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Report – Recent trends in the Northumberland brown crab fishery. Indications about the status of the stock.

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Client: Northumberland Inshore Fisheries and Conservation Authority

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Abstract

Knowledge of stock structure is essential for successful management of a fishery. This study aims to build knowledge on the Northumberland brown crab stock and explore spatial and temporal trends within the fishery. There is seasonal spatial variation within the fishery with a small inshore fishing area covered in summer with high pot densities, and a larger area covered in winter with lower pot densities with both seasons yielding similar landings by mass of brown crab. Temporally, brown crab landings and fishing effort have doubled since 2003, while catch per unit effort remained constant. It is unknown whether the population of brown crab is growing to support the increased landings or whether it is on the edge of collapse. Length-frequency analysis suggests the latter with the low densities above minimum landing size. Results gained here can inform local management and aid in future decision making.

1. Introduction

Declines of major fisheries worldwide have led to concerns about the effects of commercial fishing on stocks (Myers and Worm, 2003; Pauly *et al.*, 2005) with nearly a quarter of fish stocks worldwide depleted or in recovery from overexploitation (Branch *et al.*, 2011; FAO, 2014). Management schemes often do not sustain fisheries (Trenkel *et al.*, 2015), due to uncertainty about the structure and dynamics of stocks in many fisheries (Sumaila *et al.*, 2016). For successful management of a fishery, knowledge of stock structure is required (Begg *et al.*, 1999).

The importance of commercial shellfisheries has increased following the decline of commercial and pelagic fin fisheries (Turner *et al.*, 2009). In the UK, shellfish accounted for 31.6% of the mass of all species landed and 45.3% of the total value of landings in 2014 (MMO, 2015). In some regions shellfish made up more than 90% of landings both by weight and economic importance in 2015 (Hold *et al.*, 2015). The Northumberland potting fishery is a mixed fishery comprising brown crab (*Cancer pagurus*), European lobster (*Homarus gamarus*) and velvet crab (*Necora puber*) (Turner *et al.*, 2015b). While European lobster are the most commercially important species, brown crab consistently make up a larger proportion of the catch by mass (Turner *et al.*, 2014), however they remain understudied.

Current brown crab stock assessments are undertaken by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and require data on landings, effort, carapace width and sex of individuals (Cefas, 2014). Data collection for commercial fishing often comes from small areas to represent much larger scales (Brehme *et al.*, 2015). Assessments are undertaken for the whole central North Sea region covering Northumberland, Yorkshire and the western side of the North Sea (Cefas, 2015); with such a large region covered the structure of the Northumberland brown crab population is uncertain. The current management objective is to achieve maximum sustainable yield (MSY), which relies on age at size data collection methods (Cefas, 2014), however assessments of most shellfisheries cannot follow ageing methods as Crustacea lose age determining structures with every moult (Cefas, 2011). Furthermore previous assessments of the Central North Sea brown crab stock are based on limited landings and quayside sampling data of individuals above the legal landing size, omitting information on the proportion of the catch below minimum landing size (MLS) (Cefas, 2015). Therefore the stock of Northumberland brown crab is largely understudied.

1.2 Aims and Objectives

This study aimed to increase the current knowledge of the Northumberland brown crab fishery by using landings, vessel sightings, crab length-based and fisher social survey data to gain a holistic view of the NIFCA district fishery. The project objectives were to:

1. Analyse historic brown crab catch and effort data to determine any temporal trends or changes.
2. Spatially analyse crab landings to understand where fishing effort is attributed to crab and whether this varies seasonally.
3. Conduct length-frequency analysis of the proportion of the catch above and below minimum landing size (MLS, 130mm).
4. Determine whether fishery target patterns exist among fishermen and how accurately effort is reported.

1.3 Study Area

The study focussed on the Northumberland Inshore Fisheries and Conservation Authority (NIFCA) district off the North East coast of England from the River Tyne to English/Scottish border extending from the national tidal limit out to six nautical miles (Figure 1). The area encompasses 5 main fishing ports: North Shields, Blyth, Amble, Seahouses and Berwick as well as 9 smaller fishing locations. NIFCA allocates commercial shellfish permits; 123 were issued in 2015 with 97 active (NIFCA, 2015, pers. comm.) (Table 1).

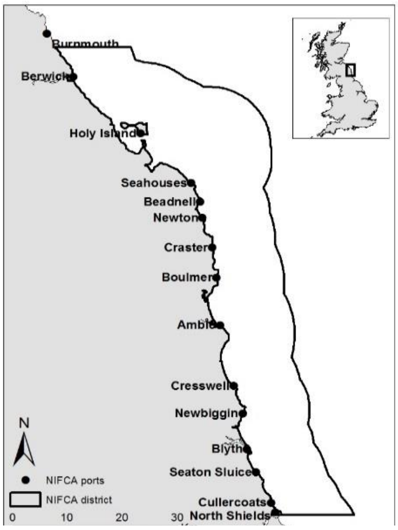

Figure 1 Map of the NIFCA district with local ports.

2. Methodology

2.1 CPUE

2.1.1 Data source

NIFCA provided landings data compiled from monthly activity returns forms from all licensed fishers in the district holding a potting permit. Details included landing port, weight of landed catch (kg) and the number of pots at sea per vessel. Data collected from 2003-2015 were provided in an excel spreadsheet. Data were available for vessels <10m for all years, but a change in reporting between 2006-2010 meant no data were available for 10-12m vessels during this period.

2.1.2 Data analysis

Data were organised in Microsoft Excel. The number of pots at sea was used as a unit of effort. The data provided information on the number of pots hauled per month, which would have given greater detail to effort estimations, however fishers do not have to declare exact values. The number of pots at sea must be declared on monthly returns forms and was therefore deemed a more reliable unit of effort. To calculate CPUE the catch (kg) was divided by the number of pots hauled per month for each vessel. Catch and effort values for 2006-2010 were estimated by adding the percentage contribution of 10-12m vessels from 2003-2005 and 2011-2015 to the data for vessels <10m.

Changes in CPUE over time were analysed using a linear model in "RStudio", version 3.0.1. A model with a negative binomial was chosen due to overdispersion of the data. A harmonic function was added to account for the inherent seasonality within the fishery (Stephenson, Unpublished). Limitations the data available mean it was not possible to separate the effort fishers apportioned to crab and lobster accurately therefore analysis was performed on effort put into the shellfishery as a whole. Further the number of pots at sea does not give any information about the number of times the pots were hauled or the soak time, only about the number of pots fishers are using per month.

2.2 Landings

2.2.1 Data source

Sightings data collected by NIFCA officers during routine enforcement patrols contained information on fishing vessel locations and observed activity of vessels sighted throughout the district from 2004-2014. Crab and lobster potting were recorded as one activity and were extracted from the data set. All sightings outside of the NIFCA district boundary were excluded. These data were anonymised and provided in an excel spreadsheet.

2.2.2 Data Analysis

Fishing vessel sightings were affected by the patrol vessel route and the frequency of patrols (Breen *et al.*, 2015; Turner *et al.*, 2015). Sightings were biased towards the South of the district due to the patrol vessel's mooring location on the river Tyne. All sightings were weighted by patrol effort following methods described by Turner *et al.* (2010). A $3nm^2$ grid was superimposed onto the NIFCA district with the assumption that any patrol vessel could accurately observe a fishing vessel and activity within this area. The number of patrol routes in each square were counted. There were vessel sightings in squares with no patrol routes, assuming that patrol effort decreases with distance from a patrol route, patrol effort can be calculated as:

$$PE = (1 - n/N) + (1 - ((D_{max}-D_g) / (D_{max}-D_{min}))) \qquad \text{(Equation 1)}$$

Where n = number of patrols passing through a grid square; and N = total number of patrols, D_{max} = maximum distance to patrol route; D_{min} = minimum distance to patrol route; and D_g = grid square distance from patrol route.

