Restoration and long-term monitoring of *Modiolus modiolus* in Strangford Lough

Interim Report 2014

Research and Development Series 15/01
A report commissioned by the Northern Ireland Environment Agency

Restoration and long-term monitoring of *Modiolus modiolus* in Strangford Lough: Interim Report 2014

Authors: Nathan Geraldi[1], Mark Emmerson[2], Nessa O'Connor[2], Julia Sigwart[2], Emma Boston[1], Camilla Bertolini[1] and David Roberts[2]

Contractors: [1] *Quercus*, Queen's University Belfast (QUB)
Collaborator: [2] Queen's University Belfast (QUB)

Funders: Northern Ireland Environment Agency (NIEA)

Quercus hosts the Natural Heritage Research Partnership (NHRP) between the Northern Ireland Environment Agency and Queen's University Belfast.
www.quercus.ac.uk

This report should be cited as:

Geraldi, N.R., M. Emmerson, N. O'Connor, J. Sigwart, E. Boston, C. Bertolini and D. Roberts (2014) Restoration and long-term monitoring of *Modiolus modiolus* in Strangford Lough: Interim Report 2014. Report prepared by the Natural Heritage Research Partnership (NHRP) between *Quercus*, Queen's University Belfast and the Northern Ireland Environment Agency (NIEA) for the Research and Development Series No. 15/01.

For further information on this report please contact:
Mr Joe Breen,
Department of the Environment,
Marine Division,
Klondyke Building,
Gasworks Business Park,
Lower Ormeau Rd,
Belfast.
BT7 2JA.

EXECUTIVE SUMMARY

1. *Modiolus* reefs throughout their range have been severely degraded and even locally extirpated. However, continued monitoring of the existing reefs is extremely limited. Monitoring is necessary not only to determine current abundance and population parameters, but also establish best practices to restore these biogenic habitats.

2. This study resumes monitoring natural *Modiolus* reefs and a restored reef in Strangford Lough, which have not been surveyed since 2011. It also describes the recent surveys of *Modiolus* reefs along the Outer Ards Peninsula.

3. Survey sites were chosen based on the presence of *Modiolus* from past studies. Surveys conducted depended on resource and environmental constrains but included acoustic substrate mapping, benthic grabs, video tows, and diver photo quadrats.

4. Surveys suggest that natural reefs within Strangford Lough continue to degrade. Only clumps of a few individuals (1-3 individual adults per reef) were seen in areas that historically had *Modiolus* reefs.

5. The restoration site within Strangford Lough has very few *Modiolus* individuals remaining on the cultch (scallop shell) and no obvious *Modiolus* reef remained at the site. Further survey techniques within the Lough should rely mainly on drop camera surveys to cover a larger area, while diver surveys should be used to assess small scale dynamics and recruitment.

6. The two surveyed areas along the Outer Ards have high densities (up to 600 m^{-2} and 180 m^{-2} respectively) of *Modiolus* and each of the two reefs covers approximately 1km^2.

7. Population estimates indicate that a translocation experiment would only remove a small fraction of the individuals (0.1-1%) that currently create the reefs along the Outer Ards Peninsula

8. Consistent annual monitoring is necessary to quantify the current status of *Modiolus* reefs and make appropriate restoration actions and management decisions to restore this biogenic habitat into a favourable conservation status.

CONTENTS

INTRODUCTION

Bivalve reefs are important for biodiversity and provide multiple ecosystem services including improved benthic pelagic coupling and the associated nitrogen removal, and enhanced production of economically important bivalves, crustaceans and fishes (Grabowski and Peterson 2007). Globally, enormous investment has been made in restoring reefs such as oysters (Brumbaugh and Coen 2009, La Peyre et al. 2014). Far less is known about the ecological importance of *Modiolus modiolus* (horse mussel) reefs (Ragnarsson and Burgos 2012) and throughout their range these mussels have been severely degraded and even locally extirpated. The loss is exemplified in Strangford Lough where multiple stressors, including mobile fishing gear, have resulted in an estimated > 90% loss in reef coverage from 1975 to 2009 (AFBI report). Hence, the loss of *Modiolus* reefs has not only resulted in depleted mussel populations but also the loss of multiple ecosystem services. Strangford Lough, specifically its *Modiolus* reef, is protected under the EU Habitats Directive (SAC; UK0016618) and is a Marine Conservation Zone (MCZ; NI Marine Act 2013). By definition, MCZs must be managed to ensure protection of the features for which they were selected and support the functioning of an ecologically coherent network of MCZs. The severe degradation or complete loss of *Modiolus* reefs in some regions necessitates drastic management intervention, including restoration via bivalve translocation to attempt to restore the reefs and their associated ecosystem services.

M. modiolus is long-lived and it may take a long period to recover after disturbance. This project collects data to make robust predictions of the timeline and conditions required to achieve restoration of reef communities and to position Strangford Lough *Modiolus* populations at the forefront of international research on mussel reef conservation. Specifically, the objectives of this project are to

1. Establish an annual monitoring programme for *M. modiolus* in Strangford Lough including natural and restored reefs.
2. Determine strategic plan for long-term monitoring
3. Predict restoration timescale

4. Evaluate the demonstrable impact and efficacy of live translocations of *M. modiolus* from outside Strangford Lough for restoring favourable conservation status.
5. Review the impact of top predator removal due to pot-fishing on *M. modiolus* reefs
6. Host *Modiolus* workshop at Queen's University Marine Laboratory
7. Identifying further lines of enquiry

This report focuses on data collected during the first 14 months of this project, from September 2013 to October 2014. Surveys were conducted to initiate annual monitoring in Strangford Lough (Objective 1). The surveys conducted will contribute to both a long-term monitoring plan and restoration timescale which will be forth coming (Objectives 2 and 3). Surveys along the Outer Ards Peninsula indicate there are multiple areas of healthy modiolus reefs which may be used for translocation into the Lough (Objective 4). Proposals to fund a study to determine the effect of pot fishing on *Modiolus* reefs were submitted to Seafish and DARD (Objective 5; Appendices 1 and 2). The Modiolus researchers meeting is planned and will be held at QUML on 22nd-23rd of January 2015 (Objective 6). The first year of this project has produced results that are relevant to both Strangford Lough and to restoration ecology.

METHODS

Strangford Lough sites

Site selection

Seven sites were chosen to survey within Strangford Lough based on previous surveys (Fig. 1A and B). The sites were based on the presence of *Modiolus* during both the Strangford Lough ecological change investigation (SLECI) and by the original *Modiolus* restoration research group (MRRG) or had *Modiolus* densities quantified in the MRRG (Fig. 1A).

