Newcastle University

MSc in International Marine Environmental Consultancy

MST 8023 Marine Consultancy 2016 - 2017

Report: Stock assessment - An evaluation of the minimum landing size and the pot limitation byelaw in the Northumberland lobster fishery.

James Woodruff

Client: Northumberland Inshore Fisheries and Conservation Authority

Supervisor: Clare Fitzsimmons

Contents

Table of figures

1. Abstract

The European lobster (*Homarus gammarus*) is one of the most commercially important species in UK coastal waters. Recent assessments of the Northumberland inshore fishery indicate that exploitation rates are above sustainable levels. Poor mobility can lead to considerable spatial variability in stock status and the growth rates of individuals. Given the current status of the fishery it is vital that management takes a precautionary approach and the appropriateness of current measures are reviewed. This study aims to assess the status and trends of *H. gammarus* in the fishery. In addition to evaluating the current Minimum Legal Size (MLS) of 87mm Carapace Length (CL) and the recently introduced 800 pot limitation byelaw. Catch Per Unit Effort (CPUE) was found to have increased significantly in the fishery over the last decade. However, fishing mortally rates (F) were found to be above recommended levels. F was found to be particularly high in the south of the district, and is slightly higher for males than females. Female lobsters were found to be more abundant in the samples. Although estimates for F are high, fishers on average currently only operate 316 (SE±36) pots per day. This is considerably less than the current 800 pot limit, however it is estimated a reduction to 139 (SE±51) would be required to maximise yields. Functional and morphometric Size at Maturity (SOM) were found to be 91.6mm (SE±0.2) and 84.3mm CL respectively. Functional maturity was also found to differ significantly between sectors.

2. Introduction

Lobsters are highly valued in the global seafood market and provide an important source of protein and income to many fishing communities (Bondad-Reantaso 2012). Declines in the trophic level of targeted fisheries due to overexploitation of finfish stocks has led to increased importance of macro-invertebrate fisheries (Molfese et al 2014). *H. gammarus* is the most commercially important species in the Northumberland inshore fishery, with landings valued at approximately £3 million (MMO 2015; Turner et al 2009). In addition to the value derived from landings, the inshore fleet provides communities with social and cultural benefits through employment (DEFRA 2007).

Management of the fishery is undertaken by the Northumberland Inshore Fisheries and Conservation Authority (NFICA). NIFCA has the power to draft and review specific byelaws based on local requirements and to address specific environmental and social concerns (DEFRA 2015). Recent assessments of the Northumberland fishery indicate exploitation rates are high (Masefield et al 2014). Increasing effort in the district has been a major concern over the last decade for NIFCA (Stephenson et al 2017; Wallace 2014). In order to manage further increases, NIFCA introduced an 800 pot limitation byelaw in 2009 (Turner et al 2009; NIFCA 2017), the first of its kind in the United Kingdom (Spencer 2013). This has however had little influence on fishing effort, coinciding with increases in effort in the district (Stephenson et al 2017; Masefield et al 2014). Wallace (2014) found that when questioned, fishers reported the pot limitation having little effect on their current activates, raising the question over whether a limit of 800 pots is currently too high (Stephenson et al 2017). However no research has currently been conducted in order to recommend a more appropriate limit.

Another management measure in the NIFCA district that requires evaluation is the current Minimum Legal Size (MLS) (Wallace 2014). MLS are implemented to protect juveniles and ensure sufficient spawning occurs before individuals are vulnerable to the fishery (Le Bris et al 2017). The European Union (EU) wide MLS of 87mm Carapace Length (CL) is the only management measure not created by the NIFCA (NIFCA 2017). Size at Maturity (SOM) is an indicator of the suitability of the MLS, and has been found to vary in *H. gammarus* (Lizarraga-Cubedo et al 2009; Laurans et al 2009). A number of factors have been linked to variations in SOM for *Homarus* species, including temperature (Landers et al 2001; Le Bris et al 2017), fishing pressure (Haarr et al 2017), intraspecific competition (Grabowski et al 2010), and predation (Le Bris et al 2017). In the NIFCA district high exploitation rates (Masefield et al 2014), reduced predation due to declines in finfish abundance (Turner et al 2009), and increases in water temperature (Baudron et al 2014), all have the potential to significantly influence the SOM of *H. gammarus*. It is therefore important that the suitability of the current MLS is evaluated to protect the breeding stock and optimise future recruitment.

Studies have found *H. gammarus* to be relatively immobile compared to other crustacean species, such as *Homarus americanus (*Skerritt et al 2014; Smith et al 2001). Even when taking into account larval dispersal and migratory behaviour, populations of *H. gammarus* remain unexpectedly restricted (Skerritt et al 2014). Therefore, localised differences in environmental conditions and exploitation rates likely cause significant spatial variations in stock status and SOM. Small scale difference is stock status resulting from differing exploitation rates have been observed in other lobster species, including *Palinurus* species (Goñi et al 2006), and *H*, *americanus* (Rowe 2001). Spatial variations in SOM have also been widely reported in both *H. gammarus*, (Linnane et al 2009; Lizarraga-Cubedo et al 2009; Tully et al 2001b; Fee et al 1992) and *H. americanus* (Le Bris 2017; Little and Watson 2005). It is therefore important for assessment methods to incorporate small scale spatial variation stock characteristics into their methodologies (Skerritt 2014).

2.1. Aims and objectives

The aim of this study was to assess the status and trends of *H. gammarus* stocks in the Northumberland inshore fishery, in addition to evaluating the appropriateness of the 87mm CL MLS and the 800 pot limitation bylaw as management restrictions. The project achieved this through the following objectives:

1. To identify trends in Landings Per-Unit Effort (LPUE) and fishing effort in the fishery between 2003 and 2016.
2. Provide estimations of current fishing morality rates, yield per recruit and SOM in the district, and identify spatial differences.
3. Based on these findings identify a suitable MLS and pot limitation for the district.

2.1.1. Study Area

The NIFCA district encompasses a 130 km stretch of coastline from the River Tyne to the Scottish border (Spencer 2013) (Figure 1.). The district extends from the National Tidal Limit out to six nautical miles offshore and has a total area of 1400 km^2 (See 2015). The district is made up of seven sectors used for management purposes (Figure 1), these vary significantly in size and are based on the location of fishing ports (NIFCA pers. comm.). Lobster are landed at 11 ports in the district, however the ports Seahouses, Amble, Holy Island and Blyth account for over 80% of lobster landings by weight (MMO 2015). There are currently 92 commercial lobster permit holders in the district, however only 70% of these permit holders are currently active (Stephenson et al 2017).

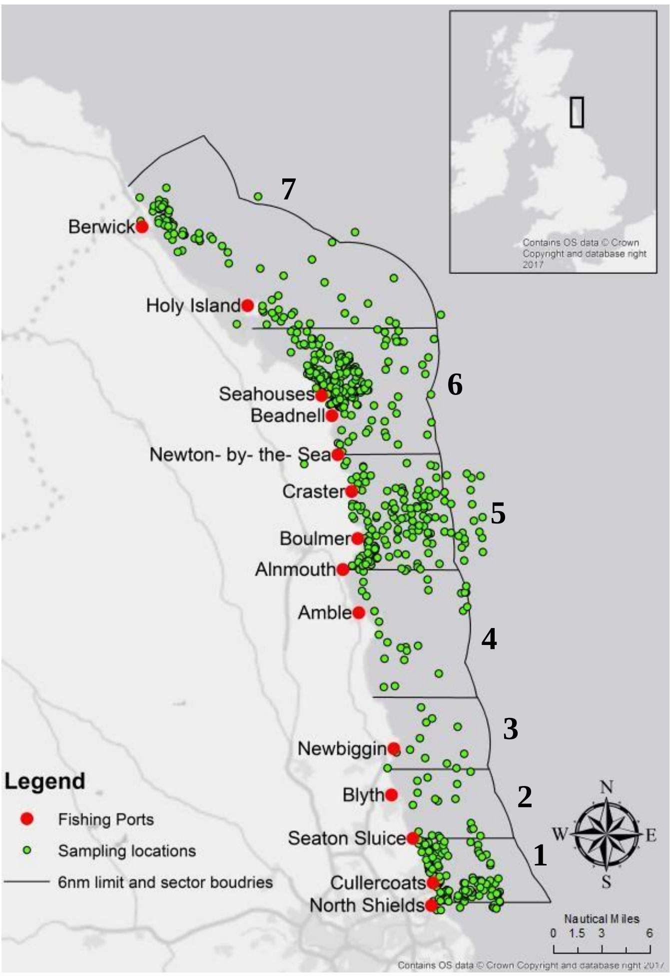


***Figure 2** . Map of NIFCA district including the numbered sectors 1-7, major fishing ports, and sampling locations for length frequency data.*

3. Methodology

3.1. Fishery assessment

3.1.1. Analysis of Permit Returns

This study used the data from permit returns submitted to NIFCA by fishers, detailing total monthly catch (Kg), and effort (number of pots), along with the location. Permit returns data were first processed and then screened for reporting errors. Prawn pots were assumed to have a negligible catchabity for legal sized *H. gammarus* (NIFCA pers. Comm.), therefore only crab and lobster pots were included in the analysis so as not to overestimate effort. To calculate effort, the average number of pots hauled per day reported by fishers was multiplied by the number of days fished. The proportion of prawn pots was then removed from the average number of pots hauled per day.

Data were then sorted into sectors based on the area fished (Figure 1). If fishing was reported in multiple areas, the sector where fishing took place was based on the reported main area fished, or landing port. Time series of Landings Per Unit Effort (LPUE) were then generated for each sector. Time series of fishing intensity were also generated, showing the number days spent fishing, along with the average number of pots deployed each day, for vessels in each sector. It was not possible to estimate MSY using biomass dynamic or surplus production models as these require the fishery to be characterised by decreasing CPUE with increasing effort (King 2007), conditions that were not found in any sectors.

3.1.2. Length Converted Catch Curve and Yield Per-Recruit analysis

To provide insight into the population dynamics of the stock, size frequency data was required in order to conduct Length Converted Catch Curve (LCCC) and Yield Per-Recruit (YPR) analyses. The data was collected by NIFCA in two ways: (i) random sampling during routine enforcement patrols, and (ii) planned sampling trips on board participating fishing vessels. Between the years 2014 and 2016 NIFCA sampled the catches of 138 vessels during routine patrols and carried out 74 sampling trips. Whilst the planned samplings only took place at sea, patrol sampling took place either at sea or at the landing port (where only legal sized individuals were sampled). The landing port of the catch was recorded, and GPS coordinates were also used to indicate at sea sampling locations. In this study the fishing locations for port based sampling, for which GPS coordinates were not available were inferred via comparison to permit returns data. This allowed the sector where the sampling took place to be located.