Sightings were pooled from 2004-2014 to give more accuracy and separated by season. Kernel density estimation of fishing vessel sightings in ARCGIS 10.3.1 was used to create a probability distribution of fishing activity covering areas where samples were not available. A cell size of 100m x 100m was used with a smoothing factor of 1500 as it most accurately represents the area around a point within which the data contributes to the distribution for that point (Turner *et al.*, 2010).

Percent volume contours (PVCs) were created using the Isopleth tool in Geospatial Modelling Environment (GME) (Beyer, 2012). Contours produced contain the corresponding proportion of the probability density distribution. For example a 60% PVC contains an area with 60% chance of observing a fishing vessel (Turner *et al.*, 2010); 50, 60, 70, 80, 90 and 95% contours were created and turned into polygons and the relative landings (kg per km^2) were assigned to each contour. The maps produced represented average catch (kg per km^2) for each season from 2004-2014.

2.3 Length-frequency

2.3.1 Data collection

Fishery independent size data on crabs above and below minimum landing size were obtained by setting 4 fleets of 10 double eyed parlour pots at 4 separate locations at Blyth and Seaton Sluice (Appendix II) using R.V. Princess Royal. Pots were set and left for a minimum soak time of 48 hours, after which the pots were hauled and the sex and carapace width of each crab caught were recorded. Each site was fished twice, in May and June 2016. Locations were determined by assessing habitat data and using recommendations from experienced local commercial fishers to best reflect fishing practices (Armstrong, N, 2016, pers. comm.).

2.3.2 Length-frequency analysis

Length frequency analysis was carried out using ggplot2 in R-studio 3.0.1 (Wickham, 2013). Data were sorted into 10mm size bins and a density plot produced showing the proportion of brown crab above and below the minimum landing size within the southern section of the NIFCA district (130mm). Data were separated by sex and a second density plot was produced showing variation in size between males and females.

2.4 Social survey

2.4.1 Data collection

Semi-structured interviews were conducted to determine drivers of target species choice within the fishery (Appendix III). Questions focussed on seasonal influences on decision-making, perceptions of habitat, targeting patterns, the costs of fishing and effort allocation. Questions were mainly open in order to elicit as much information as possible. Six interviews were conducted with skippers from Seahouses, Amble, Blyth and North Shields. It was not feasible to statistically randomise participant selection due to time constraints and the length of interviews, therefore a snowballing technique was used where respondents identified and referred other respondents (Atkinson and Flint, 2001). An information sheet and consent form was presented and discussed at the start of each interview. The interviews were conducted by two students, each lasting 50-60 minutes, and at a prearranged location at the convenience of the respondent.

2.4.2 Data analysis

Results were transcribed and where possible compiled into an Excel spreadsheet. Results were analysed descriptively and used to explain the results gained in objectives 1-3.

3. Results

3.1 Effort

Northumberland fishery statistics were summarised for years 2003-2015 (Table 1). Not all fishers are active throughout the year because some vessels hold shellfish permits but do not actively target shellfish (Turner et al., 2010). Active permits decreased from 2003-2011 and increased again from 2011-2015 (Table 1). In 2006 there was a change in data collection therefore the number of active permits for 2006-2009 are unavailable (NIFCA, 2016, pers. comm.).

Table 1 Northumberland shellfish permits, fishing effort, crab landings and CPUE 2003-2015.

Year	Permits issued	Active vessels (% total)	Monthly returns	Total number of pots at sea	Total landings (kg yr^{-1})	Average CPUE (kg 100 pots at sea^{-1})
2003	142	109 (77)	1383	217,737	334,363	82.1
2004	131	93 (71)	1296	222,830	390,057	87.0
2005	124	93 (75)	1228	219,241	418,302	82.6
2006	118	61 (52)	805	184,531	321,253	81.8
2007	NA	54	762	185,289	261,475	69.4
2008	NA	60	741	199,964	310,886	76.6
2009	NA	59	745	226,969	381,055	128.4
2010	121	52 (43)	611	195,917	390,949	115.0
2011	107	41 (38)	1101	345,086	542,422	82.7
2012	114	82 (72)	1084	332,471	768,385	114.0
2013	110	91 (83)	1212	354,193	797,194	108.0
2014	120	91 (76)	1413	388,575	897,215	104.6
2015	123	97 (79)	1306	397,714	882,835	103.1

The average number of pots at sea remained fairly constant with small fluctuations from 2003-2010. After 2010 there was a large increase in the number of pots at sea which continued to increase from 2011-2015 (Table 1). Overall effort (the number of pots at sea), increased over the 10 year period (Table 2 and Appendix I).

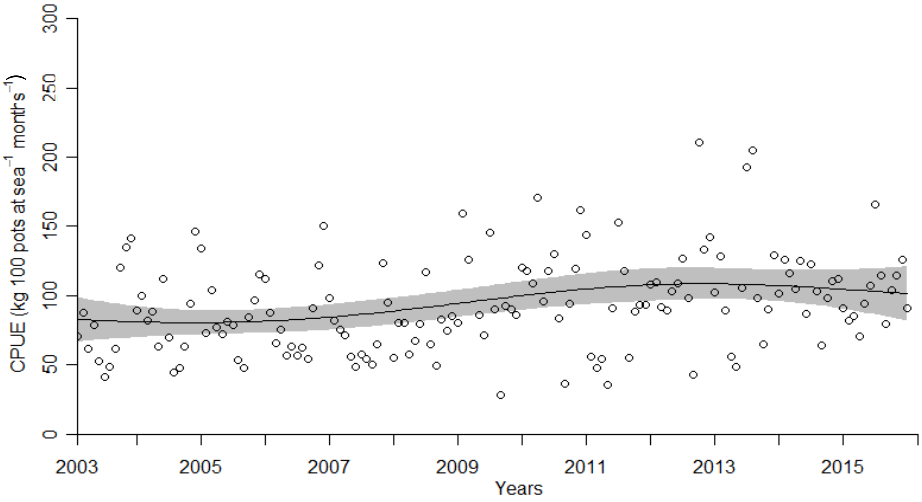

Figure 2 Monthly brown crab CPUE in the NIFCA district (2003-2015) with a line of best fit (black line) and 95% confidence interval (grey polygon) from regression coefficients in regression analysis.

3.2 CPUE

There was a slight increase in CPUE during 2003-2015 (Table 2, Figure 2). It fluctuated between 2003-2008 after which it increased slightly and remained relatively constant to 2015, apart from a decrease in 2011 (Table 1).

Table 2 Regression coefficient, standard error, z-value and p-value for analysis of CPUE, landings and effort data over time from 2003-2015 using a negative binomial regression model.

	Estimate	Standard Error	Z - value	P - value
CPUE				
Time (continuous months from 2003)	0.001	0.001	1.21	0.23
Landings				
Time (continuous months from 2003)	0.006	0.001	6.16	<0.0001
Effort				
Time (continuous months from 2003)	0.004	0.0004	7.72	<0.0001

3.3 Landings

Total brown crab landings (kg) increased overall from 2003-2015 (Table 2). During 2003-2005 landings increased, then decreased during 2005-2007 (Table 1). After 2007 landings increased steadily to 2015 (Table 1, Appendix I). There were seasonal patterns in crab landings, with a higher ratio of crab:lobster caught from October to January (Figure 3). These peak catches coincide with lower catches of lobster within the fishery, with peak lobster catches occurring in late summer (Figure 3). Brown crab made up the largest proportion of the catch by mass for the majority of the year. There were greater

