BILLIA CROO FISHERIES PROJECT: FINAL REPORT TO THE SCOTTISH GOVERNMENT

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EMEC ORKNEY®

The European Marine Energy Centre Ltd

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Contents

1. Executive Summary

The European Marine Energy Centre (EMEC) wave energy converter test site, at Billia Croo, Orkney Islands, is within an area commonly used as a lobster fishery. In summer 2010 a Scottish Government funded project to investigate the possible effects of marine energy converter deployments on resident crustacean species within the area of the EMEC Billia Croo test site was established. This collaborative project, led by EMEC, had scientific input from Herriot Watt University's International Centre for Island Technology (ICIT) and Seafood Scotland, and industry input from Orkney Fishermen's Society (OFS) and Orkney Fishermen's Association (OFA).

The project encompassed two broad aims: firstly, to determine the likely influence of a small-scale refuge area on local lobster population abundance and availability to the fishery; and secondly to explore the potential for using such areas to augment local lobster stocks by using them as nursery grounds for the release of hatchery-reared juveniles. A supplementary aim of the project was to characterise experimental creel catches of all crustacean species in the area in the context of catches experienced by the commercial fishery operating in adjacent areas open to fishing.

The study concludes that the area within the EMEC wave test site at Billia Croo provides suitable feeding and refuge habitat for lobster, and has the potential to act as a nursery area to both the local fishery and to the Orkney Islands as a whole. Continuation of the project will be essential in order to assess the survivability and mobility of juvenile lobster electronically tagged and released during this project. The potential for artificial structures placed on the seabed during development of marine renewable projects to act as juvenile lobster habitat also requires further investigation. Previous sampling of lobster and brown crab landings across Orkney can provide valuable information on catch composition, but data on effort and catch rate are lacking and should be an important component of any future monitoring programme in order to determine stock abundance.

2. Introduction

Currently, little in-depth scientific information is available in respect of marine energy device interactions with marine species or habitats. This is a result of missing or poor ecological baseline information and the newness of the marine renewable technologies overall. However a small number of reviews, reports and scientific papers do exist, which begin to outline the potential effects of such technologies including wind, wave and tidal energy devices at both the small scale (1 – 10 device deployments) and the large (10+ deployments) developments. These sources mainly follow the life cycle of the marine renewable development schemes in terms of device installation, operation, and decommissioning activities within the marine environment. Annex 1 gives a basic view of the stages involved in the marine renewable development process and the potential interactions with marine species and habitats.

Shellfish species may potentially be affected by marine renewable developments in terms of habitat loss/alteration, marine noise, sediment smothering/ alterations, changes in wave exposure, and contamination effects. These effects may influence shellfish species directly or indirectly, on spatial or temporal scales, in either positive or negative terms. Positive effects include the potential for enhanced productivity following artificial reef scenarios and agreed no-take fishing zones, whilst negative effects include the potential for population dynamic alterations or displacements, with most of these effects outlined as being of low to moderate risk. However it must be stressed that such effects are currently unknown due to limited knowledge of marine ecological interactions with marine renewable developments. Current scientific and strategic environmental assessment (SEA) recommendations suggest that research be undertaken to enhance information at the baseline level, and then follow across each stage of marine renewable development schemes with complimentary monitoring surveys.

In 2010 the European Marine Energy Centre (EMEC) received funding from the Scottish Government to undertake research at its wave energy converter test site at Billia Croo, Orkney Islands, within an area commonly used as a lobster fishery. This year long project looked at the possible effects, positive as well as any negative, of marine energy converter deployments on resident crustacean species.

A fishery scientific monitoring zone (SMZ) was established in the vicinity of the Billia Croo test site for the project duration. The main focus of the project was lobsters and their commercial fishery. The aims of the project were to determine the likely influence of a small-scale refuge area on local lobster population abundance and availability to the fishery, explore the potential for using such areas to augment local lobster stocks by using them as nursery grounds for the release of hatchery-reared juveniles, and to characterise experimental creel catches of all crustacean species in the area in the context of catches experienced by the commercial fishery operating in adjacent areas that are completely open to fishing. Data from the project will also be used to inform fisheries science on the growth rate and movement patterns of lobster in the area.

The original scope of the project was amended, due to a change in the catch and release programme, to include analysis of brown crab landings from within the SMZ.

This report summarises the findings of this project and makes recommendations for continued studies.

3. Methodology

The initial phase of the project focused on rearing of juvenile lobster for release into the test site at Billia Croo, together with developing protocols for tagging and release of the juveniles. Engagement with the local fishing community was a high priority throughout the project and the services of local fishermen were utilised for the release of the lobster juveniles and recording of catch data. Meetings with local fishermen were coordinated and facilitated by OFS and OFA. A public awareness leaflet was produced early in the project to raise awareness and to describe the spatial extent of the Billia Croo site to be covered by the study (see Annex 2). Unfortunately it was not possible to agree a voluntary no-take zone with local fishermen, but agreement was reached that a scientific monitoring zone (SMZ) be established within the area of the test site, and a local commercial fishing vessel was utilised for the monitoring.

The Orkney Lobster Hatchery set aside 11,000 stage 4 lobster juveniles for the project. By October 2010 some 3,500 of these had survived to stage 8 and were suitable for tagging by injection of a microscopic metal strip into one leg. Approximately 2,600 of these tagged juveniles survived and were released into the SMZ area at the end of November 2010 (see Annex 3). It was initially hoped that habitat enhancement utilising gabions of a test device already installed at the site could be put in place prior to release of the lobster juveniles. This was not possible due to the absence of gabions from the installation. The lobster juveniles were released in calm weather conditions in 10-15 metres of water on a rocky substrate with good weed cover. It will be approximately three years before these tagged juveniles would be large enough to start to appear as undersize lobster catches in experimental prawn creels (subject to licence).

During the development phase of the Billia Croo wave test site, EMEC commissioned a number of benthic surveys of the surrounding area. These surveys used a range of sampling methods, including bathymetry, ROV video footage, dive surveys and grab sampling techniques. A desk-based review of the reports and data obtained from these surveys was carried out by Melanie Broadhurst of University College London in order to assess the suitability of the habitat and topographic conditions present at the test site as a nursery site for lobster (see Annex 4).

A review of catch data for 2010 and 2011 from the lobster fishery around Orkney's inshore water was carried out by Orkney Sustainable Fisheries (OSF) to give an indication of the lobster stock in Orkney. The data were collected on-shore at lobster ponds in Stromness and Lamb Holm, using an electrical calliper PDA system donated by Marine Scotland. A summary of this review is provided at Annex 5.

The original project scope stated that background data on catches from the area would be gathered using a catch and release programme throughout the year using 50 experimental creels hauled 2 days per month. However, this proved impractical for the following reasons:

- Unavailability of suitable vessels in the winter months
- Short daylight hours in the winter months
- Poor winter weather and subsequent hazard risks

The project scope was amended such that OSF recorded real catch data from regular fishing in the vicinity of the SMZ, supported by a limited catch, tag/v-notch, record and release programme over the summer months. Local fishermen recorded a number of pot hauls in the area between the Black Craig and Breckness and all shellfish species caught (lobster and brown crab) were weighed and recorded at the Orkney Fishermen's Society (OFS) ponds. This has the potential advantage of providing a longer term data stream. Berried female lobster were v-notched and released, with records made of subsequent recapture. The main expected outcome of the monitoring activities would be a description of the levels and seasonal patterns of crustacean catches in the wave test site. These patterns would be set against two contexts: firstly, catch levels and patterns seen more generally within the Orkney creel fishery; and secondly, the local population dynamics and movement patterns of lobsters. The latter is dependent upon an effective tag/v-notching and recording programme. The combined result would be a synthesis of the potential effect of inshore wave energy developments on the local creel fishery, one that can be used in both descriptive and (potentially) predictive modes in considering potential interactions of wave energy development proposals. The results of this monitoring are reported in Annex 6.

In a parallel, separately funded project focusing on brown crab, OSF undertook a two year study into the migratory and life history patterns of brown crab around Orkney waters, with the aim of establishing the identity of Orkney stocks in terms of a wider stock distribution. A summary of the results of this study is presented for contextual purposes in Annex 7.

4. Summary of Findings

The work carried out at the Orkney Lobster Hatchery to rear and electronically tag lobster juveniles for the project demonstrated the high mortality rate involved with this process, with only around 25% of the juveniles surviving to the release stage. It is hoped that some of these tagged juveniles will be detected in 2016-2018 using standard fishing gear. Further research is required to assess the success of released juveniles into the area. This could be combined with studies into habitat enhancement due to developments in marine renewables, e.g., introduction of new seabed structures which provide juvenile lobster habitat.

The review of available benthic data carried out as part of this project (Annex 4) concludes that overall, the types of substrate, habitat and topographic conditions found within the EMEC wave energy converter test site are favourable to crustacean species such as lobsters, for refuge and feeding opportunities. This suggests that the site has the potential to act as an important nursery site for lobsters.

The analysis of catch data from the SMZ area (Annex 6) together with the review of catch data for 2010/11 (Annex 5) indicates that Billia Croo is an important and productive creel fishing area for lobster. Through these studies much is known about catch composition, but there is a lack of data on fishing effort and few records of catch rates for the area. Catch rates are commonly used as an index of stock abundance in fishery monitoring schemes, and it is proposed that logbook records and other methods of obtaining effort and catch rate data should be an important component of future monitoring programmes. Opportunities for enhancement of the lobster stock include release of hatchery-reared juvenile lobsters to supplement natural sources of recruitment, and introduction of new juvenile lobster habitat provided by, e.g., device mooring structures, cable armouring, etc.

The original aim of monthly sampling proved to be impractical due to the seasonal nature of the fishery. The alternative of undertaking more intense monitoring during the summer months, with limited scientific observer involvement during fishing trips, meant that it was not possible to undertake tagging studies alongside the catch monitoring, but only to undertake a limited amount of on-board discard sampling. A key lesson for future scientific monitoring is the requirement for proper scientific control of operations in order to ensure optimum data gain from monitoring efforts. This should include dedicated charter of a fishing vessel to allow fishing when and where directed, with all aspects of the survey under the control of the project.

5. Recommendations

This project can be seen as the first stage in a longer term local population and distribution study of lobster at an operational wave energy (test) site. Future funding would enable long term monitoring of both 'hatchery-reared and tagged' and naturally occurring lobster populations. Recommendations for further studies are described below.

5.1 A key learning from this project is information on survivability rates of hatchery-reared and tagged juvenile lobster. Hatchery-reared lobsters are unlikely to recruit to the commercial fishery until around 7 years after release, but it should be possible to detect the presence of undersized individuals after 2-3 years through scientific surveys using fine-meshed prawn traps (under licence). To fully utilise the potential for scientific learning from this project, EMEC intends to seek funding to continue the monitoring beyond the end of the current project. This may involve the rearing of more juveniles and their introduction into the EMEC test area, but it should as a minimum enable monitoring of the hatchery-reared juveniles electronically tagged under this project. There may also be scope for releasing advanced stage tagged juvenile lobster into the SMZ to look at the effectiveness of the seeding area. These juveniles could either be hatchery-reared or caught by local fishermen using prawn creels (under licence) for the purpose of the project. The results of such a study could be used by developers to inform their EIA. In addition, opportunities for enhancement of habitat for juvenile crustaceans around wave and tidal marine energy developments should be explored.

5.2 Continuation of the SMZ with on-shore market sampling and off-shore discard sampling of undersize population. Commercial potting methods can help complement tag and release schemes by providing basic biological information on the species population dynamics, such as the interaction between tagged and wild individuals, age structure, disease, and reproduction activities (Annex 4, Dunnington *et al*., 2005). These survey techniques can also provide spatial and bathymetric information, i.e., pot location, water depth, and seabed type. This could then further determine population distribution movements in terms of benthic habitats and other biological influences.

5.3 Expansion of the sampling regime to include dedicated (non-fishermen led) scientific surveys to allow optimal control of outcomes. This would help gain valuable information on the movements of species within the local area, potential interactions with marine renewable energy activities, and lobster population dynamics within the Orkney Islands as a whole.

5.4 Continued recording of log-book returns from fishermen targeting Billia Croo and surrounding areas. Logbook records for fisheries across Orkney will be an important source of information on catch rates and catch quantities and how they are distributed between areas with and without marine energy development potential.

5.5 Investigation into whether releases of hatchery-reared juveniles augment wild stocks as opposed to replacing existing sources of recruitment.

5.6 Expand test species to include velvet and brown crab. Building on the results of inshore fishery mapping studies undertaken recently by Marine Scotland and by Orkney Fisheries Association, further studies will be needed to demonstrate the true potential for overlap of wave (and tidal) energy developments with fishing grounds for brown crab and other species such as velvet and green crab.

5.7 Incorporation of v-notching into field measurements with area definitions in and around the EMEC marine renewable test sites.

5.8 Undertake a lobster monitoring scheme with specific reference to marine renewable energy test site activities. As marine renewable energy activity grows around Orkney, a monitoring scheme would increase knowledge of species interactions with marine energy converter technologies. Such a scheme could also compliment recommendations 5.2 and 5.3 above in terms of understanding the population dynamics within the area to outline natural variation and potential interactions with marine renewable energy activities. In addition, other surveys carried out within the site (eg ROV cable surveys, independent device developer surveys, etc) could be integrated within this scheme. Such information would be useful in terms of further benthic habitat mapping and lobster population information, whilst reducing the cost of implementing further studies.

By enabling the monitoring to continue beyond the end of this project, a long-term knowledge of the local population level and distribution of lobster around the EMEC wave test site can be built up. This will help to establish the extent of migration of lobster from the release sites and should also give an indication of survival rates, which will contribute to an assessment of the effects of marine energy devices on the local lobster population. Continuation of the monitoring will also help to enhance links between local fishing interests and the marine renewable energy industry overall.

ANNEX 1: Potential Generic Effects of Marine Renewables on Shellfish

Introduction

Due to the increased interest in marine renewable development within and around Orkney waters, the focus on understanding the potential interactions or effects with the marine environment has also increased. This is a result of growing concerns for the marine environment as a whole, caused by other natural and anthropogenic pressures such as acidification, climate change and finite resource exploitation. Therefore it is important to outline potential changes in the marine environment from new activities such as marine renewable development schemes.

This review outlines the potential interactions and effects from marine renewable developments, with reference to shellfish. This is due to their commercial importance within Orkney and also their biological presence within in the marine environment as a whole. Most shellfish species show demersal and pelagic life stages and mobile or sessile characteristics, and may therefore come into contact with marine renewable developments either on the seafloor or within the water column (see Table 1.1). Shellfish species may be sensitive to a number of potential direct and indirect effects in terms of population dynamic alterations (recruitment, reproduction, and mortality) and displacement and behavioural changes (refuge behaviour and feeding regimes). These effects could influence species both positively and negatively and across short or long temporal time scales, with significance levels taken from the Marlin online database and past SEA documents where possible (see table 1.2 and Appendix I, table 1.3).

The review describes the potential effects in terms of the life cycle of the marine renewable development scheme to compliment past reviews and strategic environmental assessments (SEA). This will be based on past SEA reviews, reports and scientific literature where possible (see bibliography). However it must be noted that in-depth information on marine ecological interactions and device technology is still lacking, which may affect the overall perspective of this review. Therefore future studies are recommended from the outset to determine the potential interactions and impacts from marine renewable developments across all life cycle stages of marine renewable development schemes in the long term.

ANNEX 1: Potential Generic Effects of Marine Renewables on Shellfish

Species	General Distribution	Habitat	Water Depth (m)	Migratory Species	Location in Water Column		
					Adult	Eggs/Larvae	Juvenile
Norway Lobster	Study area	Sandy and muddy sediments	20 – 800	No	Demersal	Berried females, pelagic larvae	Demersal
Common Lobster	Study area (coast out to 60 m)	Rocky shores, reefs, cobble and boulder fields	0 – 60	No	Demersal	Berried females, pelagic larvae	Demersal
Edible Crab	Study area (coast out to 100 m water depth)	Rocky shores and softer sediments	0 – 100	Yes	Demersal	Berried females, pelagic larvae	Demersal
Velvet Crab	Study area (coast out to 15 m water depth)	Rocky or stony habitats	0 – 15	No	Demersal	Berried females, pelagic larvae	Pelagic
Green crab	Study area (intertidal area)	Wide variety of shores usually associated with rocks and seaweed	Intertidal	No	Demersal	Berried females, pelagic larvae	Demersal
King Scallop	Study area	Sandy, muddy and shell gravel bottoms	0 – 100m	No	Demersal	Pelagic eggs and larvae	Demersal
Queen Scallop	Widespread but concentrations in Clyde Sea and Scapa Flow	Sandy, muddy and shell gravel bottoms	0 – 100 m	No	Demersal	Pelagic eggs and larvae	Demersal
Cockle	Orkney, the Uists, Barra and Ardnamurchan peninsula (intertidal)	Sand, mud or fine gravel	Mid tide to low water springs	No	Demersal	Pelagic	Demersal
Native Oyster	West coast; Western Isles and Orkney and Shetland	Sandy, muddy gravel and boulder bottoms	Intertidal	No	Demersal	Pelagic	Pelagic
Horse Mussel	Study area	Sandy, muddy gravel and boulder bottoms	Intertidal	No	Demersal	Pelagic	Pelagic
Mussel	Study area	Sheltered shores, or on man made structures down to 12 m	0 – 12	No	Demersal	Pelagic	Demersal
Whelk	Study area (intertidal)	Rocky shores – soft sediments	Mid tide to low water springs	No	Demersal	Demersal eggs and pelagic larvae	Demersal
Periwinkle	Study area (intertidal)	Rocky, boulder and pebble shores	Mid tide to low water springs	No	Demersal	Demersal	Demersal
Razor shell	Study area	Fine clean sand; Coarse clean sand	0 – 60 m	No	Demersal	Pelagic	Demersal
European spiny lobster (crayfish)	Study area (except south of Firth of Clyde)	Bedrock Boulder bottoms	5 – 70 m	No	Demersal	Pelagic	Pelagic

Table 1.1. Key shellfish species found within Scottish waters (taken from Faber Maunsell and Metoc, 2007)

ANNEX 1: Potential Generic Effects of Marine Renewables on Shellfish

Species	Smothering	Change in Suspended Sediment	Increased Turbidity	Collision Risk	Substratum Loss	Decrease in Wave Exposure	Decrease in Water Flow	Contamination (Synthetic Compound)	Contamination (Heavy Metals	EMF Fields	Marine Noise
Norway Lobster (*Nephrops norvegicus*)	Low	Medium	Not sensitive	Unknown	Medium	Not relevant	Low	Unknown	Low	Not sensitive	Unknown
Common Lobster (*Homarus gammarus*)	Low	Not relevant	Unknown	Unknown	Unknown	Low	Low	Unknown	Unknown	Not sensitive	Unknown
Edible Crab (*Cancer pagurus*)	Low	Not relevant	Not sensitive	Unknown	Medium	Low	Low	Unknown	Unknown	Not sensitive	Unknown
Velvet Crab (*Necora puber*)	Low	Not relevant	Unknown	Unknown	Unknown	Low	Low	Unknown	Unknown	Not sensitive	Unknown
Green crab (*Carcinus maenas*)	Not sensitive	Not relevant	Not relevant	Unknown	Low	Low	Low	Low	Very low	Not sensitive	Not sensitive
King Scallop (*Pecten maximus*)	High (inhibits filter feeding)	Medium	Unknown	Unknown	Medium	Not relevant	Low	Unknown	Unknown	Not sensitive	Not sensitive
Queen Scallop (*Aequipecten opercularis*)	High (inhibits filter feeding)	Medium	Not sensitive	Unknown	Unknown	Not relevant	Low	Unknown	Unknown	Not sensitive	Unknown
Cockle (*Cerastoderma edule*)	High	Medium	Not sensitive	Unknown	Medium	Medium	Low	Low	Low	Not sensitive	Not sensitive
Mussel (*Mytilus edulis*)	Medium	Medium	Not sensitive	Unknown	Medium	Medium	Medium	Low	Low	Not sensitive	Not sensitive
Whelk (*Buccinum undatum*)	Low	Low	Unknown	Unknown	Unknown	Low	Low	Unknown	Unknown	Not sensitive	Unknown
Periwinkle (*Littorina littorea*)	High	Low	Very low	Unknown	Medium	High	Low	Very low	Low	Not sensitive	Not sensitive
Razor Shell (*Ensis* spp)	Not sensitive	Low	Low	Unknown	Medium	Low	Low	Medium	Low	Not sensitive	Not sensitive
Spiny Lobster (*Palinurus elephas*)	Not sensitive	Not sensitive	Not sensitive	Unknown	Not relevant	Not sensitive	Not sensitive	Unknown	Unknown	Not sensitive	Not sensitive

Table 1.2: Marine shellfish sensitivities to potential effects from marine renewable developments (taken from Faber Maunsell and Metoc 2007)

Installation Stage

Marine renewable device installation and construction activities have the potential to affect shellfish species in terms of disturbance, habitat loss, noise, smothering, increased suspended sediments and contamination. These are described below.

Disturbance

General disturbance in terms of device deployment and other on-site activities (noise, moorings, anchorage and other physical structures on the seafloor) during the installation stage may affect shellfish species. This may result in localised individuals and species being displaced into adjacent habitats in the short term for refuge. These effects are considered low in terms of impacting on shellfish but may increase during important reproduction or recruitment processes. Therefore the timing of such installation works should be carefully considered.

Habitat Loss

Habitat loss from the physical deployment of devices and additional structures including sub-sea cables may affect shellfish. The presence of jack-up barges could displace species in the short term, whilst deployed devices and sub-sea cables could displace or reduce productivity of shellfish species in the long term. This will depend on the type (structure complexity) and size of the device and additional structures deployed within the area and regarded as low to moderate effects.

ANNEX 1: Potential Generic Effects of Marine Renewables on Shellfish

Noise

Noise disturbance from marine renewable device deployment and additional on-site activities such as pile-driving, drilling and survey activities may cause shellfish to displace from the local area. Noise vibrations can displace shellfish in the short term, with greater effects potentially from pilling activities overall. Displacement may also be extended during important time periods within the year, in terms of shellfish reproduction or moulting stages. However noise effects must be reviewed in terms of the existing overall baseline noise conditions within the local area in terms of other marine noise activities from shipping. Therefore the effect is regarded as low overall.

Smothering

The installation of marine renewable devices has the potential to cause sediment smothering on the surrounding benthic habitats. Installation activities such as drilling could disperse sediments quickly to these habitats. This could affect the feeding activities, reproduction and recruitment processes for shellfish and is therefore regarded as a potentially important effect, with low to moderate significance levels (Faber Maunsell and Metoc, 2007). However this depends on the nature of the seabed and the localised hydrodynamics of the area. Coarse sediments found in high energy environments may return to the seafloor quickly, reducing sediment translocation to within 50 meters of the installation works location. These effects may also occur in the short term, due to the time length of installation activities, with fine sediments re-suspended and distributed from the local site due to natural hydrodynamic processes.

Increased Suspended Sediments

Increased suspended sediments have the potential to cause increased turbidity and reduce light penetration within the water column. This may affect mobile shellfish such as lobsters and crabs in terms of food web/predator- prey relationships and foraging activities. Sessile shellfish such as cockles may be more sensitive to suspended sediments due to their filter feeding preferences. However the overall effect is considered potentially low or currently unknown.

Contamination

During the installation works, contaminated sediments may be disturbed or new contaminants such as oil and fuel from installation vessels could be added to the marine environment. Overall, the effects of contaminants from such activities on shellfish are considered low, as it is regarded that the strong hydrodynamic conditions within the area will disperse contaminants quickly.

Operational Effects

After the installation stage, marine renewable developments progress into a long-term operational phase which is largely viewed as device maintenance activities. A number of potential effects from this stage on shellfish include disturbance, habitat alteration, noise, smothering, increased suspended sediments, hydrodynamic alterations and contamination. This also includes potential effects of shellfish life stages, seasonality and marine renewable development locations acting as potential fishing restriction zones.

Disturbance

General on-going disturbance in terms of on-site activities (device maintenance, noise, vessel anchorage and other physical structures on the seafloor) during the operational stage may affect shellfish species. The effects are considered low but this may change in respect to the type of mooring chain design used (particularly for wave energy converters) i.e. a dead weight mooring system could have minimal effects compared to a catenary mooring system and may further habitat loss.

The overall physical presence may also disturb shellfish species in terms of marine renewable developments acting as barriers to species movements. This may be potentially of low significance with reference to demersal species but may be greater during larval development stages.

Noise

Marine noise during the operational stage will comprise largely of device operation and vessel activities. Therefore the impact of noise on shellfish species is considered low.

Habitat Alterations

Operational activities can alter the benthic habitat structure and complexity and in turn affect shellfish. Substratum and habitat loss may occur as a result of the increased size of the development (large scale device deployments) and may affect foraging and reproduction activities. Alternatively, marine renewable developments represent new structures within the marine environment and create artificial reef or aggregation scenarios (see habitat review section). These could provide further resources to localised shellfish species such as refuge, recruitment and feeding opportunities from bio-fouling species, whilst also displace individuals from the adjacent areas for such reasons. Therefore habitat alteration, whether positive or negative has a potentially important low to moderate effect on shellfish.

Smothering

Sediment changes may occur during the operational phase of marine renewable development and potentially affect shellfish species. Sedimentation patterns may change due to the extraction of energy from devices and may result in both increases or decreases in sediment suspension or deposition, with estimates up to 50 meters. This is likely to impact upon the surrounding benthic habitats and species, including sessile shellfish such as cockles, scallops or mussels. For other mobile shellfish, this could have an indirect effect in terms of altering foraging activities. Therefore the effect is regarded as low to moderate overall.

Increased Suspended Sediments

The operational activities of marine renewable developments are thought to have minimal effects upon shellfish, compared to the installation stage. However, in-depth knowledge on how increased sediments from such activities may alter shellfish feeding regimes i.e. predatory chemical cues or filter feeding regimes in the long term is currently unknown.

Hydrodynamic Alterations

Marine renewable developments have the potential to alter the local hydrodynamics of an area in terms of reducing wave exposure or tidal flows. This may alter the type of benthic habitat present and therefore the local benthic community therein, including shellfish species. Reduced wave exposure could alter larval dispersal and nutrients in the littoral zone, and in turn affect the population dynamics and food webs within this zone where some shellfish are found. This is of particular importance to tidal flow alterations for sessile shellfish such as mussels for filter feeding regimes. However mobile shellfish species are generally regarded as resilient organisms and therefore a decline in wave exposure may not have a direct significant effect. This is therefore considered a potentially low or moderate effect on shellfish in the long term, with further studies required.

Contamination

Shellfish species may be exposed to contamination fluids and materials such as anti-fouling and fuel leakages during the operational activities of marine renewables developments. However, these are accepted as low potential importance overall.

Life stages and seasonality

Marine renewable developments could have potential interactions with shellfish at important life stages or seasons. Shellfish show different life stages, from the larval pelagic stage to different juvenile and adult demersal stages, with operational activities potentially affecting each life stage differently. Shellfish also undergo important recruitment, reproductive and moulting stages at different seasons throughout the year. Therefore this review further recommends careful consideration on operational activities although in-depth information is limited.

Fishing Restriction Zones

Marine renewable developments may reduce certain fishing practices such as trawling within the area. This is due to the physical presence of such developments hindering fishing practices within in the marine environment. In this context, these areas may be recognised as ‘volunteer’ fishing restriction zones or nursery areas and may therefore protect the benthic habitats and species therein. This may therefore affect local shellfish species in terms of enhancing local productivity and biomass in these species and seen as an important positive effect overall.

Decommissioning

The potential effects for the decommissioning stage of marine renewable developments are comparable to the installation stage. This includes potential effects such as disturbance, habitat loss, noise, smothering, increased suspended sediments and contamination. Potential effects also include the alteration of tidal flows and wave exposure to the site following decommissioning and therefore may affect the benthic habitats and species. However the scope of how large scale marine renewable developments may alter shellfish after decommissioning is unknown at this current time.

