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Report: Lobster, fishing effort and habitat interactions in the Northumberland Lobster Fishery.

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1. Abstract

Identifying spatial differences in the distribution of fishing effort and the target species is essential for successful management. This study aims to explore the distribution of the European lobster and potting activity in relation to habitat in the Northumberland pot fishery. European lobster catch data indicated catch per unit effort is inversely related to habitat (OLEX data). Questionnaires were conducted to establish fishers' behaviour in response to the introduction of the NIFCA pot limitation in 2009. Findings indicated that most fishers were unaffected by the limitation which aimed to limit effort. Despite this Monte Carlo map comparison of estimated fishing effort maps highlighted a significant increase in effort. Areas of increased effort are concentrated in shore, and does not appear to correspond with habitat selection.

2. Introduction

Almost a quarter of all global fish stocks have been overexploited, depleted or are recovering from depletion (FAO, 2007). Following declines in demersal and pelagic fish, the economic importance of shellfisheries has increased (Turner *et al.*, 2009). The Northumberland potting fishery is a multi-species fishery targeting the European lobster (*Homarus gammarus*), Brown crab (*Cancer Pagurus*), Velvet swimming crab (*Nectora puber*) and prawns (*Nephrops norvegicus*) (Turner *et al.*, 2009). European lobster is the most commercially important species (Bannister, 2006) and is preferentially targeted by pot fishers (Turner *et al.*, 2014).

Lobster stocks in Northumberland are being exploited beyond recommended levels, and are believed to be declining (Cefas, 2011). The Northumberland Inshore Fisheries and Conservation Authority (NIFCA) introduced a pot limitation byelaw in 2009 to manage lobster stocks by limiting potting activity to 800 pots per permit holder and five pots for non-permit holders (NIFCA, 2010). Several European Marine Sites (EMS) have been designated within the district and a recommended Marine Conservation Zone (rMCZ) has been proposed from Coquet to St Mary's (Fitzsimmons *et al.*, 2015). Further limits to fishing activity may also result in the revised approach of the management commercial fisheries in EMS (Article 6 of the EU Habitats Directive 92/43/EEC) (DEFRA, 2013).

Economic, social and cultural factors associated with fishing activities can cause unanticipated changes to fishers' behaviour, which can potentially undermine management measures (Fulton *et al.*, 2010). For example, spatial displacement of fishing activities may increase fishing pressure in alternative locations (Turner, 2010). Decisions about where to fish are often informed by fishers' knowledge of the target species (Turner *et al.*, 2014). Habitat is a key determinant of spatial distribution and abundance of the *Homarus* spp. (Geraldi et al., 2009). Fishers have been shown to target different ground types at different times of year (Skerritt, 2014), targeting hard over patchy or soft grounds (Turner *et al.*, 2009) to correspond with high lobster densities (Trembley and Smith, 2001). Identifying spatial difference in the distribution of a species can also have important implications for management (Geraldi *et al*., 2009).

2.1 Aims and Objectives

This study aimed to increase current understanding of habitat utilisation by both *H. gammarus* and fisher potting behaviour, linking species distributions and targeted effort to inform future management of the Northumberland fishery. This project achieved this by meeting the following objectives:

1. To bring together habitat maps and catch data from geo-referenced fleets of pots, to investigate whether the size distribution, abundance and gender of catch varies with habitat type.
2. To look at fishing effort across the district (following methods developed by Turner, 2009 and conducting questionnaires with fishers), to determine if there was a change in effort since the introduction of the pot limitation in 2009.
3. To relate fishing effort to habitat type using Geographic Information System (GIS) mapping, to determine if fishers are targeting a particular ground type.

2.1 Study Area

The study focussed on the NIFCA district off the North East Coast of England. NIFCA manages the waters of Northumberland out to 6nmi. The district extends from the River Tyne to the northern boundary of Northumberland (Figure 1).

The district is composed of distinct patches of both hard and soft substrates (Skerritt, 2014) (Figure 1), comprising a range of habitat types: infralittoral rock, circalittoral rock, subtidal coarse sediment, subtidal sand, subtidal mud and mixed sediments (Fitzsimmons *et al.*, 2015).

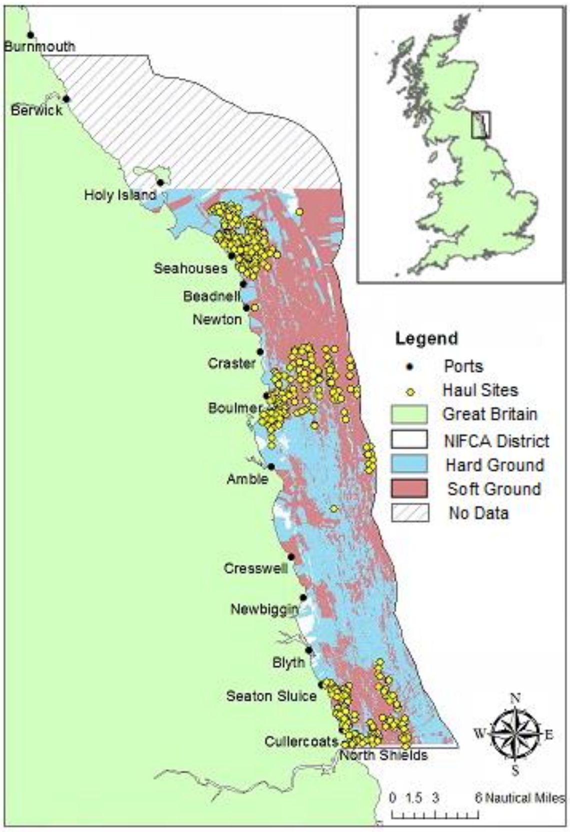

Figure 1: Location of the NIFCA District. Hardness data was collected by NIFCA patrol vessels using on-board OLEX mapping software. Haul sites were recorded by NIFCA officers at the start and end of each string of pots.