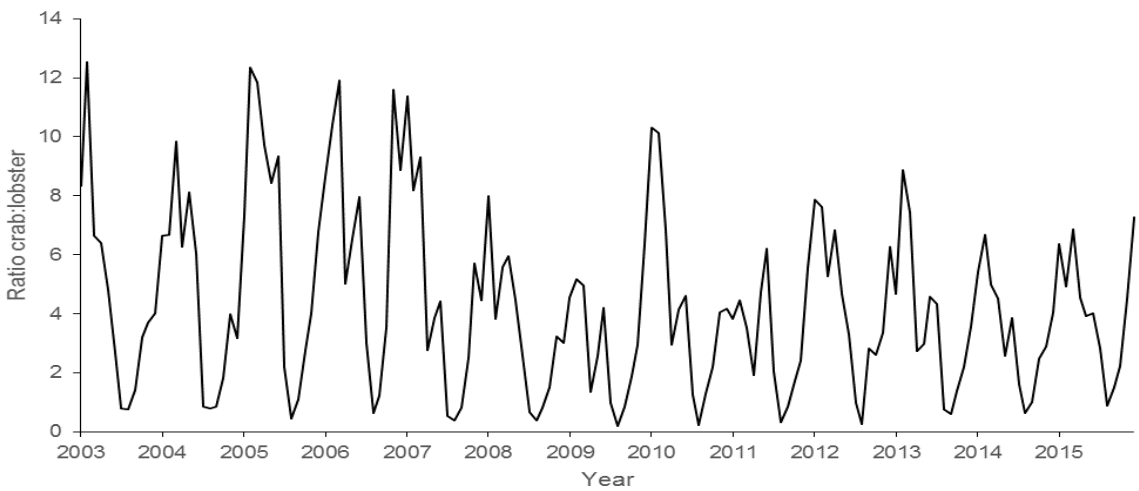

Figure 3 Monthly ratio of crab to lobster landings (2003-2015).

crab:lobster ratio peaks in winter from 2003-2007 after which the ratio decreased, apart from a peak in 2014, the ratio of crab to lobster in the catch decreased in winter months.

3.3.1 Spatial differences in landings

Brown crab landings followed spatial seasonal trends (Fig 4). In winter the area fished expanded throughout the district to 748km^2; because the area fished was larger the catch per km^2 decreased during winter to a mean of 291.7 kg^{-1} km^2 (Fig 4a). Effort was lowest in winter with a mean of 58,158 pots at sea. In summer the area fished contracted to 591km^2 and fishing was concentrated inshore. With a smaller area fished catch per km^2 increased to a mean of 566.7 kg^{-1} km^2 (Fig 4b). Effort also increased with a mean of 75,319 pots at sea. In spring the area fished decreased (722 km^2) and moved closer inshore (Fig 4c), in autumn it moved further offshore and the area expanded (703km^2). Though the area fished in autumn was smaller than that fished in spring, the catch per area was larger (autumn: 415.0 kg per km^2, spring: 325.2 kg per km^2) (Fig 4d).

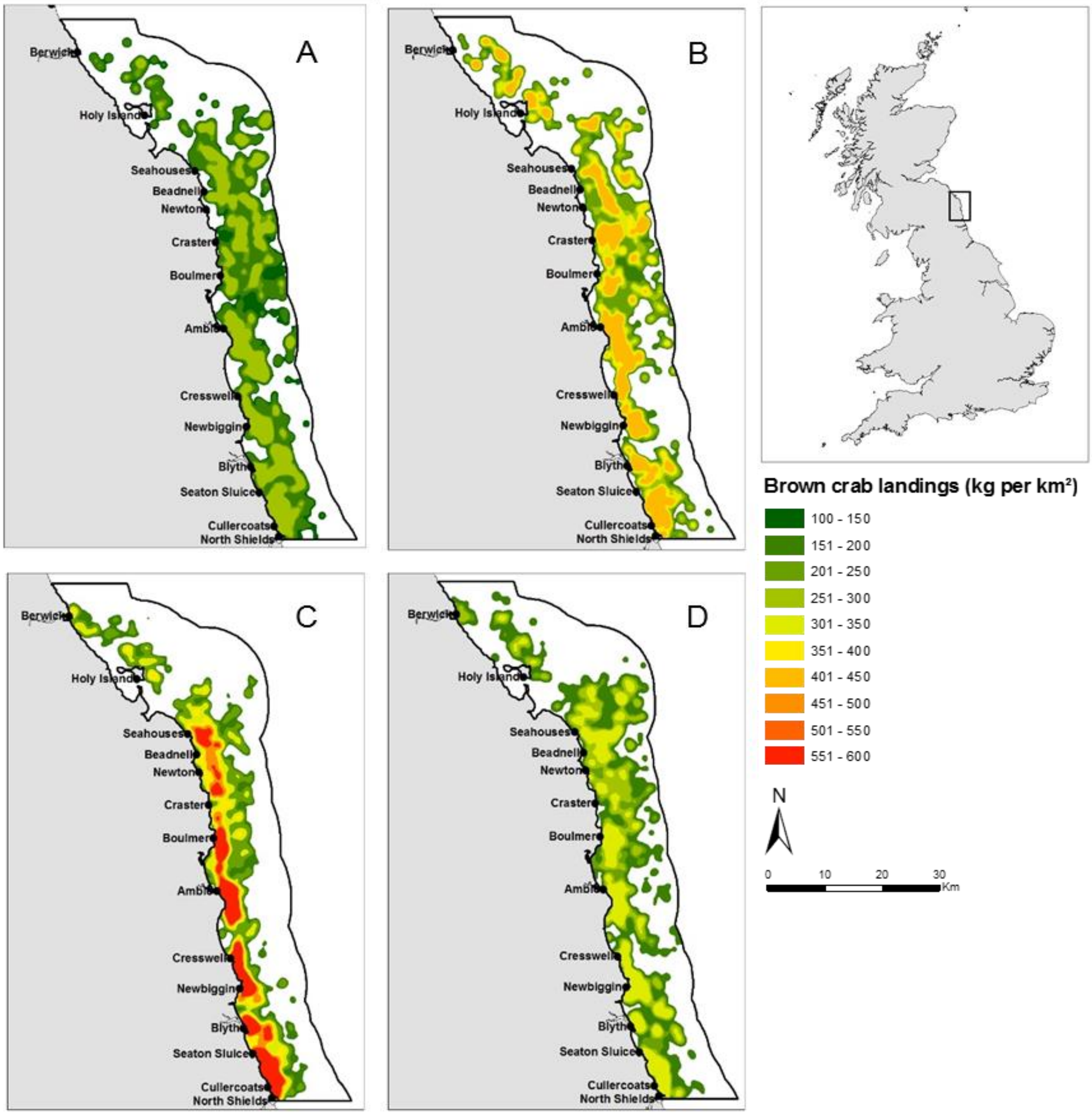

Figure 4 Distribution of mean annual brown crab landings (kg per km^2). Jan-Mar (A), Apr-Jun (B), Jul-Sep (C), Oct-Dec (D). NIFCA district (black line).

3.4 Length frequency analysis

For May and June 2016, in Blyth and Seaton Sluice, 84.2% of brown crab were below MLS (130mm) and the modal length was 91mm (Fig. 5a). Data were combined for all hauls; 152 individuals were caught in total (63.2% male and 36.8% female). The frequency peaked at 100mm after which there was a decline to the MLS. Below MLS there was a higher density of females which decreased from 105mm to 120mm. Males were more evenly spread through the size ranges below MLS, the density decreased at 115mm to 140mm. Above MLS males had a relatively constant low density, and there was a peak for females at 145mm (Fig 5b).