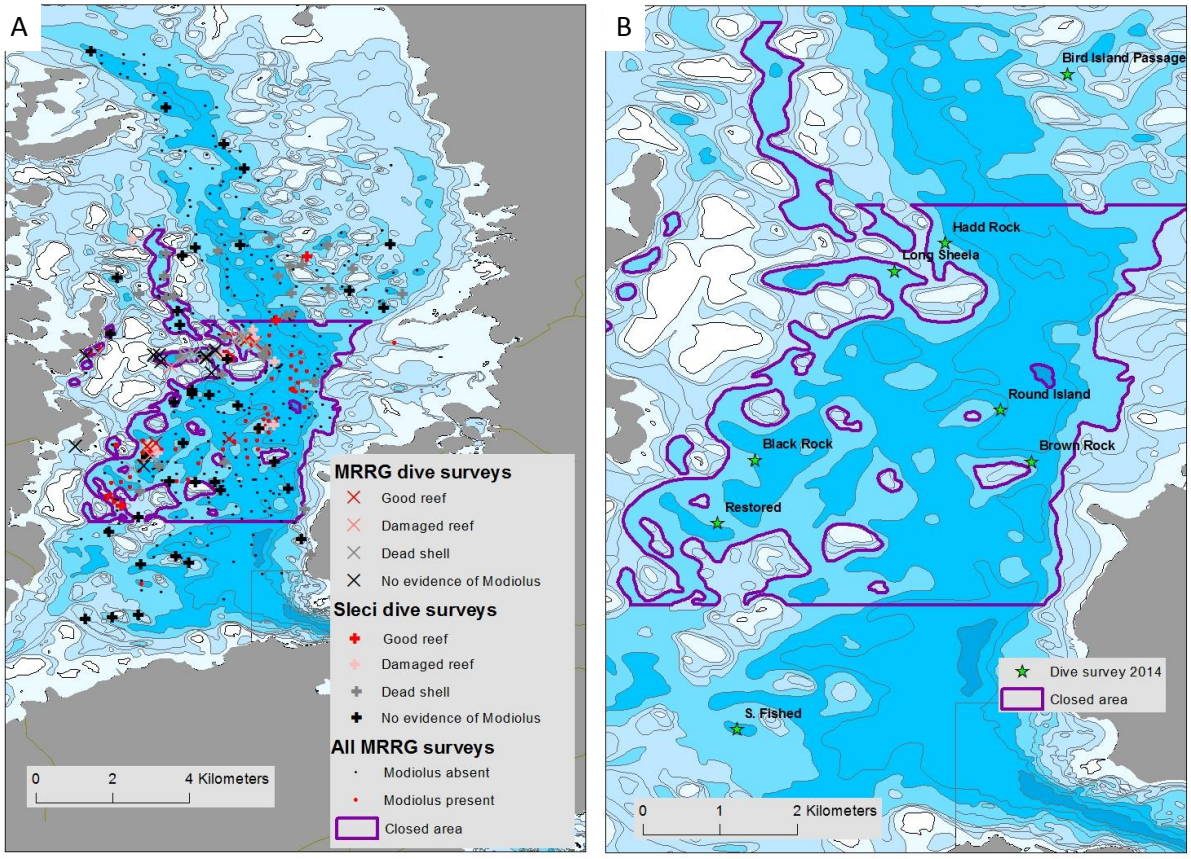

Fig 1 Map of Strangford Lough showing previous survey locations (A) and locations of this study (B).

.

Natural reefs surveys by divers

Sampling within the Lough consisted of deploying a 100 m leaded line marked every 5 m. Photographic quadrats (25x25 cm) were taken by divers every 5 m along the line for a total of 21 pictures per site. Presence of *Modiolus* within 3m of either side of the line was noted by divers. If a clump of *Modiolus* (>3 individual adults) was identified within the area of the photo quadrat, a 30cm diameter core was taken at

the exact same spot. A maximum of 5 cores were taken per transect. Coring was performed to quantify biodiversity within *Modiolus* reefs. Coring consisted of pushing the core 5-10 cm deep into the substrate and placing all material within the core into a plastic mesh bag (1 mm mesh) which was then returned to the boat. The contents within the bag was then sieved through 1mm mesh and frozen. Samples were frozen to reduce the use of preservation carcinogens. The preserved sample was then sorted and all organisms were identified to lowest possible taxon, counted, and weighted. Photographs were analysed in the lab and the number of live *Modiolus* were counted. Live *Modiolus* in the photographs were identified by the conspicuous red mantle.

Restoration site

Coinciding with the natural reef surveys, the 8 artificial reefs created in 2010 in Strangford Lough were surveyed (restore site; Fig. 1B). The reefs were created with mounds of dead scallop shell (cultch) and were either raised or flattened. A small patch of modiolus (1-2 m^2) was than translocated onto the cultch mounds from a nearby site in Strangford Lough. Survey methods were similar to those used for the natural reefs except 3 photographic quadrats and 1 removal core were collected at each artificial reef. Each reef height (high and low relief) were replicated 4 times for a total of 8 reefs created using dead scallop shell (referred to as cultch). Because the mounds were created with cultch, coring could not be conducted. Instead, everything within 25x25 cm quadrat was removed to a depth of 10cm and place in a plastic mesh bag. Samples were then analysed following the procedures for core samples.

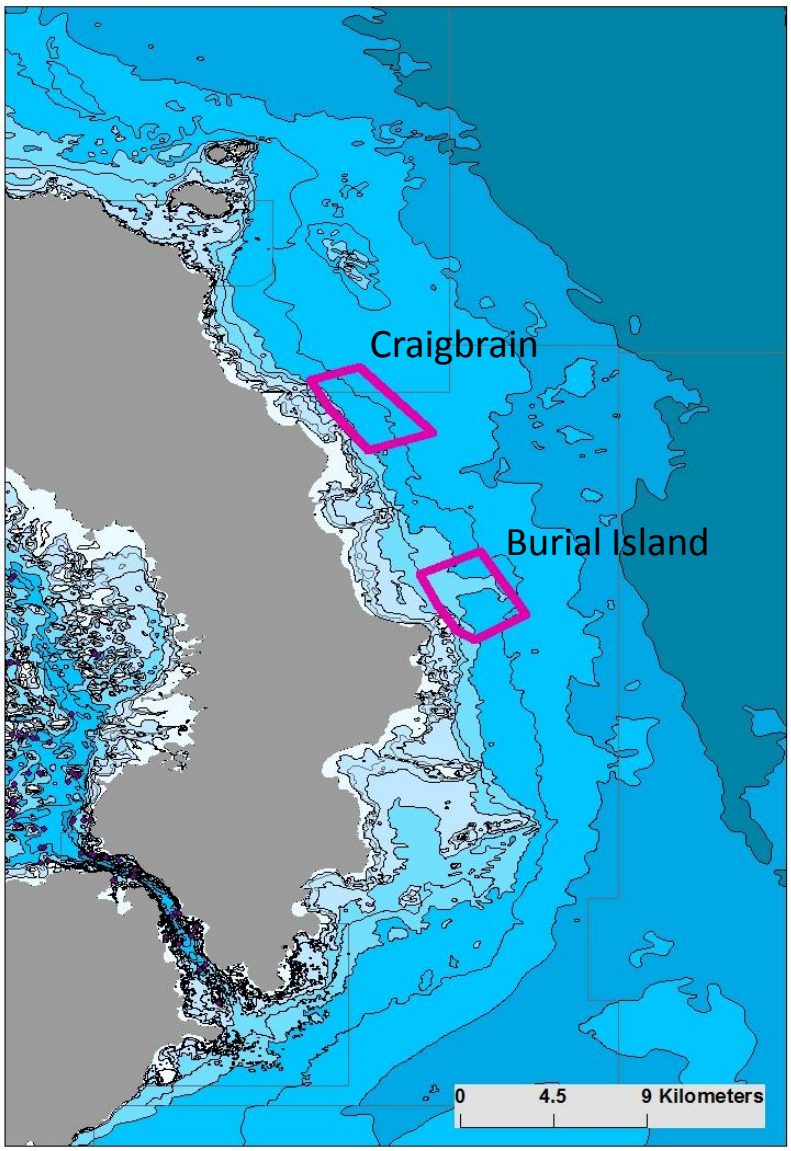

Fig 2 Map showing the 2 areas along the Outer Ards Peninsula identified as having *Modiolus* reefs.

Outer Ards sites

Site Selection

Surveys concentrated within 2 areas, Craigbrain and Burial Island, identified by the Department of the Environment (DOE) as containing *Modiolus* reefs based on past diver and grab surveys (Fig. 2). During two days in September 2014 on the FPV Banrion Uladh (DARD 40 m vessel) we surveyed Burial Island and Craigbrain (Fig. 2) using both single beam sonar and side scan sonar, as well as video sled tows. Single beam and side scan sonar acoustic surveys were conducted to test the ability of these techniques to accurately map the extent of *Modiolus* reefs. Survey sites

within each area were chosen to 1) not overlap with samples taken by Agri-Food and Biosciences Institute (AFBI); 2) be evenly dispersed throughout the area; and 3) sample multiple sites within the different substrate types based on initial analysis of the single beam sonar (represented as light green in Fig. 3). A second round of sampling was conducted to determine the extent of the *Modiolus* reef and focused on sampling near previous sites that included *Modiolus* (represented as dark green in Fig. 3).

