Workshop on Lobster (*Homarus americanus* and *H. gammarus*) Reference Points for Fishery Management Held in Tracadie-Sheila, New Brunswick, 8-10 September 2003: Abstracts and Proceedings

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2003

Canadian Technical Report of Fisheries and Aquatic Sciences No. 2506

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Cat. no. Fs97-6/2506E ISSN 0706-6457

Correct citation for this publication is:

Comeau, M. (ed.). 2003. Workshop on lobster (*Homarus americanus* and *H. gammarus*) reference points for fishery management held in Tracadie-Sheila, New Brunswick, 8-10 September 2003: Abstracts and proceedings. Can. Tech. Rep. Fish. Aquat. Sci. 2506: vii + 39p.

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Abstract

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An ICES workshop on lobster (*Homarus americanus* and *H. gammarus*) reference points for fishery management was held in Tracadie-Sheila, Canada, from 8-10 September, 2003 to gather worldwide knowledge and information on female lobster size at maturity and reproductive cycle. Objectives of the workshop were grouped into three working sessions: (1) overview of current knowledge on female maturity, (2) modeling, and (3) techniques.

A total of 26 participants from Canada, Italy, Ireland, Norway, Sweden, the United Kingdom and the United States of America attended the workshop, and 14 presentations were given. A panel discussion was held after both the session on models and techniques to summarize the presentations generate a discussion to prepare the recommendations, and establish guidelines for future investigations of this type. Hand-on demonstrations of some of the techniques presented during the workshop were also performed.

Three major recommendations were formulated following the panel discussions. First, in order to accommodate models for fishery management purposes, the size at functional maturity of female lobsters needs to be established base on the size at which a female will extrude eggs and at what time. Secondly, of the four techniques proposed to establish female lobster maturity (direct observation of the presence/absence of eggs under the abdomen, morphometric measurements of the abdominal width, the cement-gland staging technique, and observation of the ovarian condition), it was agreed at the workshop that the cement-gland staging technique would be used as the standard technique. Finally, the protocol to establish the size of female lobster maturity requires the following three important elements (*i*) a large size range from well below the smallest ovigerous female to the largest sizes should be sampled, (*ii*) sampling should be stratified by size, and (*iii*) the sampling should be carried out immediately prior to the spawning period.

All participants agreed that this type of meeting should occur on more regular basis and has to be formalized. It was suggested that a working group on *Homarus* within ICES could be created, or a theme session could be incorporated in future ICES annual meetings.

This document presents the extended abstracts of the presentations at the workshop as well as the panel discussions and the recommendations.

Résumé

Comeau, M. (ed.). 2003. Workshop on lobster (*Homarus americanus* and *H. gammarus*) reference points for fishery management held in Tracadie-Sheila, New Brunswick, 8-10 September 2003: Abstracts and proceedings. Can. Tech. Rep. Fish. Aquat. Sci. 2506: vii + 39p.

Un atelier de travail du CIEM ayant comme thème les points de référence pour la gestion de la pêcherie du homard (*Homarus americanus* et *H. gammarus*) s'est tenu à Tracadie-Sheila du 8 au 10 septembre 2003. L'objectif était de mettre en commun les connaissances et l'information internationales dans le domaine de la taille à maturité et du cycle de reproduction des homards femelles. Pour ce faire, l'atelier était divisé en trois sessions de travail : (1) le survol des connaissances actuelles sur la maturité des femelles, (2) les modèles mathématiques, et (3) les techniques utilisées.

Un total de 26 participants en provenance du Canada, de l'Italie, de l'Irlande, de la Norvège, de la Suède, du Royaume-Uni et des États-Unis d'Amérique a pris part à l'atelier et 14 communications ont été présentées. Des panels de discussions ont été formés après les sessions sur les modèles et les techniques pour résumer les présentations, générer une discussion afin de préparer les recommandations, et établir un guide pour les recherches futures sur la maturité des femelles. Des démonstrations pratiques de certaines techniques ont également eu lieu.

Trois recommandations majeures ont été formulées à la suite des panels de discussion. Premièrement, afin d'accommoder les modèles à la gestion de la pêcherie, la taille à maturité fonctionnelle des femelles devrait être établie en se basant sur la taille à laquelle celles-ci vont pondre et quand ceci aura lieu. Deuxièmement, des quatre techniques proposées afin d'établir la maturité (observation d'œufs sous l'abdomen, mesures morphométriques de la largeur de l'abdomen, techniques des glandes cimentaires et de l'observation de la condition des ovaires), celle des glandes cimentaires serait utilisée comme la technique standard. Finalement, tout protocole visant à établir la taille à maturité des femelles devrait inclure les trois éléments suivant (*i*) une grande gamme de taille de carapace, incluant des individus bien en dessous de la taille des plus petites femelles ovigères observées en mer ainsi que des femelles de très grosse taille, (*ii*) un échantillonnage stratifié selon la longueur de carapace, et (*iii*) un échantillonnage effectué immédiatement avant la période de la ponte.

Tous les participants se sont accordés pour dire que ce type d'atelier devrait être formalisé et se tenir sur une base régulière. Il a été suggéré qu'un groupe de travail sur *Homarus* dans le cadre du CIEM pourrait être créé ou une session thématique pourrait être incluse dans une rencontre annuelle du CIEM.

Le présent document présente les résumés des présentations à l'atelier ainsi que le résumé des panels de discussion et les recommandations.

Acknowledgements

I wish to thank all that took time to contribute to the success of this workshop. First, I would like to thank Oliver Tully and Carl Wilson that help me organizing the workshop by contacting participants in Europe and the United States of America. Doug Pezzack and Carl Wilson that agreed on a very short notice to chair the panel discussions for the models and techniques session during the workshop. The speakers producing high quality presentations on research topics including female's maturity and reproductive cycle. All the participants that contributed to the discussions during the presentations, the panel discussions and the plenary session. Finally, Manon Mallet and Gilles Paulin for their technical assistance before, during and after the workshop.

Background for meeting

Recently at a workshop held in Halifax (Reference Points for Invertebrate Fisheries, 2 – 5, December 2002; Can. Tech. Rep. Fish. Aquat. Sci. 2448), the necessity of a good egg production was recognized as the most important parameter for crustacean fisheries and could be considered as the limit reference point. It was also recognized that means to measure and ensure adequate egg production are still lacking for some crustacean fisheries. For lobsters (*Homarus americanus* and *H. gammarus*), the only management tool commonly used everywhere to insure good egg production is the minimum legal size since lobster fisheries are not managed by quotas, and some areas have very limited input controls (to limit effort). In most lobster fishing areas, the minimum legal size is loosely set based on the female size at sexual maturity to protect a certain percentage of primiparous females.

Over the past years, improvements have been made in the understanding of female lobster size at maturity and reproductive cycle. New concepts for assessing and modeling the lobster population using the egg-per-recruit model incorporating female maturity have been developed. The egg-per-recruit model is being used for lobster on both sides of the Atlantic, however, standard methodology to establish the size at the onset of sexual maturity and reproductive cycle has been lacking in some areas. Standardization of the methodology could allow for geographical comparisons and may lead to new insights of female lobster maturity. In turn, this new information could be used to improve the egg-per-recruit models.

Objectives

The main goal of this workshop was to gather worldwide knowledge and information on female lobster size at maturity and reproductive cycle. We primarily wanted to:

1. investigate several methodologies from biological samples and already existing data to elaborate a standardized method to establish female lobster (*H. americanus and H. gammarus*) maturity and reproductive cycle;

2. investigate methods to incorporate the results in models to provide reference points for fishery management;

3. provide guidelines for future investigations of this type.

Format of the meeting

The workshop was held in Tracadie-Sheila, New Brunswick Canada, at the Complexe des deux rivières from 8 – 10 September 2003. The workshop began with presentations of overviews of existing data and case studies from North America and Europe. The presentations focused on the level of lobster female maturity knowledge and identified areas for future investigations. Presentations of models to assess the egg production followed. The second day of the workshop, techniques to establish lobster female maturity and reproductive cycle were presented. At their discretion, participants jointed working groups revisiting data sets the last day of the workshop.

A demonstration of the lobster life history model was performed and new analyses done during the workshop were presented. The workshop ended with a plenary session and recommendations from the presentations and discussion during the meeting.

List of participants

Anne-Lisbeth Agnalt	Institute of Marine Research, Bergen, Norway
Thomas Angell	Department of Fish and Wildlife, State of Rhode Island, USA
Solange Chiasson	Centre de recherche sur les aliments, UdeM, Moncton, Canada
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Mats Ulmestrand	Institute of Marine Research, Lysekil, Sweden
Carl Wilson	Department of Marine Resources, Maine, USA

Agenda

8 September	Welcome, background for the workshop and its objectives	M. Comeau
	Overview of current knowledge on female maturity	
	United States of America	C. Wilson
	Canada	M. Comeau
	Europe	E. Fahy

	Session on Models: Lobster maturity and fecundity information for models	
	The use of maturity information in a current life history model based on the growth of female and male clawed lobsters	J. Idoine
	Evaluating impacts of maturity parameter estimation and uncertainty on the assessment of American lobster fishery in the Gulf of Maine	C. Wilson and Y. Chen
	Panel Discussion (Models)	
9 September	**Session on Techniques: Establishing maturity and reproductive cycle**	
	Morphometric techniques used to estimate size at maturity of female American lobster (*Homarus americanus*)	D. Landers presented by T. Angell
	A field data-collection technique for categorizing ovary development stage and determination of size at sexual maturity in female American lobster (*Homarus americanus*).	T. Angell
	Allometry and size at maturity for the American Lobster (*Homarus americanus*)	M. Mallet
	Techniques to establish female lobster, *Homarus americanus*, size at maturity based on ovaries condition and pleopod reading	M. Comeau
	Determination of sexual maturity of female American lobster (*Homarus americanus*) in the Magdalen Islands (Québec) based on cement gland development	L. Gendron
	Presentation of techniques (hand-on) for ovaries observation by dissection and the less intrusive method presented by T. Angell	
	Establishing the reproductive cycle of female American lobster, *Homarus americanus*	M. Comeau
	Female lobster maturity and reproductive cycle: its implication in the fishery management of the Lobster Fishery Area 25	M. Comeau
	Geographical variation in size-at-maturity and fecundity in *Homarus gammarus*: implications for management	Addison *et al.* presented by E. Fahy
	Reproduction of female lobsters (*Homarus gammarus*) on the Swedish west coast	M. Ulmestrand
	Panel Discussion (Techniques)	
10 September	Analyzing data and a demonstration of the lobster life history model	
	Presentations of results from new analysis	
	Plenary session	
	Research recommendations	

Session on Models

Lobster Maturity and Fecundity Information for models

A life history model based on the growth of male and female lobsters, known as LobSense, was presented, followed by and an exercise on uncertainty of the model parameters. Lobsense incorporates the knowledge on growth, natural mortality, size at maturity, fecundity and reproduction cycle (egg extrusion and hatch) of the lobster and calculates the production of eggs of a fished population subject to various fishing regulations. The given egg-per-recruit value is calculated relative to a hypothetical unfished population. Fishing regulations considered include fishing mortality, v-notching, minimum and maximum legal size, fishing season and the release of ovigerous females. The model also includes knowledge of male lobsters to assure the availability of males for mating.

