from where the current measurements were taken. Cage shadowing is likely, causing a reduction in current speed. Sensitivity of the model predictions to reduced current was therefore tested.

The resuspension model caused some resuspension events at the site as near bed current speeds exceeded 9.5 cm s^{-1} , resulting in 39 % of the total released mass being exported from the immediate area around the farm. The resuspension model was switched off to test sensitivity. Reducing current also effectively reduced the number of resuspension events so that the total exported was less than 5 %.

Objective – to test the sensitivity of benthic impact predictions to resuspension model predictions, additional cages and reduced current; particular attention was paid to the southern transect stations S25 and S50.

Control scenario – this is the scenario using measured current and available information on cage layouts.

Summary of tests:

1. Resuspension model OFF using measured current
2. Resuspension model ON. Current speed was reduced at all depths by scaling down 25 % to simulate the effect of cage shadowing of the inshore southern transect and a more quiescent period than that measured in November 2001
3. Resuspension model ON. Using measured current, 2 additional cages were then added at the southern end of the group and the biomass at this end of the group was evenly distributed over 6 cages instead of 4; this was to simulate the effect of cage movements near sampling transects and the effect of benthic sampling over previously farmed areas
4. Resuspension model ON. Both reduced current and additional cages in a combination of tests 2 and 3

To undertake a rigorous test, the July 2006 scenario only was used as this was where the observed impact was the highest and the model performance was the lowest, as seen by the number of data falling outside the EAP (Table 15). In addition, reference stations were excluded as these are well outside the Allowable Zone of Effect and so are not a stringent test of the model.

The results of this sensitivity test and model performance are shown by the regression plots in Figure 23 and a contour plot showing the additional cages and deposition footprint is given in Figure 22 for test 4.

Where cage rotation effects were modelled (test 3) as well as reduced current (test 4), R^2 values for predicted and observed ITI improved from 0.46 to approximately 0.8. This was primarily a result of increased model performance at the south transect. Switching resuspension off or reducing current, degraded model performance.

In conclusion, this sensitivity analysis demonstrates the importance of cage rotation and representative hydrographic data in both modelling and locating sampling stations transects.