3. Methodology

3.1 Data Collection

3.1.1 Habitat data

Data representing marine habitat was available from NIFCA's on-board OLEX mapping software. OLEX records ground hardness, which can be used as an approximation of substrate type. OLEX provides continuous data on substrate hardness determined by backscatter, received by the vessel's single-beam echo-sounder given on a scale of 1 (low reflection) to 100 (no energy lost) (Skerritt, 2014). The primary cause of error of this technique is that OLEX values are interpolated for areas with no data (Parnum *et al.*, 2009). Poor coverage by the patrol vessel in the north of the district, resulted in vast areas of interpolated data. The area to the north of the port at Holy Island was deemed unreliable based on poor coverage by the patrol vessel and was excluded from the analysis (Figure 1).

Visual comparison between OLEX data for the Coquet to St Marys Marine Conservation Zone (MCZ) and a Cefas habitat map (Fitzsimmons, *et al.*, 2015) of the area showed only subtle differences between the distributions of hard substrate. Parnum *et al.* (2009) show similar results identifying only a 10% difference in accuracy of habitat classification between single beam and multi beam sonar. OLEX hardness data were deemed suitable proxies for habitat in this study. Both continuous OLEX hardness data and reclassified hardness data were used in this study. OLEX values <23 were classed as soft ground and ≥23 as hard ground, the value was determined in ArcGIS by comparing polygons of known hard and soft features with the corresponding location on a map produced from OLEX data (Figure 1). The values obtained were consistent with previous work (Skerritt 2014).

3.1.2 Habitat effects on catch data

Potting data was collected by NIFCA as part of a pilot study, gathering fishery-dependent data monthly, over a 12 month period. Data collection began on May 2014. NIFCA worked with five local fishers over this time, deploying a total of 430 fleets of pots at sites selected by the fishers based on criteria such as distance from port and season. The location of the start and end of each fleet of pots was recorded from the vessels on-board GPS (Figure 1). Fishers were selected for this study based on location and willingness to participate in the study. Only three fishers (North Shields, Amble and Seahouses) were selected for inclusion in the analysis due to the availability of habitat data. The home ports and corresponding haul sites included in the analysis were distributed throughout the district, therefore it was assumed that catch was representative of the whole district.

The GPS coordinates for the start and end of each fleet of pots were imported into ArcGIS as point data. Habitat type was determined for each fleet by recording corresponding OLEX values for each location. If either the start or end coordinate occurred over hard ground, it was assumed that fishers were targeting hard ground, otherwise the fleet was classified as targeting soft ground.

3.1.3 Effort pre and post pot limitation data

NIFCA Data

Between 2005 and 2014, NIFCA officers recorded all sightings of fishing vessels during routine patrols, reporting vessel name, activity and location sighted. These data have been collected and maintained in a database. Data were anonymised and provided by NIFCA in Microsoft Excel Worksheets. Patrol routes and sightings of crab and lobster potting are biased towards the south of the district, limited availability of point data results in increased uncertainty in interpolated data (Parnum *et al.*, 2009). Sightings data and patrol routes were therefore combined for a two year period before and after 2009 to ensure the data was statistically robust, and mapped into Arc GIS.

To account for this bias in sightings and patrol routes, vessel sightings were weighted by patrol effort (PE) to create estimated fishing effort maps using Turner's (2010) method. PE is calculated based on the proportion of patrols passing through each cell of a 3km x 3km grid and the distance of each grid cell to the nearest patrol route (Equation 1). It is then assumed that patrol effort decreased linearly with distance from patrol routes. Sighting were normalised by weighting sightings negatively in areas of high patrol effort and transformed into a continuous surface raster image, using kernel density estimation (KDE). The Kernel Density (Spatial Analysis) Tool in ArcGIS was used to calculate the probability distribution of fishing activity with a cell size of 100m x 100m and a smoothing factor of 1500 square map units (which determines the search radius around a location, within which data points can contribute to the probability estimate). The resultant maps represented estimated fishing effort for 2007-08 and 2010-11used to indicate the spatial distribution of potting activity before and after the implementation of the pot limitation in 2009.

$$PE = (1 - n/N) + (1 – Dmax – Dg / Dmax - Dmin)$$

Equation 1. Calculating patrol effort. Where n = number of patrols passing through each grid cell; N = total number of patrols; Dmax = maximum distance to patrol route; Dmin = minimum distance to patrol route; and Dg grid square distance from patrol route (Turner, 2010).

Questionnaire Data

A semi-structured questionnaire was used to establish fishers' behaviour in relation to NIFCA Byelaw 15, which limited the number of pots fished to 800 pots per permit (Appendix I). This was designed to collect information on the number of pots fished, establish the balance of potting inside and outside the NIFCA district and look at the distribution of potting activity pre and post 2009. Questionnaires were conducted by two Postgraduate students accompanied by NIFCA officers on the 2nd and 3rd July, 2015. In order to avoid bias within the questionnaire data, NIFCA officers were not present for the duration of the interviews to encourage respondents to be more open with their views. Pot fishers were identified by NIFCA officers at their home port. Fewer active fishers are located in the north of the district. A representative sample of 19 interviews were conducted at ports throughout the district (Table 1), this provided responses from 41.67% of the active permit holders. Due to time constraints and availability of fishers, not all ports were sampled.

Table 1. The number of interviews at each port.

Port	No. of Interviews
North Shields	1
Blyth	3
Amble	5
Seahouses	3
Holy Island	3
Berwick	2

3.2 Data Analysis

Statistical analysis was carried out using Minitab 17 statistical software and "R" Version 3.0.1. All data were subject to tests for normality of distribution (Kolmogorov-Smirnov) and homogeneity of variance (Levene's Test). Where necessary a log transformation (natural log) was used.