It was stated that models have attained their maximum level of precision and the lobster life cycle cannot be more thoroughly detailed. It is now required to work on standardizing the parameters required for the model:

- Obtain a more accurate picture of the complete reproductive life cycle. Sole knowledge of the size at maturity is not sufficient. There is evidence of female hatching on 2 consecutive years with or without molting. Could this result in a decrease in fecundity (half clutch)?

- Could we determine the hatching (extruding) status of a lobster? Even if a female is mature, she may not lay eggs that particular year.

- It may now be desirable to include uncertainty on the parameters included in the model.

Session on Techniques

Establishing maturity and reproductive cycle

During the course of the workshop, a suite of techniques to establish the size at the onset of sexual maturity (SOM) for female lobsters was presented. Essentially, there is four techniques used to establish SOM:

1. ***Direct observation of the presence/absence of eggs under the abdomen***. Undeniably, the presence of eggs under the abdomen is a good indicator of functional maturity. Unfortunately, that technique is not reliable to establish the SOM where landing of berried females is prohibited (North America) as the fishery widely biases the ratio of berried and non-berried females.

2. ***Morphometric measurements of the abdominal width***. The morphometric technique has been criticized for real statistical difficulties in determining inflection point. However, a new technique using splines could possibly be used to detect changes in the female lobster morphometric growth. This technique could be an alternative to the more

traditional technique using the maturity index (ratio of the abdominal width and carapace length plotted against the carapace length).

3. ***Formation of cement glands in pleopods (cement-gland staging technique)***. Although the cement-gland staging technique tends to slightly overestimate the SOM, it is a fast and non-destructive technique, and yields a more accurate estimation of the SOM if a protocol taken into considerations a wide size range and a good timing of sampling is done. Also, another advantage of this technique is that the growth status of the female could be known simultaneously of her maturity status.

4. ***Observation of the ovarian condition.*** The SOM could be estimated using the color and/or the weight of the ovaries. It also allows determination of whether a female has already spawned at least once. This technique has yield better and more accurate estimation of the SOM since a direct relationship has been established between the physiological and functional maturity. The condition of the gonad (color and weight) is the best technique, but is very intrusive.

During the discussion, it became clear that a good definition of maturity is needed. Maturity of female lobsters can be defined as the ability either to produce mature oocytes (gonadal or physiological maturity) or to mate and spawn efficiently (functional maturity). For fishery management purposes, a good knowledge of the functional maturity is needed. Hence, techniques using criteria for establishing functional maturity are essential. It was agreed that the definition of maturity should include both the functional maturity status and growth status of the female.

It was also recognized that a good and standard protocol to establish the SOM is paramount. Recommendations were made concerning three important elements of a good protocol:

1. It was suggested that pleopods, used for cement-gland staging, should be collected from the widest size (carapace length) range possible of non-berried females. Pleopods from females well below the size of the smallest berried female observed in the fishery within a given area should be sampled.

2. Sampling should be stratified by one-mm size class and include at least 5 animals per size group. Use of a random sample of the commercial catch is not advisable since different fishing techniques and strategies will introduce a bias in the observations (monitoring of the fishery instead of the lobster population).

3. Finally, sampling should be carried out immediately prior to the spawning period. Hence, the fall, winter and early spring period should be avoided.

Although the cement-gland technique is a physiological observation proven to give accurate results in the southern Gulf of St. Lawrence, it should be validated in other areas. There were some uncertainties regarding stages 2 and 3 in relation to the sampling period, and the functional maturity status of female lobsters. The validation would only be needed once. The most accurate technique to validate the cement-gland technique is the ovarian condition. It was recognized that the proportion of berried females in the catches could be used as a validation technique in Europe.

Recommendations

- For fishery management purposes, the size at functional maturity of female lobsters needs to be established base on the **size** at which a female **will** extrude eggs.

- Four techniques were proposed to establish female lobster maturity: (1) direct observation of the presence/absence of eggs under the abdomen, (2) morphometric measurements of the abdominal width, (3) the cement-gland staging technique, and (4) observation of the ovarian condition. In order to standardize the estimates of the functional SOM, it was agreed at the workshop that the cement-gland staging technique would be used.

- Three important elements should be taken into consideration for a good protocol to establish the female lobsters SOM:

    1. A large size range from well below the smallest ovigerous female observed in the fishery in a given area to the largest sizes should be sampled.

    2. Sampling should be stratified.

    3. Finally, the sampling should be carried out immediately prior to the spawning period. Hence, the fall, winter and early spring period should be avoided.

- It is important to validate the cement-gland technique at least once with the ovarian condition. It was recognized that the proportion of berried females in the catches could be used as a validation technique in Europe.

- Monitoring of egg bearing females in the fishery should continue in both North America and Europe. This is more relevant in Europe since this information could be used to establish the maturity ogive. In North America, the landing of berried females is prohibited and causes a (large) bias within the population. Although monitoring of egg bearing females cannot be used to establish the size at maturity in North America, this information could be used to indicate the smallest females that reach functional maturity.

- Adjustments to the life history model are needed to accommodate the size at maturity and the reproductive cycle for female lobsters. In terms of the SOM, the proportion of females that will produce eggs at a given size (i.e., before she molts to a new and larger size) is needed. For the reproductive cycle, the parameters needed in a model refer to when during the **molt** cycle a female will produce eggs. More specifically;

    1. which year(s) at a given size (e.g., year 1, year 2, year 3, year 2 and 3,…),

    2. when (month or months) during the year she will extrude (e.g., June, June and July, June and July and August,…), and finally,

3. how long she will carry the eggs (knowledge of egg extrusion and egg hatching is essential).

- During the workshop, topics that were outside the narrow scope of this meeting (size at maturity and reproductive cycle of female lobsters), but quite relevant to the life history model and good fishery management, were also briefly discussed. Additional information that would be useful for a better management of the lobster fisheries include:

  1. Are there fecundity differences for females with "non-normal" egg production pattern? This is relevant for primiparous females that will molt and extrude eggs the same year, and multiparous females that will produce 2 batches of eggs during the same molt cycle.

  2. Is there sperm limitation? This is relevant in fisheries with no landing of berried females and v-notching that would bias the sex ratio. Knowledge of the link between the size composition of the population and effective reproduction is needed.

  3. The viability/quality of the eggs related to the issues above.

  This additional information could be the scope or included in future meetings.

- Throughout the meeting, the exchange of knowledge and data regarding female lobster maturity and reproductive cycle generated constructive and important discussions. All the participants agreed that this type of meeting should occur on more regular bases. Although numerous collaborations between different groups working on lobster were initiated during this workshop, the consensus was to formalize future meetings. It was suggested that a working group on *Homarus* within ICES could be created. It was also suggested that a theme session in the 2005 ICES annual meeting on biological parameters link to life history model of the *Homarus* lobster could be the follow-up meeting to this workshop where new knowledge on female maturity and other related biological parameters could be presented.

Overview of current knowledge on female maturity

United States of America

Carl Wilson

The size at maturity in the United States of America (USA) has been established by the presence of eggs, the ovary condition, cement-gland staging and morphometry of the abdomen (Table 1). There are three assessment stock areas in the USA: the Gulf of Maine (GOM), the inshore waters from south of Cape Cod to Long Island Sound (SCCLIS), and the offshore of Georges Bank and South (GBS). The size at maturity for each assessment area was estimated using multiple methods. Individual functions were used and although variations within each assessment was observed, the size at the onset of sexual maturity varied from the smallest size of 72 mm of carapace length (CL) observed in SCCLIS to the largest in both GOM, at 91 mm CL, and GBS at 93 mm CL.

Table 1. Authors, year, area, and methods for female lobster maturity studies conducted in the United States of America.

Author	Year	Area	Ovary color	AW/CL	Ova diameter	Cement gland
Skud and Perkins	1969	Canyons	+	+	+	
Krouse	1973	Coastal Maine	+	+	+	
Briggs and Mushacke	1979	Long Island Sound	+	+	+	
Briggs and Mushacke	1980	South shore Long Island	+	+	+	
Aiken and Waddy	1982	Canyons				+
Cooper and Uzmann	1977	Canyons				Ovigerous condition
Fogarty and Idoine	1988	Offshore				Ovigerous condition
Angell	Ongoing	Canyons	+			
Landers	Ongoing	Coastal Connecticut		+		
Estralla		Coastal Massachusetts	+		+	
Nutting	1994–1998	Coastal Maine	+	+	+	
Little and Watson	2002	Canyons, Offshore GOM	+		+	

AW: Abdominal Width
CL: Carapace Length

Canada

Michel Comeau

In Canada, the size at sexual maturity for female lobster has been established by either morphometry, staging the formation of cement glands or observations of the ovarian condition. Detecting sexual maturity by morphometry is achieved by plotting the maturity index (the ratio between the abdominal width and the carapace length: AWI) against carapace length (CL). The staging of the formation of specialized glands called cement glands in the pleopods needed to attach the eggs after spawning has been used to determine size at maturity. Finally the determination of the size at the onset of sexual maturity (SOM) using ovarian condition has been done using the diameter of the ova, the color and/or weight of the gonad as criterion. Often the size at which 50% of the primiparous females reach maturity (SOM_{50}) is used to compare different areas and as a reference point to define the minimal legal size at capture for lobster.

The SOM_{50} in Canada ranged from 71 mm CL in the Baie des Chaleurs and part of the southwestern Gulf of St. Lawrence to 108 mm CL in Grand Manan (Table 1). Although the strait of Belle-Isle is the most northern limit of the lobster distribution in North America, there is no relationship between SOM_{50} and the latitude (north-south). Instead, the estimates of SOM_{50} from areas that experience wide seasonal temperature fluctuations (-1.5 to 25 degrees Celsius) seem to be lower. In some areas however, differences observed could be related to the different techniques used. For example, stages 3–4 is used in some areas to establish the SOM by the staging of cement gland while stages 2–4 is used in other areas. Recently in the southern Gulf of St. Lawrence, the validation of the staging of cement glands technique revealed that within the week of egg extrusion stages 3–4 is correct, but if the staging is done a month before egg extrusion stages 2–4 have to be used.

Table 1. Authors, size at the onset of 50% sexual maturity (SOM_{50}), methods and locations of female lobster maturity studies conducted in Canada.

