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Report: Pot Luck: The impact of fisher's choices and lobster pot size on fishing effort within the Northumberland fishing district.

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Acknowledgements

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Abstract

Understanding in full, and accurately representing fishers gear choices is key to successful management of a sustainable stock. Managing bodies such as the Northumberland Inshore Fisheries and Conservation Authority depend upon this knowledge. In 2009 NIFCA implemented a bylaw limiting the number of pots a fisher could use, but this stopped short of restricting pot size which may have varying consequences for the stock. Varying pot size may influence catch size, soak time, efficiency of fishermen, or environmental impact within the fishery. It can also alter the effort used to fish, impacting Catch Per Unit Effort (CPUE) values for the fishery. Misrepresentation of CPUE through inappropriate inclusion of underlying factors can negatively affect the health of a fishery which contributes to the economy of the Northumberland district. This study therefore aims to determine the impact pot size and soak time have on landable catch and CPUE. Questionnaires were conducted to establish what gear fishers were currently using, how they perceived effort had changed throughout the district, and how current regulations were viewed. Fishers views then informed pot size catch comparisons where small, medium, and large pot sizes were left to soak for 24, 48 and 72hrs. It was found that the average size of *H. gammarus* caught did not vary across pot size or soak time but the number of landable organisms increased. CPUE values were conducted across the total number of pots and were recalculated according to varying effort factors. Values significantly varied when considering pot size and soak time, meaning catchability of organisms is not the same across variables, potentially impacting sustainability.

1. Introduction

The NIFCA (Northumberland Inshore Fisheries and Conservation Authority) district extends to 6 nautical miles (nm) offshore, ranging from the Scottish border in the North, down to the River Tyne. The fishery within the district is mixed species (Garside et al. 2003),primarily composed of <10m fishing vessels operating largely close to shore (Stephenson et al. 2017). Baited pots (traps) are the main equipment used within the fishery.

The multi-species Northumberland shellfishery and its fisher communities host a vast resource of hereditary knowledge (Turner et al. 2014). Local incomes rely heavily on crustacean sales, meaning the health of the Northumberland shellfishery is crucial within the area. Following the crash of cod stocks, fleets moved further towards trap fishing as a necessary diversification (Cefas 2011). Protecting and understanding shellfish stocks, therefore securing the future of local commercial fishing practices, is essential.

Primarily targeted species include the European lobster (*Hommarus gammarus*), prawns (*Nephrops norvegicus*), brown crab (*Cancer pagarus),* and velvet swimming crab (*Nectora puber*) (Turner et al. 2009). European lobster is prioritised within the fishery due to its economic and commercial importance (Turner et al. 2014). Since the declines in pelagic and demersal fish stocks, the overall economic importance of shellfisheries has increased (Turner et al. 2009). Exploitation beyond recommended levels has led to the belief that Northumberland lobster stocks are in decline (Cefas 2011). The NIFCA pot limitation bylaw, implemented in 2009, was to prevent further decline in stocks. This limited commercial fishers to 800 pots per vessel and recreational to 5 (NIFCA 2013), but did not mention any restriction on the size of pot fishers use.

Number of pots per fisher, has previously been investigated and is regulated within the Northumberland district. Despite this, pot volume in relation to size of pots used by fishers, is not regulated and may negate previous pot limitations. There is currently very little scientific understanding of the relationship between pot size and overall catch, with unknown consequences for soak time, catch size, catch composition, environmental impact, and efficiency of fishers. For fisheries management to be effective, there must be both an ecological and biological understanding of target species (Skerritt et al. 2015), and a social understanding of the fishers who rely upon the resources. The social dimensions of fishers' behaviours and drivers are still understudied despite worldwide exploitation of fisheries (Turner et al. 2014). Regulations and scientific investigation will only be effective if they accurately represent the fishing gear used within a district. Understanding the impact of equipment and fishing habits could prevent a stock collapse, similar to that of Atlantic cod. Studies on European lobster have shown a marked tendency towards stock collapse when fishing effort is high (Bannister and Addison 1986). Modern worldwide failures in fisheries management have been attributed to an insufficient understanding of fisher's knowledge (Hilborn 2007).

Catch Per Unit Effort (CPUE) is relied upon for many fisheries as annual indices of stock abundance. Although some standardisation has been possible through development of statistical methods, reliability of CPUE is questioned (Campbell 2004). CPUE is often found to be a poor indicator of species distribution and abundance, especially when considering baited trap fisheries (Addison 1995; Skerritt et al. 2015). Despite the debate around underlying resources and catch rates (Campbell 2015), CPUE remains integral in stock assessment processes (Campbell 2004). Early methods depended on assumptions that nominal effort could be simply adjusted to account for differences in vessel efficiency, or that catchability would remain constant over entire fleets of pots (Beverton and Parrish 1956; Gulland 1956). Despite the simplicity, these methods, were widely adopted and are still used in fisheries assessments (Campbell 2015). It was discovered early that assumptions of constant catchability are not reliable. Garrod (1964) showed that variation in catchability not only depended on a vessel's fishing power, but also relied on spatial patterns of stock and fishing effort, changes in stock abundance, and variances in vulnerability to fishing gear. All of these factors show that CPUE needs to account for more than it already does.

This project aims to explore how fisher's choice of pot size may impact catch distribution and CPUE within Northumberland, alongside determining how current regulations are perceived within the district. This will be achieved by conducting:

1. Semi-structured surveys to determine fishing equipment currently in use and if gear use has changed in relation to limitations within the district;
2. The impact of pot size/soak time on catch composition will be investigated by comparing catches for three different pot sizes (small, medium, large), left to soak for three time periods (24hrs, 48hrs, 72hrs);
3. And finally, through calculation of CPUE using NIFCA methods for experimental catch to discover if pot size influences fishing efficiency.

2 Methods

2.1 Data collection

2.1.1 Questionnaires

Fishers were interviewed over a two-month period (June and July, 2017) across six ports (Table 1). The targeted population were skippers of boats holding potting licenses. A total of 17 skippers were questioned, representing 25% of active fishers in the Northumberland district.

Table 1 – The number of active Fishers and their landing ports within the NIFCA district and the proportion of active fishers surveyed within the June/July 2017 period.

Landing Port	Number of Active fishers	Percentage surveyed
North Sheilds and Cullercoats	5	80%
Holy Island	6	50%
Amble	22	22%
Blyth and Seaton Sluice	9	22%
Seahouses	10	20%
Beadnell and Craster	6	17%
Boulmer	3	0%
Berwick	4	0%
Newbiggin by the sea	3	0%

Prior to surveys taking place, an information sheet and consent form (Appendix C) were presented to fishers and discussed then signed and dated. Questionnaires were semi-structured, including a mix of both open and closed questions to allow for a 10-15 minute survey time. (Appendix D). Interview questions were piloted with a key informant from within the University for appropriate style and wording. Interviews were conducted with the specific goal of obtaining unbiased data through open, none-leading questions.

Due to low participation rates, time constraints, and unknown whereabouts of fishers, statistically randomized participant selection was not possible. Fishers were contacted through a mix of key informants within the university, contacting NIFCA officers, and a snowballing technique. NIFCA officers advised on locations most likely to have fishers present and were present to identify active pot fishers. To avoid any bias within the results the officer would remove themselves from the vicinity of the interview. Time constraints and unavailability of fishers meant some ports remained under sampled. Many part time drift net fishers, located in ports such as Beadnell, were unavailable to survey as questionnaires were undertaken during salmon season. There remains an uneven balance of fishers sampled in the north of the district to those sampled in the south as there is a higher number of active fishers in the south. Some of the data collected through this survey, such as average soak time and measurements of pots, were used to inform the methods of the experimental process.

2.1.2 Pot Size Catch Comparisons

Advice from the University Skipper provided a suitable fishing ground for experimental data collection (Figure 1). Due to time constraints only one site could be tested at one time of year, future research should consider spatial and temporal variations in catch. Mean depth fished within the site was 20.3m (± 1.2m S.D.).

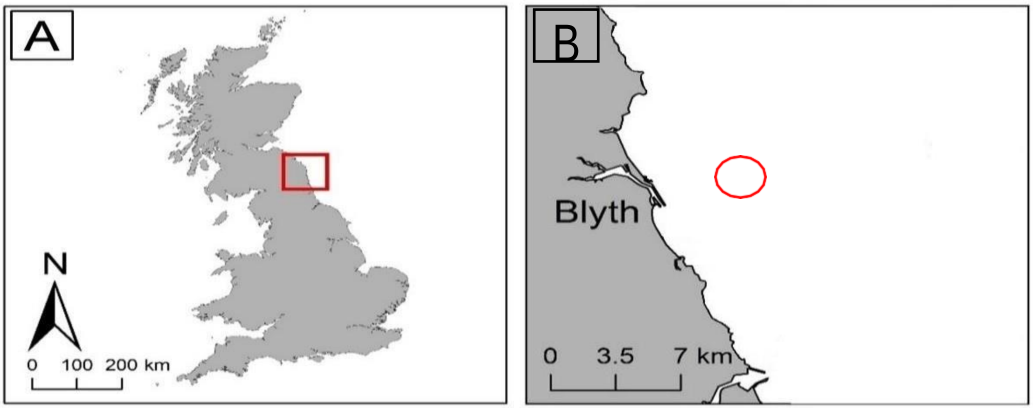

Fig 1 – A) Location of study site within Great Britain. B) Area experimental pots were fished. All experimental pots were fished within the area shown by the red circle, off the coast of Blyth, Northumberland.

Three different pot sizes were tested: small (31"x 16"; mesh size= 3cm; 8cm opening diameter); medium (27" x 18"; mesh size = 5.5cm; 16cm opening diameter, single eyed); and Large (40"x 21"; mesh size = 6cm; 18cm opening diameter). The dimensions of pots used were drawn from survey data and fishers' knowledge of 'standard' pot dimensions. Fishers were asked for an estimation of small, medium, and large pot size; the three pot sizes used fit within the mean ± S.D. length values given (Small = 27.7 ± 4.5"; Medium = 33 ± 5"; Large = 40 ± 3.6"). Three fleets of pots were assembled, each fleet contained three pots of each size, alternating in size along the line (Figure 2). All fleets were dropped at the same time, with 9 pots of each size, 18 total. When questioned, fishers revealed that soak times for pots did not vary in accordance to size, but instead diverse weather, habitat, and catch size were more likely to impact soak time. Therefore, all three sizes of pot were dropped for three individual soak times, 24 hr, 48 hr, and 72hr. Survey data showed that soaks typically ranged between 24 – 72hr, hence their use in this experiment. However longer soak times have been known and future research should look at extending soak periods to a week to simulate the impacts of adverse weather.