Sampling the Outer Ards reefs

The Outer Ards reefs are deeper, more exposed to wave action, and have greater currents than the sites within Strangford Lough. As a result, we attempted to minimise our dependence on diver surveys to sample these reefs. Quantifying abundance and extent of *Modiolus* was therefore dependent on day grabs. The day grab removes approximately 0.1 m^2 area of substrate (Appendix 3). The grab is deployed from a boat and the two jaws are released when the grab makes contact with the substrate. The jaws are pulled closed when the grab is pulled back to the boat. Sample area is dependent on the two jaws making contact and penetrating the substrate, and then closing so that contents are not lost on retrieval. Jaws can be obstructed by large solid objects such as rocks or shells. Grabs with minimal substrate (< 1 l of substrate) were recorded as misfires and the grab was deployed again. High densities of *Modiolus* likely reduce the chance of a successful grab which could underestimate the density of *Modiolus*. Three successful grabs were taken at each site. The first sample was sieved through 1 mm mesh and preserved in 4% formalin. The preserved samples were transferred to 80% alcohol after 1 week. The second and third samples were thoroughly searched and all bivalves, crustaceans, echinoderms, and fish were collected and frozen. Samples were then analysed and all organisms were identified to the lowest possible taxa, counted and weighted for a total taxa biomass.

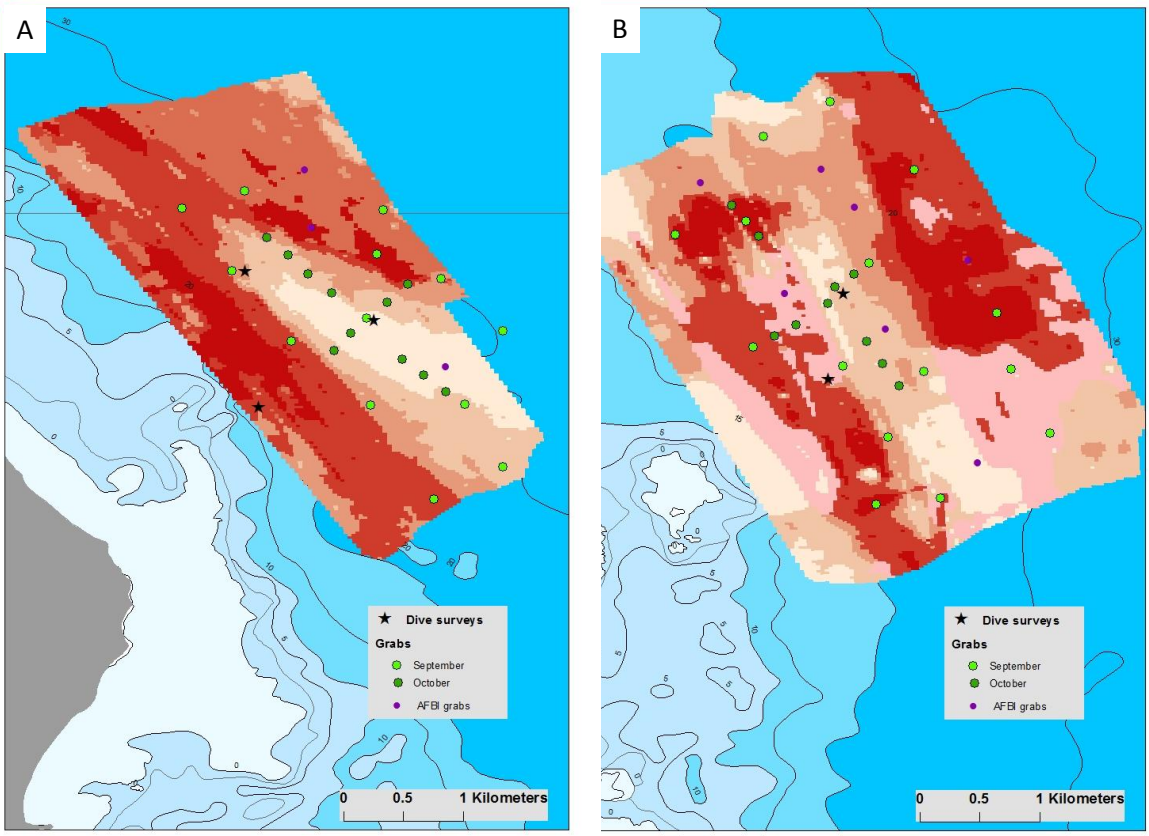

Fig. 3. Map showing Craigbrain (A) and Burial Island (B) areas along the Outer Ards Peninsula. Different shades of red indicate different substrate types determined by single beam sonar. Survey methods and locations are shown by unique symbols as follows; dive surveys-black stars, grabs conducted in September-light green circle, grabs conducted in October-dark green circle, and grabs conducted by AFBI-purple circle.

Analyses

Modiolus reefs extent and population

For both conservation decisions and to determine the efficacy of using the Outer Ards *Modiolus* reefs as donor sites to translocate *Modiolus* into Strangford Lough, it is necessary to estimate the extent and abundance of *Modiolus* within the 2 designated areas (Fig. 2). The population within the areas was estimated from day grab data using two different approaches. The first method calculates the density of *Modiolus* using data directly from the grabs and the second method used the data from the grabs to interpolate the density of *Modiolus* using ArcGIS.

The reef extent within each area was estimated by enclosing in a polygon the sites that had *Modiolus* and sites adjacent to those sites (Fig. 5). The area of this polygon at each site is likely the maximum area covered by *Modiolus* and was

considered the estimated reef extent. The mean and standard error of the density of *Modiolus* at sites within the estimated reef extent was then multiplied by the m^2 of the estimated reef extent to calculate the population of *Modiolus* within each area (*Modiolus* per grab x 10 x estimated reef extent).

The second method used to calculate the *Modiolus* population was based on interpolation using ArcGIS. Inverse distance weighted (IDW) was used to interpolate *Modiolus* density. IDW estimates a value for each unknown point based on nearby known values with the influence of known values decreasing with distance from the unknown point. IDW was chosen over kriging, which includes spatial trends, because IDW interpolation was logically more accurate (high abundance estimates did not extend into areas where *Modiolus* probably does not exist). All sites were included in the interpolation, which was run on both areas separately. The interpolation was then cut to only include the estimated reef extent. The mean and standard deviation of the points within the interpolation was then used to estimate the population at each site (mean point value per grab x 10 x estimated reef extent in m^2)

Results

Strangford Lough sites

No *Modiolus* were quantified within the pictures at any of the 7 sites in the Strangford Lough (147 samples total). These 7 sites historically had *Modiolus* reefs (Fig.1 and Fig. 4). Cores were not taken because of the minimal reef coverage. However, the coring method was tested in a few preliminary trials and appears to be an appropriate technique to sample *Modiolus*. Divers did note the presence of small clumps of *Modiolus* (2-5 individuals) at 3 of the 7 sites (Black Rock, Brown Rock, and Round Island; Fig. 1B).