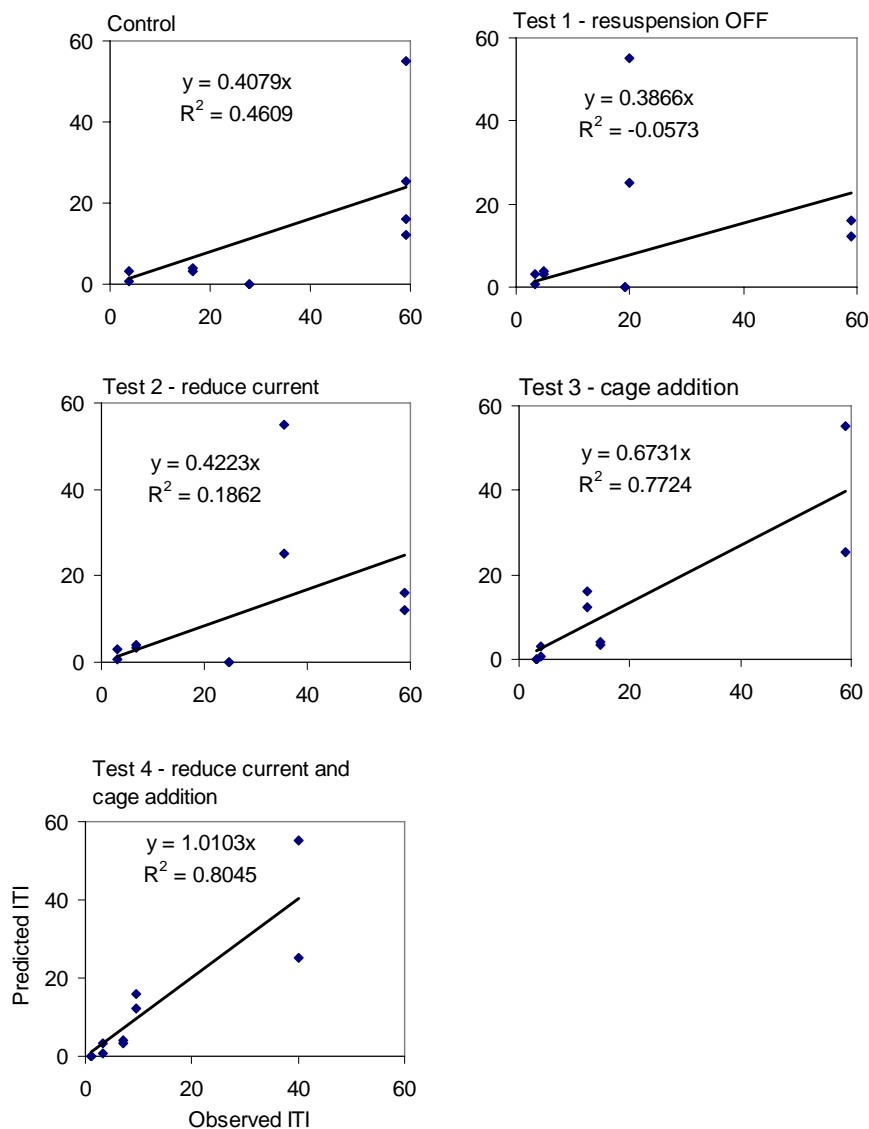


Figure 23. Sensitivity analysis of model performance. When cages were added to the end of the group to simulate cage rotation and current reduced, model performance improved.

4.8 Site specific conclusions

Zone A

Using the most recent survey for Vidlin for 2006, the indicators used in assessing the site describe impacted sediments up to 25 m in the north transect (N0, N25) and up to 50 m in the south transect (S25, S50). For this survey, all of the biotic indices the benthic fauna indicators species, abundance, ITI, Margelef's D, Pielou's Evenness J, Shannon H', Simpson's and Brillouin's showed impact at these stations. This suggests they are all useful indicators. Using the sediment indicators to assess these impacted stations, the indicator LOI describes the effect adequately, correlating with biotic indices.

None of the physical sediment indicators (RPD, Redox_{2 cm}, TOC, TON, labile OM, Rp, Distance, Depth or TOP) correlated with the biotic indices at three out of the four biologically impacted stations. Redox measured at S50 indicated a greater impact than was described by the biotic indices.

TOC and TON indicators have generally flat gradients showing little difference between the stations, apart from station S25. Therefore, these indicators do not correlate well with the biotic indicators for these impacted stations.

The impact of the farm is up to 25 m to the north and 50 m to south in zone A.

With regards to modelling, the impact described was to some extent confirmed by the CODMOD model which was validated at the site. Predictions of flux and ITI at stations suggest impact, but the impact at the 50 m station (S50) was not predicted by the model. In the previous modelling section, sensitivity analysis showed that model performance was improved by including some cage rotation effects and modifying the current flows at the southern end of the group.

Zone B

No water column or benthic samples were taken from other areas of the Voe, with the exception of the 2 reference stations for the benthic monitoring survey. These reference stations included the full suite of measures undertaken at each of the sampling stations.

All of the biotic indicators suggested that control station C2 was disturbed. In addition, sediment chemistry indicator Redox correlated with biotic indicators at this station describing disturbed sediments, but % carbon and % nitrogen did not describe C2 as disturbed. Station C2 is towards the head of the voe and to the south of the cages, whereas the other reference station C1 is to seaward of the cages, where flushing with the outside sea will be greater than at C2. Given the enrichment of control station C2 and station S50, the area to the south of the cages is likely to have reduced current, longer flushing time and has disturbed sediments. It is not possible to conclude the source of enrichment at the head of the voe and whether this disturbance at zone B is caused by the aquaculture activities. As a result, development of aquaculture in the southern corner of the voe should be avoided.