Data collection was completed twice with 54 individual pots, 27 of each size, for each soak time. However, one fleet on a 72hr soak could not be retrieved, leading to an uneven number of final pots. The number of organisms caught, size of organism, landability, gender, any damage, v-notched lobsters, and if they were carrying eggs, were noted for each pot. All species caught were noted.

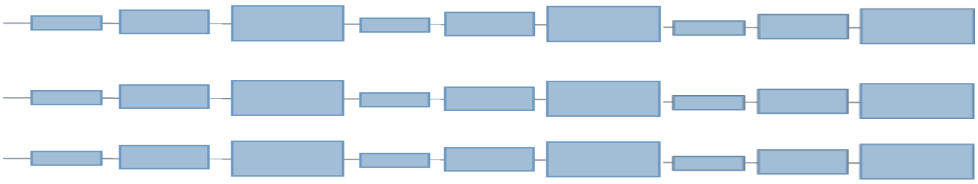

Fig 2 – Layout of the three varying pot sizes along the three fleets constructed. All three fleets were left to soak for 24hrs twice, 48hrs twice, and 72hrs twice.

2.1.3 CPUE Calculations

NIFCA provided current methods for calculating CPUE, however values have not yet been used for formal stock assessment. NIFCA calculations are not comparable to other IFCA districts as they rely upon number of lobster per pot, opposed to weight. To remain consistent with current methods within the district, CPUE calculations used for this research were compiled using number of lobsters per pot. Landings Per Unit Effort

(LPUE) and Not retained Per Unit Effort (NRPUE) were calculated to represent commercial success of catch:

LPUE = Number of Lobsters Retained (Sized, without v-notch etc.) / Number of pots hauled

NRPUE = Number of Lobsters NOT Retained (undersized, with v-notch etc.) / Number of pots hauled

CPUE = Total Number of Lobsters caught / Number of pots hauled OR LPUE + NRPUE

Initial LPUE, NRPUE, and CPUE calculations accounted for all pots fished throughout the experiment. Then calculations were conducted for individual size of pots fished (regardless of soak time), individual soak time fished (regardless of pot size) and individual pot size fished within each soak time. These values were compared to determine significant difference. Catch data for 2016 were obtained from NIFCA and CPUE calculations, also accounting for single, and doubled eyed pots were conducted.

2.2 Data Analysis

2.2.1 Questionnaires

Open ended questions underwent manual thematic coding (Richardson et al. 2005), applied using NVIVO-11. Thematic coding were compared using MDS and ANOSIM analysis on PRIMER 6, based on similarity of coding regularity. Views represented in thematic coding belong the fishers that were interviewed.

2.2.2 Pot Size Catch Comparisons

2.2.2.1 Commercial Catch Comparisons

Size of commercially important species *H. gammarus, C. pagarus, and N. puber,* were compared across pot size and soak time using two-way analysis of variance (ANOVA). The overall catch of the three species, per pot, across pot size and soak time were also compared using 2 way analysis of variance (ANOVA). This was then analysed as landable catch per pot for pot size and soak time (ANOVA). Landable catch discounts those caught under the MLS, lobsters carrying eggs, v-notched or any damage to tails. Analysis of variance conducted using IBM SPSS 22.0. Prior to ANOVAs, normality tests were conducted. All length data were transformed using a Log_{10} transformation and then conformed to normal distribution (Kolgomorov Smirnov, $P > 0.05$). Count data per pot were tested for normal distribution; total number of lobsters per pot conformed to normal distribution (Kolgomorov Smirnov, $P > 0.05$). Remaining variables tested did not conform to normal distribution and transformation failed to normalise data. Parametric testing was still undertaken due to the robust nature of ANOVA (Vaughan and Corballis 1969). Variances of all length samples could be considered equal (Levenes test, F= 0.004, $P > 0.05$). Square root transformation was applied to volume of organisms per pot data, after which all samples could be considered to have equal variance (Levenes test, F= 0.412, $P > 0.05$).

2.2.2.2 Population Dynamics

Community comparisons were conducted between pot size and soak times using Principal Components Analysis (PCA) on PRIMER 6.

2.2.3 CPUE Calculations

Individual independent T-tests were conducted between the overall CPUE value calculated and those including effort consideration to determine if consideration of various effort factors differed significantly from the overall CPUE value. All tests were conducted on SPSS 22.0 data, and all data conformed to normal distribution (Kolgomorov Smirnov, $P > 0.05$). The variances between all values could be considered equal (Levenes test, F= 0.004, $P > 0.05$). CPUE data retrieved from NIFCA were tested using independent T-tests to determine if values calculated differed significantly.

3 Results

3.1 Questionnaires

3.1.1 Data used for experimental design

When asked average soak times for pots, all responses ranged between 24-72hrs, with any longer periods reported due to detrimental weather, or inability to fish. All fishers asked responded that they would not vary soak times of pots dependent on size.

3.1.2 Fishing gear currently used in the district

Parlours within pots appear to be standard within the region, with all fishers questioned claiming that all pots they use contain parlours. Reasons given included holding stock for longer, and further ability for stock to move and without being damaged.

When asked about overall health of the fishery, 94% responded that it has improved in recent years. 88% of fishers also believe that the average pot size across the district has increased in the last 15 years, and 52% use a variation in pot size when fishing. 88% of fishers claimed that the pot limitation had no impact on size of pot they chose or number they currently use. 82% of fishers also stated that number of potting trips they make have remained the same over the past 15 years. There was a significant difference in assemblage similarity between themes frequently and infrequently mentioned in relation to cause for perceived pot size increase across the district (ANOSIM, Global R = 0.763, P = 1.3%) (Figure 3).

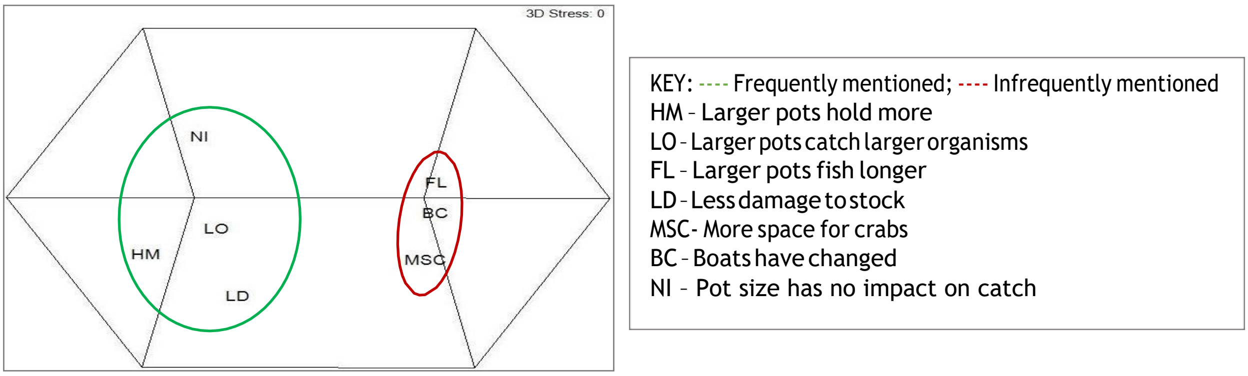

Fig. 3– MDS analysis on a Bray-Curtis similarity matrix for key themes presented when questioned on **c**ause for overall perceived increase in pot size throughout the region. Themes clustered by similarity of presence throughout interviews. Prominent reasoning was found to be larger pots ability to hold more, with less damage. The stress value of 0 indicates this was a very good representation of the similarity between samples.

3.1.3 Perceptions of Current Regulations

Fishers were questioned on whether current regulations aided the health of the fishery. There was a significant difference in assemblage similarity between themes frequently and infrequently mentioned (ANOSIM, Global R = 0.763, P = 1.3%) (Figure 4).

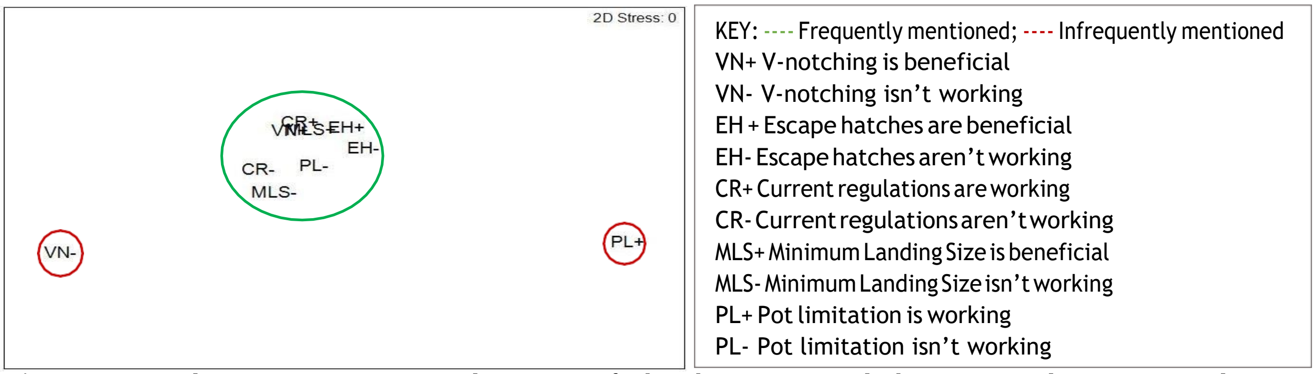

Fig. 4 – MDS analysis on a Bray-Curtis similarity matrix for key themes presented when questioned on current regulations in the NIFCA district. Clustered by similarity of presence in responses. V-notching was frequently seen as beneficial, whereas the Pot limitation was commonly mentioned as not working. V-notching was infrequently mentioned negatively. The stress value of 0 indicates this was a very good representation of the similarity between samples.

Fishers were then asked to give their views on what needs to be done within the district to maintain the health of current stocks. There was a significant difference in assemblage similarity between themes frequently and infrequently mentioned (ANOSIM, Global R = 0.639, *P* = 1.8%) (Figure 5).

