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Isle of Man crab and lobster fishery consultation evidence document (3)

Size at onset of maturity (SOM) of European lobster (*H. gammarus*), Isle of Man

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1 | Introduction

The European lobster (*Homarus gammarus*) fishery is of significant importance to the Isle of Man, worth £618,328 in 2019 (DEFA, 2020). Despite being a well-established and traditional fishery, there are several knowledge gaps in the species biology of European lobster that need to be addressed to support evidence-based management. Accurate estimates of size at the onset of sexual maturity (SOM) are required to inform minimum landing size (MCRS) regulations, in order to avoid overfishing and allow for reproduction to occur (Bianchini et al., 1998; Öndes et al., 2017). In lieu of data concerning the size at maturity of European lobster, the Isle of Man currently enforces the European MCRS (minimum conservation reference size) of 87 mm carapace length (CL) (Council Regulation No 850/98), which was established many years ago based on market demand and non-empirical observations of egg-bearing females. However, size at maturity can vary regionally depending on environmental conditions, and therefore the current MCRS may not be biologically appropriate for the Isle of Man and other regions where it is implemented.

This study coincides with parallel studies in Scotland and Wales examining SOM in European lobster. The aim of these studies is to achieve regionally appropriate fishery management and identify a standardised approach to determining sexual maturity in the species. There are various methods for assessing lobster SOM in the literature (Table 1), mainly based on the American lobster (*Homarus americanus*). However there is little understanding as to the relationship among multiple techniques which can be used to determine SOM in *H. gammarus* and hence currently no consensus for assessing maturity in this species. These methods are largely female-specific, as male maturity is more difficult to assess. Therefore only female lobsters were collected for this study, with the aim of applying multiple techniques to the sample population.

Table 1: Summary of methods used in the literature to assess lobster maturity (*H. americanus*).

Method	Females	Males
Functional maturity (SOM_F)	Presence/absence of eggs [d]	*NA*
Morphometric maturity (SOM_M)	Width of the abdomen [a]	Size of the crusher claw [a,c]
Physiological maturity (SOM_P)	Staging of the ovaries [a,b]	Presence/absence of spermatophores [d]
Behavioural maturity (SOM_B)	Staging of the pleopods (cement glands) [b]	*NA*

[a] Aiken & Waddy (1980)
[b] Aiken & Waddy (1982)
[c] Aiken & Waddy (1989)
[d] Conan et al. (1985)
[e] Krouse (1971)

2 | Methods

A total of 92 female lobsters (*Homarus gammarus*) were collected across a large range of sizes (63-120 mm CL) (Figure 1) in order to capture the full range of maturity. This included 31 undersized individuals (below MCRS 87 mm), for which permission was acquired from DEFA. Lobsters were sourced from Island Seafare and FV Shelgeyr, at the south of the Isle of Man, during peak spawning period (August-September) and stored in a freezer until processing occurred. Some additional morphometric data for lobsters was acquired from DEFA, collected by fishery observers at the south of the Island between 2012 and 2015 (landings and onboard observations).

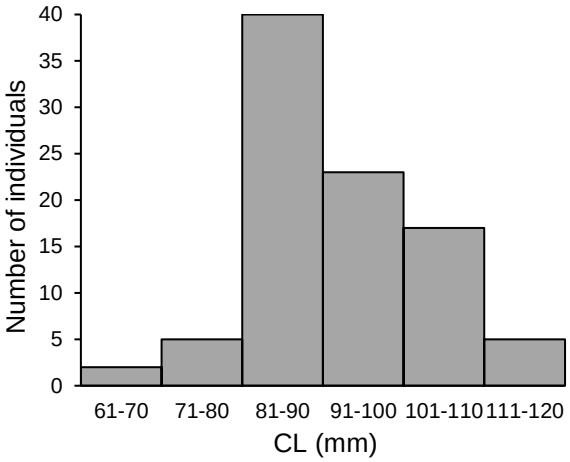

Figure 1: Size distribution of the 92 female lobsters collected for this study.

2.1 | Data Collection

After defrosting overnight, the lobster samples were processed using a standardised dissection protocol (Coleman, 2017) also being used in the Scottish and Welsh studies. Firstly, each individual was assigned a unique ID code, photographed (dorsally) and weighed, and the presence or absence of eggs under the abdomen recorded (functional maturity). Key measurements for assessing female morphometric maturity were taken using a calliper: carapace length (CL) and abdomen width (AW). A pleopod was removed from each individual for cement gland staging at a later date (behavioural maturity), and these were preserved in sea water at -20 °C in labelled vials. Secondary information regarding the moult stage of the animal was also recorded: shell rigidity (Aiken, 1980; Tully et al., 2001) and the abundance of encrusting organisms (percent cover estimation).

To assess physiological maturity, a portion of the dorsal carapace, from the base up to just above the cervical groove, was removed using scissors, allowing for a direct view of the ovaries (see Figure 3). The ovaries were staged using a standardised categorical system (see 2.5 | Physiological Maturity) (Aiken & Waddy, 1980; 1982). A photographic record of the ovaries (with the lobster ID code) was also taken to allow for subsequent assessment if necessary, and any evidence of previous spawning (indicated by yellow reabsorbing ova) was noted. The ovaries were then removed and weighed – a further indicator of physiological maturity.

2.2 | Functional Maturity (SOM_F)

Functional maturity, referring to the ability of the lobster to mate and spawn effectively, can be assessed non-invasively in females by the presence of eggs under the abdomen. None of the dissected lobsters that were over MCRS were gravid (bearing eggs) as it is illegal to land berried lobsters on the Isle of Man and these samples were sourced on-island from a commercial shellfish processor. This method therefore could not be applied to the dissected sample population. However onboard fishery observer data (DEFA, 2012-2015) recording CL and berried status were used for this analysis, only including the egg-bearing period (September through May). The proportion of gravid lobsters was

modelled against CL using logistic regression, with SOM identified as the size at which 50% of lobsters bore eggs (L50).

