RESEARCH REPORT

2018

Crab and Lobster Stock Assessment

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Contents

1. *EXECUTIVE SUMMARY*

As the regulatory Authority, a primary objective of EIFCA is to ensure sustainable exploitation of commercial fish populations in order to fulfil duties under Section 153 of the Marine and Coastal Access Act (2009) and to ensure the sustainable exploitation of sea fisheries resources whilst achieving good environmental status in all EU marine waters by 2020 set by the Marine Strategy Framework Directive (MSFD). EIFCA initiated the crustacean stock assessment project in 2013, focusing on Brown crab (*C. pagurus*) and European lobster (*H. gammarus*) stocks. The objective, to build on the current understanding of potting fisheries operating within the district with the aim of developing the techniques necessary to conduct stock assessments at a localised level. This includes a long-term monitoring strategy that uses catch return data and biometric sampling (bio-sampling) to analyse the district's fishing grounds by ICES rectangle, estimating fishing mortality by sex/species using Length Converted Catch Curve (LCCC) and Yield Per Recruit (YPR) models. While quantifying Maximum Sustainable Yield (MSY) in the district's crustacean fishery is not directly stated as a MSFD term objective, it does state that 'stocks should be exploited sustainably consistent with high long-term yields which implies the same desired outcome as achieving MSY, however there are limitations in using the LCCC model for establishing this threshold in crustacean populations. Consequently, alternative methods have been employed to set and monitor progress towards sustainability in the fishery using LCCC as the primary driver for management and Landings Per Unit Effort (LPUE) to provide an overview of stock health. MSFD descriptors and mortality estimates and reference points can be used as proxies for indicating stock health and assessing progress towards F_{max}. Used in this way, long-term stability in LPUE would indicate contemporary levels of effort were not having an observable impact on the stock, while declining LPUE would suggest effort is too high. Reference points derived from the YPR models can provide objectives to work towards and annual mortality estimates can be used as a monitoring tool and measure of success in achieving the MSFD Descriptor 3 targets. For Brown crab, LCCC has identified that the fishery is likely to be operating beyond maximum sustainable yield, however the fishery is not in imminent danger of collapse – landings per unit effort (LPUE) have been relatively stable since 2013. For European lobster there is much less data available, however results indicate that the fishery is operating above maximum sustainable yield. Progress towards the reference points will be achieved through a suite of management options that look to address MSFD descriptor criteria, and in doing so improve the health and productivity of the stock. Sampling effort of *C*. *pagurus* has reached a point where data requirements are achievable. Sampling for H. *gammarus* falls short of this target and as yet has failed to provide adequate data from which appropriate control measures could be based. A revised approach for surveying *H*. *gammarus* at processors will be an intrinsic part of recommendations moving forward. Recommendations based on the current stock assessment would look to address high fishing mortality in the fishery identified through the Yield Per Recruit models whilst the continuation of bio-sampling and MSAR data acquisition and analysis will facilitate management and the subsequent monitoring of necessary measures, including monitoring of data to establish patterns in migration and recruitment. Ensuring modelling methods for crustacean for the stock assessment are current provides opportunity to promote better working relationships between organisations and maintain and build relationships with industry members to promote knowledge sharing and inclusion in decision making.

2. *INTRODUCTION*

2.1 Background

EIFCA initiated the Crustacean stock assessment project in 2013, focusing on Brown crab (*C. pagurus*) and European lobster (*H. gammarus*) stocks. The objective, to build on the current understanding of potting fisheries operating within the district with the aim of developing the techniques necessary to conduct stock assessments at a localised level. This includes a long-term monitoring strategy that uses catch return data and biometric sampling (bio-sampling) to analyse the district's fishing grounds by ICES rectangle, estimating fishing mortality by sex/species using length converted catch curve (LCCC) and yield per recruit (YPR) models. This feeds into an adaptive management approach, protecting the health of stocks and the viability of the fishery.

The main season for *C*. *pagurus* commences around late March/early April with peak landings in May and June, dropping off through to late September/early October. The main season for *H*. *gammarus* generally follows closely behind, starting around May/early-June, peaking in late-June/July and dropping off in October (Cefas, 2014). As a mixed fishery, both crabs and lobsters are important species for the fishing industry operating within the Eastern IFCA district, from Saltfleet in Lincolnshire, throughout Norfolk and down to the southern limits of the District in Felixstowe. Although potting activity is prevalent throughout the district, it is predominantly focused along the North Norfolk coast; an area with long standing historical and cultural traditions of fishing for these species. Economically, the fishery supports many fishers and businesses with average annual combined crab and lobster landings of 771 tonnes at a value of first sale of £1,758,000.

Historically the fishery was an inshore mixed species creel fishery operating within 2nm of the coastline (MAFF, 1975), primarily due to accessibility restrictions on vessels. However, improved technology and the ability to store and transport live animals in subsequent years has increased the range in which potters operate, enabling fishing grounds further afield to be utilised (Turner et al. 2009) and ultimately leading to the development of an offshore fishery for brown crab. This, and the development of new markets for brown crab has resulted in a substantial increase in effort over the past 50 years, driven by an increase in efficiency and speed at which pots can be deployed and hauled from a vessel. Despite this, a significant number of potters still fish in close proximity to the shore, consequently the fleet is represented by a range of vessels with varying capability. The majority of vessels operating within the EIFCA District are categorised as <10m. Smaller vessels target inshore grounds whilst larger vessels accessing less pressured deeper water target individuals further offshore.

Potting fisheries specifically target crab and lobster through the deployment of static gear consisting of a string of 20-30 baited pots which are typically left to soak for 24-48 hours before being hauled. Vessels will fish several shanks on a rotational basis, hauling between 100-500 pots each trip (*Pers. Comms., 2018*). Catch is sorted at sea with any undersize or poor-quality individuals returned immediately, whilst the remainder is sold to processors and restaurant outlets once landed. Static gear use has low mortality rates of incidental bycatch in pot fisheries compared to other fishing gear and survival rates are high amongst discards (Rodrigues et al. 2015), allowing them to grow to a size where they will recruit to the fishery.

Importantly, to caveat the landings and effort data for 2018, as with previous years of data reporting for the crustacean stock assessment, there is a cut-off point of March in which to collate all current data and compile the stock assessment for the year of reporting. As a result, a small number of MSARs will not have been returned and entered into the database by this date, therefore landings and effort data can be expected to rise not significantly whilst final forms are returned. This has no impact on the fishing mortality and exploitation modelled outputs as these are derived from bio-sampling data. A number of differences are evident in the reported landings and effort values between the 2017 crustacean stock assessment and the current assessment. During this period the data held in the MSAR database has been scrutinised and a small number of erroneous data entries including landed weight, pots hauled and the incorrect/non recording of ICES statistical rectangle when recording area fished, identified and rectified, however this has not affected the general trend in landings and effort of the fishery.

2.2 Brown Crab (Cancer pagurus)

While sharing a similar geographic range as *H. gammarus, C. pagurus* is found on a wider range of habitats, including rocky reefs, soft mud and sand. The species can be found from Scandinavia to Portugal, however stock boundaries for edible crab remain poorly understood and both sexes move quite widely at times; females in particular have been shown to travel large distances in relation to spawning activity. As with *H. gammarus*, studies have revealed a smaller size structure in *C. pagurus* populations in North Norfolk when compared to adjacent areas. Unlike *H. gammarus* however this has not been associated with habitat requirements but is believed to be a consequence of migration and recruitment (Bennett 1995). Due to this smaller average size of *C. pagurus* within the District, there is a dispensation from the national MLS of 130mm carapace width for this species, allowing individuals of 115mm to be caught and landed. Egg carrying females are largely inactive over the winter brooding period but the eggs hatch in the spring and summer. After around five weeks in the plankton, the crab larvae settle on the seabed. Growth is dependent on the frequency of moulting as well as the increase in size on each moulting occasion and it typically takes about four or five years for a juvenile crab to grow to commercial size. Mating activity peaks in the summer when the female has moulted with spawning occurring in the late autumn or winter (Cefas, 2017).

2.3 European Lobster (Homarus Gammarus)

The population range for European lobster extends from Scandinavia to North Africa, however, they are mainly centred around the British Isles where a large proportion of annual landings occur (Cefas, 2017). *H. gammarus* is one of the most commercially exploited shellfish species found in UK waters and has one of the highest value/Kg (*Pers. Comms., 2018*). They occupy solitary shelters in rocky substrate and crevices between rocks and boulders and availability of suitable habitat of this type has been suggested as a key driver in influencing the carrying capacity and size structure of *H. gammarus* populations (Seitz et al. 2014). Moulting occurs in summer approximately once a year for adults, becoming less frequent in older animals, and mating occurs soon after the female has moulted. After the eggs hatch the larvae are in the water for 34 weeks before the first juvenile stages settle on the seabed. Larval distribution depends on local hydrographical conditions and the behaviour of individuals. With such a lengthy time in the plankton, the probability of individual larvae surviving is low and consequently recruitment levels are highly variable. Both sexes are considered fairly sedentary, although some inshore/offshore and longshore migration is known to take place at some locations (Cefas, 2014).

Figure 1. Brown crab (*C. pagurus*) and European Lobster (*H. gammarus*).

2.4 Management

The Authority's Strategic Assessment identified the districts crustacean fishery as a high priority based on limited regulation to address effort, gear or catch control combined with low confidence in activity data. This prompted the consideration of management needs driven by the following points:

- Assessments indicating that stocks are approaching or exceeding exploitation rates that would be required to achieve Maximum Sustainable Yield (MSY).
- Requests from the industry to consider revised management.
- Obligations under the Marine and Coastal Access Act 2009 (MACAA) and the Marine Strategy Framework Directive 2008 (MSFD).

Furthermore, the EIFCA Strategic Assessment 2019 outlines assessing the impact of fishing activities on the Cromer Shoal Chalk Beds (MCZ) and delivering management measures (if required) as a high priority, providing a concurrent driver to establish management measures for the fishery. The Cromer Shoal Chalk Beds site was designated in January 2016 and management assessments and activities are less advanced than for Special Areas of Conservation (SACs) and Special Protected Areas (SPAs). As the regulatory Authority, a primary objective of EIFCA is to ensure sustainable exploitation of commercial fish populations in order to fulfil:

- Duties under Section 153 of the Marine and Coastal Access Act (2009) to ensure the sustainable exploitation of sea fisheries resources and;
- Achieving good environmental status in all EU marine waters by 2020 set by the Marine Strategy Framework Directive (2008).

- Descriptor 3: Commercial Fish and Shellfish, as described in the Marine Strategy Framework Directive (MSFD), implies that stocks should be:
  1. exploited sustainably consistent with high long-term yields
  2. have full reproductive capacity in order to maintain stock biomass and;
  3. the proportion of older and larger fish/shellfish should be maintained (or increased) being an indicator of a healthy stock

All three attributes must be fulfilled to achieve Good Environmental Status. In fulfilling the criteria, all commercially exploited stocks should be in a healthy state and exploitation should be sustainable, yielding the Maximum Sustainable Yield (MSY). This equates to an increasing pressure to ensure that management measures are in place to support the sustainability of commercially exploited stocks. Based on these implications, and in line with duties under MACCA and MSFD, requirement for the introduction of technical measures may be necessary to address issues identified within the fishery.

The benefits of introducing technical measures include:

- reducing the rate of exploitation (as identified with fishing mortality estimates)
- affording protection to a higher proportion of mature individuals
- reducing incidental mortality on immature individuals in the stock and;
- improve spawning and subsequent recruitment within the stock.

While quantifying Maximum Sustainable Yield (MSY) in the district's crustacean fishery is not directly stated as a MSFD term objective, it does state that 'stocks should be exploited sustainably consistent with high long-term yields which implies the same desired outcome as achieving MSY, however there are limitations in using the LCCC model for establishing this threshold in crustacean populations. Instead, alternative methods have been employed to set and monitor progress towards sustainability in the fishery using LCCC as the primary driver for management and LPUE to provide an overview of stock health[1]. MSFD descriptors and mortality estimates and reference points can be used as proxies for indicating stock health and assessing progress towards F_{max}. Used in this way, long-term stability in LPUE would indicate contemporary levels of effort were not having an observable impact on the stock, while declining LPUE would suggest effort is too high. Reference points derived from LCCC Yield Per Recruit (YPR) models can provide objectives to work towards and annual mortality estimates can be used as a monitoring tool and measure of success in achieving the MSFD Descriptor 3 targets. Progress towards the reference points will be achieved through a suite of management options that look to address MSFD descriptor criteria, and in doing so improve the health and productivity of the stock.

[1] LPUE cannot be relied upon in isolation as it fails to inform on the specifics of stock health, including the descriptors set out in the MSFD. It only tells us how the stock as a whole is reacting to fishing pressure, if indeed it is reacting at all.

2.5 Regulations

The target species fishery is currently managed nationally through Marine Management Organisation (MMO) licensing and regionally by IFCA byelaw. International EU regulations set limits on minimum landing size (MLS). EU minimum landing size restrictions for crab are reflected in UK law by statutory instrument, however there is a smaller MLS in the EIFCA district than outside due to a dispensation for smaller crab to be fished. (Undersized Edible Crabs Order 2000 (2000 No 2029)). Minimum landing sizes are set at 115mm carapace width for *C. pagurus* and 87mm carapace length for lobster within the EIFCA district. These were reflected nationally for *C. pagurus;* however, these were reviewed in 1986 and 1990, raising MLS to between 130-160mm in other districts. The area falling within EIFCA jurisdictional boundary was given derogation to retain the smaller MLS based on research that identified individuals of the Norfolk population to be, on average, smaller than in other areas (Addison and Bennett, 1992). In the Eastern IFCA District vessels fishing for brown crab and lobster must have a licence with a shellfish entitlement. The quantities that are permitted to be landed are not restricted. Owners of vessels that are 10m and under with a shellfish entitlement are required to complete Monthly Shellfish Activity Returns (MSARs) for all landings of crab and lobster and submit them on a monthly basis to the Marine Management Organisation (MMO). For vessels over 10m in length, data on fishing activity must be recorded in an EU logbook and submitted to the MMO. The crab and lobster fishery is not subject to EU TAC regulations or national quotas. Details of the regulations relevant to the fishery are outlined below in table 1.

Table 1. Regulations relevant to trap fisheries targeting crustaceans in the EIFCA district.

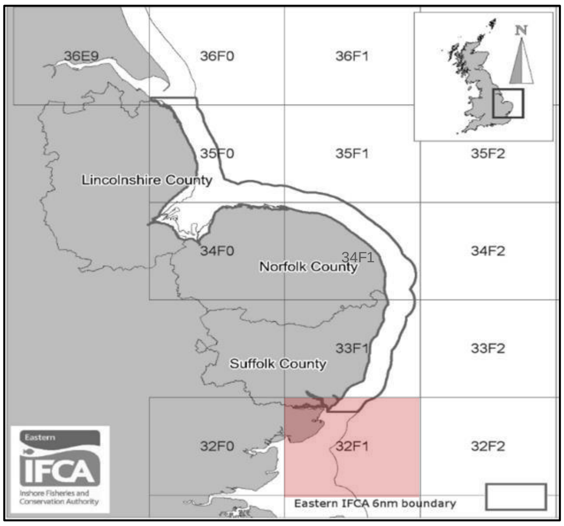
Regulation	**Effect**	**Intent**
MMO Vessel Licencing shellfish permit	Prohibits the fishing for shellfish without relevant permits	Limits entry into the fishery as no new permits are being issued.
Council Regulation 850/98 ANNEX XII for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms.	Prohibits landing of organisms below minimum legal landing sizes (115mm CW for brown crab, 87mm CL for European lobster)	Prevents removal of organisms from the fishery before reproductive maturity is reached.
Statutory instrument: Undersized Edible Crabs Order 2000 (2000 No 2029)	Increases MLS for brown crab (*Cancer pagurus*) to at least 130mm CW in areas outside of the Eastern Sea Fisheries Committee district.	Increases MLS for crab in areas outside of the EIFCA district while maintaining the lower 115mm CW EU MLS for the Norfolk population.

