Appendix 1: Cefas edible crab stock assessment methods

Cefas Document Control

Submitted to:	Defra
Date submitted:	March 2023
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Version:	V1

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1. General methodology

The general approach of these stock assessments is to use data from two sources, which are partially, but not fully independent. These are:

- A time series of aggregate reported landings and effort data which provide a perspective on the fishery and exploitation level
- Aggregated length distribution data, used to model length based Virtual Population Analysis (VPA) and per recruit analysis which provides a perspective on stock and fishery status, including reference points.

There are major uncertainties in the commercially reported (landings and effort) data which vary widely through time in response to changes in the reporting and recording systems. Length sampling has varied in quality over time but provides a perspective on the stock status. However, aggregation of length distributions to annual and fishery management scale relies on commercial landings data in order to raise to the different strata, so the two data sources (landings and lengths distributions) are not truly independent.

The length-based assessment methodology assumes dynamic pool and steady state conditions which are frequently violated but provides a snapshot of stock and fishery status, as well as trends over time. As well as the consideration of the steady state snapshots, time series of simple length-based metrics and outputs from assessments (average F and reference point trends) provide an indication of trends in the length-based characteristics of the fisheries. The VPA model is applied to aggregated length distributions individually by sex and averaged over three years to smooth out inter-annual variability.

High levels of uncertainty in the data and violations of methodological assumptions mean the assessments should be considered as providing evidence that is broadly indicative of status rather than precise.

1.1 Biological parameters

Biological parameters used in the assessments are based on the best available data and are reviewed periodically (Table 2).

Length-weight relationship

Length-weight relationship parameters are applied using the standard relationship

$$w = al^b$$

where *w* is weight, *l* is length or in the case of crabs carapace width (CW) and a and b are the parameters.

Proportion mature

Maturity is modelled using a logistic relationship

$$p = 1 - 1 * (1 + ae^{(b*l)})^{-1}$$

where p is the proportion mature and a and b are the parameters.

Fecundity

Fecundity is modelled as a function of size

$$f = ae^{bl}$$

where a and b are the parameters. Linear and logarithmic functions were considered but these provided negative fecundity when the model was extrapolated beyond the available data and down to sizes where maturity was evident.

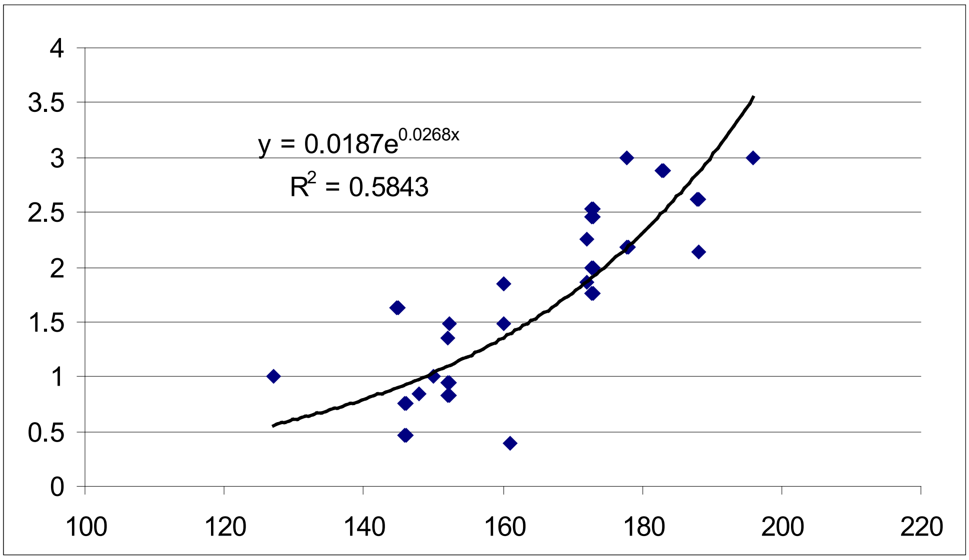

Figure 1. Fecundity in millions of eggs with size (carapace width mm). Solution and correlation coefficient inset (source Cefas unpublished).

