FINAL REPORT
MONKFISH RSA 2011-2013

Report title: Influence of temperature on the distribution and catch rates of monkfish, *Lophius americanus*

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1. Abstract

Information on fish reproductive biology is useful for assessments of spawning stock biomass (SSB), as this can provide input data for models such as total egg production (TEP). Ovarian development presents evidence of fecundity type and spawning strategy, which dictate the capacity of a fish to contribute recruitment to a SSB. The ovarian development of goosefish (*Lophius americanus*) in the western North Atlantic Ocean was evaluated from samples collected in the Northeastern United States, from 2009-2012. Asynchronous oocyte development appears to exist through vitellogenesis, with group-synchrony present during oocyte maturation. Post-ovulatory follicles (POFs) were observed in developing ovaries, providing evidence to support a theory of batch spawning in *L. americanus*. Fecundity estimates for 55 female monkfish ranged from 78,200 to 2,243,300 mature oocytes per female, increasing with fish length (total length range: 55.5 – 112 cm), weight (carcass weight: 3.99-24.5 kg) and age (6-10 years) but not body condition (Fulton K, hepatosomatic indices). The results of this study support our earlier findings (Biology of Large Monkfish-NA07NMF4540022) that monkfish are serial spawners with individuals spawning over a protracted period. In addition, new information on fecundity, spawning frequency and seasonality suggests stock productivity and resiliency maybe higher than previously assumed but the largest fish, those with the highest batch fecundity estimates, now appear to have lower fecundity compared to the 1980s.

2. Statement of Problem:

The American monkfish or goosefish, *Lophius americanus*, is a fast growing, benthic species belonging to the family Lophiidae (Steimle et al., 1999). This species is found in the western North Atlantic Ocean from the Grand Banks in Canada, south to Florida along the east coast of the United States (Martinez, 1999; Johnson *et al.*, 2007, 2008; Richards *et al.*, 2007, 2008). Monkfish inhabit benthic environments from coastal waters through depths possibly exceeding 1,000 meters (Armstrong *et al.*, 1992; Johnson *et al.*, 2007; Richards *et al.*, 2008). Seasonal inshore-offshore migrations have been observed and are believed to be related to spawning and feeding activities (Almeida *et al.*, 1995; Richards *et al.*, 2008). *L. americanus* is the only lophiid to inhabit the southern waters of Atlantic Canada, a region where it is abundant throughout the Gulf of St. Lawrence, Scotian Shelf, and southwestern Grand Banks (Beanlands & Annand, 1996). The species appears to reach the northern limit of its distribution at 48°N Latitude (Beanlands & Annand, 1996). Thermal habitat associations for monkfish have been documented and sea temperature (4.5-13.0°C) is believed to influence migratory behavior and distribution shifts (Richards *et al.*, 2008). A highest abundance has been observed within a temperature range of 3-11°C, and can be described more precisely with respect to season and latitude (Beanlands & Annand, 1996). This may be pertinent to reproductive output since temperature is known to influence growth rates, metabolic processes, and physiological condition in fish (Wootton, 1998). Furthermore, incidence of feeding in *L. americanus* is highest in near- spawning fish (Johnson *et al.*, 2008). Consequently, energy and nutrient availability during oocyte maturation may effect egg production and viability, as demonstrated in yellowtail flounder (*Pleuronectes ferruginius*) by Manning & Crim (1998). *P. ferruginius* is a

demersal fish and shares a similar thermal tolerance and overlapping distribution. Additionally, evidence exists to suggest both fish are multiple spawners, thus indicating the species share aspects of their reproductive strategies. Furthermore, fecundity was concluded to be positively correlated with sea temperature and food availability for female Atlantic cod (*Gadus morhua*) (Kjesbu *et al.*, 1998), another sympatric species to *L. americanus*. Ultimately, environmental factors may impose direct and indirect variability in reproductive output through influencing growth rates and metabolism, as well as fish size and condition, respectively (Wootton, 1998; Murua *et al.*, 2003).

The reproductive biology of *L. americanus* has been described by numerous sources with published documentation dating back to the 1870s (Baird, 1871). The species is iteroparous, highly fecund, and spawns eggs in a gelatinous veil. The spawning season of *L. americanus* in the western North Atlantic Ocean is suggested to be protracted from January to August, with predominant activity from late winter to early spring and during early summer (Armstrong *et al.*, 1992; Richards *et al.*, 2008; Johnson *et al.*, 2008). Recent documentation indicates that the characteristics of reproductive biology in female monkfish have not yet been fully described. For instance, *L. americanus* has previously been termed a total spawner – spawning a single time during a spawning season (Feinberg, 1984; Yoneda *et al.*, 2001; Murhua and Saborido-Rey, 2003). However, histological assessments of ovarian development (Martinez, 1999; Johnson *et al.*, 2007, 2008) have presented evidence that suggests some individual females may spawn multiple times per spawning season. Multiple (batch) spawning has been documented for other Lophiids, including *Lophiomus setigerus* (Yoneda *et al.*, 1998) and *Lophius litulon* (Yoneda *et al.*, 2001). Furthermore, these species and most other Lophiids, share similar ovarian morphology and reproductive biology with *L. americanus*, suggesting spawning strategy could also be common (Armstong *et al.*, 1992; Alfonso-Dias and Hislop, 1996; Yoneda *et al.*, 1998; Johnson *et al.*, 2008).

A valuable commercial fishery for monkfish exists in the northeastern United States, where the *L. americanus* is targeted between the Gulf of Maine and North Carolina (Johnson *et al.*, 2007, 2008; Richards *et al.*, 2007, 2008). Commercial catch (landings plus discards) increased drastically from the late 1970s as the domestic market expanded, and eventually peaked at 31,000 metric tons (MT) in 1997 (NEFSC, 2010). Catch remained above 20,000 MT until 2006 when management regulations induced reductions, and consequently declined landings to 9,900 MT in 2009 (NEFSC, 2010). While catch reporting and management have expanded greatly over the past half-century, the sustained market demand for monkfish throughout the past two decades suggests the need for continued stock assessments and precautionary fishery regulation.

Information on fish reproductive biology can be useful for characterizing stock-recruitment (SR) relationships and therefore can be valuable for fisheries management. A spawning stock biomass (SSB) index is commonly used to fit SR models; however, total egg production (TEP) is an alternative index that is arguably more relevant to actual stock reproductive potential (Mehault *et al.*, 2010). TEP considers size and age-dependent variability in reproductive potential in addition to stock recruitment, where SSB does not (Witthames and Marshall, 2008; Kurita and Kjesbu, 2009; Mehault *et al.*, 2010). Describing reproductive biology in regard to spawning strategy and spawning stock distributions would be beneficial for an accurate assessment of reproductive potential (fecundity), and thus stock projections.