3.2.1 Habitat effects on catch

Potting data were combined for the three ports (North Shields, Amble and Seahouses), a number of factors were examined in relation to OLEX derived habitat type: carapace length (CL), Sex and catch per unit effort (CPUE). CPUE was used as a proxy for lobster abundance and was calculated as mean number of lobsters per pot for each string of pots. Linear regression was used to test for a relationship between CL and hardness value using the continuous OLEX data. A two-factor ANOVA was used to determine if there was a difference in carapace length as a result of sex and classified ground type. A t-test (with Satterthwaite approximation for unequal variance) was used to determine whether there was a difference between mean hardness value for male and female lobsters. Chi Square goodness of fit test was used to determine whether there was a difference between expected and actual proportion of male and female lobsters on each habitat. Linear Regression was used to test for a relationship between CPUE and hardness value using the continuous OLEX data.

3.2.2 Fishing Effort Pre and Post Pot limitation

Monte Carlo simulation (Stephenson, Unpublished) was used to compare maps, evaluating whether fishing effort had changed since the introduction of the pot limitation in 2009. This was conducted in R version 3.0.1 using dismo, raster and rgdal packages (Appendix II). Five thousand random points were sampled with replacement (Manly, 2007) from the 2007-08 fishing effort map. Effort values were extracted from these points and corresponding locations on the 2010-11 map. A paired t-test was then used to determine whether those points were significantly different. This process was repeated for a total of 10,000 repetitions (Jackson and Somers, 1989), and a frequency distribution created from the 10,000 resulting t-statistics. The mean t-statistic and associated *p*-value were used establish whether effort differed significantly between years.

Questionnaire data was entered into an Excel spreadsheet. Due to the low number of respondents (19) statistical analysis was not conducted and data were analysed descriptively.

3.2.3 Change in effort in relation to habitat

The location of vessels sightings were estimated based on the location of the patrol vessel at time of sighting, this creates positional errors. To visualise spatial changes in effort between these periods, 1km by 1km grids containing mean fishing effort per grid cell were created in ArcGIS for both 2007-08 and 2010-11 fishing effort maps. Effort values were reclassified with equal intervals on a scale of 0 (no effort) to 5 (high effort). The 2007-08 data for each grid cell was then subtracted from the 2010-11 data and a new map produced to visualise where changes in effort had occurred across the district. Positive values indicate an increase in effort, and negative values a decrease. The 2007-08 and 2010-11 maps were tested for spatial autocorrelation using Moran's I (Spatial Statistics) in ArcGIS.

Mean OLEX value per 1km by 1km grid cells was also calculated in ArcGIS. The grid cells containing an increase in effort were identified, and analysed along with corresponding OLEX value to determine whether fishers' were increasingly targeting hard ground due to the pot limitation. It is assumed that the expected use is proportional to availability of a particular ground type (Turner *et al.*, 2009). A Chi Square goodness of fit test was used to determine if there was a difference between proportions of hard and soft ground available in the study area and proportions of hard and soft ground corresponding with an increase in effort. Ivlev's Electivity Index (Equation 2) was then used to access whether potters had a preference for a particular ground type.

E = (ri-pi) / (ri+pi)

Equation 2. Ivlev's Electivity Index for determining preference. Where ri = proportion of habitat available and pi = proportion of habitat used (Turner *et al*., 2009).

4. Results

4.1 Habitat effects on catch

Data from 7903 lobsters were included in the analysis, with a sex ratio of 1:1 (3952 females and 3951 males). Size distribution was skewed toward smaller sized lobsters, with undersized lobsters (mean CL of 80.26mm ± $0.12_{s.e.}$ well below minimum landing size (MLS)) representing 77% of total catch (n=6115). No significant relationship between hardness and mean CL (Linear Regression, R-sq.=6.05%; n=47; p=0.096) was found. There was no significant difference between CL on different ground types (ANOVA, DF=1, F=0.15, p=0.695), between sexes (ANOVA, DF=1, F=2.52, p=0.113) or interactions between the factors (ANOVA, DF=1, F= 0.00, p=0.985).

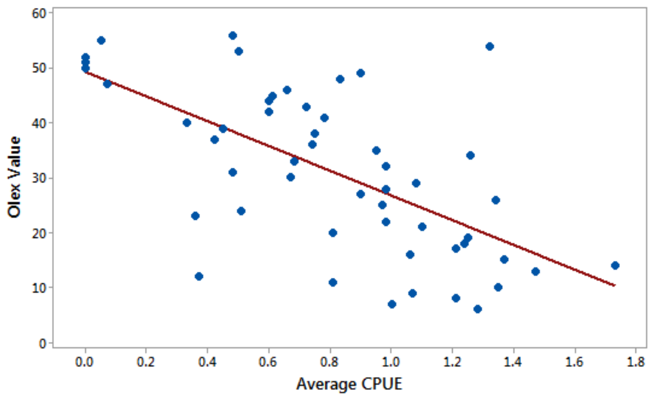

Figure 2. Relationship between Average CPUE and OLEX value.

Mean OLEX values for the ground over which female and male lobsters were caught were 28.82 (±$0.16_{s.e.}$) and 26.71 (±$0.19_{s.e.}$) respectively. A significant difference was found between ground hardness (OLEX) and gender (T-test, DF = 7713; T = -8.52; p <0.001). However, there was no significant difference between the proportion of female and male lobsters on each habitat type (Chi-squared, χ^2 = 0.018; DF = 3; p = 0.999). There was a significant inverse relationship between average CPUE and OLEX value (Linear Regression, R-sq.=39.68%; n=51; p=<0.001) (Figure 2).

4.2 Fishing Effort Pre and Post Pot limitation

Fishing effort maps represented by kernel densities for 2007-08 and 2010-11 are shown in Figure 3. Comparison using Monte Carlo methods, showed a significant increase in effort between 2007-08 and 2010-11 (DF = 9999, Mean T-value = -6.45, p = <0.001). Other spatial changes are also observed, and are further explored below.