Length frequency data from both patrol based and planned sampling activates was used to construct the LCCC. To allow the analysis of different sectors (Figure 1), data from the years 2014-2016 were combined. Despite this, there was still insufficient data coverage for the analysis of sectors 2 and 3 and these were not included in the analysis. Data was sorted into sectors using GPS coordinates or by the comparison to permit returns. Only legal sized (≥87mm CL) individuals were included in the analysis.

LCCC and YPR analysis constructed based on the methodology used by Wel l (Equation 1) . To create the LCCC, length frequency data were converted into pseudo-ages using the inverse of von Bertalanffy (1934) growth equation (Equation 1), and the growth parameters given in Table 1.

$$t = t_0 - \frac{1}{k}\ln\left(1 - \frac{L_t}{L_\infty}\right)$$

Where t= pseudo age at length, L_t = Length at time and t_0 = age at length zero. The log transformed frequencies were then plotted against pseudo-age using R statistical software (Version 0.99.903) A regression line was then fitted to the data from when individuals entered the fishery where pseudo-age corresponded to 87mm CL (t_c), and ended when small sample sizes compromised the data reliability.

The total mortality rate (Z) was then estimated from the slope of the regression line. This was converted to fishing mortality (F) by subtracting the estimate for natural mortality (M), as s (Equation 2) , (Welby 2015; 2016 Masefield et al 2014; Tully et al 2006). These estimates for were converted into a percentage using Equation 2.

$$B = 1 - \exp(x)$$

Where B = the biomass lost as a percentage and x = removal rate. To generate the YPR curves, first the growth parameters were converted from L_∞ to weights (W_∞). This was done using Equation 3 and size/weight parameters a and b given in Table 1.

$$W = aL^b \quad \text{(Equation 3)}$$

Based on the results of the LCCC, YPR curves were generated using the method described by King (2007). This uses a series of five calculations which are summed then multiplied by the hypothetical rate of F to provide an estimate of yield per recruit for any given rate. In this analysis rates for F ranged from 0 to 2. Current rates of exploitation were then estimated based on the results of the curves. Two biological reference points $F_{0.1}$ and F_{maz} were used to evaluate the current levels of F on the stock. $F_{0.1}$ is a more precautionary reference point and represents F when the slope of the YPR curve is 10% of the slope of the origin (Hilborn and Walters 1992). In this study F_{max} was used as a proxy for F_{msy}, and is the rate of F maximises YPR. The changes in F required to meet these reference points were reported as a percentages using Equation 2. The reductions in F required to reach these reference points were combined with the analysis of the permit returns data (Section 3.4.1.) to evaluate the pot limitation bylaw.

Parameters		Male	Female	Reference
VBGF	k	0.0913	0.1088	Welby 2015; Masefield et al 2014
	L_∞	209.25	168.71	Welby 2015; Masefield et al 2014
Size/Weight	a	0.000447	0.001086	Masefield et al 2014
	b	3.01	2.896	Masefield et al 2014
	W_∞	4320.27	3059.35	Equation 2
Recruitment	t_c	5.842	6.608	Derived from LCCC

Table 2. *Parameters used in the LCCC, and YPR analyses and the reports from which they were obtained.*

3.2. Size at maturity analysis

3.2.1. Abdominal Width : Carapace Length Ratio

Use of the ratio of abdomen width to carapace length (AW/CL) of females to estimate size at maturity was first described by Templeman (1935, 1944). This method is based on observations that the abdominal width of females markedly increases when they reach maturity. Although less accurate, this method is preferable to examination of the cement glands or ovarian dissection as it is less labour intensive and non-fatal.

Only the data collected by NIFCA during at sea sampling operations containing both female CL and AW measurements could be used in analysis. To provide sufficient data for the analysis across different sectors, the years 2014-2015 were combined. Insufficient data was available for sectors 2 and 3 and were therefore excluded from analysis. The ratios of AW/CL were then calculated and averaged for each 1mm CL length. The mean AW/CL was then plotted against CL, and a nonlinear polynomial regression created for each sector using R statistical software. Increments of 0.5 mm CL were created along with their corresponding AW/CL intersections based on the regression line. The steepest part of the regression line, or 'inflection point', was then found by looking at the maximum difference between AW/CL ratio values for all of the 0.1mm increments. The infection point represents size at which 50% of females have reached sexual maturity. To analyse the difference between sectors, analysis of covariance (ANCOVA) were applied to the AW/CL ratios. These estimates were compared with the values obtained from the size frequency distribution of ovigerous female's method.

3.2.2. Size Frequency Distribution of Ovigerous Females

In addition to length measurements, details of the condition of individuals in the catch were also reported in both the patrol based and planned sampling. These included information on v-notching, shell condition and egg development. Any reference of egg development (black eggs, developed eggs, eyed eggs, hatching eggs) were included in the analysis. Data from 2014-2016 were combined to provide sufficient coverage for each sector, and port based samples were excluded from the analysis. Insufficient data was available for sectors 2 and 3. The average CL mm of ovigerous females was obtained from length frequency data, and used as an estimate of sexual maturity. Size frequency profiles were generated for each sector and the district as a whole. A Kruskal-Wallis one way ANOVA was used to compare the mean size of ovigerous females between districts.

4. Results

4.1. Trends in fishery

Trends in LPUE and the fishing effort (the number of days fished and average number of pots hauled per day) for individual vessels operating in the NIFCA district were plotted for the years 2003 to 2016 (Figure 2). This was done for the whole district (Figure 2 a and b), and for each sector (Figure 2 c-p), to provide insight into both local and general trends in the fishery.

LPUE effort for the whole fishery (Figure 2a) increased by 6kg/100 Pots between 2003 and 2016. After a period of stability between 2003 and 2006. LPUE increased from 5.5 to 11 kg/100 pots before stabilising again from 2010 to 2016. Fishing intensity in the form of days spent fishing has remained relatively stable between 2003 and 2016 ranging from 65 to 85 days fished (Figure 2b). One the other hand, the average number of pots deployed per day has increased gradually from 225 (SE±28) in 2003 to 317 (SE±36) in 2016 (Figure 2b). Trends and relative values of LPUE and fishing intensity also differ between sectors within the district.


(a)
CPUE (Kg/100 Pots)
(b)
Days Fished
Pots Hauled
(c)
CPUE (Kg/100 Pots)
(d)
Days Fished
Pots Hauled
(e)
CPUE (Kg/100 Pots)
(f)
Days Fished
Pots Hauled
(g)
CPUE (Kg/100 Pots)
(h)
Days Fished
Pots Hauled
(l)
CPUE (Kg/100 Pots)
(i)
Days Fished
Pots Hauled
(k)
CPUE (Kg/100 Pots)
Year
(l)
Days Fished
Pots Hauled
Year

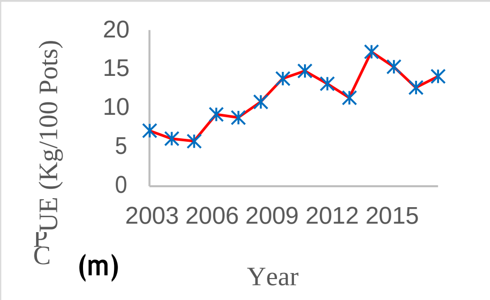


Figure 3 *Catch per unit effort (Kg/100 pots) and fishing effort in days fished and the average number of pots hauled per vessel per day between the years 2003 and 2016. Where a-b is the whole district, c-d is sector 1, e-f is sector 2, g-h is sector 3, i-j is sector 4, k-l is sector 5, m-n is sector 6 and o-p is sector 7.*

Sector 3 exhibited the largest overall increase in LPUE, with a total increase of 12.5kg/100 Pots between 2003 and 2016 (Figure 2g). The smallest overall increase in LPUE was in sector 1 at 1.6 kg/100 Pots (Figure 2c), closely followed by sector 2 at 1.9 kg/100 Pots (Figure 2e). Excluding sector 3 (Figure 2e), LPUE the northern districts (5-7) (Figure 2k; Figure 2m; Figure 2o) increased to a greater extent than in the more southern districts (1, 2 and 4) (Figure 1a; Figure 2c; Figure 2j). LPUE in all the sectors tended to be low between the years 2003 and 2006, with the lowest LPUE for most sectors in 2006. LPUE exhibited a peak in all sectors between 2009 and 2012, the most pronounced of which was in sector 3, where this increased from 6.5 to 17.7 in 2011 kg/100 Pots (Figure 2g). LPUE then tended to level off in most sectors after 2012, with the exception of sector 2 where it decreased from 17.4 to 6.4 kg/100 Pots (Figure 2c), and sector 3 where it increased from 12.4 to 16.5 kg/100 Pots between 2012 and 2016 (Figure 2g).

The number of days fished by vessels in each district was highly variable both over time and between districts. Vessels operating in more northerly sectors (6 and 7) (Figures 2n; Figure 2p) tended to fish more days each year than those in the more southerly sectors (1-3) (Figure 2d; Figure 2f; Figure 2h). Between 2003 and 2016 the average number of days fished increased in sectors 1, 3 and 6 (Figure 2d; Figure 2h; Figure 2n); but decreased in sectors 2, 4, 5 and 7 (Figure 2f; Figure 2j; Figure 2l; Figure 2p). Sector 1 exhibited the greatest increase of 30 days fishing (Figure 2d) followed by sector 6 with 18 pots per day (Figure 2n), the largest decreases were observed in sector 2 at a loss of 18 days fishing (Figure 2c).

The average number of pots deployed per day showed a gradual increase across all districts between 2003 and 2016, however this was not evenly distributed. Vessels in sectors 6 and 7 tended to fish 300-400 pots per day (Figures 2n; Figure 2p), with vessels in sectors 1-4 fishing between 150-300 pots per day (Figures 2d; Figure 2f; Figure 2h; Figure 2j). The largest increase in pots fished over the studied time period was in sector 6 at 174 extra pots (Figure 2n), the smallest increase was observed in sector 1 at 30 pots (Figure 2b). The effects of the introduction of the pot limitation are not pronounced for the whole district (Figure 2b), however noticeable increases proceeding or just following 2009 can be observed when each sector is taken on its own.