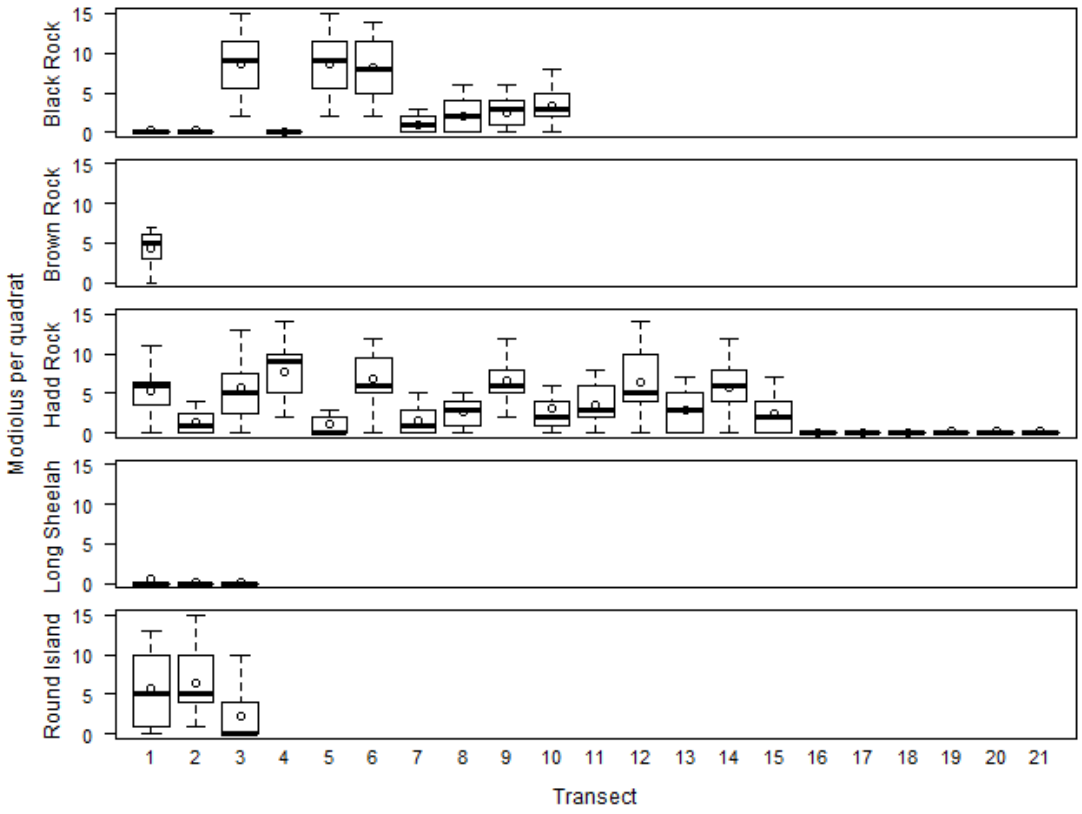

Fig. 4. The number of *Modiolus* per photo quadrat (50x50 cm) at 5 sites in Strangford Lough collected from 2008-2010. Each site had 1 to 17 transects conducted during the 3 years. A transect consisted of taking 15 or 25 photographs. Refer to Fig. 1 for location of sites. Boxplots show inner 2 quartiles within box and whiskers extend to 1.5 times the respective inner quartile. The line through the box and circle indicate the median and mean respectively.

Data collected using photo quadrats from 2008 to 2010 at sites sampled in 2014 was compiled to compare *Modiolus* abundance then and now (Fig. 4). At some of the sites surveyed in 2008-2010 quadrat data was not collected in 2008 -2010 photo data was collected at only four of the seven sites sampled in 2014. In 2008-2010,

photo quadrats were 50x50 cm and 15 or 25 photos were taken along individual transects. The number of transects at each site ranged from 1 to 17. Hadd Rock included approximately 8 different locations within 500 m. Hadd Rock and Black rock included locations with “good” and “poor” sites that were separated by less than 500 m (Roberts et al. 2011).

Restored site

We found very few *Modiolus* on the restored reef within the Strangford Lough. Out of 5 haphazardly taken photographs at each of the 8 different cultch mounds (40-25x25 cm pictures total) only 2 pictures contained 1 *Modiolus* each, which resulted in a mean of 0.05 modiolus per m^2. However, only a small fraction of the cultch mound surface area (8-10 m^2 surface area) was covered by the translocated *Modiolus* (1-2 m^2) and this area was not marked. As a result, comparisons then and now of the density of *Modiolus* are difficult. Removal quadrats from each of the 8 reefs contained 34 species (Table 1). The most abundant species from greatest to least abundant included *Ophiothrix fragilis, Pisidia longicornis, Nucula nucleus,* and *Ophiocomina nigra*.

Table 1. Species identified in removal quadrats sampled from the cultch at the restored site in Strangford Lough. Mean abundance and standard error were calculated from 8 samples. P indicates presence of taxa.

Group	Taxa	Abundance	St err
Porifera	*Myxilla incrustans*	P	
	Halichondria panicea	P	
Cnidaria	*Nemertesia antennina*	P	
	Eudendrium sp	P	
Annelida: Polychaeta	*Lepidonotus squamatus*	1.0	
	Ophelina acuminata	2.0	
	Owenia fusiformis	1.0	
	Pomatocerso spp.	P	
Crustacea: Cirripedia	*Balanus balanus*	P	
Crustacea: Decapoda	*Pisidia longicornis*	5.0	1.27
	Galathea sp	1.5	0.20
	Thoralus cranchii	1.5	0.25
Mollusca: Polyplacophora	*Tritonia hombergii*	1.0	
Mollusca: Gastropoda	*Callistoma lyonsi*	1.3	0.20
	Diodora graeca	1.0	
	Gibbula cineraria	1.3	0.20
	Emarginula fissura	1.5	0.35
	Diodora graeca	1.5	0.25
Mollusca: Pelecypoda	*Abra alba*	3.4	1.53
	Hiatella arctica	3.5	0.75
	Modiolus modiolus	1.6	0.32
	Sphenia binghami	2.0	
	Nucula nucleus	4.7	0.74
	Pododesmus sp	P	
	Chlamys varia	2.0	0.00
Echinodermata	*Asterias rubens*	1.0	
	Nassarus incrassatus	1.5	0.25
	Ophiothrix fragilis	11.2	2.38
	Ophiocomina nigra	4.5	0.25
	Ophiura albida	1.0	
	Leptasteris muelleri	1.8	0.57
Tunicata	*Ascidiella aspersa*	P	
	Clavelina lepadiformis	P	
	Sycon ciliatum	P	

Outer Ards sites

We surveyed two areas (Burial Island and Craigbrain; Fig. 2) using both single beam sonar and side scan sonar, as well as video sled tows. Initial analysis of the single beam sonar data indicated 6 different substrate types (Fig. 5). Both single beam sonar and side scan sonar will be ground-truthed to determine if these survey techniques are appropriate for measuring the extent of M*odiolus* reefs. However this

analysis is not completed and initial results are variable as indicated by the congruence of *Modiolus* abundance and substrate type at Craigbrain but not Burial Island (Fig. 5). Depending on the results, this data can be used as an additional method to calculate the area covered by the reef and the density of *Modiolus*.

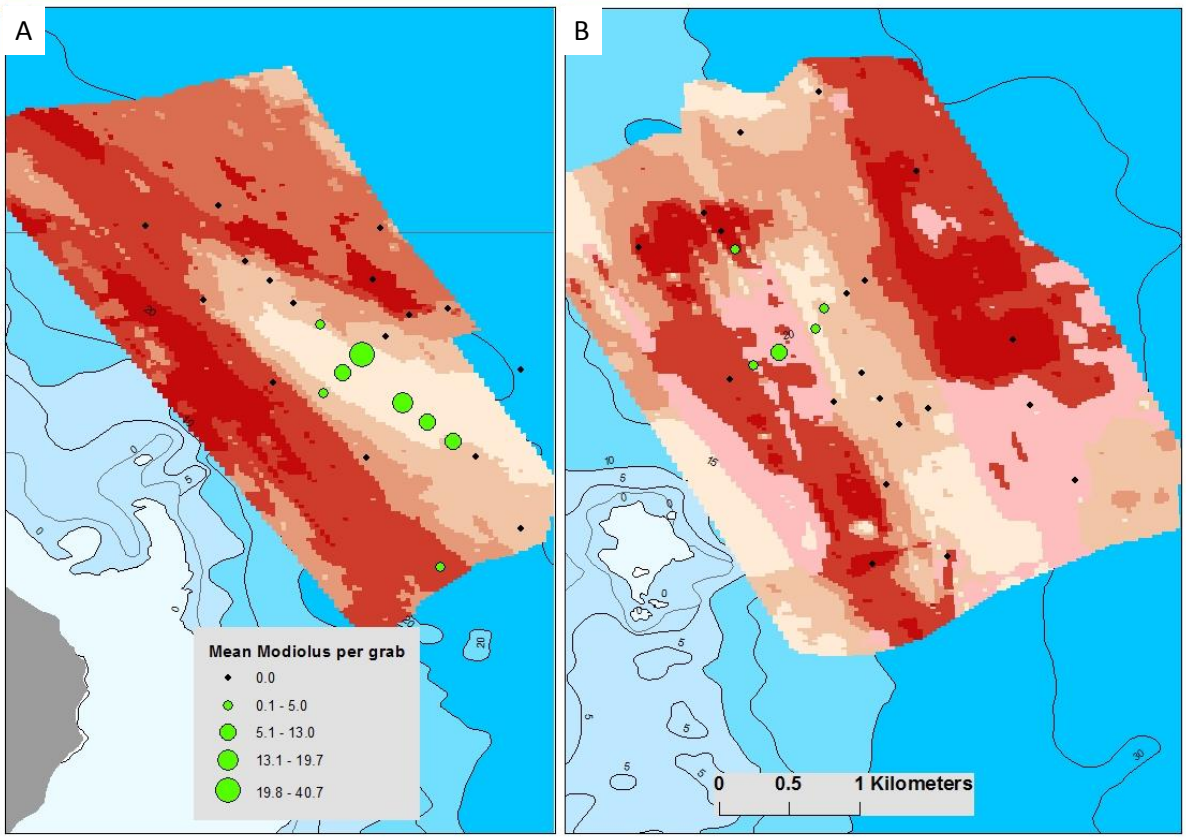

Fig. 5. The mean number of *Modiolus* per grab at each site along the Outer Ads Peninsula at Craigbrain (A) and Burial Island (B). Substrate type determined by single beam sonar is shown under sample locations.