Authors and reference	SOM_{50}	Method	Location
Squires (1970)	72 mm	Ova diameter	West coast of NF
Ennis (1971)	76 mm	Ova diameter and color	Bonavista Bay, NF
Ennis (1980)	71–76 mm	Ova diameter and color	Various locations in NF
Squires *et al.* (1971, 1974)	69–73 mm	AWI and ova diameter	Bay of Island, NF
Gendron (unpub. 2000)	99 mm	Cement gland	La Tabatiere, QC
Gendron (unpub. 1997)	94 mm	Cement gland	Anticostie, QC
Gendron (unpub. 1994)	84 mm	AWI	Gaspé, QC
Gendron (unpub. 1996–2000)	83 mm	Cement gland	Gaspé, QC
Dubé and Grondin (1985)	85 mm	Cement gland and AWI	North of Magdalen Islands, QC
	84 mm	Ova color	
	79 mm	Cement gland and Ova color	South of Magdalen Islands, QC
	81 mm	AWI	
Campbell and Robinson (1983)	79 mm	Cement gland	Lismore, NS
	93 mm	Cement gland	CB, Eastern, NS
	108 mm	Cement gland	Grand Manan, NB
Comeau (unpub. 2002)	77 mm	Cement gland	Cheticamp, NS
	76 mm	Ova condition	Cheticamp, NS
	73 mm	Cement gland	Malpeque, PEI
	72 mm	Ova condition	Malpeque, PEI
	105 mm	Cement gland	Alma, NB
	101 mm	Ova condition	Alma, NB
Comeau and Savoie (2002)	71 mm	Ova condition and cement gland	Baie des Chaleurs, NB
	72 mm	Ova condition and cement gland	Val Comeau, NB
Conan *et al.* (1985)	71 mm	Ova color	Malpeque, PEI
	72 mm	Cement gland	
Watson (unpub. 1988)	73 mm	Cement gland	Ingonish and Glace Bay, NS
	77 mm	Cement gland	Gabarus, NS
	83 mm	Cement gland	Petit de Grat, NS

AWI: Morphmetric method of the ratio between the abdominal width and the carapace length
CB: Cape Breton
NB: New Brunswick
NS: Nova Scotia
QC: Québec
PEI: Prince Edward Island

Europe

Edward Fahy

In the United Kingdom (UK), five different techniques were used to establish the size at sexual maturity in Wales in the 1970s, in Yorkshire and South Wales in the 1980s, and finally in Yorkshire, South coast, and Wales in the 1990s:

1. Ovary factor (OVF) could be used to determine onset of maturity in the UK samples, but increase in variability of OVF with increasing carapace length (CL) implies that we should use ovary development stages instead;

2. Ovary development stage provide clear estimates of the size at onset of maturity;

3. Abdomen width (AW) and relative abdomen width vs. CL were used, but were considered highly dubious because widening of abdomen appears to occur before size at functional maturity and before commencement of ovary development (i.e. onset of physiological maturity). Plus real statistical difficulties in determining inflection point;

4. Cement gland development technique is not reliable;

5. Proportion of females with eggs provides an index of size at maturity.

In Ireland, these techniques were also used, and the results were published by Tully *et al.* (2001; J. Mar. Biol. Assoc. UK 81: 61–68).

Physiological maturity

A total of 446 lobsters were examined from 4 coastal regions in Ireland (northwest, west, southwest, southeast). The following combinations of criteria were used to indicate maturity:

1. Ovary color dark green and ovary factor > 150. This indicates advanced secondary vitellogenesis in preparation for spawning.

2. Cement gland stage > 1. The timing of the development relative to that of egg extrusion is unknown so that any significant activity may indicate preparation for spawning.

3. Molt stage C_4 (intermolt). If the lobster is not in intermolt then egg extrusion may not occur at the current size and the lobster is regarded as immature at the current size.

4. Ova size > 1.0 mm indicating well developed eggs (the maximum size depends on lobster size and is approximately 2.2 mm)

5. AW / CL ratio of > 0.5. This was the minimum value of the ratio observed in ovigerous females and therefore indicates the minimum value in functional mature lobsters.

6. Evidence of previous spawning. Because spawning only occurs on alternate years perhaps 50% of mature lobsters may not be preparing for egg extrusion in any given year and the criteria as used above would indicate immaturity. Evidence of previous spawning is crucial, therefore, and was indicated by the presence of non-extruded yellow resorbing eggs from the previous spawning. The yellow coloration of the distal oviduct used by Aiken and Waddy (J. Crust. Biol. 2: 315-327. 1982) to indicate previous spawning in *H. americanus* was not found during this study.

Functional or expressed maturity

The relationship between body size and the proportion of females that were ovigerous (functional maturity) was calculated from the 22,530 female lobsters from the same 4 coastal regions. The proportion of lobsters in each size class that were mature was estimated and logistic functions fitted to the relationships between CL and proportional physiological and functional maturity (P_m) as follows:

$$P_m = 1/(1+\exp(a+b*CL)$$

Results

The maturity ogives indicated a size at 50% maturity (SOM_{50}) of 96 mm in the northwest, 92.5 mm in the west, 94 mm in the southwest, 95 mm in the southeast and 96 mm for all regions combined. The SOM_{50} (i.e. when 25% of females were ovigerous to allow for biennial spawning) was 107 mm in the northwest, 116 mm in the west, 122 mm in the southwest and 140 mm in the southeast.

Issues

1. Difficult to detect previous spawning in lobsters that will not produce eggs in the current season. Yellow coloration of the oviduct not apparent.
2. There are very significant differences in physiological and functional size at maturity estimates. Morphometric indices also give very large differences in estimated size at maturity.
3. Morphometric maturity would seem to be an unreliable index of egg production potential. Lobsters with low ratios of body size (abdomen width of 0.5) have eggs.
4. Fecundity: The relationship between body size and fecundity is statistically better explained by a linear function but functionally the power function seems more appropriate. Power functions best explain the relationship between body size and ovary mass and body size and egg mass. There is a progressive decline in the value of the exponent of the function from ovary mass to egg mass to egg number. A number of factors reduce the exponent in the case of egg number

   a) increase in egg size with body size

b) loss of eggs during incubation
c) often an under representation of large lobsters in the sample.

5. Interpretation of possible geographic variation in the size of the onset of the sexual maturity (SOM) and fecundity is compromised by inconsistent methodologies between studies.

In Norway and Sweden, the SOM was established using the proportion of females with eggs under the abdomen in the catch.

Session on Models

Lobster Maturity and Fecundity Information for Models

The use of maturity information in a current life history model based on the growth of female and male clawed lobsters

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A current life history model that is a basis for reference point evaluation is based on the growth of female and male lobsters, variability in growth rates and size specific estimates of: maturity, molt frequency and molt increment, fecundity and weight, vulnerability to fishing (both capture and landing aspects). Fishing strategies are based management regulations and harvesters practices. Regulations set the "rules", size limits, various protections (e.g., prohibiting landing of berried or v-notched animals), seasons, etc. Harvesters then work within these rules by concentrating fishing in certain areas and during certain parts of the year. Since lobster growth and expression of maturity (i.e., carrying eggs externally) can fluctuate during the year, it is beneficial to be able to describe this form of life history when overlaying fishing strategies of concern. The model described below offer the ability to examine the interaction between maturity and growth, and extend analyses to the interaction of the life history and harvesting strategies for clawed lobsters.

Model

The life history model describes growth of lobsters based on the interaction of molt frequency and molt increment. There are links between molting and maturity (especially for females) since energy devoted to production of eggs and the physical constraints of carrying eggs externally for a period of time retard the frequency of molting for functionally mature lobsters. Growth and reproduction are currently described by six life history events that are temporally (within a year) distinct for each event and sex. These events include:

1. Primary molting (for those that will molt in a given year)
2. Second molt (for those that will molt twice in a given year)
3. V-notching
4. Death (both M and F)
5. Egg extrusion
6. Egg hatch

The timing can be discrete (all animals complete an event in one time step) or protracted (proportions of population completing an event over two or more time steps). It utilizes a time step appropriate for defining these events (i.e., the life history of clawed lobsters) and the interaction of the range of fisheries that occur. This time step should be set at the finest level of detail for which data are available for a population of clawed lobsters. Size specific information on functional maturity, molting schedules, growth increments, fecundity, and weight as well as fishery descriptions (seasonal timing of effort, gear retention characteristics, size limits and other protections) are needed to generate reference point calculations. These maturity schedules needs are described below.

Maturity

The life history/reference point model assumes there are differences between “physiological” and “functional” maturity. Physiological maturity implies that a female could produce eggs at a given size, while functional maturity implies a female will produce eggs at a given size. Some of the factors that can affect difference include size, age, fishing pressure and associated size composition of population, region/environment, and genetics. Since there is some link between maturity and growth the model employs the functional form.

Maturity information required by the model

Functional maturity interacts with growth and in part determines vulnerability to fisheries for lobsters. Females that are berried are not legal to land in *Homarus americanus* fisheries and are the focus of v-notching in some areas. Therefore, when the lobsters are berried becomes important in assessing management measures and how effective they would be under different harvesting strategies. Clearly, information about life history and maturity must be specific to the region being examined. In addition, there are temporal aspects that must be addressed. By size, there is the need for estimates of:

- the molt cycle for both males and females, maximum number of years until all lobsters at a size will molt, what proportion will molt in each year of this maximum, when during the year molting will occur (e.g., which month(s)?) for females: which year(s) of a given molt cycle females will carry eggs (e.g., year 2, year 1, year 2&3…) and what proportions for each?
- when during year she will extrude (e.g., which month(s)?) and what proportions for each?
- when she will hatch eggs (e.g., which month(s)?) and what proportions for each?

These last two estimates will determine duration of berried period, and therefore the periods of protection/vulnerability based on presence of some management regulations. The effectiveness of many management measures is dependent upon the interaction and individual effectiveness of all measures.

Evaluating impacts of maturity parameter estimation and uncertainty on the assessment of American lobster fishery in the Gulf of Maine

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Introduction

For the American lobster (*Homarus americanus*) stock assessment in the Northeast United States and Atlantic Canada, the stock status is evaluated by comparing deterministic estimates of (1) current fishing mortality rate (F_{cur}) for female lobsters and (2) a biological reference point (BRP), $F_{10\%}$, the rate of the fishing mortality which reduces the expected egg production for a cohort of female lobsters to 10% of that produced in the absence of a fishery (Fogarty and Idoine 1988; ASMFC 2000). $F_{10\%}$ is estimated using an egg-per-recruit (EPR) model which calculates the sum of the expected egg production over the life span of a lobster cohort (Fogarty and Idoine 1988). Parameters that define an EPR model include growth, mortality, and maturation parameters.

Lack of consideration of the uncertainty in BRP in the assessment may yield erroneous conclusions about the status of fish stocks (Helser et al. 2001). Few systematic studies have been done to evaluate the impacts of uncertainty in parameter estimates and possible variability in EPR model parameters among different cohorts of the lobster on the estimation of $F_{10\%}$ (ASMFC 2000). Uncertainties in the parameters, however, can come from the uncertainty in the statistical estimation of the parameters and the natural variability in the parameters among cohorts and geographic areas.

We used an extensive Monte Carlo simulation approach to evaluate the possible uncertainty associated with $F_{10\%}$ for the female lobster in the Gulf of Maine and then compared it with a probability distribution for current fishing mortality rate estimated in the lobster stock assessment (ASMFC 2000). A probability profile was estimated for decision confidence in determining the likelihood of current fishing mortality being higher than BRP $F_{10\%}$, which was then used to determine if the lobster stock was overfished. Although this approach increases the complexity in interpreting the results, it nevertheless reflects the fact that both $F_{10\%}$ and F_{cur} are subject to large uncertainty.

Chen and Wilson (2002) evaluated different levels of uncertainty for each parameter in the simulation. The focus of this study is to identify how variability in maturation parameters may influence the determination of the lobster stock status. By using estimates of variation reported in the literature surrounding the logistic function that defines maturity, we compared the implications of variation in the size of maturity on estimating $F_{10\%}$ and subsequently on the determination of the lobster stock status.

Methods

For a concise description of the methods used in this simulation study please refer to Chen and Wilson (2002).