The ECE model classified Vidlin in terms of nutrient enrichment as borderline 3 and 4, with 1 being low risk of enhancement and 5 as high. As previously described, this model is based on tidal excursion and does not take into account wind driven flows or waves. This model will therefore classify the system as higher risk than it actually is, so the classification is likely to be 3.

There are no anticipated effects on zone C – none.

Consider the Ecosystem Approach including socio-economic aspects and the consequences of the farm for other users and stakeholders.

Comment on the capacity of the environment in terms of waste assimilation, provision of environmental services to aquaculture as well as aesthetic and cultural aspects.

Comment on sustainability and future prospects for aquaculture within Zones A, B and C.

The capacity of Vidlin Voe for supporting aquaculture is relatively high due to the quite short flushing time, connection with the northern North Sea and wind driven nature of the site. Although the site could sustain further development without impacting zone A, further hydrographic measurements would be useful for assessing the impact of zone B. The basis for this recommendation is based on the relatively high nutrient enhancement index and the disturbed sediments measured close to the head of the voe. Any further development of aquaculture in the voe is not likely to impact water body at zone C.

The area around Vidlin Voe is well set up for provision of environmental services to aquaculture. Personnel and local establishments such as the North Atlantic Fisheries College and consultants can provide the environment services required.

4.9 Culture type and environment type conclusions

During the course of the ECASA project, an ECASA model DEPOMOD was validated at Vidlin as part of another, externally funded project. Given the precautionary approach by the regulator and the lack of information available on the environmental effects of cod, the cod aquaculture operations in the voe were limited to a certain percentage of an equivalent salmon consent. As a result of the model validation work, we conclude that providing cod specific input data are used in the model, no special considerations are required when modelling cod farms (i.e. the same regulatory model procedures used for salmon farms can be used).

From the monitoring view point and incorporating the results of the ECASA biotic and sediment chemistry indicators, the cod farm in Vidlin Voe did not impact the environment any different to a salmon farm of equivalent size.

Some of the ECASA indicators did not all correlate with regards to the most impacted stations. Redox (-2 cm), % C and % N did not correlate very well with biotic indices at this site. Comparison with other ECASA data from other sites will determine whether this is a general short coming with these indicators, or if the shortcoming is related to the culture and environment type.

Vidlin Voe in Shetland is very windy, and subject to ocean swell at times. The ECASA model DEPOMOD does to some extent take account of wind driven flows, but only those measured during the period of current meter deployment only. For such a wind driven site, current meter and concurrent meteorological measurements of at east 1 month would allow a much better assessment of the site. Indeed, future development of the site may well be limited by the existing hydrographic data. The more wind driven a site, the longer the hydrographic record should be taken.

The ECE model only takes into account tidal range in calculating flushing time, and therefore for a windy place such as Vidlin, will over-estimate the nutrient enhancement index.

Evaluate and prioritize the most appropriate tools and methods for Environmental Impact studies at such sites and also comment on appropriate monitoring strategies – compare ECASA recommendations with current practice.

The ECASA indicator Loss on Ignition (LOI) evaluates components of highly degradable (labile) and non-degradable (refractory) organic material. This indicator showed better correlation with biotic indices at impacted stations than % carbon and % nitrogen analysed with CHN analyser. LOI is therefore a useful indicator and replacing CHN analyses with LOI should be investigated further.

It is well accepted that good quality hydrographic measurements are necessary for site assessment. As this site is windy, 15 days of current meter measurements are likely to be inadequate and only a snap shot of conditions. In addition, the area to the south and south east of the cages towards the head of the loch appears to be depositional. Hydrographic information on this area would help to further inform the assessment of station S50 and control station C2, as well as the assimilative capacity of the system at zone B.

Station C2 is not a reference station, as it appears to be in a depositional area of the loch. Care is required when selecting reference stations.

Cage rotation and movements can result in unrepresentative sampling station transects. Normally, monitoring surveys should be undertaken when the site is at maximum biomass, so the maximum number of cages should be in position at that time. If a monitoring survey is undertaken at any other time than at peak biomass, than future cage movements may sampling at a station may become unrepeatable.