2.3 | Morphometric Maturity (SOM_M)

Morphometric maturity assessment aims to detect changes in the relative size of body parts that infer sexual maturity. Since lobsters undergo growth by ecdysis (moulting), it is hypothesised that both female and male lobsters exhibit pubescent changes in advance of reaching sexual maturity. In females this is assessed by the abdominal width (AW), which increases rapidly in relation to the overall size of the lobster (i.e. increasing the relative volume of the area under the abdomen) as an individual approaches sexual maturity so that they may hold more eggs in a single brood. The maturity index (AW/CL) is also often used in the literature to assess morphometric maturity in female lobsters (Aiken & Waddy, 1980; Comeau & Savoie, 2002; Lizárraga-Cubedo et al., 2003). These indices were modelled against CL using piecewise linear regressions (CRAN: segmented), with SOM identified by the inflection points from where positive allometric growth occurred (Lizárraga-Cubedo et al., 2003). For this analysis, data from the dissected lobsters were combined with morphometric data for females collected by DEFA fishery observers from the same region in 2015, which sampled a larger range of sizes.

Male lobsters do not widen the abdomen but experience increased growth of the crusher claw during maturation. Although not directly relevant to this study, an assessment of male morphometric maturity using the 2015 observations is available in the Appendix (Figure C).

2.4 | Behavioural Maturity (SOM_B)

Behavioural maturity in females may be assessed by the level of development of cement glands on the pleopods, which secrete a substance for egg attachment when the lobster is mature. This method is effective in *H. americanus*, where pleopods are categorised into one of four developmental stages (Figure 2) (Aiken & Waddy, 1982). It is currently unclear whether this approach provides unambiguous assessment of maturity in *H. gammarus*. We await the outcome of discussions amongst collaborating partners before undertaking this work.

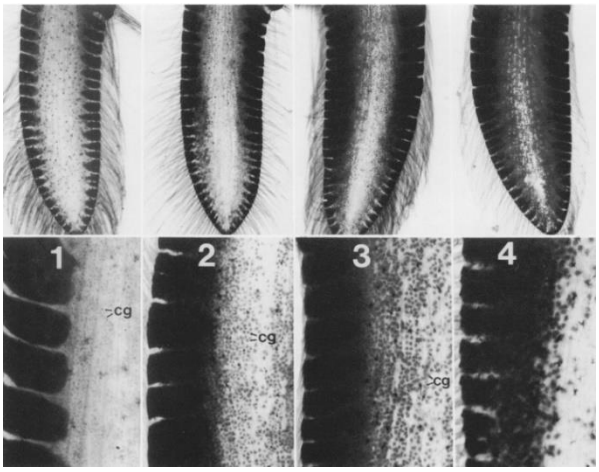

Figure 2: Stages of cement gland development in *Homarus americanus* (Aiken & Waddy, 1982).

2.5 | Physiological Maturity (SOM_P)

Physiological maturity is assessed in female lobsters by direct examination of the ovaries. Dissection allows staging into one of six categories based on the level of ovarian development (Figure 3). This is determined by overall size/weight, colour and texture. As the lobster matures, the ovaries gradually grow and darken, and when fully mature the internal eggs are visible.

To assess size at maturity, ovary stages 5-6 are considered mature and stages 1-4 immature (unless demonstrating evidence of previous spawning). The proportion of mature individuals was then

modelled against CL using logistic regression, with SOM identified as the size at which 50% of female lobsters are mature (L50).

Figure 3: Stages of ovarian development used to assess physiological maturity in female lobsters.

3 | Results

3.1 | Functional Maturity (SOM_F)

The sample population used to assess functional maturity (onboard observations) consisted of 1165 females ranging in size from 55 to 145 mm CL (Figure 4). 47% of lobsters were gravid, with size at 50% maturity (SOM) reached at 93 mm CL (Figure 5).

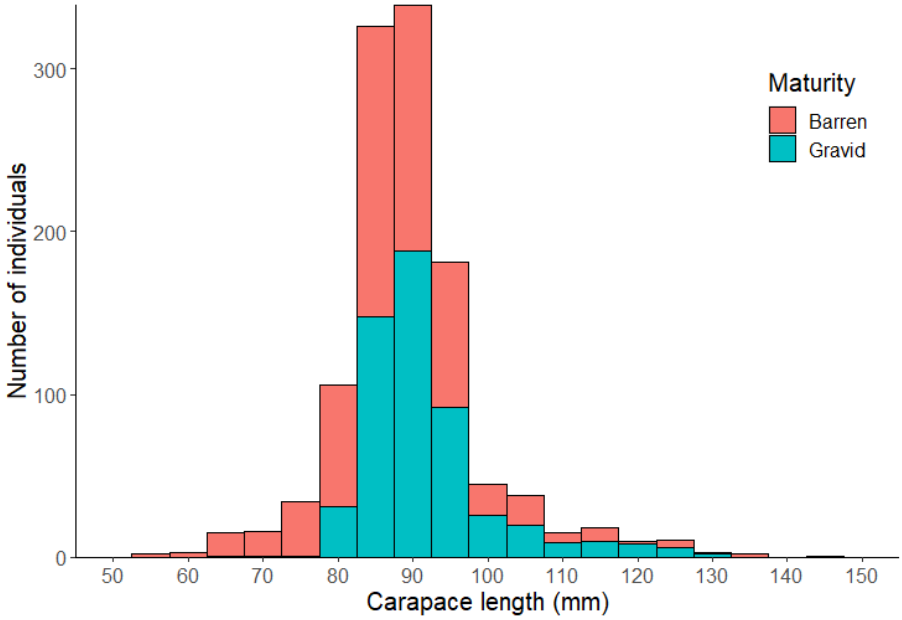

Figure 4: Size distribution and berried status (barren = not carrying eggs; gravid = carrying eggs) of female lobsters sampled by onboard fishery observers (2012-2015). Data from the spawning period (July-August) was excluded.