Estimating impacts of uncertainty in maturation parameters on $F_{10\%}$

A multinomial sampling approach was used to directly simulate uncertainties in maturation in the EPR model (i.e., maturity logistic function), where the proportion mature at a specified carapace length is

$$P_{mat}(CL) = \frac{1}{1+e^{\alpha_1+\beta_1(CL)}} + \varepsilon_1$$

Defined by parameters α_1 and β_1. The variation associated with "observed" proportional data was controlled by sample size n (Chen 1996) as

$$S = \sqrt{\frac{P(1-P)}{n}},$$

where S is standard deviation, n is the sample size, and P is an original proportional value.

In Chen and Wilson (2002) five simulation scenarios were considered to cover the possible ranges of the uncertainty for each parameter (Table 2; Chen and Wilson 2002). To avoid unrealistically large or small values, upper and lower boundaries were defined for some parameters (GOM maturity α=21.210 and β= -0.2320). For this study an additional simulation was conducted using maturity parameters for the Georges Bank and South stock area (α=11.145 and β= -0.1197). All other parameters were considered the same as those used in the scenario I (medium-variation scenario in Chen and Wilson 2002).

Interpreting the uncertainty in decision-making process for the lobster

We compared the probability distributions of F10% and F_{cur} using the stochastic decision-making framework described in Chen and Wilson (2002). The probability profile was plotted for each simulation scenario to describe $P(F_{cur} > F_{10\%})$ at different levels of decision confidence.

Results

The probability distribution of $F_{10\%}$ estimated using the data with medium level of variation (i.e., scenario I) had 90% confidence intervals ranging from 0.28 to 0.61. The mode of the F_{cur} distribution had a higher value than that of $F_{10\%}$ derived for scenario I (Fig. 1a), indicating that the fishery could be declared overfished based on the criteria currently used by ASMFC (i.e., compare two means). The probability distributions for F_{cur} and $F_{10\%}$ did, however, share some overlaps (Fig. 1a). The probability profile suggested that the probability of current fishing mortality being higher than $F_{10\%}$ changed with the decision confidence level (Fig. 1b). For example, at the 100% decision confidence level, $P(F_{cur} > F_{10\%})$ was around 30%, while at the 50% and 80% decision confidence levels, $P(F_{cur} > F_{10\%})$ was about 90% and 80%, respectively

(Fig. 1b). This suggests that because of the consideration of variations in F_{cur} and $F_{10\%}$, the conclusion regarding the status of the lobster stock could vary with the decision confidence level which reflects the level of risk mangers would like to take.

Similar conclusions could be derived for this scenario, but using GBS parameters for maturity (Fig. 1c and 1d). The values of $P(F_{cur} > F_{10\%})$ in the profile plot for the high-variation scenario decreased at a higher rate with increased decision confidence levels compared with those for the medium-variation scenarios. For example, at the 50%, 80%, 90%, and 100% confidence levels, $P(F_{cur} > F_{10\%})$ was 0.85, 0.68, 0.55, and 0.2, respectively (Fig. 1d).

Compared with that derived using the GBS maturity estimates, uncertainty in $F_{10\%}$ was smaller for the GOM scenario. Overlaps between the probability distribution for $F_{10\%}$ and assumed distribution for F_{cur} were smaller compared with those for GBS maturity scenarios, indicating larger differences between the two distributions.

Discussion

This study suggested that the determination of maturity in the parameters of the EPR model could affect the estimation of $P(F_{cur} > F_{10\%})$ for a given decision confidence level, thus affecting the conclusion as to whether the fishery was overfished. Using inappropriate values for maturity resulted in higher uncertainty in the estimates of F10%. This, for a given decision confidence level, could lead to a large uncertainty in determining whether the fishery was overfished.

In the 2000 lobster stock assessment one set of parameters were used for the Gulf of Maine stock assessment area (ASMFC 2000). These parameters were based on a landings weighted average of maturity ogives that were developed using different methods. Ogives developed in coastal Maine (southern, midcoast and downeast) were based on ova diameter resulting in a length at 50% maturity to 86, 88 and 92 mm CL (Nutting 1997). The estimate for offshore GOM was derived in Canadian waters using pleopod staging (D. Pezzack, Department of Fisheries and Oceans, Canada personal communication). By weighting each maturity function by reported landings in GOM, the assumption was made that the different methods were comparable and that landings represent the appropriate contributions of each area to egg production and subsequent recruitment. If offshore egg production contributes significantly more to inshore recruitment than landings would indicate, this study would imply that there is greater uncertainty associated with the F10% estimate (Fogarty 1995). Conversely if inshore egg production leads to local retention and recruitment than the reported estimate of uncertainty might be less than considered by Chen and Wilson (2002).

This study demonstrates that it is important to consider the uncertainty in estimating parameters for the lobster stock. Considering the possibility of large variability in biological/ecological processes among different areas is necessary to determine appropriate stock assessment areas.

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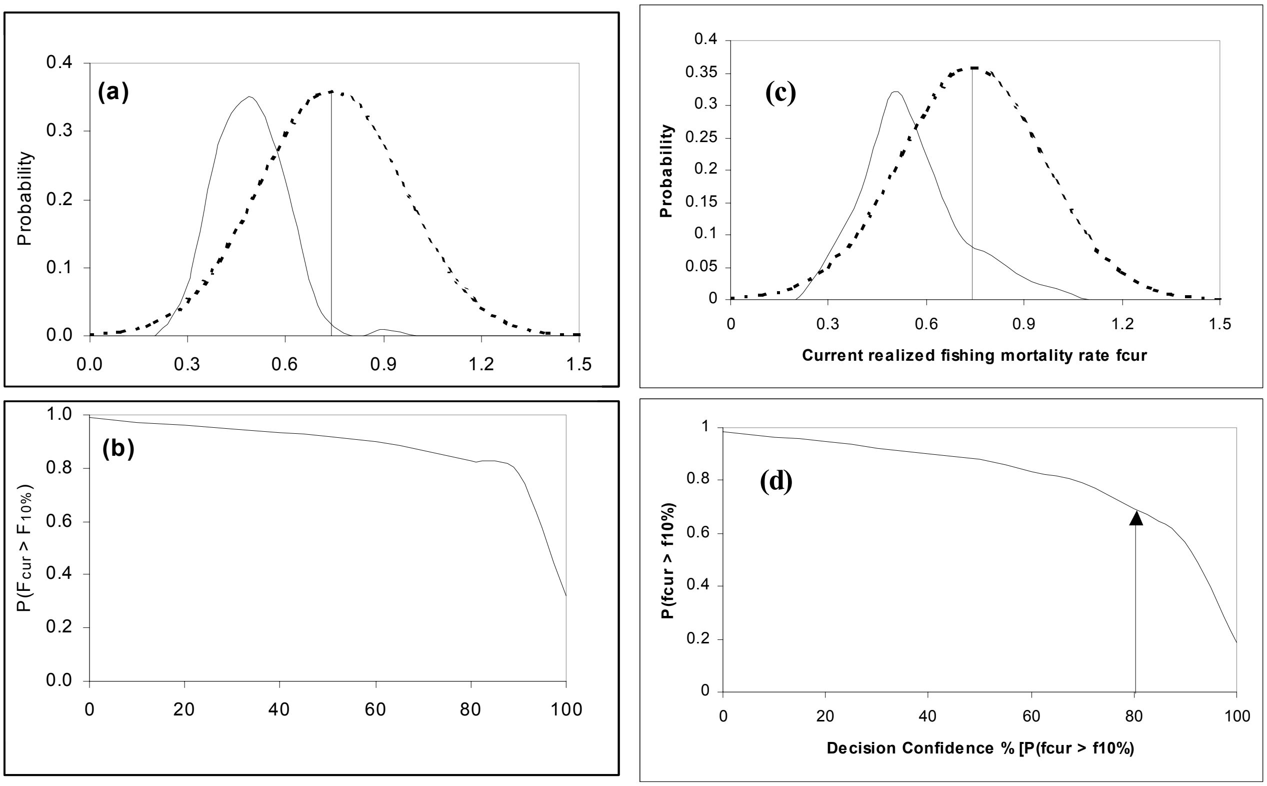

Figure 1. Probability distributions of $F_{10\%}$ (solid line) and F_{cur} (with the mean of 0.74 and standard deviation of 0.222; broken line)(top panels) and probability profile specifying the $P(F_{cur} > F_{10\%})$ for different levels of decision confidence (bottom panels) for simulation scenarios (GOM maturity parameters medium-variation; a and b), (GBS maturity parameters medium-variation; c and d).

Session on Techniques

Establishing Maturity and Reproduction Cycle

Morphometric techniques used to estimate size at maturity of female American lobster (*Homarus americanus*)

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Population characteristics of American lobster (*H. americanus*) have been monitored consistently since the mid 1970s in Connecticut waters of eastern Long Island Sound near the Millstone Power Station (Waterford, CT) to assess power plant impacts on this commercially important species. As part of this lobster monitoring study, we have estimated female lobster size at maturity using morphometric techniques described in the early work of Templeman (1935, 1944); he observed that the abdominal segments of female lobsters markedly increased at the first onset of sexual maturation. In our study, abdominal width (AW) and carapace length (CL) were measured (nearest 0.1 mm) for more than 67,000 female lobsters since 1981 to calculate AW/CL ratios, which was then plotted against CL.

At small female sizes (<55 mm CL), the slope of a curve fitted to the data is flat and corresponds to the sizes at which females are immature. The size at which the slope of a curve fitted to the data begins to increase represents the beginning of maturity. At larger female sizes (>90 mm CL), the slope becomes flat again, indicating that all females are mature. Maturation curves and cubic regression estimates of non-ovigerous female lobsters are presented in Fig. 1 for the a) early 1981–1987, b) mid 1988–1993, and c) recent 1994–2002 study years. A significant curvilinear relationship was found between the AW/CL ratio and CL for non-ovigerous females during the early study periods. Small fluctuations were observed in the annual mean AW/CL ratios (range=0.610–0.620) of the early study years (Fig. 2). During the mid study years, annual mean AW/CL ratios fluctuated widely, increasing from 0.606 in 1988 to 0.637 in 1993 (Fig. 2); in addition, no significant curvilinear relationship was found between the AW/CL ratio and CL of non-ovigerous females during this period (Fig. 1b). In recent study years annual mean AW/CL ratios stabilized at higher levels, relative to the early study years, ranging between 0.627 and 0.646. The cubic regression fitted to the recent study year AW/CL ratio data was significant and exceeded the regression line fitted to the early AW/CL ratio data (Fig. 1c). An obvious indication that females are mature is the presence of external eggs and a number of small (~60 mm CL) ovigerous females have been collected in our studies (Table 1). Assuming that small lobsters grow 14% per molt (from our tag and recapture studies), these small ovigerous females were between 50–55 mm CL when oviposition first occurred, supporting the results of the morphometric relationship between AW and CL.

The morphometric technique used in our studies over the past two decades has been useful for monitoring changes in size at maturity of female lobsters in Long Island Sound. Significant increasing trends in the annual mean AW/CL ratios from 1981 to 2002 (Fig. 2), suggests that the size at the onset of sexual maturity of female lobsters in Long Island Sound has recently decreased (Landers *et al.* 2001). Changes in the time series of morphometrics of non-ovigerous females was followed by an increase in the number of and decrease in the average size of ovigerous females collected in our research traps (Table 1). It is unclear whether the decrease in female size at maturity was related to a significant rise in seawater temperature, selection pressure from high fishing rates or a combination of these factors. Currently, the small size at maturity allows females to spawn once or twice before reaching legal size, which may be significant to population dynamics in Long Island Sound.