4.2. Length Converted Catch Curve and Yield Per-Recruit analysis

Length frequency data from a total of 8831 lobsters (46% male and 54% female) with a CL of ≥87mm were used in the LCCC and YPR analysis. The analysis was done for the whole NIFCA district and for each individual sector where sufficient data was available (sectors 1 and 4-7). The total mortally rate (Z), the fishing mortality rate (F) are shown in Table 2 (full table see Appendix 1).

Fishing mortality in the district as a whole is higher for females with an annual removal rate of 56% compared to 52% for males. Rates of *F* for males and females show considerable variably between sectors. Sector 1 has the highest fishing mortality rate of all the sectors at 70% for males and 79% for females. The lowest fishing mortality rate for males was observed in sector 5 and for females in sector 6, both at 53%.

Table 3. *Results from the Length Converted Catch Curve and Yield Per-Recruit analysis for each sector 1 and 4-7) and the district as a whole. Showing the sex specific total mortality (Z) and fishing mortality (F) and the required changes in F required to reach the biological reference points* $F_{0.1}$ *and* F_{max}.

Sector	1		4		5		6		7		District	
Sex	M	F	M	F	M	F	M	F	M	F	M	F
F (%)	70	79	61	61	53	60	62	53	58	62	56	52
Implications for moving to F_{max} (% change in F)	58	61	41	18	28	16	43	1	36	19	34	0
Implication for moving to $F_{0.1}$ (% change in F)	71	85	56	53	46	51	58	41	52	54	50	14

The effects of fishing mortality on H. gammarus stocks was estimated using YPR analyses, resultant curves and target reference points can be found in Appendix 2. The rates for $F_{0.1}$ and F_{maz} were found to be 0.22 and 0.74 for females and 0.19 and 0.39 for males respectively. The changes in F and YPR required to reach $F_{0.1}$ and F_{maz} are shown in Table 2.

When the data for all sectors were combined, F for females was at F_{max} with a further 41% reduction required to reach the precautionary reference point of $F_{0.1}$. The reductions in F required to reach the BRPs were higher for males than for females at 34% for F_{max} and 50% for $F_{0.1}$. When the sectors were analysed separately, the largest reductions to reach F_{max} were required in sector 1, at 58 and 60% for males and females respectively. The districts that require the smallest reductions in F to reach F_{max} were sector 6 for females (1%) and sector 5 for males (28%).

4.2.1. Reductions in fishing effort required for F_{msy}

Based the required reduction in F to reach F_{max} derived from the YPR analysis combined with effort data, it is possible to evaluate the suitability of the 800 pot limitation bylaw (Table 3 Appendix for full table). In order to operate the fishery at F_{msy} the average number of pots deployed each day by fishers in the district should be reduced from 316 (SE±36) to 139 (SE±51), or 19% of their current total potting allowance. In sector 1 where F was especially high, to reach F_{msy} the number of pots deployed would need to be 54 (SE±14). Sector 6 where fishers operate the largest number of pots per day 450 (SE±57), requires a reduction in effort to 171 (SE±97), which would be 26% of the total pot quota only.

Table 4 Current effort (2016), and sex specific reduced effort required to operate the fishery at F_{msy}, and that effort as a percentage of the 800 pot limitation; based on the results of the YPR analysis (section 4.2) and effort data (section 4.1) for each sector, sectors 1, and 4-7 and the district as a whole.

		Sex	2016 fishing effort (pot operated per day) (±SE)	Effort at F_{msy} (±SE)	Effort as a % o 800 pot limitati
Sector 1		M	181±26	54±14	7
		F	181±26	38±10	5
Sector 4		M	222±33	86±29	11
		F	222±33	86±29	11
Sector 5		M	329±28	154±43	20
		F	329±28	132±36	17
Sector 6		M	450±57	171±97	21
		F	450±57	211±120	26
Sector 7		M	380±44	160±70	20
		F	380±44	144±64	18
District		M	316±36	139±51	17
		F	316±36	152±55	19

4.3. Size at maturity anayisis

4.3.1. Abdominal Width : Carapace Length Ratios

Non-linear polynomial regressions of CL against AW/CL were fitted to the data. These curves were used to estimate the size at which 50% of Individuals reach sexual maturity ($CL_{50\%}$), in the district Figure 4, and for the individual sectors 1, and 4-7 within the district (Appendix IV).

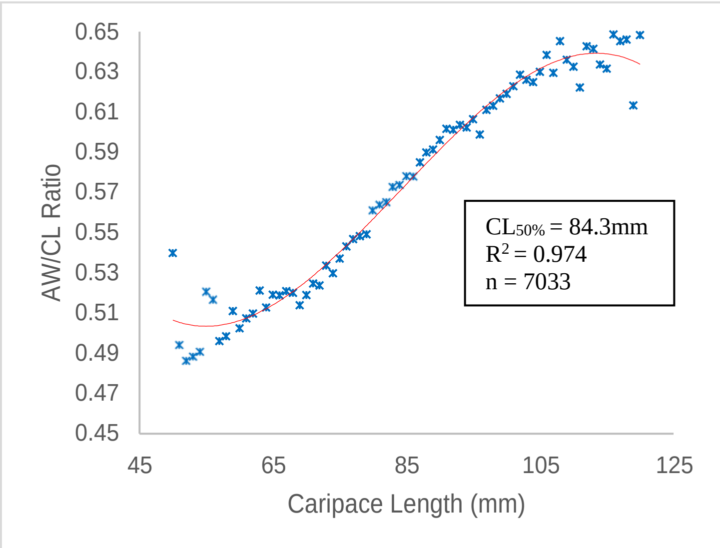


Figure 4 *Abdominal width : carapace length ratios for H. gammarus in 1mm size classes from 50 to 110mm CL in the NIFCA district*

The results showed that 50% of individuals in the NIFCA district reach sexual maturity at 84.3mm CL. An analysis of covariance (ANCOVA) showed significant variation in $CL_{50\%}$ between sectors (F (1, 4) = 2860.55, P= <0.05). A post hoc Tukey test showed that only $CL_{50\%}$ between sectors 4 and 7 differed significantly (P = <0.05), with $CL_{50\%}$ not differing significantly between the remaining sectors. The largest estimates for $CL_{50\%}$ were in the northern sectors at 84.2 and 83.1mm in sectors 6 and 7 respectively. The lowest value for $CL_{50\%}$ was found to be in sector 4 at 80mm, followed by 80.3mm in sector 5, and 81mm in sector 1

The results showed that 50% of individuals in the NIFCA district reach sexual maturity at 84.3mm CL. An analysis of covariance (ANCOVA) showed significant variation in $CL_{50\%}$ between sectors (F (1, 4) = 2860.55, P= <0.05). A post hoc Tukey test showed that only $CL_{50\%}$ between sectors 4 and 7 differed significantly (P = <0.05), with $CL_{50\%}$ not differing significantly between the remaining sectors. The largest estimates for $CL_{50\%}$ were in the northern sectors at 84.2 and 83.1mm in sectors 6 and 7 respectively. The lowest value for $CL_{50\%}$ was found to be in sector 4 at 80mm, followed by 80.3mm in sector 5, and 81mm in sector 1.

4.3.2. Size Frequency Distributions of ovigerous females

The mean size of ovigerous females in the district were calculated, and the size frequencies shown in (Figure 4). The size frequency profiles for sectors 1, and 4-7 are shown in Appendix V.

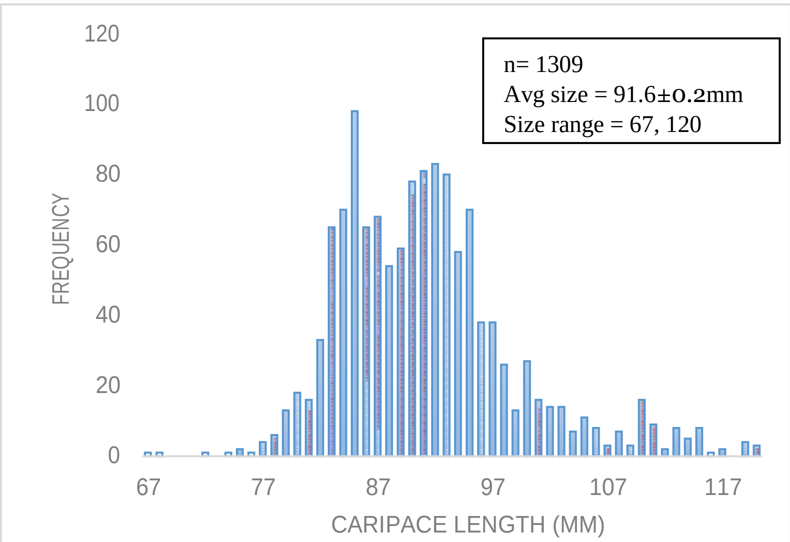


Figure 5. *Size frequency profiles of ovigerous females in the NIFCA district, including the number of samples, mean size, and range.*

There were significant differences in the length frequency of ovigerous females between all sectors (Kruskal-Wallis, H = 193.29, P = < 0.001) (Figure 4; Appendix V; Table 3). The mean size for ovigerous females in the NIFCA district as a whole was 91.6mm (SE±0.2) CL, however this varied between sectors. This was 87.6mm (SE±0.5) in sector 1, 94.3mm (SE±0.8) in sector 4, 92.2mm (SE±0.5) in sector 5, 92.7mm (SE±0.4) in sector 6, and 91.2mm (SE±0.5) in sector 7. The mean CL for ovigerous females in all five sectors analysed were significantly different from each other. The smallest ovigerous female observed in the study was 67mm CL and the largest was 120mm CL, the greatest size frequency for ovigerous females was 84mm CL.

Table 5 Multiple comparisons (2-tailed Kruskal-Wallace test, Chi-square and P values) of carapace length frequencies of ovigerous females from different sectors in Northumberland.