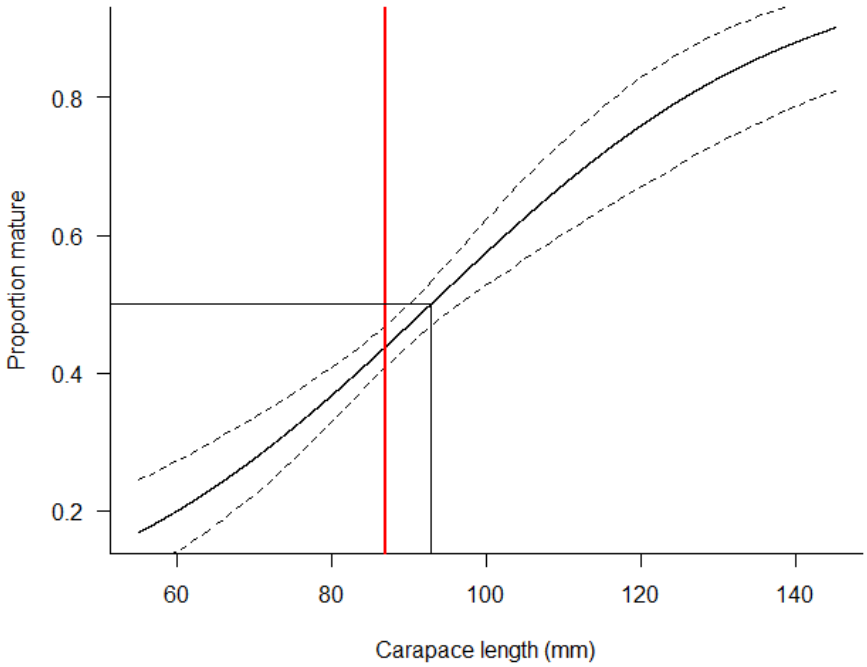

Figure 5: Functional maturity ogive (with 95% C.I.) for female lobsters sampled by onboard fishery observers (2012-2015), based on the presence of eggs under the abdomen (gravid vs barren). Data from the spawning period (July-August) was excluded. Red line: current MCRS (87 mm CL); black lines: L50 estimate.

3.2 | Morphometric Maturity (SOM_M)

Based on the abdominal width (AW) and maturity index (AW/CL), the size at onset of maturity (SOM) of female lobsters at the south of the Isle of Man occurs at around 66 mm CL, from when the abdomen grows at a faster rate (Figure 6). From 96 mm CL the growth rate slows down again, indicated by the second inflection point in the maturity index model (Figure 6).

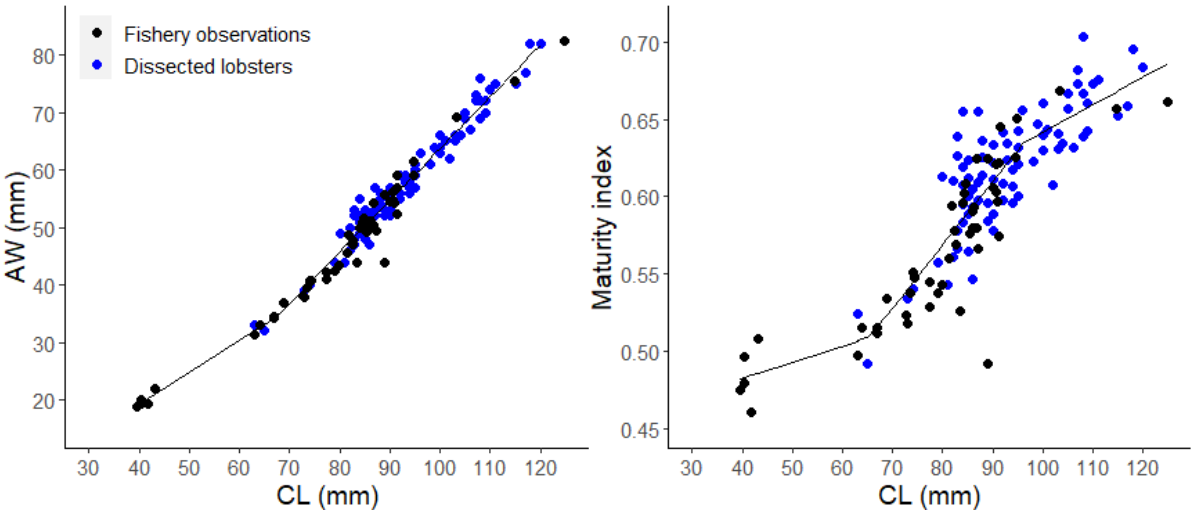

Figure 6: Female morphometric maturity indices (abdominal width and maturity index [AW/CL]) modelled against carapace length using piecewise linear regressions, for dissected lobsters and fishery observer data from landings and offshore measurements.

3.3 | Behavioural Maturity (SOM_B)

Thus far the cement-gland staging technique has proven inconclusive for European lobster (Tully et al., 2001). Pleopod imaging has been completed in Scotland and Wales but there was difficulty in identifying any consistent developmental stages. Based on existing guides, some immature lobsters (stage 1 ovaries) appear to have fully mature pleopods (N. Hold pers comm, 2019). It has also been noted that pleopods can be staged differently under different lighting. The Isle of Man is currently awaiting decision from the parallel studies as to whether to proceed with this method.

3.4 | Physiological Maturity (SOM_P)

Of the 92 dissected female lobsters, 65% were mature (ovary stage 5-6, or evidence of previous spawning) and 35% immature (ovary stage 1-4, with no evidence of previous spawning). All maturity stages were represented in the sample population (Figure 8). Size at 50% maturity (SOM) for females was 83 ± 4 mm CL (Figure 9).