The information from the sampling stations at this site was adequate to assess the cod farm and this type of environment. The new sampling station strategy for monitoring of Scottish sites which is near cage and boundary of effect (Allowable Zone of Effect ± 10 m), was not tested at Vidlin. Due to the historical sampling strategy at Vidlin, it was prudent to continue sampling at the same stations so that a time series was obtained.

Of the sediment indicators, only redox_{-2cm} correlated in 2005 with AMBI and ITI; depth and no. of species were the only correlated biotic/abiotic indicators in 2006.

In conclusion, with regards to current monitoring practice, ECASA partners from this report recommend:

- Redox values seem uncorrelated with degree of impact; LOI values for labile OM appear more appropriate
- take care with siting of reference stations
- question operator with regards to cage movements pre-survey, to ensure that 0 m and boundary stations are true representations

5 Acknowledgements

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Appendices

Appendix 1. Environmental policy, codes of good practice etc of farmer.

The Cod sites and Hatchery are fortunate to be situated amid a pristine, natural environment. It is fundamental to our future that in conducting our farming operations we minimise any negative impact on the environment. To this end we place a strong emphasis on environmentally sensitive production methods.

As an aquaculture stakeholder we shall work together with other water users to assure equitable use of the resource and mutual understanding. This will be done not only through the regulatory process, but also through local community liaison and involvement.

All our sites shall be designed, developed and managed with a view to the equitable and efficient use of resources. Sites shall be compatible with:

- Long term sustainable operations
- Acceptable ecological effects.

Site selection shall be maximised through the use of Environmental Impact Assessment at the initial stages of application – consideration shall be given to all factors relating to the sites interaction between the environment and local surroundings.

We shall apply site specific best available technology and procedures in order to optimise both the farm husbandry and the interactions of the farm with the environment.

We shall seek to minimise the potential risks that are presented by farmed fish escapes to wild fisheries.

Appendix 2. Details of all methods used (indicators, models, etc)

Indicators:

Biotic	Physical
ITI	RPD
No. species S	Redox _{-2cm}
Abundance N	TOC
Margalef's d	TON
Pielou's J'	labile OM
Brillouin's	Rp
Shannon H' log _e	TOP
Simpson's 1-λ	Distance
AMBI	Depth

Models:

DEPOMOD/CODMOD

Hydrographic data for Vidlin

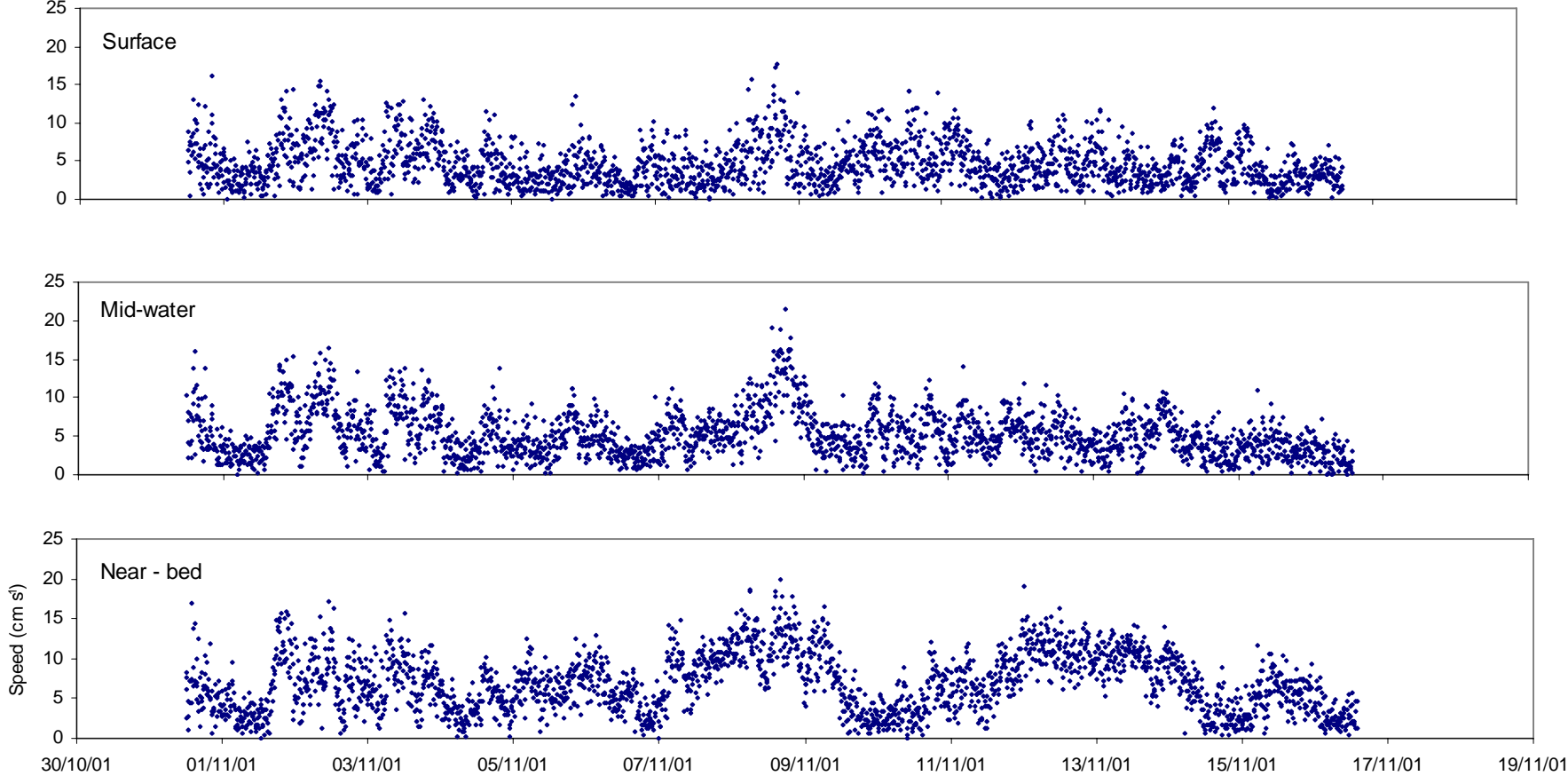


Figure 24. Historical time series of current speed measured at Vidlin at three different depths.