Lobster and Crawfish (Prohibition of Fishing and Landing) Order 2000	Prohibits fishing for, and landing of, lobsters and crawfish bearing a V notch or mutilated in such a manner as to obscure a V notch.	Protects brood stock that has been marked for protection using a V notch cut into the tail of the animal.
EIFCA Byelaw 5: - Prohibition on the use of edible crab (*C. pagurus*) for bait.	Prohibits the use of edible crab in any form (cooked or uncooked) as bait.	Prevents animals below MLS or of low value from being removed from the fishery without being landed.
EIFCA Byelaw 6: - Berried (egg-bearing) or soft-shelled crab (*C. pagurus*) or lobster (*H. gammarus*)	Prohibits removal from the fishery any edible crab or lobster that is soft-shelled or bearing eggs.	Protection of current and future brood stock and prevention of poor practice in landing low quality catch.
EIFCA Byelaw 7: - Parts of shellfish	Prohibits landing of edible crab (*Cancer pagurus*), Velvet crab (*Necora puber*) or lobster (*Homarus gammarus*) or parts thereof which cannot be measured to ensure compliance with MLS.	Closes a loophole where parts of undersized animals could be landed potentially removing immature organisms from the fishery.
EIFCA Byelaw 9: - Redeposition of shellfish	Requires that any shellfish, the removal of which is prohibited, be returned to the sea immediately and as near as possible in the place from which they were taken.	Ensures that organisms are returned the habitat from which they were taken, thus ensuring a greater chance of their survival on return to the sea.
EIFCA Byelaw 10: - Whitefooted edible crab	Prohibits the landing of ‘whitefooted’ crab (*Cancer pagurus*) between the 1st of November and the 30th of June.	Further prevents the landing of poor-quality catch by prohibiting ‘whitefooted’ crabs which have not fully hardened from being landed

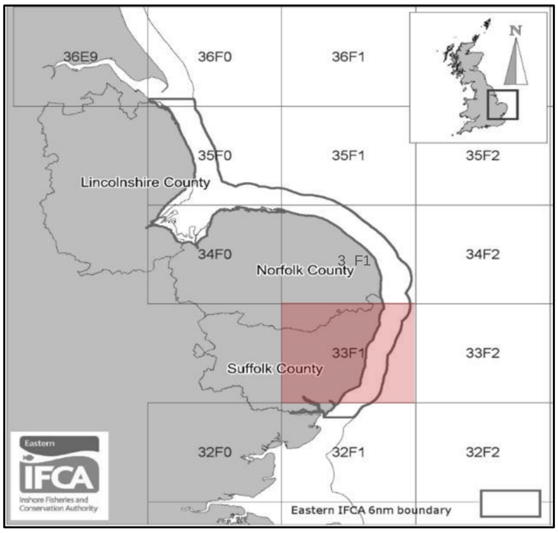
3. DATA COLLECTION AND METHODS

3.1 Assessment Areas

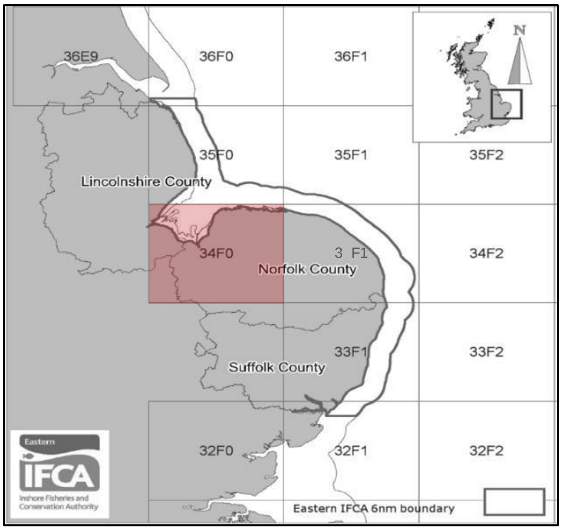
To facilitate the analysis and assessment of fished stocks in the North Sea, ICES divide the North Sea into 3 broad areas; IVa, classed as the Northern North Sea, IVb classed as the Central North Sea and IVc classed as the Southern North Sea, the latter inclusive of the area for which EIFCA is the relevant Authority. These are further divided into gridded Statistical Rectangles providing greater resolution. Statistical Rectangles define boundaries of fished grounds by operators in the district, enabling analysis on a site by site basis and this is further supported by the requirement of fishers to submit MSAR forms, clearly stating which ICES Statistical Rectangle has been fished in. Importantly, effort and catch is unevenly distributed throughout all fishing grounds within EIFCA’s jurisdictional boundary and is concentrated in certain areas, corresponding closely with the position of major contributing ports, with key production areas located off the North Norfolk coast as defined by ICES, outlined below (figure 2).



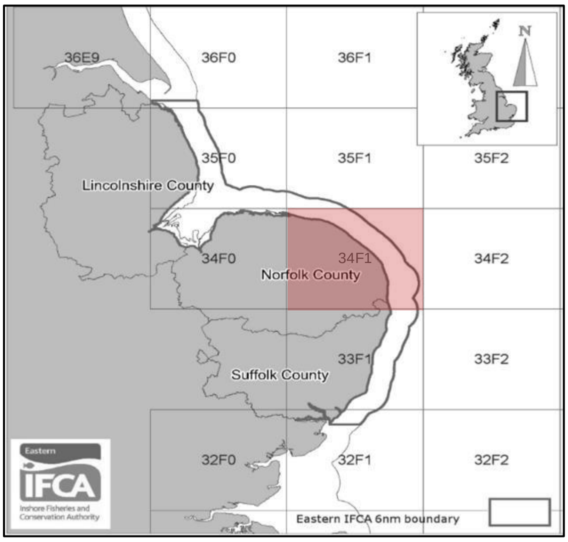
ICES Rectangle 32F1, located at the southern extremity of the district, overlaps considerably with Kent and Essex IFCA. The area is fished by a small number of ports and vessels from our district, reflected by relatively low levels of reported effort and landings.



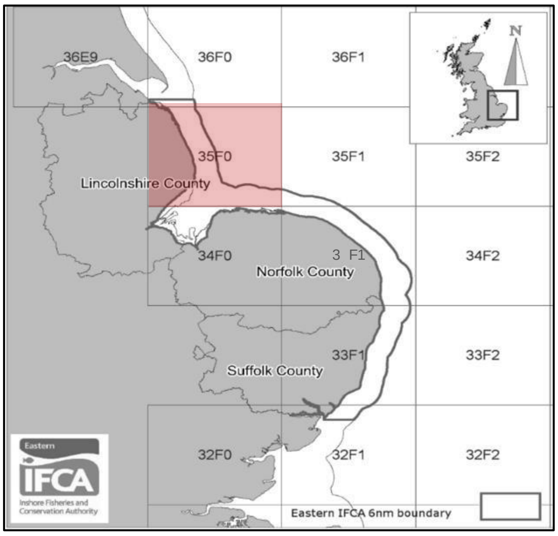
ICES Rectangle 33F1, situated off the Suffolk coast, covers an area between the Orford and Lowestoft. A comparatively small number of ports and vessels fish this area and this is reflected in the relatively low landings and effort compared to the Norfolk coast.



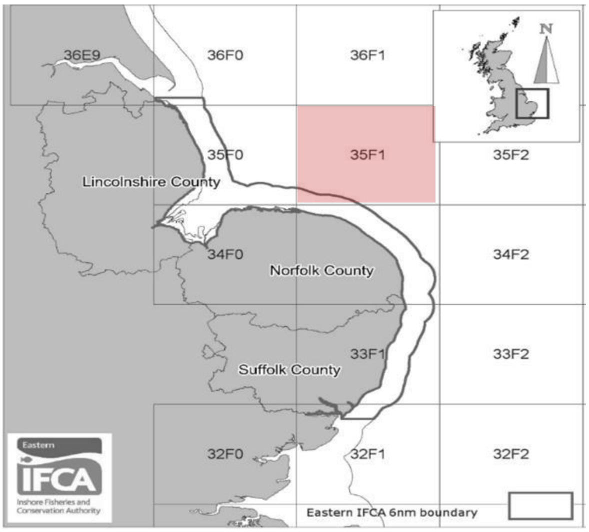
ICES Rectangle 34F0 straddles the Norfolk/Lincolnshire border, including The Wash and a partial section of the North Norfolk Coast. Relatively low effort is currently dedicated to crab and lobster fishing in the area, however this appears to be increasing steadily.



ICES Rectangle 34F1 contains the primary fishing grounds for vessels operating out of Cromer and is fished by many vessels from ports along the North Norfolk coast. Effort and landings figures reflect the high number of vessels fishing this area, making this the most productive potting ground in the district.



ICES Rectangle 35F0 is the main offshore potting ground fished by vessels operating out of Wells and Lincolnshire. Although vessels outside of the EIFCA district fish these grounds, only data captured on MSARs originating from vessels landing within the EIFCA district are included in the analysis.



ICES Rectangle 35F1 falls largely outside of the 6nm district limits, however as the third most productive potting ground in the district it is still considered within this assessment as it is fished by a few ports and vessels originating within the EIFCA boundary.

Figure 2. ICES statistical rectangles fished within the Eastern IFCA district.

3.2 Landings and Effort Data – Monthly Shellfish Activity Returns (MSARs)

Monthly Shellfish Activity Returns (MSARs) are standardised forms in which fishers report on catch to be sent to the Authority, forming a foundation dataset which arrives primarily in paper format. Data is then digitised and captured in a bespoke Access database, providing opportunity to perform queries on elements that form the database. Submission of MSARs has been obligatory for shellfish entitlement holders operating vessels <10m since 2006, providing daily records of fishing activity including; areas fished (by ICES Statistical Rectangle), landings (Kg), effort (number of pots hauled) and port of landing. MSAR data is used to generate statistics on landings and effort annually, monthly or daily; by port, area fished or vessel. This approach provides an overview of the fishery; highlighting productive grounds, relative port activity and concentrations of fishing activity. Landings Per Unit Effort (LPUE) compares landings figures with effort to determine an approximation of productivity. Compared annually it provides a method of monitoring changes in productivity of the fishery. Landings and effort data can be further utilised to determine LPUE by fishing ground. LPUE can also be used conservatively as a proxy for abundance, potentially highlighting areas with higher LPUE as having higher population densities (Welby 2016).

Discard data is not currently collected within the Eastern IFCA district for the crab and lobster fishery and any mortality due to discarding practices is not taken into account within the annual stock assessment. Current research (Rodrigues et al. 2018) indicates that survivability of discarded individuals is high in brown crab fisheries, with some results suggesting an estimated survival rate of up to 92.7%. Anecdotally this is widely recognised within the fishery due to the passive nature of pot fishing with pots often being fitted with escape hatches for smaller individuals. Discard rates are generally high in pot fisheries; however, this is matched by an equally high survival rate. Discards typically comprise individuals that do not meet landings requirements including undersize individuals, animals with soft shells following moult or berried female individuals. For the purposes of stock assessments within the Eastern IFCA district landings are assumed equal to catch.

3.3 Biological Data – Bio-sampling at ports and processors

Landings length-frequency data were collected by Eastern IFCA officers as part of its biometric sampling programme (bio-sampling) from processors and ports within the district. All data are held on a bespoke Access database developed by Eastern IFCA. Sampling effort is currently targeted at ports and processors on a proportion of catch from randomly selected vessels at the point of landing or once catch has been distributed to local processors. Sampling measurements include the carapace width (CW) for Brown crab, measured across the widest part of the body and carapace length (CL) for lobster, measured from the eye socket to the base of the thorax carapace. Area fished (ICES statistical rectangle) and number of pots hauled are recorded, along with weight sampled and total vessel landing weight are also recorded. This data is used to assess exploitation of the stock (fishing mortality) using the length converted catch curve and yield per recruit methodologies, outlined in the following sections.

3.4 Length Converted Catch Curve Analysis (LCCC)

LCCC models provide an insight into the amount of fishing mortality within the fishery. It looks at the rate of mortality between different size classes and estimates how much can be attributed to fishing. Catch curve analysis was conducted using length frequency data collected from bio-sampling, converted to age frequency using the inverse of the Von Bertalanffy Growth Formula (VBGF) (Equation 1) and the growth parameters t = pseudo age at length, L_t = Length at time and t_0 = age at length zero.

Equation 1. $t = \left(-\frac{1}{K}\right) \ln(1 - L_t/L_\infty) + t_0$

Log transformed frequencies were plotted against pseudo age and a regression line fitted through the descending points, starting from points where animals had fully recruited to the fishery and ending where data reliability was compromised due to small sample size. The slope of this regression provided estimates of total mortality rate (Z) which was then converted to fishing mortality rate (F) by subtracting natural mortality (M), assumed to be 0.2. Rates were then converted to percentage biomass loss using equation 2 where x is substituted for Z, F or M.

Equation 2. $\%\ biomass\ loss = 1 - \exp(x)$

3.5 Yield per recruit analysis and reference points

Yield per recruit models were then developed based on mortality estimates to provide insight into the effect of exploitation on the stock. Initially, growth parameters for L_∞ were converted into weights (W_∞) and YPR curves generated using the method, which uses a series of five calculations the sum of which is multiplied by a hypothetical rate of *F* to provide an estimate of yield per recruit for any given rate. Once plotted rates of *F* derived from catch curve analysis were added indicating current rates of exploitation. Biological reference points Fmax and F0.1 were calculated from the curves as the highest achievable yield and the point on the curve where slope = 10% of its initial value respectively. Changes in current rates of *F* necessary to meet these references point were then calculated, with the results converted to percentage changes using equation 5 (Welby 2015).

The results of the LCCC were used to calculate yield per recruit (YPR) relative to changes in fishing mortality (F) which give an indication of stock status when observing growth overfishing. The relationship between YPR and F is typically dome shaped – low levels of F result in low landings. Typically, when these models are used for tropical finfish population, for which they were developed, the relationship between YPR and F is usually domed shape where both low and high levels of F may result in a reduction in yield, either due to fewer individuals being caught or a reduction in yield and biomass as animals are caught before they have had time to grow to a size that would contribute much weight to the yield (growth overfishing). In between these is F_{MAX}, the fishing mortality rate that maximises YPR and $F_{0.1}$ which identifies F at which the slope of the YPR curve is 10% of the slope of the YPR of the unexploited stock. There are inherent problems in directly estimating the maximum sustainable yield (MSY) for data limited stock such as crab and lobsters, therefore Eastern IFCA adopt an approach widely used by ICES (ICES, 2010) for numerous crustacean species including *Nephrops*, where F_{max} was used as a proxy for F_{MSY}. A summary of stock status in terms of fishing mortality in relation to F_{MSY} was provided for both crab and lobster stocks.

The available information is used together to build an understanding of the sustainability of the fishery. The models and data do not tell us the size of the stocks or what management measures are needed. Information from the industry, including discussions at the quayside provide useful context to the outputs of the models and data.

4. Summary statistics of Monthly Shellfish Activity Returns

4.1 District overview

Historically, crustacean stock assessments conducted by Eastern IFCA have included data for landings and effort reaching back to the inception of MSARs in 2006, providing a more substantial data period from which to infer trends within the fishery. Errors can be found within the MSAR database, derived either from source when forms are filled out by fishers at sea or at the data entry stage by ourselves. The database is routinely QA'd for errors, which will identify the larger errors, for example an entry for Kg landed for crab read 102102Kg (assumed to be 102Kg and repeated on entry) when only a small number of pots were deployed and hauled. This immediately flags an issue and is rectified if possible or removed if this isn't possible as it has the potential to inflate the LPUE had it not been found. For the purpose of the current assessment, MSAR data between 2015-2018 has been scrutinised and small erroneous data entries rectified. An overview of the effort and landings figures for 2006-2017 has been provided in figure 3. highlighting the overall trend in the data and that there are no significant changes in overall trends following the rectifications in the MSAR database.