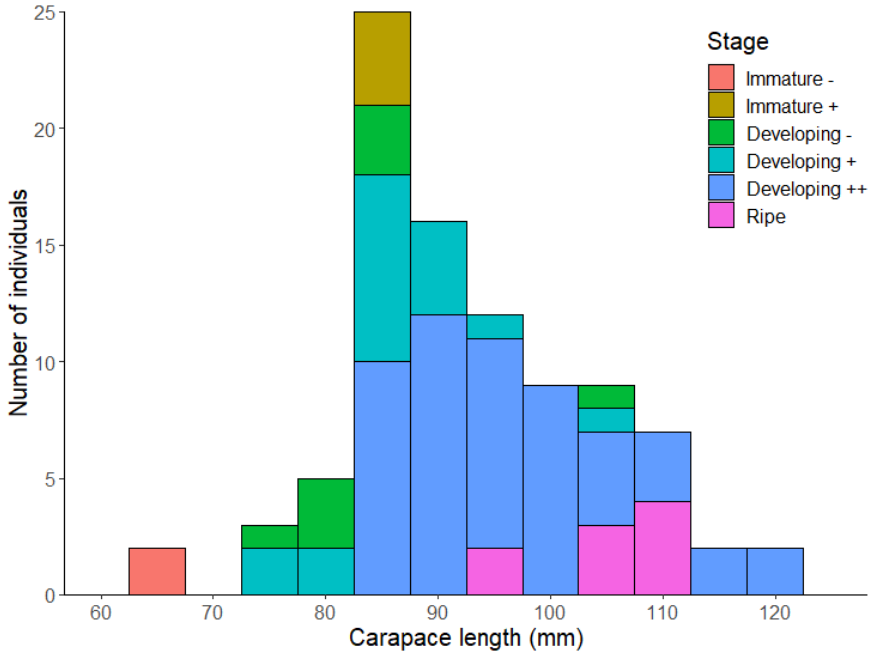

Figure 8: Maturity stages of the 92 dissected female lobsters based on visual inspection of the ovaries.

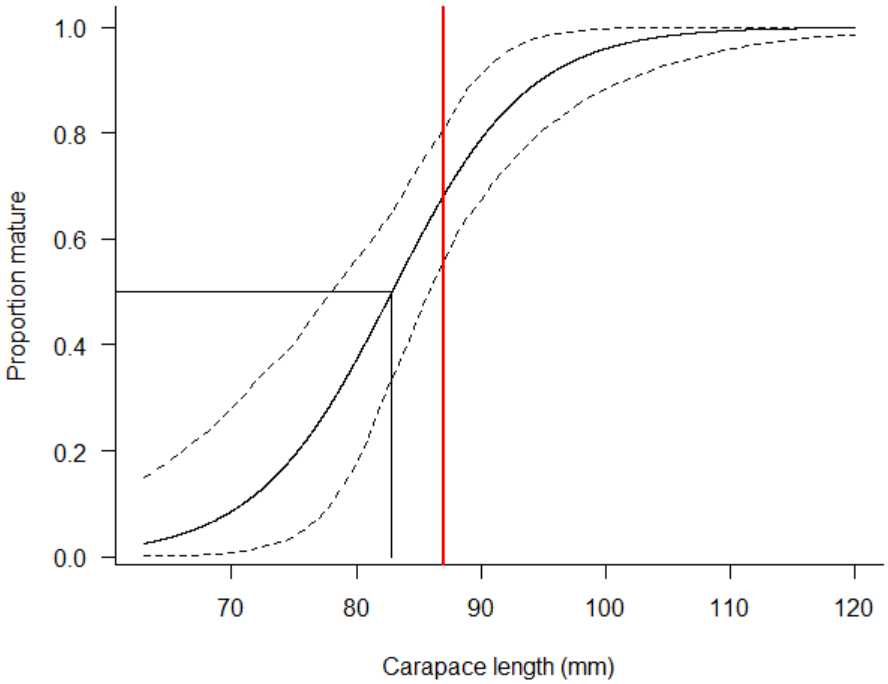

Figure 9: Physiological maturity ogive (with 95% C.I.) for dissected female lobsters, based on examination of the ovaries (stage 1-4: immature; stage 5-6 or evidence of previous spawning: mature). Red line: current MCRS (87 mm CL); black lines: L50 estimate.

4 | Discussion

Size at onset of maturity (SOM) in female European lobster (*H. gammarus*) was assessed on the Isle of Man based on three factors: (a) presence of eggs under the abdomen (onboard observations); (b) width of the abdomen (offshore and onshore observations); and (c) condition of the ovaries (dissection). The results of these techniques are not directly comparable as they examine different aspects of maturity, although each provides useful information. Female morphological SOM occurred in the fishery at 66 mm CL, indicative of the onset of a prepubescent moult, from when the abdomen widens more rapidly to make room for the eggs. This was based on the dissected sample population and additional data from onboard observers. The average size of physiological maturity was 83 mm CL, based on visual inspection of the ovaries of 92 females, and there was 95% confidence in that value ranging between 78 and 86 mm. Finally it is estimated that 50% of females in the fishery are gravid (functional maturity) at 93 mm CL, based on 1165 onboard observations. This indicates the ability of the population to mate and spawn effectively, which is key to fishery sustainability.

Of these methods, the most precise assessment of sexual maturity in females is achieved via direct examination of the ovaries (physiological maturity), since non-berried females may be still be mature depending on the age of the individual and the season. However, this is also the most work-intensive and requires animals to be sacrificed (high cost). Observations of the external eggs and morphological measurements can be collected easily and efficiently without the need for dissection, although the information provided by these techniques is only an inference of maturity, rather than a direct observation of the developmental stage of the sexual organs. For example, functional maturity assessments are affected by biennial spawning cycles at larger lobster sizes (Tully et al., 2001; Aiken et al., 2004), which can artificially increase the SOM estimate and dragging the right-hand side of the logistic regression curve down (Figure 10). Similarly, morphological maturity is considered to be the identification of the size at which an animal undergoes a pubescent moult, and not necessarily the size at which the average individual can reproduce effectively within the population.