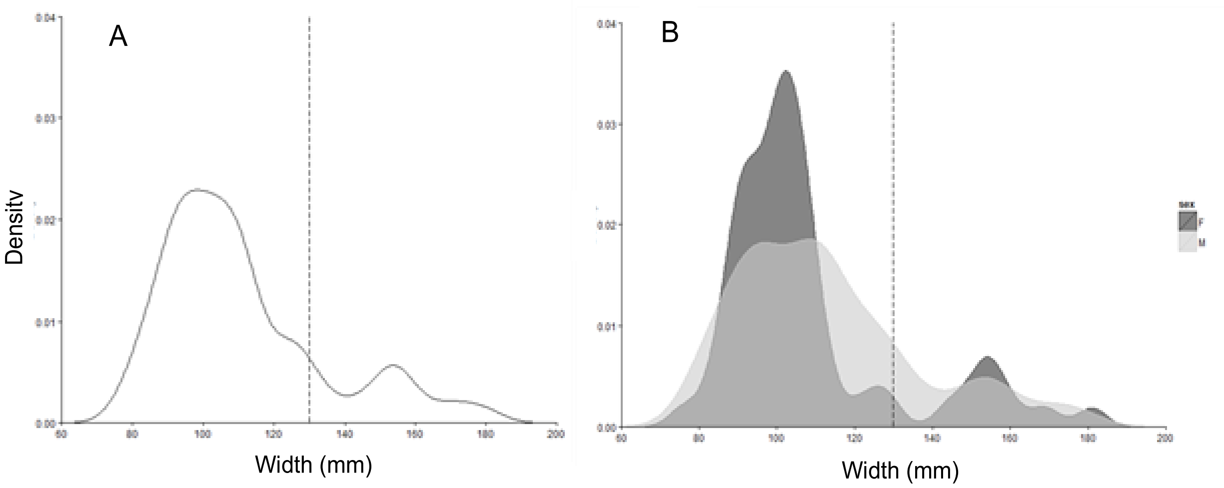

Figure 5 Size composition of brown crab, (A) overall and (B) by sex (dark grey: female, pale grey: male). MLS is shown as a dashed line (130mm).

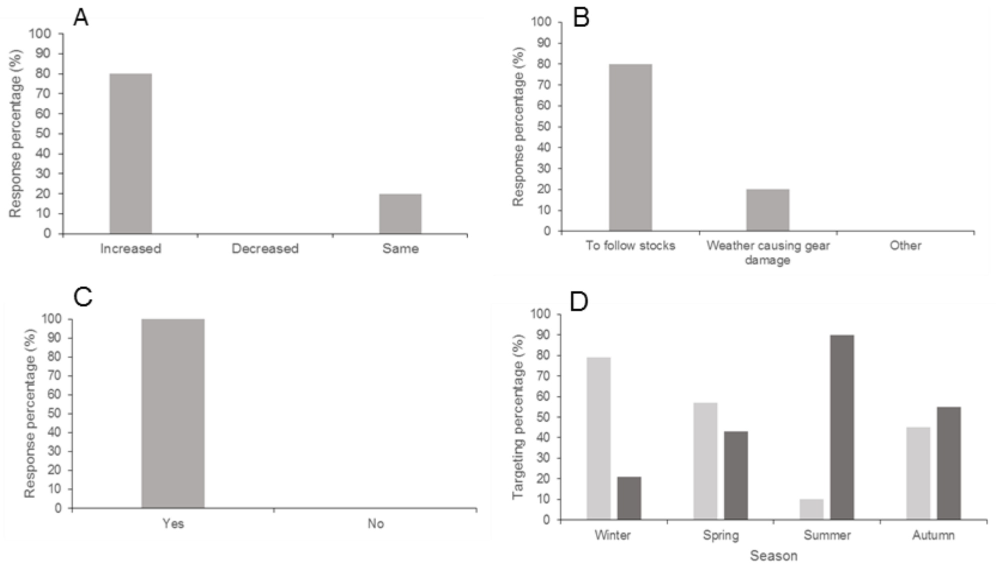

Figure 6 Fishers responses regarding the increase in technology on-board vessels (A), reasons behind seasonal changes in potting locations (B), if weather affects the number of pot hauls per month (C), the seasonal targeting of crab and lobster within the fishery (D) (crab: pale grey, lobster: dark grey).

3.5 Social survey

From 6 interviewees, 80% believed boats equipped with GPS and echosounder had increased over the past 15 years (Figure 6a). Any seasonal changes in potting locations were due to either following biological stock patterns (80%) or to limit damage to gear (20%) (Figure 6b). 100% of respondents said that weather affected the number of pots hauled per month (Figure 6c). Respondents also indicated that targeting behaviours exist within the fishery with crab targeted in winter, lobster targeted in summer and both targeted throughout spring and autumn (Figure 6d).

4. Discussion

4.1 Northumberland fishing effort

Effort increased from 2003-2015 (Table 2 and Appendix I), with the number of pots at sea almost doubling. This may have been influenced by increased vessel capability in the district over the past 15 years (Figure 6a), an increase in the use of GPS and sonar, engine size and efficiency of vessel design, which may have allowed a greater number of pots to be worked (Marchal *et al.*, 2002). These factors make the entire fishing practice more efficient and therefore the number of pots at sea must be viewed as a conservative indication of the increase in fishing power (Fahy *et al.*, 2002). From expert elicitation, it is clear that the number of pot hauls made per month is dependent upon day to day conditions, such as weather and swell, which affect fishing (Figure 6c). An increase in technological efficiency has allowed fishers to increase their knowledge and forecasting of day to day conditions leading to greater efficiency in setting and hauling pots (Tingley *et al.*, 2005).

4.2 Northumberland CPUE

CPUE has remained relatively constant, with slight fluctuations, from 2003-2015 (Figure 2) and both landings and effort have increased (Table 2 and Appendix I). CPUE has previously been used as a metric of stock health in fisheries management, however the use of CPUE to assess stocks has been questioned as CPUE may often not reflect true abundances (Gillis and Peterman, 1998; Harley *et al.*, 2001; Maunder and Punt, 2004; Quirijns *et al.*, 2008) as it assumes that the catchability of all species remains constant (Winker *et al.*, 2013). In reality a variety of factors affect catchability such as environmental effects (Maunder *et al.*, 2006), increases in efficiencies of fishing (Quirijns *et al.*, 2008; García-Carreras *et al.*, 2015) and targeting behaviour of fishers (Biseau, 1998). Therefore, it is unknown whether the stock is healthy and increasing, allowing the increasing catch trends to continue, or, whether further increase in effort and landings could cause collapse in the future. In the Alaskan pot fishery catches of the red king crab (*Paralithodes camthaticus*) increased by 95% from 1970-1980 after which they fell by the same amount in one year as the fishery collapsed; there was no indication of an unhealthy stock before this point (Litzow *et al.*, 2013).

The nature of the Northumberland shellfishery means that many factors affect the catchability of brown crab. There is inherent seasonality within the fishery with a higher ratio of brown crab in the catch in late autumn and winter (Figure 3). This trend was confirmed by fishers who stated that in winter months the proportion of crab targeted reached 70-80% but fell to 0-5% in summer when lobster were preferentially targeted (Figure 6d). Variability in weather conditions throughout the year causes the number of pots hauls to vary (see section 4.1) and therefore the amount of effort attributed to each species within the fishery varies correspondingly. Respondents describe discrepancies between the sizes of pots used and the differences in the catchability of brown crab within the Northumberland fishery. A larger pot may have the capability to catch a greater biomass than a smaller pot however further work is required to understand the effect larger pots have on catch and effort (Miller, 1990). Within the fishery catchability does not remain constant and CPUE may not reflect the true abundance of brown crab (Biseau, 1998).

4.3 Northumberland Landings

Brown crab landings followed spatial seasonal trends (Figure 4). The area fished was largest in winter as fishers moved gear further offshore (Figure 4a). Social survey results indicated that fishers do this both to follow the biological patterns of target stocks and to limit damage to gear in bad weather by placing these in deeper water (Figure 6d). This pattern was more pronounced north of Newbiggin as habitat further offshore in the south of the district is more heavily comprised of soft sediment targeted for prawns (Turner *et al.*, 2010).

Within the district, lobster is preferentially targeted over brown crab as it is more economically important (Turner *et al.*, 2010; Skerritt, 2014). European lobster generally moult in late spring and shelter until their shells have hardened in late summer (Pawson, 1995), coinciding with peak catches of lobster (Figure 3). Lobsters were targeted during this time and fishing was focussed inshore where lobsters are abundant and weather conditions allow pots to be placed in shallow water as risk of damage is reduced; the area fished was smaller than other seasons but more concentrated with higher pot densities (Figure 4c). Although brown crab is not the target species during summer, landings per km^2 were the highest for the year. Overall summer catches of brown crab were as high as winter catches over the 10-year period suggesting that the importance of the summer season for brown crab catch has been underestimated in the past.