Natural mortality

Natural mortality is poorly quantified for edible crabs *Cancer pagurus* and the parameters used for assessment are therefore highly uncertain. The length structured VPA and per recruit analysis are highly sensitive to the level of natural mortality used. To try and account for this, in 2012 Cefas undertook a brief review of the literature available on edible crab natural mortality in order to obtain the best estimates with the current knowledge available.

A range of parameter values were identified varying from a low of 0.06 (for females; Bennett, 1979) to the high values of 0.48 cited by Sheehy & Prior (2008) derived using Hoenig's (1983) formula and based on longevity estimates from lipofuscin analyses, very few based on strong data (Table 1).

Table 1. Values of natural mortality for edible crabs, estimated or used by a range of authors

Author	Natural mortality	Comment on estimation and/or usage
Bennett, 1979	0.14(M), 0.06(F)	Estimated from tagging data and catch curve methodology
Bennett, 1979	0.1, 0.2, 0.4 & 0.6	Range used for modelling
Edwards, 1979	0.05	Moult mortality only from observations in aquarium experiments
Addison & Bennett, 1992	0.1 (default) 0.2 & 0.3	Range used for modelling
Fahy *et al.,* 2004	0.2	Used for modelling with seasonal structuring options
Tully *et al*., 2006	0.1	Used for modelling. Hoenig's (1983) formula on stated longevity of 15 would give M=0.3
Sheehy & Prior, 2008	0.48-0.49	Based on lipofuscin estimate of longevity and empirical M formula
Chapman, 1994; Mill *et al.*, 2009	0.1	Also Bannister, 2009
Tallack, 2002; Mill *et al.*, 2009	0.242(M), 0.256(F)	Shetland - longevity based
Tallack, 2002	0.437(M), 0.396(F)	Shetland - maturity based

Historical estimates of edible crab mortality made by direct observation are low, including 0.05 for moult mortality observed in aquaria Edwards (1979) and 0.06 and 0.14 for annual mortality estimated by Bennett (1979) on the basis of relative age catch curve and tagging returns. Tallack (2002) produced moderate to high estimates of around 0.25 and 0.4 using empirical formulae based on longevity and maturity, whilst Sheehy & Prior (2008) used Hoenig's (1983) empirical formula together with a maximum age based of 9 on lipofuscin studies to estimate high natural mortality rates of 0.48-0.49. Other authors have generally provided values of natural mortality used in assessments and simulations without direct evidence of estimation and in many cases, these may be assumptions rather than estimates. These values have tended to range from around 0.1 (Bennett, 1979; Addison & Bennett, 1992; Chapman, 1994; Tully *et al*. 2006, Mill *et al.*, 2009) at the lower end of the range, through 0.2 (Bennett, 1979; Addison & Bennett, 1992; Fahy *et al.,* 2004), with upper limits of 0.3 (Addison & Bennett, 1992) and 0.4-0.6 (Bennett, 1979).

In summary, of these cited values 0.1 was frequently used as the default or most plausible value, with 0.2 another frequently used plausible value and higher values included as upper extremes.

Two of the estimated values cited fall at opposite extremes, Bennett (1979) and Edwards (1979) suggesting low natural mortality rates and Sheehy & Prior (2008) suggesting a very high rate, while others (Tallack (2002) tend to be moderate to high. Sheehy & Prior's (2008) estimate of longevity at 9 years for edible crabs seems low compared with other authors, e.g. Tully *et al*. (2006) suggesting a maximum age of around 15 years and Tallack (2002) suggesting 18-19 years.

A crab return from the Cefas tagging programme had been at liberty for just under 5 years. It was tagged at 194mm so assuming growth parameters used for stock assessment, was 8+ years old at that time and would now be around 13. Unfortunately, size and condition information relating to the recapture were poor but no information was provided to suggest this crab was of exceptional size or had moulted during its time at liberty. If not recaptured, it would be likely to moult once or twice more, before attaining L_∞. Assuming similar inter-moult durations for these moults, this suggests they might occur at ages 18 up to 23. The crab would then live for a further length of time at that size, suggesting a maximum age potentially in excess of 20.