Taking into account the limitations, practicality and relevance to management of each female SOM technique, we recommend focusing efforts on collecting large functional maturity datasets (observations of external eggs and CL measurement) and adjusting for biennial spawning based on a small subsample of dissected individuals. For example, in this study physiological maturity was evident in 100% of observations in the dissected group at 104 mm CL (within 95% confidence), and therefore any lobsters over 104 mm in the functional maturity dataset (fishery observers noting the presence of eggs) can be assumed to be mature. This has a corrective effect on the functional maturity ogive and L50 prediction by addressing biennial spawning in large individuals (see adjusted ogive, Figure 10), reducing the estimate from 92.8 mm CL to 89.4 mm CL. Data from July and August are excluded to control for the effect of spawning season, where mature females release eggs and are recorded as barren (non-mature).

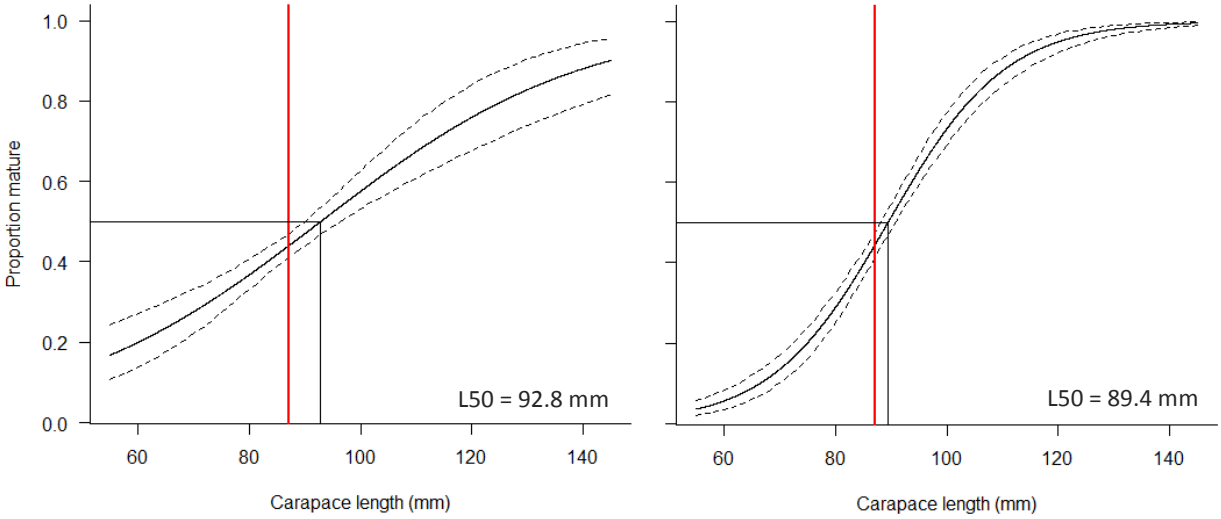

Figure 10: Functional maturity ogives for female European lobster (*H. gammarus*) on the Isle of Man. Left: unadjusted observations; right: adjusted data based on dissections (all lobsters ≥104 mm CL assumed mature).

With regard to management implications for the fishery for European lobster within the Isle of Man, these results suggest the current MCRS of 87 mm CL is biologically appropriate for females based on examination of the ovaries (i.e. MCRS is above 50% physiological maturity, at 83 mm CL). However, onboard observations suggest functional maturity (89 mm CL) may be higher than the current MCRS (87 mm CL) after accounting for biennial spawning in large individuals and spawning season effects.

There is an additional requirement to account for male SOM and to replicate the current study in lobster grounds around the island, since all data was collected from within the Baie ny Carrickey area. There may be subtle regional differences in population ecology as we know lobsters rarely move large distances and have high site fidelity (Garratt et al., 2019). Previous studies looking at male lobster maturity have focused largely on morphometric techniques using the dimensions of the crusher claw which, similar to the abdomen in females, grows more rapidly during maturation (Aiken & Waddy, 1980; 1989; Lizárraga-Cubedo et al., 2003). However, assessment of functional or physiological maturity is critical for management purposes. Research on the American lobster suggests male physiological maturity can be assessed by the presence of spermatophores (Krouse, 1971), however more research is required for the European lobster.

This study provides information on the reproductive biology of European lobster within Isle of Man waters that are key for sustainable fishery management. Combined with the results of parallel studies in Scotland and Wales, this information will also contribute towards formulating a standardised procedure for assessing size at maturity in the species.

5 | References

Aiken, D.E. (1980). Molting and growth, In "The Biology and Management of Lobsters" (J.S. Cobb and B.F. Phillips, eds), Vol. 1, pp. 91-162. Academic Press, New York.

Aiken, D.E. & Waddy, S.L. (1980). Reproductive biology of *Homarus americanus*. Proceedings of the Canada - US Workshop on the Status of Assessment Science for N.W. Atlantic Lobster (*Homarus americanus*) stocks. *Canadian Technical Report of Fisheries and Aquatic Science*, 932.

Aiken, D.E. & Waddy, S.L. (1982). Cement gland development, ovary maturation, and reproductive cycles in the American lobster Homarus americanus. *Journal of Crustacean Biology*, 2(3), 315-327.

Aiken, D.E. & Waddy, S.L. (1989). Allometric growth and onset of maturity in male American lobsters (*Homarus americanus*): the crusher claw propodite index. *Journal of Shellfish Research*, 8, 7-11.