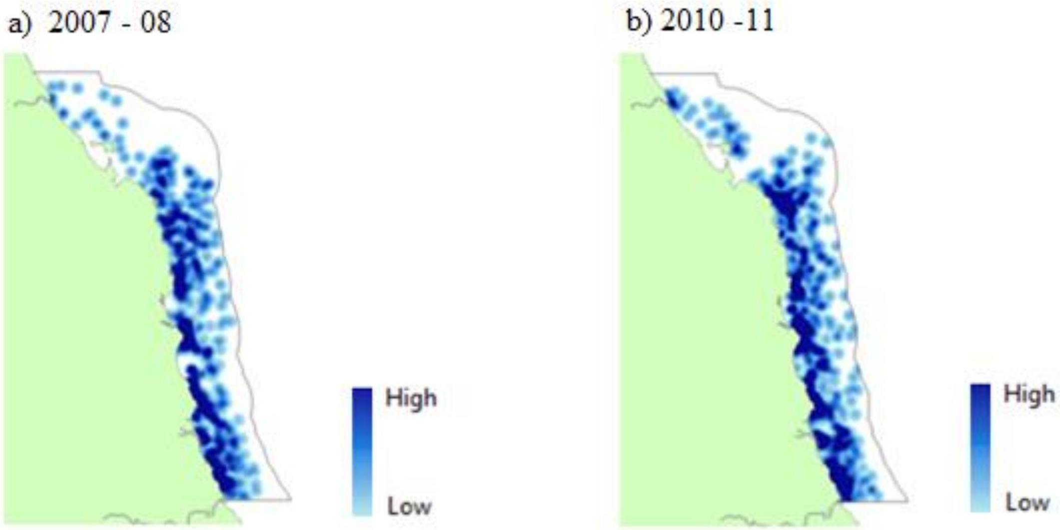

Figure 3. Estimated distribution of fishing effort calculated from vessels sightings using Kernel Density Estimation (KDE). a) 2007-2008, b) 2010-2011.

Data from 9 interviewees indicated that 100% of fishers in the south of the district believed the number of pots fished in their area (Amble, Blyth and North Shields) to be unaffected by the introduction of the pot limitation. In contrast of 10 respondents in the North (Beadnell, Seahouses, Holy Island and Berwick) 50% claimed to have increased the number of pots they fished during this period (Figure 4a). Three potters had purchased an additional vessel due to the pot limitation, comprising 30% of those interviewed in the North (Figure 4b). Only two fishers felt that they were more selective in terms of where they fished since the introduction of the pot limitation. Several fishers throughout the district stated that they were "*not fishing enough pots to be affected*" with claims by fishers in the south stating that 800 pots "*is too high*", suggestions for the maximum number of pots per vessel ranged from 250 to 500 pots. Three vessels operating from the North of the district had increased the number of pots fished outside the district since 2009. Two of these fishers are the same individuals who also purchased an additional vessel.

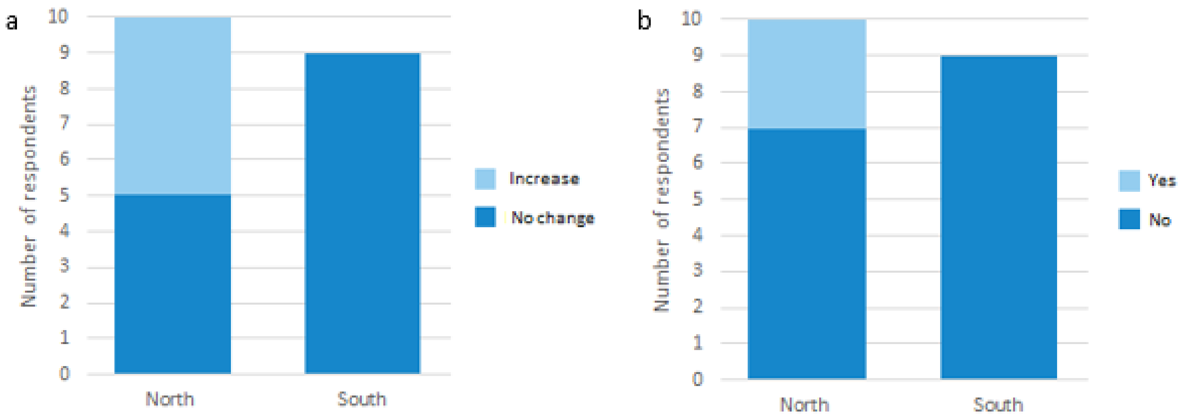

Figure 4. The responses of fishers regarding a) number of pots fished since introduction of pot limitation b) purchase of an additional vessel due to the pot limitation.

4.3 Change in effort in relation to habitat

Areas fished (as mean effort per grid cell on a high to low scale) in 2007-08 before and 2010-11 after the pot limitation are shown in figures 5a and b. Resultant change in effort is shown in Figure 5c. The difference in effort map highlights areas of increased effort in inshore areas, corresponding with the locations of several ports (including Amble, Seahouses and Berwick).

Habitat in areas of increased effort was not significantly different to habitat available for the whole district (Chi-squared, χ^2=1.340; DF=1; p=0.247). Areas showing an increase in effort indicate a weak preference for soft ground (E = 0.071) and a weak avoidance of hard ground by vessels (E = -0.048).

The data used to produce the mean fishing effort maps exhibited significant spatial autocorrelation for both 2007-08 (Moran's I = 0.829; Z = 43.144; p = <0.001) and 2010-11 (Moran's I = 0.853; Z = 44.368; p = <0.001) maps.