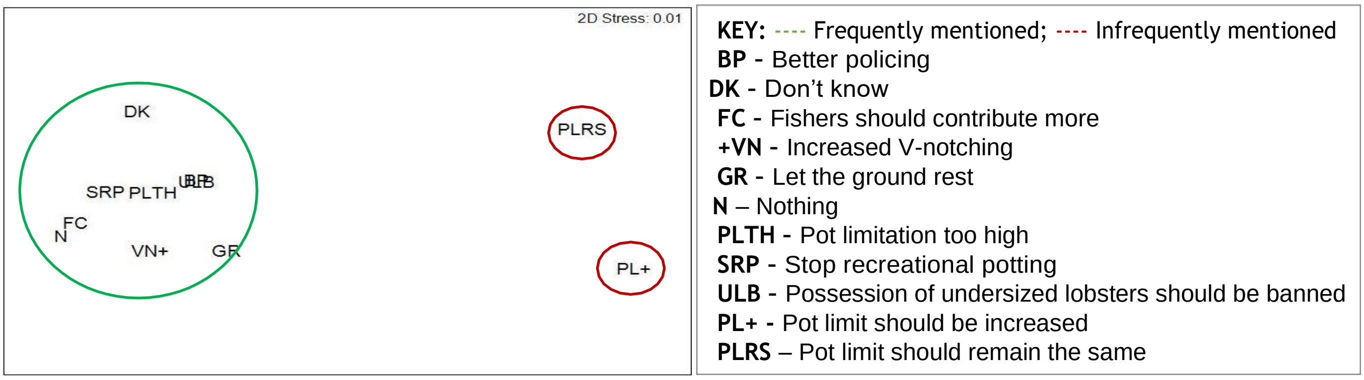

Fig. 5 – MDS analysis on a Bray-Curtis similarity matrix for **t**hemes presented when asked what needed to be done within the district to maintain health of stocks. Further v-notching, banning undersized lobster possession, and the pot limitation being too high, were commonly presented. With a pot limitation increase being infrequently mentioned. The stress value of 0.01 indicates this was a very good representation of the similarity between samples.

3.2 Pot Size and Catch Comparisons

3.2.1 Commercial Catch Comparison

Size of organisms between pot size and soak time

There was no statistically significant difference in the mean length of lobster across pot size (ANOVA, F= 1.477, df= 2, *P* > 0.05); soak time (ANOVA, F= 0.816, df= 2, *P*>0.05); or pot size*soak time (ANOVA, F= 1.52, df = 4, *P*> 0.05). There was also no significant difference in mean carapace width of velvet crab across pot size (ANOVA, F= 0.212, df= 2, *P*>0.05); soak time (ANOVA, F= 0.381, df= 2, *P*>0.05) or pot size*soak time (ANOVA, F= 0.857, df= 4, *P*>0.05). No v-notched lobsters were retrieved by researchers during the experimental period.

There was a statistically significant difference in mean carapace width in edible crab across the three different pot sizes (ANOVA, F= 3.979, df= 2, *P*< 0.05). *Post hoc* Tukey pairwise comparison showed the medium pot size, with singular hard eye opening, caught significantly larger crabs (mean = 16.18 ± 0.70 cm S.D.) when compared to the small (mean = 11.38 ± 1.66 cm S.D.) or large pot sizes (mean = 15.51 ± 0.49 cm S.D.). However, soak time (ANOVA, F= 1.573, df = 2, *P*> 0.05) and the interactive effect of pot size*soak time (ANOVA, F= 0.178, df= 4, *P*> 0.05) had no significant influence on mean crab length, suggesting medium, single hard eye pots consistently catch larger crabs. Velvet swimming crab remained the most consistent size across all variables, with edible crab varying the most, and two sizes failing to catch any edible crabs. Lobster were consistently caught above MLS (Figure 6).

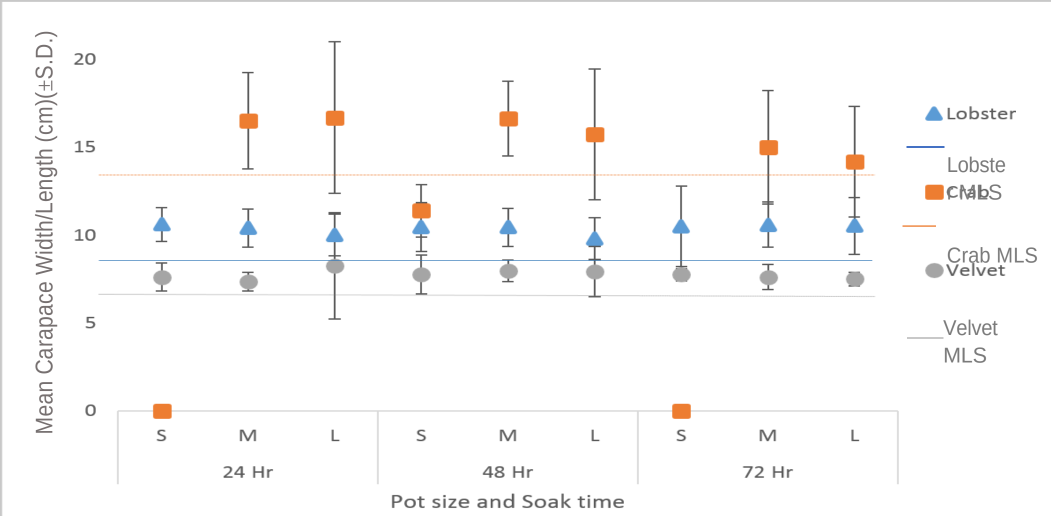

Fig 6 - Comparison of mean (± S.D.) sizes of A) *H. gammarus,* B) *C. pagarus,* C) *N. puber,* across 3 pot sizes and soak times, including Minimum Landing Size for each species.

No. organisms in pot/ size of catch

There was statistically significant difference in number of lobsters and number of landable lobster caught when considering pot size (ANOVA, F= 0.857, df= 2, *P*<0.05) and soak time (ANOVA, F= 10.04, df= 2, *P*<0.05), but not when considering the interactive effect of pot size*soak time (ANOVA, F= 0.864, df= 4, *P*>0.05). Overall more lobsters were caught in large pots soaked for 72hrs (mean = 2.4 ± 1.91 S.D.). Post hoc Tukey pairwise comparison (P=0.05) showed that large pots caught significantly more (mean = 1.58 ± 1.50 S.D.) than both small (mean = 0.78 ± 0.98 S.D.) and medium (mean = 0.96 ± 1.03 S.D.) pots. Pots soaked for 72hrs also caught significantly more (mean = 1.69 ± 1.59 S.D.) than pots which soaked for 24hrs (mean = 0.94 ± 1.21 S.D.) or 48hrs (mean = 0.85 ± 0.96 S.D.).

There was statistically significant difference in number of edible crab and number of landable edible crab caught when considering pot size (ANOVA, F= 13.292, df= 2, *P*<0.05) and soak time (ANOVA, F= 4.694, df= 2, *P*<0.05), but not when considering the interactive effect of pot size*soak time (ANOVA, F= 0.911, df= 4, *P*>0.05). Overall large pots soaked for 72hrs caught more edible crab (mean = 1.4 ± 1.06 S.D.). Post hoc Tukey pairwise comparison (P=0.05) showed that small (mean = 0.07 ± 0.44 S.D.), medium (mean = 0.64 ± 0.91 S.D.), and large pots (mean = 1.07 ± 1.29 S.D.) all caught significantly different amounts of crab. 72hrs (mean = 0.69 ± 0.92 S.D.) was not significantly different to a 24hr soak (mean = 0.27 ± 0.0.56 S.D.), or a 48hr soak (mean = 0.85 ± 1.35 S.D.), but 48hr caught significantly more than 24hr.

There was no statistically significant difference in number of velvet crab and number of landable velvet crab caught when considering pot size (ANOVA, F= 0.789, df= 2, *P*>0.05), soak time (ANOVA, F= 0.897, df= 2, *P*>0.05), or when considering the interactive effect of pot size*soak time (ANOVA, F= 0.924, df= 4, *P*>0.05). Landable numbers of commercial organisms caught per pot are displayed on Figure 7, Total organisms per pot are available in Appendix A2, and did not vary significantly from landable numbers.

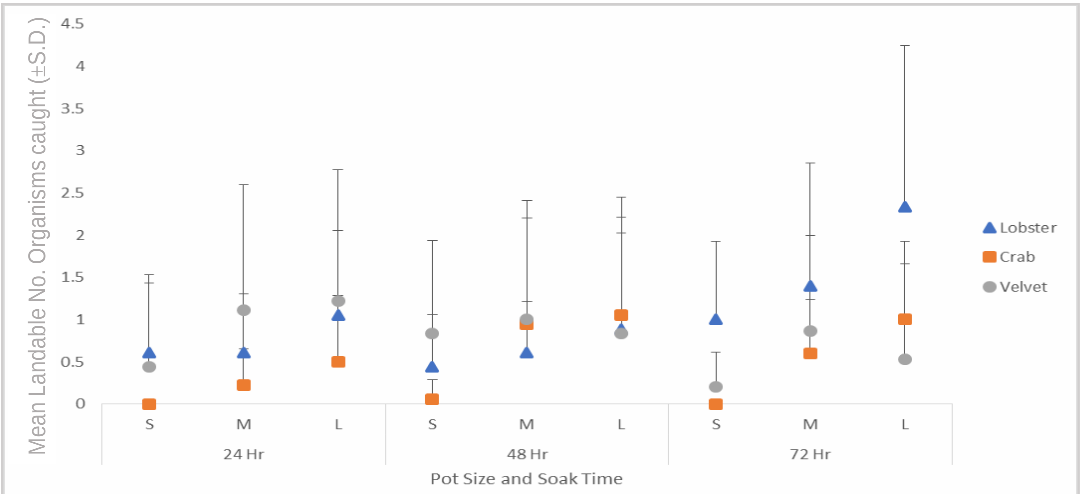

Fig 7- Mean (± S.D.) number of landable organisms caught during the experimental process, separated by pot size (Small, Medium, and Large) and soak time (24hrs, 48hrs, 72hrs).

3.2.2 Population Dynamics within Catch

PCA revealed presence of four components with Eigenvalues exceeding 1, which accounted for 85.9% of the total variance. The main species loading on component 1 were *H. gammarus,* whereas *N. puber* loaded strongly on component 2 (Figure 8). Small pots at all soak times were more closely related to non-commercially important species such as *A. rubens, Buccinida, and C. papposus. H. gammarus* and *C. pagarus* are closely linked to large pots at 72 hr, whereas *N. puber* is closely linked to large pots at 48 hr soak. Larger pots and longer soak times are more likely to have a more commercially viable catch, with less space taken by non-commercial species.