In summary, Sheehy & Prior's (2008) estimate of longevity of 9 years gives a high natural mortality rate (0.48) using Hoenig's (1983) formula. Other estimates of longevity would suggest M in the region of 0.22 (Tmax=20) to 0.3 (Tmax=15) according to this formula. Hoenig's alternative equations for fish and molluscs suggest slightly lower and higher values, respectively, whilst the Alagaraja (1984) formula for Tmax 1% suggests very similar values. Information on crab maturity has been reviewed elsewhere and a wide range of L50% values (typically between 110mm to 140mm) have been estimated by different authors. Males generally mature at smaller sizes than females. Assuming L50% in the range above and the current growth rates, the age of 50% maturity is around 3 to 4, possibly 5, which equate to natural mortality rates of 0.41-0.53, or 0.32, using the Rikhter & Evanov (1976) formula.

UK sea temperatures typically fluctuate between below 10°C to almost 20 °C and average around 12°C or 13°C. Pauly's (1980) temperature and growth rate empirical formula would suggest natural mortality rates for edible crabs around 0.27-0.28.

The empirical formulae used with plausible considerations for maximum age, age at maturity, growth rates and temperature (made above) would therefore tend to suggest rates of natural mortality significantly higher than the 0.1 that has traditionally been considered most plausible and also higher than the alternative value of 0.2 often used. They appear to suggest values that are most often around 0.3, and usually in the range 0.2-0.4, with the maturity-based formula generally giving higher natural mortality estimates than longevity based estimates.

It should be remembered that the empirical formulae have generally been derived from fish rather than invertebrates and rarely from crustaceans. Sparre *et al*. (1989) explicitly warn against the use of Pauly's (1980) formula for crustaceans. It should further be noted that natural mortality in crabs is highly likely to be size structured due to the direct consequence of size in relation to predation rates and because moulting may induce direct mortality. Crabs are particularly vulnerable when moulting and this process is also size structured. However, at the present time, determining a constant value for natural mortality is difficult without the additional complexity of realistically structuring this according to size.

The natural mortality parameter value of 0.1 currently used as the default for stock assessments may be low, but should be retained as a lower limit, with 0.2 - 0.3 being used as alternatives and as an upper limit. Sheehy & Prior's (2008) estimate rounded to 0.5 is substantially higher than this, but their estimate of longevity appears to be low for an unexploited condition in comparison with other authors. Some of the empirical estimates based on age at maturity tend to give high estimates of natural mortality rate.

Natural mortality is estimated as 0.2 for the current assessments. Further work to improve knowledge and quantification of natural mortality for crabs should be developed as a priority. This should explore the use of existing data, as well as developing new directed data collection programmes.

Growth

Growth is probabilistic, based on moult probability and moult increment. Although reference aged data for crabs are available, these are generally limited to relatively young crabs, so extrapolation well beyond the range of the data is used to predict the age of older animals. Growth data for the older part of crustacean populations are particularly lacking, because intermoult periods are long and this causes additional problems for both tagging and aquarium experiments. The key problems with data obtained from aquarium studies relate to the artificial environment and whether observed growth reflects what would occur under natural conditions, while differential tag loss during moulting and tag loss and over extended intermoult periods (where variable reporting rates may also occur) are critical difficulties with tagging programmes. Growth parameters used in current assessments are derived from tagging experiments in the North Sea (Table 2).