Therefore, the proposed study investigated the fecundity and spawning variability of *Lophius americanus* in relation to fish size and environmental variables (e.g., temperature, lunar phase), both spatially throughout coastal waters of the Northeastern United States and temporally

throughout the spawning season. Information on monkfish spawning distribution and environmental variables was collected by commercial gillnet vessels participating in the Monkfish Research Set-Aside (RSA) program. Potential batch fecundity in goosefish was assessed using an automated gravimetric enumeration technique in regard to a batch fecundity. Batch fecundity was defined in accordance with histological observation and oocyte size frequency distributions. The objectives of this study will permit examination of goosefish spawning strategy and the potential effect of abiotic factors on reproductive output. Such consideration may provide a more in-depth understanding of the reproductive biology of monkfish. The comprehensive data acquired in this study will help improve estimates of monkfish stock resiliency and, therefore, improve fishery management.

Project Objectives

Objective 1: ***Determine how batch fecundity relates to somatic condition***
The relationships between fecundity and maternal size and body condition (Fulton's K, hepatosomatic indices) were assessed.

Objective 2: ***Investigate whether fecundity varies spatially and temporally***
Relative fecundity estimates were compared between sampling locations and times to determine whether variation is evident through the seasonal progression of spawning.

Objective 3: ***Investigate the influence of environmental variables on spawning condition and catch rates***
The relationships between environmental factors *(temperature and lunar phase)* and spawning condition (fecundity, GSI, MAOS) were investigated to quantify potential sources of temporal variation.

3. Methods

Sampling Sites

Monkfish were collected by gill-nets from our industry collaborators participating in the 2011 Monkfish Research Set-Aside (RSA; Table 1; Fig. 1) program and by trawl-net during the Northeast Fisheries Science Center's (NEFSC) 2009 Cooperative Monkfish Survey. In addition, a few monkfish (< 10%) were collected by the Northeast Fisheries Science Center 2012 spring bottom trawl survey. Samples were collected from the northern and southern management areas (NMA and SMA; Fig. 2) in depths ranging from 22 to 430 m.

Fish Collection and Processing

Fish collected during the NEFSC monkfish surveys were processed directly onboard while fish collected from monkfish gillnetters were either picked up or shipped to the University of Maryland Eastern Shore where they were processed within 1-2 days. Total length (TL, cm), body weight (W_B, kg), ovary weight (W_G, g), and liver weight (W_H, g) were measured directly. An organ-free body weight (Carcass Weight, W_C, kg) was measured directly in 2012 and a regression was used to estimate the W_C in other years. Vertebrae were removed, frozen, and aged following the methods of Armstrong et al. (1992). Body condition was calculated as $W_C/\mathrm{TL}^3\times10^5$. Organosomatic indices (gonadosomatic index (GSI) and hepatosomatic index (HSI)) were calculated as follows:

$$\mathrm{GSI}=100W_G\,(W_C)^{-1}$$

$$\mathrm{HSI} = 100 W_H (W_C)^{-1}$$

Reproduction

Gonad samples were collected from locations within the three geographic regions: NMA, N MAB and S MAB for histological examination (Fig. 2). Macroscopic stages were assigned as follows: immature, developing, resting or spent. For histological analyses, mid-sections from one lobe were collected from mature fish and whole gonads and mid-sections from immature fish. Initially, subsamples were excised from the right and left anterior of the gonad, as well as the posterior end, of 10 ovaries to determine whether there were differences in maturity stages of oocytes within the ovary (Fig. 3). The oocyte density and the diameters of the advancing oocyte cohort were compared between these three sections for four ovaries (Fig. 4). As reported elsewhere (Colmenero et al. 2013) there was no difference in density between sections, and we did not note any differences in oocyte diameters either. Therefore, additional subsamples were taken without regard to position within the ovary.

All gonad samples were fixed in 10% formalin in 0.1M phosphate buffer (pH 7.4) and stored for at least one month before further processing. All histology samples were either processed at the Fish and Wildlife Research Institute histology lab in St. Petersburg, Florida or at the University of Maryland Eastern Shore. The specimens were dehydrated and embedded in either paraffin or glycol methacrylate (JB-4; Polysciences) and sectioned at 4-6 µm. Sections were stained with either haematoxylin and eosin (H & E), haematoxylin and napthol yellow or periodic acid Schiff-metanil yellow (PAS/MY) and haematoxylin (Quintero-Hunter *et al.*, 1991). Histological sections were examined by light microscopy, photographed with an Olympus DP71 digital microscope camera and assigned maturity stages following the adaptable staging schema of Grier et al., (2009) with slight modifications for monkfish (Table 2). Ovarian stages [primary growth, secondary growth and oocyte maturation (OM)] were classified based on the maturity of the most advanced-stage oocytes stages (MAOS; Table 2).

Fecundity

Female gonads selected for this study were either developing or ripe so the MAOS used for fecundity was either vitellogenic or hydrated. Oocyte diameters were measured from digital images. Because the oocytes were not circular, the final estimated diameter of each cell was an average of the maximum and minimum axis of measurement; measurements were made with ImageJ software using the ObjectJ plug-in (Thorsen and Kjesbu 2001, Press et al., in review). Diameters were initially measured in relation to three oocyte stages (each with their steps), using the staging scheme modified from Grier et al. (2009; Table 2). A series of digital images were made of a complete section of the tissue subsample, and all cells sectioned through the nucleus were measured to produce a sample of oocyte diameters. Plotting these measurements depict only the three stages (PG, SG, and OM; Fig. 5).

Whole oocyte diameters were also measured from a larger number of samples. During the process of estimating batch fecundity, the diameters of at least 200 oocytes were measured using the ImageJ software (see above). The oocytes were manually teased apart and spread out in small reservoirs to capture with a digital image. Examination of these additional plots has 3 purposes: 1) to confirm the hiatus formed between primary oocytes and the advancing cohort of secondary and mature oocytes, 2) provide examples of the asynchronous reproductive development between individual females during a quarter period (February-April), and 3) to document if advancing clutch existed in fish that had spawned already, which was determined based on the presence of post-ovulatory follicles (POFs) in the corresponding gonad histology slide for that individual. The latter purpose, in particular, is a test of whether multiple batches are produced within a single spawning season.

Batch fecundity (BF) was estimated for 55 fish collected from February to July (range of total length: 55.5 – 112 cm; carcass weight: 3.99 – 24.5 kg; age: 6 – 10 years [only 22 females were aged]). A determinate method to estimate batch fecundity was used, where the number of oocytes in the advancing cohort was expanded gravimetrically to the gonad weight (Murua et al. 2003). The leading cohort of oocytes was > 0.5 mm, as measured from fixed tissue. This cohort had typically advanced well into the mature stage, but cohorts still in a late stage of vitellogenesis were also used if the hiatus was well formed, leaving no ambiguity in terms of counting only the advancing cohort. This method has been used with other *Lophius* spp., including *L. americanus* (Armstrong et al. 1992, Yoneda et al. 2001, Colmenera et al. 2013). Batch fecundity estimates were enumerated only for fish without POFs; an unambiguous oocyte size hiatus was not evident in our collections of fish with POFs, so we were not able to estimate the number of oocytes maturing in a second (or later) batch, but we comment on evidence that this second batch did not appear smaller than the first batch.