	Sector 1	Sector 4	Sector 5	Sector 6	Sector 7
Sector 1	N/A	81.07; <0.01	86.91, <0.005	87.98, <0.005	92.19, <0.001
Sector 4	81.07, <0.01	N/A	74.88, <0.05	78.29, <0.05	86.60, <0.005
Sector 5	86.91, <0.005	74.88, <0.05	N/A	100.56, <0.001	94.68, <0.001
Sector 6	87.98, <0.005	78.29, <0.05	100.56, <0.001	N/A	95.34, <0.001
Sector 7	92.19, <0.001	86.60, <0.005	94.68, <0.001	95.34, <0.001	N/A

5. Discussion

5.1. Spatial and temporal trends in the fishery

The increase in LPUE observed between 2003 and 2016 is similar to that reported in other studies (Telsnig 2013; Masefield et al 2014). After a relatively stable period between 2003 and 2006, LPUE increased by 5.5 kg/100 pots between 2006 and 2009. It is probable that improved data collection due to the new reporting system RSLS, and the registration of buyers and sellers is at least partly responsible for this observed increase (Masefield et al 2014). However, it is also likely that management strategies such as NIFCA's V-notching scheme have had a significant impact on the reproductive capacity of the stock resulting in increased recruitment (Nifca 2015; Telnig 2013; Tully 2001a). LPUE was also found to vary spatially between sectors. Excluding sector 3 which had the highest LPUE of any sector, trends in LPUE tended to have increased more in the northern sectors (5-7), compared to the southern sectors (1,2 and 4). Spatial differences LPUE between sectors may be linked the greater size of the more northern sectors allowing vessels to expand into new areas when other are depleted (Wahle 2013). This however, is contradictory to observations in the fishery of increased fishing effort concentrated nearer the shore (Stephenson et al 2017). Habitat type varies spatially though the NIFCA district, with the largest proportion of hard habitat located in sectors 2, 3 and 4 (with insufficient data available for sector 7) (Wallace 2014). Although studies have shown lobsters have a preference for hard habitat (Skerritt 2014), Wallace (2014) observed higher abundances on soft habitat in the district.

Although trends in LPUE increased over the study period (2003-2016), it is likely these trends are part of long term variability observed since the 1980's. (Masefield et al 2014). LPUE has been found to vary in for a number of factors including environmental and seasonal changes, soak times and changes in vessel or gear performance (Tully et al 2006). The latter two factors may contribute to a process termed “effort creep” where the effectiveness of effort increases over time (Gardner et al 2013), due to factors such as improved gear efficiency resulting from increases in pot size (NIFCA pers. comm.). As such, this has the potential to influence reported LPUE in the fishery.

The significant increase in fishing effort observed over the 2003 and 2016 period in this study are consistent with other studies (Masefield et al 2014; Stephenson 2017). However, the substantial increase in effort reported between 2007 - 2010, and 2010 - 2011 coinciding with the introduction of the 800 pot limitation bylaw was not as clear (Wallace 2014; Stephenson 2017). This may be due to the use of mean effort per vessel in both days and pots in the present study, rather than use of aggregated effort for the whole district. Significant number of permit holders have been found to be relatively inactive or totally inactive (Spencer 2013; Stephenson 2017), although the latter were removed from the analysis this may explain for slight differences in observations.

5.2. Current status and the 800 pot limitation bylaw

The current status of *H. gammarus* stocks derived from the LCCC and YPR analyses suggest that stocks are currently undergoing growth overfishing, in that individuals are being harvested before growth has been maximised. But this is occurring at differing intensities. When the district was taken as a whole, females were harvested at F_{max} or F_{msy}. This is far in excess of the precautionary reference point $F_{0.1}$. The results of this assessment were similar to those estimated by Masefield et al (2014) for the Northumberland and Durham. These showed a similar 1% reduction for females, however a higher 52% for males to reach F_{max}. There is no crossover in the data due to the use of later years in the present study. Therefore the results suggest that females YPR has improved slightly, whilst male YPR has increased by 18% since 2013 (Masefield et al 2014). The assessment carried out by Masefield et al (2014) has been criticized for basing assumptions on scarce data (Seafish 2013; NIFCA 2016). It is likely that the results of the present study have also been influenced by these same constraints and may explain for similarities. However, the estimations of YPR and F_{max} are not inconsistent with values derived for *H. gammarus* in other parts of the U.K. (Welby 2015; 2016). It is unclear why the increasing trends in CPUE suggest continued productively of the fishery, whilst results derived from the LCCC and YPR analysis show the population is currently over exploited. As mentioned in section 5.1., CPUE is not necessarily a reliable index of abundance (Tully et al 2006; Smith and Addison 2003). Therefore it may be prudent to base management decisions on LCCC and YPR analysis which are considered more robust (Punt et al 2013).

YPR and F were highly variable between sectors and sexes. The slight trend towards lower F and higher YPR in the more northerly districts (5-7) may be due to reduced fishing pressure due to their larger area. The reason for the high levels of F and low YPR in sector 1 for both male and female lobsters is uncertain. However this may be due to the small size of the district and its proximity to multiple fishing ports resulting in high exploitation rates. The higher rates of F observed for males a trend seen in other assessments (Welby 2015; 2016; Masefield et al 2014), and is likely due to management measures that favour the growth of females such as v-notching and the prohibition on ovigerous females (Nifca 2017). In extreme cases this may cause an unequal sex ratio towards females resulting in sperm limitation and decreased recruitment (Goldstein et al 2014). The ratio observed in this study (46% male and 54% female) shows a slight skew, however this is fairly consistent with almost 1:1 ratios observed in previous studies in the district (Wallace 2014; Skerritt 2014; Masefield et al 2014).

Based on the results derived from the YPR analysis in this study it would appear that the current 800 Pot restriction is not sufficient to constrain fishing effort. However large reductions in fishing effort even from current comparatively moderate levels would be required to reach F_{MSY}. Few fisheries for *H. gammarus* impose effort restrictions in the form of pot limitations, these however, tend to have considerably larger effort quotas. For example, in the English Channel vessels from Normandy, France and Jersey are limited to 1000 and 1500 pots respectively (MEP 2010). As fishers in Northumberland are currently fishing, on average, under half their pot quota, adjustments to the pot restriction would need to be significant to have any meaningful influence on effort. Although it is possible that a small reduction to the limit may be able to influence the behaviour of the few fishers operating at the upper range.

5.3. Size at maturity and the 87mm MLS

The estimations of SOM derived from the size frequency of ovigerous females was found to be significantly larger 91.6mm (SE±0.2) compared to 84.3mm observed for the whole district in AW:CL method. The AW:CL method only estimates morphometric maturity (Tully et al 2001b), which proceeds functional maturity (Aikin and Waddy 2005). Therefore it is recommended that the results of this method should be interpreted with caution (Emond et al 2010; Agnalt et al 2009). In addition, discrepancies between morphometric and functional maturity could arise from reduced catchability of ovigerous females and under representation in the catch (Tully et al 2001). This is unlikely to be a major factor however, as Laurans et al (2009) found that catchability of *H. gammarus* was not different between ovigerous or non-ovigerous females in Le Croisic (France). Due to the potential influence of these factors it is recommended that AW:CL method should be used to support the estimate of functional maturity obtained from the size frequency of ovigerous females method (Landers et al 2001).

The only sectors that differed significantly using the AW:CL method were sectors 4 (80mm) and 7 (83.1mm), this may however be due to the poor fit of the model for sector 4 ($r^2 = 0.71$). The estimates derived from the length frequency of ovigerous females method differed significantly between sectors, although they did not vary significantly ranging from 87.6mm (SE±0.5) in sector 1 to 94.3mm (SE±0.8) in sector 4. The slight spatial patterns observed in this study may be liked to high exploitation rates. These have been found to decrease size at maturity of lobsters by favouring slower-growing, earlier maturing individuals resulting in decreased SOM (Landers et al 2001; Haarr et al 2017). This would explain the low value for SOM obtained in sector 1 which was found to have the highest rates of exploitation in this study.

Estimates of female size at maturity for *H. gammarus* from other studies range from 80mm CL and 98mm CL for east and west Scotland (morphometric maturity) (Lizarraga-Cubedo et al 2009); 107 – 140 mm CL for Ireland (functional) (Tully et al 2001b); 103-106mm CL for north-western France (Functional) (Laurans et al 2009); 90 and 85 in South England and Wales respectively (Functional) (Free et al 1992). The only estimate of SOM in the vicinity was carried out by Free et al (1992) who obtained a functional estimate for SOM of 90mm CL. This result corresponds to the range of estimates of functional maturity obtained in this study. Ideally the MLS should be based on the CL_{50}(Le Bris et al 2017), therefore the current MLS of 87mm CL is probably insufficient to offer maximum protection to breeding stock. Changes in MLS have been shown to have significant benefits to egg production per recruit, with an MLS increase to 90mm CL achieving the same relative benefit as the v-notching scheme where 50% of mature females were v-notched (CEFAS 2005).

5.4. Limitations

A major limitation of the present study was the availability of length frequency data and data on the frequency of ovigerous females for the LCCC and SOM analyses. Assessing each sector individually introduced significant problems due to the concentration of sampling locations in sectors 1 and 4-7 with, only a few samples collected in sectors 2 and 3. Even between the sectors with sufficient data, sampling was not evenly distributed, with sector 4 only just having sufficient data to qualify for analysis. The reporting structure of the permit returns data made it difficult to subtract prawn pots from the total number of pots fished each day. This had to be estimated based on the total number of prawn pots fished.

To allow a more robust assessment of the fishery and of F_{msy} it would have been useful to have compared the results from the YPR model (F_{max}) to an estimate of F_{msy} derived from a surplus production model (Smith and Addison 2003; King 2007). Unfortunately the conditions in the fishery did not meet the model requirements of declining CPUE and increasing effort, and therefore surplus production models could not be used (Welby 2015). As no current estimates of natural mortality exist for the fishery, an estimate of (20%) was used in this study (Welby 2015; 2016). Other studies have assumed M is 15%, resulting in higher estimates of exploitation rates in the fishery (Tully et al 2006; Masefield et al 2014).

Although the size frequency of ovigerous females and the AW:CL ratio provide a useful indication of size at maturity, the most accurate estimates are derived from ovarian dissection methods (Aikin and Waddy 2005). This study was unable to undertake any ovarian dissections to support the other estimates due to restraints placed on time and resources.

5.5. Recommendations and Further research

A precautionary approach to fisheries management is recommended by the FAO, which aims to set agreed cost effective measures and actions, to reduce or avoid risks to the resource and people, taking into account existing uncertainties and potential consequences of being wrong (Garcia 1995).