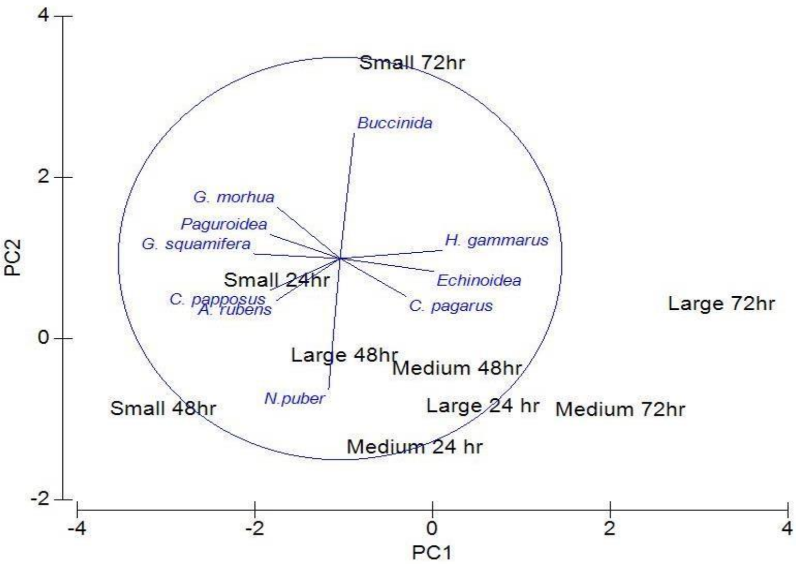

Fig.8–The impacts of Small, Medium, and Large pot sizes at 24 hr, 48 hr, and 72 hr soak time on species caught.

3.3 CPUE Calculations

Experimental data

The majority of CPUE values accounting for varying effort factors were not significantly different from the overall CPUE value calculated (1.098 ± 1.2). However, values that accounted for the overall soak time of 72hrs (t-test, t= -2.65, df = 205, P< 0.05, 1.68 ± 1.59), all pots considered large (t-test, t= -2.16, df = 202, P< 0.05, 1.59 ± 1.51), and large pots soaked for 72hrs (t-test, t= -3.580, df = 166, P< 0.05, 2.4 ± 1.91) were all significantly larger than the overall CPUE value (Figure 9).

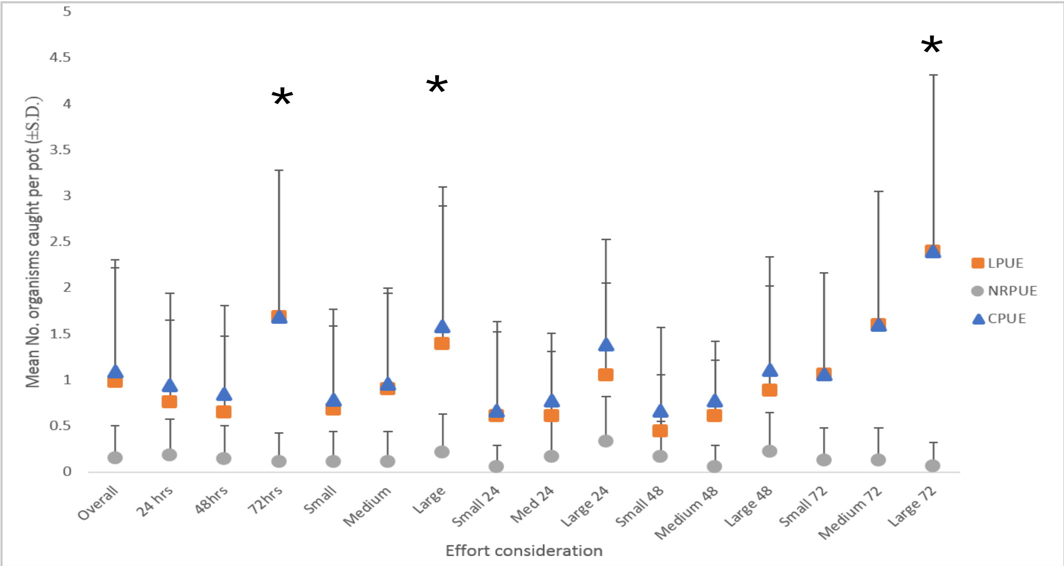

Fig 9. - Overall CPUE, LPUE, and NRPUE values for all pots released across the experimental period, compared to values accounting for various factors impacting effort levels. CPUE values that differ significantly from the Overall value are marked with a *.

NIFCA data

There was no statistically significant difference between the overall NIFCA CPUE value (0.23 ± 0.29) and the value calculated for single eyed parlours (t-test, t= -1.713, df = 163, P> 0.05, 0.32 ± 0.05) and double eyed parlours (t-test, t= 1.47, df = 179, P> 0.05, 0.23 ± 0.03) (Appendix A3).

4 Discussion

By combining interview data and experimental procedure, this study aimed to accurately represent and replicate the fishing practices within the Northumberland district to investigate potential impact on CPUE values through variation in effort considerations.

4.1 Fishers Views

Data derived from fishers' answers lead decisions made in the experimental process, such as size of pots used, how to set fleets, soak times, and inclusion of parlours. This resulted in accurate representation of gear used within the Northumberland district.

There is a perceived increase in fishery health among the fishermen, with most saying that the current fishing is the best it has been in five years. Most fishers have noticed an apparent increase in the average size of pots used across the district within the last fifteen years. The most common reasons given for an increase in pot size were the ability of larger pots to hold more stock, fish for longer, and catch larger organisms. This effectively increases the catch size with a minimal increase in effort. Multiple previous studies have shown that larger catches are yielded by larger traps (Miller 1990), however there was no consistent amount of increase. The catch of tropical fish increased proportionally to trap size (Munro 1974); the catch of *Cancer* crabs increased greater than trap size (Miller 1979), and catches of prawn and spider crabs increased less than the increase in trap size (Miller 1990). As there is no current research dedicated to change in lobster catch with increasing pot size, colloquial knowledge is relied upon. An increase in fishery health should be able to sustain regular use of larger pots, but until a formal stock assessment is conducted and further investigation into change in fishing effort is completed, the sustainability of the fishery is unknown.

The pot limitation appears to not have influenced the size of pots fishers' use, with many fishers claiming to use a lower number of pots than specified by the bylaw. Most current regulations within the district are positively received, with v-notching, MLS, and escape hatches all seeming popular among fishers. Despite this during the experimental process researchers failed to catch any v-notched lobsters. A 2011 stock assessment of the Northumberland and Durham areas found that stock was in decline (Cefas 2011), despite v-notching having been implemented in the district since 2000. This further solidifies the need for accurate stock assessments within the area and supplementary study into the efficacy of the v-notching scheme to determine how well perceived it is. Positive perceptions of remaining regulations could coincide with apparent increase in fishery health, with previous studies finding that decrease in health leads to concerns about livelihoods, increased fishing pressure, and a larger disregard of regulations in place (Slater et al. 2014). An understanding of regulations and ability to see positive impacts on the health of a stock leads to a greater respect by the fishers. Regulations that are deemed unnecessary or do not represent the actions of fishers are more likely to be disregarded, either through individual fisher's decisions or through peer pressure within a fishing community (Turner et al. 2014).

When asked what was needed to further improve the health of the fishery the main topics presented were to increase v-notching, a better policed presence within the fishery, with stronger reprimands for those landing undersized lobsters, and the limitation on pots currently being too high, with one fisher remarking "if you can't make a living with 800 pots then you shouldn't be at sea".

Data Reliability

Due to a lower return rate (22%) and geographic spread excluding certain areas, it is unlikely that viewpoints of the whole NIFCA district were represented by the questionnaire process. Quality of data may also be questioned, with close communities within fishers in the area (Turner et al. 2014) and sensitive subject matters. Fishers were regularly asked to expand on answers and most questions used were of a categorical basis.

4.2 Pot Size and Catch Comparisons

Commercially important data within the fishery are based upon size of organisms between pots and number of commercially viable species caught across pots. Despite it being one of the main themes presented in preference of larger pots, there was no significant different found in size of *H. gammarus* and *N. puber* between pot size and soak time. Overall soak time was found to have no impact on size of organisms caught, and pot size only impacting the size of *C. pagarus*, with a single eyed, medium pot size catching significantly larger crabs, and small pots failing to catch any *C. pagarus* for two soak times. Studies recording the impacts of intra-specific and inter-specific interactions on catch rate sand catchability found that lobster presence can significantly lower crab catchability (Skerritt 2014). Smaller pots providing less space and already occupied by lobster are likely to dissuade crabs from entering. However, features responsible for difference in catch cannot be positively identified as traps compared differed in more than one design feature. This is common among experiments of this nature, Miller (1990) wrote a comprehensive review on the impact of various trap features upon catch and often came across this problem. Unless traps are created for the specific intention of experimental procedure then they cannot be completely identical, and traps created identical would then no longer represent gear used in situ.

Both lobster and edible crab were caught in significantly higher numbers in larger pots and across longer soak times, with numbers of landable organisms also increasing significantly. Numbers of organisms not retained across all three commercially important species were very low. An increase in landable organisms when using larger pot sizes means less of the stock is being returned, potentially leading to a decreased health of the stock overall. The mechanism responsible may be reduced saturation effect in larger traps (Miller 1990). If captured animals may produce an odour or sound detectable by others that may discourage further entry, a larger trap has a higher dispersal area, reducing stimulus concentration. Organisms in the parlour would also be a greater distance from the bait, creating less competition (Austin 1977). A Principal Component Analysis found that a cleaner more efficient catch may be more likely with a larger pot size, reducing time taken to process non-commercial species, or any maintenance related to them. Therefore, further increasing efficiency. Increased soak time also showed a higher catch rate but not an exponentially higher catch, with rates slowing with each further day soaked. (Miller 1979) found similar results, with compared catches between 1 and 2 day soaks with gill nets. If the catch on the first day was small then the second days catch would only increase by half, and if the first day's catch was large then the second days catch could only decrease by 10%. It has established that future catch was partly dependant on previous catch. Although these are similar results they are not directly comparable as there has been little work relating to this on lobster species. Kennedy (1951) plotted catch per trap against soak time and although this provided reasonable fit to several data sets, it was theoretically troublesome due to predicting a constantly increasing catch (Miller 1983).

Although this may be beneficial to the fishers from a commercial aspect, with lower effort catching higher numbers of marketable stock, it may only be a short-term benefit, with potential negative impacts in the long term if stocks are not monitored closely. The over fishing of demersal fish has led to a rise and replacement by shellfisheries (Molfese et al. 2014). However, in the event of a crash it may be necessary to return reliance to previously suffering demersal fish stocks, but this is a completely different method of fishing. Bannister and Addison (1986) found when fishing pressure was high, lobster stocks had an increased tendency to crash. A change in an organism's catchability depends not only a vessel fishing power, but an organism's vulnerability to fishing gear (Garrod 1964). Increasing the size of a pot may increase a species catchability, negating the constant catchability that was suggested by Gulland (1956) and is still used in CPUE methods. As previously discussed, the presence of lobster within a trap can impact the catchability of crab species (Skerritt 2014). This may explain some of the discrepancies in data relating to *C. pagarus.* However the majority of interaction studies are limited to laboratories and semi-natural mesocosms, including interactions with traps themselves (Fogarty and Addison 1997; Bannister 2006), meaning we have little understanding of how representative this is of natural situations.