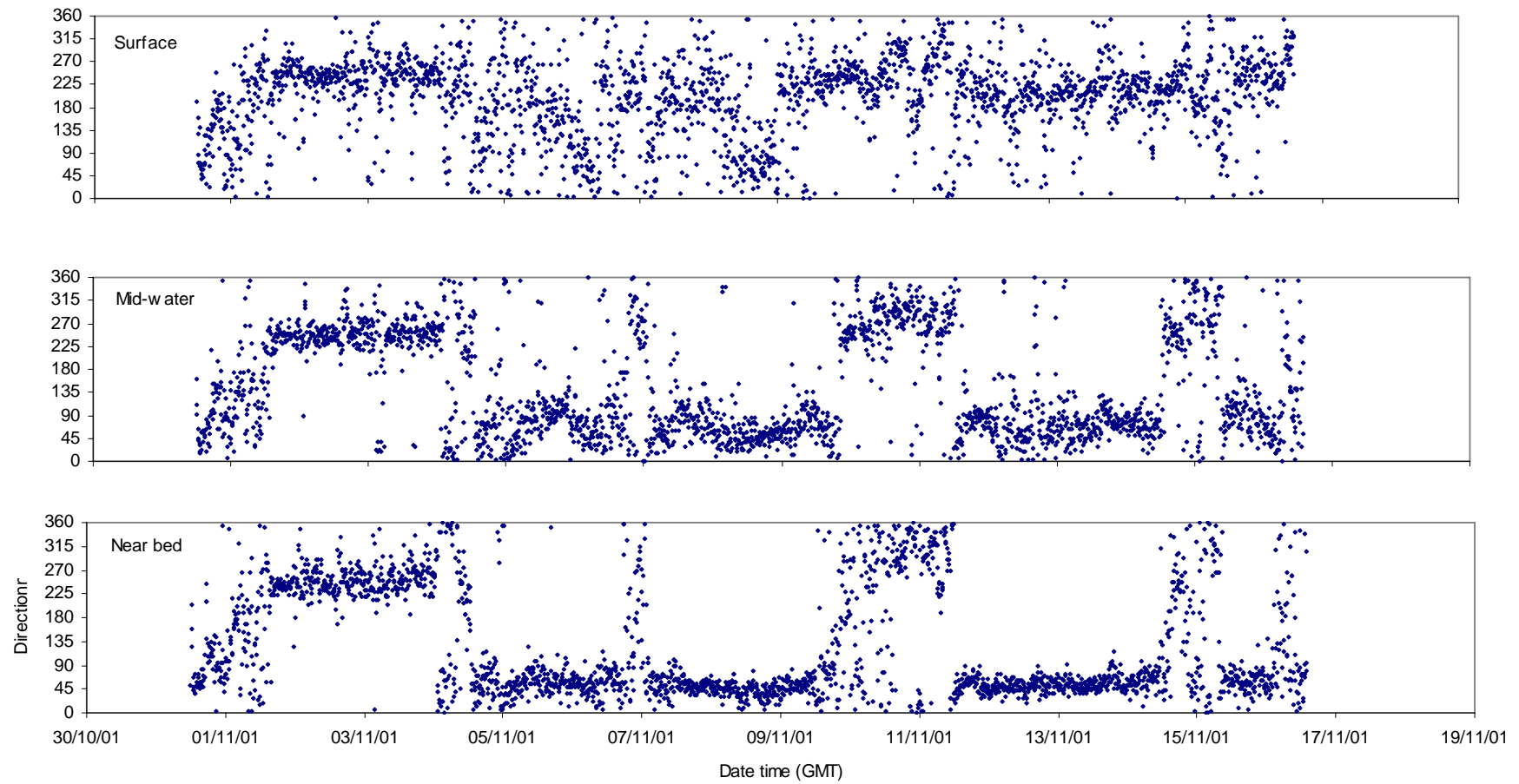


Figure 25. Historical time series of current direction measured at Vidlin at three different depths.