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Appendix I

Rank	Definition
Very High	"Very high" sensitivity is indicated by the following scenario: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (either killed/destroyed, "high" intolerance) and is expected to recover only over a prolonged period of time, i.e. >25 years or not at all (recoverability is "very low" or "none"). • The habitat or species is adversely affected by an external factor arising from human activities or natural events (damaged, "intermediate" intolerance) but is not expected to recover at all (recoverability is "none").
High	"High" sensitivity is indicated by the following scenarios: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, "high" intolerance) and is expected to recover over a very long period of time, i.e. >10 or up to 25 years ("low" recoverability). • The habitat or species is adversely affected by an external factor arising from human activities or natural events (damaged, "intermediate" intolerance) and is expected to recover over a very long period of time, i.e. >10 years (recoverability is "low", or "very low"). • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is not expected to recover at all (recoverability is "none"), so that the habitat or species may be vulnerable to subsequent damage.
Moderate	"Moderate" sensitivity is indicated by the following scenarios: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, "high" intolerance) but is expected to take more than 1 year or up to 10 years to recover ("moderate" or "high" recoverability). • The habitat or species is adversely affected by an external factor arising from human activities or natural events (damaged, "intermediate" intolerance) and is expected to recover over a long period of time, i.e. >5 or up to 10 years ("moderate" recoverability). • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is expected to recover over a very long period of time, i.e. >10 years (recoverability is "low", "very low"), during which time the habitat or species may be vulnerable to subsequent damage.
Low	"Low" sensitivity is indicated by the following scenarios: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, "high" intolerance) but is expected to recover rapidly, i.e. within 1 year ("very high" recoverability). • The habitat or species is adversely affected by an external factor arising from

	human activities or natural events (damaged, "intermediate" intolerance) but is expected to recover in a short period of time, i.e. within 1 year or up to 5 years ("very high" or "high" recoverability). • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is expected to take more than 1 year or up to 10 years to recover ("moderate" or "high" recoverability).
Very low	"Very low" is indicated by the following scenarios: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, "high" intolerance) but is expected to recover rapidly i.e. within a week ("immediate" recoverability). • The habitat or species is adversely affected by an external factor arising from human activities or natural events (damaged, "intermediate" intolerance) but is expected to recover rapidly, i.e. within a week ("immediate" recoverability). • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is expected to recover within a year ("very high" recoverability).
Not sensitive	"Not sensitive" is indicated by the following scenarios: • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is expected to recover rapidly, i.e. within a week ("immediate" recoverability). • The habitat or species is tolerant of changes in the external factor.
Not sensitive*	The habitat or species may benefit from the change in an external factor (intolerance has been assessed as "tolerant*").
Not relevant	The habitat or species is protected from changes in an external factor (i.e. through a burrowing habit or depth), or is able to avoid the external factor.

Table 1.3. Marine species and habitat sensitivity/ significance ranks and definitions (taken from the Marlin online database, 2011). (**) 'Reduced viability' includes physiological stress, reduced fecundity, reduced growth, and partial death of a colonial animal or plant.

ANNEX 2: Project Awareness Leaflet

Orkney Fishermen's Society

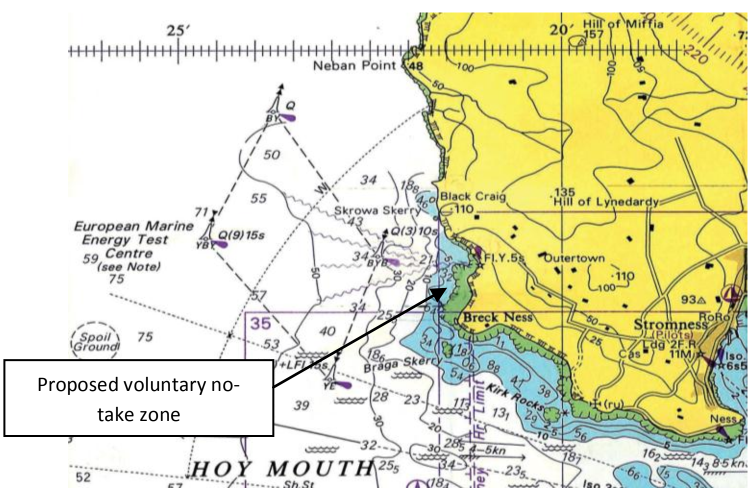
EMEC Orkney — The European Marine Energy Centre Ltd

Orkney Fisheries Association

Lobster Monitoring at the EMEC Wave Test Site, Billia Croo

EMEC has initiated a project to assess the potential effects of marine energy installations on fish and fisheries at their wave test site at Billia Croo. Unique to Orkney, this project will investigate any effects of wave energy devices on lobsters resident and released into the EMEC site. The project involves local fishermen in sampling, and would ideally involve local support for a voluntary no-take zone within the test site, in the area shown on the map below. Data from the project will also be used to inform fisheries science on the growth rate and migratory behaviour of lobsters in this area.

EMEC is working closely with OFS, OSF, OFA, local fishermen, Seafood Scotland and the International Centre for Island Technology (ICIT) on this project. The hatchery has been supported to allow the rearing of a large batch of juveniles, to be electronically tagged and released into the area. This gives scope to both study the migratory behaviour and survival of the lobster released as juveniles, and to improve the lobster catch in the surrounding waters in later years. The project also aims to undertake specific tag & release potting runs in the spring and summer months to independently assess lobster numbers in this area.



We value very highly any input from local fishermen to this project, and anyone interested in helping with the monitoring or finding out more is encouraged to get in touch with the appropriate contact shown overleaf.

ANNEX 2: Project Awareness Leaflet

Project details:

The project has initially been set up to run from summer 2010 through to autumn 2011, although it is hoped that the monitoring can be extended.

The project will be most successful if it has the support of the local fishing community, both for assistance with monitoring, and in providing expertise. It is hoped that local fishermen will participate in the capture, tagging and release of lobsters in the area.

Sarah Lamb, who is working with Orkney Sustainable Fisheries on a variety of projects, will be leading the lobster tagging work along, with Mike Bell from ICIT in Stromness and Craig Burton from Seafood Scotland.

The project also involves Dawson Shearer from the Orkney Lobster Hatchery who has been tasked with growing the lobster juveniles which will be tagged and released into the area.

Craig Butler from Seafood Scotland brings a sound research background to the project, having previous experience from numerous similar projects across the UK.

Finally, at a wider level the project will have an industry input from Stewart Crichton at Orkney Fisherman's Society, Alan Coghill/Fiona Matheson at Orkney Fisherman's Association and Jennifer Norris from the European Marine Energy Centre.

We hope that this project will provide a first step in developing a suitable pathway for the co-existence of the fishing and marine renewable energy industries and welcome any further input from the Orkney fishing community.

Project Contact Details		
Orkney Fishermen's Society	EMEC	Orkney Fishermen's Association
Stewart Crichton	Jennifer Norris	Fiona Matheson
Email: Stewart@ofsorkney.co.uk	Email: Jenny.Norris@emec.org.uk	Email: orkneyfisheries@btconnect.com

ANNEX 3: Billia Croo Lobster Tagging Project

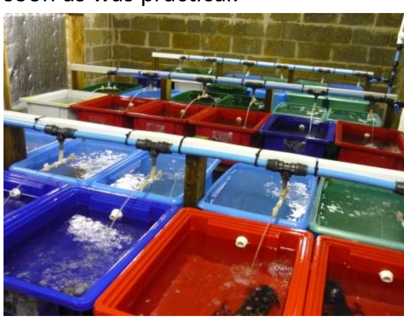
INTRODUCTION

The aim of the hatchery at the beginning of the season was to allocate the first 11,000 stage 4 lobsters produced to the fisheries project for on growing in the Aqua-hive upweller units. It was hoped that during the summer months a sizeable proportion of these could then be reared to a minimum of stage 8, large enough to allow ease of handling for the tagging process. Based on previous growth rates within the upweller units it was our intention to have the juveniles tagged and ready for release from mid-October 2010 onwards.

PRODUCTION

The first brood stock were introduced to the hatchery during April 2010 with stage 4 production beginning in late May. Numbers slowly built up through June and all three upweller units were loaded with discs by 13th. These juveniles were fed entirely on a diet of calanus powder and monitored regularly to assess growth and survival rates.

In common with previous years mortality was relatively high in the first few weeks, as early juveniles tend to fair less well when water temperatures are lower and during the ‘settling in’ period required by the filtration systems at this time. Consequently only about 50% survived to stage 5/6, although any that made it this far showed much lower mortality thereafter. By late October 2010 approximately 3,500 juveniles had reached stage 8 or above and with falling water temperatures and slowing growth rates it was decided to proceed with tagging and releasing as soon as was practical.



Brood stock room

Conical room

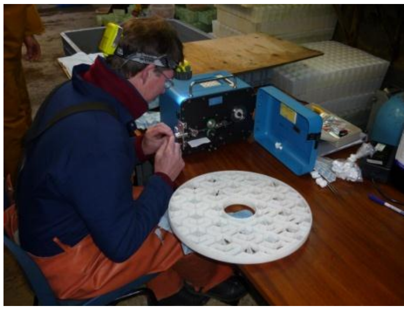
Feeding upwellers

METHOD

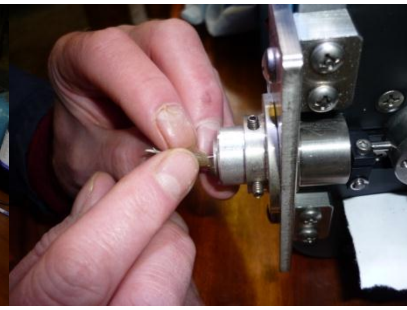
Craig Burton from Seafood Scotland, being one of only a handful of people in the UK with previous experience of lobster tagging, had kindly agreed to carry out the procedure for the project and arrived in Orkney on 5th November 2010 with the tagging equipment. All the juveniles were tagged over the next three days by injecting a microscopic metal strip into the soft tissue above one of the walking legs of each individual. Each disc of tagged lobsters was then returned to the Aqua-hive system where they remained for the following two weeks prior to release. Mortality due to the tagging process over this period was estimated at 25%, which was much as expected given the size of the individuals being handled and this ultimately gave a total of 2,600 lobsters for release.

Prior to release the lobsters were removed from the upweller units and a total of 26 discs were loaded, each with approximately 100 juveniles. A sheet of perforated tissue was then sandwiched between each disc of juveniles and a bottomless blank disc, which would eventually allow each lobster to escape as the tissue disintegrated at sea. The discs were individually weighted with a length of chain to hold them in position on the sea bed and three longlines were prepared, two consisting of 10 discs and the other of six, each with a spacing of 7 metres between discs.

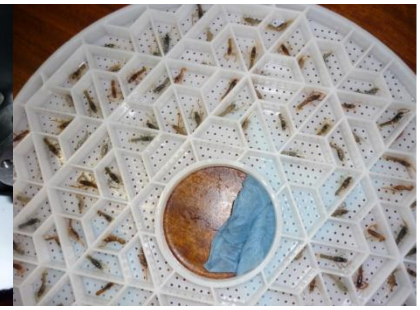
ANNEX 3: Billia Croo Lobster Tagging Project



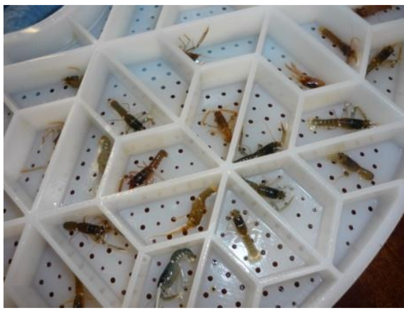
Tagging juveniles



Tag injector



Discs loaded with stage 8's



Discs loaded with stage 8's

Perforated tissue placed between discs

Longlines ready for release

<u>RELEASES</u>

With the weather looking favorable for a number of days the releases were carried out on 21st November 2010 with the help of local fisherman Michael Flett. Conditions were ideal with good visibility and a light NE'ly breeze which we hoped would allow the discs to be deployed and retrieved while the weather remained settled. The three longlines were set at a depth of 10-15 metres on a rocky substrate with good weed cover and their positions noted. They were then collected on 1st December 2010 and inspected to ensure that all juveniles had escaped. Past evidence suggests that it is unlikely these lobsters will be seen in catches for 2 - 3 years, dependant on the type of fishing gear being used. At that stage we will begin monitoring the "undersized" juveniles being caught in the area, using a detector to identify any of the tagged individuals to establish whether they have remained close to the release sites and also to give an indication of survival rates.

The positions of strings were as follows:

String 1 (10 discs) – from 58°58'.2087 N, 003°21'.5538 W to 58°58'.2391 N, 003°21'.5536 W

String 2 (10 discs) – from 58°58'.3464 N, 003°21'.4848 W to 58°58'.3751 N, 003°21'.4606 W

String 3 (6 discs) – from 58°58'.4382 N, 003°21'.6151 W to 58°58'.4505 N, 003°21'.6243 W

ANNEX 3: Billia Croo Lobster Tagging Project

Releasing juveniles

Marker buoys

Release area

The next phase of the project involves the monitoring of crustaceans within the designated zone by inspecting catches from boats fishing in the area. From this it's hoped to build up a picture of the population structure and abundance of the main commercial species, eventually gaining evidence of any apparent changes due to the presence of wave energy devices.

ANNEX 4: Review of Benthic Marine Habitat Data for the EMEC Billia Croo Test Site

Introduction

The benthic zone is commonly regarded as a '3d' environment which sustains a diversity of marine species and habitats (Ierodiaconou *et al*., 2011). Benthic habitats describe the seafloor topography, substratum and water quality characteristics such as wave exposure, salinity and turbidity, and ultimately influence the presence of ecological communities (Brown *et al*., 2011). A number of benthic species show preference for certain habitat types, based on biological strategies such as feeding or recruitment, which can change throughout a species' lifetime. Species which show habitat preferences include commercially important species such as Crustaceans, with selection based on larval settlement, shelter and predator avoidance strategies. Habitat selection is an extremely advantageous characteristic, particularly during Crustacean larval and juvenile life stages, due to the high risk of predation associated with mortality and moulting periods.

Knowledge of the habitat type, distribution and associated information such as substrate type is therefore useful for benthic species studies. This is applicable to Crustacean fishery release programmes, whereby outlining habitat information can give an informed view on the long term implications of Crustacean release and capture activities. Therefore this review will aim to provide information on the benthic habitats within the area of the European Marine Energy Centre's (EMEC) wave energy test site at Billia Croo, Orkney Islands, with application and reference to current biological knowledge of Crustacean and the Billia Croo European lobster (*Homarus gammarus*) fishery release programme.

Methodology

The review will be conducted as a desk-based analysis of the benthic habitats surrounding EMEC's Billia Croo wave energy test site from key data sources. These will be sourced from a number of national marine habitat schemes and benthic surveys undertaken within the site. The analysis will include a literature review of current scientific research on crustacean biology/ behaviour and species release programmes with specific reference to benthic habitats. A list of recommendations is also included to outline the potential for future studies on the benthic habitat and crustacean associations to aid the fishery crustacean release scheme.

Data sources

Data sources comprised of qualitative predictive mapping datasets and benthic surveys within the Billia Croo wave energy test site (see Appendix 1). Predictive mapping sources were sourced from online national GIS application databases such as Mapping European Seabed Habitats (MESH) and UKSeaMap. These give broad scale reference maps of the potential benthic habitats within Scotland, British Isles and Europe based on biological, physical and chemical information.

Data sources included a number of benthic surveys which had been conducted within the surrounding Billia Croo area, from 2002 and onwards. These surveys were undertaken for EIA and engineering objectives in relation to the development and testing of wave energy converter devices, instigated by EMEC. These surveys were conducted either throughout the entire Billia Croo area or focused specifically on test device site reference points such as cable route locations. They used a range of sampling methods including bathymetry, video camera methods, dive surveys and grab sampling techniques.

The literature assessment included sourced material from scientific journals and past fisheries and Strategic Environmental Assessment (SEA) reports on the site, Orkney, and the benthic environment as a whole.

Benthic Habitats

The predictive mapping techniques and benthic surveys outlined comparative habitat types within the surrounding area of the Billia Croo wave energy test site. These described the site as a high to moderate energy environment, influenced by the strong wave and tidal conditions. The predictive mapping data sources outlined a mixture of bedrock, rocks and coarse sediments, which change from rock habitats in the inner-shore region to coarse sediments in the offshore region (see figure 1.1).

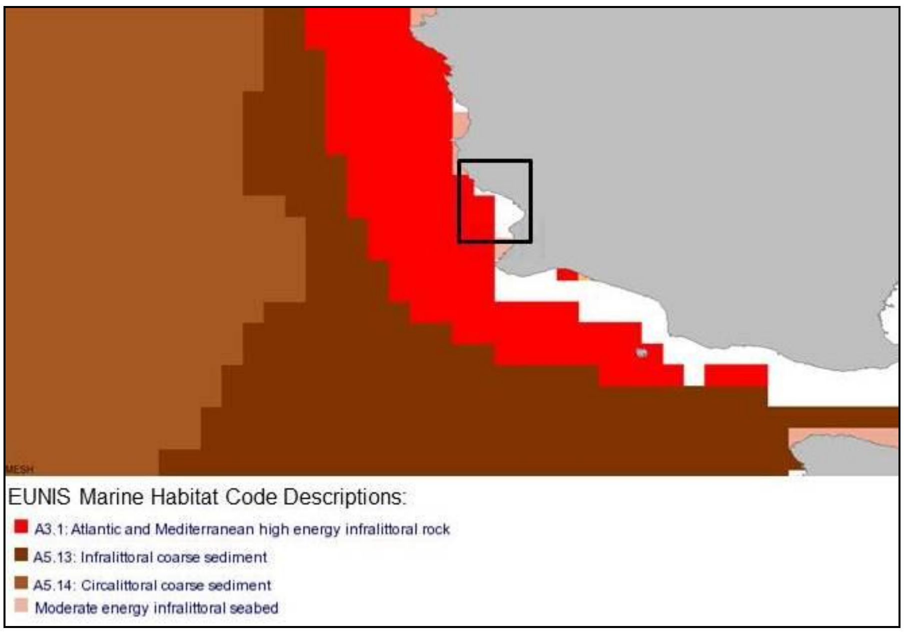
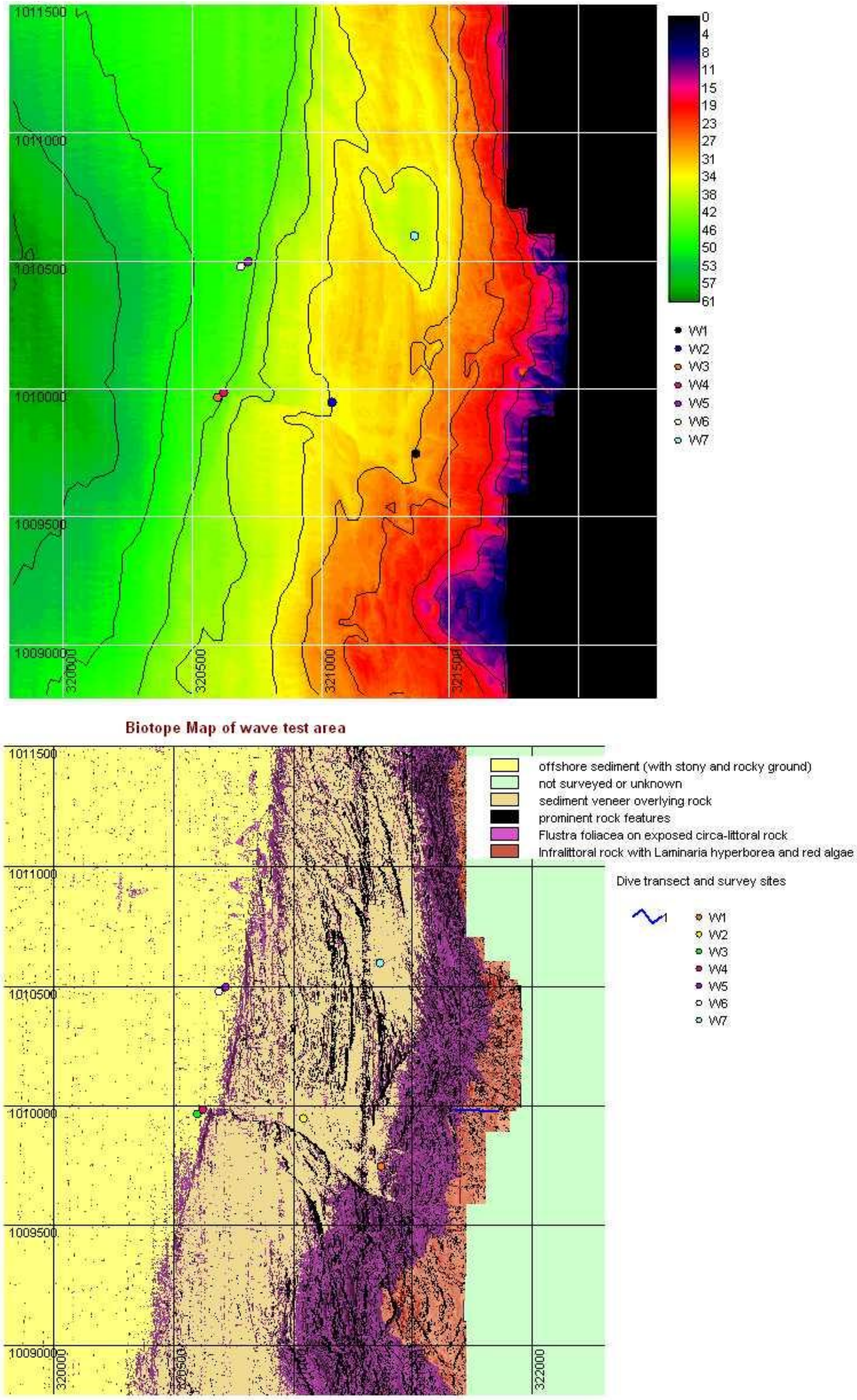


Figure. 1.1. Predicted EUNIS habitat types and distribution within the surrounding area of the Billia Croo wave test site from the UKSeaMap online database (UKSeaMap, 2011). The lined square represents the location of the Billia Croo area, with habitat types distinguished by block colours. Predicted habitats are based on past physical, geological and biological records throughout the UK, and assessed in terms of knowledge of benthic variable variations i.e. salinity gradients and data confidence interpretation.

Benthic surveys completed within the Billia Croo area complimented these broad habitat predictions and included additional, finer scaled habitat and species information (see figure 1.2). The bathymetry and video ground-truthing surveys revealed a progression of increasing water depth with distance from the shoreline within the Billia Croo area. In the inner-shore/ infralittoral region, bedrock habitats comprised of gullies and substrates such as; cobbles, boulders and coarse sands, from the low water mark to approximately 20 – 25 meters. This changed into transitional coarse sediments covering bedrock with large broken rock features, to deep offshore coarse sediments in the offshore/ circalittoral region at approximately 45- 47 meters (Carl Bro, 2002; Aurora Environmental, 2009).
The video reference points from both the scuba dive surveys and video cable surveys outlined differences in the biological habitat communities within the overall Billia Croo wave energy test site, corresponding to the changes in water depth, substrate type and hydrodynamic regimes. In the infralittoral region, *Laminaria hyperborea* kelp forest and habitats dominated the area, comprising of species such as the

herbivore *Echinus esculentus* and the predator *Asterias rubens* (ICIT, 2006; also identified in the EMEC ROV/Scuba dive sub-sea video camera footage, 2009). The sub-sea cable video surveys also revealed large quantities of broken down algae and detritus in the infralittoral zone, potentially due to the localised strong hydrodynamic regimes. In the circalittoral region, habitats predominately comprised of sessile or turf like, filter feeding species including the bryozoan *Flustra folica*, the soft coral, *Alcyonium digitatum* and the anemone *Urticinia felina*. This also included key stone species such as *Ophiothrix fragilis*, which are suspension feeders that dominate the seafloor in strong tidal and wave areas (ICIT, 2002; also identified in the EMEC ROV/Scuba dive sub-sea video camera footage, 2009). Species and habitats identified in both the infralittoral and circalittoral regions represent environments that are heavily influenced by strong hydrodynamic regimes, which is a true description of the Billia Croo area and also other benthic regions within the Orkney Islands overall.



a)

b)

Figure 1.2. Bathymetric maps of the Billia Croo area for a) depth gradients and b) biotope type and distributions, with ground-truthing benthic scuba diving surveys locations (taken from ICIT, 2002). a) water depths represented by colour key, b) biotope type and distribution represented by colour key Circles represent scuba dive benthic survey locations, classified from W1 – W7.

Crustacean Habitat Associations

Benthic species, particularly decapod Crustaceans can show non-random distribution in the benthic zone, and related to the type of habitat present and also their life stage for feeding, recruitment, shelter and reproduction activities (Comeau and Savoie, 2002; Pardo *et al*., 2007). Crustaceans show active habitat selection during the early settlement periods, which sets the initial distribution. This is subsequently modified by a dynamic secondary dispersal and habitat selection as Crustaceans reach juvenile stages and then on to full adult stages (Moksnes, 2002; Pardo *et al*., 2007). Crustaceans are also known to show movements related to seasonal temporal factors, where they seek shelter during moulting periods, or avoid predation and, are also influenced by other abiotic factors, such as decreasing water temperature and increasing exposure (Dunnington *et al*., 2005).

Literature suggests that the habitats identified within the Billia Croo area are favourable to such Crustacean species, including commercially important species such as lobsters. Rossong *et al.,* 2011, describe that juvenile American lobsters (*Homarus americanus*) use sediment substrates to bury themselves, whilst also exhibiting preferences for natural shelters created by rocks and crevices. Juvenile lobsters have also been known to prefer macroalgae and cobble substrates and actively select refuge type habitats in later juvenile stages (Moksnes, 2002; Pardo *et al*., 2007). These types of substrates and habitats were identified within the Billia Croo area from the benthic surveys, which could therefore act as potential habitats, particularly for juvenile lobsters and other crustacean species (Galparsoro *et al*., 2008; Schmalenbach *et al*., 2011; see figure 1.3). Furthermore the present surround area is used for lobster fishing, which further increases the perspective that the area and habitats within are suitable for lobsters and in turn act as a valuable release and nursery site.

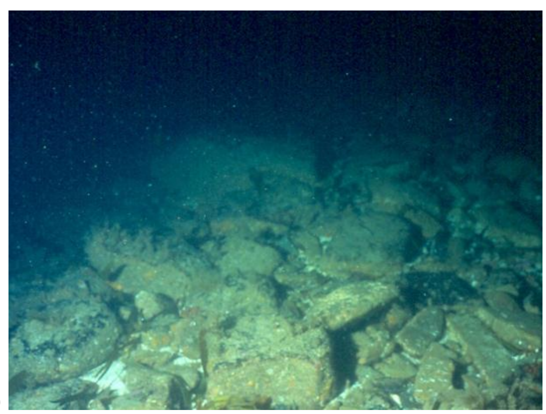
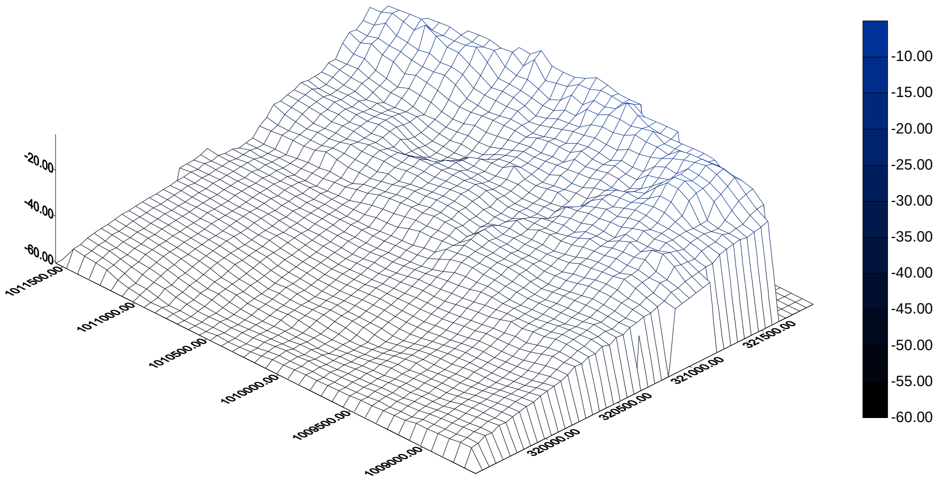
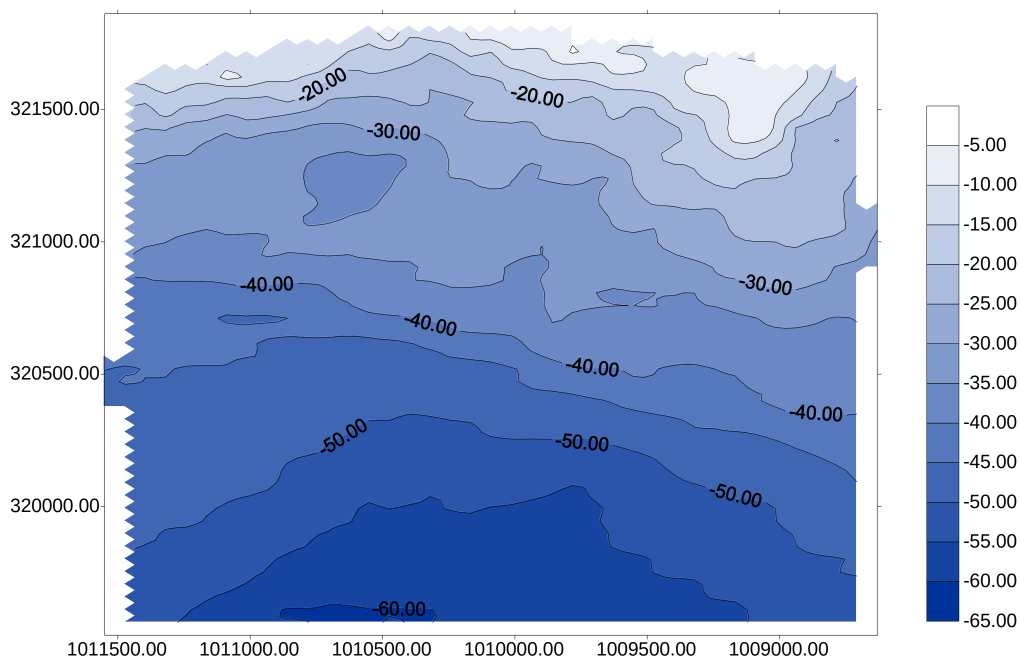
a)  **b)** 

Figure 1.3. Examples of benthic substrate and habitat types from scuba dive video and photography techniques, within the Billia Croo area, which could act as potential crustacean habitats (taken from ICIT, 2002). a) showing sandy seabed with stone patches, b) showing boulder patches.