4.3 CPUE Comparisons

Considering further factors impacting effort value within CPUE calculations lead to a significant difference in values when large pots and increased soak times were used. The number of organisms not retained per unit effort did not vary significantly across pot size and soak time. The variation in CPUE values shows that including only pot number as a measure of effort may not be effective in assessing the overall health of the fishery, and may lead to inaccurate predictions of a stock health. CPUE needs a greater standardisation before it can be used to produce a stock assessment to allow for accuracy within values. However, within a district as large as Northumberland it may be difficult in gaining a 'standardised' unit of effort which is fully representative of fishing effort. These findings agree with Addison (1995), and Skerritt et al. (2015), who found that when used in a baited trap fishery, CPUE is often a poor indicator of species abundance and distribution.

5 Conclusions

In terms of number of fishing trips taken by fishers, effort in recent times seemingly has not changed within the district. However, a shift in the 'standard' gear used by fishers had led to an increase in average pot size being used. This increase across the district could lead to a higher volume of catch for the same, if not less, fishing gear used within the same area. Although there is not standard measurement for a small, medium, or large pot in Northumberland, an increase in pot size in general could increase the efficiency of fishing. The main drivers of this increase can be attributed to a higher catch, although vessel size was also highlighted as a main factor impacting pot size used. This shift towards a larger, more efficient gear, may unknowingly impact the CPUE values, with an impact to the health of the fishery potentially going unnoticed.

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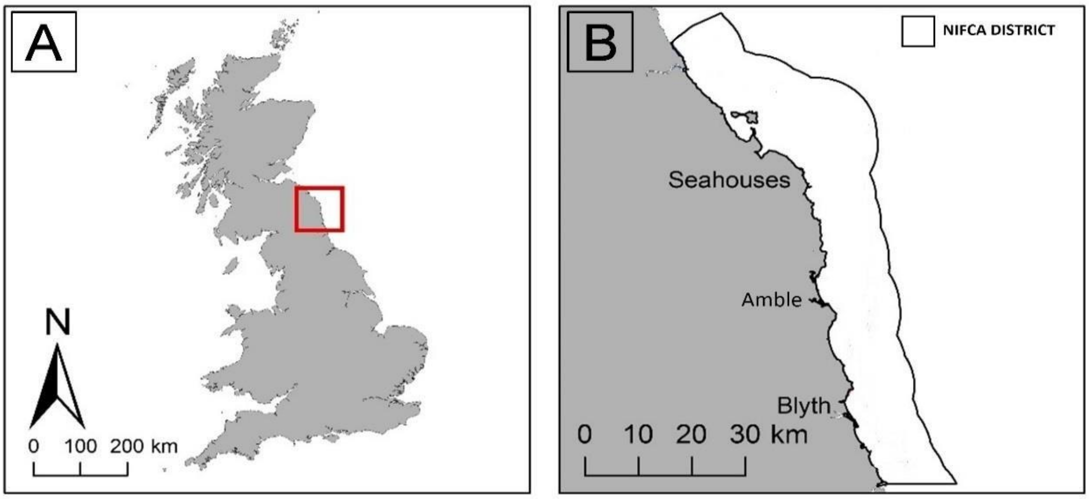
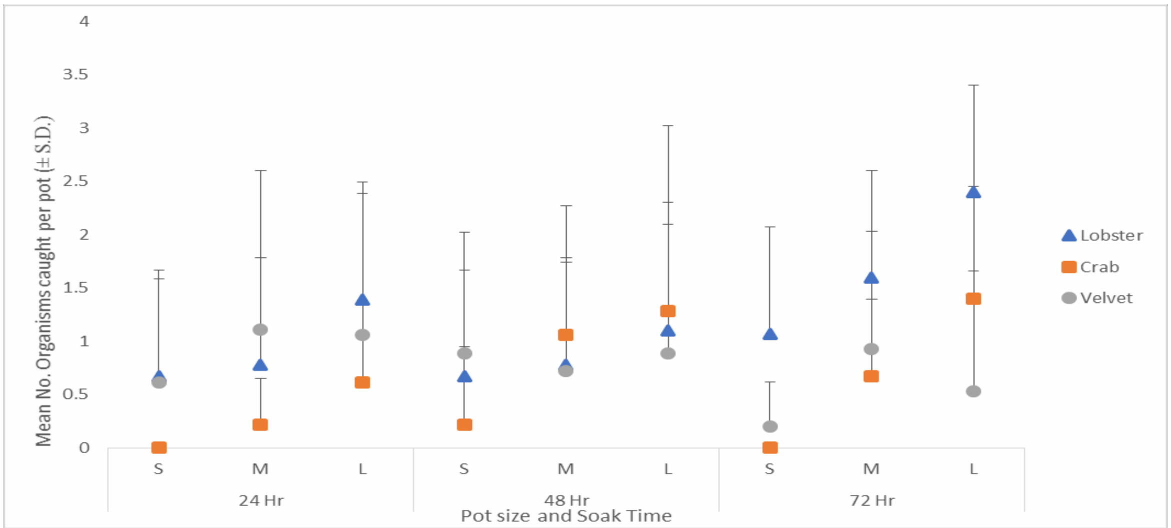
7. Appendices

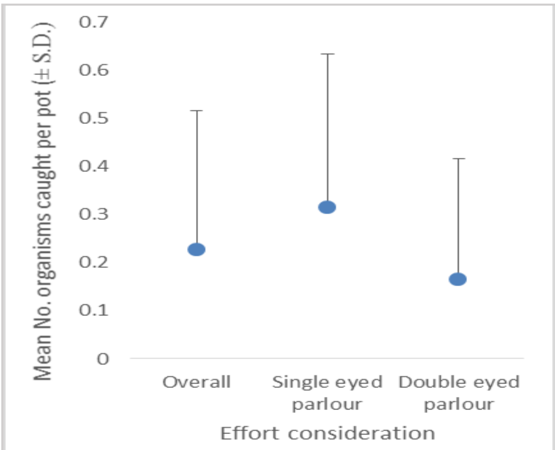
A. Figures and Tables



Appendix A1- A) Northumberland coastline and its location within Great Britain. B) The boundaries of the NIFCA district from the Scottish border to the river Tyne, including 6nm offshore.



Appendix A2- Mean (± S.D.) number of total organisms caught during the experimental process, separated by pot size (Small, Medium, Large) and soak time (24hrs, 48hrs, 72hrs).



Appendix A3 –CPUE calculated using data obtained from NIFA and values considering number of entrances to a pot.

B. Literature Review

An Introduction to the Dynamics of Lobster Fishing with a Specific Focus within Northumberland Fishing Grounds

1.0 Introduction

Through the decline of pelagic and demersal fish, the economic importance of shellfisheries has grown in recent times (Turner et al. 2014). This growth has cause a requirement in understanding how biological factors can impact the catchability of a target species, and how effective current potting methods are. The Northumberland shellfishery is an area where species such as the European lobster (*Homarus gammarus)*, velvet swimming crab (*Nectora puber*), prawns (*Nephrops norvegicus*), and brown crab (*Cancer pagarus*) have a significant impact on the local economy (Turner et al. 2009b). In this area, European lobster is targeted preferentially by pot fishers' due to it being the most commercially important species found here (Bannister 2006). The Northumberland Inshore Fisheries and Conservation Authority (NIFCA) manage and regulate the fishery, up to 6nm offshore. Despite various NIFCA regulations, it is believed that Northumberland lobster stocks are in decline due to persistent exploitation (Cefas 2011). This highlights a need for an effective and accurate stock assessment method. Many fisheries assessments rely upon annual indices of stock abundance based on catch and effort data. Catch Per Unit Effort (CPUE) is often found as an unreliable indicator of stock abundance and distribution, particularly when investigating baited trap fisheries (Fogarty and Addison 1997; Skerritt et al. 2015). Calculating effort across a fishing fleet is difficult as many factors can impact the efficiency of fishing. Alongside a clear and reliable measurement of stock, there needs to be compliance from fishers to regulations in place. Effective management preventing stock decline and collapse will only work if an ecosystem based approach is adopted and fishers' views and knowledge are accounted for. Not only is an understanding of the behaviour, distribution, and population of a focal species required (Skerritt et al. 2015), but a social understanding of fishers' behaviour and relationships is also equally as important.

Here we debate the biological factors and potting methods potentially impacting general lobster catch. We go on to introduce the Northumberland district for lobster fishing, investigating current trends and methods used in the industry. The current regulations and bylaws relating to shellfishing within the district will also be introduced and the efficacy will be discussed. This report will also highlight potential benefits in using fishers' knowledge to aid in informing management strategies, and how understanding their social networks may aid in the success of regulations. We also debate the appropriateness of CPUE as an abundance measure for shellfisheries.

2.0 General factors affecting lobster fishing

2.1 Lobster biology and catchability

An understanding of the basic biology of the European lobster, *H. gammarus*, is key in the successful management of the species. For example, a lack of early benthic phase (EBP) creates difficulty ascertaining the success of management and enhancement programmes, and accurate stock assessment (Sheehy and Bannister 2002). Biology also impacts the catchability of a species, with previous studies demonstrating dependence on biotic factors such as sex, size, and moult status. Environmental factors such as current and water temperatures can also have an impact. It is fundamental to understand catchability trends for improved stock assessments which rely on trap data (Smith and Tremblay 2003). However, catch rates are subject to additional factors, causing uncertainties, such as selectivity and saturation effects, escapements, species interactions, seasonality (Frusher and Hoenig 2003), changing of area and bait attractiveness, and gear design (Montgomery 2005). Understanding how external factors influence observed catch is often summarised as catch probability and effort. This means that data can be standardised to be more representative of actual abundance of the target species. Four key factors may determine catchability: the ability of an individual to detect the bait, seasonal and diurnal patterns, its willingness to enter the trap, and its ability to locate the trap in the first place. Complex interactions between physiological, behavioural, biological, and environmental factors, influence each process (Fogarty and Addison 1997; Montgomery 2005). Regardless of configuration or design, all baited traps are selective in sampling both target and non-target populations. Despite some aspects of trap design (e.g. the entrance diameter, escape vents) creating some intentional selectivity, the majority are not.