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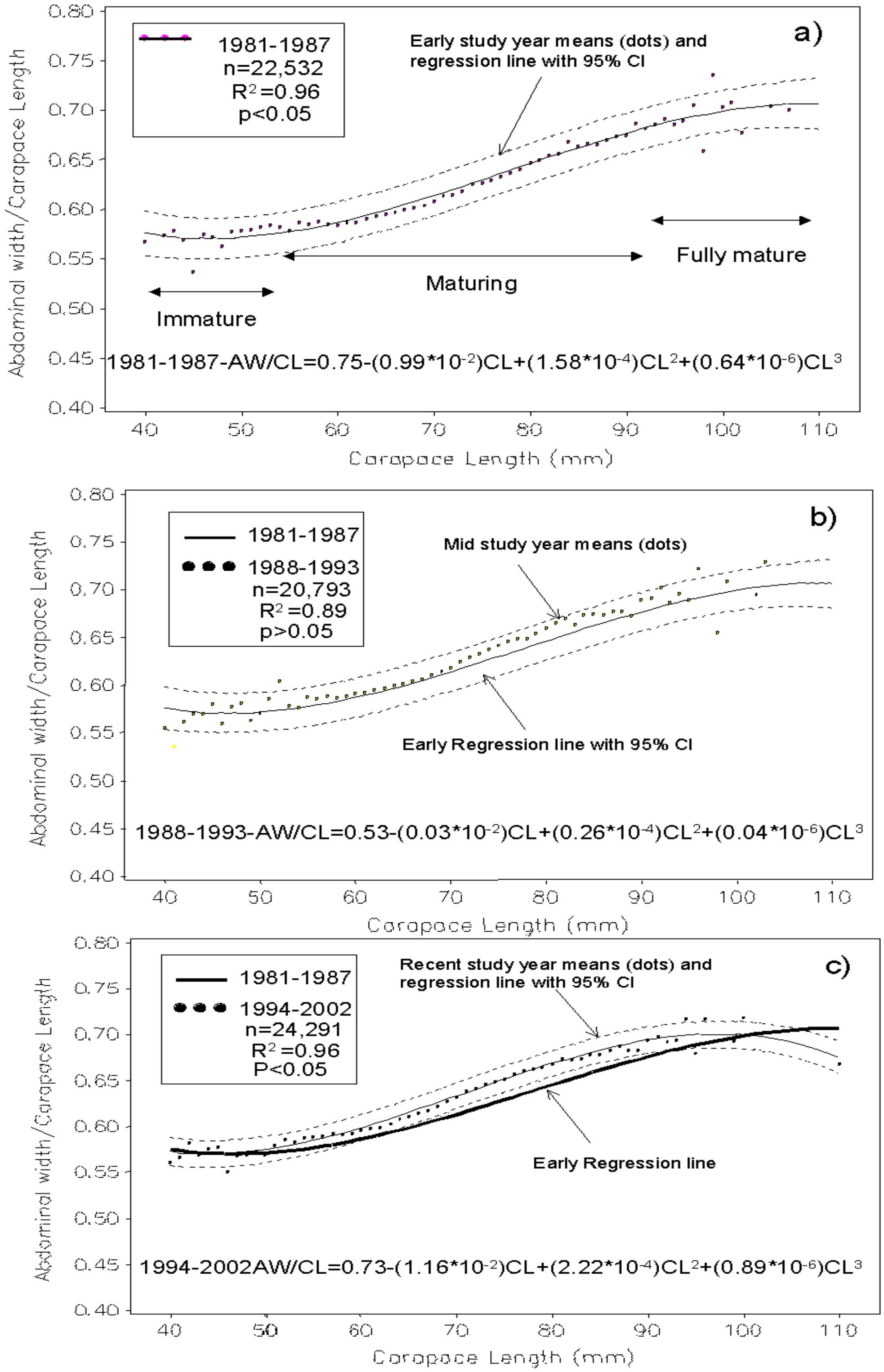

Figure 1. Maturation curves and regression estimates for female lobsters in eastern Long Island Sound based on AW/CL ratios during: a) early study years 1981–1987, b) mid study years 1988–1993, and c) recent study years 1994–2002.

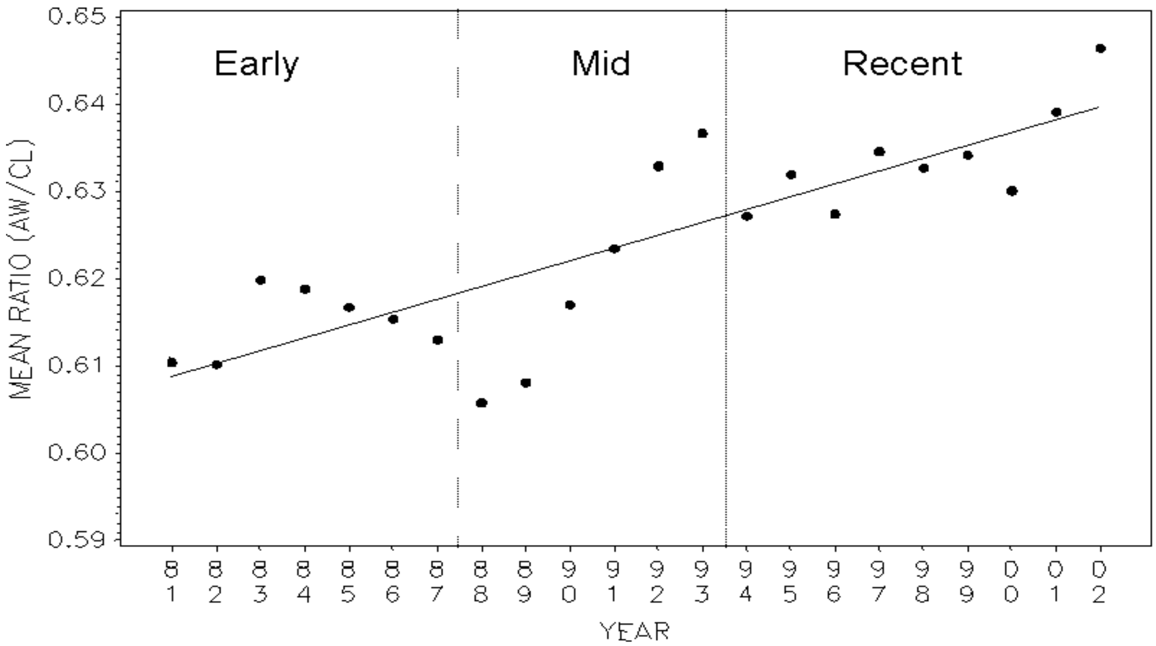

Figure 2. Annual mean AW/CL ratio and linear trend of the ratios for non-ovigerous female lobsters from 1981 to 2002.

Table 1. Percentage and size characteristics of ovigerous female lobsters collected in eastern Long Island Sound, CT 1978–2002.

Year	N	Percentage of females with eggs	Carapace Length (mm)				Percentage sublegal-sized
			Min.	Max.	Mean	Std. Err.	
1978	96	4.4	73.1	88.4	80.2	0.41	66.7
1979	101	4.5	64.1	92.5	79.9	0.52	64.4
1980	98	4.4	65.9	93.0	79.0	0.51	71.4
1981	116	5.2	69.2	97.1	80.6	0.55	62.6
1982	190	4.3	64.0	98.5	79.4	0.42	61.5
1983	187	6.1	66.1	103.3	80.2	0.39	64.7
1984	282	8.3	61.8	95.0	78.9	0.34	69.1
1985	236	7.4	63.1	93.5	76.8	0.34	83.6
1986	188	6.0	65.2	94.0	77.4	0.38	79.8
1987	220	7.0	61.6	90.2	76.4	0.30	90.1
1988	193	5.0	63.2	89.9	76.6	0.31	90.9
1989	222	6.7	65.2	97.7	77.1	0.31	85.7
1990	214	7.8	63.9	101.5	77.7	0.37	86.0
1991	268	9.1	62.1	96.2	77.8	0.34	80.7
1992	631	15.4	60.4	92.9	75.2	0.19	93.8
1993	626	16.1	61.5	89.5	75.5	0.18	93.6
1994	544	14.9	60.7	90.7	75.8	0.21	94.4
1995	280	12.1	63.9	90.5	76.0	0.27	95.4
1996	218	10.4	63.2	90.6	76.4	0.37	88.8
1997	338	13.4	58.6	93.2	76.0	0.28	91.2
1998	490	13.6	63.9	94.9	76.5	0.22	92.8
1999	433	11.7	60.0	109.7	76.8	0.25	92.5
2000	291	11.1	62.1	98.2	76.3	0.30	93.8
2001	319	15.0	63.4	94.4	75.5	0.29	92.8
2002	221	13.5	59.3	89.0	74.7	0.38	92.3

A field data-collection technique for categorizing ovary development stage and determination of size at sexual maturity in female American lobster (*Homarus americanus*)

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Introduction

Knowledge of size (or age) at the onset of sexual maturity (SOM), as well as other vital biological parameters (growth rate, natural mortality rate, fecundity, longevity) is necessary for proper management and stock status assessment of commercially important marine fishery resources. Methods to evaluate the status of commercially-exploited marine fishery resources (egg-per-recruit, yield-per-recruit, spawning stock biomass, biomass dynamic, etc.) use these biological parameters. The accuracy of the estimation of these various biological model input parameters can have profound affects on model output. Additionally, inaccurate assessment of commercially-important marine fishery resources based on inaccurate biological input parameters can have profound affects regarding resource management decisions. Management measures generally provide restrictions that allow an adequate portion of the population to reach sexual maturity prior to recruitment to the fishery, and thus provide the necessary reproductive output to support (or perhaps increase) the population.

Female American lobster, *Homarus americanus*, SOM has been examined by several researchers and a variety of methods have been used estimate this particular biological parameter (Herrick 1909, Templeman 1944, Saila and Flowers 1969, Krouse 1973, Aiken and Waddy 1980, Aiken and Waddy 1982, Briggs and Mushacke 1979, Ennis 1980, Russell and Borden 1980, Estrella and Mckiernan 1989, ASMFC Lobster Stock Assessment 2000). Techniques involving intensive and intrusive internal examination of the female lobster reproductive organs require sacrifice of the sample. To minimize the need to perform this type of lethal examination, a method for at-sea collection of data necessary for determination of the SOM in female American lobster was developed. The data and methods presented are an attempt to develop a standardized field technique for determination of this important biological parameter based on at-sea external visual examination of pleopods for cement gland development and ovaries for development stage. This field technique was developed based on the description of cement gland and ovary development stages by Aiken and Waddy (1982) and laboratory examination of non-ovigerous female American lobster sampled from the coastal waters of Narragansett Bay and Rhode Island Sound, Rhode Island.