The bathymetry surveys also revealed that the benthic habitats are continuous throughout the area, with some rock faces and steep gullies identified (Fathoms Ltd, 2002; figure 1.4). This implies that the area would not restrict the overall movements of the released individuals into the surrounding coastline, and help encourage lobster population stocks within the surrounding area in the long term. However additional mark-release schemes or commercial potting exercises would be required to determine the spatial movements of the released lobsters in more detail.



a)



b)

Figure 1.4. 3-Dimensional model of seabed topography a) and depth gradients b) for the Billia Croo area (taken from Fathoms Ltd, 2002).

Spatial movements by lobster species are known to be generally small (≤ 5 km), which is independent of sex or age/ size cohorts, except during the berried state of female lobsters to maximise egg development (Smith *et al*., 2001; Comeau and Savoie, 2002; Schmalenbach *et al*., 2011). Juvenile lobsters are also known to move less frequently than adults, and show longer periods of time in sheltered conditions due to the higher risk of predation (Rossong *et al*., 2011). However, Dunnington *et al.*, 2005, also described that juvenile lobsters do not aggregate in the immediate area of their release, and that recaptured lobsters can move in all directions. These studies suggest that sites of release such as the Billia Croo area have the potential to act as nursery areas, with released individuals then moving into the adjacent surrounding areas as older juveniles and adults over time. Benthic species are also influenced by other biological and environmental factors at both the temporal or spatial scale such as water temperature, depth and reproduction. Therefore further complimentary studies are recommended to enhance information regarding spatial movements and population dynamics specific to this release scheme.

Application to wave energy converter developments

The increased use of the Billia Croo area for renewable energy developments can potentially influence the benthic communities therein. A small number of studies suggest that the deployment of renewable energy devices and/or additional structures such as sub-sea cables and buoys can enhance local species diversity and composition (see Langhamer and Wilhelmsson 2009; Langhamer *et al*., 2009). These structures can act as new '3d' structures within the marine environment, which can potentially act as 'artificial reefs' (Langhamer *et al*., 2010). Artificial reefs can increase habitat complexity within the local area, and in turn may allow increases in ecological niches and diversity, following biological recruitment and aggregation processes (Langhamer *et al*., 2009).

Crustaceans such as edible crabs (*Cancer pagurus*), can exploit such developments, using wave energy converter device foundations for shelter purposes (Langhamer *et al*., 2009). This is also applicable for juvenile life stages, for example juvenile *Carcinus maenas*, are known to select more structurally complex microhabitats for refuge (Moksnes, 2002). For Crustacean species that travel short distances or show large fidelity to their release sites such as lobsters, the availability of shelter from predation may cause a demographic population bottleneck within the local area (Langhamer and Wilhelmsson, 2009; Schmalenbach *et al*., 2011).

Langhamer and Wilhelmsson 2009, observed lobsters in dug out cavities below wave energy converter device foundations, and that lobster prey species such as the mussel *Mytilus edulis*, were also found attached to the device foundations. Renewable energy development sites can enhance the biomass of certain species including lobsters, by providing shelter and additional food sources. Therefore the Billia Croo site has the potential to act as refuge or nursery site for such species, particularly with respect to lobster release programme in the local area and to the other release sites within Orkney overall.

Complimentary benthic surveys of the development activities within the Billia Croo area could further knowledge, particularly with focus on lobster observations or shelters in proximity to structures. This may help develop habitat enhancement structures suitable for lobsters within the site to aid the lobster release programme overall.

In the long term, the Billia Croo site could be recognised as a suitable nursery or refuge area for juvenile lobsters and other Crustacean species. Such nursery or refuge areas are important, particularly for sustaining local population stocks for fisheries in the long term. Greater collaboration between fisheries managers and renewable energy developers could help such commercially important species, but decisions must be based on sound management and monitoring techniques overall.

Summary

The Billia Croo wave energy test site is strongly influenced by exposed wave and tidal hydrodynamic conditions, which is represented by the types of benthic habitats and species identified in this review. Both the broad-scale computerised habitat databases and fine-scale site bathymetry and video camera surveys outlined comparable benthic seabed, habitat and substrate information overall. The inner-shore benthic region comprised of kelp beds, bedrock with tide-swept communities and rock gullies, leading to coarse sediments located in the offshore benthic region. Substrates consisted of coarse sands, cobbles, rocky outcrops and bedrock, with a range of epifaunal and benthic species such as Sponges, Bryozoans, and Molluscs identified throughout the site.

Overall, the types of substrate, habitat and topographic conditions found within the Billia Croo site are favourable to Crustacean species, such as lobsters (*Homarus gammarus*), for refuge and feeding opportunities. This species is commercially important throughout the Orkney Islands, and in and around the Billia Croo wave energy test site. This suggests that the site has the potential to act as an important nursery site for lobsters, both to the local fishery but also to the Orkney Islands as a whole.

Therefore the review recommends further support of the juvenile lobster release programme within the site, to help enhance lobster stocks for long-term sustainable fishing activities. Complimentary studies are also recommended, in terms of lobster population dynamics, stock levels and habitat preference research within the local and regional area. Such studies can provide further knowledge on commercially important species such as lobsters, whilst also help to develop valuable links between fishing and renewable energy practices.

Melanie Broadhurst
December 2011

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Appendix 1: Data Sources used in the Desk-based Study

Type	Author	Year	Title	Published by	Source location
Computerised GIS Marine Habitat/ Species Database	UKSeaMap	2010-11 (accessed 02/12/2011)	UKSeaMap 2010 Interactive Map	UKSeaMap, JNCC	Online source: www.jncc.defra.gov.uk/5534
	MESH	2008 (accessed 03/12/2011)	Mapping European Seabed Habitats	MESH, funded by INTERREG New programme	Online source: www.searchmesh.net
	JNCC	1995	1995 MNCR West Mainland and Hoy (Orkney) survey. South of Skrowa Skerry (SW Mainland, reference: 449 030).	JNCC	JNCC
Report/ paper datasets	Aurora Environmental Ltd	2009	Environmental Description for the EMEC Wave Test Site Billia Croo, Orkney.	Aurora Environmental Ltd	EMEC
	Carl Bro	2002	Marine Energy Test Centre, Environmental Statement.	Carl Bro	EMEC
Type	**Author**	**Year**	**Title**	**Published by**	**Source location**
Report/	Fathoms Ltd	2002	Report on	Fathoms Ltd	EMEC

paper datasets (continued)			the bathymetric survey of the proposed European Marine Energy Test Centre, Orkney. Report No: 1016-73.		
	ICIT	2002	Marine Energy Test Centre, ITT-8 (Benthic Survey: Sublittoral) Report.	ICIT, Heriot Watt University	EMEC
	ICIT	2006	Marine Renewable Test Centre, Nearshore Seabed Survey for Cable Routes, Version 2.	ICIT, Heriot Watt University	EMEC
Raw datasets	Sula Diving	2009	Scuba dive video camera surveys of deployed sub-sea cables	EMEC	EMEC
	Roving Eye Enterprises	2009	ROV video camera surveys of sub-sea cables	EMEC	EMEC

ANNEX 5: Review of Lobster Catch Data for the Billia Croo Area

Introduction and background

Orkney Sustainable Fisheries (OSF) is industry-led with the company board represented by local fishermen, merchants and processors with the common aim of taking forward various initiatives relating to the sustainability of the local shellfisheries. Recent Scottish Sea Fisheries Statistics (2010) show Orkney's shellfish fishery valued at £7,464, 000 in 2010 with the three main species brown crab *(Cancer pagurus),* velvet crab *(Necora puber)* and European Lobster *(Hommurus Gammurus)* accounting for £6,572,000 of this total. The importance of Orkney's shellfish fishery is also highlighted on a Scotland wide scale with velvet crab landings from the county contributing 33% of the Scottish total, brown crab 20% and lobster 12%. Out of the three main species caught in Orkney the European Lobster has the highest monetary value.

OSF has collected catch data on the lobster fishery around Orkney's inshore waters. The data has been collected as part of the market sampling research to aid the understanding of the lobster stock around Orkney. In Scotland the minimum landing size (MLS) for the European Lobster are 87 mm carapace length and a maximum landing size of 220 mm carapace length. It is legal in the United Kingdom to land female lobster carrying eggs (Berried).

This report has been prepared to provide a further insight into the lobster data collected by Orkney Sustainable Fisheries and should be used with the Orkney Sustainable Fisheries Project Review (see Annex 7).

Market Sampling Data Collection and Analysis

The data was collected on shore at the Orkney Fisherman's Society ponds in Stromness and at the merchant O-Fish Shell's ponds in Lamb Holm. The method of data collection was an electrical calliper PDA system, donated to the company by Marine Scotland. The sex and the length of the lobster's carapace was measured and recorded as well as boat name and fishermen. This data has been sorted into size frequencies for Males and Females and size frequency distribution graphs have been plotted (Figure 1- 17).

Results

For the purpose of this report the data for male and female lobsters has been analysed separately. The female lobster data has been further analysed and separated into berried females (carrying eggs) and non-berried females. Table 1 shows the total average size of lobster which was sampled over the Market Sampling project carried out by OSF.

Average size of Lobster	**98 mm**
Average Size of Male Lobster	99 mm
Average Size of Female Lobster	98 mm
Average Size of Berried Female Lobster	98.7 mm
Total number sampled	1909

Table 1 Average Size of Lobster sampled

The average size of lobster sampled for 2010 and 2011 combined was 98mm carapace length. The average lobster sampled in 2010 was 97mm carapace length with a varying range from 85-145mm carapace length. The average size of lobster sampled in 2011 was 98.6mm carapace length with a varying range from 86-149mm carapace length. The average size of male lobster is larger than female at 99mm compared to 98mm. Within the female data the average size of berried female is slightly larger than non-berried females.

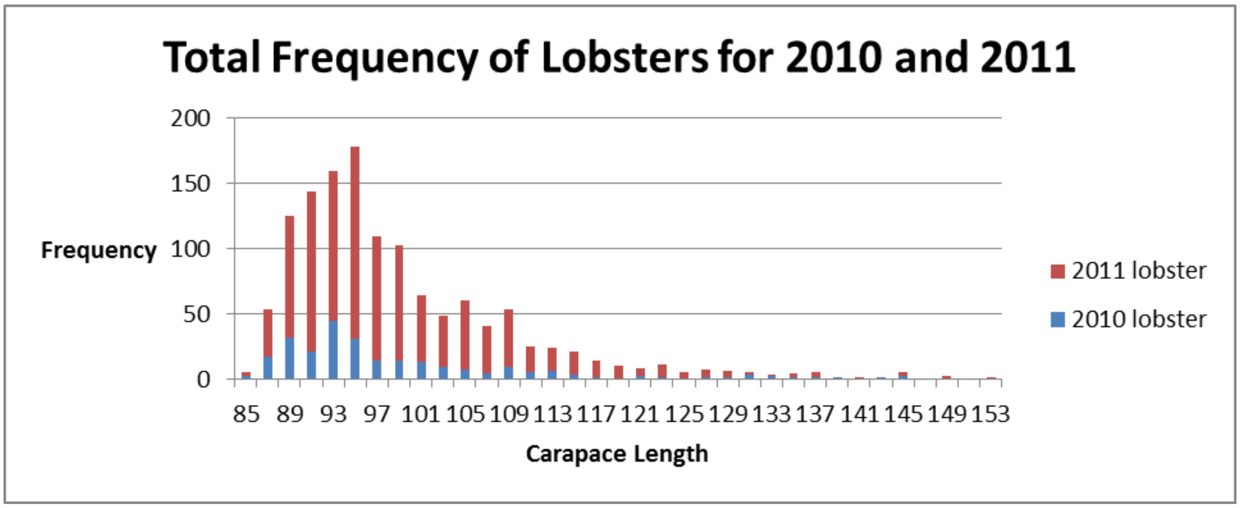

Figure 1 The total size frequency of Lobsters sampled in 2010 and 2011

Size frequency distribution graphs have been plotted for all the lobsters sampled in 2010 and 2011 by OSF (Figure 1). It should be noted that frequencies are in terms of actual numbers sampled. Plots have also been constructed for male and females separately to look for patterns in the size frequency of lobsters caught in Orkney (Figure 2 and 3). The data was also analysed by month size frequency plots were constructed for male/female distributions for each months that data was available for (see Appendix 1). There are higher frequencies of lobster seen in 2011 this is due to the increased level of individuals that were sampled. The trend of size frequency is similar over the two years with most lobsters being landed between 89-97mm carapace length.

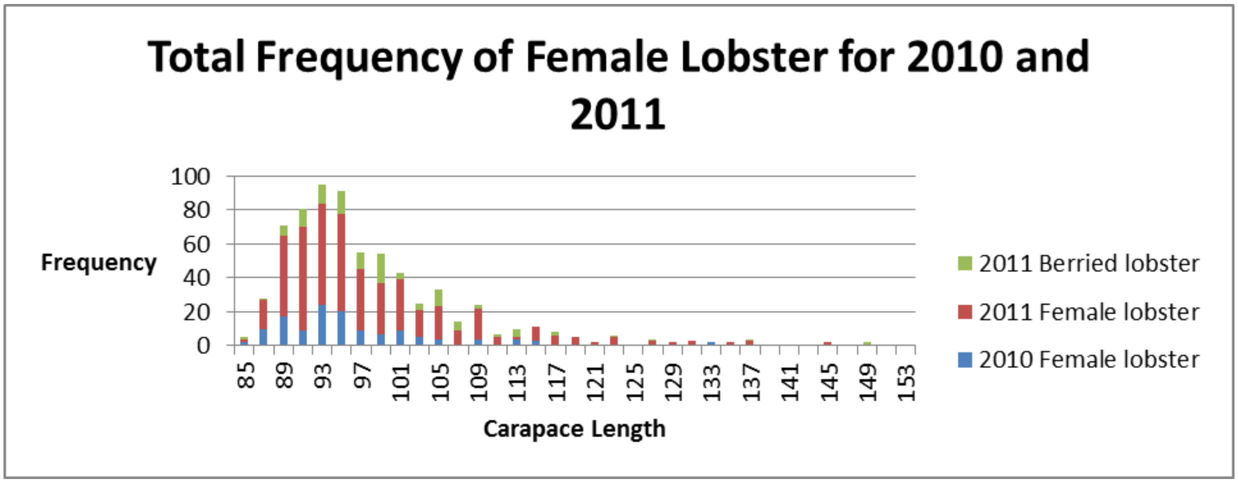

Figure 2 The total Frequency of female lobster sampled over 2010 and 2011

The size frequency plots for female and male lobsters separately show a similar pattern with the most frequently sampled lobsters ranging from approximately 89-97mm carapace length. Berried females follow the same trend however the data shows that berried females were sampled in much lower numbers than non-berried females and males.

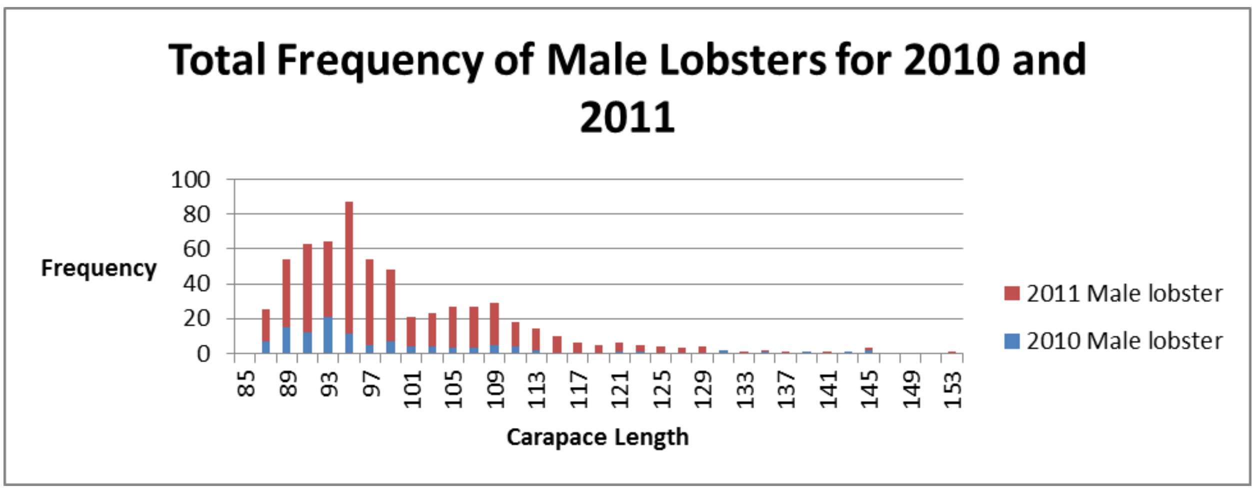

Figure 3 The total Frequency of male lobster sampled over 2010 and 2011

Concluding Remarks

This report was set out with the aim of highlighting trends in the lobster catch data which was collected by Orkney Sustainable Fisheries in 2010 and 2011. The data shows that the lobsters which are being landed in Orkney are on average 98mm carapace length which is 11mm over the legal minimum landing size this could be due to market pressure for this size of lobster but undoubtedly helps in the sustainability of the fishery as it allows female lobsters more time to

reproduce and add to the stock. The trend is similar for both males and females including berried females.
To draw solid conclusions from this data is difficult as the sampling was only carried out over the summer months, from May to September 2010 and 2011. These graphs and numbers therefore only represent the summer months and may not represent the fishery for the winter months. It should also be noted that the number of lobsters sampled for each month varied and there were no weights recorded.

The data does however give an indication into the lobster fishery in Orkney and give an idea of the size of male, female lobster which is caught. To make the data more robust and give a better insight into the fishery sampling needs to carried out over the winter months to see if there is a change in the size which is being landed. Sampling should also identify the geographical areas in which the lobsters are caught to see if there are changes locally throughout Orkney's inshore waters. Continued market sampling should be done in order to build on the data already collected by Orkney Sustainable Fisheries so that the trends in the lobster stock can be identified which will insure its sustainability. Also starting to gather information on the fishing effort would allow more conclusions to be drawn and give a more comprehensive insight into the fishery and factors that will have an effect on the fishery. For further information on the projects carried out on Orkney's inshore fisheries please consult the Orkney Sustainable Fisheries Project Review (Annex 7).

Kate Walker, Shellfish Scientist, Orkney Sustainable Fisheries
November 2011

Appendix 1

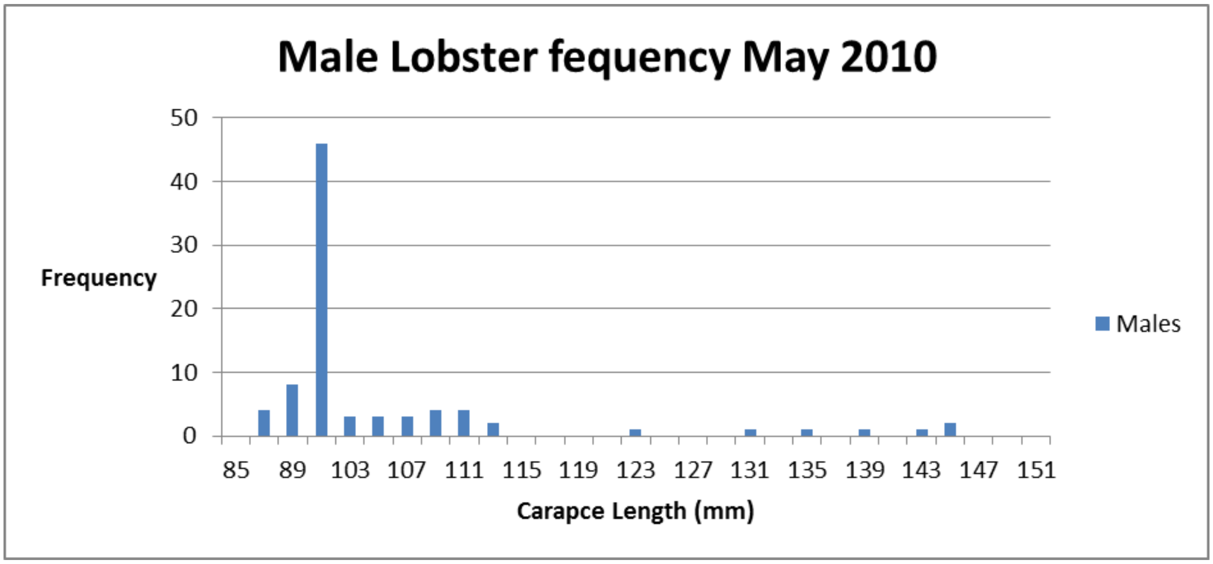

Figure 4 Male lobster frequency May 2010

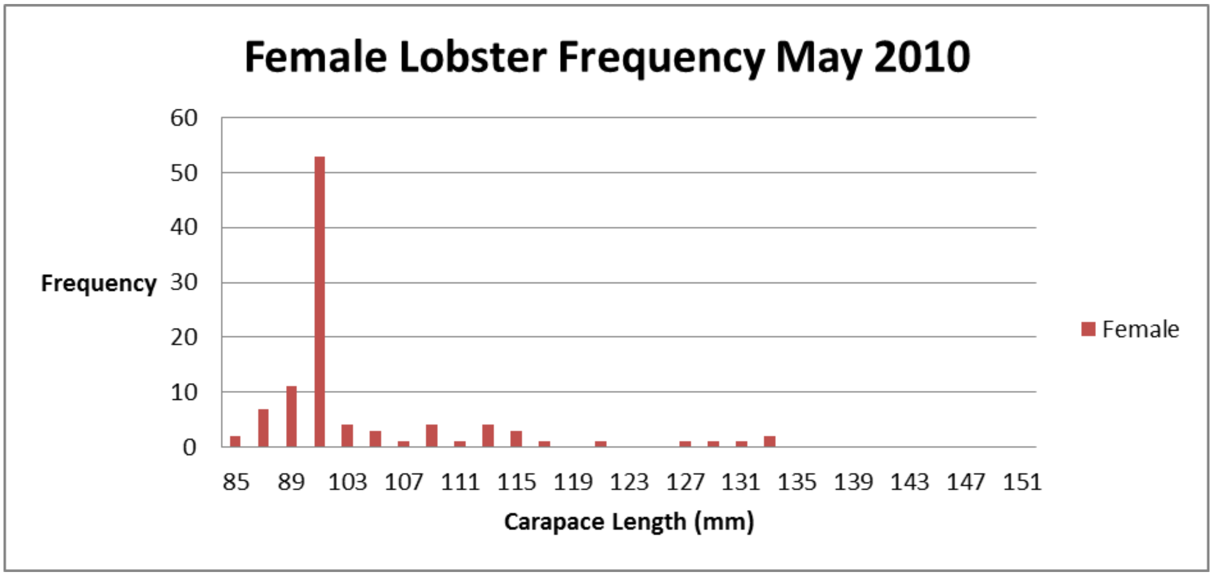

Figure 5 Female Lobster Frequency May 2010

ANNEX 5: Review of Lobster Catch Data for the Billia Croo Area

May 2010	
Average Size	98.2
Average Size of Female	97.83
Average Size of Male	99.8
Number sampled	185

Table 2 Average sizes for May 2010

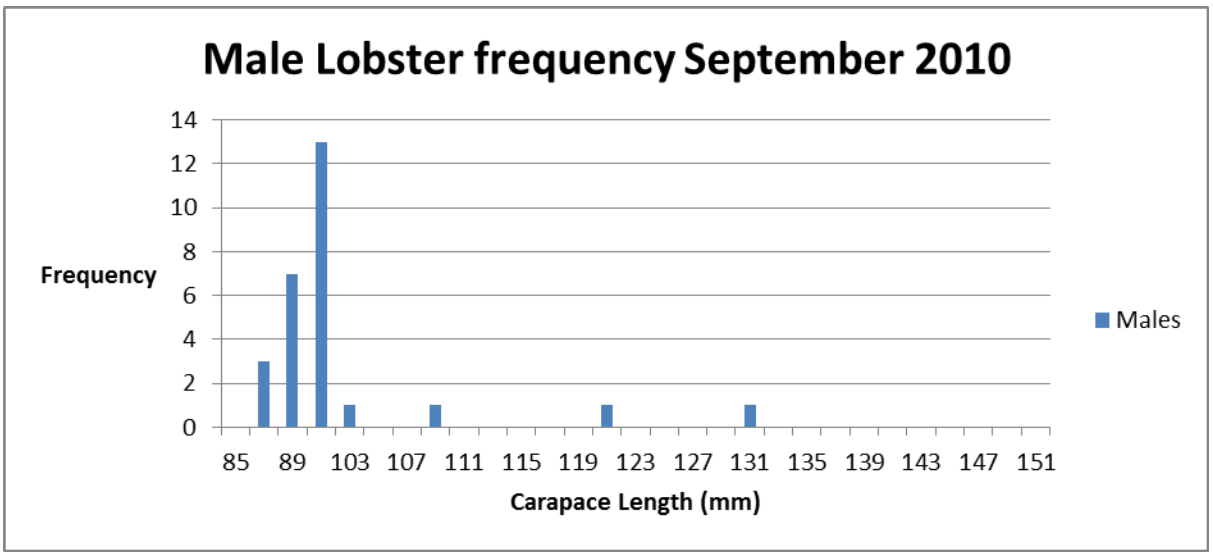

Figure 6 Frequency of Male lobster September 2010

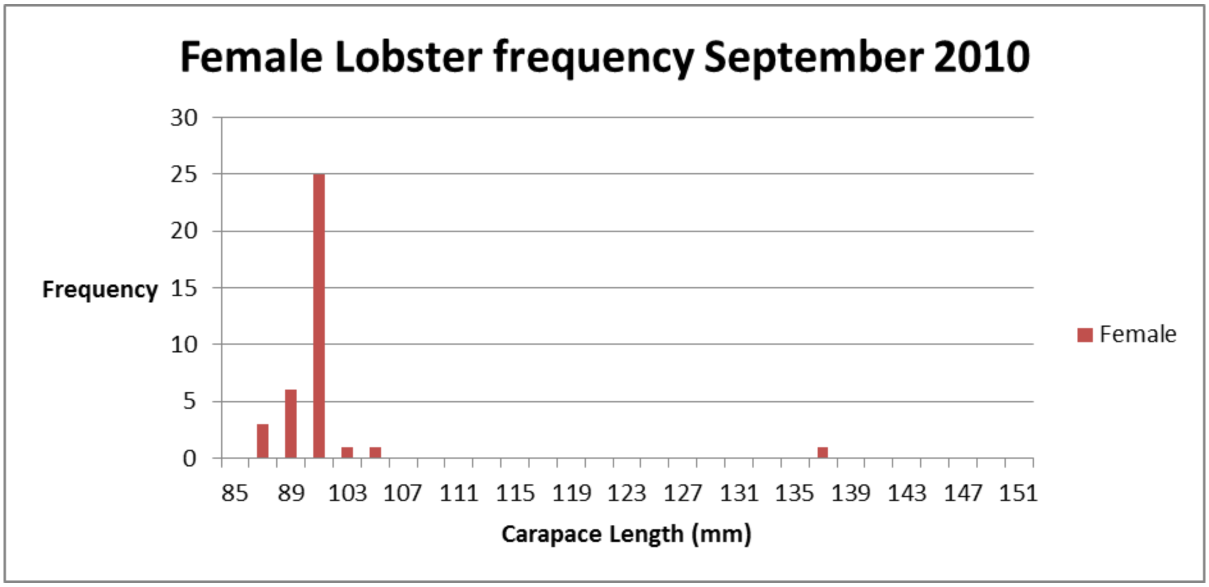

Figure 7 Frequency of Female lobster September 2011

September 2010	
Average Size	94.2
Average Size of Female	94.62
Average Size of Male	93.89
Number sampled	64