The results of this study suggest *H. gammarus* in the Northumberland district is currently being over exploited. Therefore it is recommended that management measures are reviewed even despite uncertainty surrounding results. Based on the estimates of SOM for the NIFCA district, it is recommended that MLS is increased from 87mm CL to 90mm CL. This increase has already been undertaken by other IFCA districts in south west England (SEAFISH 2013). The results also suggest that effort is currently high in the district. It is clear that the 800 pot limit is currently too high to have any meaningful influence on current levels of effort. A review of the pot limitation is suggested, however, it is understood that the reduction to 139 (SE±51) pots required to reach F_{msy} is unlikely to be possible due to social and economic reasons. It is therefore suggested that further research is undertaken regarding the suitability of the pot limitation byelaw before a new level is set.

To aid in future assessments of the district, it is recommended that sampling is more evenly distributed across the district to allow for a better spacial assessment of *H. gammarus*. It is also recommended that research is carried out with the aim of establishing a more precise estimate for natural mortally in the district, therefore increasing the quality of future assessments.

6. Conclusion

CPUE has increased in the fishery between 2003 and 2016 across all the sectors suggesting increased population productivity. However, this may be due to long term fluctuations. This is contradictory to results derived from the LCCC and YPR which suggest the fishery is currently overexploited. These findings are consistent with previous assessments of the fishery. However, deficiencies in the data make it hard to draw robust conclusions. Exploitation rates were found to vary spatially and were highest in sector 1, tending to be lower in the north of the district. Sex ratios were skewed slightly toward females, which may be a result of the slightly higher exploitation rates estimated for males. Estimations of functional female SOM were found vary between sectors. However, these differences were small and showed no district pattern. Both functional and morphometric SOM across districts suggests that individuals reach maturity at greater sizes than the current 87mm CL MLS. Although the results suggest exploitation rates in the district are high, on average fishers operate at less than half of their pot allowance. In order to operate the fishery at MSY, further reductions would be required. It is recommended that management measures are reviewed as precautionary approach. The results of this study suggest that increasing the MLS to 90mm CL could have considerable benefits for future recruitment and productivity. Also reducing the pot limit would also likely be of considerable benefit, however significant reductions would be required to have any meaningful effect on current fishing effort. It is difficult to suggest the extent of this reduction based exclusively on biological assumptions, without taking into consideration the wider social and economic factors. Future assessments could be improved by increased spatial coverage of data along with obtaining a precise estimate for natural mortality.

7. References

Agnalt, A.L., Farestveit, E., Gundersen, K., Jørstad, K.E. and Kristiansen, T.S., 2009. Population characteristics of the world's northernmost stocks of European lobster (Homarus gammarus) in Tysfjord and Nordfolda, northern Norway. *New Zealand Journal of Marine and Freshwater Research*, *43*(1), pp.47-57.

Baudron, A.R., Needle, C.L., Rijnsdorp, A.D. and Tara Marshall, C., 2014. Warming temperatures and smaller body sizes: synchronous changes in growth of North Sea fishes. *Global change biology*, *20*(4), pp.1023-1031.

Bondad-Reantaso, M. G., Subasinghe, R. P., Josupeit, H., Cai, J. & Zhou, X. (2012). The role of crustacean fisheries and aquaculture in global food security: past, present and future. *J. Invert. Path.* **110(**2):158-165.

CEFAS. 2005. Stock Conservation benefits of various lobster management measures. Centre for Environment, Fisheries and Aquaculture Science (CEFAS).

Cochrane, K.L. and Chakalall, B., 2002. The spiny lobster fishery in the WECAFC region-An approach to responsible fisheries management. *Marine and freshwater research*, *52*(8), pp.1623-1631.

Defra (2007) Fisheries 2027 a long-vision for sustainable fisheries. Department for Environment, Food and Rural Affairs.

Defra. 2015. Inshore Fisheries and Conservation Authorities. Conduct and Operatiion 2010 – 2014. Department for Environment Food & Rural Affairs. March 2015. Available at: http://www.association-ifca.org.uk/Upload/About/ifca-review-2010-2014.pdf

Emond, K., Sainte-Marie, B. and Gendron, L., 2010. Relative growth, life-history phases, and sexual maturity of American lobster (Homarus americanus). *Canadian Journal of Zoology*, *88*(4), pp.347-358.

Free, E. K., Tyler, P. A., and Addison, J. T. 1992. Lobster (Homarus gammarus) fecundity and maturity in England and Wales. ICES Document CM 1992/K: 43.

Garcia, S.M., 1995. The precautionary approach to fisheries and its implications for fishery research, technology and management: an updated review. *FAO Technical Paper*, *350*.

Gardner, C., Larkin, S. and Seijo, J.C., 2013. Systems to maximize economic benefits from lobster fisheries. *Lobsters: biology, management aquaculture and fisheries. 2nd ed. Edited by B. Phillips. Wiley-Blackwell*, pp.113-132.

Goldstein, J.S., Pugh, T.L., Dubofsky, E.A., Lavalli, K.L., Clancy, M. and Watson III, W.H., 2014. A Noninvasive Method For In situ Determination of Mating Success in Female American Lobsters (Homarus americanus). *Journal of visualized experiments: JoVE*, (84).

Goñi, R., Quetglas, A. and Reñones, O., 2006. Spillover of spiny lobsters Palinurus elephas from a marine reserve to an adjoining fishery. *Marine Ecology Progress Series*, *308*, pp.207-219.

Grabowski, J.H., Clesceri, E.J., Baukus, A.J., Gaudette, J., Weber, M. and Yund, P.O., 2010. Use of herring bait to farm lobsters in the Gulf of Maine. *PLoS One*, *5*(4), p.e10188.

Haarr, M.L., Sainte-Marie, B., Comeau, M., Tremblay, M.J. and Rochette, R., 2017. Female American lobster (Homarus americanus) size-at-maturity declined in Canada during the 20th and early 21st century. *Canadian Journal of Fisheries and Aquatic Sciences*, (ja).

Hilborn, R. and Walters, C.J., 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. *Reviews in Fish Biology and Fisheries*, *2*(2), pp.177-178.

Hoggarth D. D., Abeyasekera S., Arthur R. I., Beddington J. R., Burn R. W., Halls A, S., Kirkwood G. P., McAllister M., Medley, P., Mees C. C., Parkes G. B., Pilling G. M., Wakeford R. C., Welcomme R. L. 2006. Stock assessment for fishery management. A framework guide to the stock assessment tools of the fisheries management science programme. FAO Rome, 2006.

King, M., 2007. *Fisheries biology, assessment and management*. 2nd addition. John Wiley & Sons.

Landers Jr, D.F., Keser, M. and Saila, S.B., 2001. Changes in female lobster (Homarus americanus) size at maturity and implications for the lobster resource in Long Island Sound, Connecticut. *Marine and Freshwater Research*, *52*(8), pp.1283-1290.

Laurans, M., Fifas, S., Demaneche, S., Brérette, S. and Debec, O., 2009. Modelling seasonal and annual variation in size at functional maturity in the European lobster (Homarus gammarus) from self-sampling data. *ICES Journal of Marine Science*, *66*(9), pp.1892-1898.

Le Bris, A., Pershing, A.J., Gaudette, J., Pugh, T.L. and Reardon, K.M., 2017. Multi-scale quantification of the effects of temperature on size at maturity in the American lobster (Homarus americanus). *Fisheries Research*, *186*, pp.397-406..

Lizárraga-Cubedo, H.A., Tuck, I., Bailey, N., Pierce, G.J. and Kinnear, J.A.M., 2003. Comparisons of size at maturity and fecundity of two Scottish populations of the European lobster, Homarus gammarus. *Fisheries Research*, *65*(1), pp.137-152.

Masefield, R. Mclntyre, R., Bell, E. 2014. Cefas lobster stock and fishery status reports 2014.
MEP. 2010. Normandy and Jersey lobster (Homarus gammarus) fishery – Final report. MacAlister Elliott and Partners Ltd

MMO (2015b). Marine Management Organisation. 2011 to 2015 UK fleet landings and foreign fleet landings into the UK by port. Data available online at: https://www.gov.uk/government/statistical-data-sets/uk-sea-fisheries-annual-statistics-report-2015

Molfese, C., Beare, D. and Hall-Spencer, J.M., 2014. Overfishing and the replacement of demersal finfish by shellfish: an example from the English Channel. *PloS one*, *9*(7), p.e101506.

NIFCA 2017. Byelaws Booklet. Northumberland Inshore Fisheries & Conservation Authority. Available at: http://www.nifca.gov.uk/wp-content/uploads/2013/02/Byelaws-Jan-2017.pdf .

NIFCA., 2015. Lobster V-notching report 2015. Northumberland Inshore Fisheries and Conservation Authority.

NIFCA., 2016. "Conserving our Marine Environment and Inshore Fisheries". Annual Plan 2016-2017. Northumberland Inshore Fishery and Conservation Authority.

Punt, A.E., Huang, T. and Maunder, M.N., 2013. Review of integrated size-structured models for stock assessment of hard-to-age crustacean and mollusc species. *ICES Journal of Marine Science: Journal du Conseil*, *70*(1), pp.16-33

Rowe, S. (2001). "Movement and harvesting mortality of American lobsters (Homarus americanus) tagged inside and outside no-take reserves in Bonavista Bay, Newfoundland." Canadian Journal of Fisheries and Aquatic Sciences 58(7):1336-1346.

Seafish., 2013. Project Inshore, Stage 3 – Strategic Sustainability Review. Northumberland Inshore Fisheries & Conservation Authority. Available online at: http://www.seafish.org/media/publications/Nothumberland_IFCA.pdf

See M., 2015. Decision to fish: Fishers' behaviour within the Northumberland inshore pot fishery. Final Report: MSc International Marine Environmental Consultancy

Skerritt, D.J., 2014. Abundance, interaction and movement in a European lobster stock.

Smith, I.P., Jensen, A.C., Collins, K.J. and Mattey, E.L., 2001. Movement of wild European lobsters Homarus gammarus in natural habitat. *Marine Ecology Progress Series*, *222*, pp.177-186.

Smith, M.T. and Addison, J.T., 2003. Methods for stock assessment of crustacean fisheries. *Fisheries Research*, *65*(1), pp.231-256.

Spencer, A.D., 2013. An assessment of the Northumberland edible crab *Cancer pagurus* and velvet crab *Necora puber* fisheries. MPhil

Stephenson, F., Polunin, N.V., Mill, A.C., Scott, C., Lightfoot, P., Fitzsimmons, C. and Handling editor: Michel Kaiser, 2017. Spatial and temporal changes in pot-fishing effort and habitat use. *ICES Journal of Marine Science*, p.fsx051.