Sampling design and methodology

During 1991–1992, and as a preliminary step in development of this field technique, several hundred randomly-selected, non-ovigerous female American lobster were collected from both nearshore Rhode Island (N=1,188) and offshore waters of Block and Hudson Canyons (N=656). Lobsters were collected as part of normal sea sampling data collection for the federally-funded Rhode Island Lobster Research and Management Project (Project Number 3-IJ-164, Grant

Number NA06FI0006) and held in a flow-through seawater system at the Rhode Island Division of Fish and Wildlife's Coastal Fisheries Laboratory until examination could be done.

A portion of the ovary is visible through the tissue connecting the carapace and abdomen when the abdomen is pulled slightly away from the carapace. In order to clearly examine the ovary, a small incision was made in the tissue connecting carapace and abdomen at the mid-dorsal surface, with care taken not to damage the heart or other internal organs. Once the incision was made, the ovary was examined in the laboratory under a dissecting microscope and categorized for ovary development stage based on criteria described by Aiken and Waddy (1982), with specific attention to ovary color and size. Cement gland development stage (Aiken and Waddy 1982) was also observed and recorded. From these laboratory observations, the color categories were defined.

Result and discussion

For a variety of reasons, internal examination of ovary development stage via invasive methods (dissection) is not practical during normal sea-sampling activities. The categorization of ovary color by external visual examination and subsequent determination of ovary development stage based on ovary color is an attempt to develop a standardized field technique that is fast, accurate, and does not require extra handling or damaging the lobster. The results of ovary color observations are depicted in Table 1.

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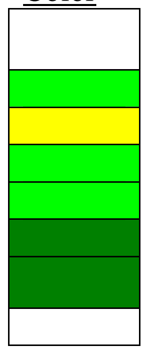
Table 1: Ovary development stage and color category.

Ovary Development Stage	Color Description	Color
Stage 1	White	
Stage 2	pale green	
	pale yellow/beige	
Stage 3	light/medium green	
Stage 4	medium/dark green	
Stage 5	dark green	
Stage 6	very dark green	
Stage 7	mixed colors	



Allometry and size at sexual maturity for the *Homarus americanus*

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Several mathematical techniques have been proposed to determine a size at morphometric maturity for crustaceans based on the change in allometric growth (Simpson 1961, Somerton 1980, Lovett and Felder 1989, Aiken and Waddy 1989, Watters and Hobday 1998). Three of the proposed methods, (1) Simpson's index, (2) Two-line regression (with least-square or Principal Component Analysis), and (3) splines, have been applied to a set of female lobster data with a known maturity status. The resulting sizes at morphometric maturity obtained by the three methods were compared to the size at functional maturity. The repeatability of the methods was also noted. Preliminary results raise questions concerning the use of methods (1) and (2). Both methods rely on *a priori* decision and visual estimates making them difficult to repeat accurately. Also, morphometric sizes at maturity obtained by the methods were different from the size at which 50% of the female reach the size at the onset of sexual maturity. The splines technique proposed by Watters and Hobday (1998) seems to give promising results with little *a priori* biological assumptions concerning the application of the method.

Table 1. Carapace length (mm) at morphometric maturity using three techniques for three fishing areas.

Methods	Alma	Malpeque	Margaree
SOM_{50}	101	72	75
Simpson's index	-	-	-
Two-line regression: Least-squares	114	81	68
Two-line regression: PCA	118+	81	67
Splines	107	70	72

PCA: Principal Component Analysis
SOM_{50}: Size at which 50% of the females reach the onset of sexual maturity

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Techniques to establish female lobster, *Homarus americanus*, size at maturity based on ovaries condition and pleopod reading

And

Establishing the reproductive cycle of female American lobster, *Homarus americanus*

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These presentations were based on:

Comeau, M, and Savoie, F. 2002. Maturity and reproduction cycle of the female American lobster, *Homarus americanus*, in the southern Gulf of St. Lawrence, Canada. J. Crust. Biol. 22(4): 762–774.

Abstract

The maturity and reproductive cycle of female American lobsters (*Homarus americanus*) were investigated in the southern Gulf of St. Lawrence (sGSL), Canada. The onset of sexual maturity of female lobsters can be established by the observations of the ovarian condition, either color or weight, and staging of cement glands but cannot be detected by the morphometry of their abdomens. Females reached 50% maturity between 68.7 and 73.3 mm of carapace length (L_C). There was a significant geographic difference ($P<0.005$) in the size at 50% maturity established by the ovarian development techniques but not the cement-gland staging technique. Also, there were no annual significant differences ($P>0.005$) between the ovarian development techniques used in a single site between 1994 and 1997. To study the reproductive cycle of females, molt stage, ovarian development, and egg spawning were monitored by dissections at the laboratory and by tagging studies in the field. The majority (80%) of small mature females (L_C <120 mm) in the sGSL had a typical two-year reproductive cycle with molting (with copulation) and spawning in alternating years. However, up to 20% of multiparous females ranging between 65 and 109 mm L_C could spawn in successive years instead of the generally accepted two-year cycle, and some could even molt and spawn during the same summer. Similarly, up to 20% of primiparous females could molt and spawn (for the first time) in the same year instead of spawning the following year. A small percentage (5%) of small mature females could also skip molting or spawning for a year. Temperature data suggested that the length of the female reproductive cycle and possibility of molting and spawning in the same year, were related to the number of degree-days in a particular season.

Determination of sexual maturity of female American lobster (*Homarus americanus*) in the Magdalen Islands (Québec) based on cement gland development

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Introduction

The conservation approach for all American lobster (*Homarus americanus*) stocks is centered on the egg production per recruit (EPR) reference point. In the United States, a reduction in EPR to 10% of a hypothetical unfished population has been adopted as a management threshold. In Canada, a goal of doubling EPR relative to 1995 levels has been adopted as a management target. Management measures taken in recent years to comply with the EPR target have mainly been oriented towards increases in escapement. In the Magdalen Islands, a management plan including the increase of the minimum legal carapace length (CL) from 76 mm to 83 mm (1 mm increments each year from 1997 to 2003) was implemented to reach the target.

In the Québec region, EPR is currently calculated using a simulation model (Gendron and Gagnon 2001) derived from the biological model developed by Fogarty and Idoine (1988). Information on the size at the onset of sexual maturity (SOM) is used in the EPR model to determine the probability that an unberried female of a given size will spawn in a given year. These probabilities correspond to the ogive of sexual maturity, to which a logistic model is fitted. In the Magdalen Islands, ogives of sexual maturity were determined by Dubé and Grondin (1985) from observations of the color and weight of the ovaries and oocytes diameter (physiological maturity) and from the cement gland development (functional maturity), according to the classification criteria defined by Aiken and Waddy (1982). Females having developing (stages 4 and 5) or mature ovaries (stage 6) are generally considered mature. Moreover, females with cement glands in development stages 3 or 4 at the end of spring (June) are regarded as mature and capable of spawning the coming summer. Cement gland development stages 3 and 4 have been shown to be correlated with ovary development stages 4, 5, and 6 (Aiken and Waddy 1982, Dubé and Grondin 1985). In a recent paper by Comeau and Savoie (2002), it was suggested that females showing cement gland developmental stage 2 could be as well considered as functionally mature since they had mature ovaries. Moreover, they found that the SOM based on stage 2 were much closer to the ones established from ovarian observations than those based on stage 3. According to these authors, the SOM based on developmental stage 3 tends to be overestimated.

Data on cement gland development has been gathered in the recent years in the Magdalen Islands. The objective was to examine variability of SOM in the last two decades by comparing recent data to those of Dubé and Grondin (1985) under the hypothesis that changes may have occurred following changes in population abundance and in the level of exploitation of the female population. This information would serve moreover to update data used in EPR calculation.

Materials and methods

Sampling was done in the Magdalen Islands annually from 1996 to 2003 (except in 1999) at the end of the fishery, between the 23 June and the 8 July, close to the spawning season. Each year, the endopodite of the left third pleopod of approximately 200 females ranging in size between 60 and 100 mm CL (five females in each 1 mm size class) was examined and cement gland development was determined according to the criteria defined by Aiken and Waddy (1982). Females were obtained from commercial traps during the last weeks of the fishing season.

The percentage of mature females as a function of size (3-mm size classes) was then determined and a logistic model was fitted to the curve using the NLIN SAS procedure. Expression of the logistic equation was however modified to allow the calculation of a confidence interval around the point of inflexion. Data were analyzed each year separately and for the whole period (1996-2003) combined. For comparison, the analysis was done using cement gland developmental stage 2 and repeated using stage 3. Data of Dubé and Grondin (1985) were also reanalyzed using stage 2 criteria.

Results and discussion

The size that which 50% of females reach the onset of sexual maturity (SOM_{50}) determined by Dubé and Grondin (1985) based on stage 3 cement gland development was 79.8 mm CL (79.1–80.6, 95% confidence interval) compared to 77.7 mm (76.5-79.0) using stage 2 criteria. For comparison, in the same work, SOM_{50} derived from ovary examination was established at 78.8 mm (78.5 – 79.8, 95% confidence interval). For the period 1996-2003, SOM_{50} established using stage 3 criteria varied between 79.0 mm and 91.5 mm, with an overall mean of 82.7 mm (81.7 - 83.7, 95% confidence interval). Conversely, SOM_{50} based on stage 2 criteria yielded smaller but less variable results, ranging from 75.2 mm to 78.6 mm, with an overall mean of 77.7 mm (76.5 mm – 79.0 mm, 95 % confidence interval). The mean SOM_{50} based on the stage 2 criteria for the whole period (1996-2003) was similar to what was observed nearly 20 years ago (Dubé and Grondin 1985). The same comparison made using stage 3 criteria showed a higher mean value for the 1996-2003 period.

The difference between the SOM_{50} established using stage 2 and stage 3 criteria was not constant throughout the period (1996-2003) and varied between 1.2 mm and 14.6 mm. These differences can be attributed to the period of sampling and spring temperatures. Although no significant relationship was established, a negative trend was observed between the SOM_{50} based on stage 3 cement gland development and the date of sampling as well as the number of degree-days accumulated to the time of sampling. Values obtained using stage 2 criteria appeared less affected by these two factors.

Correspondence between stage 2 cement gland development and mature ovaries, and the fact that some years, values of SOM_{50} obtained using stage 2 or stage 3 criteria converge give confidence on the accuracy of the use of stage 2 criteria to determine SOM_{50} and spawning probability of females of different sizes for a given year. Although less variable, values obtained using stage 2 criteria showed some level of variability among years that could be explained by factors such as sample size and variability among years in the abundance of Adult-1b (*sensu* Aiken and Waddy 1982). More studies of these factors are needed.

In this study, there was no evidence of changes of the SOM in the last 20 years, despite changes in the abundance of females, due to increases in population abundance or increased protection from changes in minimum legal size.