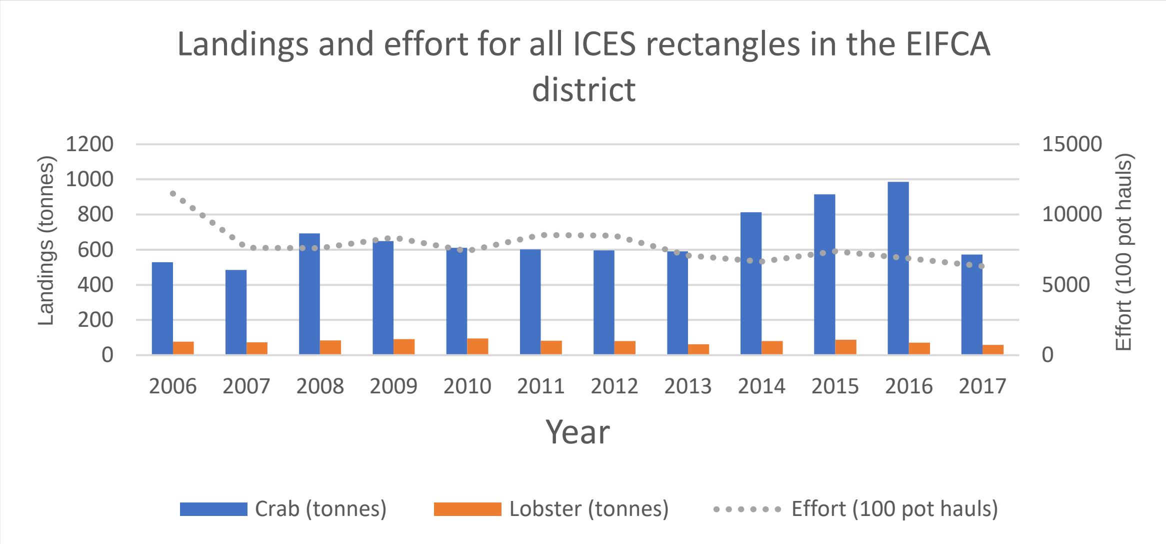


Figure 3. Annual district wide landings and effort (dashed line) by species for 2006-2017 prior to erroneous data entries being rectified.

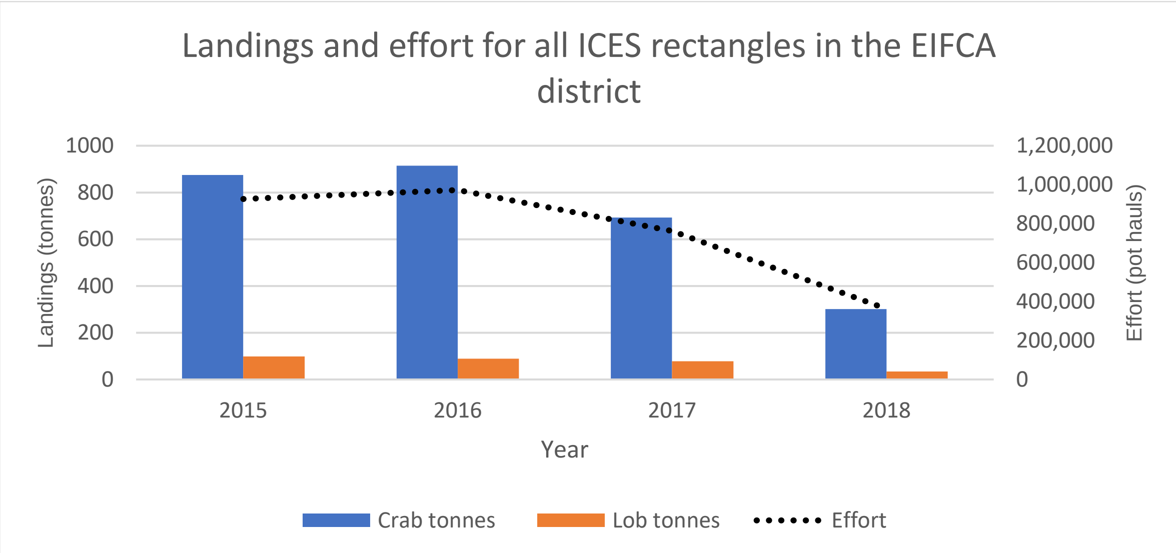


Figure 4. Annual district wide landings and effort (dashed line) by species for 2015-2018 following the rectification of erroneous entries in the database.

Key differences to note between the two graphs include a less significant increase in landings between 2015 and 2016 in figure 3. Figure 2 shows an increase of 914.5 tonnes to 986 tonnes of crab whereas figure 3 shows an increase of 875 tonnes to 915 tonnes. A difference of 71.5 tonnes and 40 tonnes respectively. Figure 4 provides the total landed weight of crab for 2017 of 693 tonnes whereas figure 3, with a cut-off point of March 2018 was incomplete with a total of 571.9 tonnes.

Figure 3 identifies significant increases in effort. In 2015 figure 3 identified 737,700 pot hauls whereas figure 4 identifies 926,761 pot hauls. In 2016 figure 3 identified 688,200 pot hauls whereas figure 4 identified 972,471 pot hauls. 2017 was an incomplete dataset therefore no comparison can be made and data for 2018 was unavailable at the time so no comparison can be made.

Historically, since the inception of MSARs in 2006 effort has remained relatively stable between 2007–2013, fluctuating around the annual mean. Between 2014-2016 landings steadily rose whilst effort remained stable across the dataset. Following a peak in 2016 of 915 tonnes of crab landed, landings fell to 693 tonnes in 2017, similar in trend to landings across the dataset. Although 2018 data is currently incomplete, the majority of MSAR have been received and recorded in the database, therefore it is likely that landings figures will follow a similar trend to 2017. Although landings data for 2017 were lower than the preceding three years, they are relatively similar to the annual means, and more representative of the years preceding 2014 where landings began to climb significantly.

The dataset reported on in the current study ranging from 2015-2018 identified a slight increasing trend from 2015 to 2016, rising from 875 tonnes crab and 98.2 tonnes lobster (combined landings – 973.2 tonnes) in 2015 to 915 tonnes crab and 89.1 tonnes lobster (combined landings – 1004.1 tonnes) in 2016. Following the 2016 fishery, there was a significant decrease in landings in 2017 to 693 tonnes crab and 77.7 tonnes lobster (combined landings – 770.7 tonnes) and this was matched by an equally significant decrease in effort. Currently, although incomplete, the 2018 data identifies 301.5 tonnes crab and 34.5 tonnes lobster (combined landings – 336 tonnes) and following trends in last year's fishery this is not expected to rise significantly due to the collation of the majority of the fishery data for the year. Combined landings for crab and lobster in 2017 equated to 645 tonnes by the March 2018 cut off point, and individually equated to 587 tonnes for crab and 58 tonnes for lobster. The 2018 stock assessment reports on a complete dataset of all landings for the 2017 fishery of 693 tonnes crab and 77.7 tonnes lobster (combined landings – 770.7 tonnes).

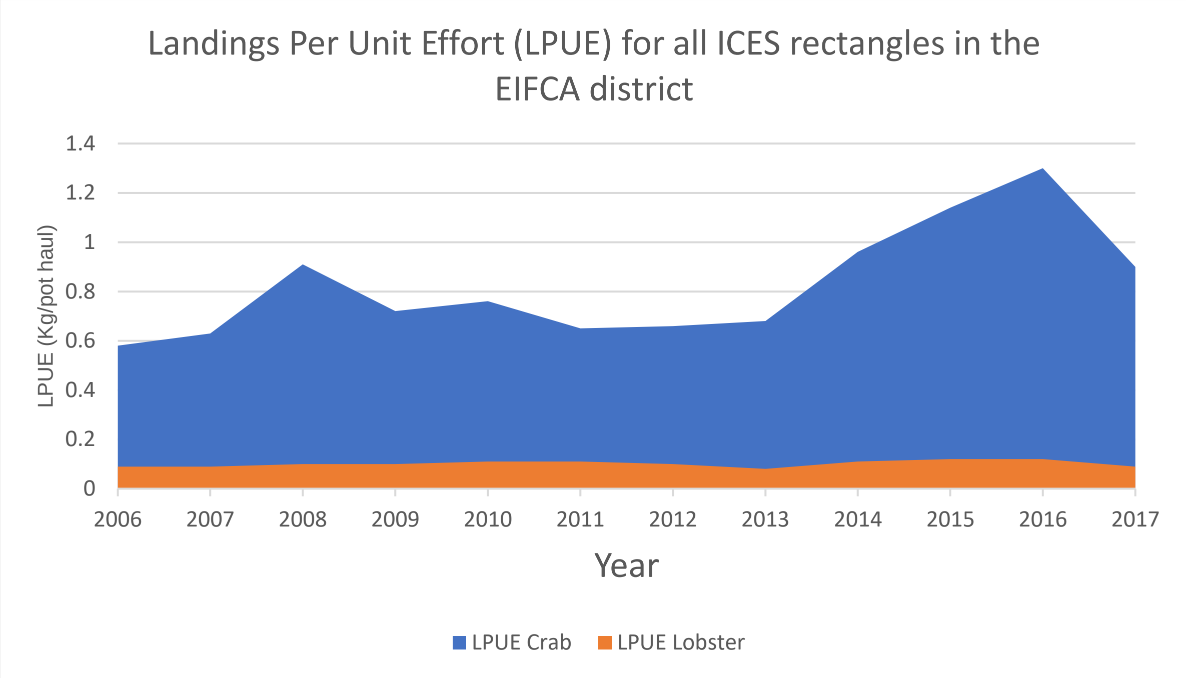


Figure 5. Annual district wide LPUE by species for 2006-2017 prior to erroneous data entries being rectified.

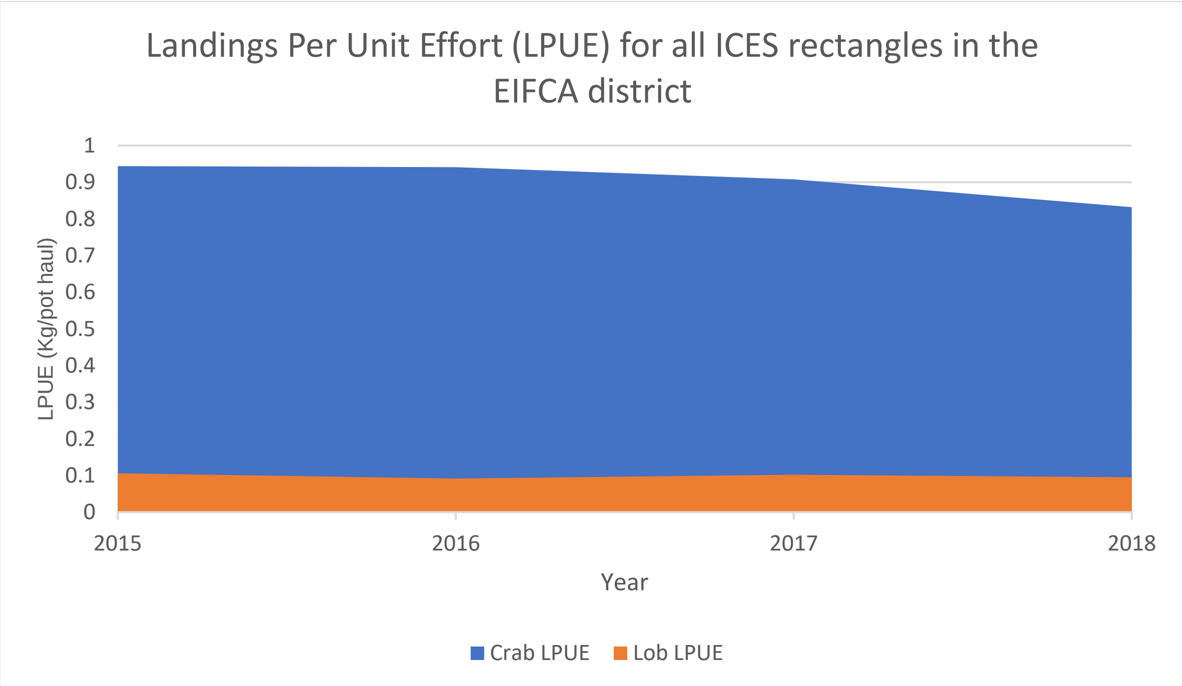


Figure 6. Annual district wide LPUE by species for 2015-2018 following the rectification of erroneous entries in the database.

LPUE (pot hauls) has remained relatively stable throughout the dataset period, for both *C. pagurus* and *H. gammarus*. Effort when fishing for crab has decreased slightly across the reported data period from a peak of 0.944Kg/pot in 2015 to 0.832Kg/pot in 2018. The average mean is 0.906Kg/pot).

LPUE for *H. gammarus* has remained more stable throughout the dataset and continues to do so in 2018 (0.095Kg/pot), decreasing marginally from 2015 (0.106Kg/pot), however this is representative of minor fluctuations around the annual mean (0.098Kg/pot).

Historically, higher market values for *H. gammarus* (£10-16.50/Kg) than *C. pagurus* (0.90p/£1.30/Kg) has offset disparity in landed weight when considering catch value. Landings are dominated annually by *C. pagurus*, however significant differences in market value per Kg mean that economically lobster is worth more to the fishery than crab, by an average of approximately £230,000 annually across the reporting period. The crab landings of 875 tonnes in 2015 and 915 tonnes in 2016 significantly exceed the dataset mean of 696 tonnes.

Landings of crab in 2017 were more representative of landings pre-2014 before landings began to climb to a peak in 2016. Landings of 693 tonnes in 2017 were similar to the dataset average of 696 tonnes. Landings of *H. gammarus* has remained relatively stable, displaying less variability across the dataset period.

Table 2. Annual value of district potting fisheries by species.

Year	**Crab (Kg)**	**Lobster (Kg)**	**Crab value range (90p-£1.30) per Kg**	**Lobster value range (£10-£16.50) per Kg**	**Crab value (£)**	**Lobster value (£)**	**Combined species (£)**
2015	875,000	98,200	787,500 – 1,137,500	982,000 – 1,620,300	962,500	1,301,150	2,263,650
2016	915,000	89,100	823,500 – 1,189,500	891,000 – 1,470,150	1,006,500	1,180,575	2,187,075
2017	693,000	77,700	623,700 – 900,900	777,000 – 1,282,050	762,300	1,029,525	1,791,825
2018	301,500	34,500	271,350 – 391,950	345,000 – 569,250	331,650	457,125	788,775
Mean	696,125	74,875	n/a	n/a	765,738	992,094	1,757,831

4.2 Summary statistics of ICES Rectangle 32F1

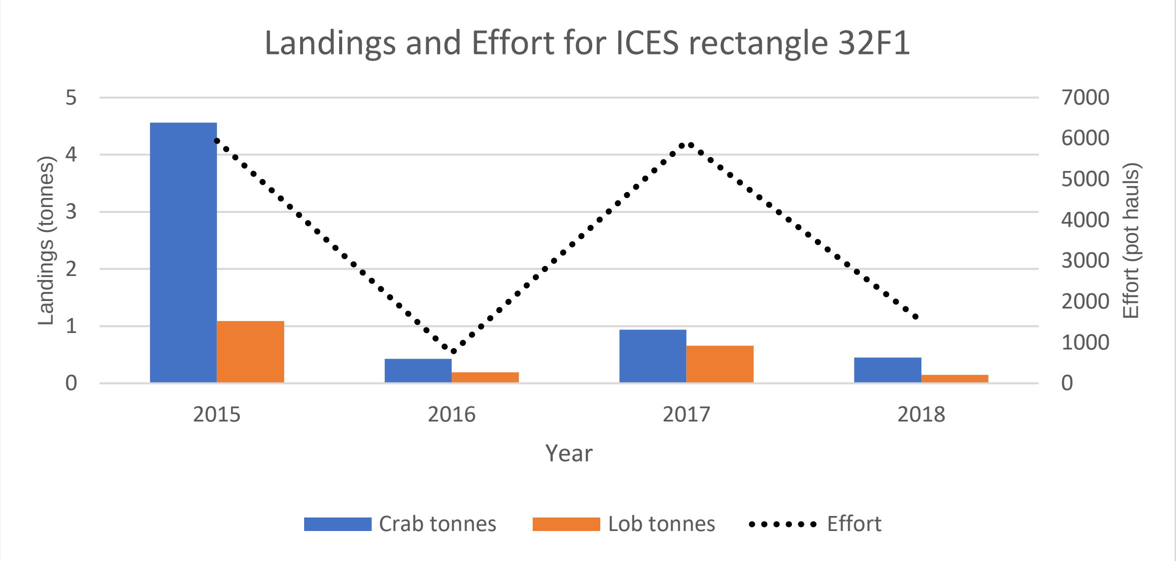


Figure 7. Landings and effort (dashed line) by species between 2015-2018.