Descriptive statistics, calculations for linear regression and correlation, and hypothesis testing using Akaike's Information Criterion (AIC), were programmed using R (R Development Core Team 2012; version 2.15.2). Spatial analysis of fecundity split the mid-Atlantic bight sampling region in two, at 39°00'N to test for latitudinal differences in fecundity within this southern management area. Temporal analysis of fecundity compared annual values in the two most complete years of sampling (2009, 2012) to historic values (1982-1985; Armstrong et al. 1992). Initial parameter estimation assumed a normal distribution of fecundity in relation to the predictor variable; uncertainty of these parameters was also characterized by bootstrapping each annual data set 1000 times using the 'boot' function in R to calculate standard error.

4. Results and Conclusions

Oocyte development of monkfish showed group synchrony (Fig. 5) which allowed batch fecundity to be justifiably estimated using a determinate fecundity method. Group synchrony was evident by the advancing cohort of secondary, vitellogenic oocytes that emerged from a mode of primary growth oocytes (Fig. 5). A hiatus formed initially behind cells in an advancing clutch of late vitellogenesis (SGl), at about 0.5 mm in diameter, and was unambiguous once the advancing cohort was mature (OMgvm). The oocytes in this advancing cohort continue to grow in size during oocyte maturation. Migration of the nucleus (OMgvm), nucleus breakdown (OMgvb), and hydration (OMmr) occur in an uninterrupted sequence prior to ovulation (release of egg veil). Fecundity was measured mainly from fish with an advanced mode in germinal vesicle migration (OMgvm, n = 36); fewer fish had an advanced mode in germinal vesicle breakdown (OMgvb, n =10), ripe oocytes (OMmr, n = 8), or late secondary growth (SGl, n = 1).

Batch fecundity of females without post-ovulatory follicles (POFs) ranged from 78,200 to 2,243,300 oocytes. Fecundity increased significantly in relation to fish length, weight, and age, but not Fulton's condition (K) or hepatosomatic index (Fig. 6). There was some evidence that sampling area within the Mid-Atlantic Bight (NMAB, SMAB) affected fecundity (Fig. 7). Fish collected in the NMAB had higher fecundity than those from the SMAB.

Differences in fecundity were observed between samples collected in this study (2009, 2012) and those from the 1980s. There was a rapid increase in fecundity (45,000 per cm of fish length) in fish from the 1980s compared to 2009 or 2012 (21,000-28,000 eggs/cm TL; Figs. 7, 8). Predicted

fecundity ranged from 150,000 to 550,000 oocytes for a 60 cm female, being highest at these smaller sizes in 2009, and from 1.3 to 2.1 million oocytes for a 100 cm female, being highest at these larger sizes in the 1980s (Fig. 7).

Although the advancing cohort of oocytes was synchronized as a group, individual fish were not synchronized with each other. During the peak spawning season (February-April) for the mid-Atlantic bight (February-April), the most advanced oocyte stage ranged from initiation of vitellogenesis (SGe) to hydration of the oocyte (OMmr) (Fig. 9). Females with an advanced mode of mature oocytes were also observed in May and July, defining an active spawning period of at least 6 months for this population.

There was also evidence of a new vitellogenic cohort developing in ovaries of some individuals with POFs (Fig. 10). The most advanced oocyte stage in these females ranged from initiation of vitellogenesis (SGe) to late yolked oocytes (SGl), but oocyte maturation was not observed. POFs are evidence of recent spawning, therefore, unless vitellogenic cohort undergoes complete atresia, which was not observed, these individuals were preparing to spawn for at least a second time in the season.

Benefits and/or contributions to management decision-making: Our results have the potential to improve several aspects of the population assessment for monkfish. This study provided additional information to support our theory that monkfish are batch spawners with spawning occurring over a protracted spawning period and more than once annually in the Southern Management Area. New information on fecundity, spawning frequency and seasonality suggests stock productivity and resiliency may be higher than previously assumed but the largest fish, those with the highest batch fecundity estimates, now appear to have lower fecundity compared to the 1980s. In addition to evidence that some females appear likely to spawn more than once per season, there is evidence of remarkable asynchrony of reproductive condition among mature females in the southern management area. Addressing these issues of fecundity, spawning frequency and seasonality – all measures of stock productivity and resiliency – should help improve data quantity or quality of this species' biology and reduce uncertainty in the assessment and management of this fishery.

5. Project Management: list individuals and/or organizations actually performing the work and how it was done.

The major collaborators on this project were from UMES, NEFSC, and the fishing industry.

1. **University of Maryland Eastern Shore**
   Monkfish gonad samples were processed by Dr. Johnson and Mr. Evan Lindsay in collaboration with Drs. Richard McBride and Anne Richards from the NEFSC and Dr. Harry Grier (Florida Fish and Wildlife Research Institute).
2. **Northeast Fisheries Science Center**
   Fishery independent research vessel bottom trawl survey data were collected and provided by NEFSC (Dr. Anne Richards). All data were analyzed by Dr. Johnson (UMES), Mr. Evan Lindsay (UMES) and Dr. Richard McBride (NEFSC). Maps of sampling areas were provided by Betty Holmes (NEFSC).
3. **Monkfish gillnetters**
   Data and sample collection by gillnetters occurred at several sites along the coast of New England and the Mid-Atlantic region (Table 1; Fig. 1).

between reproductive state (now revised during this study for monkfish) and ocean temperature and whether this can be linked to seasonal movements.

B. If significant problems developed which resulted in less than satisfactory or negative results, they should be discussed.

Significant problems did not develop despite the inability to fully attain all the objectives of the study. One problem that did arise for the gillnet fishermen involved conflicts with other fishing gear where gillnets with attached data probes were dragged away by trawlers. In these instances, the data probes were not recovered and the data were lost. A second problem encountered was the expiration of batteries during the deployment of some data loggers. The new VEMCO probes no longer provide depth information and the old probes have been discontinued so we have to rely on our industry collaborators to provide depth data.

Dissemination of project results:
Explain, in detail, how the project's results have been, and will be disseminated.

This research provided partial fulfillment of the requirements for the Professional Science Master's Program for Mr. Evan Lindsay (graduated-Fall 2013). A manuscript of the results of this study is being prepared and will be submitted for publication to the ICES Journal of Marine Science.