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Female lobster maturity and reproductive cycle: Its implication in the fishery management of the Lobster Fishery Area 25

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A good knowledge of the female size at sexual maturity and reproductive cycle is essential for a sound management of the lobster fisheries. The size at maturity is often used as a biological reference point to define the minimal legal size. Another important regulation of the lobster fisheries that relate to the female reproductive cycle in the southwestern Gulf of St. Lawrence (sGSL) is the protection of berried females (landing berried females is prohibited). In the sGSL, four of the five Lobster Fishing Areas (LFA) have a spring season (May 1 to June 30) prior to the annual molting and spawning (July-August). With such timing, primiparous females with a one-year reproductive cycle, and multiparous females that spawn in successive years, which can represent up to 20% of the females, are fully protected from the fishery. However, in one LFA (LFA25: early August-early October) fishermen can catch females with a one-year reproductive cycle in early postmolt, but before they extrude their eggs (i.e., in the same year before they become primiparous females), and multiparous females that have the ability to spawn in successive years before they can release another clutch of eggs. Hence, a portion of the potential egg-producing females are caught and kept before they have the time to extrude their eggs and get “legal protection”. Hence, taken into consideration the female reproductive cycle as a biological reference point, the reproductive potential of the population should be (fully) protected with a very high exploitation level (65%–85%) as observed for all lobster fisheries. For lobster fisheries operating during the critical period of the life cycle (summer season), it is not fully protected even if landing of berried females is prohibited. This contradicts the FRCC’s (1995) recommendations for lobster conservation. In LFA 25 (summer fishery), adjustment to the present management regime would be needed.

Reference

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Geographical variation in size-at-maturity and fecundity in *Homarus gammarus*: Implications for management

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Effective fisheries management requires that management measures are applied on a geographical scale that appropriately reflects spatial variation in population parameters. The European lobster, *Homarus gammarus,* is distributed from Morocco to northern Norway and in the Mediterranean Sea, and thus Europe-wide management measures may not be appropriate. In this presentation we review information on female size-at-maturity and fecundity in *H. gammarus* collected from studies carried out in a wide range of geographical variation or by differences in techniques for assessing size-at-maturity. Finally we use a life history model to investigate the impact on yield and egg-per-recruit levels of various management options. In particular, we examine the sensitivity of the model's predictions to observed differences in size-at-maturity and fecundity in relation to management options such as prohibiting the landing of berried females, V-notching and minimum and maximum landing sizes.

Reproduction of female lobsters (*Homarus gammarus*) on the Swedish west coast.

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Introduction

The lobster fishery in Sweden is currently managed by a minimum landing size (MLS) of 80 mm carapace length (CL), a closed season (May 1 to the first Monday after September 20), and since 1985 a ban on berried females. Lobsters can only be legally captured using lobster traps equipped with 2 circular unblocked escape openings of >54 mm in diameter in each compartment (unlike crab traps with a 75 mm escape openings). There is also a limit of 50 lobster traps per person for licensed fishers and 14 traps for non-licensed fishers. There is however no limit on the total number of traps as all Swedish citizen are allowed to use 14 traps per person and no obligation to report neither catch nor effort.

In spite of the lack of knowledge on total catch and effort in the Swedish lobster fishery, it is considered that a sustainable fishery can be obtained if a balance between catch and stock production is achieved through an appropriate MLS. This MLS will give the majority of female lobster the possibility to reproduce at least once before recruiting into the fishery. The question is then at what size and how often a female lobster contributes to the egg production. Investigations have thus been carried out to estimate the proportion of berried females in the catch, the size at onset of sexual maturity (SOM), fecundity and finally the reproductive potential.

Size at the onset of sexual maturity

The proportion of berried females per 1-mm CL was estimated from catch compositions from two different exploitation rates (Fig. 1). Firstly, data from the commercial lobster fishery between 1979 and 1982 where 5,469 female lobsters were measured. This was before the ban on berried females was introduced in Sweden in 1985 and before the escape gap was introduced in 1996. Secondly, from a lobster reserve protected from the commercial fishery since 1989. All caught lobsters in the reserve were tagged and released within the area. A total of 4,306 female lobsters from the closed area were measured. Sampling from the commercial fishery is mainly done from October to December, while the trial fishery in the protected area is carried out from May/June to November each year.

The relationship between the proportion of berried female (PB) and CL from the sum of data in the two data set can be described with a logistic curve during the SOM followed by a falling strait line as size increase (Fig. 2). Equation (1) was fit to the sum of the observed data in MS Excel Solver by estimating the constants a, b and c to 37.62, 0.48 and 0.01 respectively by minimizing the sum of squared residuals.

$$PB = \frac{1}{1+e^{(a-b*CL)}} / e^{(c*CL)}$$

The proportion berried females increase to about 50% indicating that about half of the females are berried each year and that the time period between spawning increase with length along the falling trend line for larger females.

The time of the year when spawning or hatching takes place was investigated from a tag-recapture experiment in the closed area. All individually tagged females who were caught at least twice in a year and either became berried (spawned) or released her egg (hatched) during the time period were analyzed according to the dates before and after the event (spawning or hatching). The date when the majority of females spawned or hatched was then analyzed by summing the number of dates in the periods when the event occurred as (Fig. 3). The results from this study shows that both spawning and hatching peaks in the period between July 15 to August 15 indicating that a female spawn in the summer and carries the eggs under the abdomen during about one year before the egg are hatched in the summer the following year. This suggests that hatching is biennial and that half of the mature females are berried each year.

The SOM was estimated by multiplying the proportion of berried female at CL by two to achieve the proportion of sexual mature females (Fig. 4). The CL at which 50% of the females become mature was estimated at 79 mm CL and the current MLS of 80 mm CL in Sweden imply that about 70 % are mature at MLS. If the MLS is set to 87 mm, as is legislated in most EU countries, the majority of females would be mature before reaching MLS.

Fecundity

A total of 54 berried females were collected from a control fishery during the autumn months close to the lobster reserve. All eggs were carefully removed from the pleopods and the total wet egg weight (W) was measured for each female. Three sub samples (w_1, w_2 and w_3) of approximately 3 grams each were then taken and the number of eggs (n_1, n_2 and n_3) was counted in each sub sample. The total number of eggs (N) for each female was calculated as:

$N = W(n/w)$ where $n/w = ((n_1/w_1)+(n_2/w_2)+(n_3/w_3))/3$

The highest correlation coefficient (R^2=0.887) in the relationship between the number of eggs and CL was obtained by fitting the data with a linear regression (slope=372.09 and intercept=22,598; Fig. 5).

Reproductive potential

The product of the proportion of berried females (Fig. 2) and fecundity (Fig. 5) for each size class was considered as the reproductive potential (Fig. 6) to be applied on the size distribution in a population.

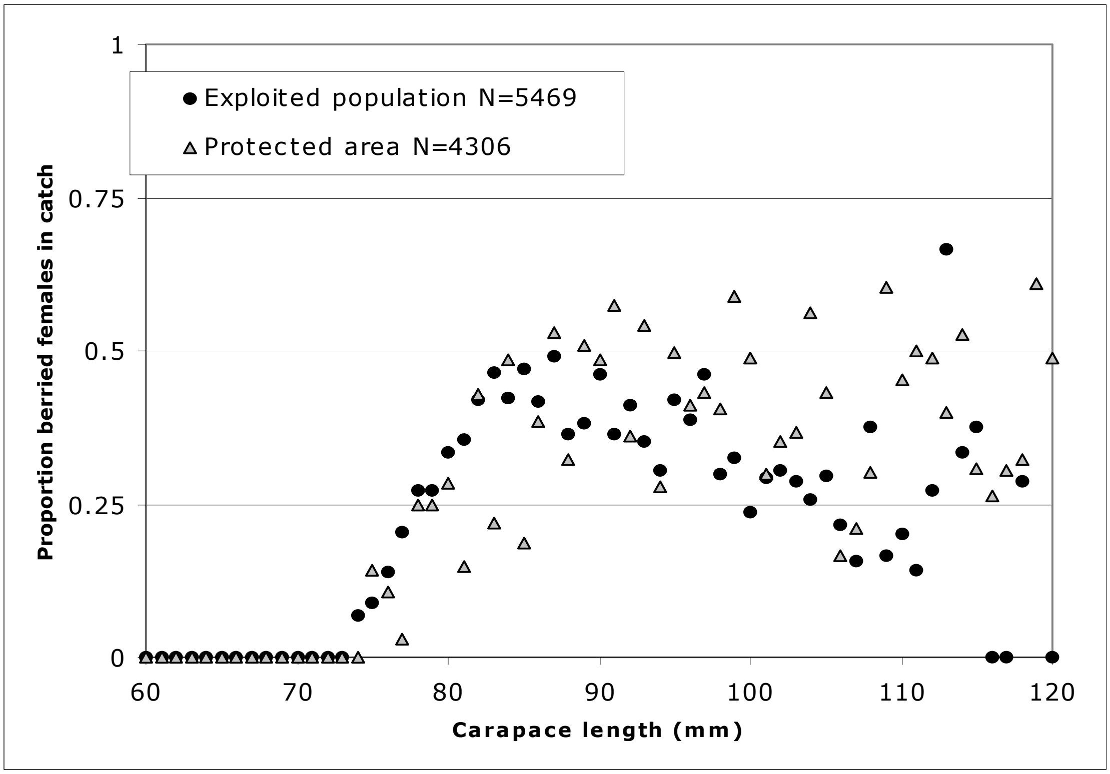

Figure 1. Proportion of berried female European lobsters in the catches against the carapace length from an exploited population and a protected area on the west coast of Sweden.

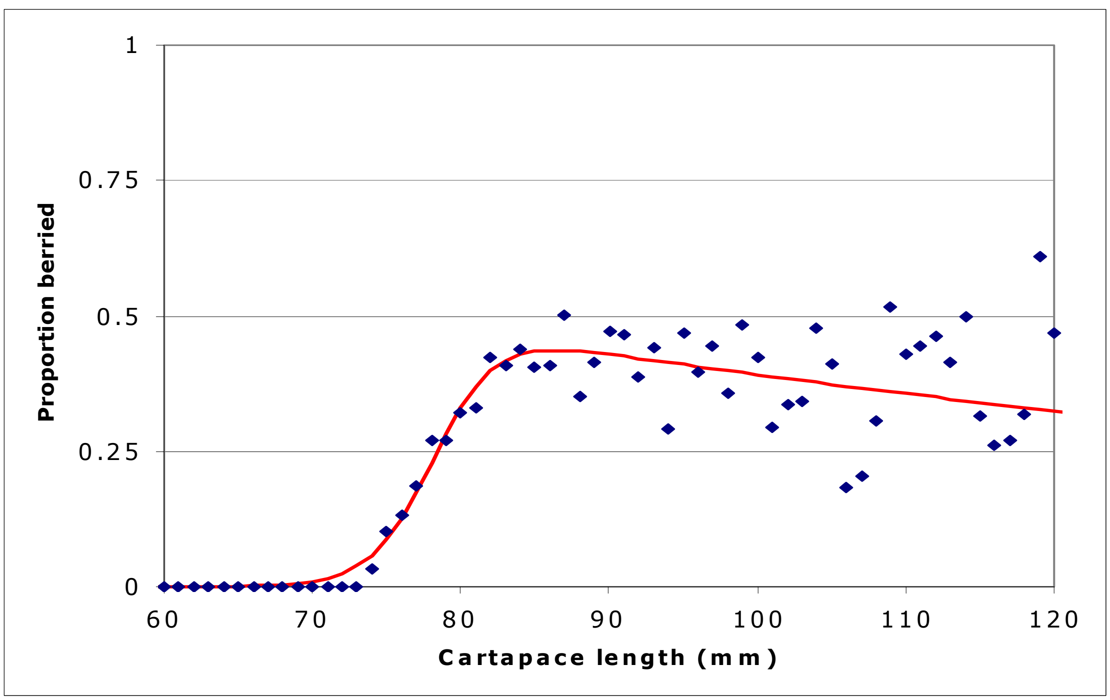

Figure 2. Relationship between the proportion of female European lobsters carrying egg under the abdomen and carapace length.