Table 2. Parameters used in current edible crab Cancer pagurus assessments

Parameter	Female	Male	Source
Plus group	210mm	210mm	
Terminal exploitation rate	1.6	1.6	Recursively estimated
von Bertalanffy k	0.191	0.196	Bannister *et al*. (1983), Hancock & Edwards (1967)
von Bertalanffy L_∞	240	240	Bannister *et al*. (1983), Hancock & Edwards (1967)
Weight length a	0.000189	0.0000367	Bannister *et al*. (1983)
Weight length b	2.947	3.301	Bannister *et al*. (1983)
Maturity a	-10.4438	-10.4166	Cefas, 2004, unpublished
Maturity b	0.093592	0.11634	Cefas, 2004, unpublished
Fecundity a	0.0187	NA	Tully *et al*., 2001
Fecundity b	0.0268	NA	Tully *et al*., 2001
Natural mortality (all sizes)	0.15	0.15	Plausible alternatives

1.2 Length sample processing

Historically biological length samples were collected by the Marine Management Organisation (MMO), augmented by Cefas sampling in some years. In 2010 Cefas took over sample collection from the MMO. Since 2013, some IFCAs (Inshore Fisheries and Conservation Authority) have been able to provide length samples to supplement the data collected for the Cefas biological sampling programme. These samples have been included in this assessment where possible. Quality assurance is carried out on the samples selected for use in the production of length distributions. Samples from the landed component of the catch were validated before the aggregation process. Historically samples were collected by market categories based around sex (hens, cocks and mixed sex) and these were combined late in the aggregation process. Since 2009, landing and sampling categories have been reduced to mixed sex only, although occasional discrepancies still occur on the databases, no change in the aggregation protocol was required to accommodate this reduction in categories. Annual length distributions by sex were created for each fishery unit area using the following raising and combination procedures and the landed weight recorded on the official Integrated Fisheries System Holding (IFISH):

a) Samples are raised to vessel landing by market category (species code) and sex
b) month, port and ICES rectangle by market category (species code) and sex
c) quarter, port and ICES rectangle by market category (species code) and sex
d) quarter and ICES rectangle by market category (species code) and sex
e) quarter and fishery unit by market category (species code) and sex
f) annual by fishery unit by market category (species code) and sex
g) annual by fishery unit for combined market categories (species codes) by sex
h) raise from pot landings to all gear landings

Shellfish Association of Great Britain (SAGB) commissioned Cefas to develop a multiple indicator framework for crustacean fishery assessment and management under their Shellfish Industry Development Strategy (SIDS) programme. R scripts to interrogate the database, aggregate length distributions and length-based stock assessments have been developed as part of this Seafish/Defra funded work, resulting in a more automated process for conducting the length-based stock assessments. Checks to exclude the use of small samples are included, which specify that at the base level stratum (port, rectangle quarter) the length distribution must contain a minimum of 10 individuals. Length distributions used for Length Cohort Analysis (LCA) and per recruit analyses were generated using length distributions archived on Cefas' biological sampling information databases, and raised using R script. R code was also used to produce the length distribution time series graphics.

1.3 Length-based VPA

Length cohort analysis (LCA; Jones, 1981; 1984) produces estimates of population numbers and fishing mortality at length given growth parameters, assumptions regarding natural mortality and a catch length frequency distribution from a population assumed to be at equilibrium. The duration of time spent in each length class is calculated using the growth parameters. Estimates of the population number entering each length class can be made by Pope's cohort analysis approximation but in this case by numerically solving the catch equation (Sparre *et al.*, 1989). The process continues recursively estimating fishing mortality and numbers backwards along the 'pseudo-cohort', or numbers in each length class. The model can be summarised using the catch equations modified to take account of the time spent in each length class,

$$N_{l+1} = N_l e^{-(F+M)\delta t}$$

and

$$C_l = N_l \frac{F}{(F+M)}\left(1 - e^{-(F+M)\delta t}\right)$$

or using Pope's mid-year approximation

$$N_l = \left(N_{l+1} e^{(M/2)\delta t} + C_l\right) e^{(M/2)\delta t}$$

where *N* is population numbers, *F* is fishing mortality, *M* is natural mortality, *l* is an index indicating length class and *δt* is the time spent in a length class, given after manipulation of the von Bertalanffy growth equation by

$$\delta t = \frac{1}{K}\ln\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right)$$

where L_1 and L_2 are the upper and lower limits of the length class, L_∞ is the asymptotic length of a fish and K a growth parameter determining how rapidly fish approach the asymptotic length.