Table 3 Average Size in Lobster September 2011

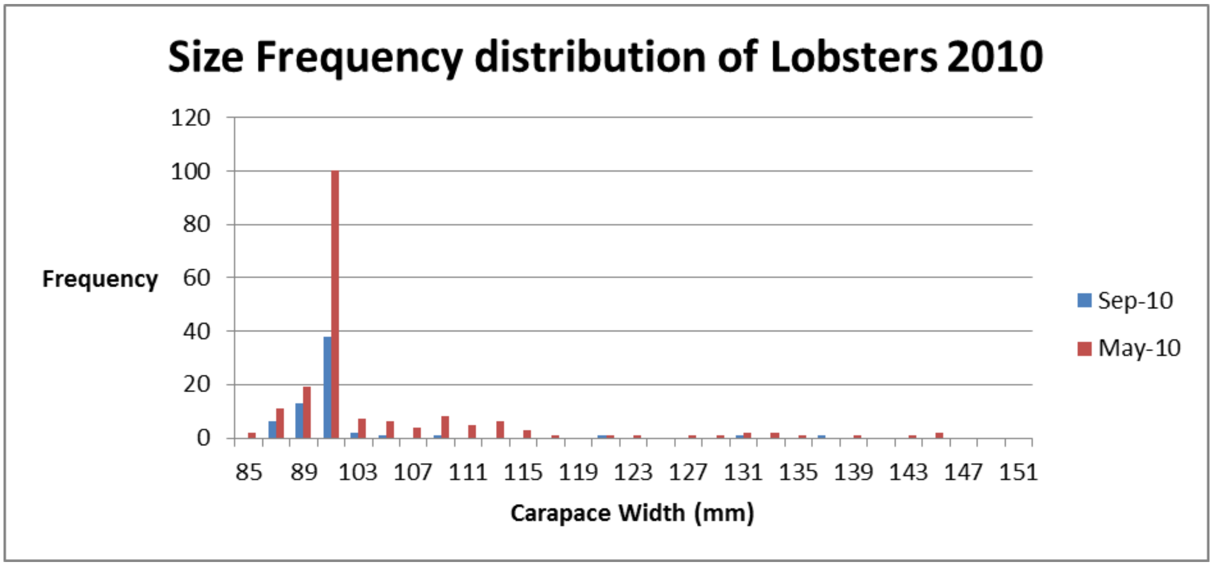

Figure 8 Frequency of Lobsters for 2010

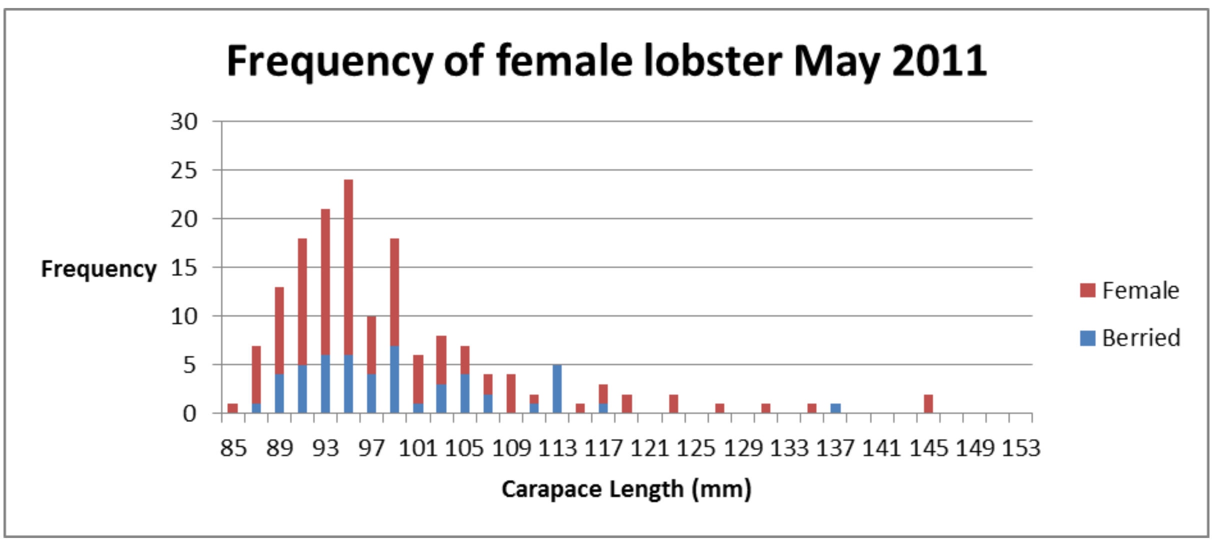

Figure 9Frequency of Female lobsters for May 2011

ANNEX 5: Review of Lobster Catch Data for the Billia Croo Area

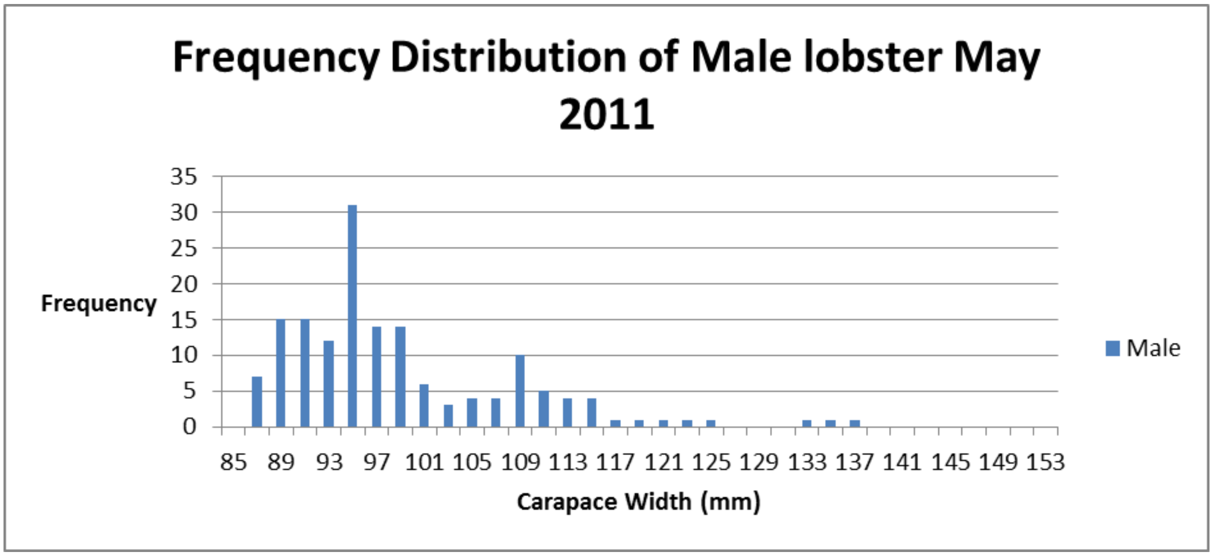

Figure 10 Frequency of Male lobsters for May 2011

May 2011	
Average size	98.84
Average Berried Female	99.0
Average Female	98.4
Average Male	99.0
Number Sampled	319

Table 4 Average size of lobster May 2011

ANNEX 5: Review of Lobster Catch Data for the Billia Croo Area

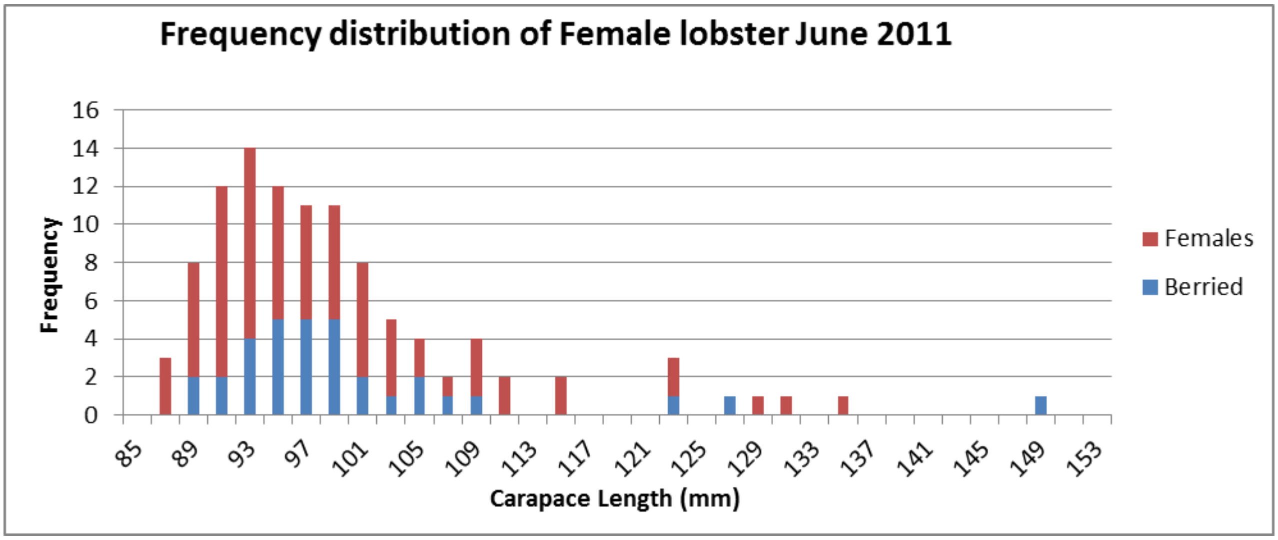

Figure 11 Frequency of Female lobster for June 2011

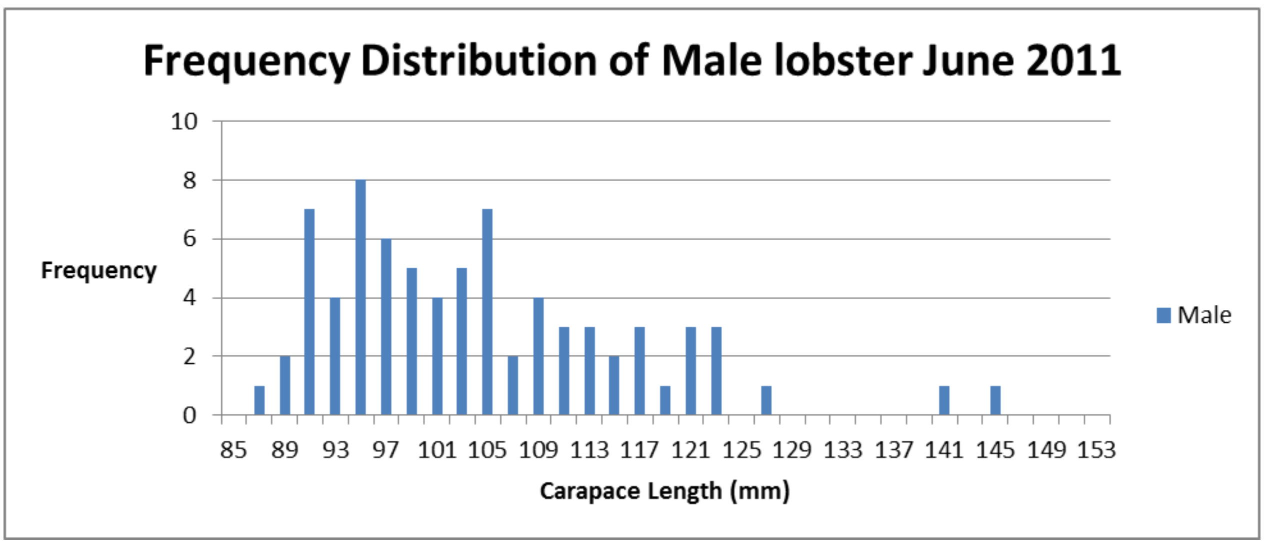

Figure 12 Frequency of Male lobster June 2011

June 2011	
Average size	100.9
Average Berried Female	99.78
Average Female	98.5

ANNEX 5: Review of Lobster Catch Data for the Billia Croo Area

Average Male	103.7
Number Sampled	183

Table 5 Average Size of lobster June 2011

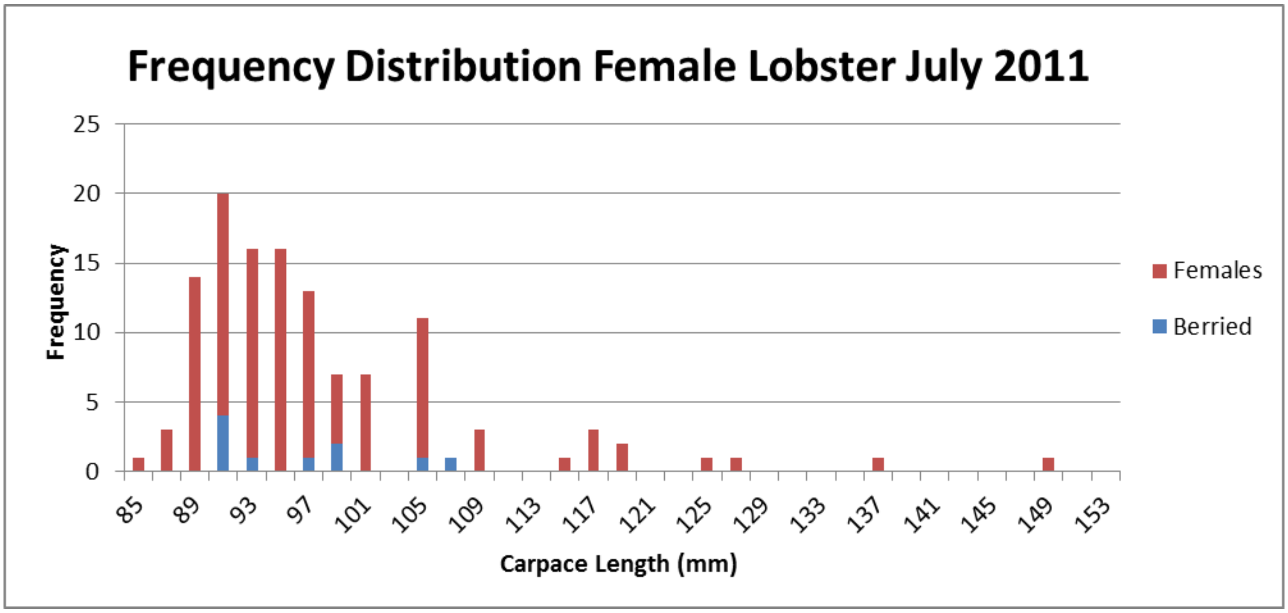

Figure 13 Frequency of Female lobster July 2011

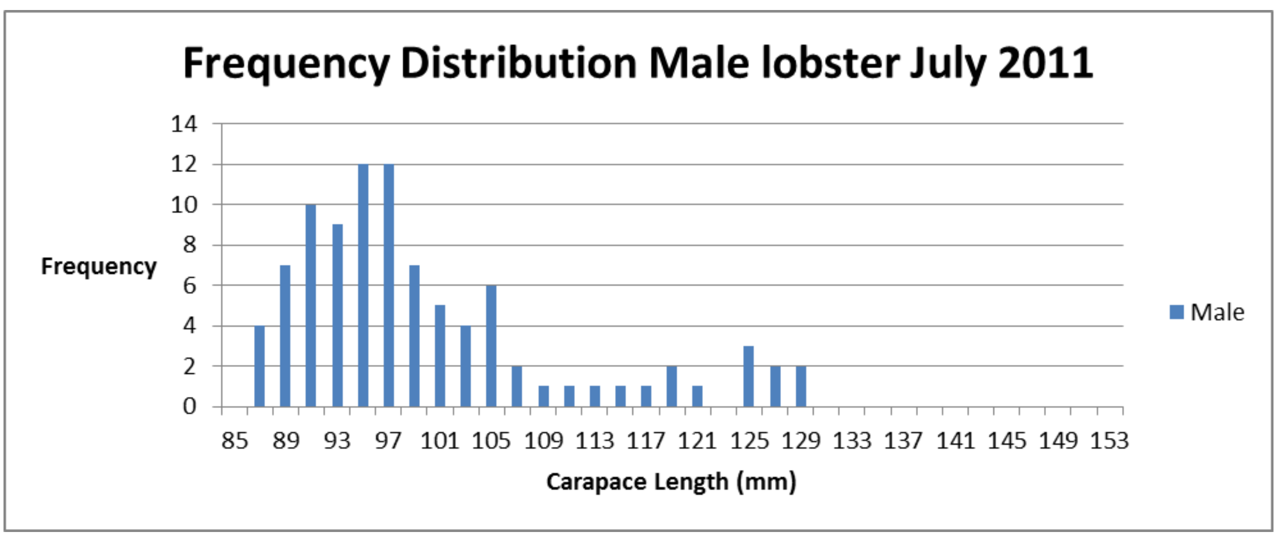

Figure 14 Frequency of Male lobster July 2011

ANNEX 5: Review of Lobster Catch Data for the Billia Croo Area

July 2011	
Average size	98.2
Average Berried Female	95.3
Average Female	97.7
Average Male	99.1
Number Sampled	216

Table 6 Average Size of Lobster July 2011

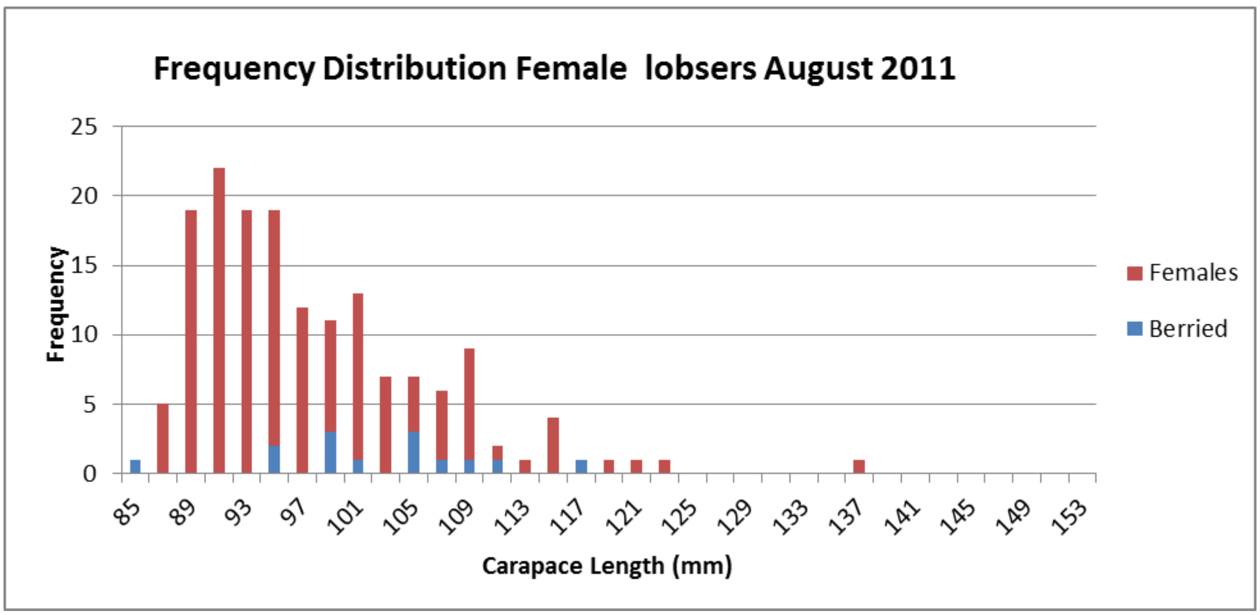

Figure 15 Frequency of Female lobsters August 2011

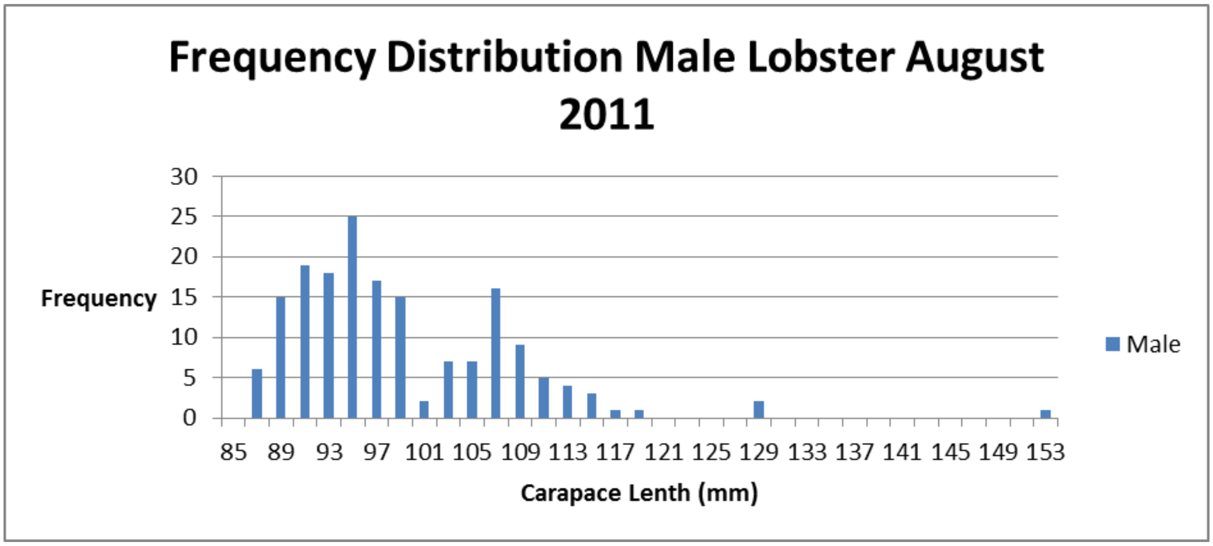

Figure 16 Frequency of Male lobster August 2011

August 2011	
Average size	97.5
Average Berried Female	97.5
Average Female	96.6
Average Male	98.3
Number Sampled	335

Table 7 Average Size of lobster August 2011

ANNEX 5: Review of Lobster Catch Data for the Billia Croo Area

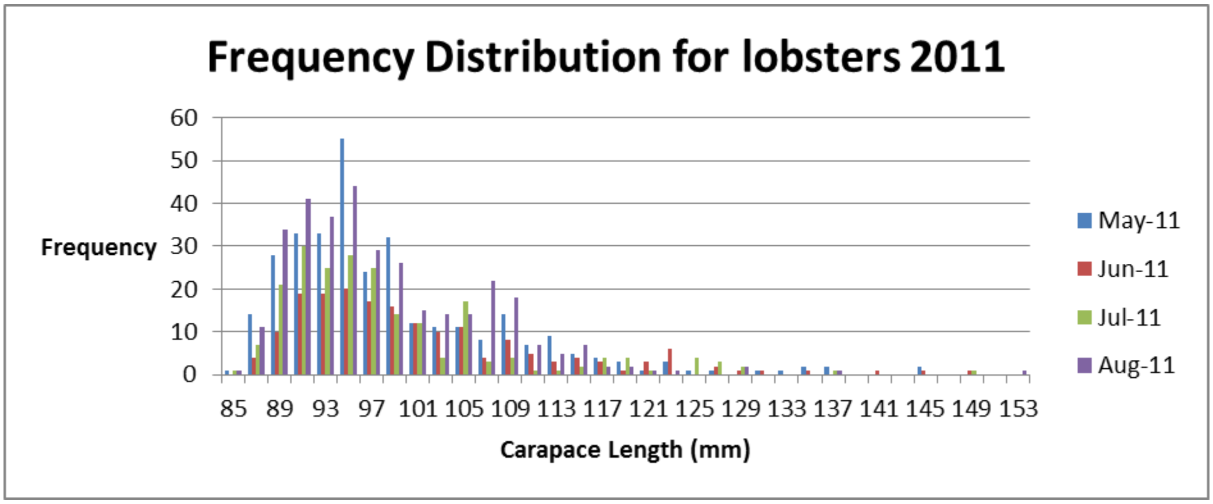

Figure 17 Frequency of Lobsters month by month over 2011

Crustacean fishery monitoring at Billia Croo, the EMEC wave test site

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December 2011

CONTENTS

EXECUTIVE SUMMARY

- As an emerging new user of the marine environment, the wave and tidal energy industry must sit alongside existing users such as fisheries. Spatial interactions between marine energy developments and fisheries are most likely to occur in inshore areas and to be important for species of low mobility such as shellfish. The creel fishery for crustaceans is an important component of the local economy in Orkney, and there is considerable potential for fishing grounds to be overlapped by wave and tidal energy developments in these waters. This report describes the results of monitoring of lobster and brown catches at EMEC's wave energy test site at Billia Croo on the west coast of Mainland Orkney, considering the potential impacts and opportunities presented by possible interactions between inshore wave energy developments and creel fisheries.
- Lobster and brown crab catches by a commercial vessel fishing creels at Billia Croo were recorded on 21 occasions during June to September 2011. Recorded data included catch rates of legal and undersized individuals and catch composition in terms of species, sizes and sexes. Background data on brown crab and lobster fisheries across the wider Orkney inshore area are available from monitoring activities by Orkney Sustainable Fisheries Ltd undertaken during 2010 and 2011 (Annex 7).
- Catch rates of legal lobsters at Billia Croo were on average higher and catch rates of legal brown crabs were on average lower than recorded elsewhere in Orkney. Conversely, availability of undersized (discarded) individuals to fishing gear at Billia Croo was relatively low for lobsters and high for brown crabs. These comparisons are made using limited data available for areas other than Billia Croo.
- Lobster landings showed a sharper truncation of numbers at sizes above the minimum legal size for Billia Croo than for other inshore areas of Orkney, but overall variation in size composition was within the range recorded for other areas of Orkney. Female lobsters were predominant in the landings, to a slightly greater degree than for Orkney as a whole. Variation in size composition of brown crab landings from Billia was also within the range seen in other areas, although small males tended to form a larger proportion of the catches at Billia Croo. Brown crab landings from Billia Croo were predominantly of males. To a lesser extent, the same was true for Orkney as a whole. These comparisons are made using extensive market sampling data from across Orkney collected during 2010 and 2011.
- Length-based assessment methods were applied to lobster landings data to assess local stock status. These analyses suggested a stock of around 900 lobsters in the Billia Croo area, around 0.1-0.2% of the Orkney population as a whole. On the evidence of the size composition of landings, fishing pressure at Billia Croo appears to be higher than for Orkney as a whole. Spawning potential appears to be reduced to less than 10% of its unexploited level. Greater levels of movement between areas by brown crabs, implying that size compositions are a result of movements as much as mortality, mean that it is not possible to perform the same type of assessment for this species.
- The overall picture for the Billia Croo fishing ground is as a locally important area for lobsters and a less important area for brown crabs. Billia Croo lobster landings are estimated to be around 0.2% of the likely Orkney total for 2011, while brown crab landings are estimated to be less than 0.1% of the Orkney total. Exclusion of fishing from inshore wave development areas similar to Billia Croo could have important implications for the local lobster fishery. The extent to which

any loss of access would be offset by gains from spill-over of protected stock to adjacent areas and from increased local egg production is currently unknown. On the other hand, wave development areas represent an opportunity for stock enhancement, both from deliberate or incidental creation of habitat for juvenile crustaceans and from release of hatchery-reared individuals to augment natural sources of recruitment.

- Improvements in future monitoring programmes are likely to depend on the extent to which commercial fishing vessels can be chartered to allow full scientific control of fishing and sampling operations. The current project relied on monitoring activities undertaken by a fisherman as part of commercial activities. Tagging of lobsters, vital to provide an objective basis to examine population turnover processes underlying the functional interactions between energy developments and fisheries, is likely to be practicable only as part of scientifically controlled monitoring activities undertaken by paid charter.
- Recommendations are made for future research and monitoring activities aimed at examining the potential interactions between wave and tidal energy developments and inshore fisheries.

INTRODUCTION

Food has been harvested from the sea for many thousands of years. The potential harvest of hydrodynamic energy from the sea has hardly yet been touched. Given ambitious targets for meeting energy demands from renewable resources (20% by 2020), and the potential for wave and tidal energy to contribute towards meeting these targets, this is set to change rapidly. It is clearly of interest to determine what conflicts and synergies are likely to arise from the coexistence of these traditional and new uses of the marine environment. Extraction of hydrodynamic energy has potential implications in terms of both spatial occupancy of sea areas and impacts on the physical and ecological processes underlying marine productivity (see review by Bell & Side, 2011). Bell *et al.* (2010) examined the spatial overlaps between marine fishery landings and wave and tidal energy resources in UK waters and determined that the potential for conflict is probably small at a national level, but may be significant for some inshore fisheries of local or regional importance. Fish and shellfish movement rates are an important factor in determining the nature of spatial interactions between marine renewable energy developments and exploited stocks. Species with low rates of exchange between areas have the greatest potential to interact with developments in terms of potential effects on fishery yields and sustainability of fishing.

In UK waters, the principal species of low mobility with potential for spatial interactions with wave and tidal energy developments are shellfish – crustaceans and molluscs. In Orkney waters, creel fishing for lobsters and crabs is the basis for a very important contribution to the local economy, in terms of both landed value (£6.7 million at first sale in 2010) and added value through the thriving processing sector. Brown crabs (*Cancer pagurus*) and European lobsters (*Homarus gammarus*) are traditionally the most important species, but velvet crab (*Necora puber*) is now almost as important as brown crab and there is a rapidly developing market for green crab (*Carcinus maenas*). See Lamb (2011) and Walker (2011) for recent information on the nature of the Orkney creel fisheries and Table 1.9 of Marine Scotland (2011) for recent landings data. Quantitative data on the distribution of fishing effort for these fisheries is currently lacking (mapping exercises by Marine Scotland and Orkney Fisheries Association are currently underway), but it is already clear that lease areas for wave and tidal energy developments recently established by Crown Estate in the Pentland Firth and Orkney Waters are likely at least to overlap with some important fishing grounds.

This report describes results from monitoring of lobster and brown crab catches at Billia Croo, EMEC's wave energy test site on the west coast of Mainland Orkney, during summer 2011. The aim of the monitoring was to characterise the creel fishery and stocks of its target species in the area, set in the context of the Orkney inshore region as a whole. This should allow conclusions to be drawn about the likely 'foot-print' of an inshore wave energy development on the Orkney creel fisheries, highlighting the potential impacts and opportunities that this presents. Monitoring of the Orkney creel fishery by Orkney Sustainable Fisheries Ltd during 2010 and 2011 (Lamb, 2011) provides a background to the results presented in this report.