Aiken, D.E., Waddy, S.L. & Mercer, S.M. (2004). Confirmation of external fertilization in the American lobster, Homarus americanus. *Journal of Crustacean Biology*, 24(3), 474-480.

Bianchini, M.L., Di Stefano, L. & Ragonese, S. (1998). Size and age at onset of sexual maturity of female Norway lobster Nephrops norvegicus L. (Crustacea: Nephropidae) in the Strait of Sicily (Central Mediterranean Sea). *Scientia Marina*, 62, 151–59. doi:10.3989/scimar.1998.62n1-2151.

Coleman, M. (2017). Estimating Lobster Size at Maturity (SOM) – Dissection Protocol. Orkney Sustainable Fisheries Ltd. 5 pp.

Comeau, M. & Savoie, F. (2002). Maturity and reproductive cycle of the female American lobster, Homarus americanus, in the southern Gulf of St. Lawrence, Canada. *Journal of Crustacean Biology*, 22(4), 762-774.

Conan, G.Y., Comeau, M. & Moriyasu, M. (1985). Functional maturity of the American lobster *Homarus americanus*. ICES CM 1985/K:29, 55 pp.

Council Regulation (EC) No 850/98 (1998). Official Journal of the European Communities L 125/1, Article 21b. Retrieved from: http://extwprlegs1.fao.org/docs/pdf/eur18268.pdf

DEFA (2020). 2019 Economic Digest: Weight and Value of Fish Landed by Species 2005-2018. Isle of Man Government, Department of Environment, Food & Agriculture.

Garratt, M.J., Sutton, G., Emmerson, J.A., Bloor, I.S.M. & Jenkins, S.R. (2019). Baie ny Carrickey lobster tagging update (2016-2018). SFAG Report, Bangor University, pp. 1-9.

Krouse, J.S. (1971). Maturity, sex ratio, and size composition of the natural population of American lobster, *Homarus americanus*, along the Maine coast. *Fishery Bulletin*, 71(1), 165-173.

Lizárraga-Cubedo, H.A., Tuck, I., Bailey, N., Pierce, G.J. & Kinnear, J.A.M. (2003). Comparisons of size at maturity and fecundity of two Scottish populations of the European lobster, Homarus gammarus. *Fisheries Research*, 65(1-3), 137-152.

Öndes, F., Kaiser, M.J. & Murray, L.G. (2017). Relative growth and size at onset of sexual maturity of the brown crab, Cancer pagurus in the Isle of Man, Irish Sea. *Marine Biology Research*, 13(2), 237-245.

Pardo, L.M., Fuentes, J.P., Olguin, A. & Orensanz, J.M. (2009). Reproductive maturity in the edible Chilean crab Cancer edwardsii: methodological and management considerations. *Journal of Marine Biological Association of the United Kingdom,* 89, 1627–34. doi:10.1017/S0025315409000010.

Tully, O., Roantree, V. & Robinson M. (2001). Maturity, fecundity and reproductive potential of the European lobster (*Homarus gammarus*) in Ireland. *Journal of Crustacean Biology*, 2(3), 315-327.

Ungfors, A. (2007). Sexual maturity of the edible crab (Cancer pagurus) in the Skagerrak and the Kattegat, based on reproductive and morphometric characters. *ICES Journal of Marine Science*, 64, 318–27. doi:10.1093/icesjms/fsl039.

6 | Appendix

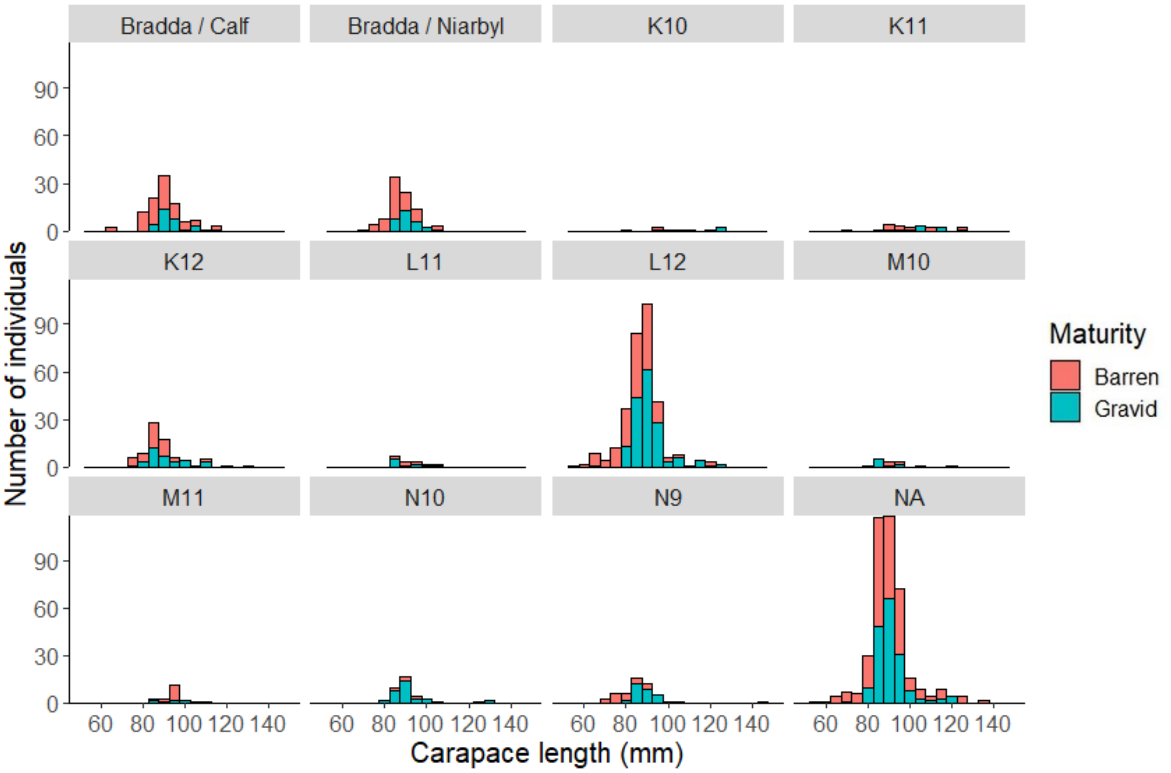

Figure A: Spatial distribution of fisheries survey data (2012-2015) used to assess functional maturity in this study. Codes refer to Port Erin survey squares.