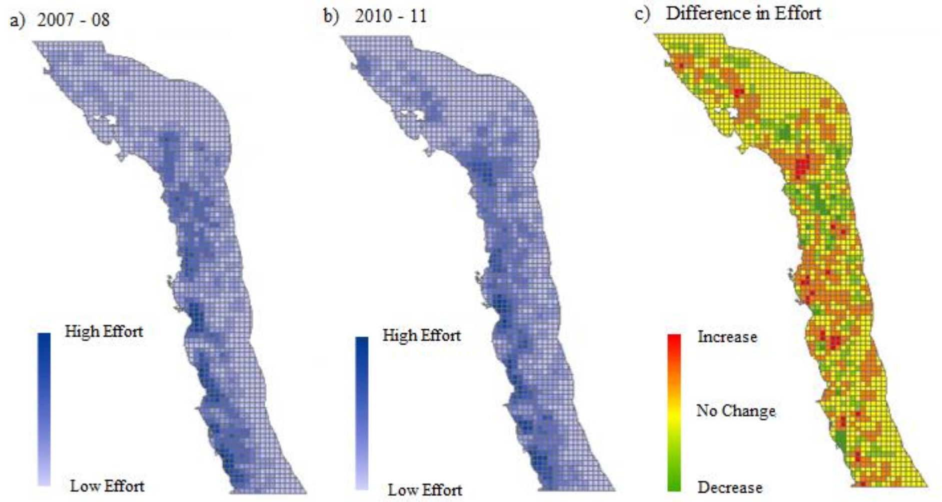

Figure 5: Estimated distribution of fishing effort (mean KDE per 1km by 1km grid cell). a & b) observed fishing effort for the years 2007-08 and 2010-11 respectively and c) difference in effort between years.

5. Discussion

5.1 Describing the NIFCA fishery

Description of the NIFCA lobster population broadly concurs with studies conducted in other locations. A 1:1 sex ratio corresponds with the work of Cooper and Uzmann, (1980) who observed equal sex ratios in catch data. However, it has been suggested that the sex ratios for *H. gammarus* in the UK is unequal (Thomas, 1955). The size distribution of the catch is skewed towards smaller classes (Figure 2); with the mean length for both sexes below MLS (as are 77% of individuals). This may be expected of a fished population, as increased targeting of individuals above MLS would reduce the number of individuals reaching larger size classes (Woolmer *et al*., 2013). Furthermore, the number of large lobsters recorded may be lower than the true abundance as lobsters above MLS can easily escape traps (Wiig *et al.*, 2013). Skerritt (2014) suggests further research is needed to determine whether the Northumberland population is naturally skewed towards smaller size classes.

5.2 Lobster habitat-use

No linear relationship was found between hardness of habitat and mean CL. This may be because dependence on shelter decreases with lobster size as risk of predation diminishes (Cobb, 1995), so any relationship between size and habitat may not be linear. *Homarus* spp. show a preference for rocky habitats which provide shelter (Cobb and Wahle, 1994). It has therefore been assumed that hard substrata provides more shelter opportunities however this may not be the case. Alternatively, any relationship may be masked by the high fishing intensity within the study site. Alexander *et al.* (2014) showed associations between habitat and lobster increased after the introduction of protected sites.

There was no significant interaction between CL, sex and classified habitat type or between the proportions of male and female *H. gammarus* on hard or oft ground suggesting equal association with habitat between the sexes. In contract, mean OLEX value was significantly higher for females than males when using habitat on a continuous OLEX scale. This suggest that the former results could be a factor of how the OLEX data were classified.

Results indicate that CPUE increased as OLEX hardness value decreased (Figure 2). Higher average CPUE occurred on soft ground, in contrast to previous studies. Population estimates for Northumberland showed higher abundance on hard ground (Skerritt, 2014) in contrast to the result of this study. This result may also be a factor of how the OLEX data was classified. Another explanation is due to uncertainty created when using baited pots for data collection (Appendix III). Examples of the limitations associated with this method include: CPUE is not a measure of true abundance, bias created by bait use, trap selectivity (Addison, 1995) and area fished often represents foraging habitats rather than shelter habitats (Bellchambers *et al.*, 2010) which could explain the results of this study.

5.3 Fishers' habitat use pre and post 2009

The pot limitation was introduced in 2009 to limit fishing effort in the district, despite this fishing effort significantly increased between 2007-08 and 2010-11. Only a small proportion of fishers fished more than 800 pots before 2009 (Telsnig, 2013). However, the pot limitation was implemented at a time when the fishery was expanding (Stephenson, unpublished), introducing a limit to future growth.

There is insufficient evidence to determine if there has been a significant change in effort directly related to the pot limitation. However, the results of the questionnaire indicate a change in fishers' behaviour during this time period, with fishers in the north increasing number of pots fished and purchasing a second boat. Economic, social and cultural drivers can cause fishers to exhibit unanticipated responses to management such as effort concentration or displacement in order to maintain catch levels (Fulton *et al.*, 2011). Possible reasons for increasing effort in Northumberland include profit maximisation (Pascoe and Robinson, 1997) and trawlers switching to potting (Turner, 2010). The increase in effort suggested by the questionnaire and Stephenson (unpublished) may be masking the effect of the pot limitation.

5.4 Change in effort in relation to habitat

Maps clearly show that fishing effort increased between 2007-08 and 2010-11 (Figure 5). This does not appear to correspond with increased habitat selectivity. This evidence suggests an increase in effort inshore, with the most notable changes occurring in the vicinity of Amble and Seahouses.

When looking at preferences of fishers regarding habitat, Ivlev's Electivity Index, results were near zero, representing almost random selection (Kohler and Ney, 1982); suggesting that fishers are not increasingly targeting a specific habitat type. This corresponds with the results of the questionnaire, which indicated most fishers do not feel they have become more selective of where they fish their pots due to the restriction. It has been suggested that fishers may target the boundary between hard and soft ground (Selgarth *et al.*, 2007) which may affect the strength of the observed relationship. The habitat requirements of species in the fishery vary with lobster and velvet crab (*Nectora puber*) associated with rocky grounds and brown crab (*Cancer pagurus*) on sedimentary grounds (Turner *et al.,* 2009). The fishers may be targeting different species, therefore different ground types, depending on factors such as economics and season (Turner, 2010) which may have reduced any association between habitat fished and lobsters in the present study.