METHODS

Monitoring of lobster and brown crab catches was undertaken by a commercial fishing vessel, *FV Shalimar*, fishing two strings of standard creels (one string of 25 creels, another of 31 creels) at the Billia Croo wave energy test site during summer 2011. Details of the catch recording programme are given in Appendix I. Catches of brown crabs and lobsters were recorded on 21 occasions during June to September 2011, representing a total of 1,176 trap hauls (56 traps x 21 occasions). Velvet crabs were not recorded in the catches. Undersized lobsters, discarded without landing, were recorded either by the fisherman or by onboard observers on all occasions up to early August. Undersized crabs were sampled by onboard observers (or onshore on one occasion) on three occasions during the summer. Data available from the monitoring programme include landings numbers, sexes and sizes in each string on every occasion and total catch numbers (including discards), sexes and sizes in each string on some occasions.

RESULTS

Catch rates

Catch rates are here described in terms of both landings per unit effort (LPUE), which is the catch per trap in numbers or weight retained for landing, and catch per unit effort (CPUE), which refers to total numbers or weight captured per trap, including individuals discarded before landing. Discarding may occur for a number of reasons related to size, condition and reproductive status, but in practice LPUE refers to lobsters or crabs of legal size or above, whilst CPUE refers to both legal and undersized crabs or lobsters. Minimum legal sizes (MLS) are 87 mm carapace length (CL) for lobsters and 140 mm carapace width (CW) for brown crabs.

Catch rates of brown crabs and lobsters at Billia Croo varied about ten-fold between fishing occasions during summer 2011 (Figures 1 and 2). There was no strong correlation of catch rates between species, but the relationship was generally positive (Figure 3) indicating that patterns over time were likely to have arisen from effects of environmental conditions rather than interspecific interactions (interspecific interactions would be likely to result in a negative correlation, since brown crabs tend to avoid traps containing lobsters). Data at a trap level (not recorded during monitoring) would be needed to confirm the absence of interspecific interactions. No strong seasonal trends were seen during the June to September fishing period, but some correspondence of catch rates with the semilunar tidal cycle is apparent (Figure 4). Lobster catch rates tended to be highest just before spring tides. The association is less clear for brown crabs, but there was some tendency for highest catch rates at intermediate tidal amplitudes. Local depletion (likely to cause declining catch rates) appears not to have affected catch rates during the monitored period, indicating either that there was sufficient population turnover (i.e. immigration into the capture area) to replace removals from landings (likely to be the case with brown crabs) or that local abundance was not the main factor determining captures. The latter is likely to apply to both species, for which major changes in catchability can be related to water movements (as evidenced by the tidal correlations) and other environmental factors such as water temperature, and particularly to lobsters for which competitive interactions between individuals can be an important factor in determining trap entry and escapement.

On average, around five trap hauls were required for every legal lobster landed (Table 1). Brown crab catch rates were slightly higher, with around three trap hauls required for each legal crab landed. Discarding of undersized lobsters was variable between occasions, but low overall with four out of five lobsters caught being of legal size. Given that competitive interactions between lobsters may exclude smaller individuals from traps, this does not necessarily imply a low abundance of pre-recruit lobsters in the Billia Croo area. Rather, it may indicate a relatively high abundance of lobsters of legal size. Undersized crabs were more numerous in the catches and on average nine out of ten crabs were discarded.

Limited data are available on catch rates of lobsters and crabs across the Orkney inshore region to provide a context for the Billia Croo data. In most cases fishing effort data are not available to link with landings records, but discard sampling during May and June 2010 provided data for catch rates of two vessels (Tables 2 and 3), one fishing off the east Mainland and southern isles, the other fishing in the western part of Scapa Flow, close to Stromness and Graemsay (referred to as vessels 1 and 2 to preserve confidentiality of catch records). Catch rates of legal lobsters (LPUE) were much lower in the eastern area (vessel 1) than the average for Billia Croo and at the lower end of the range of summer 2011 observations. Discarding of undersized individuals was much higher, however, and in terms of numbers per trap the overall catch rate (CPUE) was at the upper end of the range of observations for Billia Croo. By contrast, catch rates of legal brown crabs (LPUE) were higher in the eastern area (vessel 1) and particularly Scapa Flow (vessel 2) than the average for Billia Croo. The pattern is less clear for undersized crabs, with overall CPUE comparable between Billia Croo and Scapa Flow and at a much higher level than for the eastern area.

Based on very limited evidence, in Orkney inshore terms Billia Croo appears to have been a relatively good fishing ground for lobsters and a relatively poor fishing ground for brown crabs during summer 2011. There appear to be substantial differences in local population structure, as evidenced by discarding rates for undersized lobsters and crabs. Compared with some other inshore areas of Orkney, availability of undersized individuals to the fishing gear at Billia Croo appears to have been relatively low for lobsters and high for brown crabs.

Catch composition

Catch returns, onboard and shore-based measurements provide good information on the composition of lobsters and brown crabs catches from Billia Croo during summer 2011. Measurement of landings was complete for all fishing occasions. Measurement of lobster discards was complete for all fishing occasions up to early August, mainly undertaken onboard by the fisherman. Measurement of brown crab discards was undertaken by onboard observers on three occasions and onshore on one occasion. Complete catch size compositions are estimated under the assumption that overall average discard rates (by weight) applied on the occasions when discards were not recorded, and that the size composition of discards on these occasions was the same as the overall discard size composition on the observed occasions . Given the different levels of discard sampling, this means that the catch size composition was very well characterised for lobsters and less well characterised for brown crabs.

As already noted, legal-sized individuals predominated in the lobster catch (Figure 5). The most frequent size-classes were immediately above the MLS, with a sharp drop-off in numbers at larger sizes. Under normal growth conditions, all undersized individuals present in the catch would be likely to recruit to legal size-classes within 1-2 years. Berried females (carrying eggs) were present in most size-classes, including undersized individuals, indicating that sexual maturity was achieved in at least some individuals before becoming vulnerable to the fishery.

Undersized individuals were predominant in the brown crab catches (Figure 6). The sharp-drop off in numbers above MLS is striking, but uncertain given the low levels of discard sampling and assumptions involved in estimating the catch composition. Under normal growth conditions, brown crabs larger than about 120 mm CW would be expected to recruit to the fishery within a year. The large numbers of crabs in the 90-100 mm CW size-classes would be expected to recruit within 2-3 years. The peak in frequencies around these sizes in both males and females could represent a strong year-class (possibly 2009), but given small sample sizes and uncertainties about the size-selectivity of the fishing gear any interpretation of these data in terms of population structure must be tentative

The size composition of landings is well determined for both species, and there is also a wealth of market sampling data for landings by Orkney inshore vessels during 2010 and 2011 with which the Billia Croo samples can be compared. Females comprised 57% of the lobster landings from Billia Croo, slightly higher than the 52% recorded for all Orkney inshore landings. Conversely, berried females were less frequent in the Billia Croo landings, comprising 6% of the total compared with 10% for the Orkney inshore region as a whole. Landings size composition was similar between Billia Croo and Orkney inshore for females (Figure 7), mean size being almost identical in each case (Table 4). Billia Croo males were smaller, on average, and numbers dropped away much more rapidly with increasing size than in Orkney inshore landings as a whole.

Just over 36% of the brown crab landings from Billia Croo were female, compared with 42% for the Orkney inshore region. Similar to lobsters, the size composition and mean size of brown crabs landings was generally similar between Billia Croo and the Orkney inshore region as a whole, whereas male brown crabs tended to be smaller in the Billia Croo landings (Figure 8, Table 5). However, unlike lobsters, the smaller average size of male brown crabs was due to larger proportions of relatively small individuals in the landings rather than a truncation of the size composition at larger sizes.

Size compositions of landings were variable over time in both lobsters and brown crabs, but without obvious seasonal pattern (Figures 9 and 10). The main differences between the Billia Croo and the Orkney inshore region are the smaller sizes of males of both species and the narrower size distributions of male lobsters from Billia Croo, consistent with what was noted for the aggregated data as a whole. Considering just 2011, it is also apparent that female brown crabs were smaller in the landings from Billia Croo than from the wider Orkney inshore region.

Note that the data in Figures 9 and 10 are presented as medians and interquartile ranges, representing the central tendency and spread of the size-frequency distributions respectively. This is because the raising factors involved in collating these data makes it difficult to calculate unbiased statistical moments and the more meaningful comparisons are in terms of distribution shape rather than variance properties. We can usefully extend this non-parametric approach to analysis into a more comprehensive comparison of the shapes of size compositions between Billia Croo and the Orkney inshore region. The Kolmogorov-Smirnov (KS) test statistic, calculated simply as the maximum difference in cumulative proportional frequency between two frequency distributions, is commonly used to compare distributional data (e.g. Sokal & Rohlf, 1981). By treating this statistic as a distance metric it is straightforward to extend these comparisons to multiple distributions. For each species, we calculated the matrix of pair-wise KS distances between Billia Croo and Orkney inshore landings size compositions and used non-metric multidimensional scaling (MDS) to obtain two-dimensional representations of the pattern of inter-sample distances (Digby & Kempton, 1987). The distances between points in an MDS plot are the best representation in two dimensions of all distances between samples, thus allowing easy visual comparisons. Interpretation of the axes of an MDS plot provides information on the nature of variation between samples.

MDS plots for lobster and crab landings data are shown in Figures 11 and 12, and correlations between the MDS axes and size compositions are listed in Table 7. For both species, the main axis of variation (MDS1, horizontal axis in Figures 11 and 12) is related to overall size, being strongly correlated with medians and quartiles of the distributions. Shape parameters also contribute to the differences along this axis, notably the interquartile range (measuring distribution width) in lobsters and skewness (asymmetry of quartiles around the median) in female brown crabs. The second axis (MDS2, vertical axis in Figures 11 and 12) is less easily interpreted, relating to more subtle differences in shape between distributions. The main signal from this analysis is that the between-month differences within regions (Billia Croo and Orkney inshore) are bigger than the between-region differences. No seasonal patterns are apparent, consistent with the simpler comparisons of Figures 9 and 10.

Taken together, the results of these analyses demonstrate that the size compositions of lobster and brown crab landings from Billia Croo are broadly comparable with the compositions of landings across the Orkney inshore region as a whole. The main differences are that the size composition of male lobster landings is more strongly truncated for Billia Croo than for Orkney inshore and that the male crab landings from Billia Croo contain higher proportions of males just above the MLS.

Lobster stock status

Although lobsters and brown crabs are fished alongside one another in Orkney inshore waters, the two species are likely to be markedly different in their spatial dynamics across their stock areas. Much remains to be learnt about their local movement patterns, but in general lobsters would be expected to be much more sedentary than brown crabs, and in particular not to make extensive directed migratory movements. Given a very local scale of movements, it is reasonable to suppose that Billia Croo lobster catches reflect the composition of the local lobster population, mediated through the fishing process which is likely to include elements of size-selectivity and behavioural responses to baited traps. By contrast, brown crab catches at Billia Croo are likely to be drawn from a population which is functioning at a much larger spatial scale. Offshore movements of female crabs related to spawning behaviour are known to occur at scales of tens of kilometres, which is large in comparison with individual fishing areas such as Billia Croo (see Lamb, 2011). Billia Croo catches thus represent a very small window on the dynamics of a crab population which is likely to be exploited at different levels at different parts of its range. According to this rationale, whilst it is feasible to draw inferences on the Billia Croo lobster population from the quantity and composition of local removals, no such inference is possible for the brown crab population.

Length cohort analysis (LCA, Jones, 1990) can be applied to the size composition of fishery removals to estimate exploitation rates and, given an absolute estimate of quantities removed, the size (abundance) of the population from which the catches were drawn. A summary of LCA and its inputs and outputs is given in Appendix II, together with a description of the per recruit analyses used to provide an assessment of exploitation status. LCA was applied to the length composition of summer 2011 landings of lobsters from Billia Croo. It was assumed that this length composition was representative of landings throughout the year, and based on Figure 55 of Mesquita *et al.* (2011) quantities were scaled up to annual landings under the assumption that the monitored period represented 64% of the total. Input parameters for the LCA were mostly the same as those used in the Marine Scotland assessments (Mesquita *et al.*, 2011), summarised in Table 7. Values for terminal fishing mortality (see Appendix II) were based on the Beverton-Holt size-based estimator (see King, 1995, pp.177-179), using 92 mm CL as an estimate of the size at full vulnerability to the fishery (based on the peak frequencies in Figure 7). This estimator of total mortality is based on the mean size of fully-recruited animals in the landings scaled as a function of growth parameters. Fishing mortality was estimated by subtraction of natural mortality (M = 0.1, see Table 7), thus providing both terminal F values and separate (but not wholly independent) estimates of average fishing mortality to compare with the LCA results. Analyses were conducted separately for males and females. Yield per recruit values were combined across the sexes under an assumption of 50:50 sex ratio in the population at the size of recruitment to the fishable stock. Spawning stock biomass per recruit was considered for female lobsters only, with the assumption that all females of fishable size are sexually mature.

A single season's sampling data represents a slender basis for an assessment of this type, and the outputs should be treated with caution. We consider, nevertheless, that the analysis provides a valid assessment of the status of the lobster stock in the immediate locale of Billia Croo as implied by the size composition of landings combined with knowledge of lobster biology. Stocks in other areas of Orkney may be exploited at higher or lower levels than Billia Croo, so the assessment should not be taken as indicative of overall stock status. For comparison, a separate LCA assessment was undertaken for lobsters in the Orkney inshore region as a whole, based on market sampling data collected during 2010 and 2011. The size composition of landings was raised to a total weight of 138 t, which is the official Orkney landings total for 2010 (Marine Scotland, 2011). Other input parameters were the same as for Billia Croo assessment.

Exploitation statistics based on LCA and Beverton-Holt estimators are given in Table 8. Based on estimated landings of about 240 lobsters during 2011, and fishing mortality estimates of around 0.50 (equivalent to 38% annual harvest rate) for females and 0.68-0.89 (annual harvest 47-56%) for males, local stock size at Billia Croo is around 900 fishable lobsters, of which two-thirds are female. A corresponding biomass estimate would be 0.5-0.6 t. Note that, without estimates of capture area and the extent of suitable habitat, it is impossible to derive estimates of density on the ground. Per recruit curves corresponding to the LCA outcomes are shown in Figure 13. These imply that long-term yield (or rather its proxy, yield per recruit) would be maximised at around 30-40% of current effort levels, but the potential gains would be less than 12% in landed biomass. Spawning potential appears to be less than 10% of the value for an unexploited stock.

Compared with the Orkney inshore region as a whole, the Billia Croo lobster stock appears relatively heavily exploited. Orkney inshore fishing mortality is estimated to be lower for both sexes, being 0.33-0.51 for females (equivalent to 27-38% annual harvest rate, the lower figure being from LCA) and 0.56-0.60 (41-43% annual harvest rate) for males (Table 8). At these fishing mortality rates, annual landings of around 200,000 lobsters implies an Orkney population of around 0.5-0.6 million lobsters of fishable size (around 400 t). Per recruit curves for Orkney inshore are generally similar to, but slightly more optimistic than, those for Billia Croo (Figure 14). Potential long-term gains in yield would be less than 7% at 40% of current fishing effort, and current spawning potential appears to be at around 11% of its unexploited level.

Considerable uncertainties are associated with these assessment results, particularly for the stock local to Billia Croo, and the outcomes are also dependent on the validity of biological parameter estimates used as assessment inputs, particularly for growth. If growth rates are slower in Orkney waters than implied by the von Bertalanffy parameters derived for other areas of Scotland, this would expand the estimated duration of transitions between size-classes and reduce the estimates of fishing mortality – a reduction of 10% in growth rate, for example, would imply similar (but slightly larger) levels of reduction in fishing mortality estimates and increase in population estimates. The Orkney inshore assessment is generally similar to the Marine Scotland assessment for 2006-2008 (note that the assessments are not directly comparable owing to increases in MLS), but shows lower fishing mortality of females and higher fishing mortality of males (Marine Scotland estimates for average *F* for Orkney lobsters: 0.46 for females, 0.48 for males – see Mesquita *et al.*, 2011).

In conclusion, inferences on the nature of the lobster stock and its exploitation based on the size-composition of landings indicate that Billia Croo is a heavily utilised lobster ground, probably more heavily exploited than the average for the Orkney inshore region as a whole.

CONCLUSIONS

The main conclusion of this study is that, in Orkney inshore terms, Billia Croo is an important and productive creel fishing area, principally for lobsters. In comparison with the Orkney inshore region as a whole, catch rates of legal sized individuals at Billia Croo during summer 2011 were relatively high for lobsters and low for brown crabs. It should be noted that the basis for this comparison is very slender in terms of catch rate data from areas of Orkney other than Billia Croo. However, it is also relevant to note that analyses of the size composition of landings indicates relatively high fishing pressure on lobsters at Billia Croo. This inference depends on the assumption that fishing mortality is the main determinant of size composition in the landings. This would require careful examination in any future work, particularly in terms of movements and spatial structure within the population, but as noted above (p.7) the likely local scale of movements make this assumption tenable for lobsters at the scale of Billia Croo (but not brown crabs). Some differences in catch composition exist between areas of Orkney for both lobsters and brown crabs, in terms of sex ratio, proportions of undersized animals in the catch and frequencies of different size-classes, but overall the Billia Croo landings samples are within the range of variation observed for Orkney as a whole.

The implications of the findings for potential creel fishery interactions with wave energy developments are two-fold. First, if fishing were to be excluded from near-shore wave energy development areas this would, over the short-term, represent significant losses to the local fisheries. Billia Croo lobster landings in 2011 probably represent around 0.2% of the landings for Orkney as a whole (0.24 t estimated for 2011, worth around £2,500 at 2010 prices, compared with 138 t landed from Orkney in 2010), but scaled up from the wave test site to the total potential occupancy of near-shore wave developments across Orkney waters as a whole, the proportions may be much higher. The extent to which, over the longer term, these immediate losses from spatial occupancy would be offset by protection of egg production and spill-over from protected adult stocks to adjacent fishing grounds depends on stock-recruitment relationships and small-scale movement patterns in local lobster stocks, both of which are currently unknown. The Orkney lobster fishery was worth around £1.5 million first sale value in 2010, around 20% of the total value of fisheries in the region (Marine Scotland, 2011). Brown crabs and velvet crabs were even more important, valued at £2.8 million and £2.3 million in 2010 respectively. There is no information on Billia Croo velvet crab landings, but brown crab landings are estimated to be around 1.87 t for 2011, likely to be less than 0.1% of the Orkney total (2,215 t in 2010) and worth around £2,300 at 2010 prices. Given the spatially dynamic nature of the brown crab stock, these landings and revenue would be unlikely to be lost from the fishery if the fishing effort was displaced from Billia Croo to other areas.

Second, wave energy development areas may represent an opportunity to enhance local lobster recruitment. Given high fishing pressure in these areas, spawning potential of lobsters is, at least locally, at a low proportion (possibly less than 10%) of its unexploited levels. Two opportunities for enhancement can be identified: (i) release of hatchery-reared juvenile lobsters to supplement natural sources of recruitment; and (ii) introduction of new juvenile lobster habitat. The extent to which release of hatchery-reared juveniles is likely to augment or replace existing recruitment sources is unknown, and will depend on the functioning of any stock-recruitment relationship at both large scales (egg production) and small scales (density-dependent processes and shelter availability). Introduction of new seabed structures during development may increase the availability of habitat for juvenile lobsters and other crustaceans (although this must be considered alongside potential damage to existing seabed habitats). Juvenile lobsters may occupy the interstices between rocks in gabions or in rock armouring around cables, and there are likely to be opportunities for both deliberate habitat creation and incidental habitat creation around device and mooring structures. Habitat enhancement and release of hatchery-reared individuals may work particularly well alongside one another. There is much scope for future experimental research into this topic, and it will be essential to monitor future catches for contributions from hatchery-reared stock released at Billia Croo during 2011 (likely to be apparent around 2016-2018 in standard fishing gear).

Interactions with brown crab fisheries are more uncertain, given the larger spatial scales of movement and population processes in this species. On the face of it, areas such as Billia Croo are unlikely to represent prime brown crab fishing grounds, and the scope for protection of stocks and spawning potential in fishery exclusion zones would be much lower than for lobsters. However, the results of inshore fishery mapping studies, undertaken recently by Marine Scotland and by Orkney Fisheries Association in two separate exercises, will be needed to demonstrate the true potential for overlap of wave (and tidal) energy developments with fishing grounds for brown crab (and other species such as velvet and green crab).

Aside from the conclusions that can be drawn about the nature of lobster and brown crab fisheries and stocks at Billia Croo, it is also relevant to consider how future research and monitoring work may benefit from experienced gained during the design and running of the Billia Croo monitoring studies. Several aspects of the originally envisaged study proved not possible to implement in practice:

- A voluntary no-take zone (NTZ) was planned for the test site, with monitoring activities intended to quantify the potential outcomes of such exclusion in terms of local crustacean stocks and fisheries. Given the importance of Billia Croo as a fishing ground for at least one local fishing vessel, it was not possible to develop an agreement for voluntary exclusion. As the study developed, the lack of exclusion was turned into a positive aspect by using a commercial vessel fishing at Billia Croo as the source of monitoring effort. Legal lobsters and brown crabs were, however, retained for landing rather than returned to the seabed, so that the monitoring cannot be taken to relate to an NTZ.

- Habitat enhancement was expected in the form of one or more gabions placed around the bases of the Oyster device on site. This would have been relevant to enhancing habitat for hatchery-reared juveniles rather than having any effect on monitored catches during the present study, but future monitoring may have been able to demonstrate an effect on local recruitment to the fishery.
- The original study was envisaged as having a monthly sampling frequency, with an emphasis on tagging of both legal and undersized lobsters aimed at understanding local movement patterns and short-term population turnover. It was realised during the planning stage that monthly sampling was impractical owing to the strongly seasonal nature of the fishery. Instead, more intense monitoring was undertaken during the main summer fishing season. Given the frequency of fishing, time pressures for the commercial fisherman to service gear outside the study area on the same fishing trips and limited opportunity for scientific observers to participate in Billia Croo fishing trips, it was not possible to undertake tagging studies alongside the catch monitoring, but only to undertake a limited amount of onboard discard sampling.
- Once the decision was taken to rely on commercial fishing activities for monitoring returns, the original plan was for discards to be temporarily retained for shore-based sampling prior to being returned. However, at the start of monitoring it was immediately apparent that the high level of discard mortality arising from this approach would be unacceptable, and that return of discards to their capture locations was logistically impracticable. Instead, discard measurements relied on the commercial fisherman for lobsters (small numbers, well characterised) and on onboard observers for brown crabs (larger numbers, sampled on only a few occasions, poorly characterised).

The final monitoring programme provided a good characterisation of catch rates and catch/landings composition, in order to determine the likely ‘foot-print’ of a wave energy development area on the local creel fishery, but it was not possible to draw conclusions about movement patterns or to make direct inferences about potential NTZ benefits. Using size-based assessment methods, some conclusions were nevertheless drawn about the local lobster stock and its exploitation status. The main lesson for future scientific monitoring is that for proper scientific control of operations, and for optimum data gain from monitoring efforts, a significant investment in sampling operations is needed. This would include paid charter of a fishing vessel to allow fishing when and where directed, including time for onboard sampling and recording of all catch components and scientific operations such as tagging, gear set-up and placement under scientific control, and return of legal sized catch to the seabed. Much was achieved during this study through the goodwill and participation of a local fisherman, more could be achieved with financially subsidised fisherman-based monitoring activities in the future, and even more could be achieved with full scientific control of research and monitoring operations.

Finally, it is worth noting that much of the value of local monitoring studies lies in the context against which monitoring outcomes can be compared. Market and onboard sampling of lobster and brown crab catches and landings across Orkney during 2010 and 2011 provided an excellent background in terms of catch composition, but a lack of data on fishing effort meant that there were few records of catch rates in Orkney waters. Catch rates are commonly used as an index of stock abundance in fishery monitoring schemes, and it is expected that logbook records and other methods of obtaining effort and catch rate data will be an important component of future monitoring programmes for Orkney fisheries.

RECOMMENDATIONS

- Examination of the importance of an area for commercial fisheries and the stocks on which they depend should be considered an essential pre-requisite in spatial planning of wave and tidal energy developments. Interactions with fisheries should be considered in terms of changed access to the resource and potential effects on the productivity of the stock and sustainability of fishing.
- Monitoring of Orkney crustacean fisheries in relation to marine renewable energy developments should: (i) be continued at the Billia Croo wave test site in order to provide further resolution on levels and variability in catch rates and catch composition and on underlying stock dynamics; (ii) be extended to cover velvet crabs as well as lobsters and brown crabs; and, if fishery mapping exercises indicate likely overlaps of development with areas important to fisheries, (iii) be extended to cover potential tidal energy development areas and potential wave development areas further offshore.
- It is important that future monitoring activities should include tagging, particularly of lobsters, in order to provide information on population turnover processes at development sites. The scale of such turnover will be an important determinant of the potential for NTZs in development areas to provide benefits in terms of enhanced fishery sustainability.
- Benthic habitat mapping data should be collated for the locale of monitored areas. Coupled with information on movement patterns, this will allow conversion of stock abundance to density estimates, important for between-area comparisons and for upscaling monitoring outcomes to predict the fishery and stock implications of full scale wave and tidal energy developments.
- Logbook records for fisheries across Orkney will be an important source of information on catch rates and catch quantities and how they are distributed between areas with and without energy development potential. It is recommended that logbook schemes with spatially explicit recording or catch returns be instituted as part of ongoing monitoring efforts in Orkney.
- Scientific monitoring programmes should ideally include chartering of fishing vessel time, allowing full scientific control of operations and optimal recording of outcomes.
- Opportunities for enhancement of habitat for juvenile crustaceans around wave and tidal energy developments should be explored. The outcomes of enhancement in terms of increased recruitment to fishable stocks should be directly measured both by direct benthic sampling and by monitoring of catch rates in experimental and control areas.
- A bio-economic model should be constructed for lobster and other crustacean stocks in Orkney waters, aimed at predicting stock and fishery outcomes of future development and fishery management scenarios. Such a model should be spatially-structured and include elements of habitat distribution, movement and recruitment processes.
- Future creel catches should be monitored for the contribution of hatchery-reared individuals to the lobster stock. Experimental fishing using prawn pots may expect to detect undersized lobsters from around 2014-2015, whilst sublegal and legal lobsters may be included in

commercial creel catches from 2016-18 onwards. If further releases of microtagged, hatchery-reared juveniles are planned, consideration should be given to methods for making tag-returns identifiable by year of release.

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TABLE 1. Catch rates of lobsters and brown crabs at Billia Croo during summer 2011.

	Lobster			Brown crab		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**
LPUE (number per trap)	0.21	0.07	0.44	0.36	0.09	0.72
CPUE (number per trap)	0.27	0.07	0.80	7.77	0.95	15.52
Discard rate (% by number)	21.8	0.0	73.6	90.0	80.5	98.8
LPUE (kg per trap)	0.13	0.04	0.27	0.25	0.06	0.68
CPUE (kg per trap)	0.14	0.04	0.38	1.85	0.32	3.42
Discard rate (% by weight)	13.9	0.0	63.7	77.0	52.8	96.0

TABLE 2. Comparison of average catch rates of lobster between Billia Croo in summer 2011 and commercial fishing elsewhere in Orkney inshore waters. Data for Vessel 1 are from fishing off east Mainland and southern isles in May 2010.

	Billia Croo	Vessel 1
LPUE (number per trap)	0.21	0.08
CPUE (number per trap)	0.27	0.49
Discard rate (% by number)	21.8	83.7
LPUE (kg per trap)	0.13	0.06
CPUE (kg per trap)	0.14	0.16
Discard rate (% by weight)	13.9	61.0

TABLE 3. Comparison of average catch rates of brown crab between Billia Croo in summer 2011 and commercial fishing elsewhere in Orkney inshore waters. Data for Vessel 1 are from fishing off east Mainland and southern isles in May 2010. Data for Vessel 2 are from fishing in the west of Scapa Flow in June 2010. The average for Vessels 1 and 2 is a weighted mean, with weights based on number of traps fished.

	Billia Croo	**Vessel 1**	**Vessel 2**	**Average Vessels 1 & 2**
LPUE (number per trap)	0.36	0.49	1.12	0.69
CPUE (number per trap)	7.77	2.37	8.63	4.37
Discard rate (% by number)	90.0	79.5	87.0	84.2
LPUE (kg per trap)	0.25	0.39	0.67	0.48
CPUE (kg per trap)	1.85	0.89	2.02	1.25
Discard rate (% by weight)	77.0	56.7	66.9	61.9

TABLE 4. Mean size of lobsters landed at Billia Croo (summer 2011) and across the Orkney inshore region (summer 2010 and 2011).

Mean size (mm CL)	Female	Male
Billia Croo	98.7	97.3
Orkney inshore	98.8	99.6

TABLE 5. Mean size of brown crabs landed at Billia Croo (summer 2011) and across the Orkney inshore region (summer 2010 and 2011).

Mean size (mm CW)	Female	Male
Billia Croo	164.6	158.5
Orkney inshore	165.7	160.2

TABLE 6. Correlation coefficients comparing non-metric multidimensional scaling axes (MDS1 and MDS2) with statistics of the size compositions of Billia Croo and Orkney inshore creel landings. Q1, 25th percentile of size composition (carapace length or width); Median, 50th percentile of size composition; Q3, 75th percentile of size composition; IQR, interquartile range of size composition; Skewness, shape statistic of size composition. NS, correlation not statistically significant; +, P<0.1; *, P<0.05; **, P<0.01; ***, P<0.001.