The results have been presented at the following scientific conferences below:

1. "Fecundity estimation of American goosefish (*Lophius americanus*) in the western North Atlantic Ocean" American Fisheries Society 141st Annual Meeting, Seattle, Washington (Sept. 4-8, 2011). Poster presentation by Evan Lindsay (UMES M.S. student) and Courtnee DePass (UMES B.S. student)

2. "Influence of Environmental Variables on the Distribution and Catch Rates of Monkfish in the Northeastern United States" Monkfish Research Set-Aside Program Meeting, New Bedford, MA, June 25, 2012. Oral Presentation by Evan Lindsay (UMES M.S. student)**.**

3. Evan K. Lindsay, Richard S. McBride and Andrea K. Johnson. Exploring fecundity-somatic relationships in the American goosefish, *Lophius americanus.* UMES School of Graduate Studies 4th Annual Regional Research Symposium, April 16, 2013 – Poster Presentation

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Table 1. The industry collaborators for the 2011 Monkfish RSA Project, with allocated DAS (*n*=96) and anticipated fishing schedules. (* indicates a primary vessel)

Owner/Vessel	Location	DAS	Schedule
John Stolgitis *FV Martha Porter**	Pt. Judith, RI Montauk, NY	35	October – June
Scott Eshenfelder *FV Sharon E*	Montauk, NY	8	November – December; April
Peter Krasowski *FV Critical**	Pt. Pleasant, NJ	8	November – January; April – June
Roger Wooleyhan *FV Wooley Bully***	Ocean City, MD Cape May, NJ	25	November – May
Chris Hickman *FV Bout Time**	Pt. Pleasant, NJ Chincoteague, VA	20	November – January; April – May

Table 2. Oogenesis staging criteria developed by Grier *et al*. (2008) and adapted for application to *L. americanus*. *OMvy: new step designation specific to monkfish.

Stages	Steps		Description
Primary Growth (PG)	**PGpn**	***Perinucleolar***	• multiple nucleoli located around periphery of GV • GV centrally located in ooplasm
	PGca	***Cortical Alveolar***	• OD accumulating throughout ooplasm, may be circum-peripheral • CA forming throughout ooplasm • Oocyte diameter increasing in size • ZP visible
Secondary Growth (SG)	**SGe**	***Early Yolked Oocytes***	• LPYG forming in ooplasm, from periphery inward • LPYG relatively homogenous in size • OD occupied ooplasmic space ≥ LPYG occupied ooplasmic space • Oocyte diameter increasing in size • ZP thickening
	SGl	***Late Yolked Oocytes***	• LPY densely packed throughout ooplasm • LPYG occupied space ≥ OD occupied ooplasmic space • OD dispersed throughout LPY • CA located at periphery of ooplasm • ZP well-defined
Oocyte Maturation (OM)	***OMvy**	***Vesicular yolk***	• OD increasing in size, begin to coalesce • LPYG increasing in size • Formation of vesicles within yolk • Formation of MGM
	OMgvm	***Germinal Vesicle Migration***	• OD coalescing • LPYG coalescing • Vesicles within yolk • MGM present • GV off-center, migrating towards periphery of ooplasm (animal pole) • hydration becoming extensive in ooplasm at vegetal pole
	OMgvb	***Germinal Vesicle Breakdown***	• GV located at periphery , leading portion dissolved • majority of ooplasm hydrated • Vesicles within yolk • MGM present
	OMmr	***Oocyte Hydration Complete (Ripe)***	• GV fully dissolved • Yolk hydration is complete • Oil has coalesced into one or a few large droplets • MGM present
Ovulation	**OV**	***Oocyte Expelled***	• only follicle (POF) remains

CA = cortical alveoli; GV = germinal vesicle; LPYG = lipoprotein yolk globules; OD = oil droplets; MGM= mucogelatinous matrix; ZP = zona Pellucida

Table 3. Monkfish landings information collected from May 2011 to April 2013.

DAS	VTR	Vessel Name	Port Landed	Landing Date	Total Weight	Amt Sold ($)	Research Funds ($)
0.75	11895292	Bout Time	Pt. Pleasant, NJ	12/18/2011	1625.7	3089.65	463.44
0.63	11895295	Bout Time	Pt. Pleasant, NJ	12/29/2011	0	0	0
0.68	11895296	Bout Time	Pt. Pleasant, NJ	12/30/2011	757.8	1548.56	232.28
0.67	11895299	Bout Time	Pt. Pleasant, NJ	1/5/2012	2398.3	4961.3	744.2
0.55	11948051	Bout Time	Pt. Pleasant, NJ	1/9/2012	830	1756.34	263.44
0.23	11948052	Bout Time	Pt. Pleasant, NJ	1/15/2012	300	647.4	97.11
0.55	11948053	Bout Time	Pt. Pleasant, NJ	1/16/2012	966	2335.22	350.28
0.84	11948078	Bout Time	Chincoteague, VA	4/6/2012	1420.2	2578.6	386.79
0.85	11948079	Bout Time	Chincoteague, VA	4/11/2012	3027	5777.2	866.58
0.78	11948080	Bout Time	Chincoteague, VA	4/14/2012	934	1678	251.7
0.59	11948081	Bout Time	Chincoteague, VA	4/17/2012	876	1598.2	239.73
0.64	11505489	Bout Time	Chincoteague, VA	4/29/2012	1675	2970.4	445.56
0.54	12074951	Bout Time	Chincoteague, VA	4/30/2012	2432	3993.5	599.02
8.3					17242	32934.37	4940.13
0.672	11761405	Martha Porter	Point Judith, RI	5/20/2011	2145	4802.8	720
0.621	11761406	Martha Porter	Point Judith, RI	5/21/2011	1531.6	3549.35	532
0.664	11761407	Martha Porter	Point Judith, RI	5/22/2011	2381.44	5119	768
0.671	11761408	Martha Porter	Point Judith, RI	5/25/2011	2052.9	4738.7	718
0.625	11761409	Martha Porter	Point Judith, RI	5/26/2011	1938.8	4498.6	680
0.625	11761410	Martha Porter	Point Judith, RI	5/27/2011	1023.7	2681	402
0.647	11761414	Martha Porter	Point Judith, RI	6/4/2011	3321	6324.5	945
0.625	11761415	Martha Porter	Point Judith, RI	6/5/2011	2241.9	4702.7	705
0.625	11761420	Martha Porter	Point Judith, RI	6/12/2011	2405.55	5048.2	810
0.625	11761423	Martha Porter	Point Judith, RI	6/17/2011	2571	5410.2	811
0.69		Martha Porter	Point Judith, RI	7/1/2011	3023.7	5960	900
0.625	11761438	Martha Porter	Point Judith, RI	7/23/2011	764.47	1406.45	210
0.625	11761443	Martha Porter	Point Judith, RI	10/7/2011	1458.2	4018.6	603
0.625	11761444	Martha Porter	Point Judith, RI	10/9/2011	1264.92	3547.06	532
0.653	11761445	Martha Porter	Point Judith, RI	10/10/2011	799.1	2275.3	340
0.538	11761446	Martha Porter	Point Judith, RI	10/12/2011	1486.56	2967.48	445
0.667	11761447	Martha Porter	Point Judith, RI	10/18/2011	1388.2	3784.3	565
1.171	11761448	Martha Porter	Point Judith, RI	10/22/2011	1200	2939.22	444
1.108	11761451	Martha Porter	Point Judith, RI	10/28/2011	1220	2706.98	406
1.15	11968357	Martha Porter	Point Judith, RI	11/11/2011	1418.2	3058	458.7
1.16	11968363	Martha Porter	Point Judith, RI	12/6/2011	613.2	1696.8	225
1.3	11968366	Martha Porter	Point Judith, RI	12/18/2011	497.8	1175.8	170
1.46	11968367	Martha Porter	Point Judith, RI	12/25/2011	165	500.1	75
0.63	11968368	Martha Porter	Point Judith, RI	12/30/2011	146.6	587.29	90
0.85	11968369	Martha Porter	Point Judith, RI	1/9/2012	426.2	1000	150