Fifty sites within these two areas were sampled using the day grab (Fig. 3), which included 147 samples. Although full analysis of the samples is ongoing, the number and size of *Modiolus* in each sample has been quantified. 32% of the sites at Craigbrain included *Modiolus* (eighteen samples within 8 sites out of the 25 sites; Fig. 5A). 20% of the sites at Burial Island included *Modiolus* (nine samples within 5 sites out of 25 sites; Fig. 5B). The maximum number of *Modiolus* within a grab at Craigbrain was 65 individuals which extrapolates to 650 individuals m^{-2}. The maximum number of *Modiolus* within a grab at Burial Island was 18 which extrapolates to 180 individuals m^{-2}. The number of *Modiolus* per m^{-2} when only

considering grabs with *Modiolus* was 122 ± 34 (mean ± Standard error) and 33 ± 12 at Craigbrain and Burial Island respectively (Table 2).

Population estimates of the Outer Ards reefs

The total number of *Modiolus* within the two areas off the Ards Pennisula was estimated from grab sampling. The population of *Modiolus* at Cragbrain was 88,631,462 (range of 61,192,693 to 116,070,232) within the 1,451,983 m^2 extent of reef (Table 2). The population of *Modiolus* at Burial Island was estimated to be 15,308,400 (range of 8,929,733 to 21,687,067) within the 937,249 m^2 extent of the reef.

The interpolation of *Modiolus* density at each site shows a clear pattern with the highest densities in the middle of the reefs (Fig. 6). The interpolated densities likely overestimated the extent of the actual reef. Thus, the population estimates were based on the interpolation after reducing the area to what likely contains reef. The mean point density for the interpolation was 4.9 per grab at Craigbrain and 1.2 per grab at Burial Island (Table 2). The interpolation based population estimate of Modiolus at Cragbrain was 72,584,630 (range of 14,461,751 to 130,707,510) within the 1,451,983 m^2 extent of the reef (Table 2). The population of *Modiolus* at Burial Island was estimated to be 10,900,206 (range of 1,246,541 to 20,553,871) within the 937,249 m^2 extent of the reef.

Table 2. Density and estimated population of modiolus based on samples from a day grab at 2 areas along the Outer Ards. Population was estimated using grab data and through interpolating the grab samples based on the area within the estimated reef extent (Fig. 6). Minimum and maximum population were calculated with standard error for calculations based on *Modiolus* per grab and standard deviation for interpolation.

Samples	Area	Mean	St dev	n	St err	Area (m^2)	Mean population	Minimum population	Maximum population
Sites with Modiolus	Craigbrain	12.2	16.5	24	3.4				
	Burial Island	3.3	4.8	15	1.2				
Sites within estimated reef	Craigbrain	6.1	13.1	48	1.9	1,451,983	88,631,462	61,192,693	116,070,232
	Burial Island	1.6	3.7	30	0.7	937,249	15,308,400	8,929,733	21,687,067
Interpolation	Craigbrain	4.999	4.003			1,451,983	72,584,630	14,461,751	130,707,510
	Burial Island	1.163	1.03			937,249	10,900,206	1,246,541	20,553,871

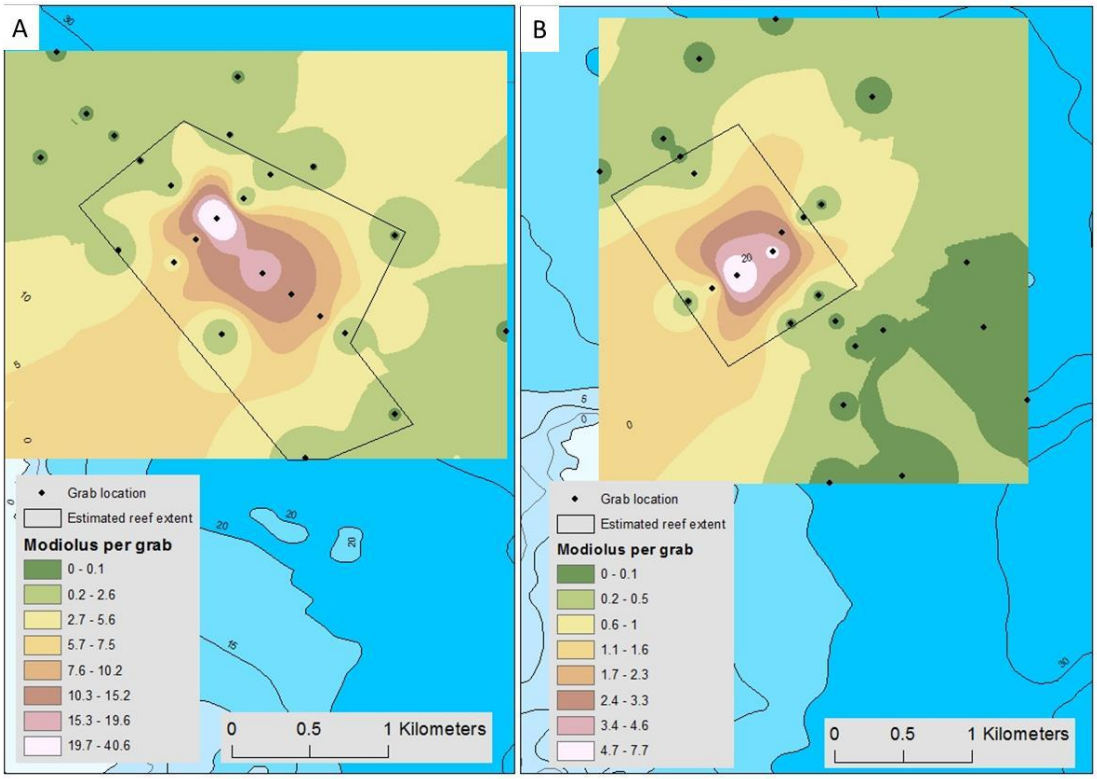

Fig 6. Interpolated density (number per grab, 0.1m^2) of *Modiolus* along the Outer Ards Peninsula at Craigbrain (A) and Burial Island (B). Sample sites are shown as black dots and potential reef extent is shown as a black polygon.