UK shellfisheries are mainly mixed-species in nature, which led to the study of inter-specific and intra-specific interactions and their impact on catch rates and catchability. Previous research has shown that same-sex lobster pairings were lower than expected, and that the presence of lobster significantly lowered the catchability of crab species (Skerritt 2014). This has shown a danger in analysing crab and lobster data as independent from each other, and highlighted that a direct index abundance cannot be drawn from CPUE alone (Watson Iii et al. 2009). Proximate and ultimate causes may create interactions, including competition for limited resources such as shelter or food (Bennett and Brown 1979). A generally cryptic and solitary nature of lobsters causes the display of agnostic behaviours when they do interact and compete (Rossong et al. 2006). The foremost factor affecting which individual is victorious in an encounter is relative size (Hyatt 1983). General condition and moult stage of the individual are other factors that may impact success (Tamm and Cobb 1978; O'Neill and Cobb 1979). As lobsters grow there are phenological changes to their behaviour patterns, leading to less time sheltering and more time foraging (Ramsay et al. 1997). Unless the diameter of the entrance is a restriction, larger lobsters may have less inhibition in entering traps (Skerritt 2014).

The majority of studies on lobster interactions are limited to semi-natural mesocosms or laboratories, including interactions with heterospecifics, conspecifics, and traps themselves (Miller 1990; Fogarty and Addison 1997; Rossong et al. 2006). A few studies have also used in situ diver observation (Miller 1995). The reduction in catchability caused by interactions can be effectively demonstrated by laboratory studies, however the comparability of this to actual catch data is unknown (Miller and Addison 1995; Jury et al. 2001; League-Pike and Shulman 2009). Outside of Canada and North America, there has been little attention paid to interactions (Addison 1995). Stock assessments usually rely on CPUE from fisheries-dependent catch data, and do not include interaction data. Ignoring the changes in catchability resulting from multiple species caught may lead to implications in fishery's management, through inaccurate representation of stock health (Addison 1995).

A study conducted in Bridlington Bay, UK, determined that the presence of one *H. gammarus* within the parlour of a trap significantly reduced the presence of conspecifics within the same catch (Addison 1995). A US study found similar results, with presence of *H. americanus* shown to reduce catch rates of conspecifics (Tamm and Cobb 1978). However, the US study had very few replications and a similar study conducted in Blyth, UK, found that one *H. gammarus* within the parlour of the trap did not significantly impact subsequent catch rates of conspecifics (Skerritt et al. 2015). Despite this, the differences in results could, in part, be due to local disparities in lobster catch rates, and differences between species. Catchability may also not be constant with density of target species; areas where lobster populations are believed to be higher have shown different results. Addison (1995) found that, regardless of surrounding density, one lobster was the most common number observed in a trap. In the context of using catch data for assessment and monitoring of a fishery, this could have important consequences (Bannister and Addison 1986). Both a random or even trap catch could be viewed from an aggregated distribution of lobsters along the seabed (Fogarty and Addison 1997). Therefore, it may not be possible to draw crustacean density using CPUE from baited traps (Fogarty and Addison 1997). The interactions between individuals inside and outside baited traps may be one of the main factors limiting the catch of *H. gammarus* and *H. americanus* (Tamm and Cobb 1978). Most studies, including laboratory and some field studies, have been conducted in the US with *H. americanus.* Showing occurrence of both inter- and intra- specific interactions leading to reduced trap saturation and subsequent entry of individuals (Rossong et al. 2006).

Another factor which may significantly impact lobster catchability is habitat. This may be due to topography or increased shelter availability; as lobsters rely on olfactory sense to locate bait, the hydrodynamics of bait odour plumes can be influenced by bottom complexity. This alters the area of bait influence (Weissburg and Zimmer-Faust 1993). Studies conducted on *H.americanus* found that the highest densities of lobsters were found on rocky habitat, yet the highest trap catch rates were found on homogenous sediment (Geraldi et al. 2009). This suggests that lobster catchability is altered by utilisation of habitat; during periods of vulnerability, hard, complex habitats are used primarily for shelter, and foraging is conducted on unstructured sediment habitat. Flawed abundance estimates can be drawn from misinterpretation of catch data and discrepancy in catchability. Odour plume released by bait is what attracts animals to the trap, therefore the shape of the area fished by a trap is likely dictated by seafloor topography, foraging behaviours and water currents. Certain habitats or obstructions may constrain the effectiveness of a trap and the catchability of the target species (Skerritt et al. 2015).

2.2 Potting methods

There is variance in potting methods between location within the UK, in terms of number of pots used per fleet, materials used for pots, distance between pots, size and weight of the anchor-weight, and the pot size and weight itself (Gunning 2012). A standard practice for fishing in the UK uses ‘fleets’ of 10-30 baited pots. This is where the pots are attached to a ‘mainline’ by 2-3m lengths of rope (Stephenson et al. 2017). Pots are traditionally evenly spaced, every 10 fathoms, along a mainline, with anchor weights at each to prevent dragging from strong currents or wave action. Retrieval is facilitated by marker buoys attached to each end of the fleet, using a rope twice the length of the maximum water depth. The first anchor-weight and buoy-line are dropped into the water to initiate deployment, the remaining pots and second anchor-weight and buoy line are pulled over board by the movement of the vessel along the fishing ground and the weight of the anchor (Stephenson et al. 2017). Once deployed, the pots are left to fish (soak) for 1-3 days, depending on size, weather, and ability to return to the fishing ground. Retrieving the pots (hauling) is the same process in reverse. Most fisheries use baited stationary parlour traps to attract animals. Traps are a relatively inexpensive tool, used extensively as a tool for population studies, and in commercial fisheries. They can also be deployed in any configuration, in any habitat, from small vessels, with minor damage to habitat or catch when compared to mobile gear. Nevertheless, indices of abundance assume that the surrounding population is represented by the catch from traps, which may not be the case (Skerritt 2014).

2.3 The ideal trap

Miller (1990) comprised a review of the factors impacting trap efficiency, concluding on what could comprise the ideal trap. A proposed model split the capture probability *P(C)* into four parts:

$$P(C) = P(E)\,P(I)\,[1-P_1(X) - P_2(X)]$$

The probability of encountering a trap is represented by P(E); P(I) represents the probability of entering encountered trap; $P_1(X)$ represents the probability of escape by the entrance; $P_2(X)$ is escape through a different part of the trap. For a trap to be ideal the probability of escape would be low and the probability of encounter/entry would be high for desired species and size. It would be the opposite relationship for non-commercial species and individuals too small for commercial purpose.

The ideal trap also relies upon the relationship between trap design and bait. The ideal bait should produce odour trails attractive at lower concentrations, will remain attractive during soak periods, and will not be consumed entirely by initial catch. A desired trait may also be to repel unwanted species, examples include placing dead crab inside the trap to dissuade conspecifics. The odour trail should also lead the desired animal to the entrance of the trap and the entrance should be easy to enter, otherwise effort may outweigh reward. However, an entrance size difficult to enter or location difficult to find may exclude undesired species. Factors such as increased trap size, bait quantity, and soak time may reduce potential catch limitation due to saturation affects, alongside preventing captured animals from reencountering the bait or entrance. Size selectivity of catch can be regulated through selection of mesh size, and shape and size of escape ports. Further escape of desirable catch can be reduced by adding a second compartment, keeping catch away from the entrance and away from the bait, and making the entrance as small as practical.

Miller (1990) also recommended two further improvements still available to trap fishing. Directing the bait odour to only leave through the entrance, enabling traps to fish faster and soak times to be made shorter. Although this may make the trap more efficient, introducing a quicker soak time to fishers may not be beneficial. Fishers tend not to haul traps more than once every 24 hrs, hauling them with increasing frequency would be impractical, and increasing efficiency of traps may increase the chance of trap saturation in shorter periods. The second improvement suggested involved the limitation to catch level related to potential repelling stimulus released by captured animals. The prevention or masking of this signature might significantly increase catch per trap haul. However, increasing the catch per trap haul and being unable to practically decrease soak time, then organisms within traps may become stressed further and cause damage to each other, leaving them less desirable commercially.

3.0 Lobster fishing in Northumberland

The Northumberland shellfishery stretches from the northern boundary of Northumberland down to the River Tyne. The Northumberland Inshore Fisheries and Conservation Authority (NIFCA) manage inshore fishing (to 6nm off coast) within the boundary (Fitzsimmons et al. 2015) (see figure1). Four main commercial shellfish species are relied upon within Northumberland, and the North East of England: European lobster (*H. gammarus*), nephrops (*Nephrops norvigicus*), brown crab (*Cancer pagarus*), and velvet swimming crabs (*Necora puber*). All four species are targeted by shellfish fishers using static baited traps (Turner et al. 2014). These species overlap in attraction to bait and spatial distributions (Smith et al. 2001); therefore, causing a multi species fishery as exclusively targeting one species is difficult. Interactions are most likely to occur are between *H. gammarus* and *C. pagarus*, resulting from overlap in design of trap targeting them and areas they are caught. Lobster is distributed from the shore to approximately 60m depth, in rocky substrata along the coast (NIFCA 2013). Potting is restricted geographically by potential conflict with trawling vessels offshore, and habitat availability. Throughout the district the extent of suitable habitat varies, extending beyond 12 nm in the north, and restricted to within 6 nm in the south (Stephenson et al. 2017).

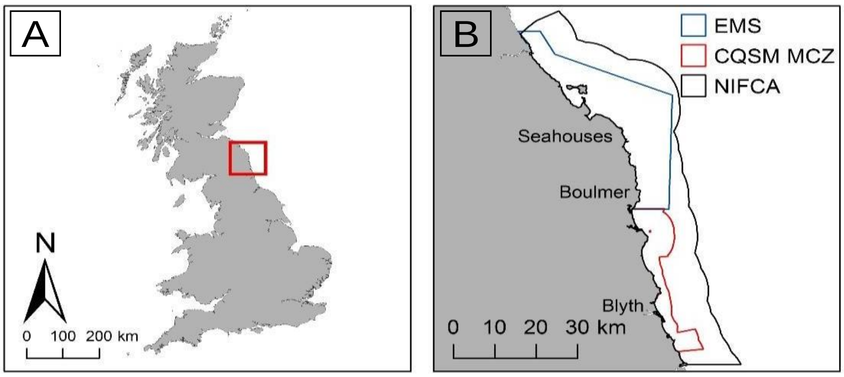


Fig 1 – (Garside et al. 2003) The location of Northumberland within Great Britain (A). The NIFCA district within Northumberland, highlighting the North Northumberland Coast European Marine Site (EMS) and the Coquet to St Marys designated Marine Conservation Zone (MCZ) (B).

There is no standard pot (trap) design used throughout the district, with variable dimensions, entry design, mesh sizes, and internal structure of pot, and many fishers choose to use more than one type of pot and build their own (Garside et al. 2003). Soak times vary between fishers and pots, depending on prevailing weather conditions, and returns from fishing. The typical period is to haul gear every 1-2 days at the height of lobster season, but pots may be left in the water longer if catches are low or poor weather prevents fishing (Turner et al. 2009a). Most pots are multi-purpose, deployed at different times of year on varying ground types to target particular species. Certain species can be excluded from pots through design, for example prawn traps preclude entry of larger lobsters, and some hard eye pots prohibit the entry of mature crabs. However, most pots can be used to target lobster if appropriate location is chosen for deployment. Within the district, potting vessels range in length between 4-12m, varying from fast workers and catamarans to traditional cobles and keels (Turner et al. 2009a).