The sightings used to construct the maps (Figure 4) were made only within the NIFCA district, however fishing activity extends beyond the 6nm limit. These offshore habitats are important targeted ground for brown crab (NIFCA, 2016, pers. comm.). Survey results showed that fishing offshore has increased over the past 15 years due to improvements to boats and equipment. Further study is required to investigate fishing outside of the district. There are limitations to the maps produced due to the difficulty in separating effort attributed to brown crab and bias in patrol effort (see section 2.1.1).

4.4 Length frequency

In light of the need for finer scale stock assessments to be carried out (Breen *et al.*, 2015; Brehme *et al.*, 2015), this study surveyed areas in the south of the NIFCA district (Appendix II). In the months of May and June 2016, 84.2% of brown crab in this area were below MLS. The modal carapace width was 91mm with a decrease from 105mm to MLS (Figure 5). If crab were fished to MLS a decrease would be expected at 130mm rather than 105mm. The abundance of smaller size classes recorded could be due to illegal landing of undersized individuals however this activity is infrequent due to penalties in place in the area (NIFCA, 2016, pers. comm.). Depth, habitat and time of year can all have an effect on the size composition of the catch (Brown and Bennet, 1980; Klaoudatos *et al*., 2013). Migration of individuals over different habitats and depths can change the size composition of the catch, with juveniles changing habitats during their growth phases (Klaoudatos *et al.*, 2013), however all sites fished were of similar depths and habitats. The time of year also has an effect on the composition of the catch, a higher number of smaller size classes have been recorded within the Devonshire fishery in late Spring (Brown and Bennett, 1980) therefore the abundance of smaller size classes may reflect the time of year this study was undertaken.

Above MLS, low densities suggest fishing mortality is high in this area. North of 56° MLS is 140mm. Increasing the MLS could prevent landing juvenile individuals and allow more time for growth and reproduction which could increase the yield of the fishery (Addison and Bennett, 1992; MarineScotland, 2016). Some wholesalers only take crabs much greater than MLS therefore crabs just above MLS may be discarded voluntarily (NIFCA, pers. comm.) At 150mm, there is a small peak in females (Figure 5b) which could be attributed to the restrictions on landing berried females or they may be more attracted to baited pots than males due to the end of an 'over-wintering' period, during which they carry eggs, remain sheltered and do not move around to feed (Klaoudatos *et al.*, 2013). Consequently, fishing may not affect larval supply (Howard, 1982).

Conclusions about the size composition of brown crab cannot be drawn confidently with the amount of data obtained. Larger spatial and temporal sampling is required to help elucidate changes in size composition of the catch and how closely the population is fished to MLS.

5. Conclusions

Both landings and effort were found to have increased significantly however CPUE remained constant from 2003-2015. Increases in landings are likely due to a greater number of pots being worked, however from the CPUE analysis it is unclear whether the population is stable and can support such an increase in landings or whether a continued increase could cause a collapse of the fishery in the future. Length frequency analysis supports the latter, with low densities above MLS, however further data collection is required to draw reliable conclusions. Results gained here can inform local management of the brown crab population and aid in future decision making regarding management of the fishery.

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Appendix I Regression analysis of landings and effort from 2003-2015

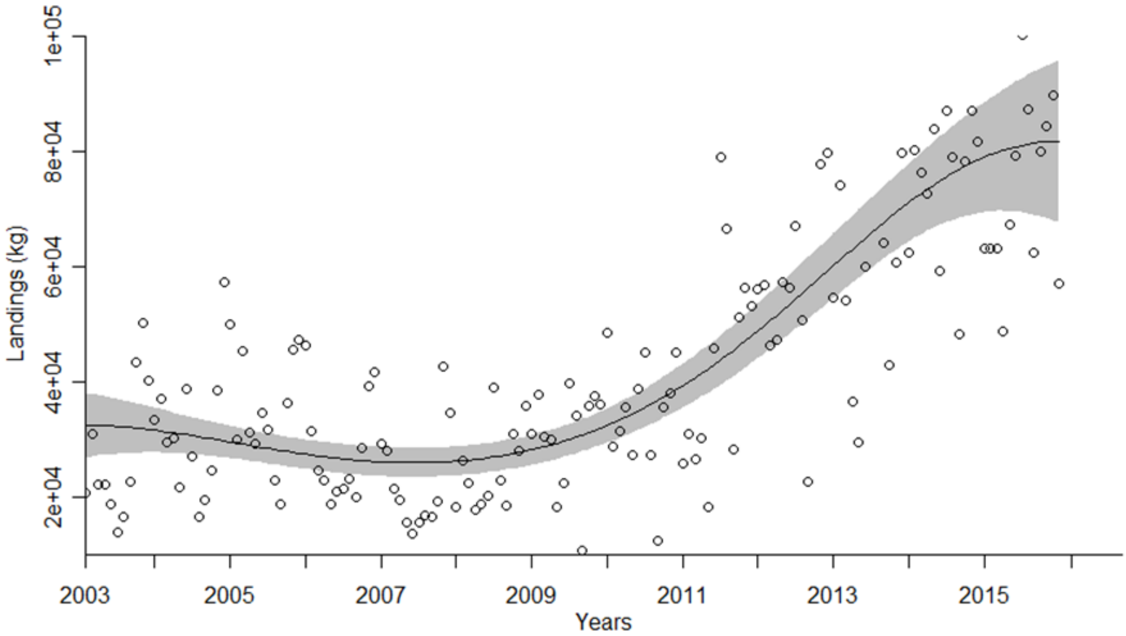

Figure 7 Total monthly crab landings (kg) in the NIFCA district (2003-2015) with a line of best fit (black line) and 95% confidence interval (grey polygon) from regression coefficients in regression analysis.

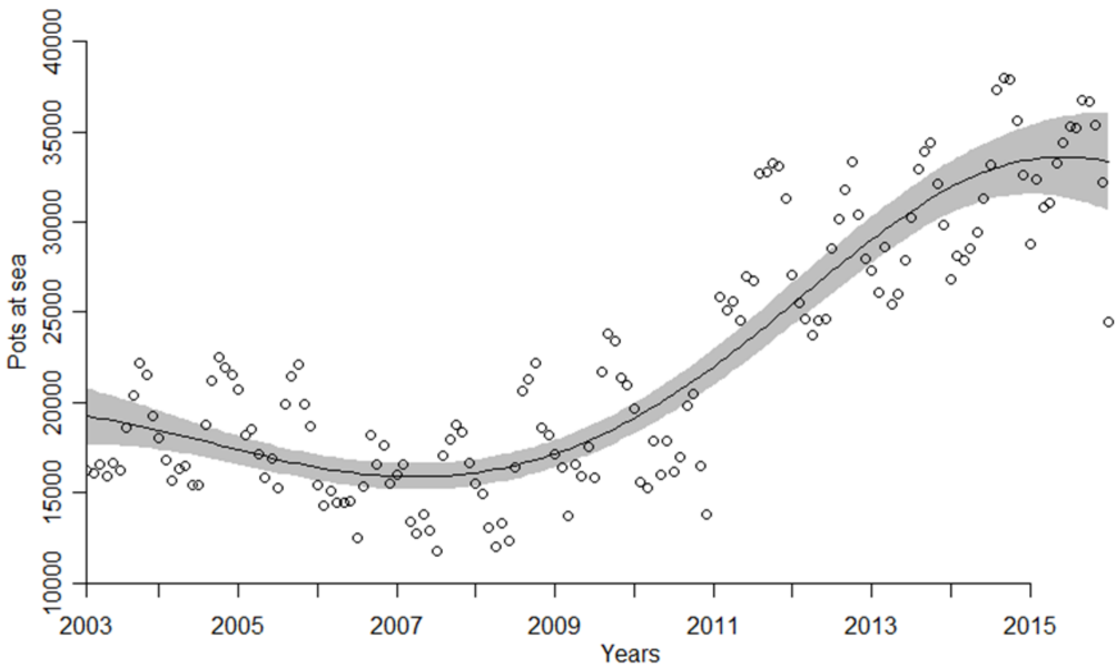

Figure 8 Total monthly effort (number of pots at sea) in the NIFCA district (2003-2015) with a line of best fit (black line) and 95% confidence interval (grey polygon) from regression coefficients in regression analysis.