Comparing *Modiolus* size among areas

Collection of samples from within Strangford Lough and at two areas along the Outer Ards Peninsula allowed us to compare the size frequency of *Modiolus* among these areas (Fig. 7). Caution should be used in interpreting the size frequency of Strangford Lough because of the low sample size. However, there is evidence of recruitment in Strangford Lough. Craigbrain contains a high frequency of smaller individuals while Burial Island is dominated by larger individuals

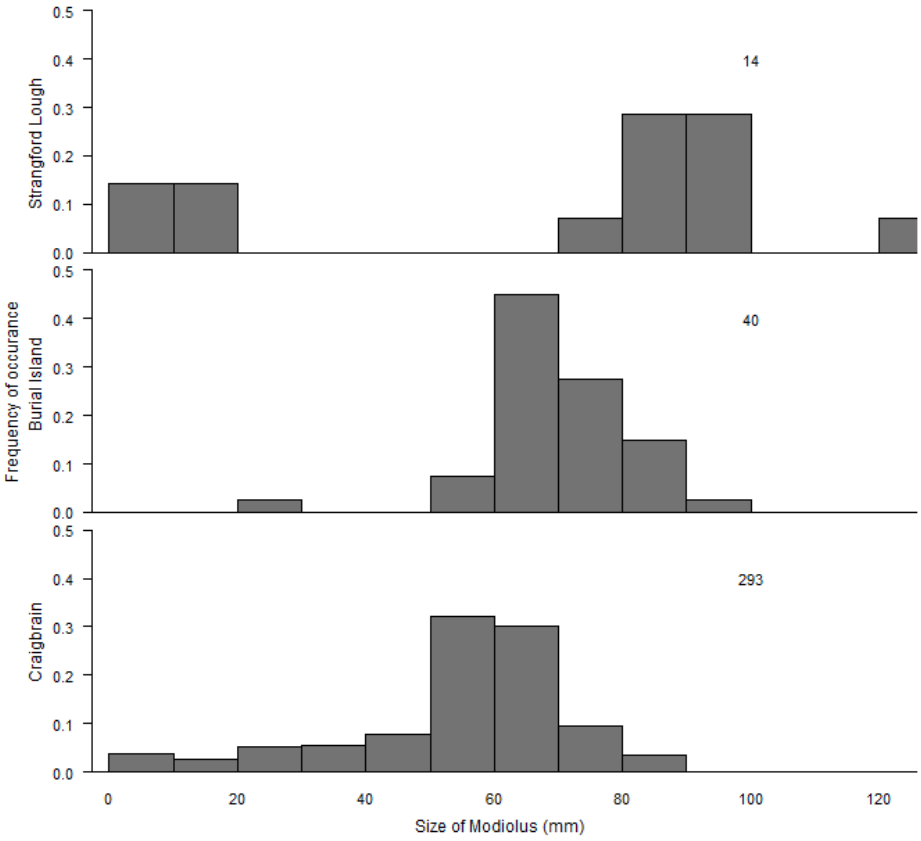

Fig. 7. Size frequencies of *Modiolu*s collected within Strangford Lough, Burial Island and Craigbrain. The number of individuals collected within each area is indicated in the top right of each plot.

DISCUSSION

Modiolus reefs are protected under the EU Habitats Directive (SAC; UK0016618). The complex habitat that *Modiolus* reefs create is recognized for its high biodiversity (Brown et al. 1976, Rees et al. 2008, Fariñas-Franco et al. 2013). However, the reefs within Strangford Lough have been severely degraded and reduced in condition and extent (Service and Magorrian 1997, Magorrian and Service 1998, Strain et al. 2012). Initial results from this study indicate that the *Modiolus* densities in areas that once had *Modiolus* reefs in Strangford Lough remain very low (Objective 1). In addition, the restoration experiment conducted in 2010 no longer has small, high density patches of *Modiolus* (Objective 1). Finding recently recruited *Modiolus* within Strangford Lough indicates that restoring self-sustaining *Modiolus* populations remains feasible. However, it will take consistent and substantial resources to return Strangford Lough to favourable conservation status.

Surveys in Strangford Lough suggest that *Modiolus* have continued to decline when compared to previous surveys at the same or nearby sites. However, *Modiolus* reefs within the Lough are patchy and transects in close proximity (within 50 m) can detect either healthy reefs or no reef at all (results from Roberts et al. 2011; Fig. 3). Revisiting exact transects based on GPS location is almost impossible because of inaccuracies in positioning devices, human error and the effects of depth and current. For example, even a site with a GPS location and marked with a large mooring took 4 dives to locate. Although dive surveys are needed to compare with previous surveys and to collect small scale data (such as removal quadrats to qualifying recruitment), diving may not be the most effective method for determining changes in *Modiolus* abundance at scales relevant to Strangford Lough. Using drop camera/video will likely be more accurate and practical at determining changes in *Modiolus* populations within Strangford Lough compared to diving. Strangford Lough is appropriate for camera/video work because of the low densities of brittle stars that often negate accurate counts of *Modiolus* in other areas (Farinas-Franco et al. 2014), such as the reefs along the Outer Ards Peninsula. These findings have important implications for selecting the best sampling techniques and will be included in the long-term monitoring plan for Strangford Lough (Objective 2).

The finding that the restored reef no longer has patches of *Modiolus* reef is disappointing. A healthy reef was still present in 2011, one year after creation

(Fariñas-Franco et al. 2013, Fariñas-Franco and Roberts 2014). We are unable to determine why the restoration experiment did not sustain *Modiolus*. The lack of surveys in 2012 and 2013 make it difficult to ascertain why and when the degradation occurred. It is worth noting that we did find a starfish consuming an adult *Modiolus* within 2 m of a reef. Translocating large numbers of *Modiolus* that create large dense reefs and mimic more "pristine" reefs may increase the success of the restoration efforts.

Modiolus reefs outside of Strangford Lough, along the Outer Ards Peninsula contain high densities of mussels (up to 600 individuals m^{-2}) and cover approximately 2 km^2. The size frequency of *Modiolus* at Craigbrain indicates a high number of recruits. This may result from high larval supply, minimal predators, and/or high survival of juveniles. The high survival of juveniles could result from the protection provided by the very high density of adults. Unlike *Modiolus* in Strangford Lough, *Modiolus* along the Outer Ards are overlaid by high densities of brittle stars. This makes using camera/video surveys inappropriate to quantify the abundance of *Modiolus*. The day grab efficiently sampled *Modiolus* and more samples were collected in less time than if divers were used.

The population estimates were similar between the two techniques, although interpolation estimates were slightly lower than estimates using sampled density (Table 2). The total population within both areas along the Outer Ards is probably between 15.7 and 151.3 million individuals, with an average of 83 million. If these areas are used as donor sites for translocating *Modiolus* into Strangford lough, then only a small fraction would be removed (Objective 4). The current design of the translocation experiment would need 176,000 individuals. Thus, translocation would remove only 0.1 to 1 % of the total population. In addition, removal could focus along the outer edges of the reef extent so that the greatest densities of *Modiolus* in the middle of the areas would remain intact and buffered from the disturbance.

These findings represent an initial summary of the data collected during the first year of this study. Identifying appropriate long-term sampling regimes for *Modiolus* will be a key next step (Objective 2). Unlike a recent report that suggested focusing on one technique for sampling *Modiolus* (Farinas-Franco et al. 2014), our experience within and outside Strangford Lough indicate that an array of techniques should be used and will depend on location.

The data collected is still being analysed and will be used to determine the efficacy of translocating *Modiolus* into Strangford Lough from the Outer Ards (Objective 4). For instance, it has also been determined that there is no significant genetic difference between *Modiolus* inside and outside of the Lough. Initial analysis of the grabs from the Outer Ards reefs indicates the absence of invasive species. Finally the population estimates indicate a very small fraction of the individuals would be removed. Thus, we recommend moving ahead on the planned experiment to restore reefs in Strangford Lough by translocating *Modiolus* from the Outer Ards population. Although it is possible the *Modiolus* reefs would recover within the Lough without intervention, there is no evidence from our surveys that supports this statement (Objective 3). In addition, the timescale would likely be 100's of years given the life history of *Modiolus*. Both continued monitoring of existing populations and initiating restoration strategies are needed to improve the conservation status of the Lough within time periods relevant to governing bodies.

ACKNOWLEDGEMENTS

This study was commissioned and funded by the Northern Ireland Environment Agency (NIEA) via the Natural Heritage Research Partnership (NHRP) with *Quercus*, Queen's University Belfast (QUB). We thank the staff at DOE, AFBI, DARD, and Queens for assistance.

REFERENCES

Brown, R., R. Seed, and R. Oconnor. 1976. Comparison of relative growth in Cerastoderma edule, *Modiolus modiolu*s, and *Mytilus edulis* (mollusca-bivalvia). Journal of Zoology 179:297–315.

Brumbaugh, R., and L. Coen. 2009. Contemporary approaches for small-scale oyster reef restoration to address substrate versus recruitment limitation: a review and comments relevant for the olympia oyster, *Ostrea lurida* carpenter 1864. Journal of Shellfish Research 28:147–161.