The overall trend in ICES statistical rectangle 32F1 indicates a decrease in landings and effort, however LPUE has steadily climbed since 2017. Landings have significantly declined for *C. pagurus* from 4.55 tonnes in 2015 to 0.43 tonnes in 2016. Landings remained low in 2017 with 0.94 tonnes and this pattern appears to continue into 2018. Effort was at its highest in 2017 with 5942 pot hauls, however a steep decline in effort in 2016 was matched by record low landings across the dataset period.

Effort was increased significantly in 2017, almost matching that seen in 2015, with 5921 pot hauls, however, landings remained low indicating that growth overfishing had potentially occurred in the 2015 fishery, with a significant impact seen in the 2016 fishery. This is supported by an increase in the fishing mortality estimate in 2016 derived from the LCCC model (figures 19 and 20), greatly reducing the number of individuals on the fishing grounds. Effort dropped in 2018 following low landings figures in the preceding years, potentially indicating a redirection or reduction of effort by the fishermen, however this is an assumption and no evidence is available in support of this theory.

Landings for *H. gammarus* are less pronounced in decline when compared to *C. pagurus,* and landings remain more stable across the dataset. Landings exceeded a tonne in 2015 when effort was highest, however in 2016 it dropped to 0.2 tonnes and has remained relatively low into the current reporting year of 2018.

Table 3. Summary of effort and landings in ICES statistical rectangle 32F1

Year	Effort	Crab Landings (Kg)	Lobster Landings (Kg)	Combined landings (Kg)
2015	5942	4,558	1092.5	5,650.5
2016	743	430	191.75	621.75
2017	5921	939	664.35	1,603.35
2018	1528	453	147	600
Mean	**3,533.5**	**1,595**	**523.9**	**2,118.9**

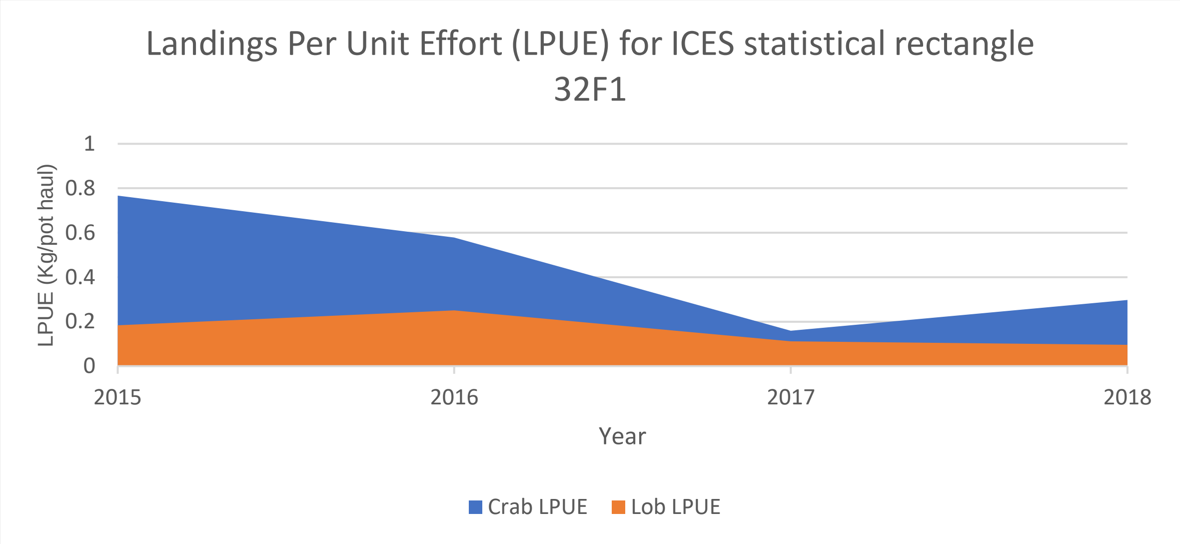


Figure 8. Annual LPUE by species between 2015-2018 for ICES statistical rectangle 32F1.

LPUE for *C. pagurus* in 2015 was highest at 0.767Kg/pot when both landings and effort were at their highest for the reported dataset. This trend declined in 2016 to 0.579Kg/pot as both effort and landings declined steeply. In 2017, effort rose sharply to similar levels seen in the 2015 fishery however landings remained low producing an LPUE of 0.159Kg/pot, an indication that the number of individuals available to be fished on the ground had greatly reduced as effort had returned to a high level. In 2018 indicative results show that effort again dropped as landings have remained low, increasing the LPUE from 0.159Kg/pot to 0.297Kg/pot, a figure closer to the dataset average of 0.451Kg/pot.

LPUE for *H. gammarus* has remained relatively stable across the dataset period as landings have remained consistent, even though effort has fluctuated. LPUE peaked in 2016 at 0.251Kg/pot, however it has steadily decreased since below the dataset average of 0.160Kg/pot.

4.3 Summary statistics of ICES Rectangle 33F1

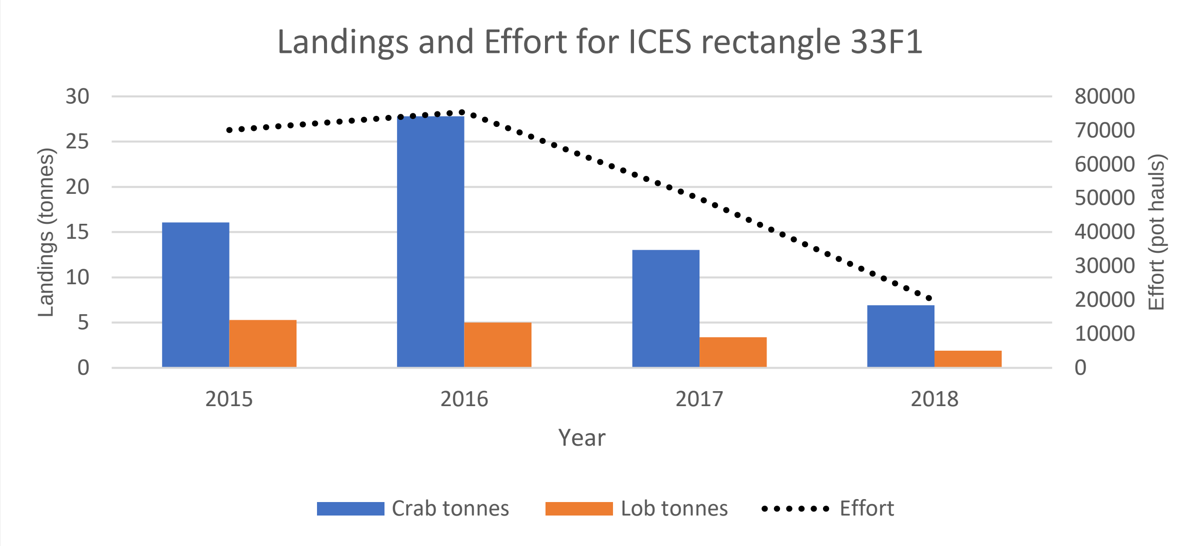


Figure 9. Landings and effort (dashed line) by species between 2015-2018.

The overall trend in ICES statistical rectangle 33F1 indicates a decrease in landings and effort, however LPUE has steadily climbed since 2017. Landings for *C. pagurus* peaked in 2016 with a value of 27.8 tonnes, increasing from 16 tonnes the previous year. Effort also increased between 2015-2016 to 75,386 pot hauls, however not as steeply as landings. Following this peak in 2016, landings for *C. pagurus* dropped steeply to 13 tonnes, closer to the average across the dataset of 16 tonnes. Indicative figures already collated for the 2018 fishery show similar landings figures as effort continues to drop in the rectangle.

Landings for *H. gammarus* have remained relatively stable across the dataset, fluctuating around the average mean for the dataset period of 3.9 tonnes.

Table 4. Summary of effort and landings in ICES statistical rectangle 33F1

Year	Effort	Crab Landings (Kg)	Lobster Landings (Kg)	Combined landings (Kg)
2015	70,131	16,066	5292	21,358
2016	75,386	27,791	5013.6	32,804.6
2017	49,902	13,030	3398.35	16,428.35
2018	19,849	6,929.5	1903.25	8,832.75
Mean	**53,817**	**15,954.1**	**3,901.8**	**19,855.9**

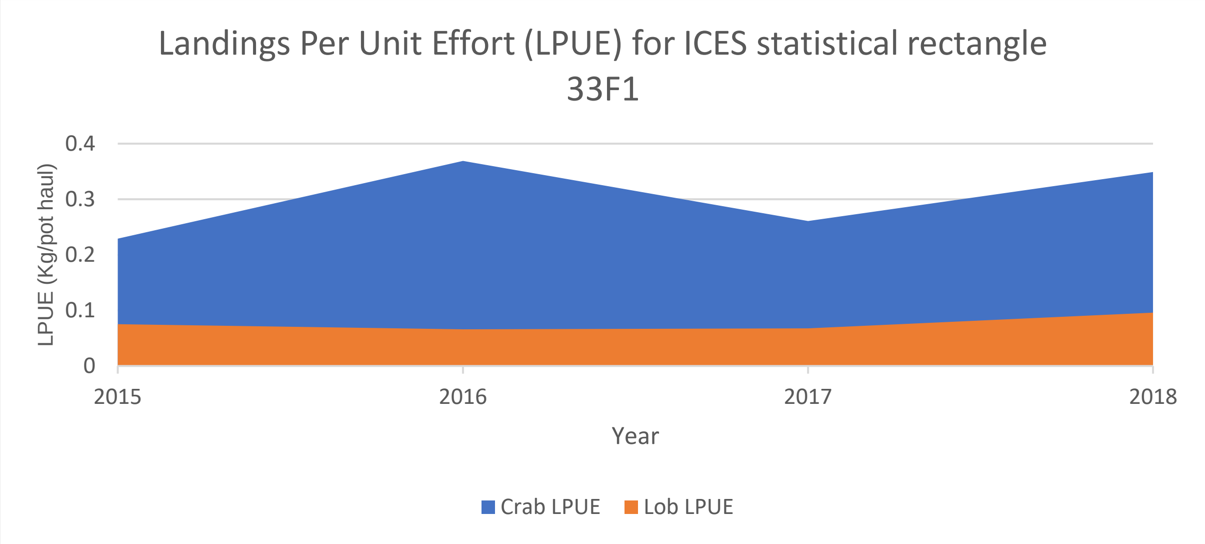


Figure 10. Annual LPUE by species between 2015-2018 for ICES statistical rectangle 33F1.

LPUE for *C. pagurus* in ICES statistical rectangle 33F1 has fluctuated across the dataset period with a peak in 2016 of 0.369Kg/pot when both landings and effort were at the highest. Landings and effort have been decreasing since 2016 and in 2017. Indicative results in the 2018 fishery show that both landings and effort remain low, however LPUE has risen from 0.261Kg/pot to 0.349Kg/pot indicating that less effort has been exerted to catch more weight of crab.

LPUE has remained relatively stable across the dataset for *H. gammarus* with a slight increase in 2018 from 0.068Kg/pot in 2017 to 0.096Kg/pot. *H. gammarus* has fluctuated around the average mean of 0.076Kg/pot.

4.4 Summary statistics of ICES Rectangle 34F0

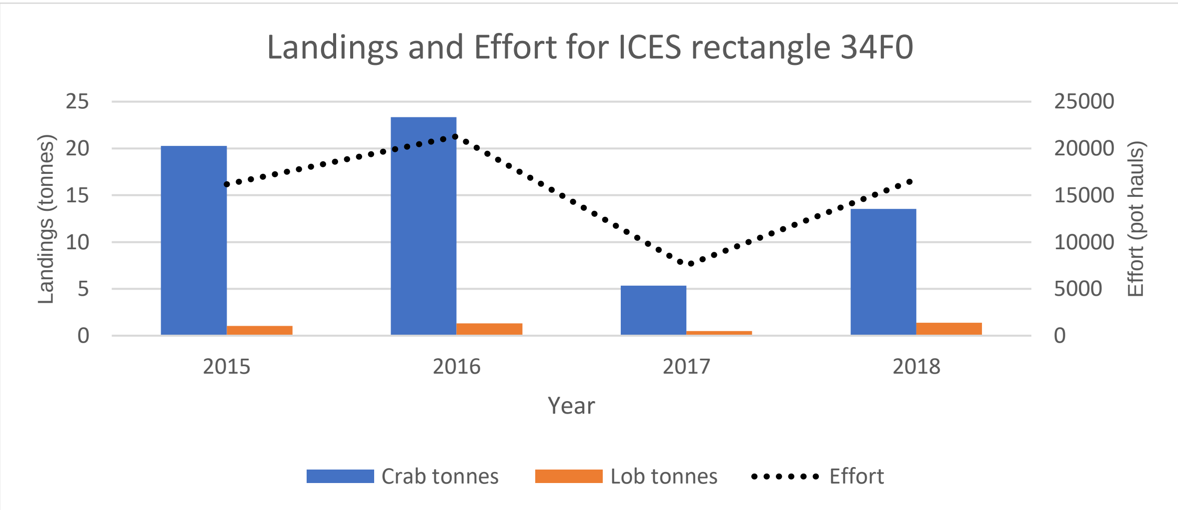


Figure 11. Landings and effort (dashed line) by species between 2015-2018.

The overall trend in ICES statistical rectangle 34F0 indicates an increase in landings and effort, and LPUE has steadily climbed since 2017. Landings for *C. pagurus* climbed steadily between 2015-2016, rising from 20.2 tonnes in 2015 to a peak in the dataset of 23.3 tonnes in 2016. This was matched by an equally steady climb in effort, rising from 16,186 pot hauls in 2015 to 21,290 pot hauls in 2016. Landings dropped significantly in the 2017 fishery to a dataset low of 5.3 tonnes, matched by a significant decrease in effort to 7,516 pot hauls. Both landings and effort have increased significantly in the 2018 fishery to 13.5 tonnes and 16,735 pot hauls respectively. Indicative results currently suggest that the 2018 fishery is now close to the average dataset mean of 15.6 tonnes.

Landings for *H. gammarus* have remained relatively stable across the dataset, fluctuating around the average mean for the dataset period of 1.05 tonnes.

Table 5. Summary of effort and landings in ICES statistical rectangle 34F0.