	MDS1		MDS2	
Female lobster:				
Q1	-0.861	***	0.406	NS
Median	-0.940	***	0.291	NS
Q3	-0.983	***	0.039	NS
IQR	-0.948	***	-0.157	NS
Skewness	0.132	NS	-0.438	NS
Male lobster:				
Q1	-0.845	***	0.126	NS
Median	-0.914	***	-0.257	NS
Q3	-0.935	***	-0.222	NS
IQR	-0.843	***	-0.367	NS
Skewness	0.171	NS	0.191	NS
Female crab:				
Q1	0.943	***	0.094	NS
Median	0.953	***	0.215	NS
Q3	0.830	***	0.335	NS
IQR	0.180	NS	0.411	NS
Skewness	-0.650	**	-0.016	NS
Male crab:				
Q1	-0.980	***	-0.018	NS
Median	-0.967	***	0.089	NS
Q3	-0.930	***	-0.255	NS
IQR	-0.042	NS	-0.538	*
Skewness	-0.041	NS	-0.475	+

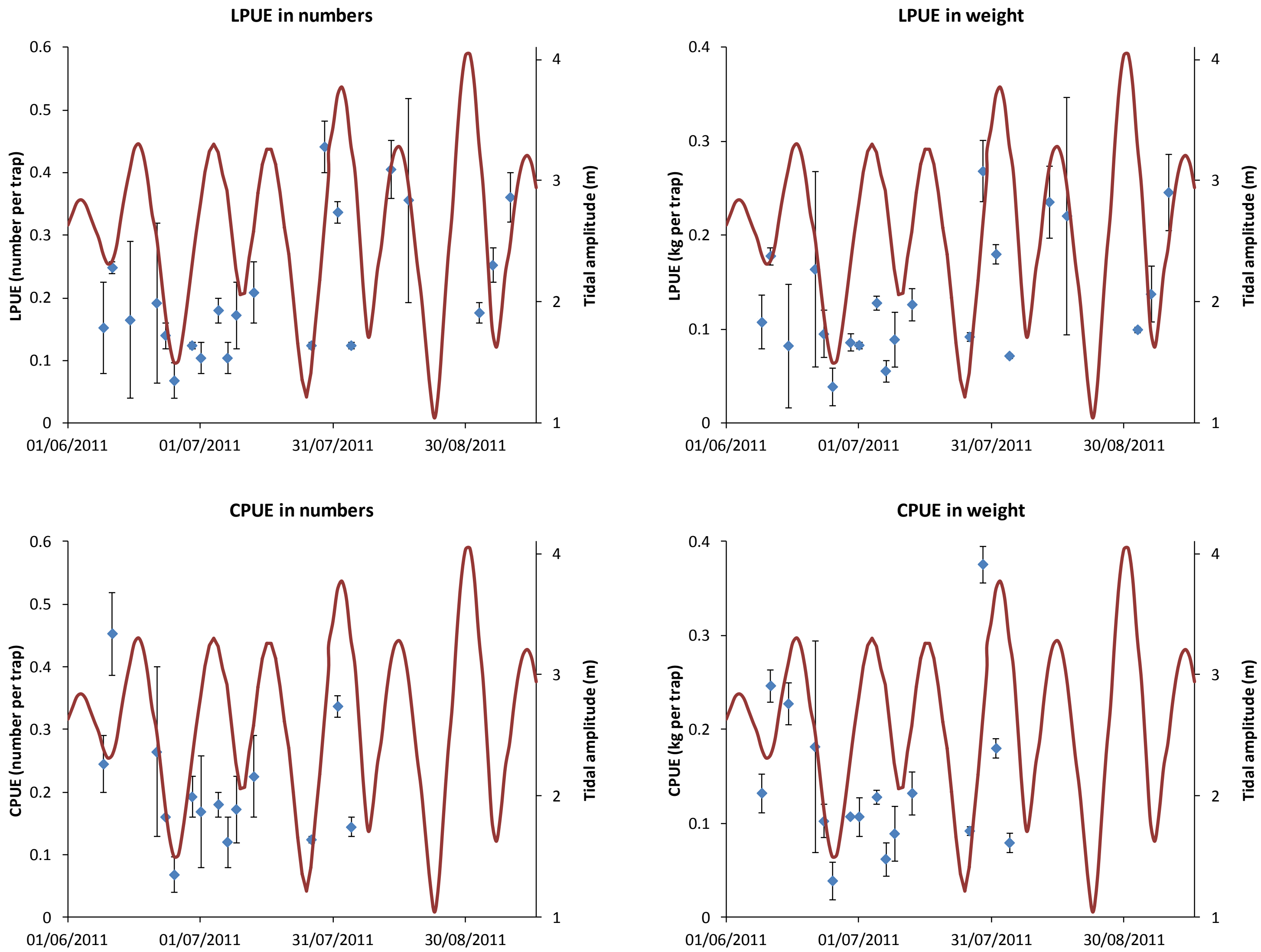
TABLE 7. Biological parameters for the assessment of Orkney lobster stocks, from Marine Scotland (Mesquita *et al.*, 2011). Lengths are expressed in mm CL, weights are expressed in g, rates (*K* and *M*) are annual.

		Females	Males
von Bertalanffy parameters for growth: $L_t = L_\infty (1 - e^{-Kt})$	L_∞	150.0	173.4
	K	0.13	0.11
Length-weight relationship: $W_t = a\ L_t^b$	a	0.000919	0.000126
	b	3.360	2.922
Natural mortality	M	0.1	0.1

TABLE 8. Mean size and exploitation statistics for lobster landings at Billia Croo (summer 2011) and across the Orkney inshore region (summer 2010 and 2011). *F* is average annual fishing mortality, estimated using the Beverton-Holt method and length cohort analysis (LCA). The implied population number and biomass are estimated by applying the fishing mortality rate to landed quantities. For the Orkney inshore region total annual landings are taken to be 138 t (2010 figure from Marine Scotland, 2011). For Billia Croo monitored landings during June to September are assumed to be 64% of the annual total, based on the monthly distribution of Orkney landings (2008 data from Mesquita *et al.*, 2011).

	Billia Croo		**Orkney inshore**	
	Females	**Males**	**Females**	**Males**
Mean size (mm CL)	98.7	97.3	98.8	99.6
Annual landings number	216	164	109,000	99,000
Annual landings weight (kg)	138	102	70,000	68,000
Beverton-Holt *F*	0.504	0.889	0.512	0.600
Implied population	570	291	284,000	229,000
Implied biomass (kg)	365	180	183,000	158,000
LCA *F*	0.497	0.680	0.334	0.561
Implied N	576	347	401,000	240,000
Implied biomass (kg)	369	215	258,000	166,000

ANNEX 6: Results of Crustacean Fishery Monitoring at the EMEC Wave Test Site



22

ANNEX 6: Results of Crustacean Fishery Monitoring at the EMEC Wave Test Site

FIGURE 1. Catch rates of lobsters at Billia Croo, summer 2011. Data are averages (± SE) for two strings of creels (blue diamonds), shown alongside a curve of tidal amplitudes (red line). Upper panels show landings per unit effort (LPUE) in terms of numbers (left) and weight (right); lower panels show total catch per unit effort (CPUE) in terms of numbers and weight, calculated for occasions when discards were sampled.

ANNEX 6: Results of Crustacean Fishery Monitoring at the EMEC Wave Test Site

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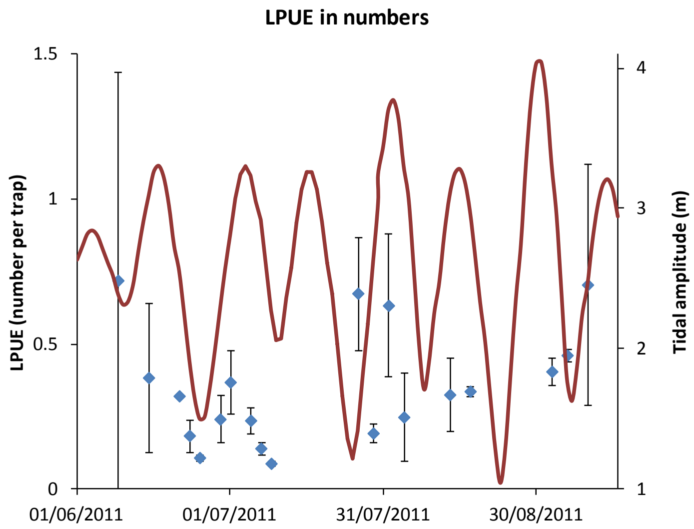
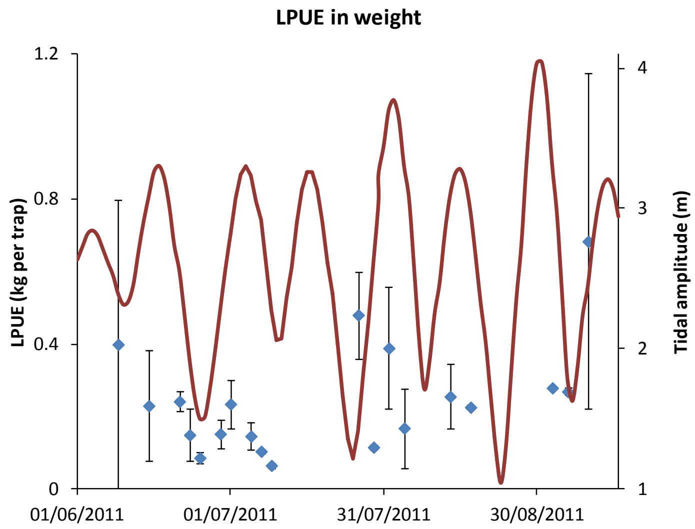
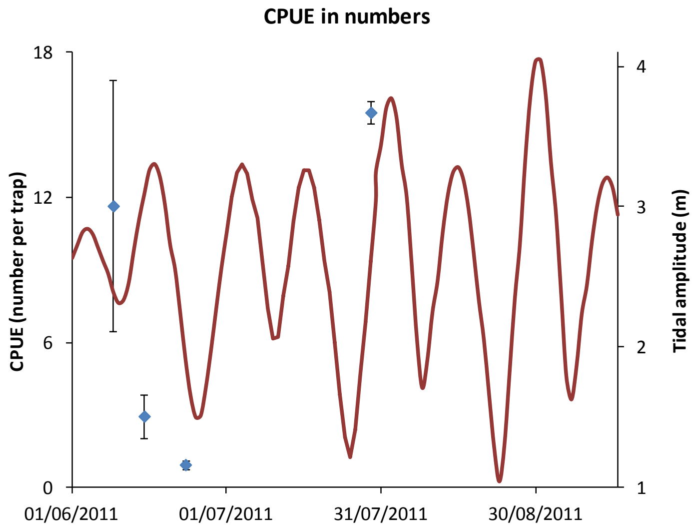






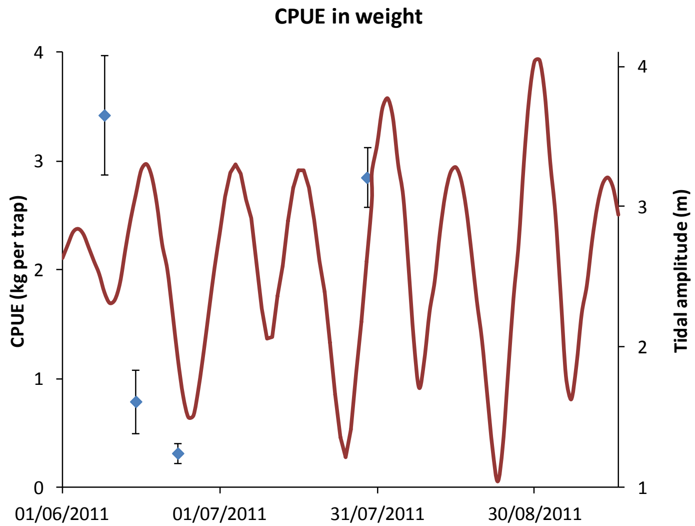


FIGURE 2. Catch rates of brown crabs at Billia Croo, summer 2011. Data are averages (± SE) for two strings of creels (blue diamonds), shown alongside a curve of tidal amplitudes (red line). Upper panels show landings per unit effort (LPUE) in terms of numbers (left) and weight (right); lower panels show total catch per unit effort (CPUE) in terms of numbers and weight, calculated for occasions when discards were sampled.

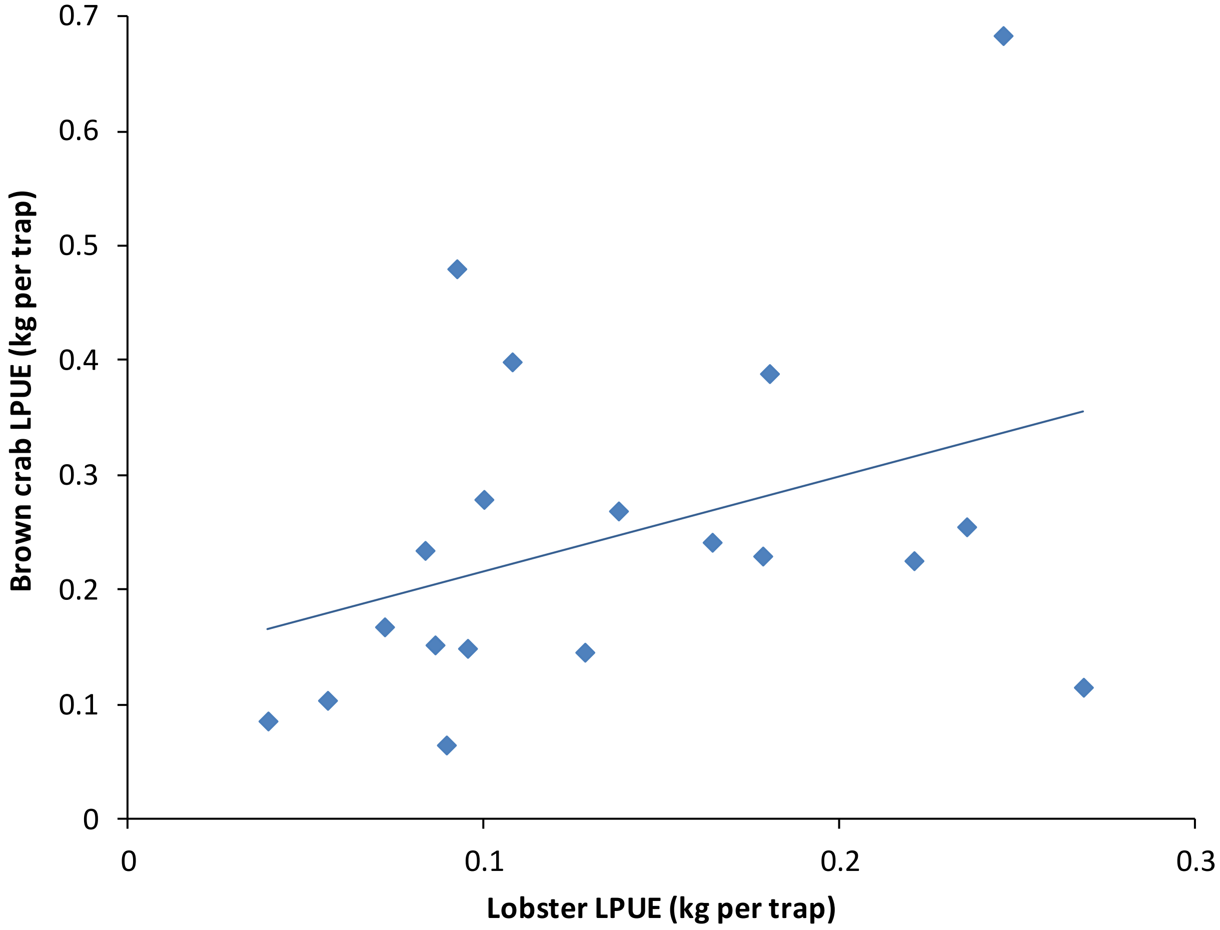


FIGURE 3. Relationship between brown crab and lobster landings per unit effort (LPUE) at Billia Croo during summer 2011.

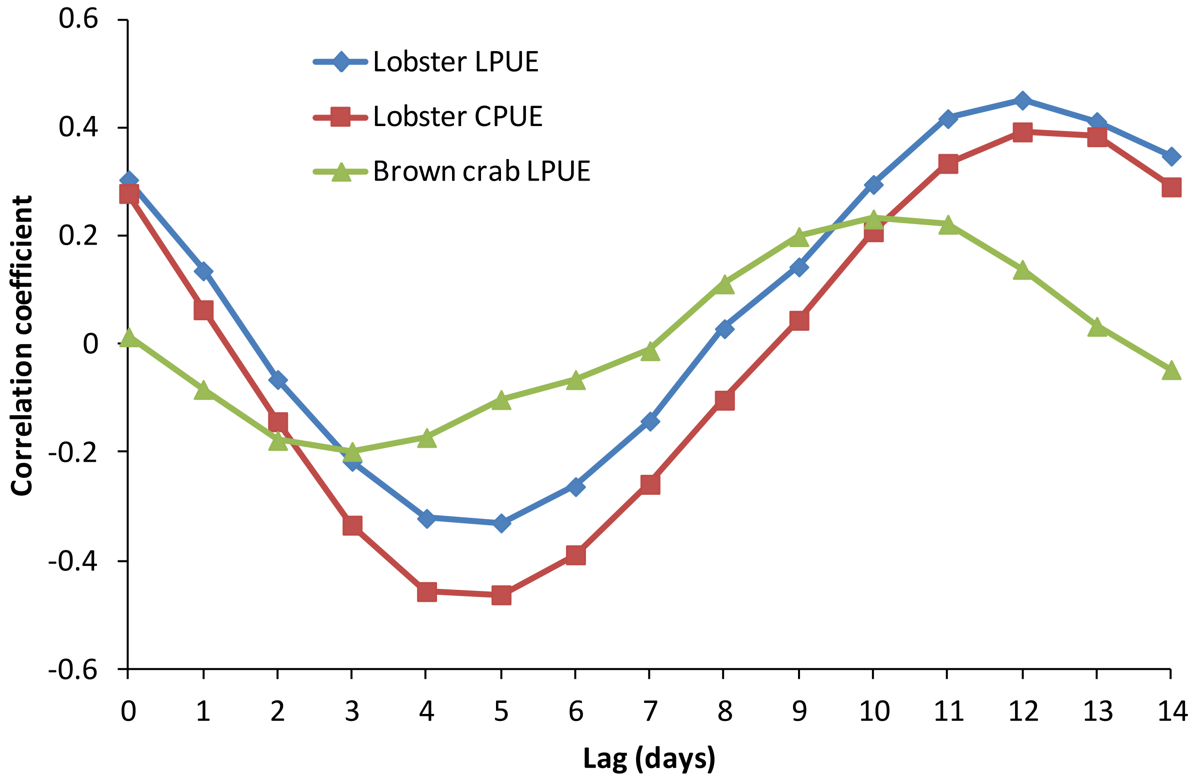


FIGURE 4. Correlations of Billia Croo lobster and brown crab catch rates (numbers per trap) with tidal amplitude. This shows, for example, that lobster catch per unit effort (CPUE) and landings per unit effort (LPUE) are negatively correlated with tidal amplitude 4-5 days after the fishing occasion. There were insufficient observations of brown crab CPUE to examine correlation patterns.

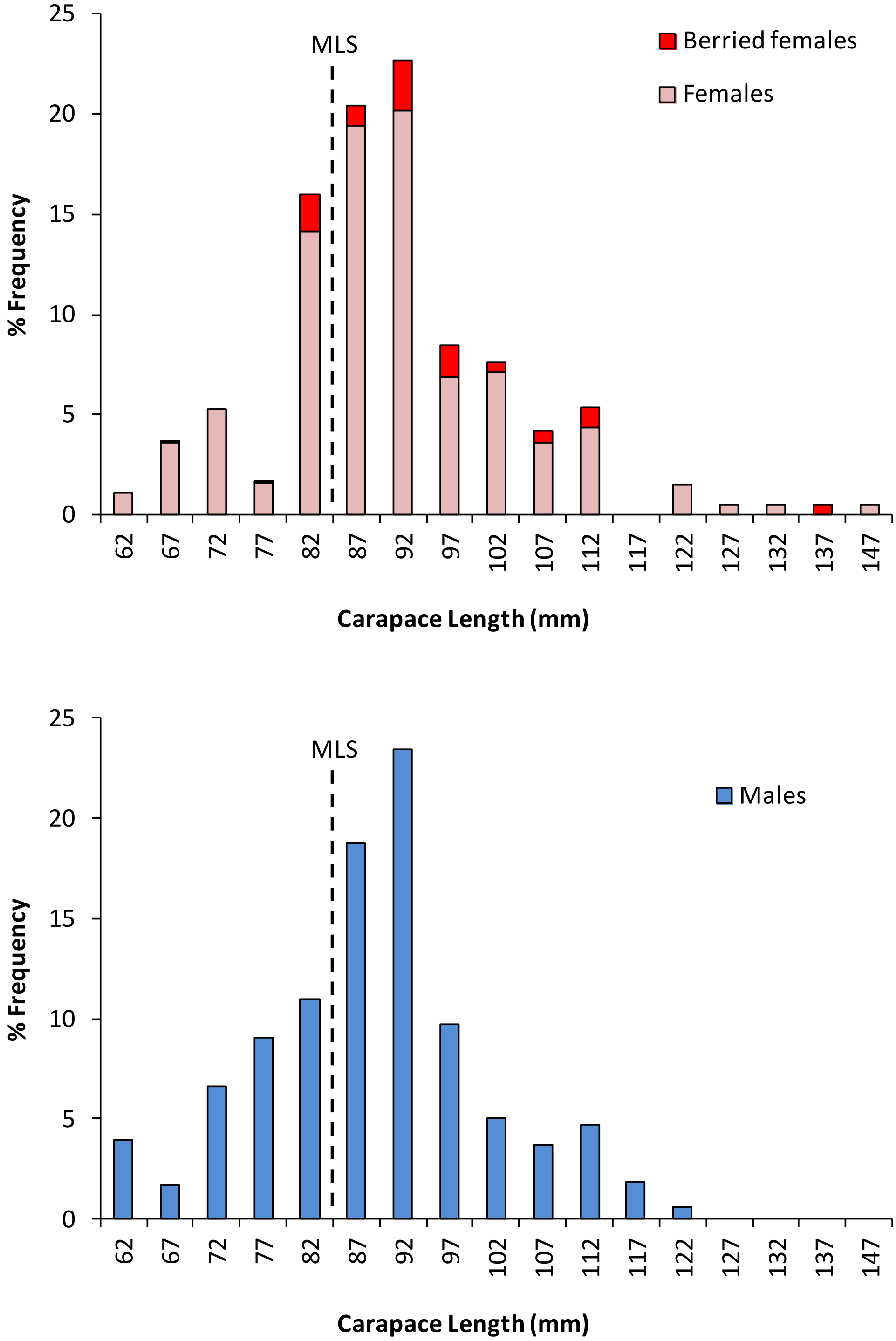
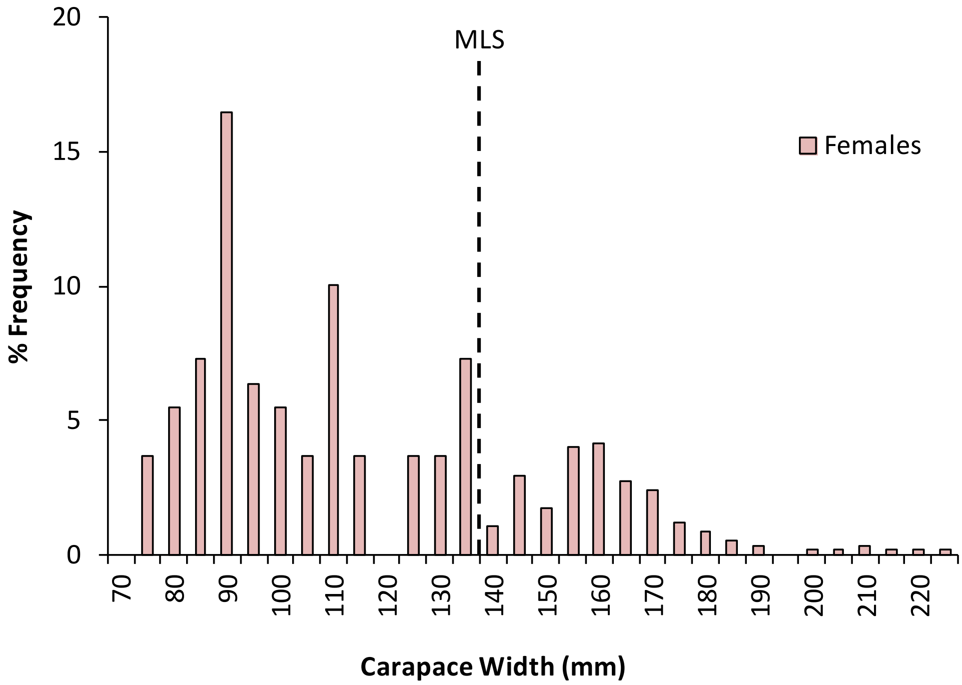


FIGURE 5. Size-frequency distributions of female and male lobsters in creel catches from Billia Croo, summer 2011. Data are shown for 5 mm size-classes, labelled by their lower size limit. Lobsters smaller than the minimum legal size (MLS – 87 mm CL) were discarded.



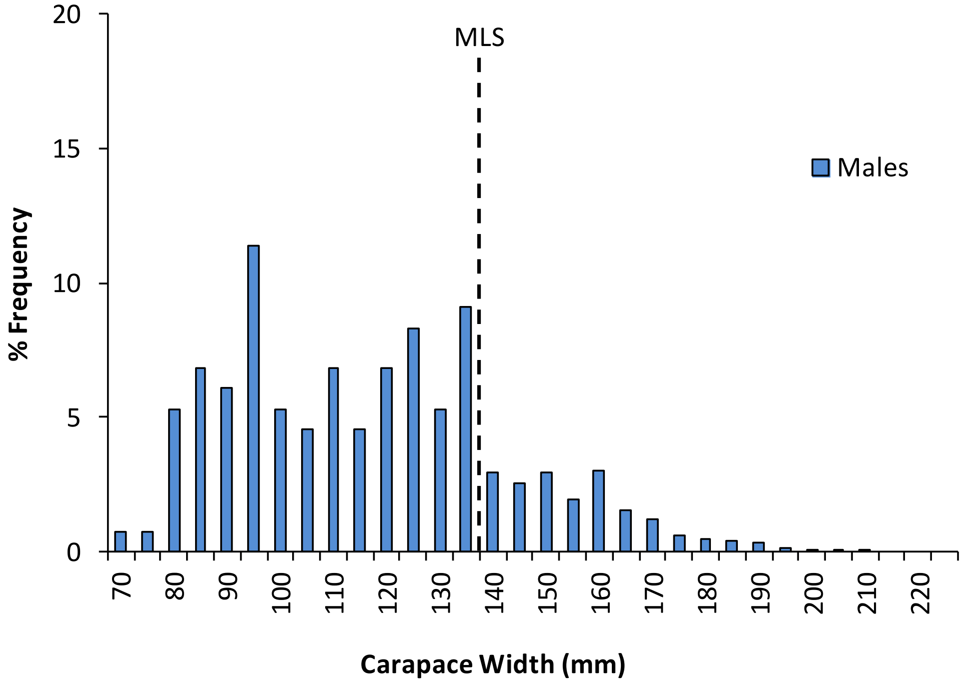


FIGURE 6. Size-frequency distributions of female and male brown crabs in creel catches from Billia Croo, summer 2011. Data are shown for 5 mm size-classes, labelled by their lower size limit. Crabs smaller than the minimum legal size (MLS – 140 mm CW) were discarded.