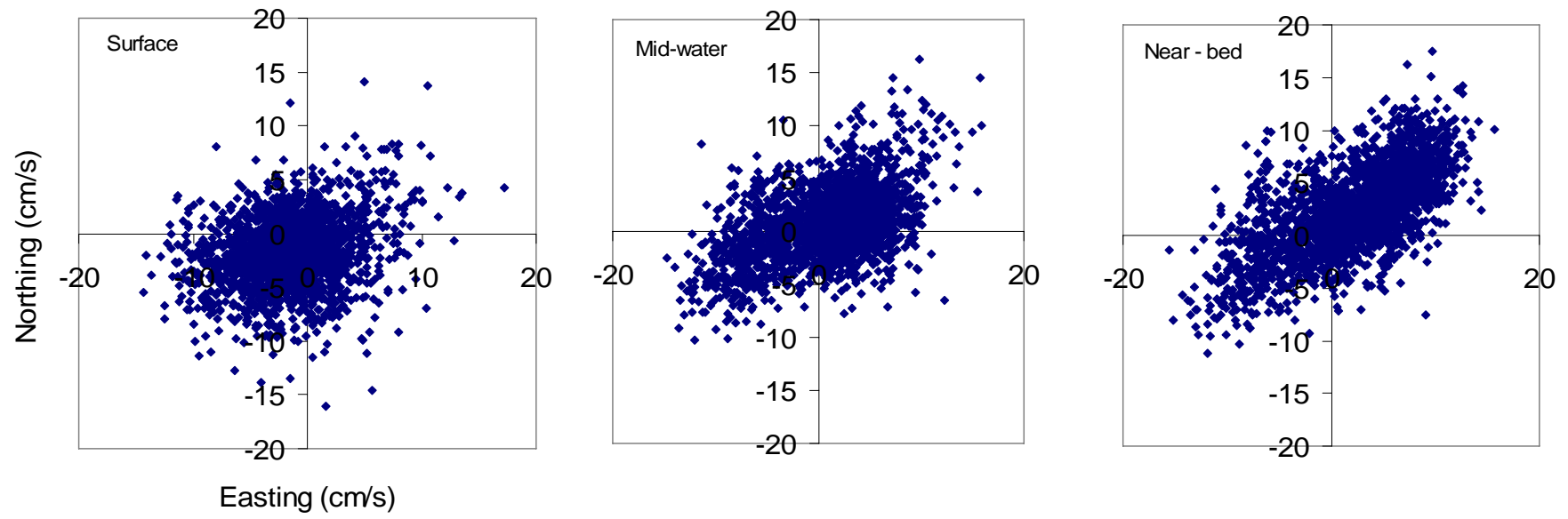


Figure 26. Historical scatter plot of current measured at Vidlin.

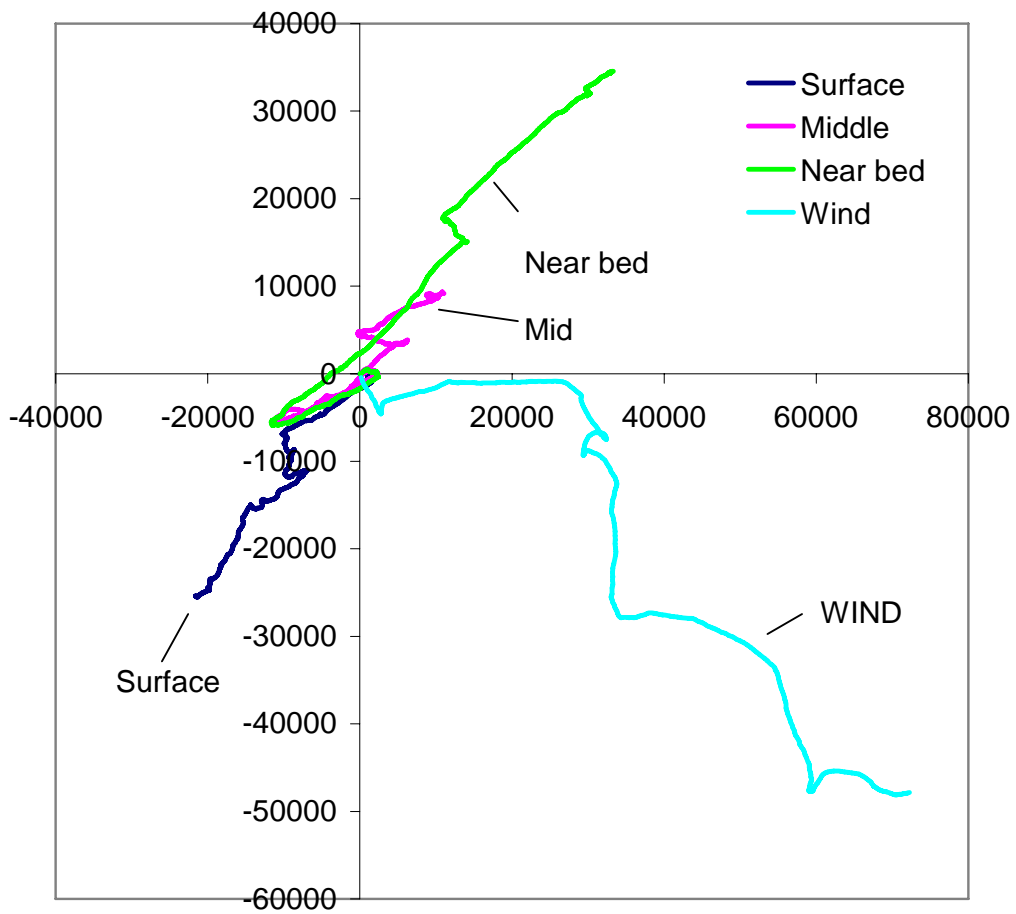


Figure 27. Historical vector plot of current and wind measured at Vidlin. Wind vector is 100 times smaller than actual.