Year	Effort	Crab Landings (Kg)	Lobster Landings (Kg)	Combined landings (Kg)
2015	16,186	20,258	1038.67	21,296.67
2016	21,290	23,339	1314.15	24,653.15
2017	7516	5,326	485.3	5,811.3
2018	16735	13,535	1376	14,911
Mean	**15,431.75**	**15,614.5**	**1,053.53**	**16,668**

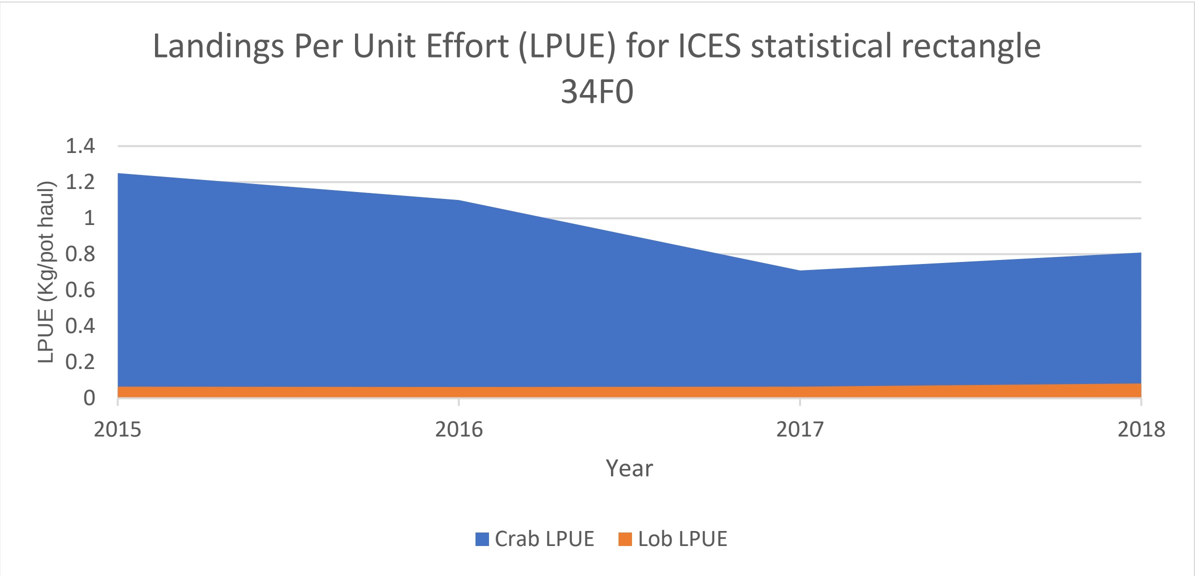


Figure 12. Annual LPUE by species between 2015-2018 for ICES statistical rectangle 34F0.

LPUE for *C. pagurus* showed a decreasing trend between 2015 and 2017 from 1.25Kg/pot to 0.709Kg/pot whilst landings and effort peaked in 2016. Both landings and effort decreased significantly in 2017 and this is represented by a drop of LPUE to 0.709Kg/pot. Landings and effort increased significantly in 2018 reflected in an increase in LPUE to 0.809Kg/pot for the fishery which is approaching the average mean of 0.967Kg/pot.

LPUE for *H. gammarus* has remained stable across the dataset fluctuating slightly around the average mean of 0.068Kg/pot.

4.5 Summary statistics of ICES Rectangle 34F1

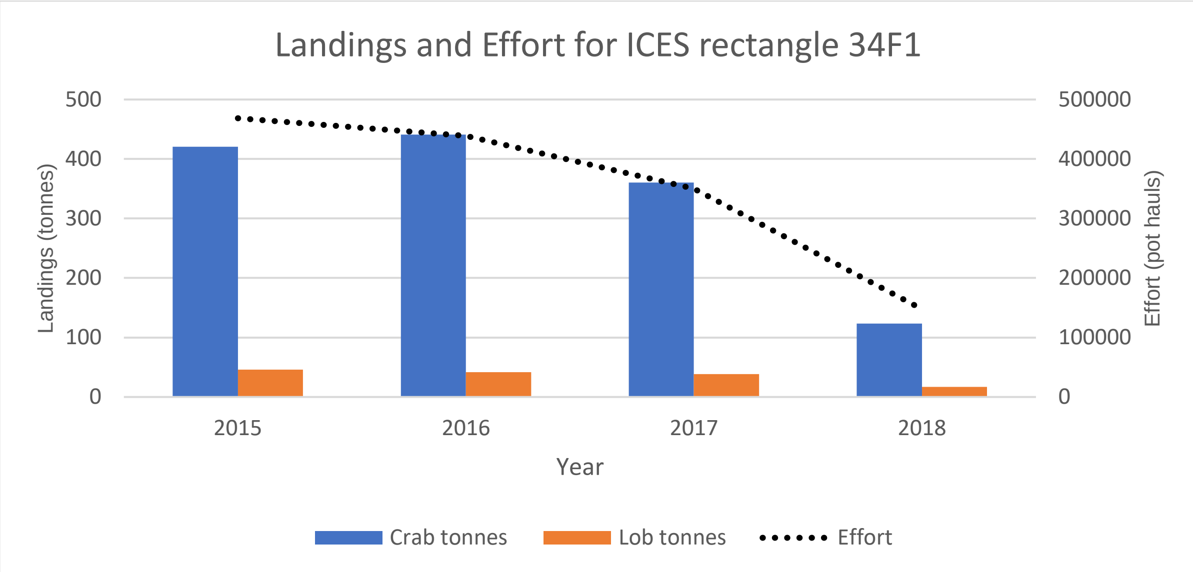


Figure 13. Landings and effort (dashed line) by species between 2015-2018.

The overall trend in ICES statistical rectangle 34F1 indicates a decrease in landings and effort, and LPUE has steadily decreased since 2017. Statistical rectangle 34F1 remains the predominant fishing ground for crustacean within the Eastern IFCA district. Landings peaked in 2016 for *C. pagurus* at 441 tonnes, up from 421 tonnes in 2015, whilst effort decreased between the years. Following 2016, landings have decreased in 2017 to 360 tonnes, closer to the average mean of 336 tonnes. Indicative results show that both effort and landings have continued to drop in the 2018 fishery.

Landings for *H. gammarus* have remained relatively stable across the dataset, fluctuating around the average mean for the dataset period of 35.7 tonnes.

Table 6. Summary of effort and landings in ICES statistical rectangle 34F1.

Year	Effort	Crab Landings (Kg)	Lobster Landings (Kg)	Combined landings (Kg)
2015	468,498	420,610	46,084.32	466,694.32
2016	438,963	440,839	41,572.7	482,411.7
2017	350,350	360,160	38,427	398,587
2018	147,707	123,355	16,823.25	140,178.25
Mean	**351,379.5**	**336,241**	**35,726.8**	**371,967.8**

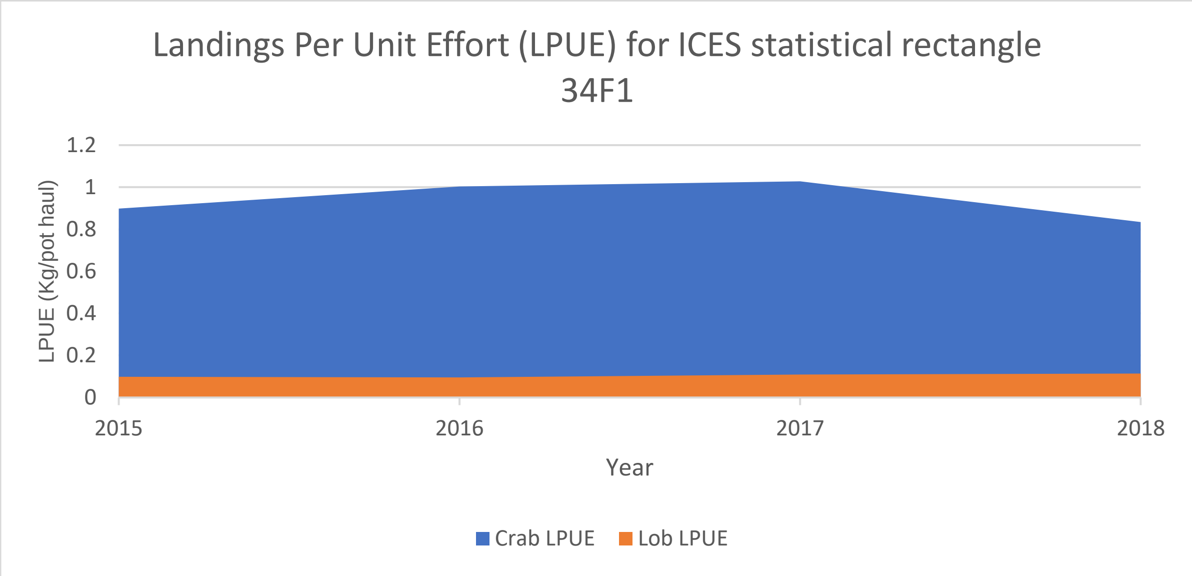


Figure 14. Annual LPUE by species between 2015-2018 for ICES statistical rectangle 34F1.

Although effort has been steadily decreasing since 2015, with a steeper decrease between 2017 and 2018 landings peaked in 2016. LPUE continued to rise between 2016 and 2017 to a peak of 1.028Kg/pot whilst effort and landings were dropping. LPUE dropped in 2018 to 0.835Kg/pot reflecting the decrease in both landings and effort. The mean for crab was 0.941Kg/pot.

LPUE for *H. gammarus* remained stable across the dataset fluctuating around the average mean of 0.104Kg/pot.

4.6 Summary statistics of ICES Rectangle 35F0

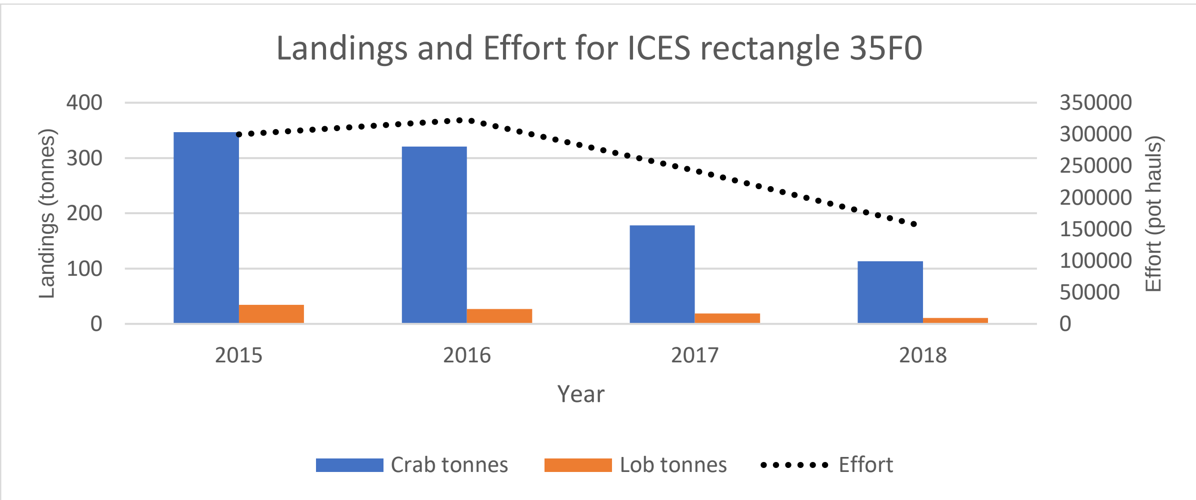


Figure 15. Landings and effort (dashed line) by species between 2015-2018.

The overall trend in ICES statistical rectangle 35F0 indicates a decrease in landings and effort, and LPUE has remained stable since 2017. Landings for *C. pagurus* steadily decreased between 2015 and 2016 347 tonnes in 2015 to 321 tonnes in 2016. Effort rose between 2015 and 2016 to a peak in the dataset of 322,940 pot hauls whilst landings were dropping. Following 2016 both landings and effort dropped significantly in 2017 to 177 tonnes and 242,391 respectively. Indicative landings and effort data for the 2018 fishery show a similar trend in landings and effort reduction.

Landings for *H. gammarus* have remained relatively stable across the dataset, fluctuating around the average mean for the dataset period of 22.7 tonnes.

Table 7. Summary of effort and landings in ICES statistical rectangle 35F0.

Year	Effort	Crab Landings (Kg)	Lobster Landings (Kg)	Combined landings (Kg)
2015	300,077	346,960	34,601.25	381,561.25
2016	322,940	320,810	26,896.4	347,706.4
2017	242,391	176,987	18,641.4	195,628.4
2018	154,550	113,085	10,589.5	123,674.5
Mean	**254,989.5**	**239,460.5**	**22,682.13**	**262,142.6**

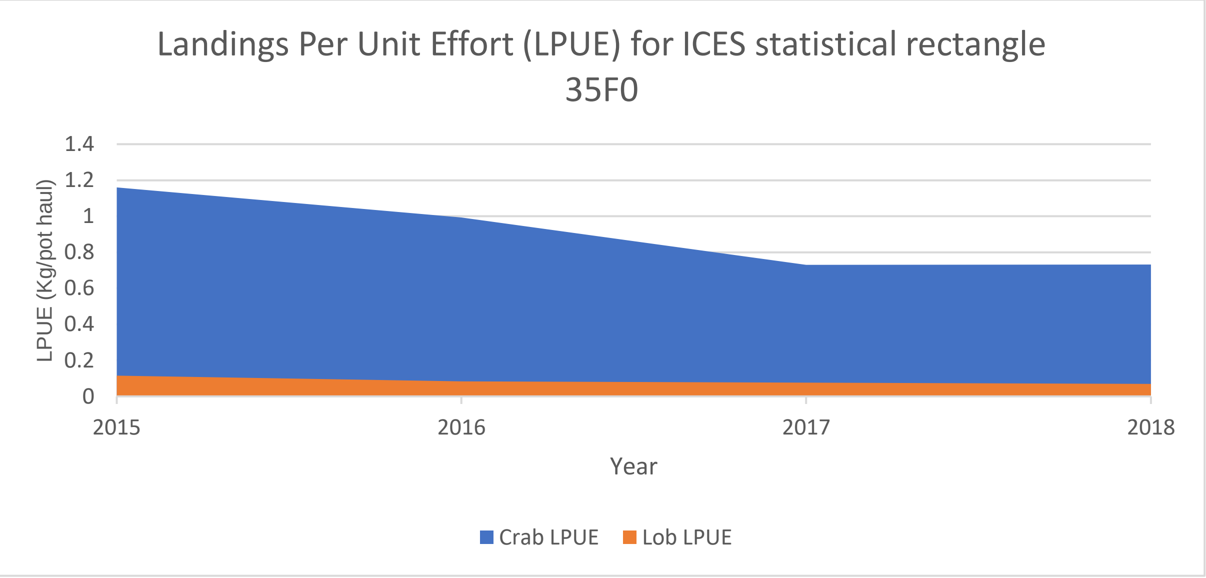


Figure 16. Annual LPUE by species between 2015-2018 for ICES statistical rectangle 35F0.

Landings dropped steadily between 2015 and 2016 and then dropped significantly in 2017 and indicative results show similar figures for 2018. Effort peaked in 2016 even though landings were dropping and then effort continued to drop in 2017 and 2018.

LPUE for *C. pagurus* dropped from 1.16Kg/pot in 2015 to 0.73Kg/pot in 2017, plateauing at this value into the 2018 fishery. Effort increased in the fishery in 2016, however LPUE continued to drop indicating less individuals on the fishing grounds. Average mean was 0.904Kg/pot.

LPUE for *H. gammarus* remained stable across the dataset, showing a slight but steady decline from 0.115Kg/pot in 2015 to 0.069Kg/pot in 2018.