Mean annual population numbers are calculated using

$$\overline{N_{li,li+1}}\Delta t = \frac{N_i - N_{i+1}}{Z}$$

This equilibrium method has been criticised as a poor alternative to age-structured VPA (Lai & Gallucci, 1988; Hilborn & Walters, 1992), but does still provide a useful method for estimating a length structured exploitation pattern which can be subsequently used for per recruit analyses (Smith & Addison, 2003).

1.4 Fishing mortality and spawning stock biomass

Time series of fishing mortality and spawning stock biomass estimates and reference levels are derived from the time series of length based VPAs (LVPAs).

Average fishing mortalities (Fbars) are estimated by averaging fishing mortality at length over a range of length classes. Two estimates are produced, a wide Fbar taken as the average over most length classes above the MLS and a narrow Fbar taken as the average of F at length over a few length classes just above the MLS. Inclusive ranges are provided below. The wide size range is used in the assessment model.

Fishery management unit	Narrow Fbar size range	Wide Fbar size range
Central North Sea	130mm-155mm	130mm-180mm
Southern North Sea	130mm-155mm	130mm-180mm
Eastern English Channel	130mm-155mm	130mm-180mm
Western English Channel	130mm-155mm	130mm-180mm
Celtic Sea	130mm-155mm	130mm-180mm
Irish Sea	n/a	n/a

Spawning stock biomass (SSB) is calculated by summing (over length classes) the product average annual population numbers from the LVPA, maturity and weight at length.

Proxy MSY levels are derived from 35% virgin spawner per recruit (SPR) reference points. Hence F35%VirginSPR is used as the proxy F_{MSY} reference level for fishing mortality, while the proxy for SSB_{MSY} is derived by taking the product of the most recent 35%VirginSPR estimate and multiplying this by mean recruitment (population numbers recruiting to the first (modelled) size class). Both arithmetic and geometric means were considered, with the latter chosen as it provided more stability to outliers that sometimes occurs. Recruitment observations are frequently log-normally distributed, hence the geomean might be appropriate to describe the likely outcome of a recruitment, however SSB is a variable made up of many recruitments and this together with long term considerations might be better represented by the arithmetic mean.

1.5 Yield, spawner and egg per recruit

The yield per recruit (YPR) model (Beverton & Holt, 1957) works by assuming an arbitrary number of recruits and projecting them forward based on fishing and natural mortality to estimate numbers in each size class during the lifetime of the cohort. Numbers are subsequently divided by the number of recruits to obtain the 'per recruit' estimates. Weight, proportion mature and fecundity by size are applied to estimate yield, SSB or number of eggs by size class, which are summed over all classes. Per recruit models have been extensively used for crustacean fisheries.

The length-based yield per recruit model may be summarised

$$YPR = \sum_{l=FirstLength}^{LastLength} e^{-\sum_{i=Firstlength}^{l-1}(F_i+M_i)\delta t_i} Wt_l \frac{F_l}{F_l+M_l}(1-e^{-(F_l+M_l)\delta t_l}) + YPR_{PG}$$

where *F* is fishing mortality, *M* is natural mortality, *Wt* is average weight for a length class, *l* is an index indicating length class and *δt* is the time spent in a length class. The yield in the plus group (YPR_{PG}) may be treated simplistically since *δt* tends to infinity and all fish will die before reaching L_∞. However, if the final length class is far below L_∞, this will lead to under-estimation of the yield in this length class.

For length-based spawner and egg per recruit (SPR and EPR) the mean number of animals present in the population over a given year are estimated in order to adjust for annual periodicity of spawning. Spawner or egg per recruit for a given fishing mortality pattern and level (e.g. F_{sq}) are often expressed as a percentage of the SPR or EPR that would result if no fishing took place (virgin SPR or virgin EPR).