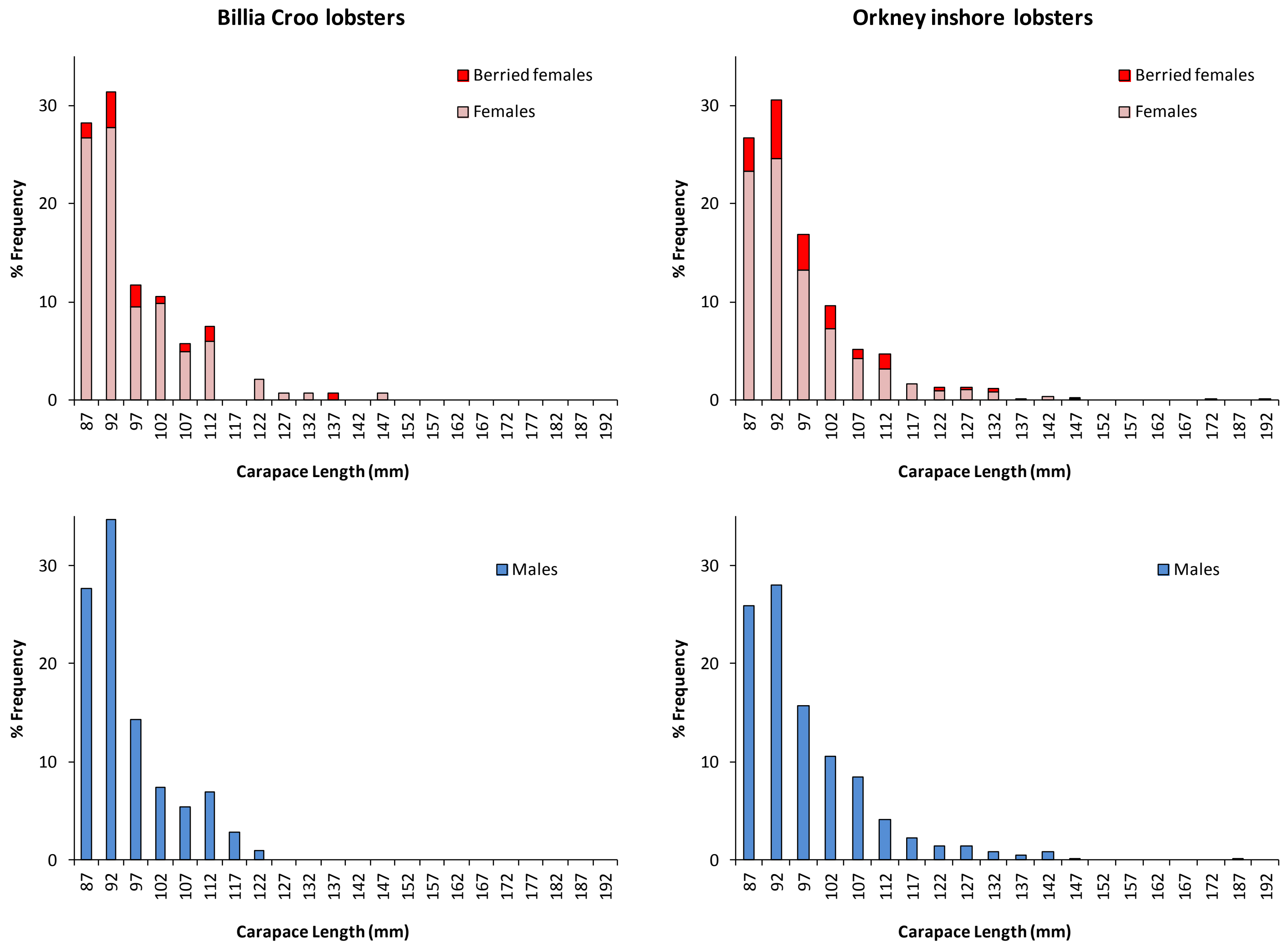
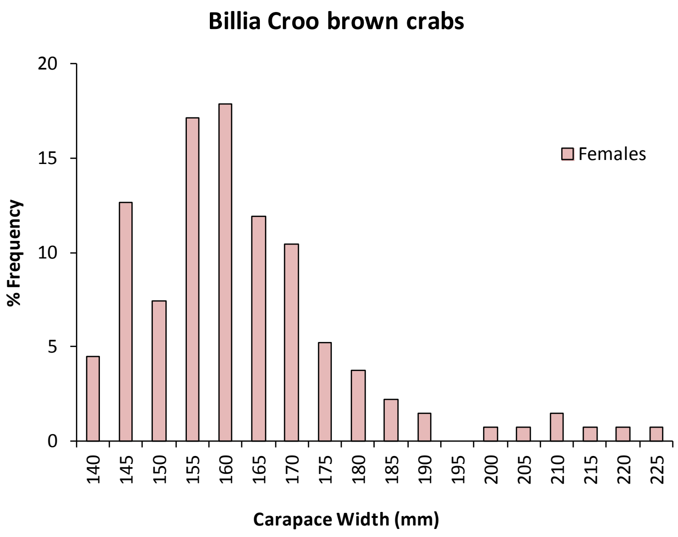
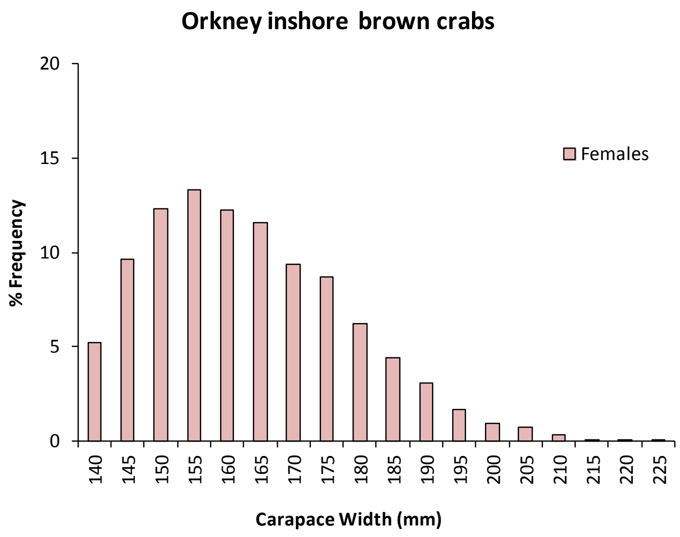
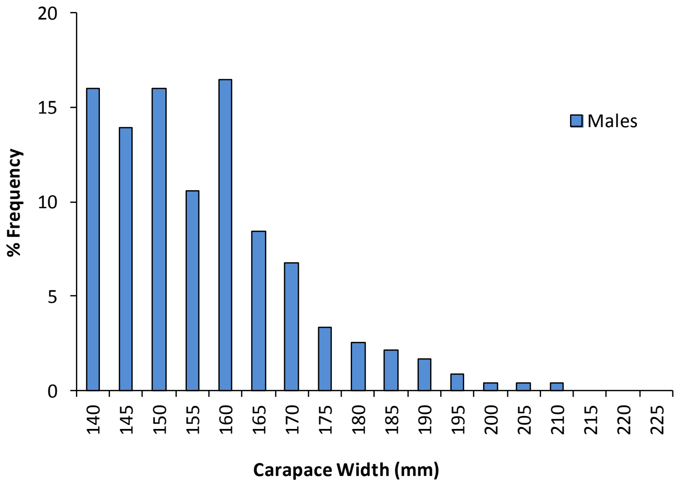

Billia Croo lobsters
Orkney inshore lobsters
Berried females
Females
Males
% Frequency
0
10
20
30
87 92 97 102 107 112 117 122 127 132 137 142 147 152 157 162 167 172 177 182 187 192
87 92 97 102 107 112 117 122 127 132 137 142 147 152 157 162 167 172 187 192
Carapace Length (mm)

FIGURE 7. Size-frequency distributions of male and female lobster landings from creel fishing at Billia Croo, summer 2011 and across Orkney inshore waters during summer 2010 and 2011.

ANNEX 6: Results of Crustacean Fishery Monitoring at the EMEC Wave Test Site







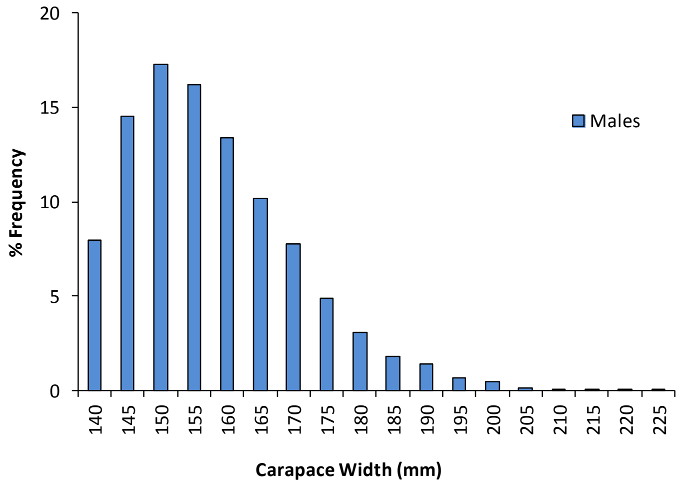
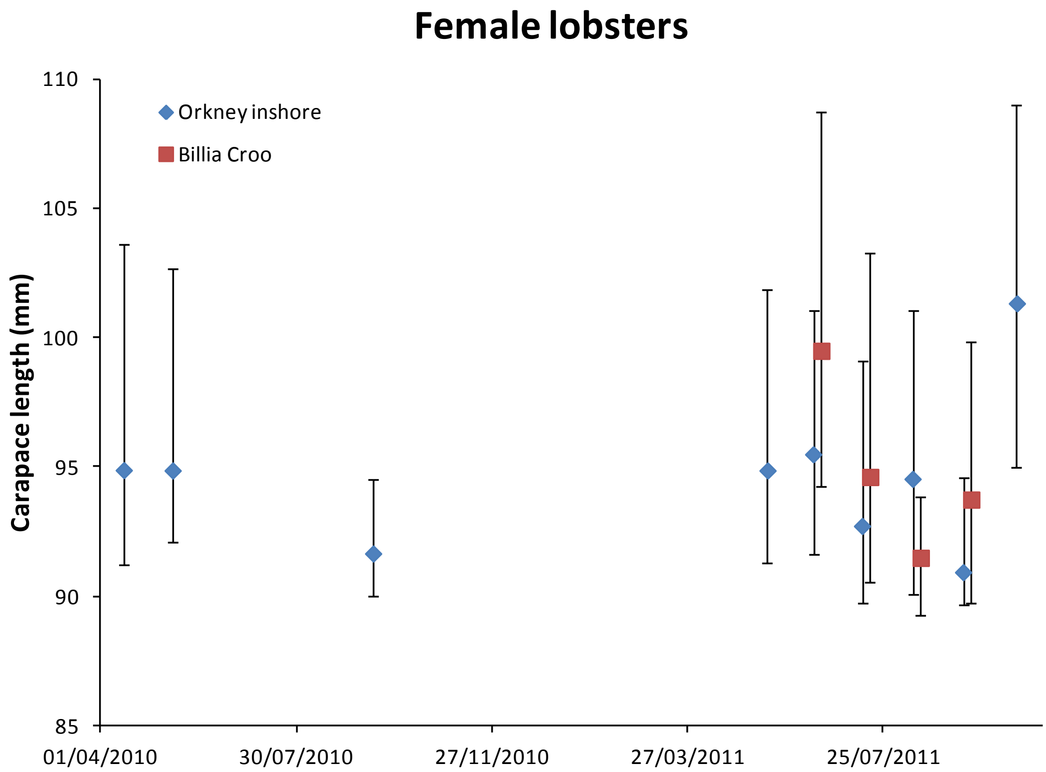


FIGURE 8. Size-frequency distributions of male and female brown crab landings from creel fishing at Billia Croo, summer 2011 and across Orkney inshore waters during summer 2010 and 2011.



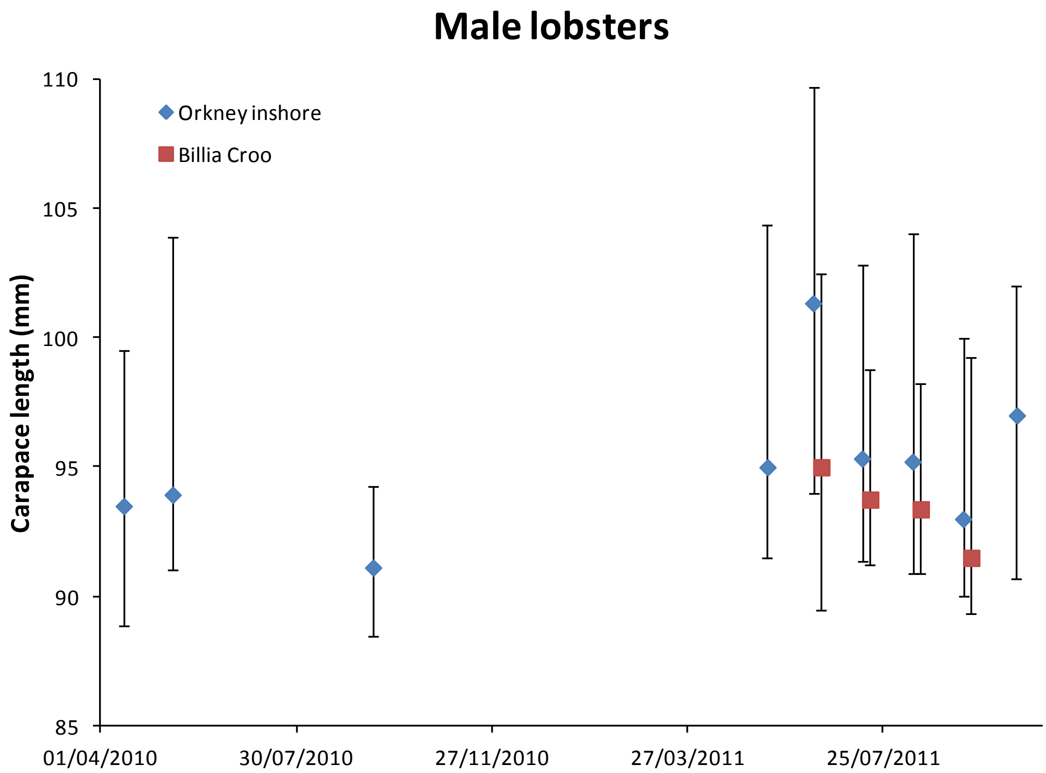
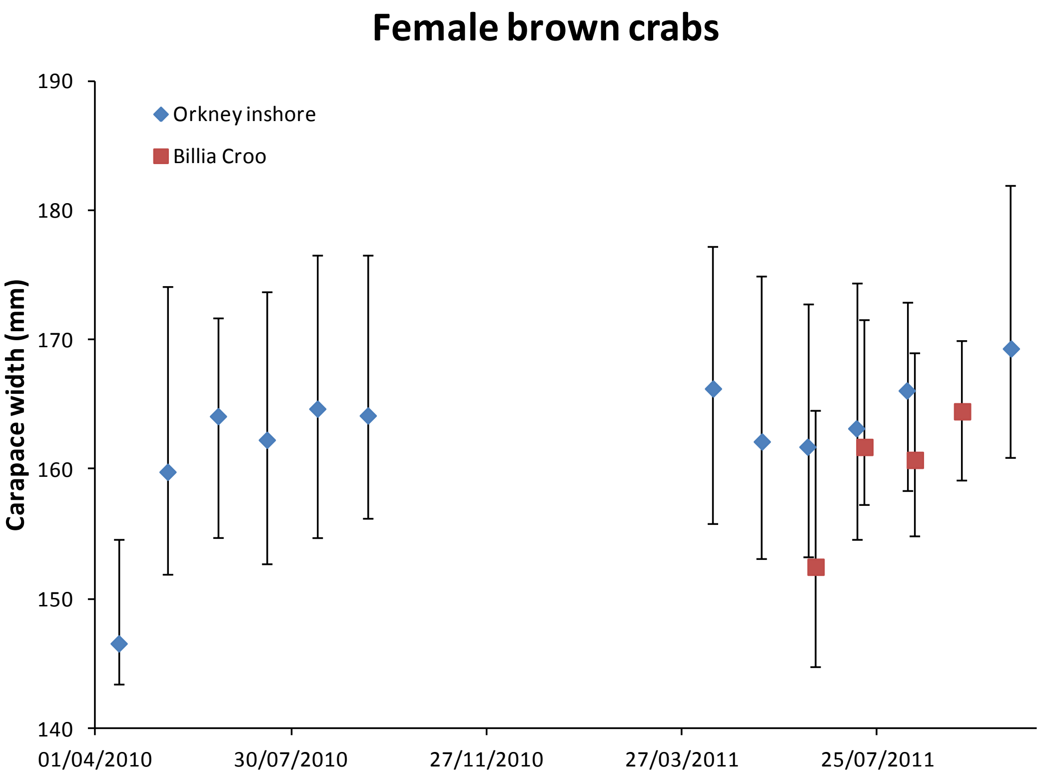


FIGURE 9. Median and interquartile ranges of monthly size compositions of lobster landings, comparing between Billia Croo samples and market samples from across the Orkney inshore region.


Female brown crabs
Carapace width (mm)
190
180
170
160
150
140
Orkney inshore
Billia Croo
01/04/2010
30/07/2010
27/11/2010
27/03/2011
25/07/2011

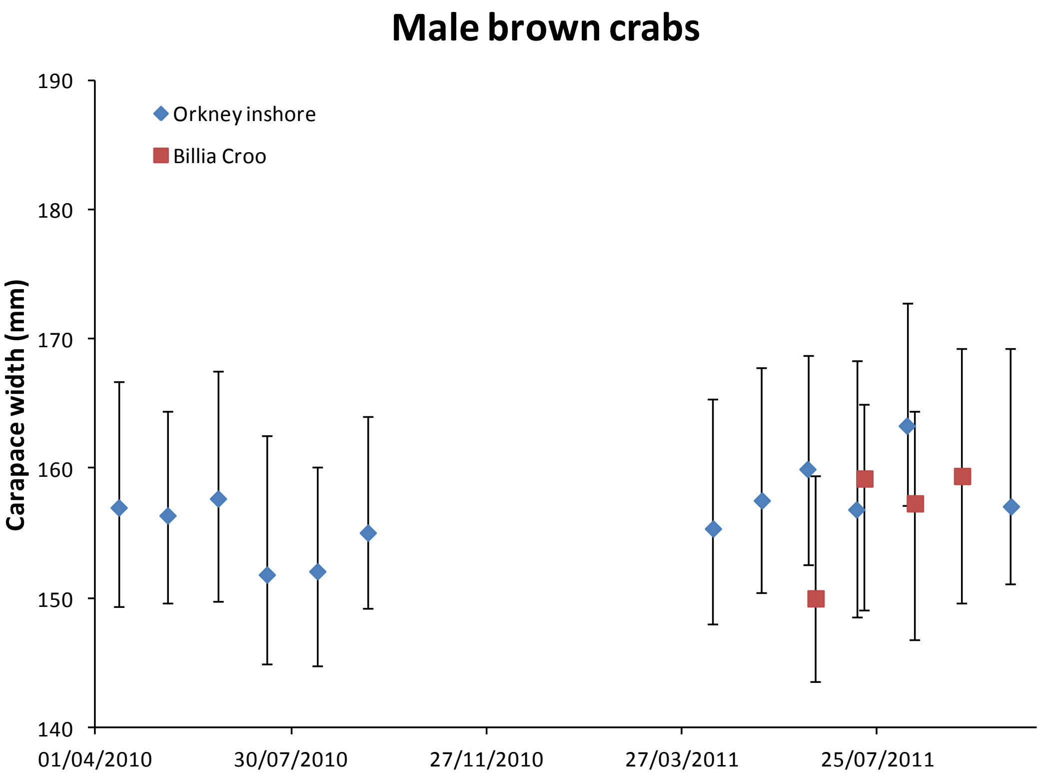
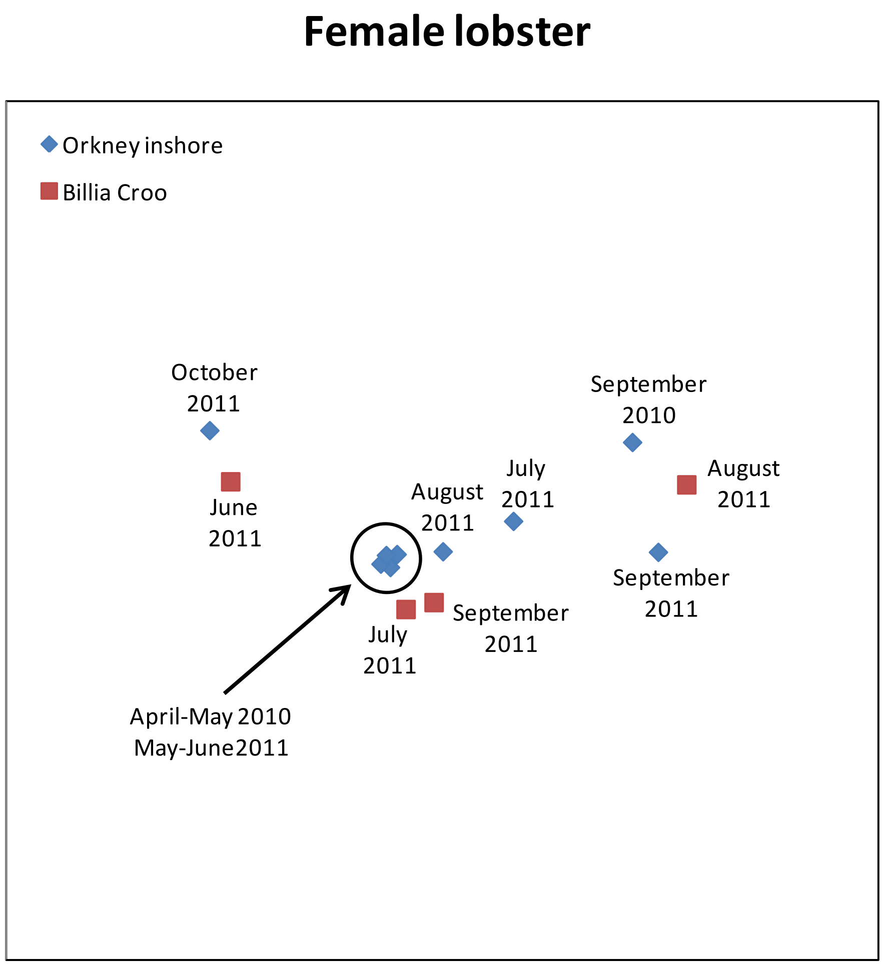
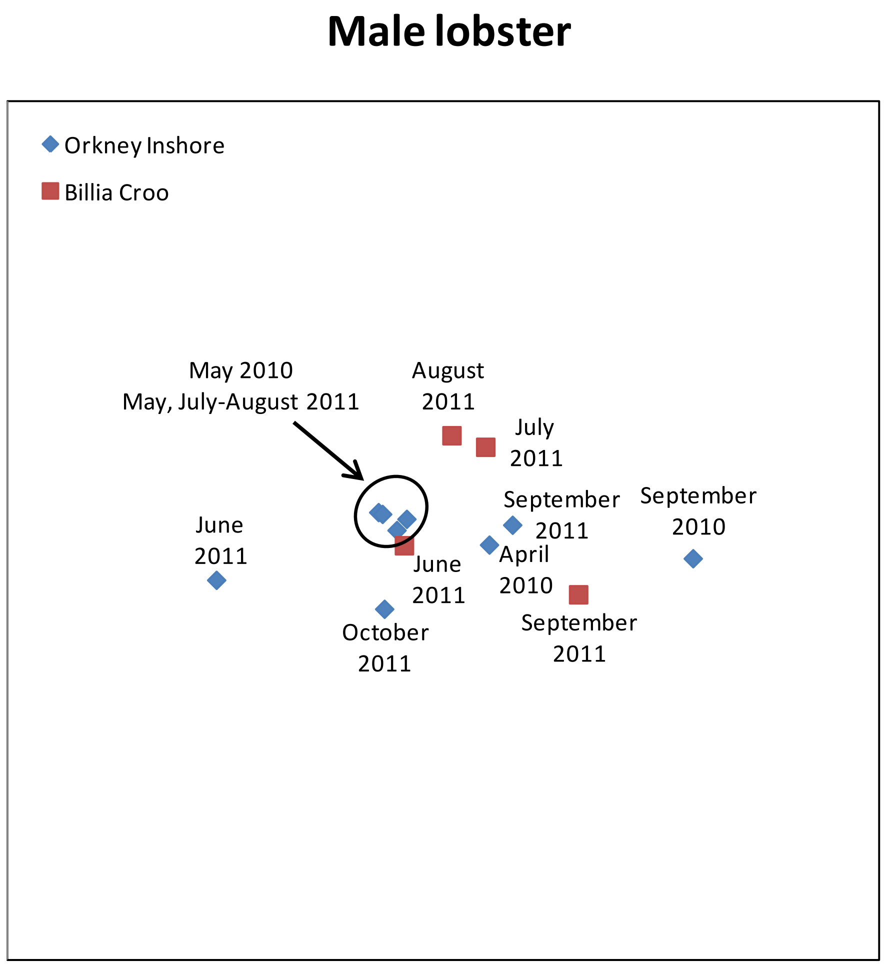

Male brown crabs
Carapace width (mm)
190
180
170
160
150
140
Orkney inshore
Billia Croo
01/04/2010
30/07/2010
27/11/2010
27/03/2011
25/07/2011

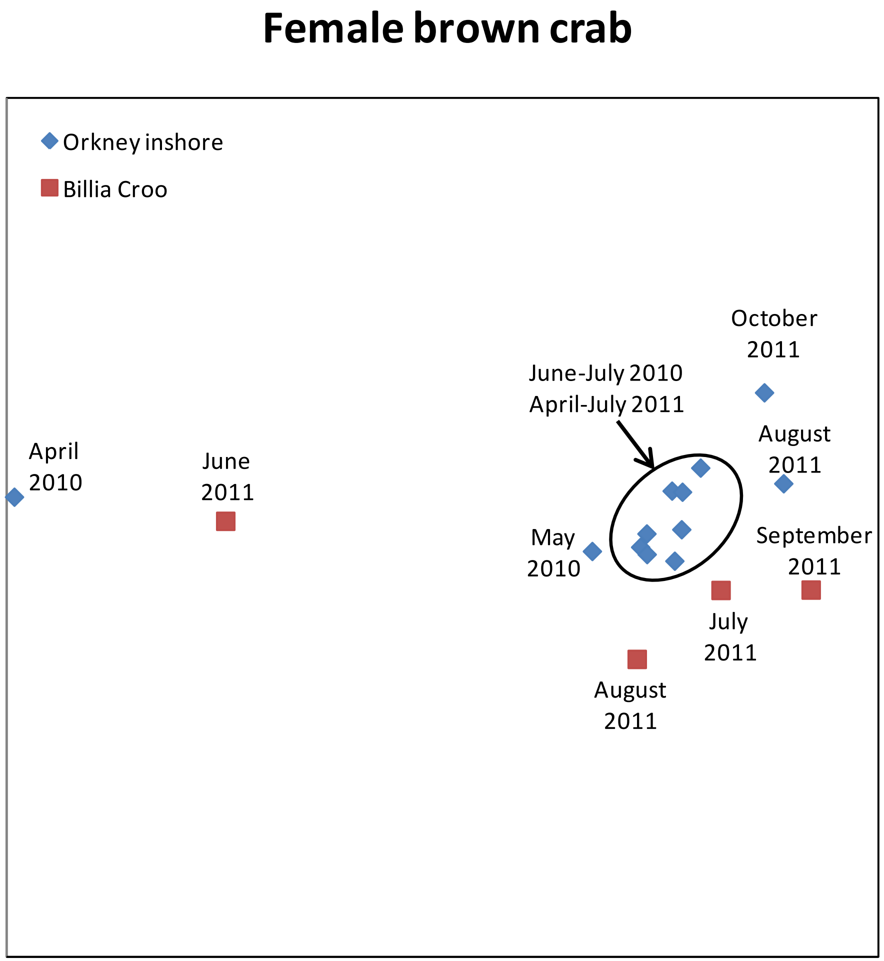
FIGURE 10. Median and interquartile ranges of monthly size compositions of brown crab landings, comparing between Billia Croo samples and market samples from across the Orkney inshore region.