Telsnig J. D., 2013. An assessment of the impact of v-notching European lobsters in Northumberland district. Final Report: MSc International Marine Environmental Consultancy

Templeman, W., 1935. Local differences in the body proportions of the lobster, Homarus americanus. *Journal of the Biological Board of Canada*, *1*(3), pp.213-226.

Templeman, W., 1944. Abdominal width and sexual maturity of female lobsters on Canadian Atlantic Coast. *Journal of the Fisheries Board of Canada*, *6*(3), pp.281-290.

Tully, O., 2001a. Impact of the v-notch technical conservation measure on reproductive potential in a lobster (Homarus gammarus L.) fishery in Ireland. *Marine and Freshwater Research*, *52*(8), pp.1551-1557.

Tully, O., Bell, M., O'Leary,. McCarthy, A., O'Donovan, V., Nee, D. 2006. The Lobster (Homarus gammarus L.) Fishery: Analysis of resource in 2004-2005. Irish Sea Fisheries Board.

Tully, O., Roantree, V. and Robinson, M., 2001b. Maturity, fecundity and reproductive potential of the European lobster (Homarus gammarus) in Ireland. *Journal of the Marine Biological Association of the United Kingdom*, *81*(1), pp.61-68.

Turner, R.A., Hardy, M.H., Green, J. and Polunin, N.V.C. (2009). Defining the Northumberland Lobster Fishery. Report to the Marine and Fisheries Agency, London.

von Bertalanffy, L., 1934. Untersuchungen über die Gesetzlichkeit des Wachstums. *Wilhelm Roux'Archiv für Entwicklungsmechanik der Organismen*, *131*(4), pp.613-652.

Waddy, S.L. and Aiken, D.E., 2005. Impact of invalid biological assumptions and misapplication of maturity criteria on size-at-maturity estimates for American lobster. *Transactions of the American Fisheries Society*, *134*(5), pp.1075-1090.

Wallace N., 2015. Lobster, fishing effort and habitat interactions in the Northumberland Lobster Fishery. Final Report: MSc International Marine Environmental Consultancy

Welby P.R., 2014. Crab and Lobster Stock Assessment. Research Report. Inshore Fisheries and Conservation Authority.

Welby P.R., 2015. Crab and Lobster Stock Assessment. Research Report. Inshore Fisheries and Conservation Authority.

Welby P.R., 2016. Crab and Lobster Stock Assessment. Research Report. Inshore Fisheries and Conservation Authority.

Wahle, R, A., Castro, K, M., Tully, O., and Cobb, J, S. 2013. Homarus. Chapter 8. Lobsters: Biology, Management, Aquaculture & Fisheries, 2nd edn.Wiley-Blackwell Publishing, Oxford, UK

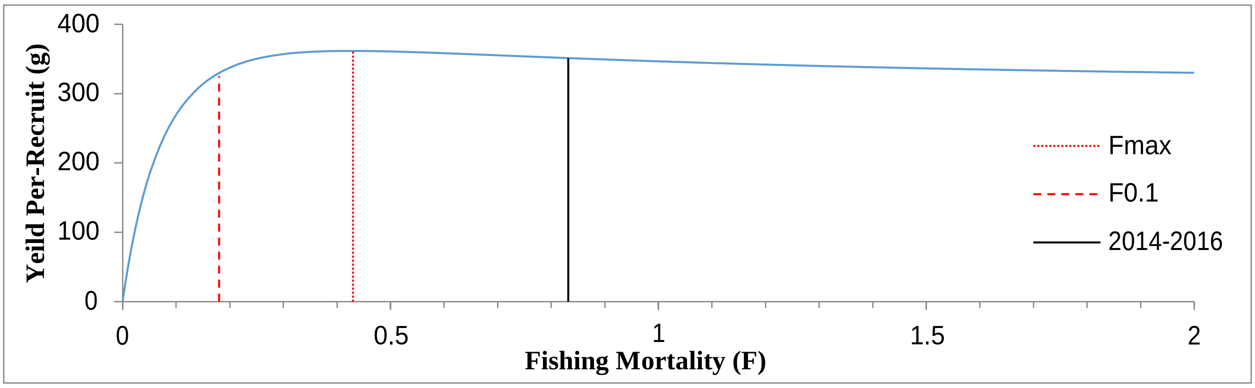
Appendices

Appendix I. Results from the Length Converted Catch Curve and Yield Per-Recruit analysis

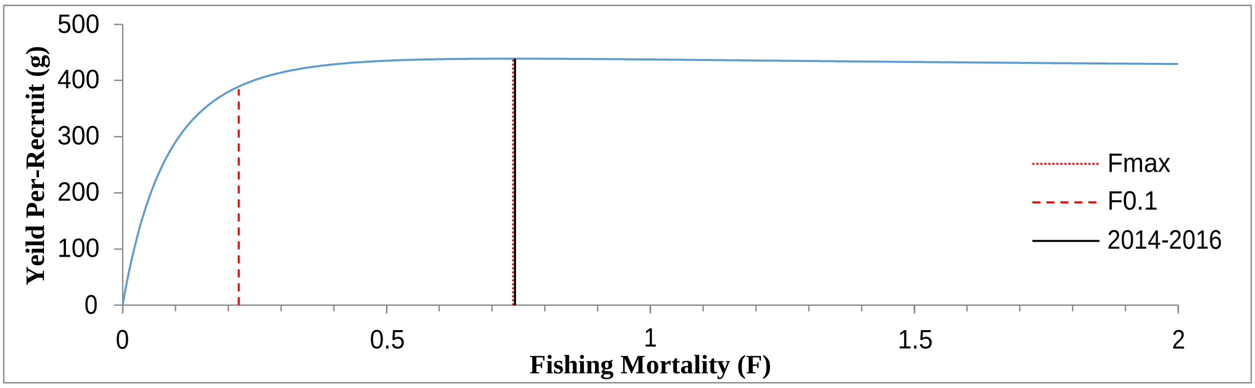
Appendix. 1. Table e of the results from the Length Converted Catch Curve and Yield Per-Recruit analysis for each sector 1 and 4-7) and the district as a whole. Showing the sex specific total mortality (*Z*) and fishing mortality (*F*) and the required changes in *F* required to reach the biological reference points $F_{0.1}$ and F_{max} and the resultant changes in yield per recruit.

									Implications for moving to F_{max}		Implication for moving to $F_{0.1}$	
Sector	Sex	n	Z	Z (%)	95% CI, upper, lower	F	F (%)	95% CI, upper, lower	% Change in F	% Change in YPR	% change in F	% change in YPR
1	M	489	1.417	76	58, 86	1.217	70	48, 83	58	5.88	71	-4.72
	F	588	1.777	83	74, 89	1.577	79	68, 87	61	1.50	85	-11.03
4	M	431	1.133	68	77, 54	0.933	61	72, 44	41	3.79	56	-6.59
	F	435	1.141	68	78, 53	0.941	61	42, 74	18	0.22	53	-12.16
5	M	1015	0.959	62	69, 52	0.759	53	63, 42	28	2.30	46	-7.93
	F	929	1.112	67	73, 60	0.912	60	67, 51	16	0.17	51	-12.20
6	M	1339	1.166	69	74, 63	0.966	62	68, 54	43	4.06	58	-6.35
	F	1816	0.952	61	65, 57	0.752	53	58, 47	1	0	41	-12.35
7	M	763	1.064	65	73, 56	0.864	58	67, 46	36	3.22	52	-7.10
	F	971	1.155	69	75, 61	0.966	62	69, 52	19	0.242	54	-12.14
Total	M	4063	1.0318	64	68, 61	0.8318	56	60, 52	34	2.9	50	-7.35
	F	4768	0.9435	61	64, 57	0.7435	52	57, 48	0	0	41	-12.35

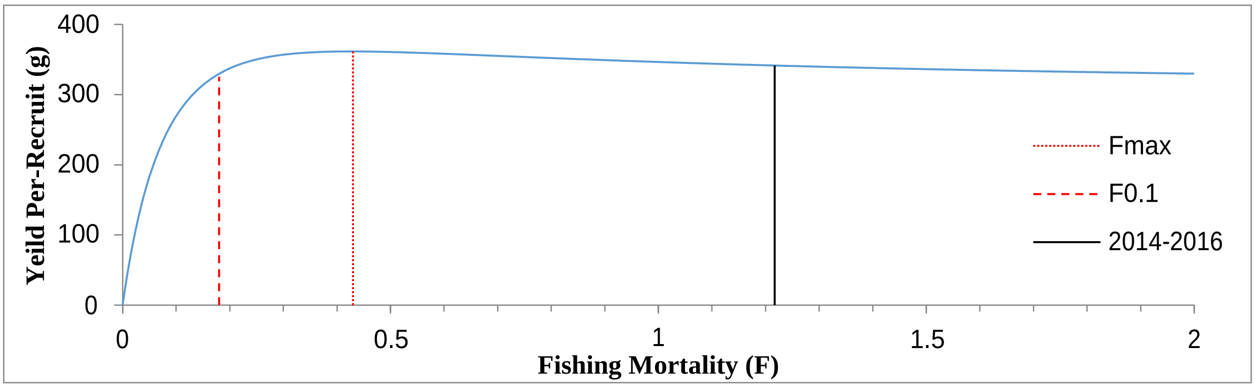
Appendix II. Yield Per-Recruit Curves



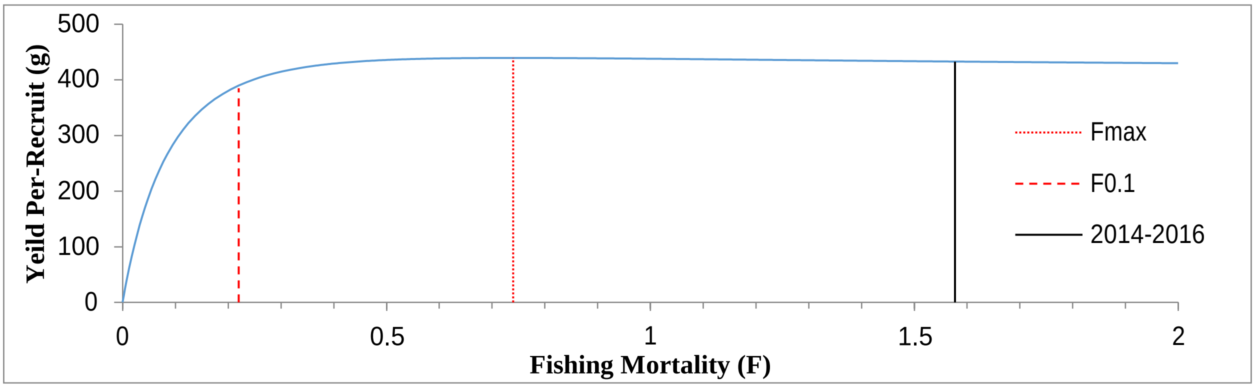
Appendix II (a). *YPR curve for H. gammarus males including current estimates of fishing mortally (2014-2016) and the target reference points* F_{max} *and* $F_{0.1}$ *for the whole NIFCA district.*