Table A: Morphometric indices used to assess lobster size at maturity (refer to Figure B).

Sex	Index	Formula
Females	Abdomen width [a]	AW
	Maturity index [a]	AW/CL
Males	Anderson Index (AI) [a]	$\frac{CPL \times CPW \times CPTH}{CL} \times 10$
	Crusher Propodite Index (CPI) [b]	$\frac{100\ (CPL \times CPW \times CPTH)}{CL^3}$

[a] Aiken & Waddy (1980)
[b] Aiken & Waddy (1989)

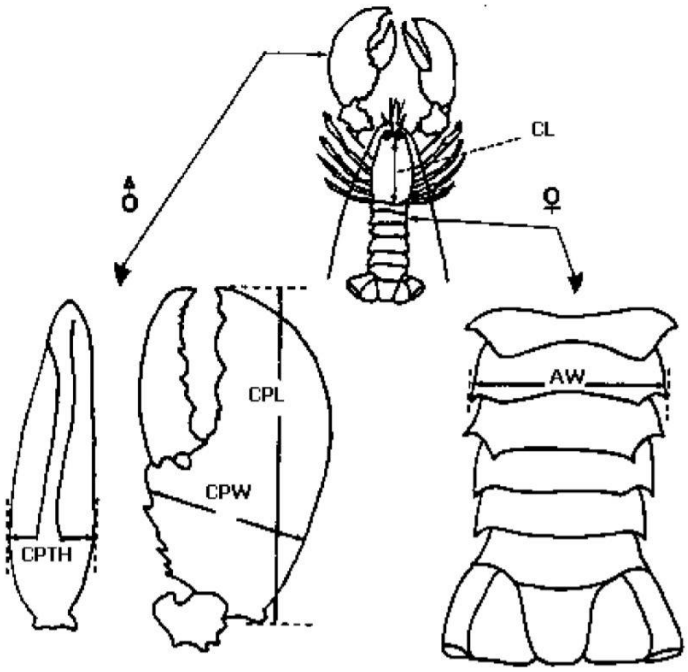

Figure B: Lobster measurements taken to assess size at maturity (Lizárraga-Cubedo et al., 2003).

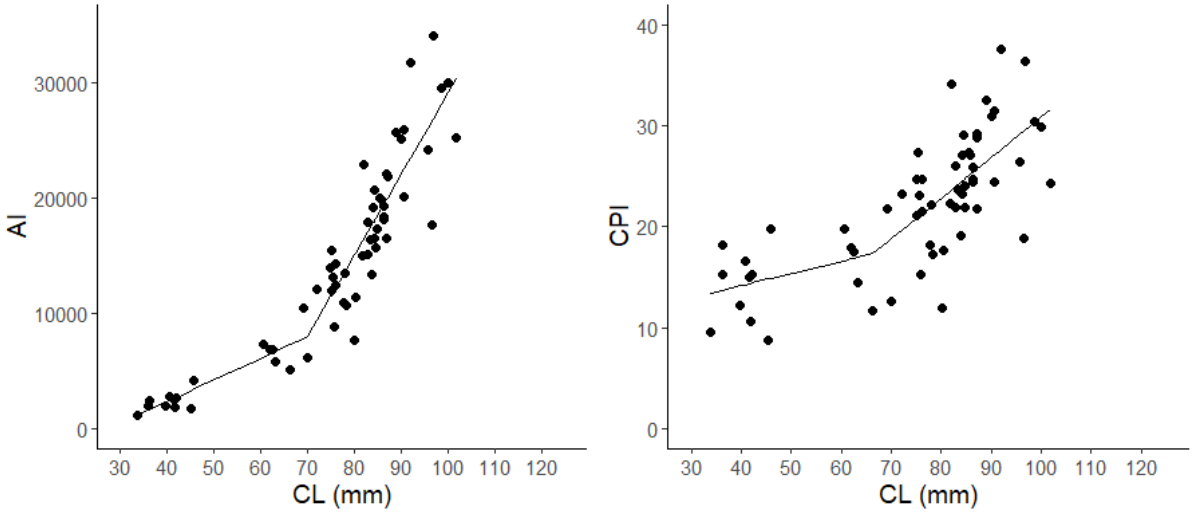

Figure C: Male morphometric maturity indices (Anderson Index and Crusher Propodite Index [see Table A]) modelled against carapace length using piecewise linear regressions, using fishery observer data from landings and offshore measurements.