5.5 Limitations

These results represent a novel attempt to spatially integrate habitat use data by both fishers and target species. Though partly successful, some important caveats should be noted. Using an OLEX derived hardness proxy for habitat is not ideal, this study assumed that habitat available in the whole district to be representative for all fishers however, this may vary within each ports home range (Turner, 2010). The most important limitation is the assumption that ground type at the start and end of each fleet of pots is representative for all pots in that fleet. The grid maps were found to be significantly spatially auto-correlated, violating the assumption of non-independence of the data (Turner, 2010). Spatial Auto-correlation is not a problem with Monte Carlo however, it is important to note that the p-value is only an estimate created from the distribution of the test statistic (Manly, 2007).

5.6 Future recommendations

Currently, literature relating to pot limitation and its effectiveness is limited. Several fishers suggested that the pot limitation may be too high. NIFCA should devote some resources to assessing this claim, taking into account factors such as total number of vessels potting in the district to determine an appropriate number of pots per permit to limit effort. Further study should also look at the proportion of potting effort occurring in the MCZ and determine how altered regulations, from the existing pot limitation to potential closure of parts of the area, would affect fishers' livelihoods.

6. Conclusion

The aim of this project was to increase current understanding of habitat utilisation by the European lobster and by Northumberland pot fishers. While results here indicate that the target species was evenly distributed across hard and soft areas, in terms of sex and size, CPUE was higher over soft substrate, perhaps indicating that lobsters were more abundant in these areas. However, this is contradicted by the literature which suggests abundance is higher on hard ground, and it is believed that some assumptions made while manipulating the data may have influenced these findings. The most striking finding in this study was the significant increase in potting effort between 2007-08 and 2010-11, contrary to expectations raised by the 2009 regulation restricting the number of pots per permit holder to 800. More pots were deployed across the district, regardless of habitat, increased effort corresponded with the locations of ports and was concentrated inshore. Fishers' describe simultaneous changes in the fishery, not directly related to the introduction of the pot limitation, such as purchasing a second vessels and fishing additional pots outside of the district. Further research is needed to determine the most appropriate restriction to number of pots, which incorporates the social, economic and environmental interests of the district.

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8. Appendices

Appendix I. Questionnaire

Date: ____________________ Time: ___________

Port: ______________________________

Name:____

Has the introduction of pot limitation (2009) influenced how many pots you have in the sea?

Increase No change Decrease

Have you purchased an additional vessel due to the pot limitation? Yes No

Are you more selective of where you fish your pots? Yes No

If yes, which criteria are you most selective about?

Habitat type Distance from port Likelihood of catch Other

If other please specify: ____

Has the introduction of pot limitation (2009) increased the number of pots you fish outside the district? Yes No

If the number of pots outside the district has increased:

Approximately how many extra pots per month do you fish outside the district (excluding any pots fished outside the district before 2009)?___________________________

Appendix II. Monte Carlo Code in R

```r
install.packages ("dismo")
install.packages ("raster")
install.packages ("rgdal")
library(raster)
rast2007 <- raster("nat07clip.txt")
plot (rast2007)
library (raster)
rast2010 <- raster("nat10clip.txt")
plot(rast2010)
test.vestor = NULL
for (i in 1:10000){
  library(dismo)
  rnd <- randomPoints(rast2007,5000)
  library(raster)
  rr <- extract(rast2007,rnd)
  rr2 <- extract(rast2010,rnd)
  test.vestor[i] <- t.test(rr,rr2,paired=TRUE)$statistic
}
mean(test.vestor)
```

Appendix III. Literature review:

An evaluation of data collection techniques for the assessment of habitat- use by the European lobster in Northumberland.

Natalie Wallace

Abstract

Understanding a species' habitat use is fundamental to understanding the biological requirements of a species and to the success of conservation and management measures. Many methods are available to assess species-habitat relationships and the selection of a method is generally based on the suitability of the technique for the proposed study and study site. Each technique has a range of strengths and weaknesses, however ongoing research is improving and developing new methods to address these limitations. Several data collection methods are reviewed to identify the most suitable for assessing European lobster (*Homarus gammarus*) habitat use in Northumberland.

Key words: Habitat-use, Lobster, Data collection.

1. Introduction

The European lobster (*Homarus gammarus*) is a long-lived, decapod crustacean distributed from Norway to North Africa (Triantafyllidis *et al*. 2005; Wiig *et al.*,2013). Crustacea are an important source of food protein, with fisheries targeting this resource worldwide (Bondad-Reantaso *et al.*, 2012). Lobster is the most commercially important species in the Northumberland fishery (Bannister, 2006) however overexploitation has resulted in the stock declining (Cefas, 2011). There are several European Marine Sites (EMS) in the district and the Northumberland Inshore Fisheries and Conservation Authority (NIFCA) is responsible for the management of fisheries out to 6nmi, through a series of Byelaws. Fishers' decisions on where to fish are often informed by their knowledge of the target species (Turner *et al.,* 2014), therefore knowledge on the spatial distribution of lobsters and fishing activity are important to determine if managers are protect the most suitable locations.

As with most marine species, *H. gammarus* is not uniformly distributed (Wiig *et al.*,2013). Species' distribution and habitat use are influenced by several factors including habitat structure, food availability, interspecific competition, predation risk and phylogenetic constraints (Luck, 2002). Many studies have assessed the distribution of crustacea at large and intermediate scales, yet few studies have addressed the factors influencing smaller scale distribution patterns, such as habitat (Wiig *et al.*,2013).

Studies which have addressed lobster-habitat relationships have determined lobster densities to be highest on complex, hard habitat capable of providing suitable shelter (Howard and Nunny, 1983; Tremblay and Smith, 2001; Skerritt, 2014) or on the boundary between hard and soft substrata (Selgarth *et al.,* 2007). The association between crustacea and habitat also differs with size and sex due to changes in behaviour and habitat preferences at different life cycle stages (Karnofsky *et al.*, 1989).

The aim of this paper is to review the available literature, to identify the most suitable methods of assessing habitat use by the European lobster. It will achieve this by meeting the following objectives:

1. Review current literature investigating habitat use by crustacea.

2. Critically review data collection methods and corresponding conclusions.
3. To determine suitable methods to inform a study on habitat use by the European lobster.