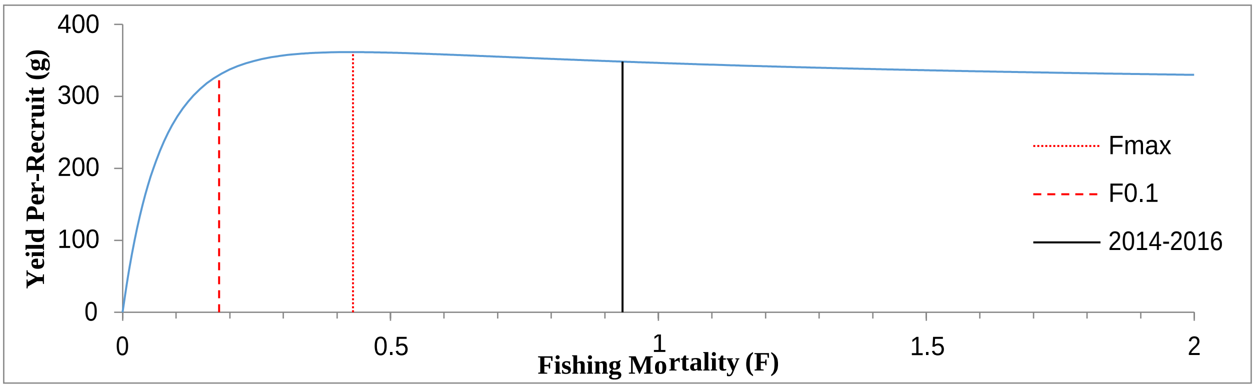
Appendix II (b). *YPR curve for H. gammarus females including current estimates of fishing mortally (2014-2016) and the target reference points* F_{max} *and* $F_{0.1}$ *for the whole NIFCA district.*



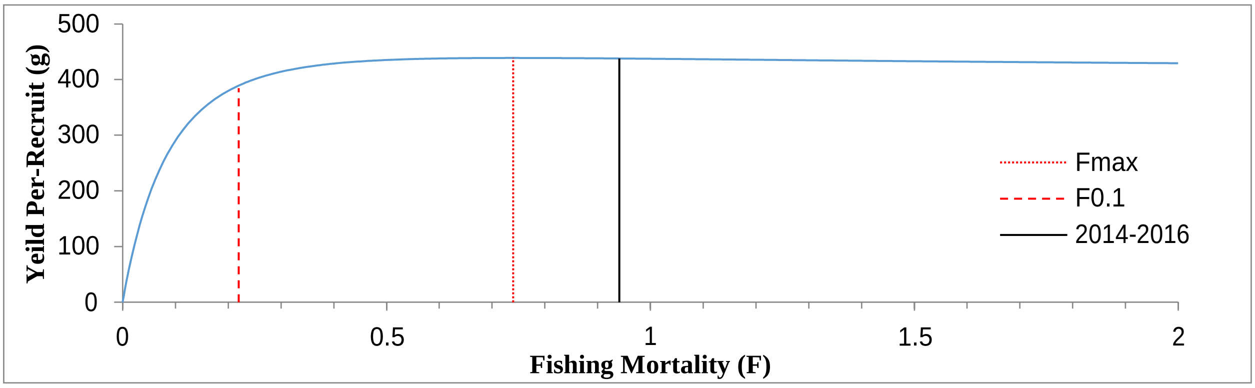
Appendix II (c). *YPR curve for H. gammarus males including current estimates of fishing mortally (2014-2016) and the target reference points* F_{max} *and* $F_{0.1}$ *for sector 1 in the NIFCA district.*



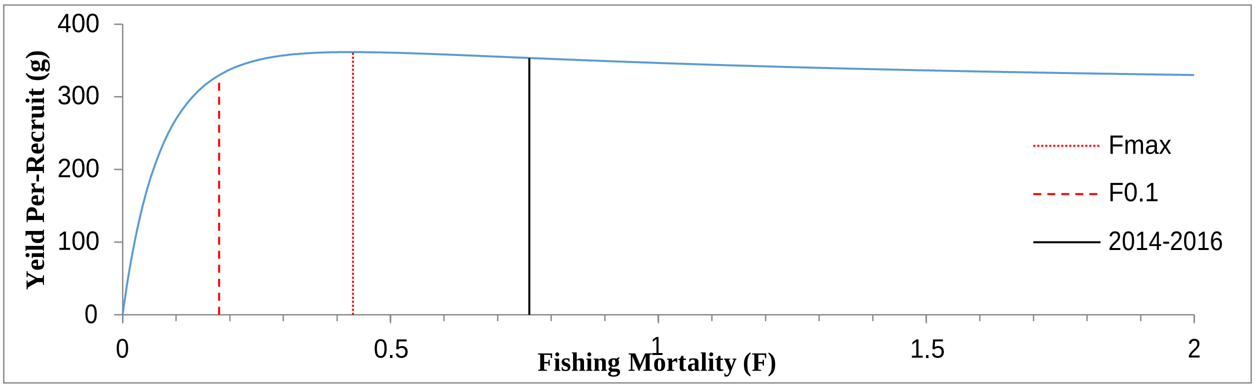
Appendix II (d). *YPR curve for H. gammarus females including current estimates of fishing mortally (2014-2016) and the target reference points* F_{max} *and* $F_{0.1}$ *for sector 1 in the NIFCA district.*



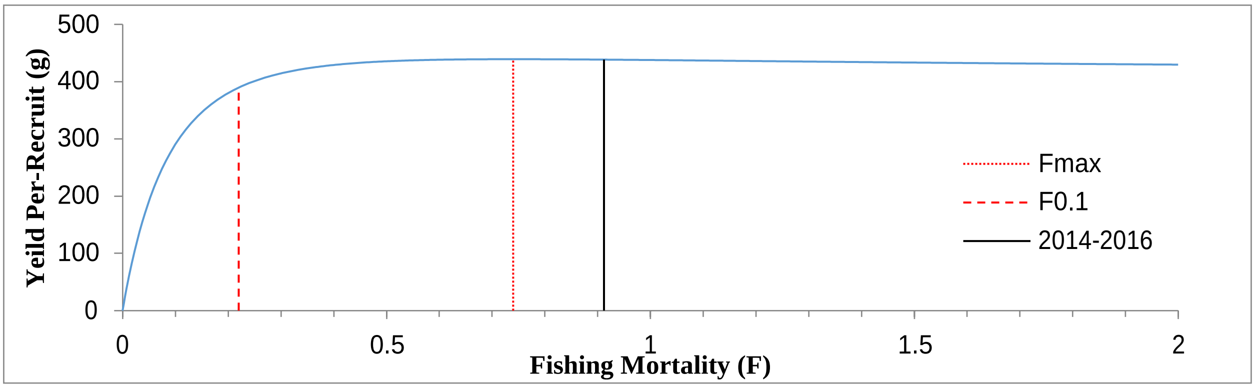
Appendix II (e). *YPR curve for H. gammarus males including current estimates of fishing mortally (2014-2016) and the target reference points* F_{max} *and* $F_{0.1}$ *for sector 4 in the NIFCA district.*



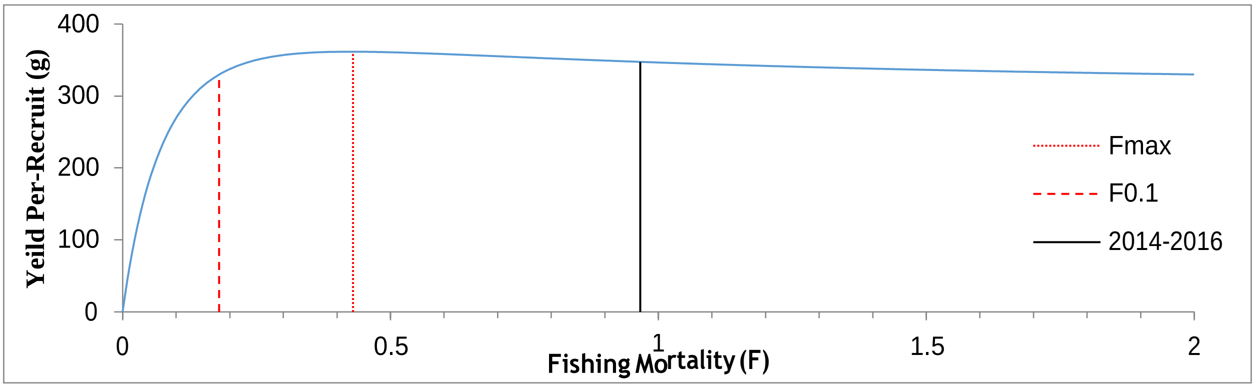
Appendix II (f). *YPR curve for H. gammarus females including current estimates of fishing mortally (2014-2016) and the target reference points* F_{max} *and* $F_{0.1}$ *for sector 4 in the NIFCA district.*



Appendix II (g). *YPR curve for H. gammarus males including current estimates of fishing mortally (2014-2016) and the target reference points* F_{max} *and* $F_{0.1}$ *for sector 5 in the NIFCA district*

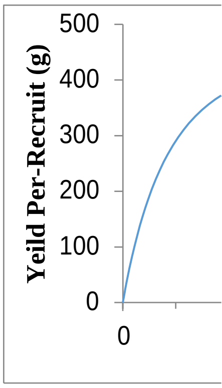


Appendix II (h). *YPR curve for H. gammarus females including current estimates of fishing mortally (2014-2016) and the target reference points* F_{max} *and* $F_{0.1}$ *for sector 5 in the NIFCA district.*