0.63	11968372	Martha Porter	Point Judith, RI	4/21/2012	1918.3	3954.3	640
0.67	1196876	Martha Porter	Pt. Judith, RI	5/6/2012	3,007.30	6619.84	992.98
1.06	11968378	Martha Porter	Pt. Judith, RI	5/11/2012	3190.1	5063.15	759.47
1.007	11968380	Martha Porter	Pt. Judith, RI	5/13/2012	1,610.00	4521.6	678.24
0.53	11968384	Martha Porter	Pt. Judith, RI	5/19/2012	1,610.00	3715.52	557.33
0.46	11968385	Martha Porter	Pt. Judith, RI	5/21/2012	1,610.00	3536.5	530.48
0.625	11968389	Martha Porter	Pt. Judith, RI	5/28/2012	1,610.00	3551.52	532.73
0.625	11968392	Martha Porter	Pt. Judith, RI	6/6/2012	1,610.00	3906.52	585.98
0.625	11968393	Martha Porter	Pt. Judith, RI	6/7/2012	1,610.00	3956.5	593.48
0.625	11968396	Martha Porter	Pt. Judith, RI	6/12/2012	1,603.20	3609.6	541.44
0.625	11968398	Martha Porter	Pt. Judith, RI	6/16/2012	1,618.70	3784.7	567.71
0.625	11968401	Martha Porter	Pt. Judith, RI	6/24/2012	1,215.10	2481.76	372.26
0.625	11752802	Martha Porter	Pt. Judith, RI	6/28/2012	1,616.40	3114.15	467.12
0.625	11752803	Martha Porter	Pt. Judith, RI	7/2/2012	1,227.80	2332.88	349.93
0.625	11752805	Martha Porter	Pt. Judith, RI	7/6/2012	208.7	461	69.15
0.625	11752804	Martha Porter	Pt. Judith, RI	7/7/2012	872.8	1832	274.8
0.625	11752807	Martha Porter	Pt. Judith, RI	7/12/2012	472.4	1406.66	211
0.63	11752834	Martha Porter	Pt. Judith, RI	4/15/2013	46	211.4	31.78
1.04	11752835	Martha Porter	Pt. Judith, RI	4/22/2013	390	833	124.95
31.261					60855.24	135038.88	20333.53
2	11641838	Sharon E	New London, CT	12/7/2011	4380	8831.75	1324
1.02	11641841	Sharon E	New London, CT	12/11/2011	2895.2	5631.4	844
1.09	11641840	Sharon E	New London, CT	12/19/2011	3100	5794.25	869
0.63	11641842	Sharon E	New London, CT	12/23/2011	400	913.25	137
0.63	11641844	Sharon E	New London, CT	12/27/2011	0	4631	694
5.35					10775.2	25801.65	3868
0.934	11888669	Wooley Bully	Ocean City, MD	5/15/2011	2702.24	2686.4	402.96
0.66	11888670	Wooley Bully	Ocean City, MD	5/20/2011	1350	2585.1	387.65
1.013	11888673	Wooley Bully	Ocean City, MD	5/25/2011	2900	5153.15	772.97
1.01	11888676	Wooley Bully	Ocean City, MD	5/31/2011	3636.5	6104.85	915.72
1.11	11870089	Wooley Bully	Ocean City, MD	12/2/2011	3067	6718.85	1007.83
0.99	11870094	Wooley Bully	Ocean City, MD	12/9/2011	1034.7	2207.75	331.16
1.09	11870099	Wooley Bully	Ocean City, MD	12/18/2011	1477.5	2955.1	443.27
1.05	11514851	Wooley Bully	Ocean City, MD	12/30/2011	1088.4	2163.15	324.47
1.13	11514858	Wooley Bully	Ocean City, MD	1/8/2012	3619.4	8035.2	1205.28
1	11967158	Wooley Bully	Ocean City, MD	2/2/2012	2886	6190.4	928.56
1.01	11967162	Wooley Bully	Ocean City, MD	2/8/2012	2122.2	4280.4	642.06
1.1	11967162	Wooley Bully	Ocean City, MD	2/15/2012	3049	6132.8	919.24
0.86	11967164	Wooley Bully	Ocean City, MD	2/18/2012	1295	911.5	250
1.27	11967168	Wooley Bully	Ocean City, MD	3/19/2012	2725	5753.25	862.99
1.43	11967170	Wooley Bully	Ocean City, MD	3/23/2012	4646.6	8614.2	1292.13

0.88	11967172	Wooley Bully	Ocean City, MD	3/28/2012	659.9	1282.6	192.39
1.3	11967173	Wooley Bully	Ocean City, MD	3/31/2012	4150.8	7755.05	1163.26
1.18	11967174	Wooley Bully	Ocean City, MD	4/4/2012	2777.6	5032.35	154.85
0.92	12050202	Wooley Bully	Ocean City, MD	4/15/2013	1116.4	1534.35	230.15
0.94	12050203	Wooley Bully	Ocean City, MD	4/18/2013	2500	2284.64	342.7
0.64	12050205	Wooley Bully	Ocean City, MD	4/20/2013	803.6	913.5	137.03
0.97	12050208	Wooley Bully	Ocean City, MD	4/30/2013	1270.4	1700.85	255.13
22.487					50878.24	90995.44	13161.8
67.398				Grand Total	139750.68	284770.34	42303.46

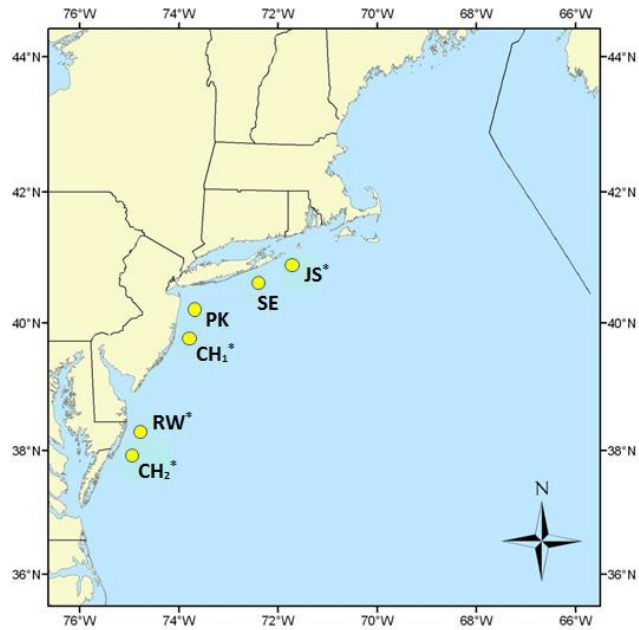

Fig. 1. Sampling locations for monkfish gillnetters during the 2011 RSA Project; CH_1, CH_2 = Chris Hickman; JS=John Stolgitis; PK=Peter Krasowski; RW=Roger Wooleyhan; SE = Scott Eshenfelder; Asterisk denotes a primary industry collaborator.