Despite the fishery being mixed species, the most economically valuable part of the catch is lobster, therefore is preferentially targeted by fishers. In 2008, 204 tonnes of lobster were landed in the district by 132 potting vessels (turner et al 2014); with a market demand in mainland Europe, lobster is a high value species. Peak lobster season occurs from July – October; outside of this, species other than lobster are targeted by deploying pots on different ground types (Garside et al. 2003). Many vessels use potting to subsidise other forms of income, meaning they are operated part-time or seasonally, sometimes combined with other fishing gear. Potting vessel range between 4 and 12m in length, and are able to work an excess of 2000 pots, within the region (Turner et al. 2009a). Among the 11 ports within the NIFCA district, there are social variances; located in the south of the district are larger, more urban communities who in addition to potting vessels also rely upon trawl fleets. The smaller, more rural ports in the north of the district are close knit communities, considered to be more traditional. Fishing forms a component of local tourism, and is often undertaken by the same families, passed down through generations (Turner et al. 2009a). Seasonal and part-time fishers entering the fishery have caused social stratification in the southern regions, as often they have little or no fishing background.

A relatively small study conducted across the NIFCA district found that the lobster population concurs with more extensive studies conducted in other locations. Cooper and Uzmann (1980) observed equal sex ratios in catch data in the Northwest Atlantic, which corresponds with a 1:1 sex ratio found in Northumberland (Wallace 2015). However further investigation is required within the area as findings conflict with that of Thomas (1955), who suggested that sex ratios of *H. gammarus* across the UK is unequal. Research conducted by NIFCA found that 77% of individuals were below Minimum Landing Size (MLS) for the region, and that the average size distribution of catch was skewed towards smaller classes. The mean length for both sexes was found to be below MLS (Wallace 2015). The increased targeting of larger individuals, above MLS, within a fished population would reduce the mean length of the whole population, with fewer individuals reaching larger size classes (Woolmer et al. 2013). Lobsters above MLS are less able to escape traps with greater ease than smaller animals (Wiig et al. 2013), meaning the representation of larger lobster may not correlate with true abundance. Further research is required to determine whether the Northumberland stock is naturally led towards a smaller size class (Skerritt et al. 2015).

4.0 Current regulations in Northumberland pot fishing

Shellfisheries stocks have been exploited beyond recommended levels in recent times, including lobster and crab (Cefas 2011); despite this UK lobster fisheries have limited management in place. Measures are often enforced by local bylaws (Turner et al. 2014). Increased gear and vessel efficiency has seen departure from the traditional seasonality of potting, turning the industry into a year-round activity (Phillipson and Symes 2001). Previously, concerns about the long-term sustainability of the fishery were raised as anecdotal evidence showed increased investment in specialized potting vessels and fishing gear. Through this a rights based management system was considered (Defra 2013) Within the Northumberland district, there is a European Marine Site (EMS), alongside a designated Marine Conservation Zone (MCZ) proposed from St Marys to Coquet (Fitzsimmons et al. 2015). The important environmental standing of the area highlights the requirement for strong, inclusive management strategies to allow for a successful and healthy stock. The cultural, social, and economic factors associated with fishing activities must also be considered when implementing regulations, as they can potentially undermine management measures through unanticipated changes to fishers' behaviours (Fulton et al. 2011).

Within the district it is believed by fishers that not all fishers meet all of the regulations, with a few fishers believing that more patrols are needed to regulate landings and harsher reprimands for those breaking regulations (Pers. Comms.).

4.1 Potting limitations within Northumberland

Northumberland lobster stocks are believed to be declining (Cefas 2011); to tackle this a pot limitation was introduced by NIFCA in 2009 (Bylaw 15). This aimed to manage lobster stocks through limiting potential potting activity to 800 pots per permitted commercial vessel and five permitted pots per recreational user (NIFCA 2013). Prior to the 2009 limitation, few fishers fished more than 800 pots, and despite the limitation aiming to control the effort within the fishery, fishing effort was shown to increase between 2010-11(Stephenson et al. 2017). The implementation of the limitation occurred at a time of growth for the fishery, with the potential expansion possibly accounting for the large number (Wallace 2015). There was an increase in the median number of pots fished within the district from 2006-2007, but this increase was from 250 pots per vessel to 300 (Turner et al. 2009a). Despite this showing growth within the fishery, it may prove a limit of 800 per boat to be arbitrary. The higher pot limit won't impact the effort of smaller vessels in the area but may allow new larger vessels to enter, fishing a much higher number of pots than the fishery can cope. Although the principle behind the regulation is understandable, the limit chosen may impact too small a number of fishers to affect the health of the fishery and could in some cases cause more fishing activity than the stock is able to cope with.

4.2 V notching and Minimum Landing Size

V-notching was introduced in the district in 2000; it involves removing small triangular pieces of somatic tissue and exoskeleton from oviparous females (Gunning 2012) (Figure 2). V-notched lobsters are returned to sea and as long as the v notch exists, they cannot be landed (Acheson and Gardner 2011; McLoughney 2013). Notches are not noticed by the organism and usually last for two years on a single lobster, with moults creating new growth. This measure removes breeding females from the portion of the fishery able to be landed, which increases the abundance of females and egg output (Deangelis et al. 2010). Although no peer reviewed investigation has been completed within Northumberland, multiple studies imply that v-notching could increase reproductive potential of populations (Acheson and Gardner 2011). An assessment completed in 2011 within Northumberland and Durham found that stocks may be declining (Cefas 2011). This could highlight the v-notch regulation as ineffective; understanding the credibility and accuracy of stock assessments is therefore important. Data gathered on the impact of v-notching within a stock could be presented in the Marine Directive Strategy Framework and aid in establishing future management schemes. Anecdotal evidence within NIFCA suggested that initially the v-notch system was not received well, and in avoidance of returning notched lobsters, fishers would damage tails. This led to an effective decision by NIFCA to ban damaged tails from being landed. Alongside this, a ban preventing the landing of berried hens is being considered nationwide (NIFCA – pers comms.). There is need for an independent study of the health of the Northumberland stocks and the impacts of v-notching. There should also be investigation into the efficacy of regulations and how often fishers uphold them.

Fig 2-: (McLoughney 2013) the process of V-notching (top) and the lobster tail fan with the resultant v-notch (bottom)

There is a minimum landing size, for lobsters, within the district of 87mm; measuring parallel to the midline, from the back of either eye socket to the distal edge of the carapace (NIFCA 2013). Personal communication with fishers shows that the MLS is currently appropriate, and should not be made smaller. Some fishers have expressed willing to increase MLS to 90mm, dependent on Scottish regulations following the same change.

5.0 Catch Per Unit Effort in relation to shellfish fisheries

Annual indices of stock abundance are required in many fisheries assessments, based on catch and effort data. Despite the further enhancement of statistical methods allowing further standardisation, constructing reliable stock abundance indices still proves a challenge (Campbell 2004). Catch Per Unit Effort (CPUE) is the indirect measure of target species abundance. An unchanging CPUE should indicate a sustainable harvest of target species, whereas a decreasing CPUE would indicate over exploitation. Some state that the changes in CPUE signify change to a species true abundance, however the inability of CPUE to indicate species distribution and abundance has been widely documented, especially within baited trap fisheries (Addison 1995; Fogarty and Addison 1997; Skerritt et al. 2015). Despite the regular debate about relationship between catch rates and resource abundance, it stands as an integral process of stock assessment for many fisheries (Campbell 2004; Campbell 2015). Temporal changes in catch rate were used to determine change in stock abundances, in early methods of CPUE. However, this assumes that differences in vessel efficiency can be accounted for by adjusting the nominal effort, or that catchability of target species remained constant over entire fleets (Gulland 1964). These methods are still routinely used fisheries assessments, despite the simplicity of assumptions (Campbell 2015). The variation in catchability based on the biological traits and interactions of target species has already been discussed, but catchability can also vary within a fishing fleet. The fishing power of a vessel, spatial patterns of fishing effort, and changes in overall stock abundance all affect overall catchability (Garrod 1964). This increases the number of factors that should be considered in CPUE calculations. The health of a fishery can suffer if abundance calculations fail to include the complex underlying factors, and underlying assumptions fail (Radovich 1976; Campbell 2015). CPUE calculations within shellfisheries are often defined as the weight of shellfish, or number of landable organisms, per number of traps hauled (Bennett 1974). However, this method fails to account for the varying effort and efficiency involved when looking at trap fishing. Variation in size of trap may alter efficiency, adverse weather may alter the soak time of a trap, seasonal and biological differences may change the efficacy, to name a few of the underlying factors. Methods should be developed to account for these variations, however with each fisher having varying techniques, a standardisation involving all factors may not be possible.

5.1 Trap saturation and CPUE

The saturation time of a lobster pot is the length of time a pot is left within water, actively fishing. Due to seasonal variations in weather, different preferences between fishers, and vessel availability, saturation times may vary. The average time a pot will 'soak' is 24 hrs, but this may change if adverse weather prevents pot collection, or if size of pot affects the time taken to reach maximum capacity. If the length of time between pot collection and reset varies then this could impact the actual effort taken to fish, with longer soak times hauling more stock being more efficient. Within the last 40 years there have been multiple studies into the impact of soak- or immersion-time on CPUE (Bennett 1974; Montgomery 2005). There has been difficulty in expressing the process quantitively. There is a commonly recognised negative relationship between catch rate and catch size, with catch rate reducing as catch in trap increases. Fogarty and Addison (1997) developed models to describe the process. Trap catches generally increase with soak time but this is not a linear relationship (Bennett and Brown 1979). There are no fixed saturation times or levels for traps; they can vary with choice of bait, freshness of bait, season, location of trap, and trap design (Munro and Therriault 1983). After 24 hrs, most studies found that catch rates of *C.pagarus, H. americanus, and H.gammarus* began to plateau (Fogarty et al. 1980). However, local fishermen have suggested that the catch rates of crabs are likely to be higher with in the first 12 hrs of a pot soak, and lobsters are likely to take longer to enter a trap, this is due to a preference between fresh, and slightly older bait. Crabs prefer bait as fresh as possible (Pers. Comms). Miller and Rodger (1996) found that saturation could be limited in less than 12 hrs by high density within the trap.