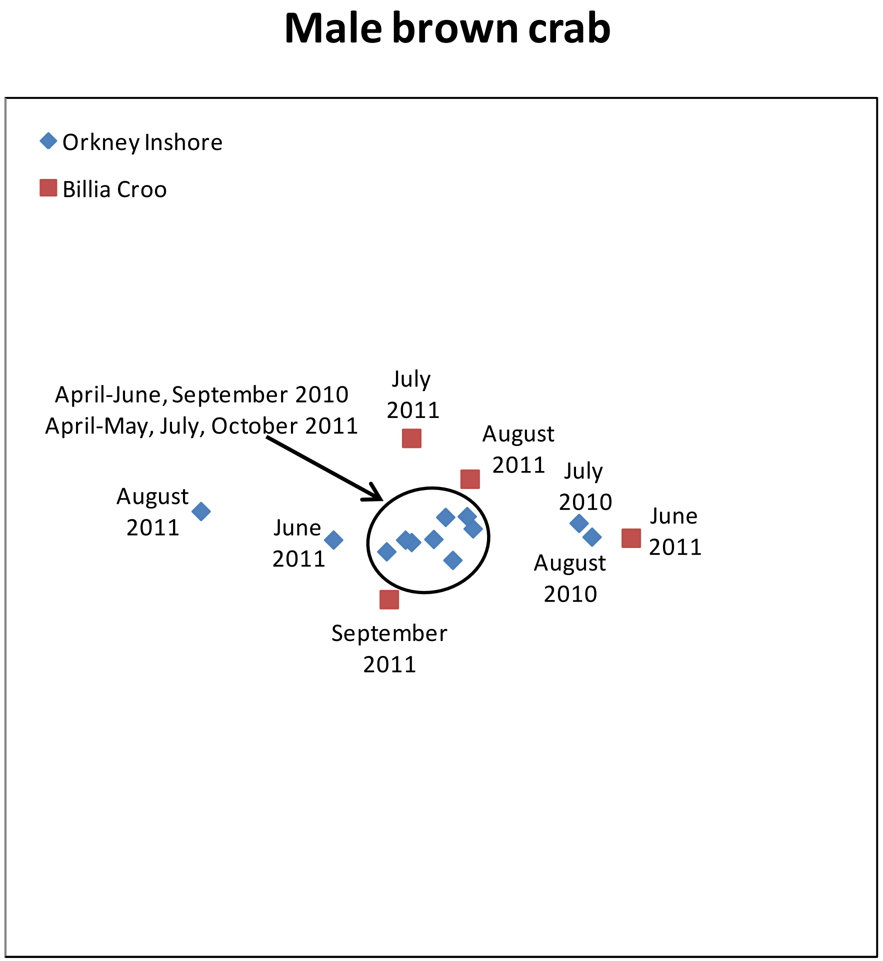

Female lobster
Orkney inshore
Billia Croo
October 2011
June 2011
August 2011
July 2011
September 2010
August 2011
September 2011
July 2011
September 2011
April-May 2010
May-June2011


Male lobster
Orkney Inshore
Billia Croo
May 2010
May, July-August 2011
August 2011
July 2011
September 2011
September 2010
June 2011
June 2011
April 2010
October 2011
September 2011

38

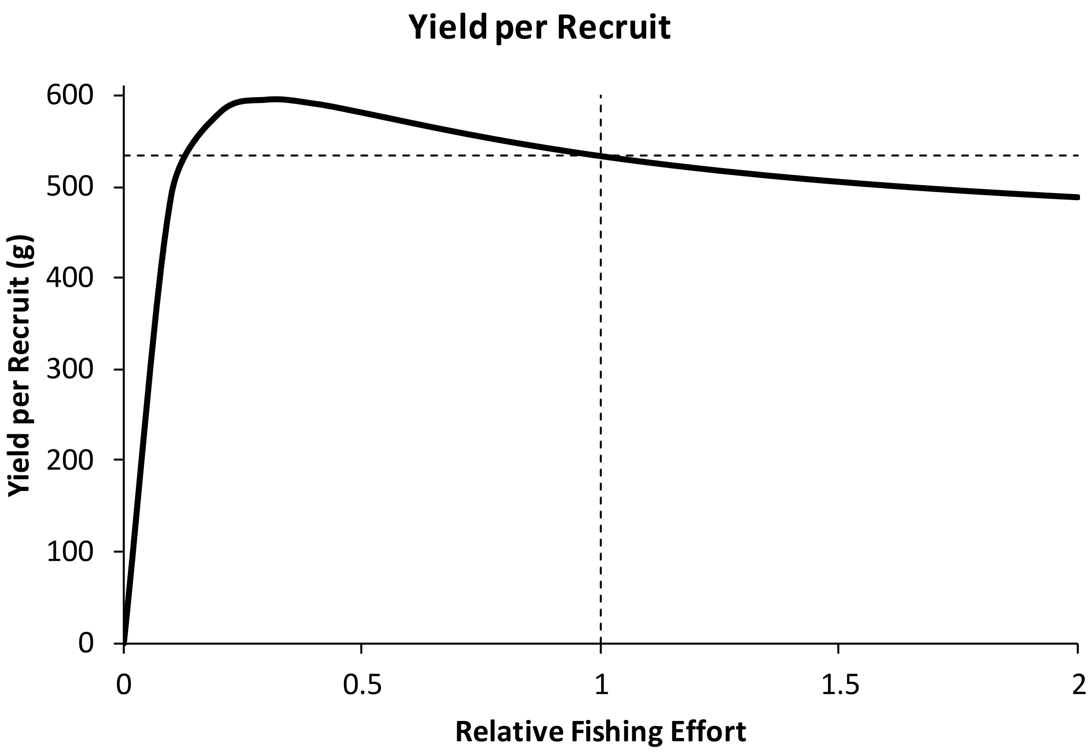
FIGURE 11. Non-metric multidimensional scaling plots comparing monthly size compositions of lobster landings between Billia Croo in 2011 and all other inshore areas of Orkney in 2010 and 2011. The inter-point distances represent the distances (dissimilarities) between the size compositions. The horizontal axes are most closely related with average size – points on the left of the plots correspond with larger average sizes. The vertical axes are related to the shape of the size composition – points towards the bottom of the plots correspond with greater variability of size in both sexes, with greater positive skewness in females and less positive skewness of the size composition in males.


Female brown crab
Orkney inshore
Billia Croo
October 2011
June-July 2010
April-July 2011
April 2010
June 2011
August 2011
May 2010
September 2011
July 2011
August 2011


Male brown crab
Orkney Inshore
Billia Croo
July 2011
April-June, September 2010
April-May, July, October 2011
August 2011
July 2010
August 2011
June 2011
June 2011
August 2010
September 2011

40

FIGURE 12. Non-metric multidimensional scaling plots comparing monthly size compositions of brown crab landings between Billia Croo in 2011 and all other inshore areas of Orkney in 2010 and 2011. The inter-point distances represent the distances (dissimilarities) between the size compositions. The horizontal axes are most closely related with average size – points on the left of the plots correspond with smaller average sizes in females and larger average sizes in males. The vertical axes are related to the shape of the size composition – points towards the bottom of the plots correspond with lower variability of size in females and less positive skewness of the size composition in males.


Yield per Recruit
Yield per Recruit (g)
600
500
400
300
200
100
0
0
0.5
1
1.5
2
Relative Fishing Effort

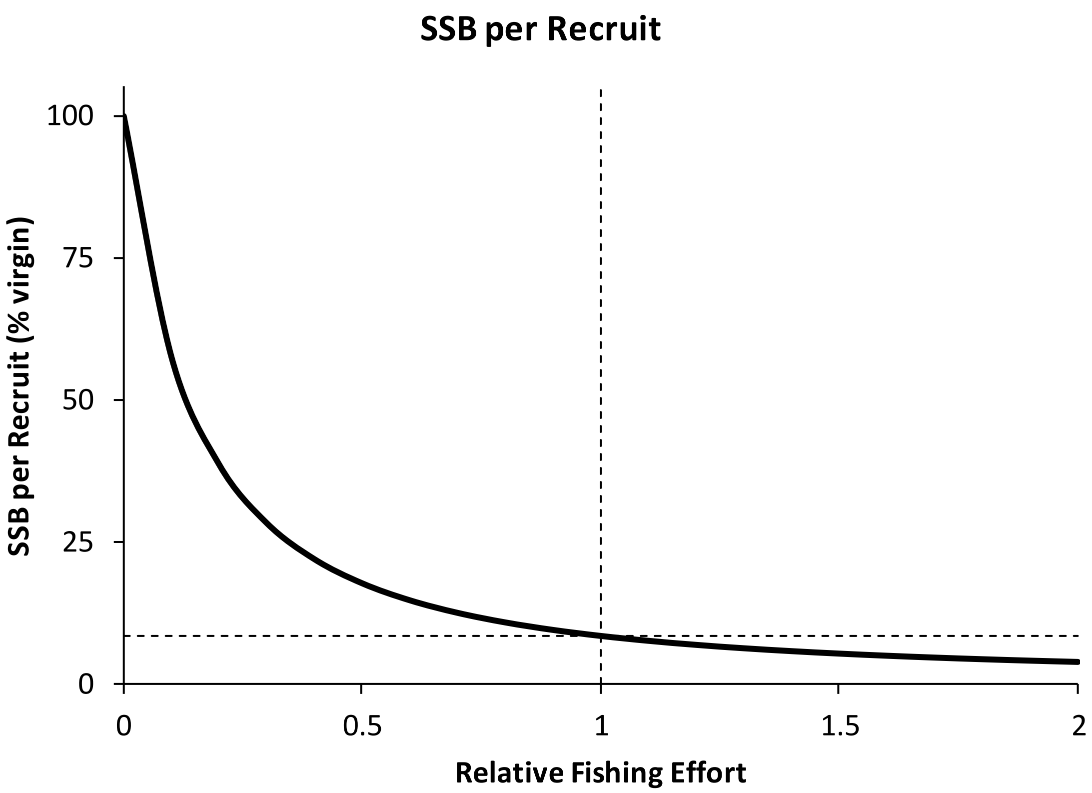
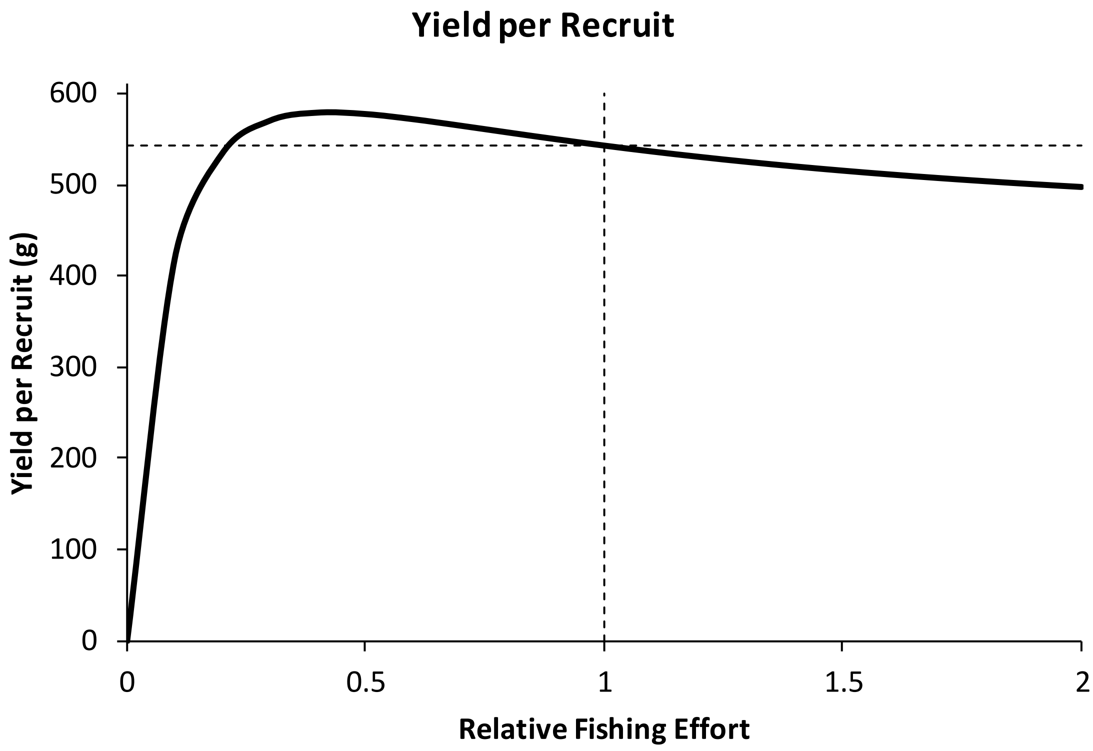

SSB per Recruit
SSB per Recruit (% virgin)
100
75
50
25
0
0
0.5
1
1.5
2
Relative Fishing Effort

FIGURE 13. Local exploitation status of lobster stock fished at Billia Croo, as implied by the size composition of landings in summer 2011. Yield per recruit, shown as the long-term expected average weight of a landed lobster, is a proxy for fishery yield. Spawning stock biomass (SSB) per recruit, shown as the percentage of the value expected for an unexploited stock, is a proxy for spawning potential.



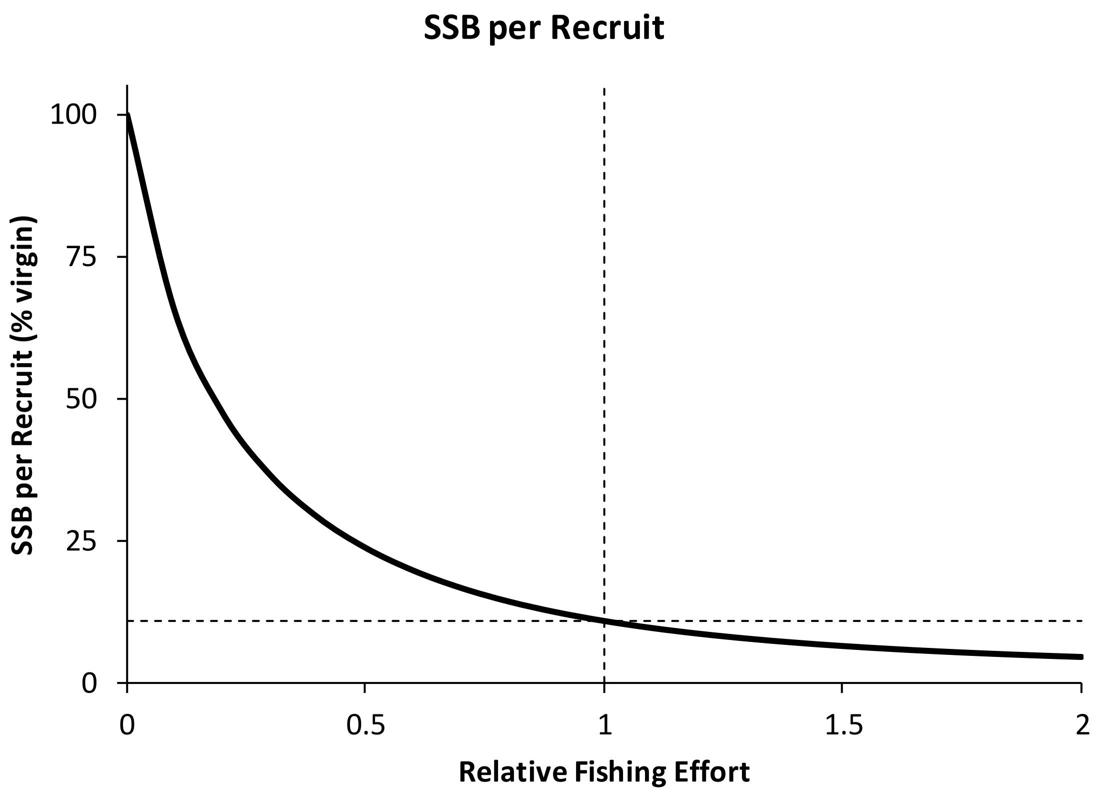


FIGURE 14. Exploitation status of lobster stock fished in the Orkney inshore region, as implied by the size composition of landings in summer 2011. Yield per recruit, shown as the long-term expected average

weight of a landed lobster, is a proxy for fishery yield. Spawning stock biomass (SSB) per recruit, shown as the percentage of the value expected for an unexploited stock, is a proxy for spawning potential.

APPENDIX I – Crustacean fishery monitoring protocol for Billia Croo

Overview of fishing operations

Crustacean catches are monitored at the EMEC wave energy test site at Billia Croo. The purpose of monitoring is to characterise the quantity and structure of catches from this area. Monitoring activities depend on the activities of a single creel vessel *FV Shalimar* (K49, Registered Length 11.95 m) undertaking experimental creel fishing in the area under a voluntary agreement with Orkney Sustainable Fisheries Ltd. Under this agreement the vessel skipper completes an onboard log-book return (see blank form appended) providing information on soak times and numbers and weights of legal and undersized catches of lobster (*Homarus gammarus*), brown crab (*Cancer pagurus*) and velvet crab (*Necora puber*) for each string of creels fished. Minimum landing sizes are 87 mm carapace length for lobsters, 140 mm carapace width for brown crabs and 65 mm carapace width for velvet crabs. Creels are arranged into strings and set and hauled at the discretion of the skipper (currently two strings, one of 31 standard creels and one of 25 standard creels), with the intention of providing catch returns on approximately a weekly basis. EMEC are notified of the intention to fish in the area.

Marketable catch handling

The marketable catch of lobster and brown from Billia Croo is kept in separately identifiable bongos onboard *FV Shalimar*, allowing it to be distinguished from catches from other areas retained during a day's fishing. This catch is covered with dampened carpet and frequently hosed with sea water to reduce mortality during transport and handling. Typically catch may be carried onboard for up to 8 hours whilst the vessel attends creels on other grounds. Catch is landed into Stromness, where numbers and the size, sex and berried (egg-carrying) status of all individuals are recorded usually within 1 hour of landing. Standard measurements are carapace width for edible crabs, being the width in mm across the widest part of the carapace (Figure A1), and the carapace length for lobsters, being the length in mm from the posterior edge of the eye socket to the posterior margin of the cephalothorax (Figure A2). Measurements are made to by Sarah Lamb and Kate Walker of Orkney Sustainable Fisheries Ltd where possible, or by staff of Orkney Fishermen's Society when Sarah or Kate are unavailable to attend within a short period of landing. All measurements are made onto a standard recording sheet (see blank form appended to this document.

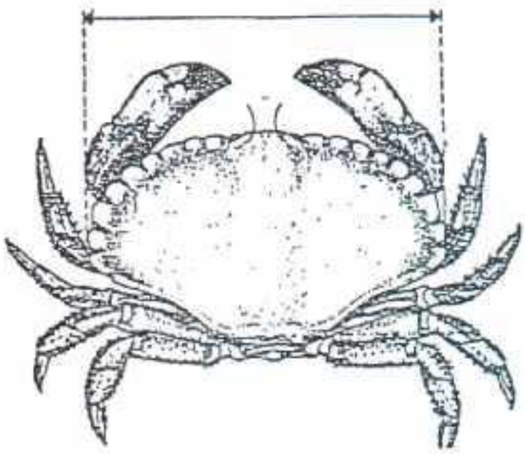


FIGURE A1. Measurement of crab carapace width.

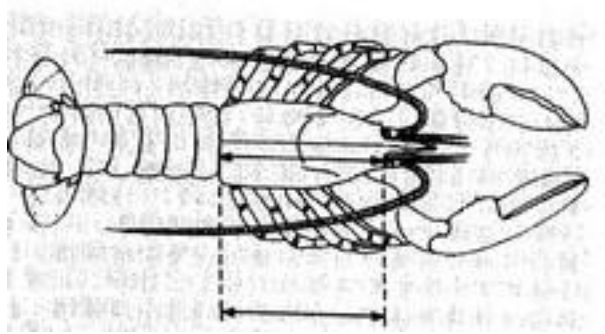
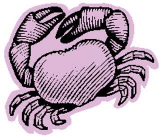


FIGURE A2. Measurement of lobster carapace length.

Discard monitoring

Discarded (mainly undersized) catches of lobster, are recorded onboard *FV Shalimar* using the standard log-book sheet (see above). Owing to excessive (nearly 100%) mortality seen in early catch monitoring trials, the non-marketable portion of the catch is not landed but is instead discarded *in situ* immediately after recording. Onboard catch monitoring by Sarah Lamb and Kate Walker is undertaken opportunistically, and involves full characterisation of the discarded portion of the catch by size and sex.



Orkney Sustainable Fisheries Log book

Billia Croo Site Catch Record

Boat: Shalimar Landing Place: Stromness

				Lobster			Brown Crab			Velvet Crab	
Date	Soak Time (Days)	String Number	Area	Number Landed	Landed weight (kg)	Number Undersized	Number Landed	Landed Weight (kg)	Number Undersized	Landed Weight (kg)	Number undersized

Notes :

Other notable species:
Sea state:

Signed: Date:

APPENDIX II – Length cohort analysis and per recruit analyses

Length cohort analysis (LCA) treats a size composition of fishery removals as representing a single cohort of animals, followed from recruitment to the fishery to extinction. Clearly, this is an approximation, the main assumption being that the stock is in a steady state, having equilibrated under conditions of constant recruitment and mortality. In practice, LCA is often performed on data averaged over several years, and provided that there are no strong stock or fishery trends during this time, the outputs are sufficiently unbiased to provide a robust assessment of stock status relative to overfishing criteria.

Inputs to LCA include:

- Fishery removals (landings plus dead discards) are needed in terms of numbers at size. Relative numbers or proportions are sufficient for estimation of fishing mortality, but data on absolute numbers will also allow removals to be scaled to an estimate of population size.
- A growth curve is needed to calculate the time taken to grow through the size-classes, i.e. to provide the time dimension of the analysis. Usually a von Bertalanffy growth function is used, requiring two parameters: L_∞, the asymptotic maximum size; and K, and a coefficient describing the rate at which this maximum size is approached.
- A value for M, the instantaneous annual rate of natural mortality is needed so that the contribution of fishing mortality to the decline in numbers with age can be separately identified. This is often poorly known, but appropriately scaled values are derived on the basis of longevity, life-history considerations and/or tagging studies.
- A value is needed for 'terminal F', the instantaneous annual rate of fishing mortality of the largest (i.e. oldest) size-class in the analysis. Given this value, fishing mortality values for all other size-classes are calculable. As with standard age-based cohort analysis methods (also termed virtual population analysis), there is a rapid convergence in this calculation such that the estimates of fishing mortality for smaller (i.e. younger) size-classes are increasingly independent of the value chosen for terminal F.
- Parameters are needed for the conversion of size to weight, commonly modelled as a power law relationship $W_i = a\, L_i^{\ b}$, where W_i and L_i are the average weight and length of size-class i and a and b are parameters of the relationship. The size-weight relationship is not required for the LCA *per se*, but if the LCA results are used to calculate yield and spawning stock biomass per recruit curves (see below) there is a need to convert sizes to weights.

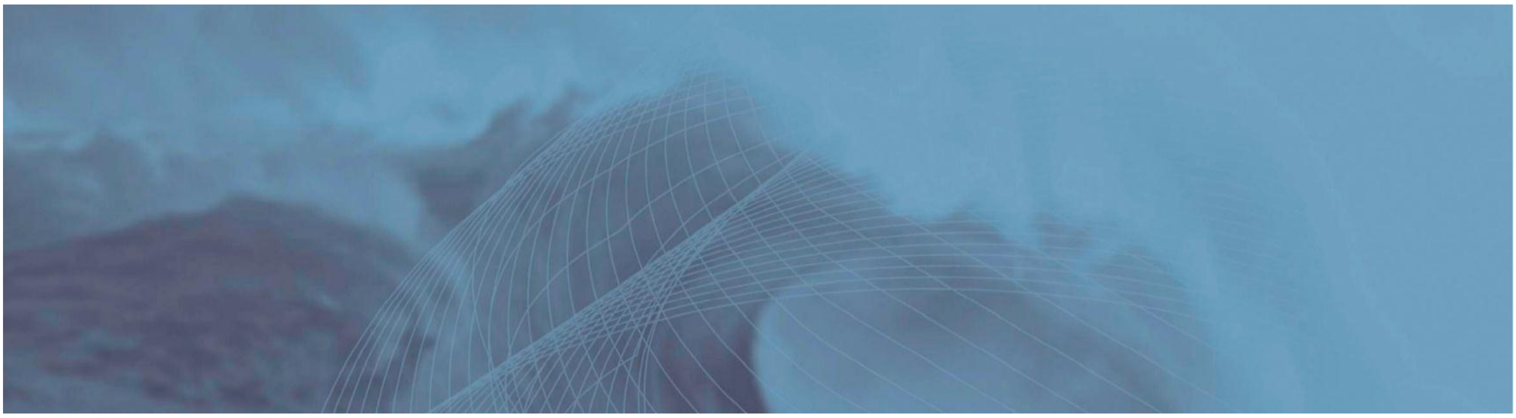
The main output of LCA is a vector of fishing mortality at size. Average fishing mortality is commonly calculated as a mean across size-classes, omitting the smallest size-classes (not fully recruited to the fishery) and the largest size-classes (estimates strongly influenced by choice of value for terminal F). Fishing mortality estimates are often not informative in their own right, but can be used to calculate per recruit curves that provide an appreciation of current exploitation in relation to targets and thresholds for sustainable exploitation.

Yield per recruit (Y/R) analyses calculate the average weight of an animal in the landings at a given level of fishing effort. This provides a proxy for fishery yield under an assumption of no relationship between adult stock abundance and numbers of new individuals recruiting to the fishable stock (such relationships are often poorly known, and in the case of lobsters it often appears that recruitment is independent of stock size for all but very depleted stocks). The fishing mortality at which Y/R is maximized is termed F_{max}, and is often treated as a criterion for defining growth overfishing. Fishing mortality levels above F_{max} represent harvesting of animals before they have reached their full growth potential in terms of contributing biomass to the landings. This potential depends on the trade-off between gains from growth and losses from natural mortality.

Spawning stock biomass per recruit (SSB/R) analyses calculate, for each individual recruiting to the fishable stock, the average weight contributed to the spawning stock at a given level of fishing effort. This provides a proxy for the spawning potential of the stock, again depending on the assumption of no stock-recruitment relationship. SSB/R curves are commonly scaled as percentages of their value at zero fishing mortality. Criteria for recruitment overfishing are commonly couched in terms of the value of fishing mortality at which SSB/R is reduced to a given percentage of the unexploited ('virgin') level, with choice of percentage based on empirical or theoretical considerations related to life-history characteristics. For fish species 30-40% of virgin SSB/R is often used as a criterion, but lower values may be appropriate for stocks that are relatively robust to exploitation.

ANNEX 7: Summary of Results and Findings of the Orkney Shellfish Research Study 2010/11

Annex 7 - OSF
Project Review Octob



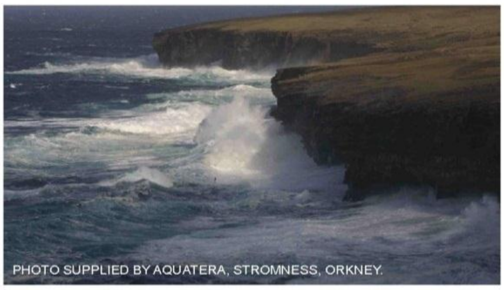
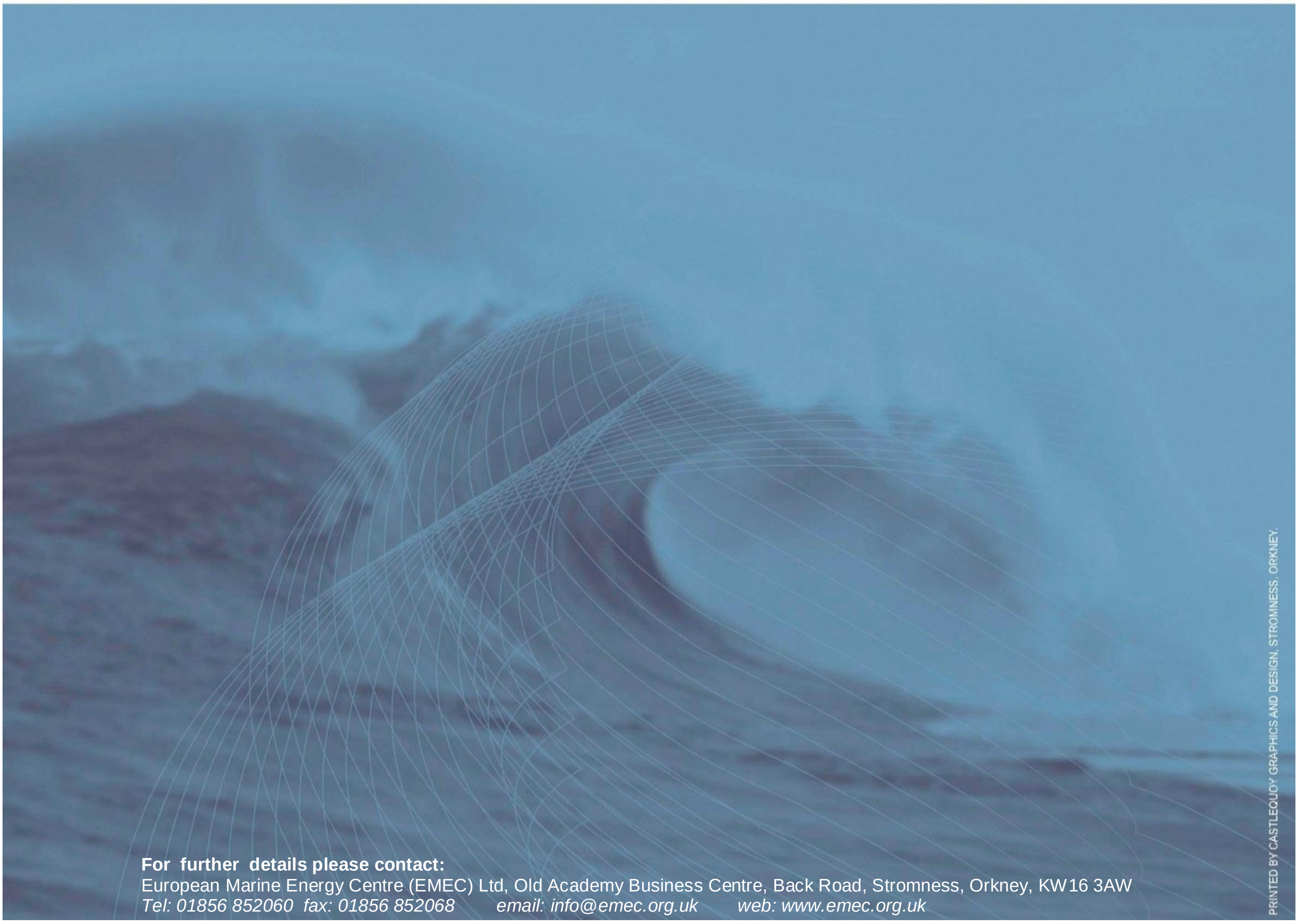


PHOTO SUPPLIED BY AQUATERA, STROMNESS, ORKNEY.



For further details please contact:
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Tel: 01856 852060 fax: 01856 852068 email: info@emec.org.uk web: www.emec.org.uk

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