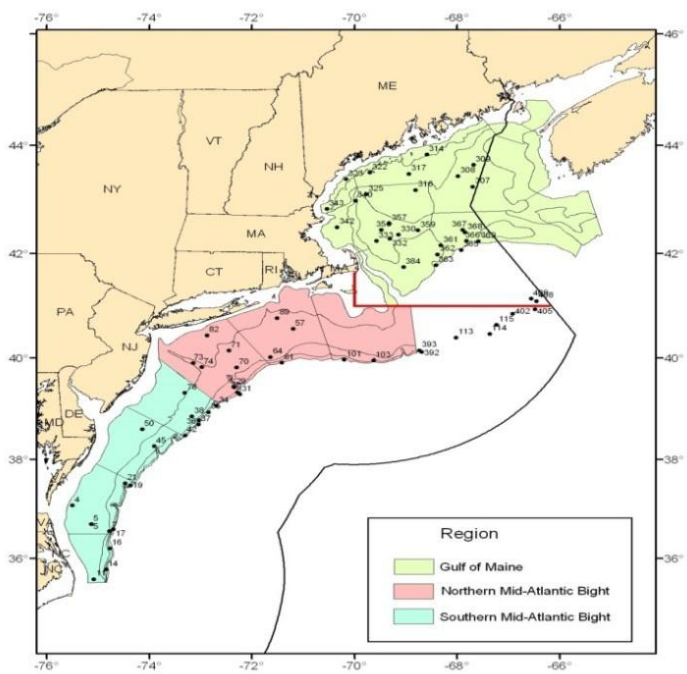

Fig. 2. Map of sampling regions and strata along the U.S. continental slope. Defined and used by NOAA Fisheries Service for fishery population surveys in the western North Atlantic Ocean. Dots indicate sampling stations of the 2009 Cooperative Monkfish Survey. (Image credit: NOAA NEFSC)

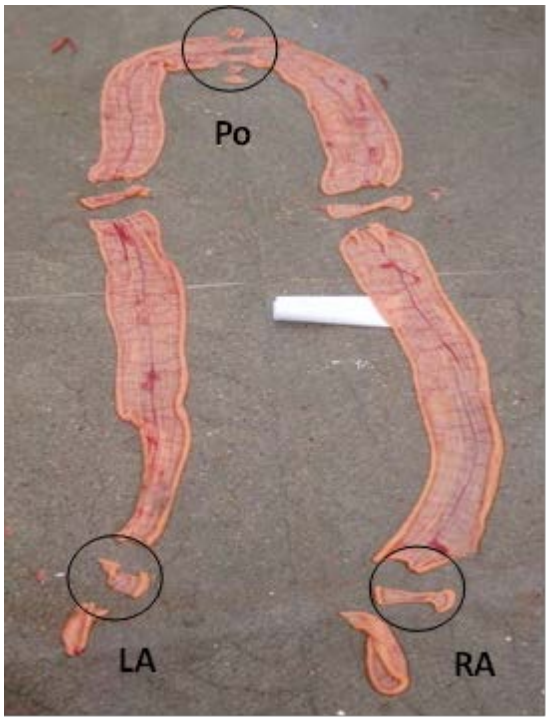

Fig. 3. Maturing monkfish ovary with subsamped locations (encircled) used to test spatial variation of oocyte maturation rate; (LA) left anterior, (Po) posterior,(RA) right anterior.

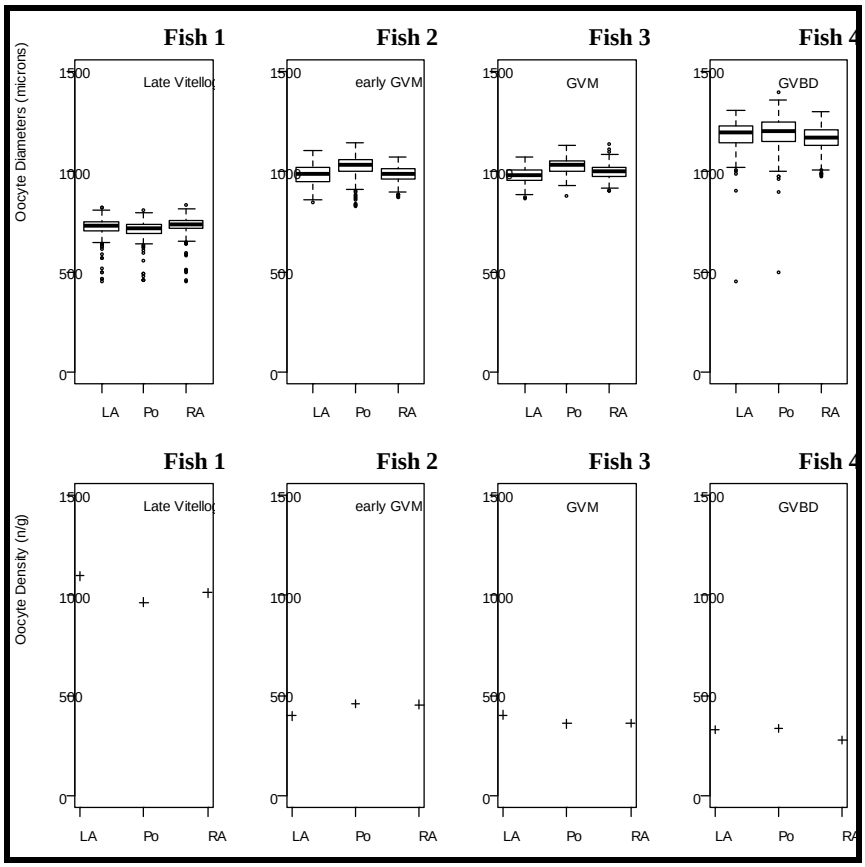

Fig. 4. Box plots (top) show nonsignificant differences in oocyte size (mean diameter, µm) for subsampled ovary regions, for fish at each developmental stage; Scatter plots (bottom) reveal nonsignificant differences in oocyte density for subsampled regions; Fish 1=SGl; Fish 2=early OMgvm; Fish 3=late OMgvm; Fish 4=OMgvbd; oocyte development progresses left to right, Fish 1-4.