Plotting the values of YPR, SPR or EPR against a range of F multipliers (on the exploitation pattern) produces a family of curves from which various reference points can be estimated. These include F_{max}, the fishing mortality at which YPR is maximised and $F_{0.1}$, the F at which the slope of the YPR curve is 0.1 of the slope at the origin, and a more conservative reference point. These reference points reflect the influence of growth, natural mortality and fishing mortality pattern and level on long-term (equilibrium) yield.

The spawner and egg per recruit reference points are often used as conservation limits or targets as they reflect the influence of maturity and fecundity as well as growth, natural mortality, fishing mortality pattern and provide a reference level for equilibrium spawning biomass or egg production. They do not take account of stock recruitment (S-R) relationships, which are difficult to estimate, but provide an indication of stock resilience. However, meta-analyses for a wide range of fish stocks where the S-R relationship was 'known' have indicated that resilience was positively related to body size, which is a proxy for fecundity, longevity and low M (Mace & Sissenwine, 1993). Such species require a lower proportion of virgin SPR (or EPR) to maintain their populations. On this basis $F_{35\%VirgSPR}$ has been suggested as a general proxy for F_{MSY}, while $F_{10\%VirgEPR}$ and $F_{25\%VirgEPR}$ have been suggested as potential limit and target reference points, respectively, for the Irish lobster fishery (pers. comm., O. Tully).

1.4 Operational assumptions and constraints applied to the assessment methodology.

Averaging length frequencies over years

Prior to the length-based assessment, length frequencies are averaged over the 3 most recent years. The length distribution is delimited by the maximum length classes sampled in any of these years and length classes not present in some years are treated as zero frequencies rather than missing values.

Plus group

Plus groups are defined to take account of the size range of animals generally occurring in the different regions. Automated scripting (in R) is used to truncate the length distribution (lower the plus group) if the frequency in the nominal plus group is zero.

Mean weight in the plus group was taken using the same offset as for other size classes rather than interpolating between the plus group size and L_{∞}. This reflects the fact that most individuals occur in the lower portion of the plus group and will also reduce effects due to accumulation of individuals in the plus group, which can cause problems in per recruit analyses.

Terminal exploitation rate

Terminal exploitation rate is estimated using a single recursive iteration. In the first instance it is set to 0.5 and a length based VPA is run. F at length is averaged over all length classes between 90mm and the 2 length classes below the plus group. This value is used along with M to calculate a new terminal exploitation rate which is fed into the length based VPA. Using the average over this wide range may tend to produce a terminal F that is quite high and reduce doming in the exploitation pattern. However, LVPA generally converges quickly and is relatively insensitive to this parameter.

Introducing leading zeros for small size classes

Spawning potential per recruit reference points are frequently expressed as percentage of virgin spawning potential. A proportion of the population may mature before recruitment to the fishery, so in order to properly represent percentage of virgin spawning potential this should be taken into account. Size classes with zero catch frequencies are therefore introduced for small sized animals not captured in the fishery down to a size where a very small proportion will be mature. This enables the full extent of the spawning potential to be assessed, taking both the level of fishing and exploitation pattern into account.

2. Stock and fishery identity

Stock boundaries for edible crab remain poorly understood, however genetic studies have suggested greater heterogeneity than previously thought and the possibility of locally differentiated stocks. Both sexes are known to move widely, the females in particular have been shown to travel large distances, generally in a direction counter to residual tidal flows which are the likely direction of larval drift.

Studies on larval distribution and hydrographic conditions in the North Sea suggest recruitment to the two areas north and south of Flamborough Head could be distinct Eaton *et al,* 2003). Similar studies in the Channel have raised the possibility of separation of spawning populations in the eastern Channel from the western Channel/Western Approaches, but the mechanisms of and factors controlling recruitment are not clearly understood.