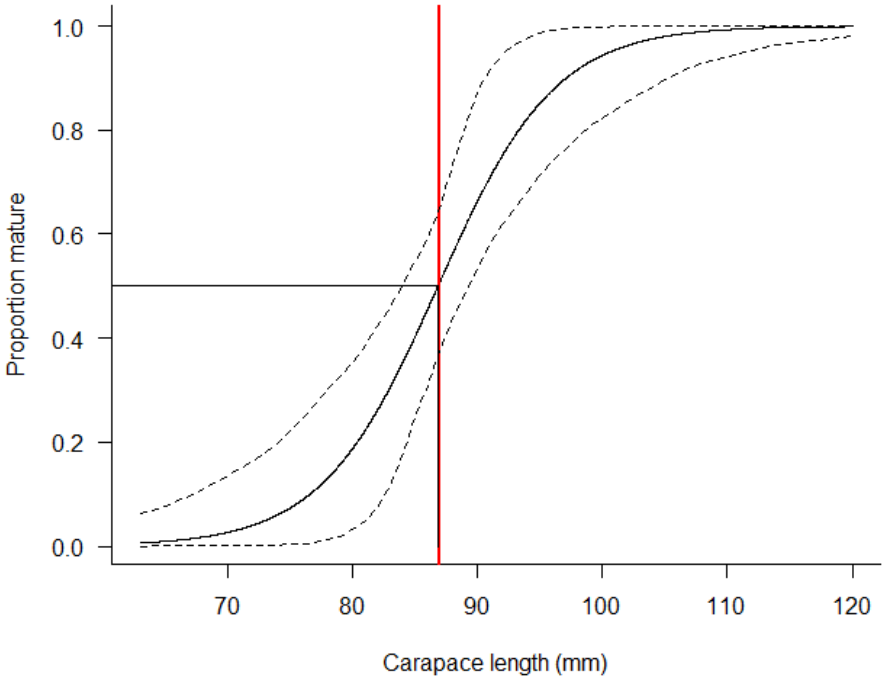

Figure D: Physiological maturity ogive (with 95% C.I.) for dissected female lobsters, based on examination of the ovaries (stage 1-4: immature; stage 5-6: mature). Evidence of previous spawning not incorporated. Red line: current MCRS (87 mm CL); black lines: L50 estimate.

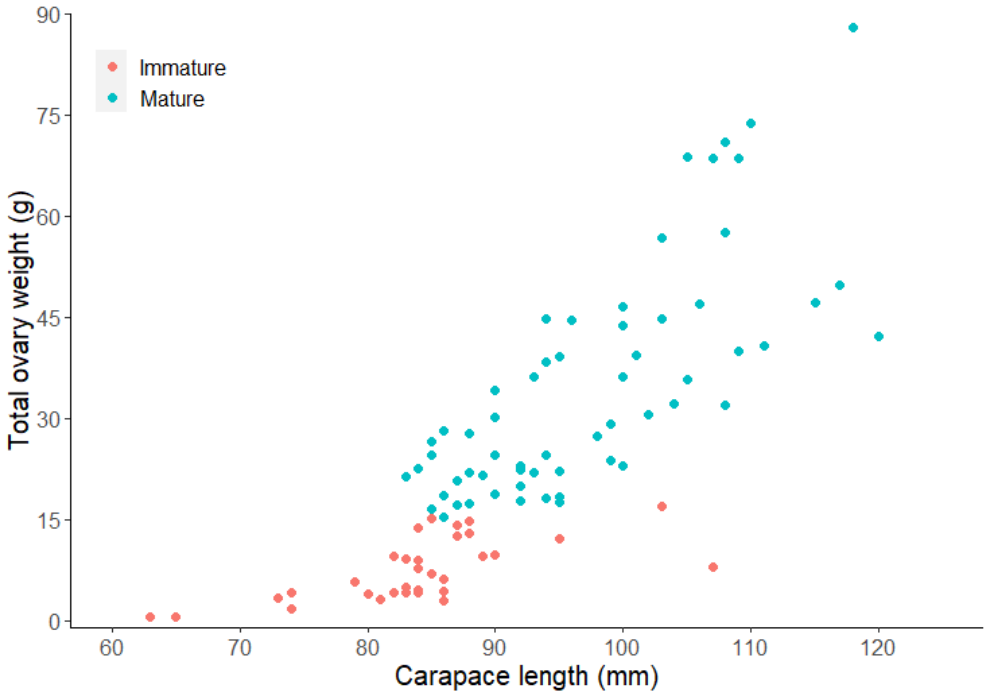

Figure E: Total weight of ovaries against carapace length for the 92 dissected lobsters. Immature: ovary stage 1-4; Mature: ovary stage 5-6.

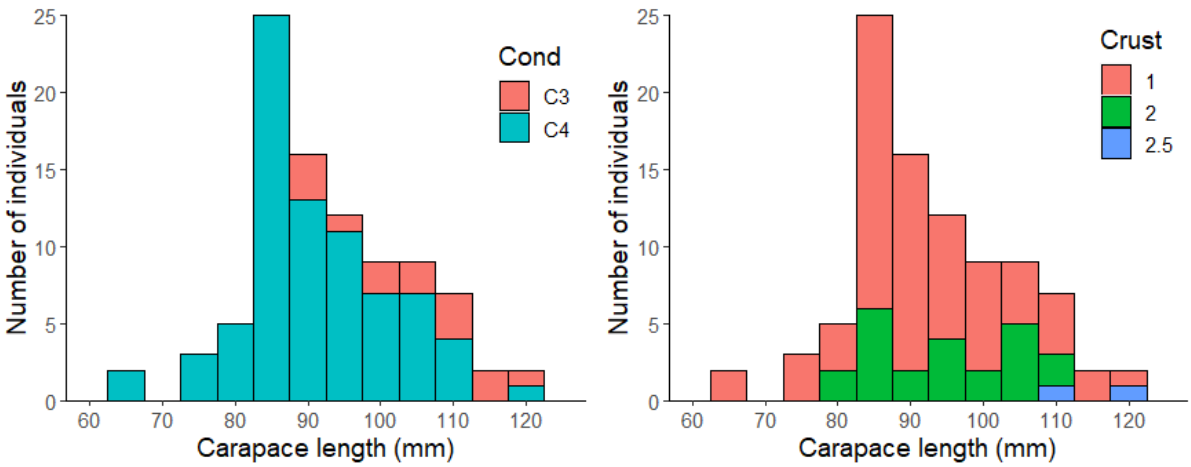

Figure F: Supplementary data collected during lobster dissection. Cond = condition index (shell rigidity); Crust = crusty stage (abundance of encrusting organisms). Indicates larger/older individuals are less likely to have moulted recently (less rigid shells and more encrusting organisms).