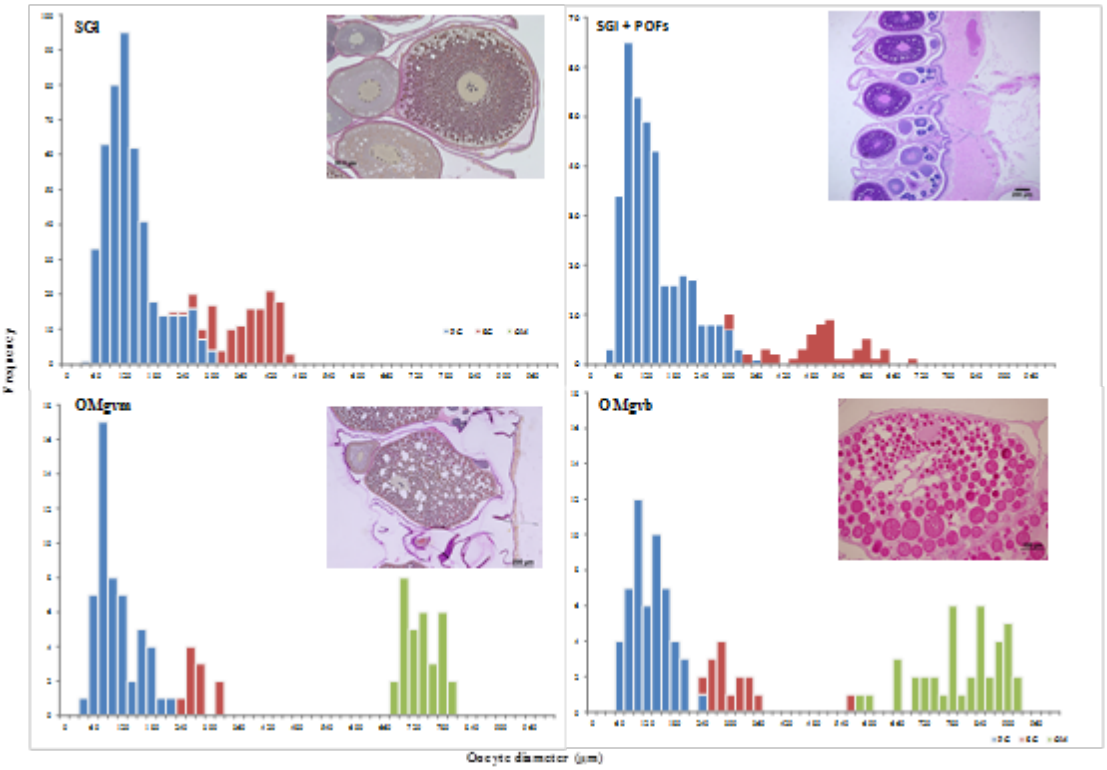

Fig. 5.Oocyte diameter distributions with corresponding images of the most advanced stage oocytes (MAOS). Diameters were measured from histology slides (see text) and are binned in 20 µm intervals, depicting primary growth (blue), secondary growth (red), or mature (green) stages. The MAOS is identified by stages: SG= secondary growth; OM= oocyte maturation; and steps: l=late; gvm=germinal vesicle migration; gvb=germinal vesicle breakdown (see Table 2).

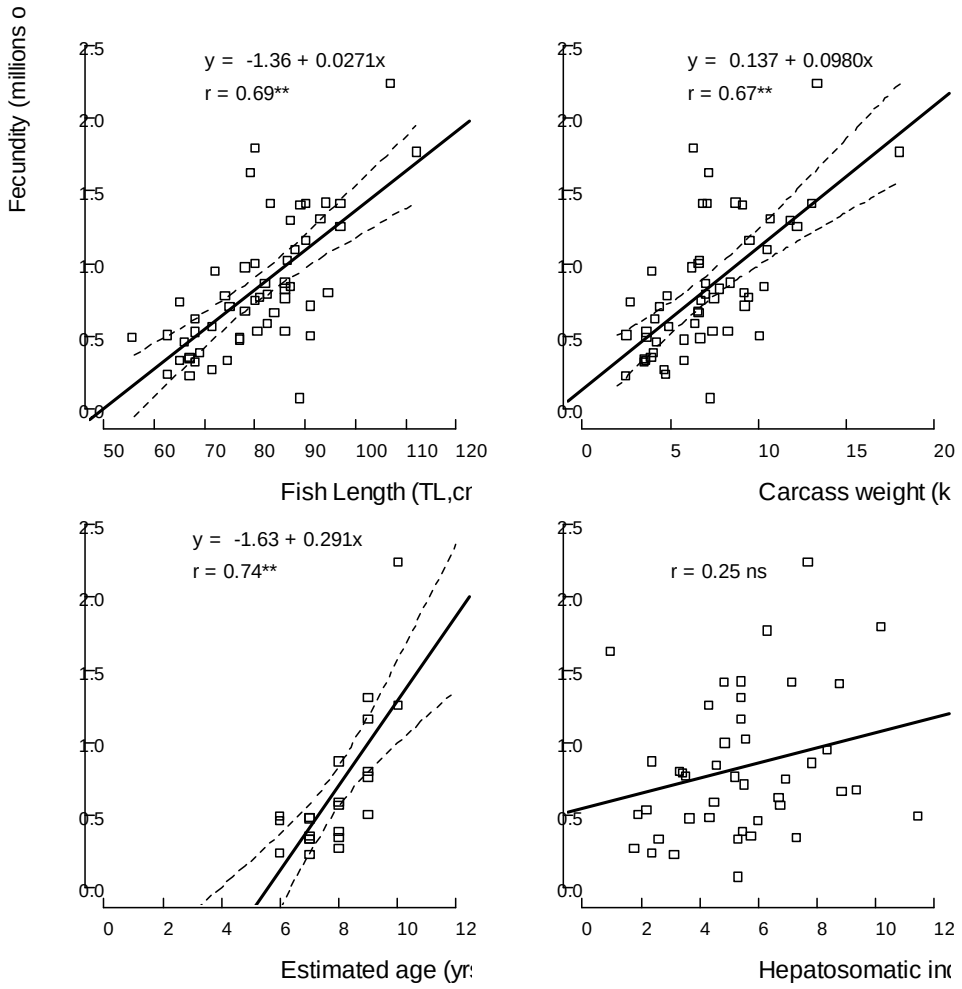

Fig. 6. Relationships between monkfish batch fecundity to female length, weight, age, or hepatosomatic index. The slopes of the first three relationships are significantly different than zero (**P < 0.01), so a linear regression was estimated (solid line) together with 95% confidence limits of the mean (dashed line). The slope of the last relationship was not significant (ns), so no regression statistics are presented. There was also no significant relationship between fecundity and condition (Fulton's K, r = -0.45; not plotted). Monkfish plotted did not have post-ovulatory follicles, so these estimates are postulated as the first seasonal batch.