Catches of edible crab are distributed throughout UK waters. There has been a general trend for traditional inshore fisheries to expand onto offshore grounds in the North Sea, English Channel and Celtic Sea in the last decade. Significant crab fisheries occur in a number of areas, mainly Yorkshire, Northumberland, and the southwest, which can be geographically defined and may or may not be separated by areas with lower levels of landings. For the purpose of fishery monitoring and assessment, six fishery management units (FMU) have been defined for England and Wales, based upon what is known of larval distributions and development, hydrographic conditions and the distribution of the fisheries (Table 3). Other major crab fisheries are prosecuted by France in Northern Biscay (VIIIa), the English Channel and Celtic Sea and by Ireland and Scotland off their northern and western coasts (VIIa, IVa).

Table 3. Edible crab fishery monitoring units in England and Wales

No	Name	Sea area boundaries
1	Central North Sea	ICES division IVb north of 54° N
2	Southern North Sea	Between latitudes 51° 30′ N and 54°N
3	Eastern Channel	ICES divisions VIId east of 1° W and IVc south of 51° 30′ N
4	Western Channel and Western Approaches	ICES divisions VIIe, VIIh, VIIIa and VIId west of 1° W
5	Celtic Sea	ICES divisions VIIf and VIIg
6	Irish Sea	ICES division VIIa

3. References

Addison J. T., Bennett D. B. 1992. Assessment of minimum landing sizes of the edible crab, *Cancer pagurus* L., on the east coast of England. Fish. Res. 13(1): 67-88.

Beverton, R.J.H. and Holt, S.J., 1957. On the dynamics of exploited fish populations. Fish. Invest. Lond. Ser. II, 19. 533pp.

Eaton, D.R., Brown, J., Addison, J. T., Milligan S. P., Fernand, L. J. 2003. Edible crab (*Cancer pagurus*) larvae surveys off the east coast of England: Implications for stock structure. Fish. Res. 65: 191-199.

Fahy E., Hickey J., Perella N., Hervas A., Carroll J., Andray, C., 2004. Bionomics of brown crab Cancer pagurus in the south east Ireland inshore fishery. Irish Fisheries Investigations No. 12., 30pp.

Hancock D.A., Edwards E. 1967. Estimation of Annual Growth in the edible crab (*Cancer pagurus* L.). J. Cons., Cons. Int. Explor. Mer., 31: 246-264.

Hilborn, R. and Walters, C.J., 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty. Chapman & Hall, New York, 570pp.

Jones, R., 1981. The use of length composition data in fish stock assessments (with notes on VPA and cohort analysis). FAO Fish Circ., (734), 55pp.

Jones, R., 1984. Assessing the effects of changes in exploitation pattern using length composition data. FAO Fish. Tech. Pap. 256: 118pp.

Lai, H.-L. and Gallucci, V.F., 1988. Effects of parameter variability on length cohort analysis. J. cons. Int. Explor. Mer. 45, 82-92.

Mace, P.M. and Sissenwine, M.P., 1993. How much spawning is enough? In Smith et al. (ed.) Risk evaluation and biological reference points for fisheries management. Can Spec. Pub. Fish Aquat. Sci. 120: 101-118.

Mill A., Dobby H., McLay A., Mesquita C., 2009. Crab and lobster fisheries in Scotland: An overview and results of stock assessments, 2002-2005. Marine Scotland: 71pp.

Pauly D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer. 39(2): 175-192.

Sheehy. M. R. J., Prior A. E. 2008. Progress on an old question for stock assessment of the edible crab *Cancer pagurus.* Mar. Ecol. Prog. Ser. 353:191-202.

Sparre, P., Ursin, E. and Venema, S.C., 1989. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fish. Tech. Pap. 306/1. 337p.

Smith, M.T. and Addison, J.T. 2003. Methods for stock assessment of crustacean fisheries. Fisheries Research 65

Tully, O., Robinson, M., Cosgrove, O'Keeffe, E., Doyle, O. and Lehane, B. (2006). The Brown Crab (*Cancer pagurus* L.) Fishery: Analysis of the resource in 2004-2005. Dun Loaghaire, Ireland, Bord Iascaigh Mhara (Irish Sea Fisheries Board) Fisheries Resource Series No. 4: 48pp.