Appendix II Potting locations

Site	Location	GPS
1	Blyth	55 07.66N – 001 27.88W
2	Seaton Sluice	55 07.74N – 001 26.15W
3	Seaton Sluice	55 05.60N – 001 26.61W
4	Blyth	55 05.46N – 001 22.65W

Appendix III Questionnaire

General

Name: ____________________ Date: ____________ Time: ______________

Home port: ______________________

Vessel length: ________________________ Engine size: ________________

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.

Vessel capability.

Q1. What proportion of the fleet fishing in the NIFCA district do you think has GPS equipped? And echosounder?

Q2. Has this stayed the same, increased or decreased over the last 15 years?

Q3. How has engine size on potting vessels in the NIFCA district changed over the last 15 years?

Q4. What would you consider a small, moderate and large engine size for potting vessels operating in the NIFCA district? (Range: 4 – 750 engine horse power)

Q5. How has potting vessel length in Northumberland changed over the last 15 years?

Q6. In terms of how capable a fishing vessel is, can you rank the importance of:

Vessel length:_________ Engine size:_________ Navigation equipment: _________

Q7. Have any changes in vessel capability over the last 15 years (i.e. vessel length, engine size, navigation equipment) allowed fishers to fish a greater number of pots?

Q8. Has the pot limitation in the NIFCA district affected the number of pots you fish? Do you think potting effort would be different without the pot limitation?

Q9. How do you think vessel capability (i.e. vessel length, engine size, navigation equipment) affects how far from the shore vessels are able or willing to pot?

Weather and seasonal influence on decision making

Q10. How does bad weather affect your fishing activity?

Q11. How does weather affect the distance from shore that fishers' pot? Does vessel length or engine size change this?

Q12. What determines seasonal changes in potting location?

Q13. Percentage time spent in each distance (1; 1-3; 3-6 nmi) to shore per season in your fishing area.

Perceptions of habitat

Q14. How do you think fishers determine habitat?

Q15. In the NIFCA district, do fishers move pots to soft sediment to limit damage to their gear in bad weather?

Q16. On what ground type do you think the highest number of lobster are found? And crab?

Target catch

Q17. For each season, what proportion of crab do you target and what proportion of lobster do you target?

Crab Lobster				
	Winter	Spring	Summer	Autumn

Q18. Do you target a particular habitat depending on the time of year?

Hard				
Mixed				
Soft				
All				
	Winter	Spring	Summer	Autumn

Q19. Has sonar and GPS increased the likelihood of better catches? Has this allowed new-comers to the potting fleet to be as successful as those with long-term knowledge? Why?

Q20. Out of ten hauls on the same fleet how often to you move these to a new potting ground? Does this vary depending on season?
Q21. Do you think that the actual number of crab and lobster on potting grounds changes between seasons or do you think it's easier to catch them at certain times of year?

Cost of fishing

Q22. In your opinion, how does vessel capability affect cost of potting?
Q23. Do you think the cost of fishing in the district has stayed the same, increased or decreased over the last 15 years? Why?
Q24. How does fuel price affect choice of fishing ground distance from port?
Q25. Has fuel price been an important consideration for your fishing activity over the last 15 years?
Q26. Does the cost of a fishing vessel license influence the decision to operate / buy large vessels? Why?

Effort

Q27. How many times per month do you haul all of the pots you fish in the NIFCA district?
Q28. What is the average soak time of pots that you fish in the NIFCA district? Does this vary seasonally?
Q28. What is the average soak time of pots that you fish in the NIFCA district? Does this vary seasonally?
Q29. Has the number of potting trips you make each month increased, decreased or stayed the same over the past 15 years?
Q30. Have you observed a change in the last 15 years in potting activity outside the NIFCA district?

Appendix IV Literature Review

A review of the use of catch per unit effort data and their role in stock assessments.

Alexandra Aitken

Abstract

There is a need to update and improve data collection and monitoring of fisheries worldwide. Catch per unit effort is commonly employed in fisheries stock abundance assessments. Extensive literature has highlighted that within mixed fisheries there is a variable relationship between CPUE and actual abundance as the complexity of the dynamics of such fisheries are not fully understood. Other methods which are not used by management on a large scale are critically appraised. Any method used on such a scale must take into account the complexities of the interactions to ensure effective, successful management of this valuable resource.

Introduction

The decline and collapse of major fisheries worldwide has led to concerns about the effects of commercial fishing (Myers and Worm, 2003; Pauly *et al*., 2005). Major fisheries such as that of the Atlantic cod (*Gadhus morhua*), once the largest in the world, was heavily depleted by overfishing in the 1960s and 1980s and is often regarded as an example of decline due to mismanagement (Rose and Rowe, 2015). Others such as the Japanese longline fishery have documented noticeable declines in pelagic species since its beginning (Myers and Worm, 2003). To restore and manage a fishery successfully an understanding of the composition and abundance of communities affected by fishing is required (Myers and Worm, 2003).

Much of the current management practice is to inform single species fisheries, however a significant number of fisheries are multispecies or mixed in some way (Nakamura, 2015). The complex nature of such fisheries must be fully understood as the management of one ecosystem component will depend on that of others and vice versa (ICES, 2013). These complexities have contributed to the limited success of management strategies thus far (Nakamura, 2015).

Legislative requirements of the European Union (EU) Marine Strategy Framework Directive (MSFD) and the Common Fisheries Policy (CFP) requires the improvement of data collection and monitoring of fisheries (Hold *et al.*, 2015). The main goal of the MSFD is to achieve Good Environmental Status (GES) by 2020 which is defined as ‘ecologically diverse and dynamic oceans and seas which are clean, healthy and productive’ (EU, 2008). Commercially fished species fall into this remit and are required to be within safe biological limits for both quota and other locally important species (EU, 2008). In the UK the importance of commercial shellfisheries have increased following the declines in demersal and pelagic fin fisheries (Turner *et al.*, 2009) and in some regions shellfish make up more than 90% of landings (Hold *et al.*, 2015). Management of crustacean stocks has been hampered by the inability to correctly age individuals, a parameter needed to understand the population dynamics and carry out stock assessments

(Kilada and Acuña, 2015). Assessments also require a measurement of the level of pressure of fishing activity and the reproductive capacity of the stock (ICES, 2014). This review aims to define CPUE in a mixed fishery, review the use and reliability of CPUE to asses stocks and discuss other methods identified in the literature to index stocks.

Defining CPUE in a mixed fishery

Definitions of mixed fisheries vary within the literature, how fishers and gear interact defines the type of fishery, resources used and the output (Table 1) (Pelletier and Ferraris, 2000; Nakamura, 2015). Within a mixed or multispecies fishery many species are caught at once and each species represents a proportion of the total catch (Pelletier and Ferraris, 2000) and contributes to the output of the fishery (Nakamura, 2015). In many mixed and multispecies fisheries, much of the revenue comes from few species with a larger number making up the total catch (Pascoe *et al.*, 2015). Complex interactions at all levels within a fishery make it difficult to measure and therefore manage. One way traditionally used to measure the effects of fishing on a population is by calculating the catch per unit effort (CPUE).

Table 1 Definitions of fisheries and differences between them adapted from Nakamura (2015).