Several methods are used to quantify habitat selection. The two main areas of research are those analysing the relationship between the distribution of a species and habitat features and those predicting distribution in relation to environmental factors using habitat models when species distribution data is not available (Strauss and Biedermann, 2005). This review focuses on the former group of studies.

2. Data collection in habitat-use studies

Data sources vary throughout the literature, with lobster habitat-use studies collecting data both in the field and in laboratory studies, using a range of techniques (Table 1). Diver observations and acoustic tracking are the most common techniques used to observe lobster activity in the field (Golet *et al.,* 2006). Species-habitat relationships are not stable over time (Alexander *et al.,* 2014) therefore studies which take into account temporal variation (e.g. seasonal components) will be more realistic (Bissonette and Storch, 2007). *Homarus* spp. are considered to be nocturnal (Wiig *et al.*, 2013) and show seasonal variations in distribution and behaviour (Golet *et al.,* 2006). It is therefore difficult to obtain direct observations on their habitat-use in the marine environment (Wiig *et al.,* 2013).

2.1 Observational Studies

Observational studies throughout the literature primarily focus on *Homarus americanus*, a considerable proportion of knowledge relating to *H. gammarus* is referred from information obtained from these studies (Skerritt, 2014). Most observations of lobster behaviour have occurred under laboratory conditions (Phillips, 2005), mesocosm experiments and diver observations are also viable options.

Laboratory studies provide opportunities to observe lobster behaviour in relation to habitat features in a controlled environment (Golet *et al.*, 2006). Most observations of lobsters in the field show similar results to those of laboratory studies (Golet *et al.,* 2006). For example, a laboratory study conducted by Wahle (1992) found that larger American lobsters (*H. americanus*) show a preference towards shelters among larger rocks which is consistent with the results of field studies (e.g. Howard, 1980). However, differences in activity have been noted between laboratory studies and field studies, as several factors influencing behaviour cannot be replicated in the laboratory (Golet *et al.,* 2006).

The construction of a large underwater enclosure, known as a mesocosm allows for the increased control exhibited in laboratory experiments, in the lobster's natural habitat. This method aims to retain lobsters within a defined area, to maximise observations and remove fishing pressure. Whilst creating several benefits this also restricts movement to the area within the mesocosm hence altering natural movement (Golet *et al.,* 2006). Mesocosm studies are dependent on data collection by methods such as underwater video, tagging, tracking (Golet *et al.,* 2006) and diver surveys (Karnofsky *et al.,* 1989).

Pitcher *et al.* (1997) identified diver surveys as the most appropriate survey method for inshore habitats. Diver surveys of *H. gammarus* are not recorded in the literature, with the exception of a few small studies (Cobb, 1995). Many factors limit the use of diver surveys such as diver time, depth, viability, and weather conditions (Skerritt, 2014). Divers can cause a disturbance, using snorkelling rather than SCUBA equipment may reduce this potentially reducing bias (Karnofsky *et al.*, 1989). Diver observations can show bias in lobster size (Alexander *et al.,* 2014) and towards areas of higher lobster density (Karnofsky *et al.*, 1989). Using GIS to visually represent data in maps, can increase the accuracy of habitat-use methods (Basille *et al.*, 2008). A preference for areas with high habitat complexity by the Spiny lobster (*Panulirus argus*) in Yucatan, Mexico was determined from geo-referenced dive transects and a habitat map in GIS (Rios-Lara *et al.*, 2007). Diver surveys were an appropriate method for this study, as environmental considerations are less of a problem in the study area. The survey was conducted between July and August and therefore would not highlight any temporal variation in habitat-use. Data collected from divers surveys were combined with fishery-dependent catch data for analysis.

2.2 Catch-dependent Studies

Catch data is often used in studies to provide information on factors such as number of lobsters, carapace length (CL) and sex (Howard, 1980; Rios-Lara *et al.*, 2007). Combined with geo-referenced coordinates for catch locations, this data can be used in combination with habitat data to assess habitat-use (Geraldi *et al.*, 2009). Fishery-dependent catch data from trawls (Roddick and Miller, 1992), traps (Howard, 1980) and diver fishers (Bello *et al.*, 2005) have been used to study lobster distributions. Commercial fishing represents a large sampling effort and trap catches have been shown to reflect spatial differences in abundance (Geraldi *et al.*, 2009). Uncertainty associated with catchability due to variables such as lobster size, sex, soak time and bait type can create bias (Geraldi *et al.*, 2009). Skerritt (2014) used fishery-independent trap catch data from four locations and determined mean substrate hardness for each site. Unlike with commercial trap data, this study controlled for variation created by individual fishers by using a consistent trap type and bait throughout the study. Highest catch occurred at the study site with the highest average hardness value (Skerritt, 2014), suggesting a relationship between lobster distribution and hard substrate. One limitation of using baited pots is that lobsters may be caught on their foraging habitat not their shelter habitat (Bellchambers *et al*., 2010). Only a small proportion of lobsters (6%) which enter traps, remain in the trap and are subsequently caught (Jury *et al.*, 2001). Despite the limitations discussed, Miller (1990) concluded that trap catch remains the most convenient method for studying lobster abundance and distribution.

Capture Mark Recapture (CMR) is a common method in the literature for monitoring lobster movement, involving the tagging and recapture of tagged individuals. Fishers represent a large sampling effort, with most tagging studies depend on repeat observations, tag returns and information such as capture location provided by commercial fishers (Miller, 1990). Some studies offer a small incentive (Cambell and Stasko, 1986). CMR provides limited information on movement and habitat-use of lobsters (Skerritt, 2014). Despite this claim, Dunnington *et al.* (2005) spatially referenced recaptures to determine associated habitat features. This study used independent diver surveys to identify the appropriate duration for recapture studies, the results indicated that longer-term studies provide results similar to those of diver studies, suggesting greater accuracy. Capture location only provides stationary information on habitat-use, to gain insight into temporal habitat-use continuous monitoring is needed.