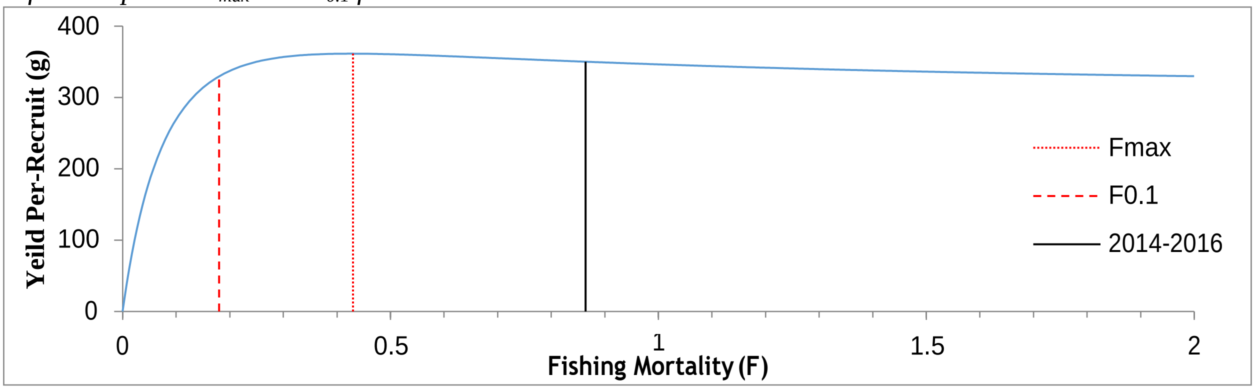


Appendix II (i). *YPR curve for H. gammarus males including current estimates of fishing mortally (2014-2016) and the target reference points* F_{max} *and* $F_{0.1}$ *for sector 6 in the NIFCA district.*

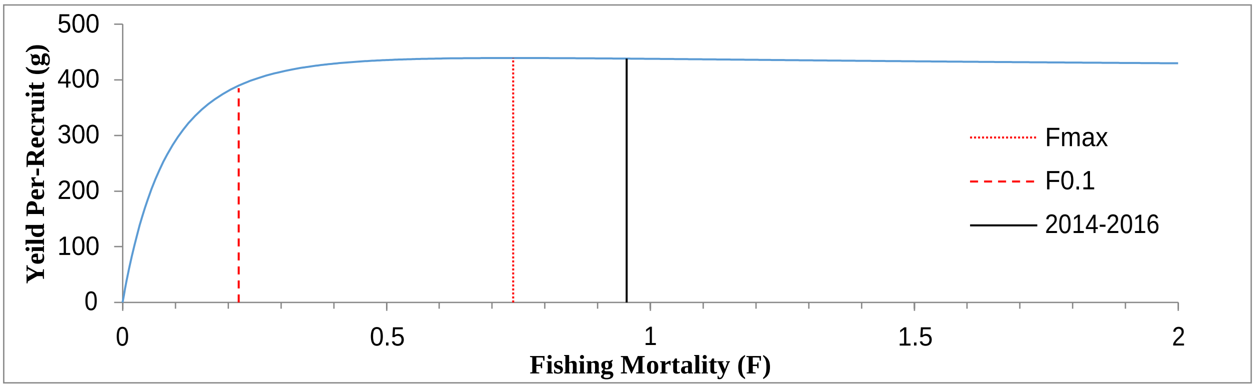
Sex	2016 fishing effort (pot operated per day)	Implications for moving to F_{max} (% change in F)	Effort reduction required to reach F_{msy}	Effort at F_{msy}	Effort as a % of the 800 pot limitation



Appendix II (j). *YPR curve for H. gammarus females including current estimates of fishing mortally (2014-2016) and the target reference points F_{max} and $F_{0.1}$ for sector 6 in the NIFCA district.*



Appendix II (k). *YPR curve for H. gammarus males including current estimates of fishing mortally (2014-2016) and the target reference points F_{max} and $F_{0.1}$ for sector 7 in the NIFCA district.*



Appendix II (l). *YPR curve for H. gammarus females including current estimates of fishing mortally (2014-2016) and the target reference points F_{max} and $F_{0.1}$ for sector 7 in the NIFCA district.*

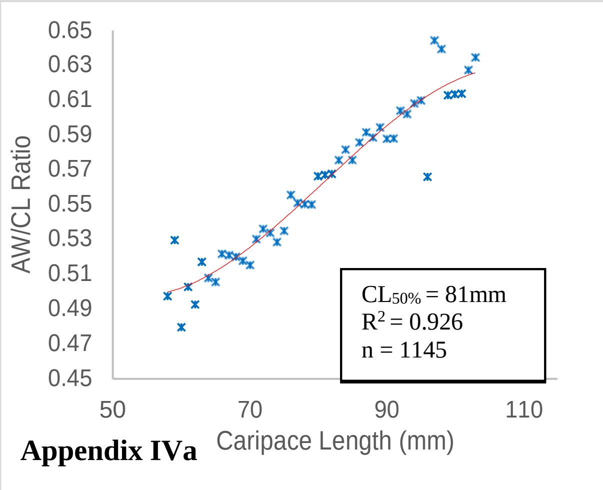
Appendix III. Full table: Evaluation of pot limitation

Sector 1	M	181±26	70	126±34	54±14	7
	F	181±26	79	143±38	38±10	5
Sector 4	M	222±33	61	135±45	86±29	11
	F	222±33	61	135±45	86±29	11
Sector 5	M	329±28	53	174±48	154±43	20
	F	329±28	60	197±54	132±36	17
Sector 6	M	450±57	62	278±158	171±97	21
	F	450±57	53	238±135	211±120	26
Sector 7	M	380±44	58	220±97	160±70	20
	F	380±44	62	236±104	144±64	18
District	M	316±36	56	177±65	139±51	17
	F	316±36	52	164±60	152±55	19

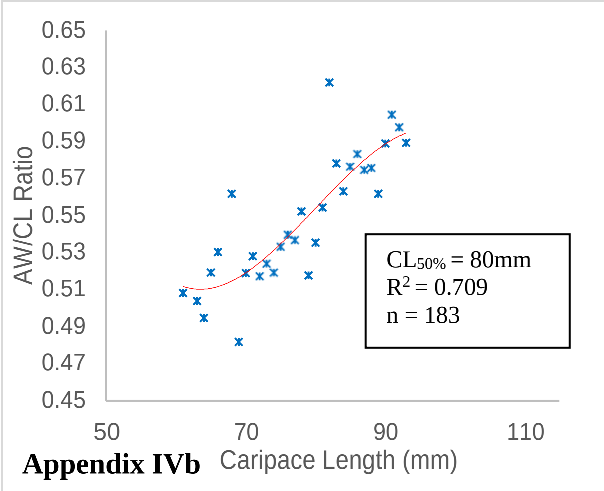
Current effort (2016), and sex specific reduced effort required to operate the fishery at F_{msy}, and that effort as a percentage of the 800 pot limitation; based on the results of the YPR analysis (section 4.2) and effort data (section 4.1) for each sector, sectors 1, and 4-7 and the district as a whole

Appendix IV. Abdominal width : carapace length ratios

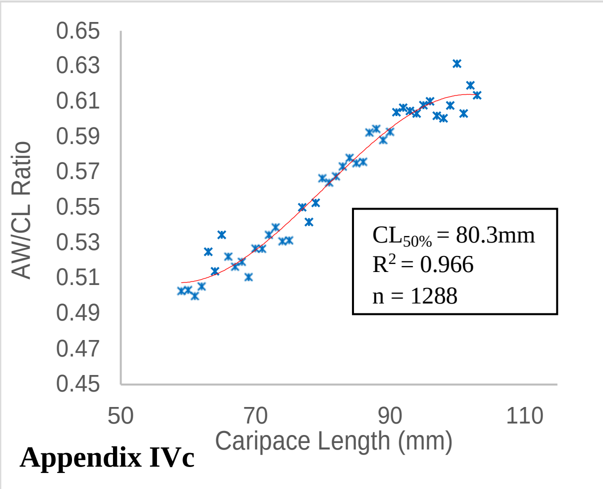
Abdominal width : carapace length ratios for H. gammarus in 1mm size classes from 50 to 110mm CL in sectors 1 (Appendix VIa), 4 (Appendix VIb), 5 (Appendix VIc), 7 (Appendix Vid).



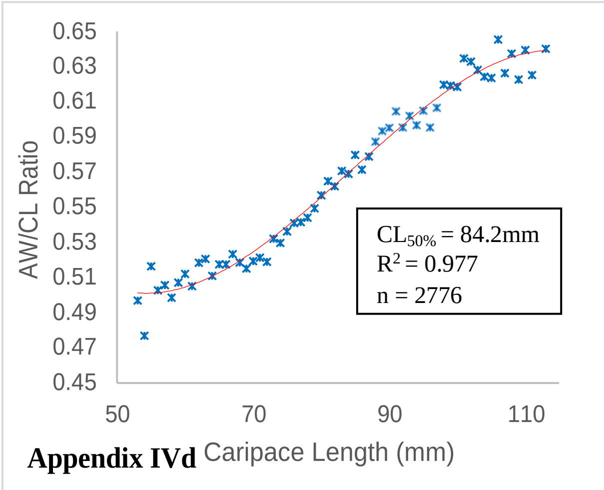
Appendix IVa



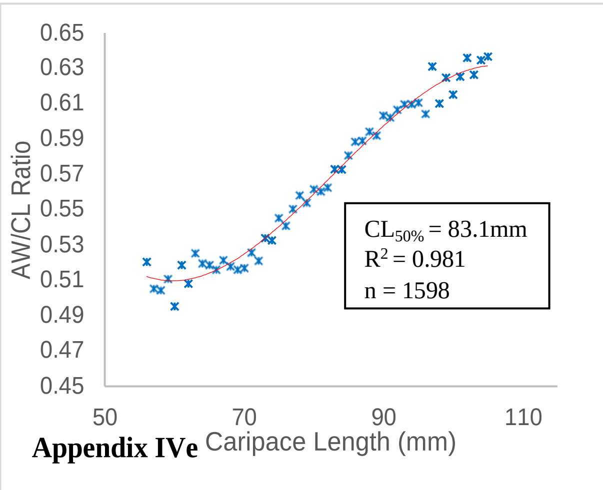
Appendix IVb



Appendix IVc



Appendix IVd



Appendix IVe

Appendix V. Size frequency profiles of ovigerous females

*Size frequency profiles of ovigerous females in sectors 1 (*Appendix Va*), 4 (*Appendix Vb), 5 (Appendix Vc), 6 (Appendix Vd); 7 (Appendix Ve) in the *NIFCA district, including the number of samples, mean size, and range*