Fariñas-Franco, J. M., L. Allcock, D. Smyth, and D. Roberts. 2013. Community convergence and recruitment of keystone species as performance indicators of artificial reefs. Journal of Sea Research 78:59–74.

Farinas-Franco, J. M., B. Pearce, J. Porter, D. Harries, J. M. Mair, A. S. Woolmer, and W. G. Sanderson. 2014. Marine Strategy Framework Directive Indicators for Biogenic Reefs formed by *Modiolus modiolus*, *Mytilus edulis* and Sabellaria spinulosa Part 1: Defining and validating the indicators. JNCC Report No: 523.

Fariñas-Franco, J. M., and D. Roberts. 2014. Early faunal successional patterns in artificial reefs used for restoration of impacted biogenic habitats. Hydrobiologia 727:75–94.

Grabowski, J. H., and C. Peterson. 2007. Restoring Oyster Reefs to Recover Ecosystem Services. Pages 281–298 Ecosystem Engineers. Academic Press.

Magorrian, B. ., and M. Service. 1998. Analysis of underwater visual data to identify the impact of physical disturbance on horse mussel (*Modiolus modiolus*) beds. Marine Pollution Bulletin 36:354–359.

La Peyre, M., J. Furlong, L. A. Brown, B. P. Piazza, and K. Brown. 2014. Oyster reef restoration in the northern Gulf of Mexico: Extent, methods and outcomes. Ocean & Coastal Management 89:20–28.

Ragnarsson, S. A., and J. M. Burgos. 2012. Separating the effects of a habitat modifier, Modiolus modiolus and substrate properties on the associated megafauna. Journal of Sea Research 72:55–63.

Rees, E. i. s., W. g. Sanderson, A. s. y. Mackie, and R. h. f. Holt. 2008. Small-scale variation within a *Modiolus modiolus* (Mollusca: Bivalvia) reef in the Irish Sea.

III. Crevice, sediment infauna and epifauna from targeted cores. Journal of the Marine Biological Association of the United Kingdom 88:151–156.

Roberts, D., A. L. Allcock, J. M. Farinas-Franco, E Gorman, C. Maggs, A. M. Mahon, D. Smyth, E. M. A. Strain, and C. D. Wilson. 2011. Modiolus Restoration Research Project: Final Report and Recommendations. Queen's University Belfast, Belfast.

Service, M., and B. H. Magorrian. 1997. The Extent and Temporal Variation of Disturbance to Epibenthic Communities in Strangford Lough, Northern Ireland. Journal of the Marine Biological Association of the United Kingdom 77:1151–1164.

Strain, E. M. A., A. L. Allcock, C. E. Goodwin, C. A. Maggs, B. E. Picton, and D. Roberts. 2012. The long-term impacts of fisheries on epifaunal assemblage function and structure, in a Special Area of Conservation. Journal of Sea Research 67:58–68.

Appendices

Appendix 1

Proposal submitted to Seafish

Project title
Can pot fishing benefit habitat restoration?

Project Summary (750 word max)
Overall aims: Pot fishing may benefit habitat provided by bivalves, such as mussels and oysters by removing predators (crabs, lobsters, and sea stars). However, a dearth of information exists on the effects of pot fishing on habitats and whether removing predators benefits conservation and restoration of these habitats. In addition, long-term information on trap catch and how catch is related to actual abundance is needed to reduce the vulnerability of the pot fishing industry to precautionary management and area closures that managers enact because of national and international mandates to conserve or restore vulnerable habitats. This study will experimentally quantify the potential benefit of pot fishing (predator removal) on the habitat provided by the horse mussel reefs (*Modiolus modiolus*).

Specific objectives:
1) Quantify the effect of pot fishing and removal of target species on reef ecosystems. 2) Determine the size and species selectivity of different sampling gear (which includes targeted and non-targeted species) by comparing different pot types used by fisherman with diver and video surveys. 3) Measure species specific pot efficiency (number of individuals that entered the pot compared to the number of individuals harvested) of three different pot types used by fisherman. 4) Determine most efficient sampling protocol for fisherman or one observer to document catch statistics. 5) Produce a short film (approximately 20 minutes) documenting how collaboration between fisherman and scientist can benefit all stakeholders.

Industry issue that needs addressing:
The fishing industry is often impacted by managers who cite the indirect effects of fishing (habitat destruction and incidental catch) as detrimental to the environment. There is an immediate need to document whether pot fishing affects protected habitats. In addition, the fishing industry needs multi-year data sets on the catch and how the catch is related to actual abundance and size frequencies to dispute management efforts to reduce fishing effort in time and space.

The main output of the work:
This study will determine if pot fishing does or does not affect horse mussel reefs and whether predator removal may benefit this protected habitat, which can be used as evidence to open existing closed areas and reduce the potential for future closed areas. The study will also enhance both the quality and quantity of data collected by the fishery so that the pot fishing can remain a profitable and sustainable industry.

Also, please outline below ho the work will help resolve the industry issue and provide widespread industry benefit (outcomes).
Conflicts between fisherman and other stakeholders will continue and likely increase in the future as more and more groups will vie for finite coastal areas (i.e. aquaculture, conservation, wind farms, wave energy, and recreation). The fishing industry needs reliable information that reduces potential conflicts with other users. This study will collect such

information and document how to continue to collect information needed to assess the health of the pot fishing industry. In addition, public opinion is very important in shaping management decisions and producing media that highlights the benefits of fishing and how the industry is collaborating with scientist to conserve the environment will have beneficial returns much greater than the resources invested into making it.

Methodology *Please outline how the work will be done (400 words max).*

This study will be conducted at eight sites with extensive *Modiolus* reefs in areas open and closed to pot fishing. The experiment will have four treatments; normal trapping with harvest, trapping with no harvest (pot entrance blocked), harvesting without pots (diver removal), and a control. **Depending on stakeholder feedback, additional treatments could be added including different pot types, single pot fishing (current trapping usually has 6-10 pots connected on a single line), or predator addition (animals caught in normal trapping sites added to this treatment).** Scientist and fishermen will collaborate to document the identity, size, and sex of all harvested animals. Frequency and number of pots fished will be dependent on current trapping practices. Diver removals will be conducted at similar frequencies as trapping and will consist of divers systematically catching and removing a similar number of individuals of each species that is caught by pots.

Sampling to determine the effect of the pot/predator treatments will consist of quantifying the cover and abundance of species using removal and photographic quadrats, mobile fauna surveys, and video monitoring of pot sets (**Objective 1**). The density of economically (crabs, scallops, and lobsters) and ecologically (sea stars) important species will be quantified by divers thoroughly searching (looking under any canopy and in all crevices) the study sites. Divers will attempt to capture fauna, which will then be measured, sexed, and released. Throughout the study pot catch of fisherman and diver sampling will be conducted sequentially so that the actual abundance and size frequency of mobile fauna in the water (from diver surveys) can be compared to pot catch (**Objective 2**). To relate pot catch and actual abundance of targeted species, without having the benefit of diver surveys, it is necessary to know the selectivity of the different pot types. Video monitoring of pot sets will be conducted throughout the experiment. A video camera will be attached to pots. The video frame will include the pot and nearby benthos. The video will be analyzed to determine the entry and exit time of animals and final number of animals in the trap (**Objective 3**). The video will also be analyzed every hour and acute effects of the trap will be noted (movement of the trap, damage to reef). The substratum complexity will also be categorized from the video so that trap efficiency and substrate complexity can be compared.

To increase the current lack of documented data on fisherman catch, a best practice protocol will be determined for fisherman or one observer to record scientific data on pot catch (**Objective 4**). It will balance the resources needed to count and measure catch with the quality and quantity of data needed by fishermen and other stakeholders to assess the population dynamics of fished species. Underwater video from pots and divers will be combined with video of pot fishing and interviews of all stakeholders to produce a short film documenting the study and how multiple stakeholders can collaborate to reduce user conflicts in the marine environment (**Objective 5**). The film will be put on the internet and played at an exhibit in Exploris, Northern Ireland's only aquarium.