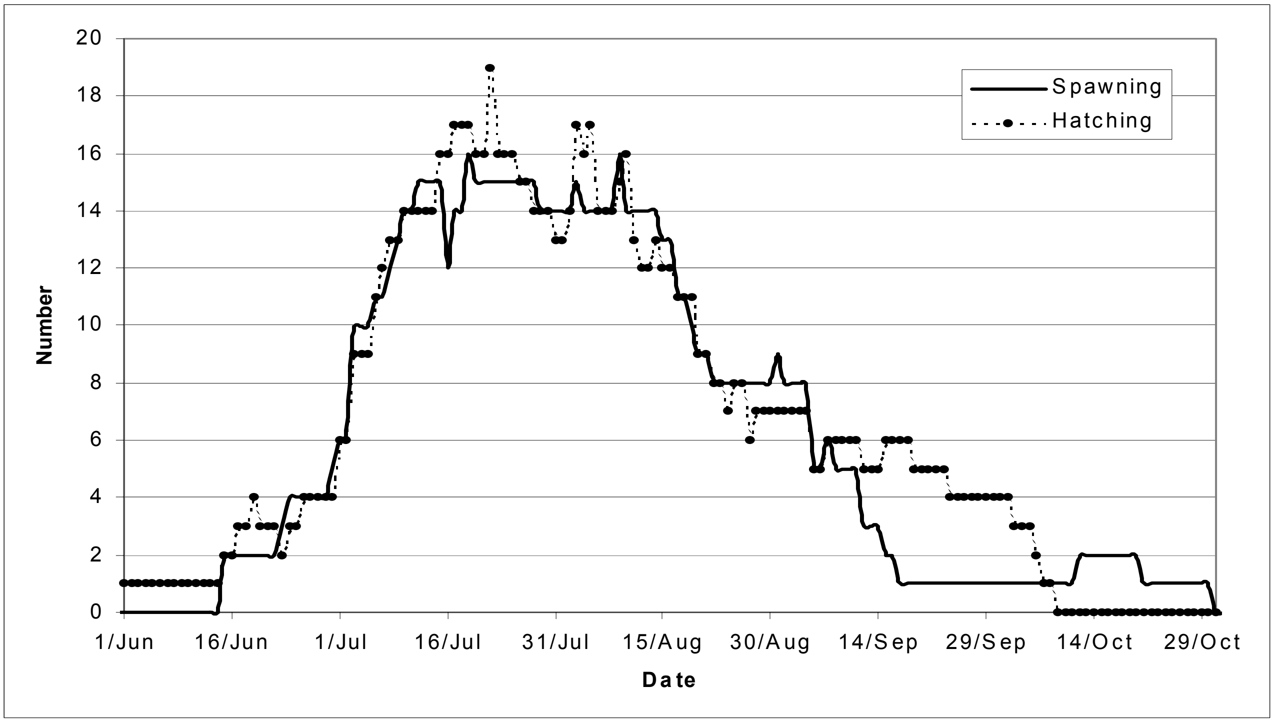

Figure 3. Time periods of hatching and spawning for female European lobsters in the west coast of Sweden.

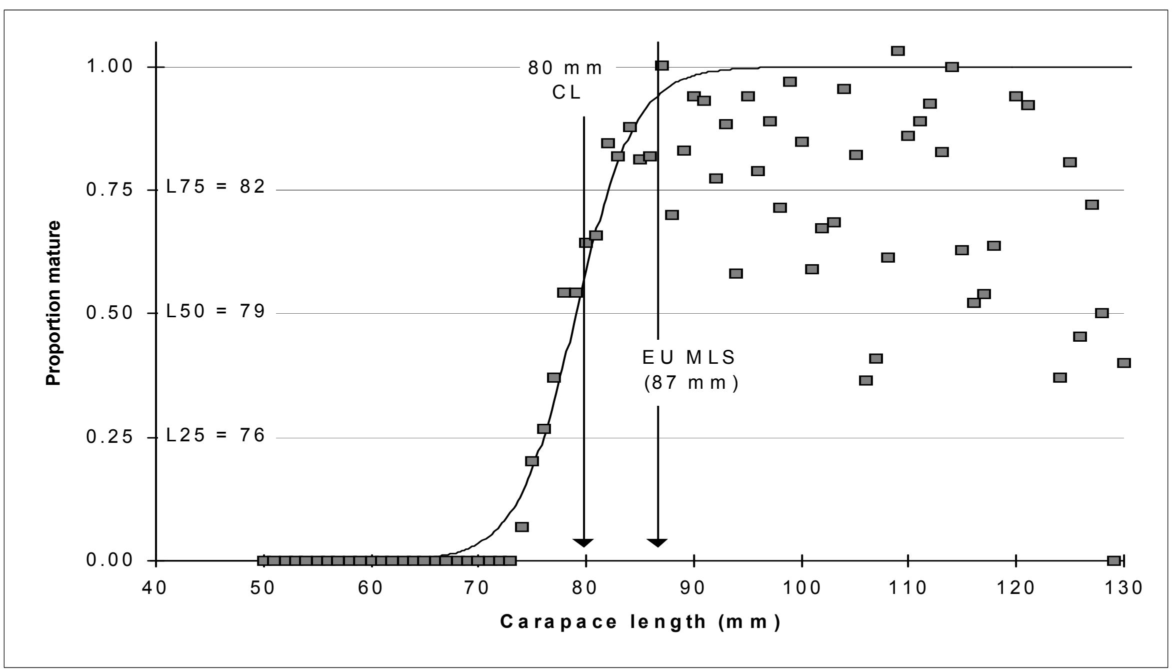

Figure 4. Proportion of mature females against the carapace length (CL) assuming a biennial spawning. Arrows show the Swedish minimum landing size of 80 mm CL and the EU minimum landing size of 87 mm CL.

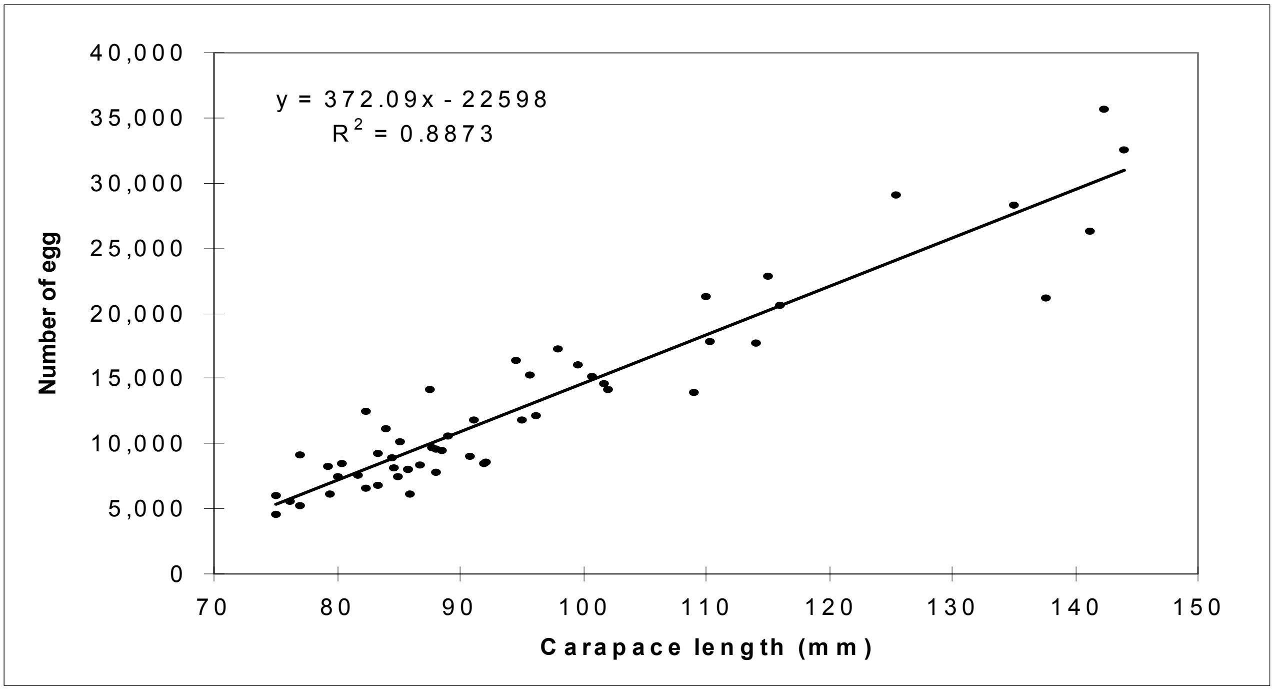

Figure 5. Relationship between the number of egg under the abdomen and the carapace length for female European lobsters on the west coast of Sweden.

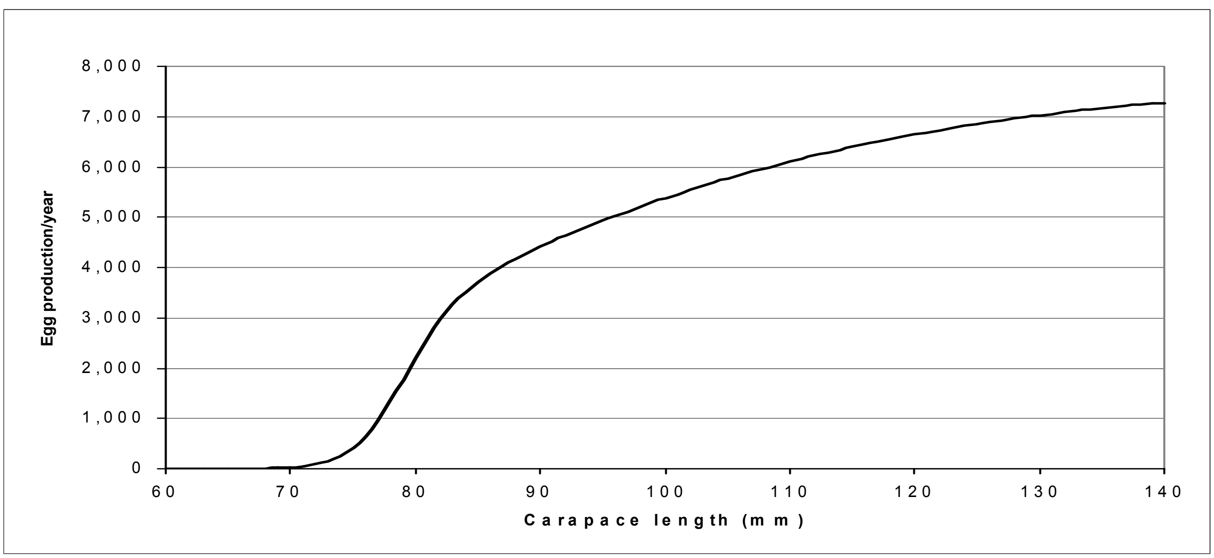

Figure 6. Reproductive potential as the product of the fecundity and the proportion of egg bearing females in the population for female European lobsters on the west coast of Sweden.