Type of fishery		**Definition**
Mixed fishery		Use of several different gear types in one fishery. Mixed catch due to interaction of more than one gear type.
Multispecies fishery	Single-fleet mixed fishery	Production of a set of species by one fleet with the species proportions determined by the effort of the fleet.
	Multi-fleet mixed fishery	More than one fleet with different fishing techniques employed. May be variations in spatial or seasonal patterns, targeting patterns or effort.
	Multi-fishery systems	Multiple fleets with some use one set of techniques to fish one set of species and another to fish another set of species. Could focus on a single target species or focus on a set of species.

CPUE gives a time-series of catch rate and is typically used to calibrate stock assessments (Quirijns *et al.*, 2008) it is fundamentally based on the relationship that links catch to abundance and effort (Maunder *et al.*, 2006). It is typically denoted by:

$$\text{CPUE} = C_t / qE_tN_t,$$

where C_t is the catch at time t, E_t is the effort used at time t, N_t is the abundance at time t, and q is the proportion of stock captured by one unit of effort. The equation assumes that q remains constant, however this is rarely the case (Winker *et al.*, 2013) due to the complexity of the interactions present in a mixed fishery and the external factors which impact upon it (Maunder *et al.*, 2006) (Table 2).

Targeting behaviour in a mixed fishery

Targeting, the extent to which fishers target certain species in a fishery and therefore how much effort is proportioned to each species in the catch, is difficult to estimate as it is largely determined by fishers and can be subject to change (Biseau, 1998). A common assumption is that the direction of targeting can be ascertained from the composition of the catch (Biseau, 1998), however other factors such as gear, fishing location and time of year should be included in analysis of the target species to achieve a view closer to reality (Winker *et al.*, 2013). Target species can be identified by analysing the spatial distribution relative to the target stock, however target and 'by-catch' species could occupy similar habitats (Quirijns *et al.*, 2008). In many mixed fisheries a small set of species can account for a large proportion of the revenue (Pascoe *et al.*, 2015) with the target species being that with the highest market value rather than the most abundant. Market value could make a species very attractive to fishers even if the amount landed is very small (Biseau, 1998).

Table 2 Summary of external influences on a fishery and the impacts of these on species catchability within the fishery.

Influences	Factors that could impact catchability	Source
Market value, environmental conditions, dynamics of populations	Fishers targeting certain species	(Biseau, 1998; Quirijns *et al.*, 2008; García-Carreras *et al.*, 2015)
Management measures	Gear restrictions and closed zones	(Kraak *et al.*, 2013; García-Carreras *et al.*, 2015)
	Discarding marketable fish if quotas are too small to land all fish caught	(Quirijns *et al.*, 2008)
Fishers' decisions	Contraction of species spatial distribution leading to an increase in catch rate (hyper stability)	(Paloheimo and Dickie, 1964; Hilborn and Walters, 1992; Rose and Kulka, 1999; Harley *et al.*, 2001; Quirijns *et al.*, 2008)
	Interference between fishing vessels leading to a decrease in catch rate (hyper depletion)	(Gillis and Peterman, 1998)
Technological advances	Increased efficiency of the fleet over time	(Gillis and Peterman, 1998; Harley *et al.*, 2001; Marchal *et al.*, 2002; García-Carreras *et al.*, 2015)
	Mobility of modern fishing vessels	(Gillis and Peterman, 1998)

In the flatfish fishery of the North Sea sole is consistently targeted over plaice due to its high market value despite the prevalence of plaice in the catch (García-Carreras *et al.*, 2015). In 1992 fishers began targeting saithe over cod in the Norwegian trawl fisheries due to a change in market value of the two species (Marchal *et al.*, 2002). If targeting behaviour is not correctly accounted for it can lead to misleading perceptions of fishery dynamics with inaccurate representation of the relationship between fishing effort and fishing mortality on individual species (Pelletier and Ferraris, 2000).

Implications of management measures on a mixed fishery

Management measures change fishers' behaviour and the way they act towards a resource; they are put in place to break down any relationship between fishing effort and abundance (García-Carreras *et al.*, 2015). Measures such as gear restrictions and closed areas change the catchability of species as they restrict fishers' behaviour making it non-random (García-Carreras *et al.*, 2015), some with positive and some with negative results. One successful example is in the Gulf of St. Lawrence where a high frequency of soft shelled crabs were found in the catch. Locations where soft shelled crabs were most prevalent were closed to fishing activity in 2000, resulting in a decrease in soft shelled crabs in the catch (Swain and Wade 2003). Conversely, landings quotas in the North Sea cod fishery were put in place to limit the number of cod in the catch. Fishers continued to fish for cod and other species in the fishery while discarding any over quota catch continuing the decline of cod stocks (Kraak et al., 2013).

Review of the use of CPUE to assess mixed fishery stocks

Using CPUE as a method of stock assessment requires the use of fishery dependent data where assessments should ideally be carried out using fishery independent data collection (Maunder and Punt, 2004). This can reduce uncertainties and avoid bias due to the variation in catchability (Swain and Wade, 2003). Biases occur as fishery dependent data do not provide representative sampling as fishers aim to maximise returns (Polacheck, 2006). However the use of separate research vessels can be very costly often only covering small areas with a relatively small sample size (Murray *et al.*, 2013). Fishery dependent data in the form of catch and effort information is easier, less costly and in some cases is the only way to collect data on a fishery (Maunder and Punt, 2004). It has become one of the main indices of abundance for many species (Maunder and Punt, 2004).

An accurate reflection of relative abundance in CPUE data means a better stock assessment (Biseau, 1998), however CPUE may not always represent true abundances (Gillis and Peterman, 1998; Harley *et al.*, 2001; Maunder and Punt, 2004; Quirijns *et al.*, 2008; Winker *et al.*, 2013). The use of CPUE as a measure of abundance assumes that the catchability of all species remains constant (Winker *et al.*, 2013). In reality a variety of factors impact catchability from both direct and indirect effects of fishing (Table 2). Further, factors affecting the way effort is measured and the actual effort exerted on a fishery can also have an effect on the representation of PUE (Davie *et al.*, 2015).

Factors affecting catchability

The dynamics of a population can change the numbers of a species in a catch without reflecting the true population size. Paloheimo and Dickie (1964) described the schooling behaviour of certain species which maintains a high catch rate even if stocks are declining. They stress the importance of understanding the spatial distribution of species in the fishery as well as effort allocation to each species. This type of dynamic, known as hyperstability, means that CPUE remains high while abundance declines which can cause overestimation of biomass (Hilborn and Walters, 1992; Harley *et al.*, 2001; Quirijns *et al.*, 2008). On the other hand, interference competition between fishing vessels could lead to a decreased catch rate while abundance remains high, known as hyperdepletion, if CPUE estimates do not take into account vessels' searching behaviour (Gillis and Peterman, 1998). Spatial distribution and expansion of the fleet must also be accounted for, averaging effort over time for an expanding fleet will make assumptions about areas that have not been fished (Walters and Parma, 1996).

Environmental effects can change the dynamics of a population influencing its catchability. The effects of El Nino between 1981-1983 on purse-seine fisheries of the Eastern Pacific Ocean caused a change in the behaviour of yellow fin tuna (*Thunnus albacares*) leading to a decrease in their catchability (Maunder *et al.*, 2006). In the North Sea, unusual extensions of cold water caused physiological damage to sole (*Solea solea*) in early 1996 making them more susceptible to capture (Horwood and Millner, 1998).

Efficiencies of fishing have increased through time which can also affect the catchability of species (Gillis and Peterman, 1998) through gear improvements due to technical innovations and improvement in the skills of the crew (Quirijns *et al.*, 2008; García-Carreras *et al.*, 2015). Fishing power, in terms of amount of gear used and horsepower of the fishing vessel, consistently increased between 1980-1992 in the Norwegian cod, haddock and saithe fishery (Marchal *et al.*, 2002). Declines in catch rates may underestimate actual declines in abundance as fishers may increase knowledge on target species location and behaviour (Maunder *et al.*, 2006; Polacheck, 2006). With better technology on-board more efficient vessels, the amount of effort required will decrease (Marchal *et al.*, 2002; Tingley *et al.*, 2005).