Still, it is impractical and unlikely for fisheries to haul traps in any less than a 24hr period; the tendency for lobsters to feed nocturnally means that greatest catch is likely to occur in a 24hr period. There is a high escapement rate within certain trap designs, meaning that observed catch only represents the catch at time of haul. Animals that may have entered and left the trap during soak are not necessarily represented.

5.2 Standardizing CPUE for Fisheries

There are various methods available for calculating stock assessment and monitoring, despite this the basis of most methods for European lobster fisheries are comprised by CPUE and catch-size data (Fogarty and Addison 1997). When calculating CPUE obtaining catch data, through commercial fishing records, is relatively easy. In contrast defining and measuring effort is problematic due to the many factors involved. There is a prevailing view that CPUE may not be an appropriate or reliable index for abundance in lobster fisheries but it remains to be used due to it being the only index available and the need for stock assessments (Fogarty and Addison 1997).

A review of methods for standardizing catch and effort data was completed by Maunder and Punt (2004)and accounted for fisheries in general. They noted that using catch rate as an abundance index assumes that catch (C) is proportional to the product of density and fishing effort:

1) $C=qEN$

Where N is population abundance, E is equal to effort, and q is the proportion of abundance captured by one effort, known as the catchability coefficient. The fundamental relationship between density and catch can be found by rearranging equation 1):

2) $C/E=qN$

Although, q only remains constant if conditions remain constant. Realistically conditions change temporally, spatially and between populations sectors. To use catch rate as an abundance of index appropriately, adjustments are required. These relate to the impact of changes in catchability over space and time, and are referred to as 'catch-effort standardisation'. Statistical models are often involved (Kimura 1981); and a number of new methods have appeared in the last few decades. Despite this, even if standardisation is applied, a linear proportion between abundance and index of abundance cannot be guaranteed.

6.0 Including fishers' knowledge in management and science

Globally marine stocks have consistently been overexploited (Boonstra and Hentati‐Sundberg 2016), and the collapse of global fish stocks must be prevented through the promotion of sustainable development and effective management techniques (Fulton et al 2011). Despite this there is a perpetual failure in fisheries management to achieve goals, often due to lacking understanding of fisher's behaviours and decisions (Salas and Gaertner 2004), and an inefficient use of the knowledge they provide.

There is a required understanding of drivers behind fisher's decisions and behaviours for effective management enforcement within a fishery. This, alongside an understanding of population, dynamics, distribution, behaviour and abundance of the focal species (Skerritt et al. 2015) are crucial in effective fisheries management. Despite fisheries worldwide facing overexploitation, fisher's behaviours and social dimensions remain understudied (Turner et al. 2014). Behaviour and decision-making within fishers is underpinned by information they gain from social interactions. There can be benefits for the Northumberland fishing industry when information-sharing networks are engaged. To accurately represent fisher's actions through management, there needs to be an understanding of impacts of equipment and fishing habits. Fisheries management strategies, worldwide, have failed through a lack of study into fisher's knowledge and the social dynamics of information sharing (Hilborn 2007). The collapse of the Atlantic cod stock can be seen as an example of management failures in recent times. If an economically important stock collapses, this not only has devastating ecological impacts but also creates widespread detrimental impacts upon the dependant fishing communities.

Fisheries management can be positively informed through understanding the dynamics of information sharing networks. This can aid managers in pinpointing individuals able to bridge information flows between managers and fishers (Turner et al. 2014). Knowledge of the marine environment can be derived from recognising the variables which underpin fisher's decision making. The influencing factors can include economic, technological, and ecological variables, such as markets, vessel power, and target species distribution (Grant and Berkes 2007). The temporal and spatial variations seen in some target species can cause uncertainties in management and fishing practices. This can be mitigated by informing decisions of where to fish with fisher's knowledge (Cashdan et al. 1983). Identifying the 'key' fishers within a network may be beneficial to managers seeking information about temporal and spatial distribution of target species, the state of the fishery and productive fishing grounds. They can also begin to understand how fishers use their accumulated knowledge and experience to adapt to changes in the environment and the resources. Central fishers may also aid in understanding and predicting the reaction of fishers to change and allow them to adjust and design effective management strategies accordingly. The opportunity to aid in informing the management of fisheries should be presented to fishers, with the aim to move towards a sustainable model. However, the data needed to inform management at local levels is lacking as fisheries are still understudied; this includes the allocation of inshore fishing activities (Defra 2013). Local managers have recognised the potential for fishers' knowledge to help accurately represent the biological resources and fishing behaviour, considered key to achieving sustainable fisheries (Defra 2013).

Concluding remarks

An understanding of the basic biology of the European lobster, *H. gammarus*, is key in the successful management of the species, through this catchability trends can be determined. These are fundamental to stock assessments which rely upon trap data. Catch rates are also subject to additional factors which cause uncertainties. These include as selectivity and saturation effects, escapements, species interactions, seasonality changing of area and bait attractiveness, and gear design. Four key factors may determine catchability: the ability of an individual to detect the bait, seasonal and diurnal patterns, its willingness to enter the trap, and its ability to locate the trap in the first place. The ideal trap relies upon the probability of escape to be lower than the probability of encounter/entry to the tap for the desired species and size. The ideal trap also relies upon the relationship between trap design and bait. The ideal bait should produce odour trails attractive at lower concentrations, will remain attractive during soak periods, and will not be consumed entirely by initial catch.

Four main commercial shellfish species are relied upon within Northumberland, and the North East of England: European lobster (*H. gammarus*), nephrops (*Nephrops norvigicus*), brown crab (*Cancer pagarus*), and velvet swimming crabs (*Necora puber*). All four species are targeted by shellfish fishers using static baited traps. These species overlap in attraction to bait and spatial distributions; therefore, causing a multi species fishery as exclusively targeting one species is difficult. Interactions are most likely to occur are between *H. gammarus* and *C. pagarus*, resulting from overlap in design of trap targeting them and areas they are caught. There is no standard pot (trap) design used throughout the district, with variable dimensions, entry design, mesh sizes, and internal structure of pot, and many fishers choose to use more than one type of pot and build their own. Soak times vary between fishers and pots, depending on prevailing weather conditions, and returns from fishing.

A pot limitation was set within the Northumberland district but there were debates about its efficacy. The 800 pot limit won't impact the effort of smaller vessels in the area but may allow new larger vessels to enter, fishing a much higher number of pots than the fishery can cope. Although the principle behind the regulation is understandable, the limit chosen may impact too small a number of fishers to affect the health of the fishery and could in some cases cause more fishing activity than the stock is able to cope with. However, the introduction of the V-notching scheme and Minimum Landing Size has been effective throughout the district and has been well received by most fishers, allowing the stock to grow.

The health of a fishery does not only depend on effective regulations but can also suffer if abundance calculations fail to include the complex underlying factors, and underlying assumptions fail. Understanding this, current CPUE calculations do not account for enough underlying factors, especially when determining effort involved. Methods need to be developed to account for more factors. Alongside this, even if a standardisation of CPUE efforts is possible, a linear proportion between abundance and index of abundance cannot be guaranteed. Local managers have recognised the potential for fishers' knowledge to help accurately represent the biological resources and fishing behaviour, considered key to achieving sustainable fisheries. The effective management of a fishery relies upon a biological and ecological understanding of the target species, alongside a social understanding of those who depend upon the resources. This knowledge alongside an operative method for assessing stock abundances will allow balanced and well researched regulations from authoritative bodies to succeed in protecting stock and preventing collapse of the fishery.

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C. Fisher Consent Form

Pot limitation and size, and the impacts on fishing in the Northumberland pot fishery

This questionnaire will inform one masters research project at Newcastle University (School of Marine Science and Technology) in partnership with NIFCA. The aim of this study is to investigate how NIFCA legislation has impacted the lobster fishing habits within the Northumberland pot fishery. It also aims to investigate how legislation has affected size of pot chosen and influences this has on fishing patterns.

The questionnaire will take approximately 15 mins and will cover aspects of your daily work potting in Northumberland.

The information from the project will be provided to Newcastle University and NIFCA and will be treated as confidential and securely stored. Following standard NIFCA confidentiality practices:

- There will be no usage or publication of data by the project authors for identification of individual people or their vessels;
- The data are not processed to support measures or decisions with the respect to particular individuals;
- The data are not processed in such a way as that damage or distress is, or is likely to be, caused to any individual;

If you would like to be provided with further information regarding this project, or have any questions, please contact: Christie Powell (c.l.powell@newcastle.ac.uk)

I,____, have read and understood the project information detailed above, been given the opportunity to ask questions and voluntarily agreed to participate in the questionnaire.

Signed:_ Date:

____

D. Fisher Questionnaire

General

Name:______________________Date:_____________Time:_______________

Home port: _______________________

Number of years potting in the NIFCA district: ___________________________

All questions in this survey refer to fishers targeting crab and lobster using baited - pots in the NIFCA district.

Pot limitation influence on gear choices

Q1. Has the pot limitation in the NIFCA district affected the number of pots you fish?

YES NO

Q2. Have you changed the number of pots you use because of the limitation?

INCREASED DECREASED NO CHANGE

Q3. Do you think potting effort would be different without the pot limitation?

Q4. Has the pot limitation influenced the size of pots you chose to use?

YES NO

Q5. If yes, then how has it influenced pot sizes used?

I use smaller pots I use larger pots There was no influence

Q6. Do you use a variation in pot sizes when fishing?

YES NO

Q7. What would you consider a small, moderate, and large pot size for potting vessels operating in the NIFCA district? (Rough measurements accepted)

Small:____________Moderate:_____________Large:_______________

Q8. Using the previous sizes given, would you say the majority of the pots you use are Small, Medium, or Large?

SMALL MEDIUM LARGE

Q8a. Do any of the pots you use contain parlours?

YES NO

Q8b. If so how many?..

Q9. Do the different sizes of pots have different soak times?

Q10. What is the average soak time of pots that you fish in the NIFCA district? (Prompt: does this vary seasonally or with size of pot?)

Q11. Do you notice an overall change in catch between pot sizes?

Q12. How has the average pot size in Northumberland changed over the last 15 years? (Prompt: stayed the same, increased, decreased)

Q13. Are you more selective of where you place your pots because of the limitations set?

Perceptions of the fishery

Q14. Do you think the Northumberland lobster stock health has changed over recent years?

Q15. Do you think current regulations aid in securing the health of the shellfish stock?

Q16. What do you think needs to be done to protect the Northumberland shellfish stock?

Fishing effort

Q17. How many times per month do you haul all of the pots you fish in the NIFCA district? Prompt: does this vary seasonally? Or with size of pot?

Q18. Has the number of potting trips you make each month increased, decreased, or stayed the same over the past 15 years? Can you expand on that please.

Appendices