4.7 Summary statistics of ICES Rectangle 35F1

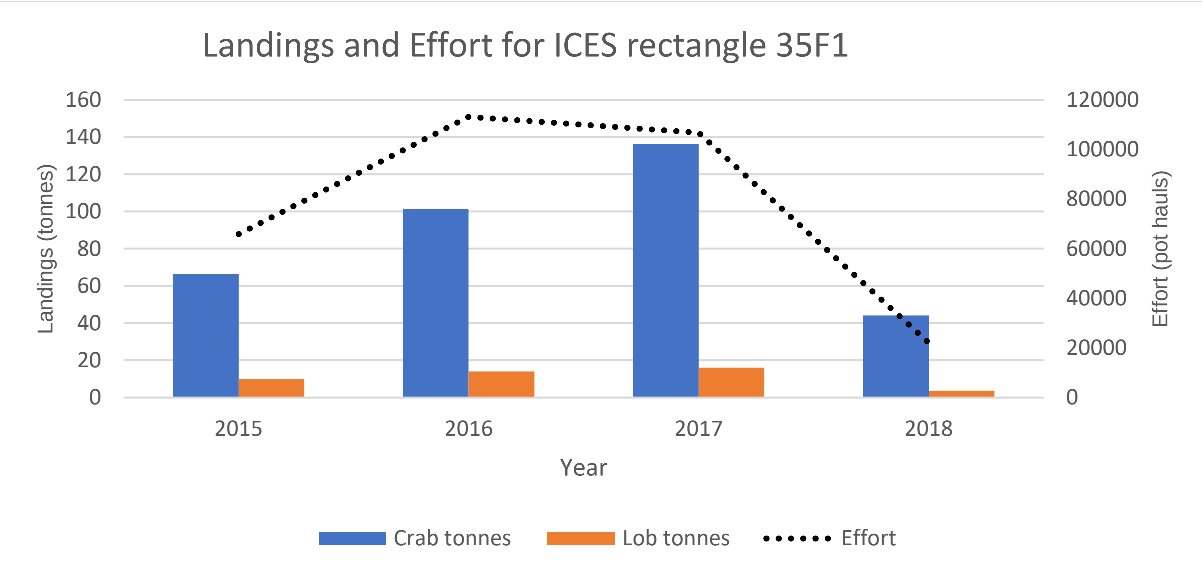


Figure 17. Landings and effort (dashed line) by species between 2015-2018.

The overall trend in ICES statistical rectangle 35F1 indicates a sharp decrease in landings and effort, and a sharp rise in LPUE since 2017. Landings for *C. pagurus* steadily increased between 2015 and 2017 from 66.4 tonnes in 2015 to 136.4 tonnes in 2017. Effort increased between 2015 and 2016 to a peak of 113,148 pot hauls, steadily decreasing to 106,762 pot hauls even though landings continued to rise. This indicates that there has been an increase in individuals available to be fished on the ground. Indicative results in the 2018 fishery currently suggest that landings and effort have decreased significantly. The return of the remaining MSAR forms will increase both landings and effort somewhat, however due to timing in the year, the majority of forms have been returned therefore values are not expected to exceed the dataset mean of 87.1 tonnes.

Landings for *H. gammarus* have remained relatively stable across the dataset, however there has been a slight increase in landings between 2015-2017 suggesting the potential for more individuals on the fishing grounds.

Table 8. Summary of effort and landings in ICES statistical rectangle 35F1.

Year	Effort	Crab Landings (Kg)	Lobster Landings (Kg)	Combined landings (Kg)
2015	65,927	66,384	10,101.27	76,485.27
2016	113,148	101,458	14,106	115,564
2017	106,762	136,376	16,060.34	152,436.34
2018	22,088	44,185	3,665.7	47,850.7
Mean	**76,981.25**	**87,100.75**	**10,983.3**	**98,084.07**

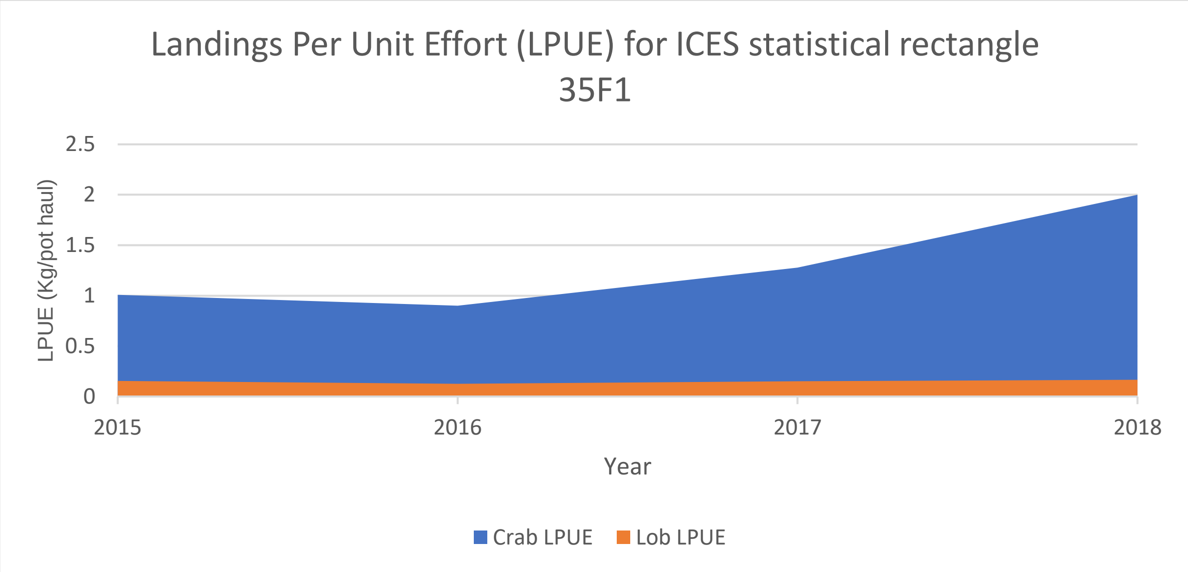


Figure 18. Annual LPUE by species between 2015-2018 for ICES statistical rectangle 35F1.

Landings have increased significantly between 2015 and 2017, with an indicative decrease in 2018 to figures closer to 2015-2016 as the data currently shows. Effort rose from 2015 to 2016 then dropped slightly between 2016 and 2017 and dropped significantly in 2018.

LPUE for *C. pagurus* was 1.007Kg/pot in 2015 when landings and effort were lowest. Landings and effort increased significantly in 2016 however LPUE reduced further to 0.9Kg/pot indicating there were less individuals on the ground to be fished. LPUE began to climb following 2016, reaching 1.277Kg/pot in 2017 whilst effort began to drop slightly, and landings reached a peak for the dataset. LPUE has continued to climb in 2018, reaching a peak of 2Kg/pot whilst indicative results for 2018 current suggest that landings and effort have decreased significantly. Average mean 1.296Kg/pot for crab across the dataset.

LPUE for *H. gammarus* remained stable across the dataset fluctuating around the average mean of 0.149Kg/pot.

5. *Bio-sampling mortality estimates*

Length converted catch curve (LCCC) was used to quantify total mortality (Z), and the rate at which the frequency of individuals in a population declines with size, attributing decline to death (mortality) either naturally or through fishing. Fishing mortality (F) can then be calculated by subtracting natural mortality (M) from Z. Estimates of mortality from bio-sampling conducted in 2018 are presented in table 9. Sampling effort remains significantly higher for *C. pagurus* in 2018, when compared to *H. gammarus*, attributable to significantly lower landings of the species providing very little sampling opportunity. Of those individuals sampled for both species, approximately double the number of males were sampled when compared to females.

5.1 Whole fishery dataset approach

Mortality estimates in previous Eastern IFCA stock assessments were based on the whole dataset approach where both inshore and offshore data were grouped together for the purposes of analysis in both the LCCC and YPR models and the following results are in keeping with this method of modelling exploitation in the fishery.

Table 9: Total Mortality (Z) & Fishing Mortality (F) estimates from 2018 bio-sampling data for C. pagurus male (CM), C. pagurus female (CF), H. gammarus male (HM) and H. gammarus female (HF).

Species/Sex	**Sample Size (n)**	**Z (rate)**	**Z (%)**	**F (rate)**	**F (%)**
CF	3207	1.682	62	1.482	53
CM	3835	1.348	61	1.148	53
HF	261	0.578	44	0.378	31
HM	410	0.412	34	0.212	19

<u>Yield per recruit analysis of inshore/offshore fishery combined</u>

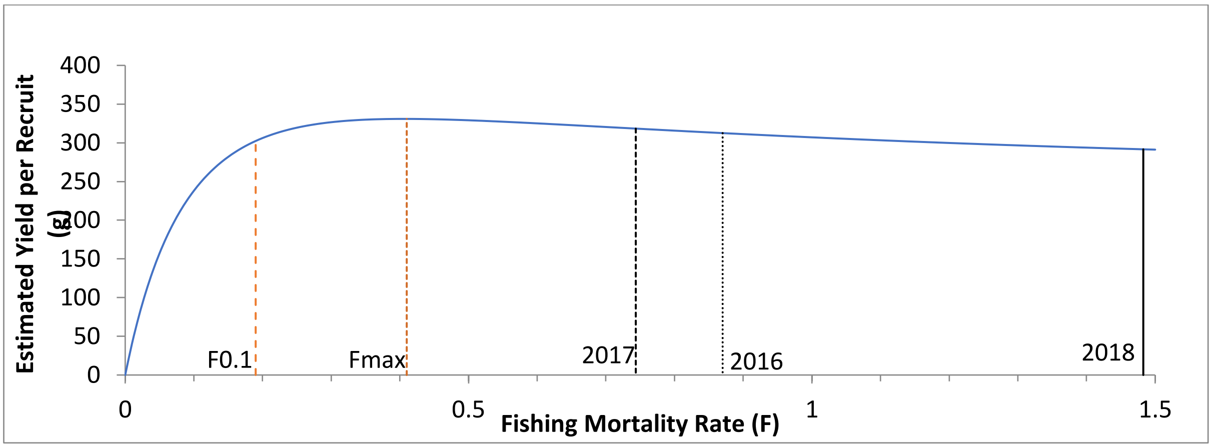


Figure 19: YPR Curves for *C. pagurus* females (CF) estimating exploitation rate for 2018 in comparison to estimates from 2016 and 2017, against target reference points Fmax and F0.1.

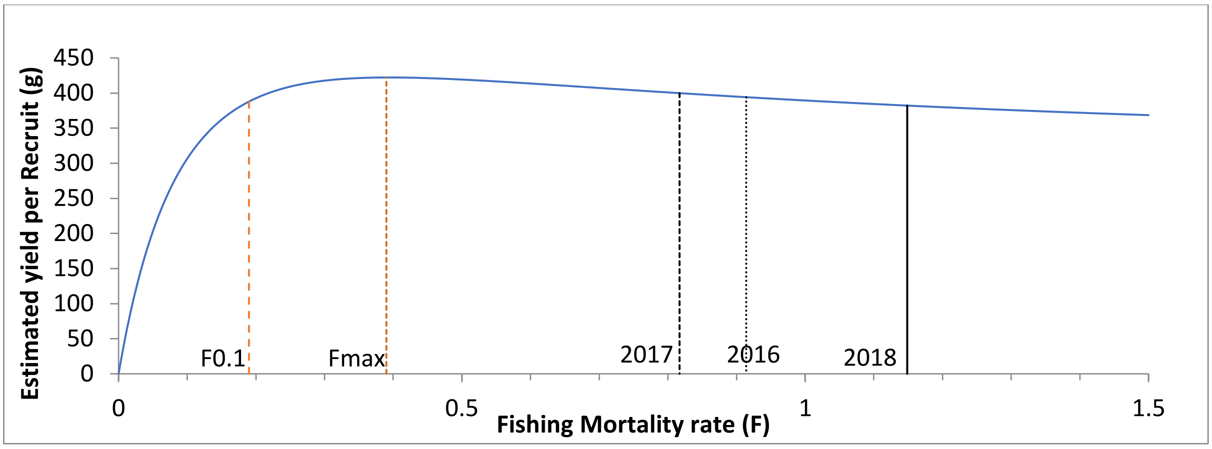


Figure 20: YPR Curves for *C. pagurus* males (CM) estimating exploitation rate for 2018 in comparison to estimates from 2016 and 2017, against target reference points Fmax and F0.1.

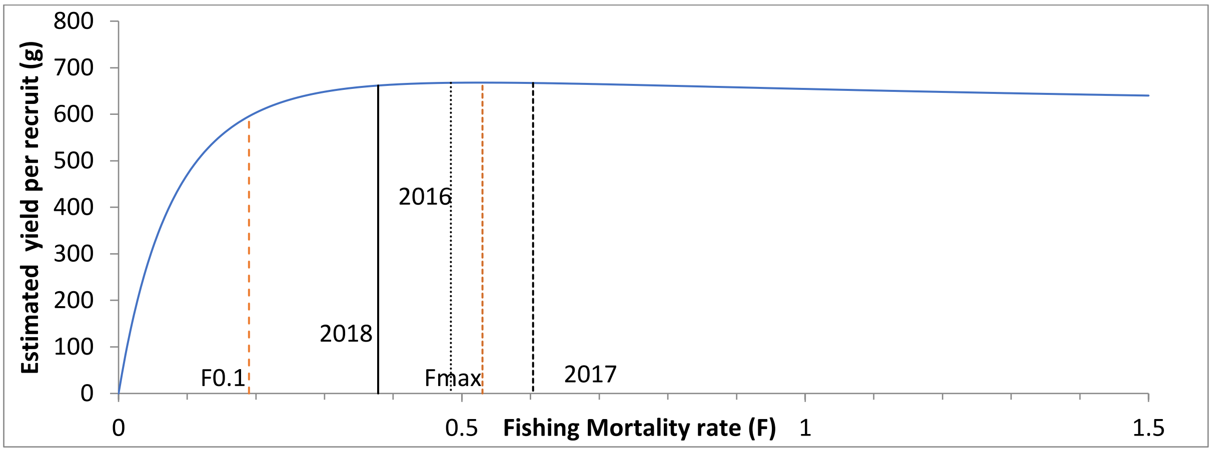


Figure 21**:** YPR Curves for *H.* gammarus females (HF) estimating exploitation rate for 2018 in comparison to estimates from 2016 and 2017, against target reference points Fmax and F0.1.

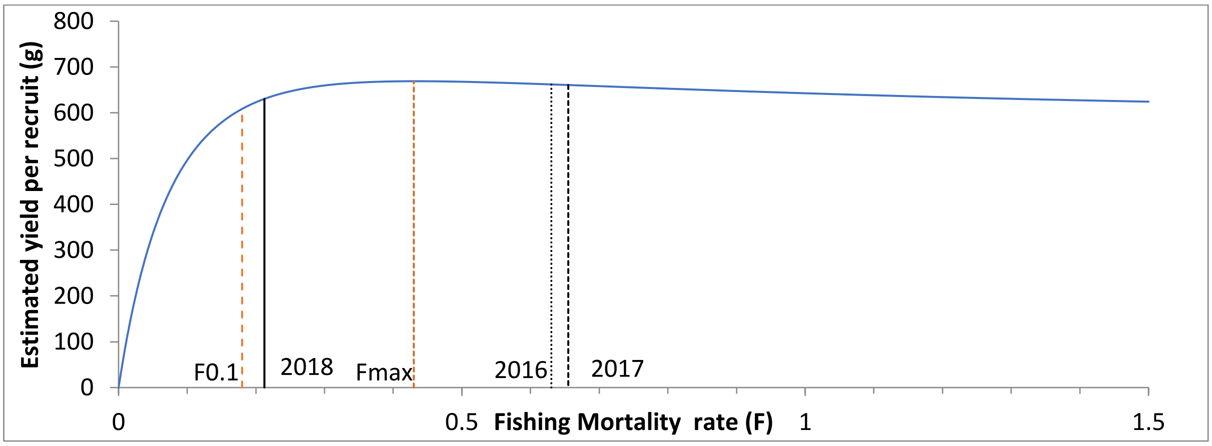


Figure 22: YPR Curves for *H. gammarus* males (HM) estimating exploitation rate for 2018 in comparison to estimates from 2016 and 2017, against target reference points Fmax and F0.1.