Appendix 3. Environmental data.

Produce a metadata table with references to electronic files (e.g. spread sheets etc) containing the data collected and analyzed. Separate data clearly into water column, sediments and benthos...

Metadata table:

Study environment	File type	Parameter(s)	Location	Headings
water column	Excel	CHN	HD:\Users\thomnick\Documents\DML\Projects\ECASA\Creran 06\ Helmut CHN Jan 07.xls	No.; Sample Site; Depth; Vol Filt; Area of original filter; Proportion of filter used; Vol Used; Peak Height Carbon; Peak Height Nitrogen; Carbon µg/l; Nitrogen µg/l; Adjusted Carbon µg/l; Adjusted Nitrogen µg/l; C:N
	Excel	Chl a	HD:\Users\thomnick\Documents\DML\Projects\ ECASA\Creran 06\ Helmut Chl a.xls	Sample; Station; Depth; Filtered ml; Extraction Vol; Loop size; Pk Area 1; Pk Area 2; Pk Area 3; Peak area average; Peak area s.d.; Calibration Gradient; Calibration Intercept; Chlorophyll a µg; Error; Chlorophyll a µg/l; Error
sediments	Excel	Redox	HD:\Users\thomnick\Documents\DML\Projects\Cod\Vidlin\redox aug 05.xls	Sampling Station; Core Sample; Eh (mv); Ave; RPD (cm)
	Excel	Redox	HD:\Users\thomnick\Documents\DML\Projects\Cod\Vidlin\redox aug 06.xls	Sampling Station; Core Sample; Eh (mv); Ave; RPD (cm)
	Excel	PSA	HD:\Users\thomnick\Documents\DML\Projects\Cod\Vidlin\PSA 06\ all psa.xls	Date; Sample ID; Operator; Comments; Bar Code; From; To; Volume; Mean; Median; D(3,2); Mean/Median Ratio; Mode; S.D.; Variance; C.V.; Skewness; Kurtosis; d10; d50; d90; Specific Surf. Area; phi; % Clay; % Silt; % Sand; %>2mm; %<63um; % <; 10; 25; 50; 75; 90; Size % <; 1; 10; 100; 1000; Volume % Particle Diameter; 10; 25; 50; 75; 90
	Excel	CHN	HD:\Users\thomnick\Documents\DML\Projects\Cod\Vidlin\ Shetland CN Results Aug 2005.xls	No; Sample ID; Date; Location; wt. (mg); Peak Height Carbon; Peak height Nitrogen; Carbon (mg); Nitrogen (mg); Carbon (%); Nitrogen (%); Adjusted Carbon (%); Adjusted Nitrogen (%)
	Excel	LOI	HD:\Users\thomnick\Documents\DML\Projects\ECASA\Creran 06\LOI Aug 06.xls	Sample; Crucible No; Crucible wt (g); Cruc + sample wt(g) = W0; Sample wt(g) Ws; Cruc + sample wt 250° (g) = W250; Cruc + sample wt 500° (g) = W500; PI=W0-W250; PII=W250-W500; Rp=Pii/(PI+PII); % labile OM =(PI/Ws)*100; % refractory OM =(PII/Ws)*100; % total OM = labile OM +refractory OM
	Excel	Sediment Phosphorous	HD:\Users\thomnick\Documents\DML\Projects\ECASA\Creran 06\ECASA Sediment Phosphorous.xls	Sample/Date; Station; Depth (cm) Inorganic P %; Total P %; Organic P %
benthos	Excel	Biota	HD:\Users\thomnick\Documents\DML\Projects\Cod\Vidlin\SAMS Shetland 05.xls	MCS Code; Station; Species Replicate 1; Species Replicate 2; Total
	Excel	Biota	HD:\Users\thomnick\Documents\DML\Projects\Cod\Vidlin\VID06.xls	MCS Code; Station; Species Replicate 1; Species Replicate 2; Total

4. Models and their output

Give details of model output for all the models evaluated. Indicate model source and availability.