Appendix 2

Proposal submitted to DARD

Quantifying effects of trap fishing on *Modiolus* reefs

Summary

Harvesting of commercially important species not only affects the target species but also has unintentional and indirect effects including removal or increased mortality of non-target species, degradation of biogenic habitat, and changes to trophic interactions. Understanding the impacts, or interactions among impacts, that alter ecosystem functioning is needed to manage natural resources efficiently. This study will experimentally quantify the effect and potential interaction of physical damage to the reef and removal of target species by pot fisheries on biogenic reef ecosystems.

The experiment will be conducted at four sites with extensive *Modiolus* reefs and efforts will be made to have fisherman involved in the research (e.g. assistance with potting) in conjunction with the scientists to record data on harvested animals. In addition, this study will be conducted in collaboration with an AFBI study led by Matt Service on the effects of static gear on multiple habitats to maximize the return on invested funds and ensure that the effect of pot fishing on the ecologically and politically important modiolus reefs is rigorously tested. The manipulative design will have four treatments (Fig. 1); normal trapping with harvest, trapping with no harvest (pot entrance blocked), harvesting without pots (diver removal), and a control treatment. The effect of traps and predator removal on *Modiolus* reefs will be quantified by scuba surveys (benthic cover; infauna, epifauna and mobile fauna abundance; and sediment dynamics).

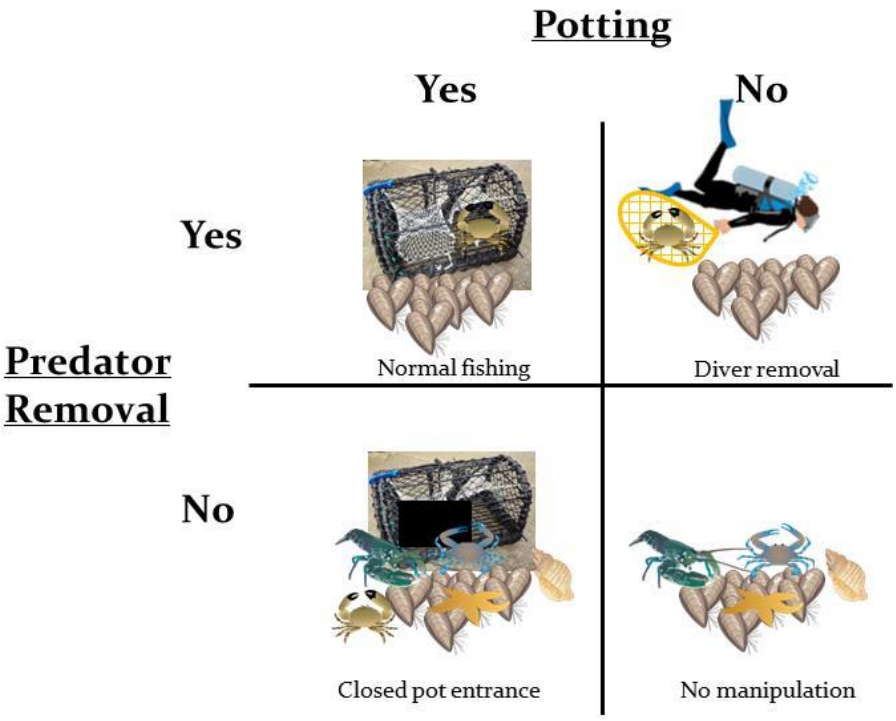

Fig. 1. The 4 treatments of the study.

Rationale

Harvesting of commercially important fin-fish and shellfish reduces the population of the target species. Harvesting also has other unintentional and indirect effects on ecosystem functioning. These impacts include removal or increased mortality of non-target species, degradation of biogenic habitat, and changes in trophic interactions. The direct and indirect effects of harvesting rarely occur in isolation, which makes it difficult to determine the mechanisms behind changes to the ecosystem. Understanding which impacts, or interactions among impacts are altering ecosystem functioning is needed to manage our natural resources efficiently.

There is a dearth of information on the effect of trap or pot fishing on biogenic habitats. This has resulted in managers either ignoring possible deleterious effects or applying the precautionary principle and closing areas of biogenic habitat to pot fishing. This study will experimentally quantify the potential impact of pot fishing, the ecological effects of predator removal, and their potential interactions on the biogenic structure and functioning of *Modiolus* reefs.

Objectives

1) Quantify the effect and potential interaction of physical damage to the reef and removal of target species by trap fisheries on biogenic reef ecosystems.

Methods

These experiments will be conducted at four sites with extensive *Modiolus* reefs within a conservation zone (either Strangford Lough or the planned zone along the Outer Ards). Efforts will be made to have fisherman involved in the research, e.g. assistance with potting, in conjunction with the scientists to record identity, size, and sex of all harvested animals. This experiment will have four treatments; normal trapping with harvest, trapping with no harvest (pot entrance blocked), harvesting without pots (diver removal), and a control. Four sites will be chosen and one replicate of each treatment will be conducted at each site. Sites will be chosen based on acoustic surveys. Each site will be divided into 4 sections and each section will be randomly assigned a treatment. All attempts will be made so that each section is separated from other sections within a site by a minimum of 20 m. Frequency and number of pots fished will be dependent on current trapping practices, but approximately monthly removals will be initially planned (11 times over 12 months). Diver removals will be conducted at similar frequencies, and will consist of divers systematically catching and removing a similar number of individuals of each species that is caught by pots. All manipulative activities will target the center point of the plot (line of traps through plot center or divers starting removal procedure at the center of the plot).

The study will be conducted for 1 year and sampling will consist of infauna/epifauna removal quadrats (0.0625 m^2), photo quadrats (0.5 m^2), mobile fauna quadrats (3.14 m^2), particle size, and sediment carbon and porewater nitrogen content (**Objective 1**). Removal quadrats, particle size and carbon and nitrogen concentrations will be sampled before the beginning of the experiment (baseline), and 1 year after the beginning of the experiment. Photo and fauna quadrats will have one additional sampling event each year (3 in total). A 20 m transect will be laid perpendicular to the depth gradient, centered on the center point of the plot. Two additional 20 m transects will be laid 5 m on either side of the center transect line. Five photo quadrats will be taken at randomly chosen points along each transect for a total of 15 photo quadrats per treatment at each site. Two photographs will be taken at each sample point, one photograph of the existing epifauna and one photograph after removal of unattached organisms (primarily brittle stars). Removal quadrats will be taken from within two photo quadrats selected randomly within each transect for a total of 6 removal quadrats

per plot. Analysis of removal quadrats will consist of estimating percent cover of fauna and substrate within the quadrat and then excavating all material within the quadrat down 10 cm and placing the material in 1 mm mesh bags. The bags will be brought back to the lab and all fauna will be identified to the lowest possible taxa, counted, total biomass recorded, and 20 individuals will be measured of each taxa for size frequency. Photo quadrats will be analyzed using image software (e.g. Image J or Photoquad) to estimate percent cover. The number of live modiolus will be measured by counting visible siphons and mobile fauna (crabs, lobsters, scallops, sea stars, whelks) will be counted and measured if possible by comparing size on screen with ruler on quadrat frame.

Six mobile fauna quadrats ($3.14m^2$) will be conducted haphazardly within each plot. Percent cover of dominating fauna or substrate will be estimated and recorded by the diver. The area within the quadrat will be thoroughly searched (looking under any canopy and in all crevices) and the mobile fauna will be counted. Divers will attempt to capture fauna, which will then be measured, sexed, and released. Throughout the study (minimum of 20 replicates) potting and sampling will be conducted sequentially so that the abundance of mobile fauna measured in the photo quadrats, fauna quadrats and pots can be compared.

Timeline:

	2014 2014					2015							
	A	S	O	N	D	J	F	M	A	M	J	J	A
Monthly removals	■	■	■	■	■		■	■	■	■	■	■	■
Photo and mobile fauna samples Strangford L.	■								■				■
Complete sampling	■												■

Appendix 3

Sampling technique

Picture of day grab used to sample Modiolus reefs (A) and a sample containing *M. modiolus* and *Ophiotrix fragilis*.

ISSN 1751-7796 (Online)

Northern Ireland Environment Agency
Klondyke Building
Cromac Avenue
Gasworks Business Park
Belfast BT7 2JA

Our aim is to protect, conserve and promote the natural environment and built heritage for the benefit of present and future generations.