Table 10: Estimated Changes in Fishing Mortality (F) required to reach reference points Fmax and F0.1 and expected yield per recruit change when the data was modelled as a whole fishery.

Species/Sex	**Fmax rate**	**Fishing Mortality (F) rate**	**% reduction in F required**	**% yield per recruit change**	**F0.1 rate**	**% reduction in F required**	**% yield per recruit change**
CF	0.41	1.48	32	4.26	0.19	45	-4.73
CM	0.39	1.15	31	4.41	0.19	44	-4.07
HF*	0.53	0.38	-0.05	0.94	0.19	0.17	-9.27
HM*	0.43	0.21	-0.24	6.12	0.18	0.03	-3.46

*Based on insufficient sampling data for lobster, Eastern IFCA were unable to develop mortality estimates for the species which can confidently be reported on.

*Mortality estimates and subsequent % reduction in F values required to attain F_{max} provided in the table above do not account for recruitment into the fishery, additional non-fishing mortality and the growth patterns and population dynamics including migration of *C. pagurus*, therefore these values are significantly higher than would be expected for fishing mortality and are not representative of fishing mortality alone.

Table 10 presents changes to fishing mortality needed to meet target reference points. The greatest change will be required by stock experiencing the highest mortality rate to attain the necessary target values. It is expected that all changes to exploitation rate to meet Fmax will result in increased yield per recruit. In contrast the opposite is expected for F0.1.

5.2 Inshore/offshore fishery dataset approach for the Brown crab fishery

The brown crabs caught from the offshore fishery are significantly larger than those caught from the inshore fishery. When the data from both fisheries are pooled in the LCCC models, there is a danger that disparities in the sampling effort and the differences in the population size structures between these two fisheries could combine to create sampling artefacts resulting in erroneous outputs. In years where a higher proportion of samples have been collected from the inshore fishery (where crab tend to be smaller) the slope of the LCCC line will be steeper, and therefore indicate higher mortality, than years when higher proportions of crab have been sampled from the offshore fishery. To remove this potential artefact, the data have recently been split by port of origin, coupled with expert IFCO knowledge, to create separate datasets for the inshore and offshore fisheries. These data have then been re-analysed using the LCCC models to create outputs for each fishery. The mortality estimates produced from this re-analysis are shown in table 11.

Table 11: Total Mortality (Z) & Fishing Mortality (F) estimates from 2018 bio-sampling data for C. pagurus male (CM), C. pagurus female (CF), H. gammarus male (HM) and H. gammarus female (HF) using the split fishery data.

Year	**Sex/location**	**Sample Size (n)**	**Z (rate)**	**Z (%)**	**F (rate)**	**F (%)**
2015	CF Inshore	805	1.1915	70	0.9915	63
	CF Offshore	*690*	*0.7169*	*51*	*0.5169*	*40*
	CM Inshore	1079	1.5381	79	1.3381	74
	CM Offshore	*1405*	*0.9994*	*63*	*0.7994*	*55*
2016	CF Inshore	343	0.7403	52	0.5403	42
	CF Offshore	*1263*	*0.6065*	*45*	*0.4065*	*33*
	CM Inshore	1252	0.7857	54	0.5857	44
	CM Offshore	*1152*	*0.8717*	*58*	*0.6717*	*49*
2017	CF Inshore	1292	1.4589	77	1.2589	72
	CF Offshore	*990*	*0.6902*	*50*	*0.4902*	*39*
	CM Inshore	1460	1.1782	69	0.9782	62
	CM Offshore	*2043*	*0.7695*	*54*	*0.5695*	*43*
2018	CF Inshore	951	2.1305	88	1.9305	85
	CF Offshore	*2536*	*1.5311*	*78*	*1.3311*	*74*
	CM Inshore	2004	1.5596	79	1.3596	74
	CM Offshore	*2119*	*0.9066*	*60*	*0.7066*	*51*

Yield per recruit analysis for inshore/offshore split fishery

In addition to analysing the data as a whole fishery dataset, the data was separated into an inshore and offshore fishery and yield per recruit analysis used to model exploitation on the stock through fishing mortality on the population. Results of the analysis are presented below alongside target reference points F_{max} and F0.1.

Inshore fishery - Results of the yield per recruit analysis indicate that fishing mortality rates for 2018 exceeded maximum recommended exploitation rates (F_{max}) for both sexes of *C. pagurus*. Results indicate that crab females and males in the inshore fishery are furthest from achieving F_{max}, with mortality at its highest across the inshore/offshore data split reporting period of 2015-2018.

Offshore fishery - Results of the yield per recruit analysis indicate that fishing mortality rates for 2018 exceeded maximum recommended exploitation rates (F_{max}) for both sexes of *C. pagurus*. The yield per recruit analysis indicates that the overall trend in fishing mortality is lower in the offshore fishery than the inshore fishery, however crab females were significantly higher than the preceding 3 years of the dataset which saw fishing mortality hover closer to Fmax, in particular 2016 which indicated that fishing mortality was at the Fmax threshold and was the only year where Fmax was not exceeded. Crab males were positioned closer to F_{max}, and close to the preceding years exploitation rates.

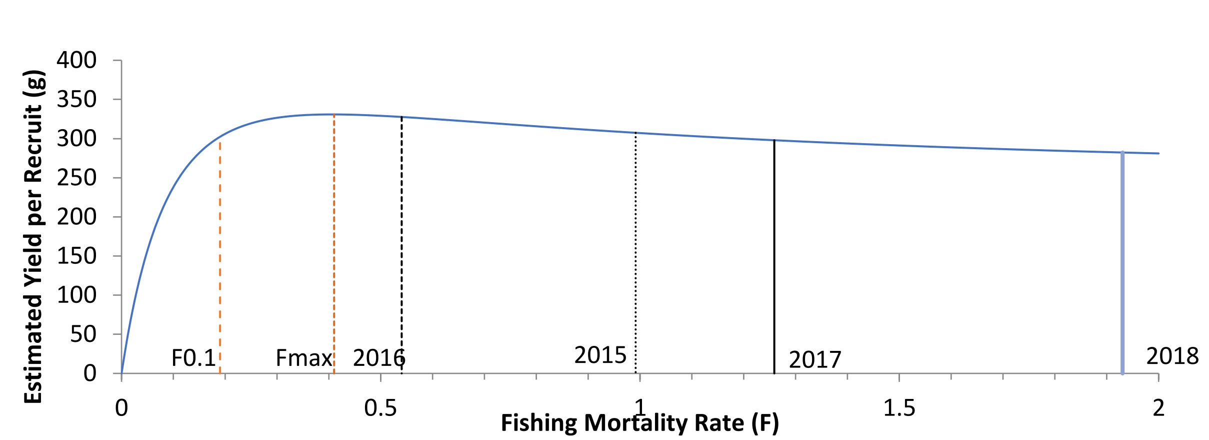


Figure 23. Yield Per Recruit (YPR) curves for Edible crab (*C. pagurus*) females (CF) in the inshore fishery indicating estimated exploitation rates for 2015-2018, against target reference points Fmax and F0.1.

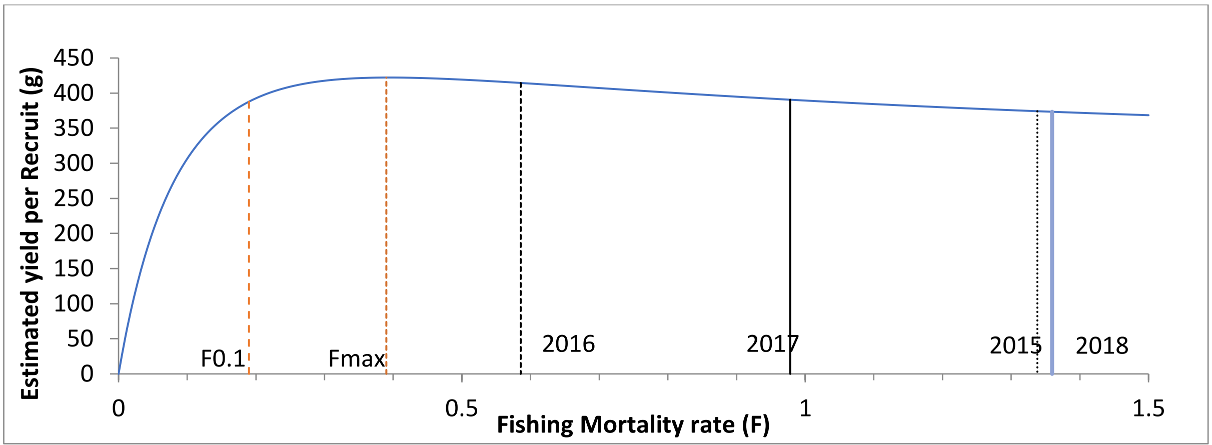


Figure 24. Yield Per Recruit (YPR) curves for Edible crab (*C. pagurus*) males (CM) in the inshore fishery indicating estimated exploitation rates for 2015-2018, against target reference points Fmax and F0.1.

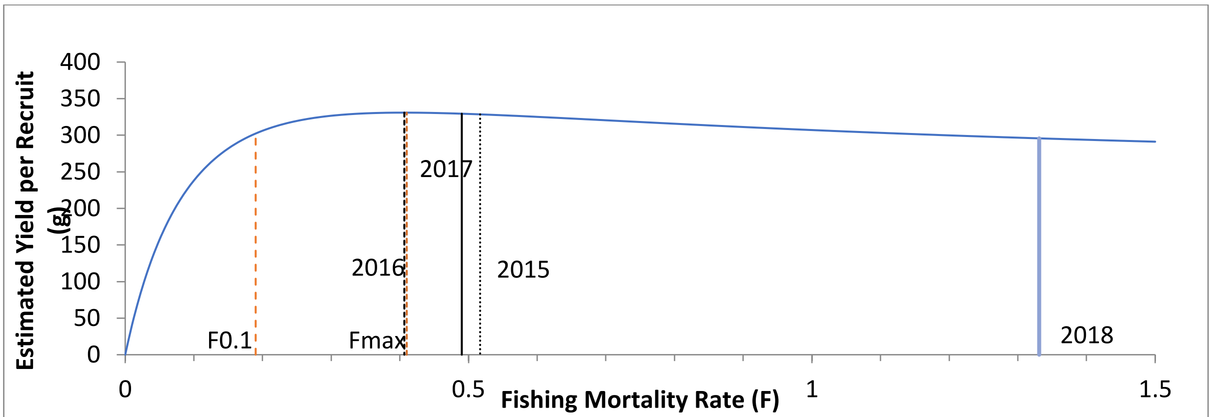


Figure 25. Yield Per Recruit (YPR) curves for Edible crab (*C. pagurus*) females (CF) in the offshore fishery indicating estimated exploitation rates for 2015-2018, against target reference points Fmax and F0.1.

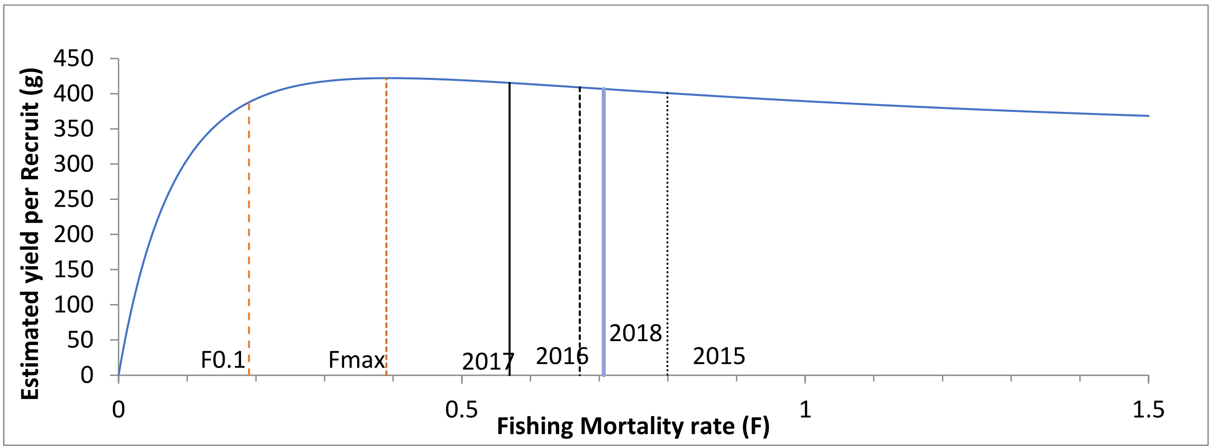


Figure 26. Yield Per Recruit (YPR) curves for Edible crab (*C. pagurus*) males (CM) in the offshore fishery indicating estimated exploitation rates for 2015-2018, against target reference points Fmax and F0.1.

Table 12. Estimated Changes in Fishing Mortality (F) required to reach reference points Fmax and F0.1 and expected yield per recruit change when the data was split into an inshore and offshore fishery for 2018.

Species/Sex	**Fmax rate**	**Fishing Mortality (F) rate**	**% reduction in F required**	**% yield per recruit change**	**F0.1 rate**	**% reduction in F required**	**% yield per recruit change**
CF Inshore*	0.41	1.93	93	17.23	0.19	100	7.12
CF Offshore*	0.39	1.33	66	11.8	0.19	76	2.23
CM Inshore*	0.39	1.36	68	13.06	0.19	77	3.87
CM Offshore*	0.39	0.71	27	3.79	0.19	41	-4.66

*Mortality estimates and subsequent % reduction in F values required to attain F_{max} provided in the table above do not account for recruitment into the fishery, additional non-fishing mortality and the growth patterns and population dynamics including migration of the species, therefore these values are significantly higher than would be expected for fishing mortality and are not representative of fishing mortality alone.

Table 12 presents changes to fishing mortality needed to meet target reference points. The greatest change will be required by stock experiencing the highest mortality rate to attain the necessary target values. It is expected that all changes to exploitation rate to meet Fmax will result in increased yield per recruit. In contrast the opposite is expected for F0.1.

6. DISCUSSION

Eastern IFCA utilise a multi-metric approach to crustacean stock assessments including LPUE and LCCC. LPUE measures overall stock sustainability, resilience and recoverability whereas LCCC is used to assess how the fishery effects stock structure, population dynamics and age (size) classes. LPUE looks at the fishery effect over the whole stock, assessing whether or not the stock as a whole can sustain current harvest levels. LPUE results suggest that the stock currently recovers from annual depletion with recruits maintaining LPUE. Fishing mortality estimates (F) derived from the LCCC model consider the frequency of sizes to estimate the depletion over time of individuals, represented as mortality rate. This is based on the difference between how many small (young) and big (old) individuals are in the population. LCCC results currently indicate that mortality estimates are above recommended indicators. Larger numbers of small individuals with a rapid decline with increasing size (age) suggests high mortality of early recruits. When individuals are removed from the fishery at a bigger size they have more time and energy to reproduce and provide recruits to replenish stocks. Recommendations for an increase in MLS will look to address this, as will other measures that protect smaller individuals increasing the efficacy of the spawning stock helping to shift mortality to focus on larger individuals in the fishery. Although results of the LPUE and LCCC appear to be contradictory, they are in fact measuring different metrics of the population and are therefore noncomparable.