Telemetry studies allow individuals to be monitored continuously over time in their natural environment (Wiig *et al.*, 2013), providing information which could not be obtained using conventional sampling methods (Guerra-Castro *et al.*, 2011). Few published studies on crustacea use biotelemetry, this could be due to the high cost of the technique, a lack of analytical methods (Guerra-Castro *et al.*, 2011) and limited sample size (Geraldi *et al.*, 2009). Skerritt (2014) used acoustic telemetry to access movement and habitat-use by *H. gammarus.* Lobsters need to be in range of the receivers for data to be recorded and detection rate varied due to environmental conditions. Another factor to consider with this study is that positions are estimates calculated based on transmissions from several receivers. The results of this study suggest that lobsters use a wider range of substrates at night and that hard and mixed substrata are used most often (Skerritt, 2014). Telemetry studies have the potential to provide detailed insight into lobster habitat-use, highlighting it as a promising technique for future research.

The methods discussed have a number of strengths and weaknesses (Table 1) it is therefore important to determine the most appropriate method for the proposed study, taking into account scale, environmental variables and available resources. Many of the studies discussed combine several methods to draw conclusions about lobster habitat-use (e.g. Geraldi *et al.*, 2009; Rios-Lara *et al.*, 2007).

3. Identifying suitable methods for Northumberland

The European lobster is the most commercially important species in the Northumberland potting fishery (Bannister, 2006). To inform future management of the fishery it is important to understand the distribution and population characteristics of *H. gammarus*. The study site is located within the NIFCA district off the North East Coast of England. An area which is composed of distinct patches of both hard and soft substrates (Skerritt, 2014).

The proposed study is concerned with the distribution of *H. gammarus* in its natural environment, ruling out the use of laboratory studies and the size of the study area eliminates the use of mesocosm studies. Skerrit (2014) conducted a series of lobster focused studies in the region highlighting the potential of fishery-indepentent methodologies includng CMR and telemety. However these studies were also confined to a relatively small area and require funding in excess of that available for the proposed study. Diver studies have been highlighted as the most appropraite technique for inshore studies (Pitcher *et al.,* 1997) however diving is restricted by environmental conditions which are unpredictable in the UK.

As mentioned above, trap catch data is the most covientent technique (Miller, 1990) and due to the high amount of potting activity in the study area it is likely to be a cost effective technique. NIFCA have collected fishery-dependent trap data recording factors such as CL, sex and capture location, the findings of this review indicate that this data has the potential to be used alongside habitat data to assess habitat-use by lobsters on a district wide scale.

4. Conclusion

This review discusses a range of data collection methods used in lobster distribution, movement and habitat-use studies. Highlighting key strengths and weaknesses in order to determine appropriate techniques to study habitat-use by the European lobster in Northumberland. Taking into account factors such as environmental variables, cost, appropriate scale and sample size the use of fishery-dependent catch data is an appropriate method for this study when combined with catch location and habitat data. It is important to remember that this technique has limitations and if resources were available combining several of the discussed method may produce the best result.

Table 1. Examples of data collection methods; their strengths and weaknesses and locations of studies which have used the technique.

Method	Strengths	Weaknesses	Location	Useful References
Diving	Limited interference, Direct observation.	Intermittent, Restricted due to visibility, Weather, Sea conditions. Seasonality, Dive Time, Time of day, Depth, Produce snap shot data, Relatively expensive.	N.E USA N.E USA Gulf of Mexico N.E USA E. Mexico	Bologna and Steneck (1993) Geraldi *et al.* (2009) Rios-Lara *et al.* (2007) Selgarth *et al.* (2007) Briones-Fourzan and Lozano-Alvarez (2001)
Snorkelling	Limited interference, Cheaper than diving, Direct observation.	See diving weaknesses (excluding cost).	Turks and Caicos Is. N.E USA Florida USA	Claydon *et al.* (2009) Karnofsky *et al.* (1989) Eggleston and Dahlgren (2001)
Tagging/ CMR	Can monitor individuals over time, Estimate population size.	Repeat observations, Catchability, Snap shot data, Small sample size, lost tags, Needs further study.	Norway N.E USA N.E USA N.E England S. England	Agnalt *et al.* (2009) Dunnington et al. (2005) Geraldi *et al.* (2009) Skerritt (2014) Smith *et al.* (2001)
Acoustic Telemetry	Measure distances, not dependent on visibility or rates of recapture. Spatial resolution, Limited interference. Continuous tracking	Limited sample size, Relatively expensive, Limited range and depth.	N.E USA N.E England Florida USA Norway	McMahan *et al.* (2013) Skerritt (2014) Bertelsen *et al.* (2009) Wiig *et al.* (2013)
Commercial catch	Cheap, Large sample size.	Repeat observations, Bias in effort, Catchability, Bait interference, Snap shot data, Variable soak time, Different gear, Bias sex ratio.	Norfolk, UK Gulf of Mexico N.E England	Howard (1980) Rios-Lara *et al.* (2007) Turner *et al.* (2009)
Fishery independent	Relatively cheap,	Repeat observations, Catchability, Bait inter-	W. Australia	Bellchambers *et al.* (2013)

catch		ference, Snap shot data, Variable soak time.	N.E USA N.E England Cape Breton, Canada Nova Scotia, Canada	Geraldi *et al.* (2009) Skerritt (2014) Smith and Tremblay (2003) Tremblay and Smith (2001)
Lab Studies	Direct observation.	Does not account for all factors, make several assumptions.	N/A	Cenni *et al.* (2010) Wahle, (1992) Miller and Addison (1995) Philips (2005)
Mesocosm Studies	Removes fishing pressure, natural environment, some the control of a laboratory experiment.	Limits long distance movement, requires other methods for observations, expensive.	N.E USA N.E USA	Golet *et al.* (2015) Karnofsky *et al.* (1989)

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