Fishing gear catches both target species and non-target species. The species caught, whether targeted or not, are directly impacted which then impacts upon the biological interactions within its community (Nakamura, 2015). If a fleet changes targeting behaviour it will decrease the catchability of the original target species and increase that of the new target species; this will in turn impact the way species interact with each other at a community level (Maunder *et al.*, 2006). It is not possible to determine whether trends in catch rates are providing information on actual abundance or giving a biased view and, if there is bias, in what direction it lies (Polacheck, 2006).

Standardising for factors affecting catchability

All factors presented above can be influenced by external elements such as market conditions and fishery regulations (Pelletier and Ferraris, 2000; Quirijns *et al.*, 2008). The accuracy of CPUE data as an index of abundance depends on the ability to account for changes to catch rates for factors other than abundance (Maunder and Punt, 2004). Standardisation of CPUE can have a significant effect on calculated abundance with the incorrect application of standardisation methods leading to biased estimates (Murray *et al.*, 2013). Maunder and Punt (2004) summarise many of the decisions that must be made when standardising catch and effort data and conclude that with removal of all other variation in the data, the variation explained by catch-effort standardisation could be very low. They also highlight the range of techniques available to standardise data with little attempt to use the most appropriate method for the correct instances. Mismanagement of the fishery and miscommunication between stakeholders can be the cause bias in the fishery (Quirijns *et al.*, 2008).

Other methods used as an index to assess fisheries stocks

There are many methods available in the literature to both assess and model many types of fishery. Some current and novel methods are discussed along with their suitability in shelffisheries.

Stock assessment modelling methods

Many models to assess stocks of fisheries worldwide have been put forward which differ in requirements, assumptions, structure, inputs and outputs. The choice of model for each individual fishery depends on the amount of data available and the multispecies nature of the fishery (Smith and Addison, 2003). Many fisheries use size at age data which is not possible in shellfisheries (Smith and Addison, 2003) (Table 3). Accurate aging of Crustacea is not possible due to the lack of growth bands which are presumed lost with each moult (Kilada and Acuña, 2015).

Table 3 Examples of models employed in the literature to inform stock assessments with the suitability of use within shellfisheries.

Model	**Description**	**Suitability in shellfisheries**	**Source**
Biomass model	Combines recruitment, growth and natural mortality but does not account for population size or structure. Assumes CPUE is proportional to abundance	Cannot address age or size issues so unable to show proportion of population below MLS.	(Smith and Addison, 2003)
Extended biomass model	Explores effects of external factors on stocks	Include aspects such as age structure, rate of population growth and predation to a biomass model which currently cannot be directly measured in Crustacea	(Polovina, 1989; Punt, 1994)
Delay-difference model	Extends biomass model to include parameters such as time delays in biological processes (such as the lag between spawning and recruitment)	Model requires a time-series data set of catch rates and recruitment indices but can account for biological effects on catch rates	(Smith and Addison, 2003)
Depletion methods	Removals from the population are measured to assess the influence of the relative abundance of remaining population	Model also assumes CPUE is proportional to abundance and does not take into account other factors that could deplete population size. Also assumes knowledge of the abundance of population which has not been fished.	(Frusher *et al.*, 1998)
Equilibrium length based models	Provides estimates of fishing mortality from growth parameters.	Recruitment and exploitation rates must be at equilibrium. Cannot assess fishing mortality from growth parameters in animals with incremental growth rates.	(Jones, 1984; Hilborn and Walters, 1992)
Age structured methods	Measure the age-at-catch of all individuals	Limited by problems in Crustacea due to difficulty in ageing individuals	(Smith and Addison, 2003)

There are a number of approaches which aim to indirectly assess the age of Crustacea including observations in captivity to understand number of moults and time between each one (Hebert *et al.*, 2002), tagging or mark-release-capture methods (Kilada and Acuña, 2015) and size frequency analysis to define year classes (Choi *et al.*, 2007). However these methods are all indirect measures of age with differing accuracies.

The use of effort data

The use of effort data rather than CPUE to assess abundance has been discussed in the literature. Using the ecological theory of ideal free distribution (IFD), Swain and Wade (2003) found that effort was a more consistent indicator of relative distribution of the snow crab (*Chionoecetes opilio*) than CPUE. By combining a fishery independent survey with fishery dependent data they were able to compare the reliability of both techniques. Gillis and Peterman (1998) found effort data may better reflect true abundance than CPUE in the trawl fishery of the Hecate Strait; they developed an alternative index of abundance to show the distribution of fishing effort in different areas which takes into account vessels' searching behaviour and the natural abundances of different fishing grounds. This method better described the distribution of abundance of species within a fishery.

Novel methods

As technology advances, new methods to assess stocks are being tested. Vessel Monitoring Systems (VMS) are used in fisheries science to show the position of fishing vessels which can define fishing grounds, assess the condition of surrounding habitats and to document fisher behaviour (Murray *et al.*, 2013). This positional data can be combined with logbook data to estimate CPUE (Murray *et al.*, 2011) or biomass indices (Murray *et al.*, 2013) to give a spatial representation to the data. Mills *et al.* (2007) examined ways to use VMS data to estimate fishing effort showing the fishing behaviour of UK beam trawlers in the North Sea with an accurate resolution down to $3km^2$. They were able to document whether a vessel was trawling or steaming with 95% accuracy and show the intensity of trawling activity over particular areas. The use of this method in current stock assessments is limited by the lack of time series data (Murray *et al.*, 2013).

Hold *et al.* (2015) used on board video capture to document catches of brown crab (*Cancer pagurus)* and European lobster (*Homarus gammarus*) fisheries. They found this a suitable method to accurately sex and to detect growth increments. This method can also improve temporal and spatial coverage of data sets. Combining the use of on board cameras with VMS and logbooks could provide information on catch and discards which is spatially referenced (Hold *et al.*, 2015). Current drawbacks to this method include initial and maintenance costs and time consuming analysis.

Use of social surveys to index data

Chen *et al.* (2003) highlight the importance of diversity of information in fisheries which encompasses the social and economic factors that affect fisheries. Data deficient assessments tend to give a biased view and increase uncertainties in stock assessments. As some of the variation in the catchability of animals can be explained by fishers' behaviour (Biseau, 1998), the use of social survey to determine behaviour could help to inform management. FAO guidelines for an Ecosystem Based Approach to Fisheries Management state that 'understanding and management of fisheries should take into account interactions between stocks as well as social and economic considerations' (FAO, 2003), however very few studies have looked into the reliability of the use of such data collection. Jones *et al.* (2008) investigated the reliability of social surveys to inform spatial and timing patterns of the crayfish (*Astacoides granulimanus*) fishery in Madagascar. They found that interviews provided reliable information on spatial patterns, quantities and effort and could detect any changes made to these aspects with reasonable power. The use of social surveys to inform management are increasingly being employed as the need to achieve a holistic view of fisheries is realised. The use of social surveys is prevalent in tropical coastal management (Cinner *et al.*, 2009; Cinner *et al.*, 2010; Daw *et al.*, 2012) and could inform management of social and economic factors affecting fisheries worldwide, although further work is required to use such methods to effect in temperate zones, where fishers' behaviour, vessels capabilities and gear types differ.

Conclusion

Current management must update the methods of data collection and monitoring of fisheries worldwide. The reliability of the use of CPUE to assess the abundance of stocks has been questioned throughout the literature as there is a variable relationship between CPUE and actual abundance. Many techniques involving modelling and standardising CPUE have been put forward, all of which have benefits and drawbacks. New technologies allow novel techniques to be introduced, any technique employed should understand and account for the complexities of mixed, multispecies fisheries if long term success is to be achieved.

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