LCCC models were originally developed to overcome issues with conducting stock assessments on tropical finfish that, like crustacea, do not produce distinctive growth rings in their otoliths from which they can be aged. LCCC determines age (pseudo age) from size using known (estimated) growth parameters, but also has the assumption that recruitment and natural mortality occur at steady rates and that there is no emigration from the population. These assumptions, and the fact that crustacea grow in steps rather than at a steady rate, mean the LCCC model is less than ideal for crustacean stock assessment. Nevertheless, while this method is not tailored to the specifics of crustacean biology it is currently the best tool available for estimating fishing mortality for this stock; providing an indication of stock health and a means of monitoring and quantifying any changes resulting from management actions. Recent examination of the modelled data has revealed additional issues with the way the data was being used in the model. LCCC models calculate mortality rates by measuring the slope of the regression line drawn through the size frequency of the population. As mentioned earlier, the model assumes a constant rate of recruitment, which does not actually occur. This means that in years of particularly good recruitment, the slope of the line measuring mortality will be artificially steep due to the large proportion of small individuals compared to large individuals. Due to this, the output of the model can confuse high mortality with good recruitment. The way the data is collected and pooled may also be creating a further artefact that can affect the model's outputs. This was a primary driver in separating the inshore and offshore fisheries and modelling the rate of exploitation (mortality) in isolation of each other.

While quantifying Maximum Sustainable Yield (MSY) in the district's crustacean fishery is not directly stated as a MSFD term objective, it does state that 'stocks should be exploited sustainably consistent with high long-term yields which implies the same desired outcome as achieving MSY, however there are limitations in using the LCCC model for establishing this threshold in crustacean populations. Consequently, alternative methods have been employed to set and monitor progress towards sustainability in the fishery using LCCC as the primary driver for management and LPUE to provide an overview of stock health. MSFD descriptors and mortality estimates and reference points can be used as proxies for indicating stock health and assessing progress towards F_{max}. Used in this way, long-term stability in LPUE would indicate contemporary levels of effort were not having an observable impact on the stock, while declining LPUE would suggest effort is too high. Reference points derived from the YPR models can provide objectives to work towards and annual mortality estimates can be used as a monitoring tool and measure of success in achieving the MSFD Descriptor 3 targets. Progress towards the reference points will be achieved through a suite of management options that look to address MSFD descriptor criteria, and in doing so improve the health and productivity of the stock. Recommendations based on the current stock assessment aim to fulfil Descriptor 3: Commercial Fish and Shellfish, as described in the MSFD.

Increases in sampling effort since 2015, primarily through access to processors has increased the acquisition of data, allowing for a greater quantity of individuals to be measured during each sampling occasion. This enables length converted catch curve and yield per recruit analysis to be carried out to evaluate fishing mortality and its effect on stock in quantifiable terms. This provides a robust method for monitoring stock dynamics, assessing how responsive a stock is to exploitation and identifying reference point objectives from which necessary changes in fishing mortality can be estimated. Whilst sampling effort has increased for *C*. *pagurus* through this approach, providing higher confidence in mortality rate estimates it has not been as beneficial for *H*. *gammarus* as sampling effort has remained low in 2018. Lower landings of *H*. *gammarus* coupled with salt water tank storage enabling mixing of individuals makes sampling difficult with the potential for erroneous results. This presents fewer opportunities to measure individuals, with approximately 10 times as many *C*. *pagurus* sampled in both 2017 and 2018 when compared with *H. gammarus*. This is supported by the recent Cefas stock assessment (Cefas 2018) of the species in East Anglian waters highlighting that inconsistencies in sampling coupled with insufficient data are making confident analysis of current stock levels difficult. It is widely acknowledged that variability of this magnitude when assessing mortality estimates is most likely the result of low sampling effort. Consequently, low confidence in mortality estimates derived from the yield per recruit models provides a driver for Eastern IFCA to establish a revised sampling approach for *H. gammarus,* increasing the number of individuals sampled to build confidence in the mortality estimates of the stock. Management objectives based on the confidence in current results for *H*. *gammarus* would not afford the correct level of protection.

Confidence in mortality estimates for *C*. *pagurus* are significantly higher, driven by higher sampling effort and consistency of results between years. *H. gammarus* displayed the lowest estimate of F with males and females experiencing losses to the population through fishing mortality of 19% and 31% respectively. Comparatively, fishing mortality for male and female *H. gammarus* in 2017 were significantly higher, equating to 48% and 45% respectively. Although confidence in these results is lower than those for *C. pagurus*, these figures suggest exploitation in the fishery in 2018 has reduced since 2017. Estimates of 53% fishing mortality for both sexes of *C*. *pagurus* were slightly higher in 2018 compared to 49% and 51% for males and females respectively in 2017, indicating that exploitation of the stock is above the sustainable

F_{max} reference point, however they remain consistently close to each other. Similarity in fishing mortality estimates for *C. pagurus* males and females suggest that neither sex is particularly susceptible to exploitation with equal opportunity of mortality through fishing.

The yield per recruit analysis indicate that fishing mortality rates for 2018 exceeded maximum recommended exploitation rates (F_{max}) for both sexes of *C. pagurus*. Results for *H. gammarus* indicate that stock exploitation has passed the optimum recommended level of fishing and is approaching F0.1, however confidence in these results is low due to insufficient sampling to create strong modelled outputs. Variation in *C. pagurus* is most likely representative of realistic changes in exploitation rate and population dynamics. Both sexes of *C. pagurus* are currently under pressure from growth overfishing due to high rates of exploitation on stocks. Inconsistent mortality estimates for *H. gammarus* represented by significant fluctuations in exploitation rate further reduce confidence in results for the species providing an additional driver to revise the sampling approach.

Based on the YPR analysis fishing mortality for *C. pagurus* would need to be reduced by ~32% to achieve maximum recommended exploitation rates (Fmax), and by ~45% to ensure maximum protective effect on the stock (F0.1). Important caveats accompany the mortality estimates and subsequent % reduction in F values required to attain F_{max} derived from the LCCC and YPR models. The models do not account for recruitment into the fishery, additional non-fishing mortality and the growth patterns and population dynamics including migration of the species, therefore these values are significantly higher than would be expected for fishing mortality and are not representative of fishing mortality alone.

Stock assessments for the District's crab fishery have historically grouped bio-sampling data from all ports into one database. This has not considered differences in the size frequencies of crabs that are caught from different parts of the fishery, whereby high proportions of small crab are landed from the North Norfolk inshore fishery and larger crabs from the offshore fishery. Although these are technically both part of the same Southern North Sea population, statistically their population size frequencies are behaving as two separate populations. Population dynamics, including recruitment and migration are widely unknown in the North Norfolk fishery, however research has shown that the North Norfolk crab population migrates through the Eastern IFCA district, eventually moving offshore as size increases, confirming that the inshore and offshore fishery target the same population. This theory is supported by anecdotal evidence provided by fishermen that crabs migrate from the inshore area once reaching a certain size, into the deeper water of the offshore area thus limiting the size of crab available to be fished by the inshore fishery and increasing the size of crab available to be targeted by the more substantial vessels on the offshore grounds. This has been attributed to a lack of suitable substrate for the larger individuals inshore, particularly when moulting and the need for protection.

Brown Crab (*Cancer pagurus*) were the only species included in the revised data approach due to insufficient lobster data. Data for the revised analysis was extracted from the full crab/lobster bio-sampling database based on year (2015-2018), separated into an inshore/offshore fishery by vessels port of origin and vessel size indicating a vessels capacity to fish inshore or offshore and by sex (Crab Female, CF and Crab Male, CM). The offshore fishery was categorised by vessels launching from Wells and

Brancaster and the inshore fishery categorised by vessels launching from Cromer, East/West Runton, Cley, Overstrand, Morston, Sheringham and Weybourne. Size/frequency data was then extracted for each category based on the aforementioned parameters in preparation for the LCCC model. The majority of the potting fishery fleet consists of vessels 6m or less in length and these are thought to be limited to the inshore fishing grounds due to limited engine capacity, deck space and a reduced ability to handle offshore sea states. We identified in the inshore/offshore screening process that there is potential for larger vessels that are 6m and over to fish both the inshore and offshore fishery, providing a mixed catch from both and rendering them unassignable to either the inshore or offshore fishery. This reduces our confidence somewhat in the accuracy of the split fishery data, however we are able to maintain a moderate level of confidence in the data as the majority of vessels in the fleet are of a smaller size and almost certainly fish the inshore grounds exclusively whereas a very small number of vessels have the ability to fish both.

Mortality estimates for crab were significantly higher when the dataset was split into an inshore and offshore fishery, in particular the inshore fishery and females sampled from the offshore fishery. Results indicate that females were impacted hardest in 2018, 85% for CF inshore and 74% CF offshore. CM inshore were significantly impacted with 74% fishing mortality, although not as significantly as CF inshore, however, in contrast CM offshore appear to have been impacted less with 51% fishing mortality. It should be considered that splitting the data further for the fishery creates more chance for the introduction of error and bias, amplifying any erroneous modelled outputs created in the LCCC and YPR models. In early 2018 there was an extreme weather event, termed the 'Beast from the East' which potentially had a large impact on crustacean stocks throughout the district. The east coast of England saw unprecedented numbers of individuals washed up on the shore, supported by anecdotal accounts of fishermen who recounted that catch for crab and lobster around Feb/March/April were the lowest they had seen in a very long time. This was also reflected in Eastern IFCAs bio-sampling programme in the early months at the beginning of the season in 2018. Visits to both processors and the quayside for sampling provided very few individuals when compared to previous years, with one processor stating that they were 40% down on crab compared with the same time the previous year and to cover orders they were needing to source crab from Scotland. This is further supported by anecdotal evidence received from the fishermen that saw very poor landings in this particular period. Significantly higher mortality for crab females in the offshore fishery could also support the theory that during the Beast from the East weather event, it was the females that were most susceptible to the event, and that males were perhaps undercover moulting and the females were in the shallower water and exposed having moulted and were more susceptible to the impacts of the Beast from the east. Potentially, this is supported by the significantly lower mortality for 2018 for crab males offshore.

Conclusions

The district wide analysis identified that the overall trend in landings, effort and LPUE decreased since 2017, however there was variability in individual ICES statistical rectangles. Generally, decreases in both landings and effort were observed in each with the exception of ICES statistical rectangle 34F0. In contrast all but one of the rectangles demonstrated a rise in LPUE. When assessing all ICES rectangle together LPUE indicates that the fishery is operating sustainably and currently is not being impacted by the level of effort and landings. In contrast, LPUE has risen in individual ICES rectangles expressing increased exploitation on the stock. This is the result of landings and effort data being more representative of individual fishing grounds and providing a finer resolution of exploitation in each of the ICES rectangles.

Addison and Bennett (1992) suggests that observable trends of increased landings correlate closely to strong recruitment years, which was identified as the potential catalyst for the highest recorded peak in landings for crab since the introduction of MSARs in 2016, therefore it is possible that significant reductions in landings for 2017, and subsequently in 2018 for *C. pagurus* is a result of lower recruitment to the district.

Offshore areas (35F0 and 35F1) are influenced by recruitment patterns taking place in inshore waters which receives larval recruits from the north as it provides settlement substrate seldom found along the district's coastline. These fishing grounds link intrinsically with what is occurring in the inshore area. Landings have continued to decrease in these areas since a peak in 2015 suggesting less individuals on the fishing grounds, potentially due to the peaks seen inshore in 2015-2016 which have removed some of the stock that would otherwise migrate offshore.

Estimates of mortality for *C*. *pagurus* identify high levels of exploitation in the districts stock, indicating the presence of growth overfishing. Annual landings for both *C. pagurus* and *H. gammarus* have continued to decrease in the district since 2016 and effort has decreased concurrently, however this said it is important to note that MSAR data will continue to be sent in until mid-year and the cut off point for the 2018 study is mid-March, with data included in the study representing all data that has been collected thus far.

Mortality estimates indicate that both target species are being fished beyond recommended maximum exploitation levels, although a higher level of confidence can be afforded to *C*. *pagurus*. Following an increasing trend in landings for *C*. *pagurus* between 2014-2016, uncertainty surrounded the rapid growth of the fishery. Continued increases in landings and effort in 2017 and 2018 would infer the need for a number of questions surrounding the sustainability of the fishery however, landings have reduced significantly since the high of 2016.

The split inshore/offshore and whole fishery data analysis approach have provided very different results when modelled using the LCCC and YPR methods. Mortality estimates and subsequent % reduction in F values required to attain F_{max} do not account for recruitment into the fishery, additional non-fishing mortality and the growth patterns and population dynamics including migration of the species, therefore these values are significantly higher than would be expected for fishing mortality and are not representative of fishing mortality alone. Splitting the data further for the fishery creates more chance for the introduction of error and bias, amplifying any erroneous modelled outputs created in the LCCC and YPR models.

Deficiency in data gives low confidence in mortality estimates for *H*. *gammarus,* however the most recent stock status report published by Cefas (2014) indicate that exploitation levels remain high, a pattern which has been consistent throughout the duration of reporting (Cefas 2004). Furthermore, Cefas (2014) highlight that data for *H*. *gammarus* is inconsistent and insufficient for assessments required to assess accurately the current level of stock, however they tentatively suggest that the species is more heavily exploited than *C*. *pagurus* within the district and that growth overfishing is occurring.

Comparatively, landings and LPUE for *H*. *gammarus* are stable throughout the district for the dataset period, with minor fluctuations around the annual mean. This indicates that fishing activity is not influencing recruitment to the point of reducing contemporary levels of stock biomass, however fishing activity may be inhibiting potential increase in species abundance through recruitment overfishing.

Fisheries targeting both species operate as mixed fisheries; using the same gear in the same area to catch both species concurrently. Candidate measures will need to be proportionate. Any measures implemented on one species has the potential to impact on the other, influencing the fishery with potential detriment. A robust monitoring regime should accompany management measures, focusing on catch data from returns and sampled landings.

The fishery needs some management to meet sustainability objectives, however stocks are not in imminent danger of collapse and there is no strong driver for a particular management measure. Eastern IFCA will approach the development and implementation of management measures using a method of monitoring, assessing and modifying measures introduced as necessary over time.

Data Gaps and Future Research Priorities

Sampling effort of *C*. *pagurus* has reached a point where data requirements are achievable, with a high level of confidence in results. In contrast, sampling for H. *gammarus* falls short of this target and as yet has failed to provide a confidence level in results from which appropriate control measures could be based. A revised approach for surveying *H*. *gammarus* at processors will be an intrinsic part of recommendations moving forward. Fisheries stock assessment modelling methods are evolving with increased usability for specific species. Active involvement in the development and progression of these modelling methods moving forward will ensure accurate and species-specific modelling techniques for future stock assessments through close liaison with Cefas.

Recommendations

The following recommendations are based on the current stock assessment and aim to fulfil Descriptor 3: Commercial Fish and Shellfish, as described in the Marine Strategy Framework Directive (MSFD).

Descriptor 3 implies the following 3 objectives to meet requirements, numbered 1-3 and these are followed by recommended technical measures to fulfil these requirements.

1. Stock exploited sustainably consistent with high long-term yields

Recommendation: High fishing mortality to be addressed through capped effort at contemporary levels, thus lowering the rate of exploitation.

2. The stock to have full reproductive capacity in order to maintain stock biomass.

Recommendation: Increase of 5mm in Minimum Landing Size, from 115mm to 120mm, affording increased protection to the spawning stock which will improve spawning potential and subsequent recruitment within the stock and reduce mortality on immature individuals.

3. The proportion of older and larger fish/shellfish should be maintained (or increased) being an indicator of a healthy stock.

Recommendation: Introduction of a maximum landing size to afford protection to older and larger shellfish.

There are many different management options which could achieve some or all of the above and Eastern IFCA seek the view of the industry to help in determining the most appropriate and effective management solutions.

Further recommendations:

- Improve availability of information to inform management decisions through focused and meaningful engagement with stakeholders.

- Continuation of Bio-sampling and MSAR data acquisition and analysis to facilitate management and the subsequent monitoring of necessary measures, including monitoring of data to establish patterns in migration and recruitment.

- Ensure analysis toolkits, in particular modelling methods for crustacean for the stock assessment are current, providing opportunity to promote better working relationships between organisations and maintain and build relationships with industry members to promote knowledge sharing and inclusion in decision making.

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