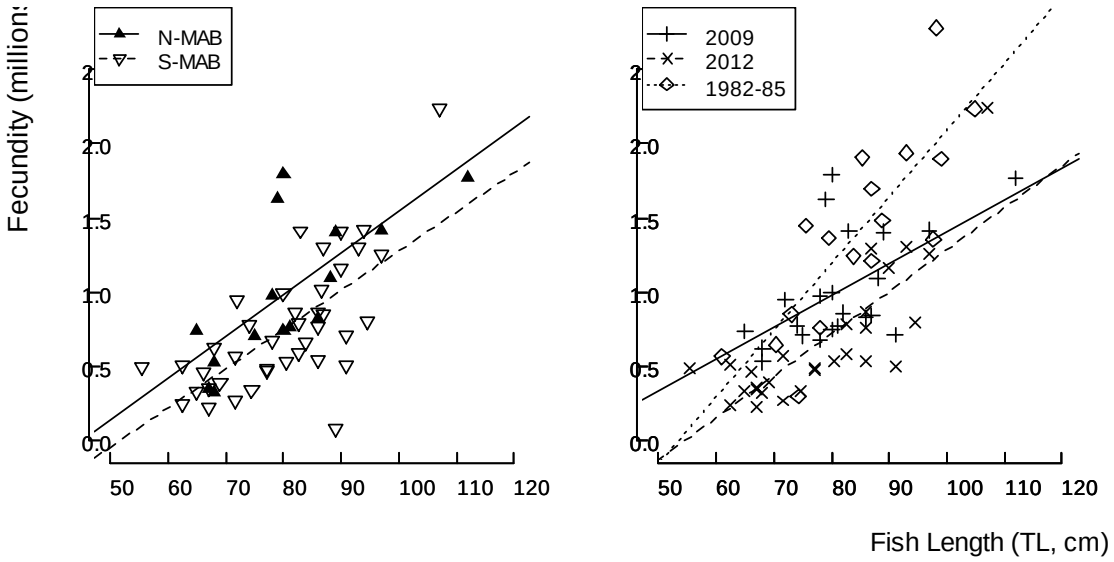

Fig. 7. Fecundity at size comparing female monkfish collected in (left) different areas of the mid-Atlantic bight (north or south of 39°N) and (right) different years of collection (1982-1985 data from Armstrong et al. 1992). Linear regression slopes are plotted for each area or year.

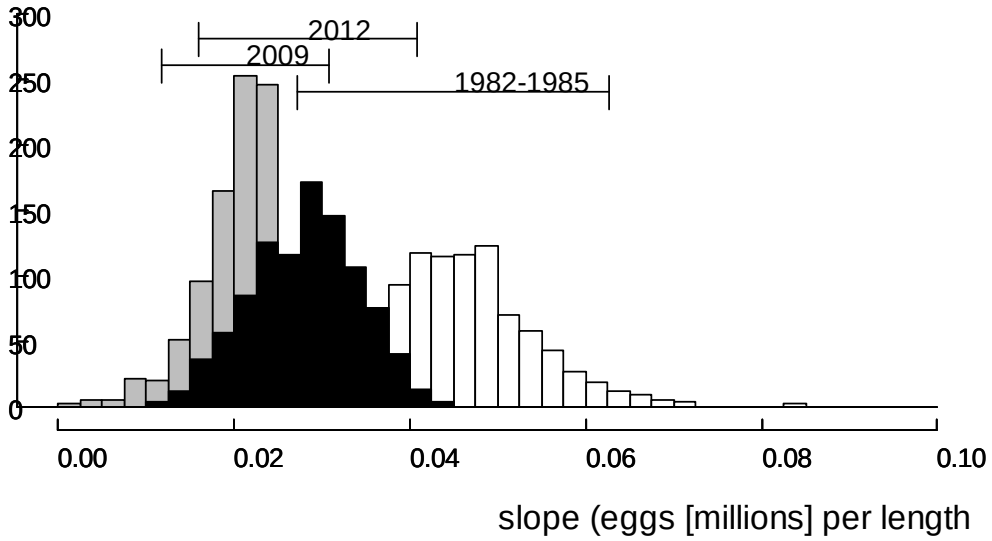

Fig. 8. One thousand boot strapped estimates of the slope for the equation: Fecundity (millions of eggs) = a + b × total length (cm), estimated for 1982-1985 (open bars), 2009 (gray bars), and 2012 (black bars). The black bars overlaps (in front of) the complete distributions of the gray and white bars. The hortizontal intervals are the mean ± 2 SE.

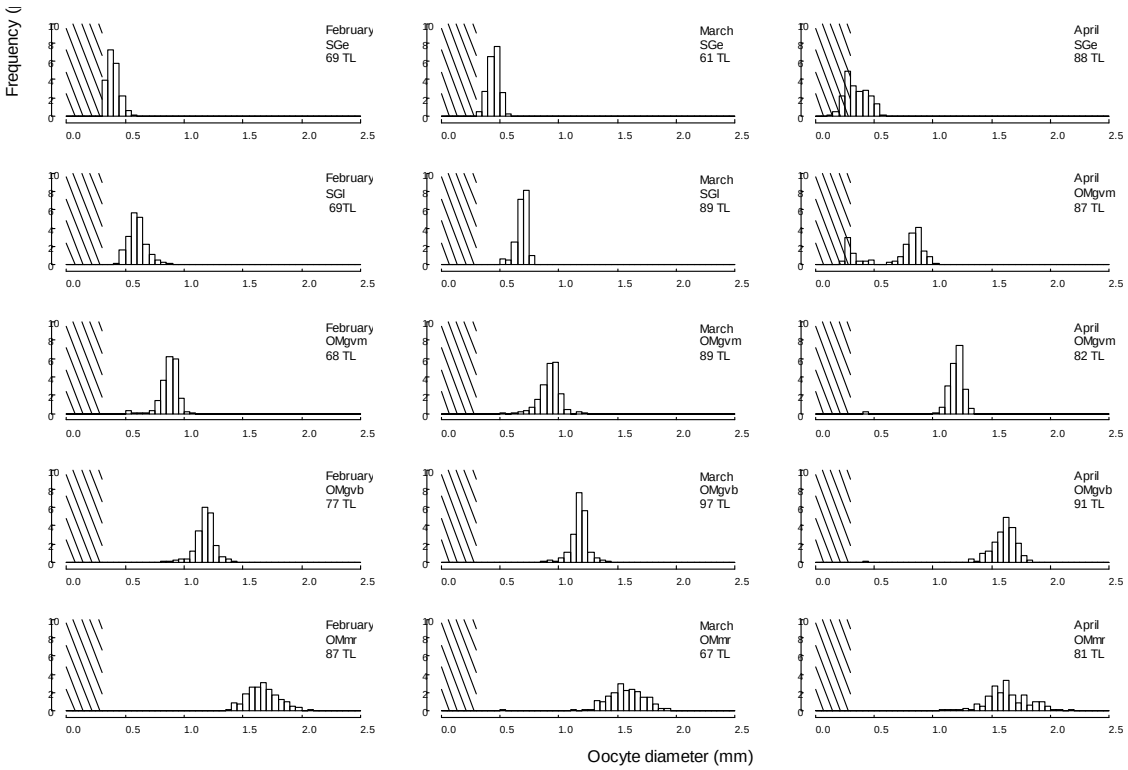

Fig.9. Whole oocyte diameter frequencies for 15 females with no post-ovulatory follicles. The focus of measurements was on the advancing cohort, with no specific attempt to measure oocytes smaller than about 0.3 mm (hatched area). Each panel represents oocytes from an individual fish, identifying the month of collection, the most advanced oocyte stage (observed with corresponding gonad histology), and the total length (TL, cm) of the female.

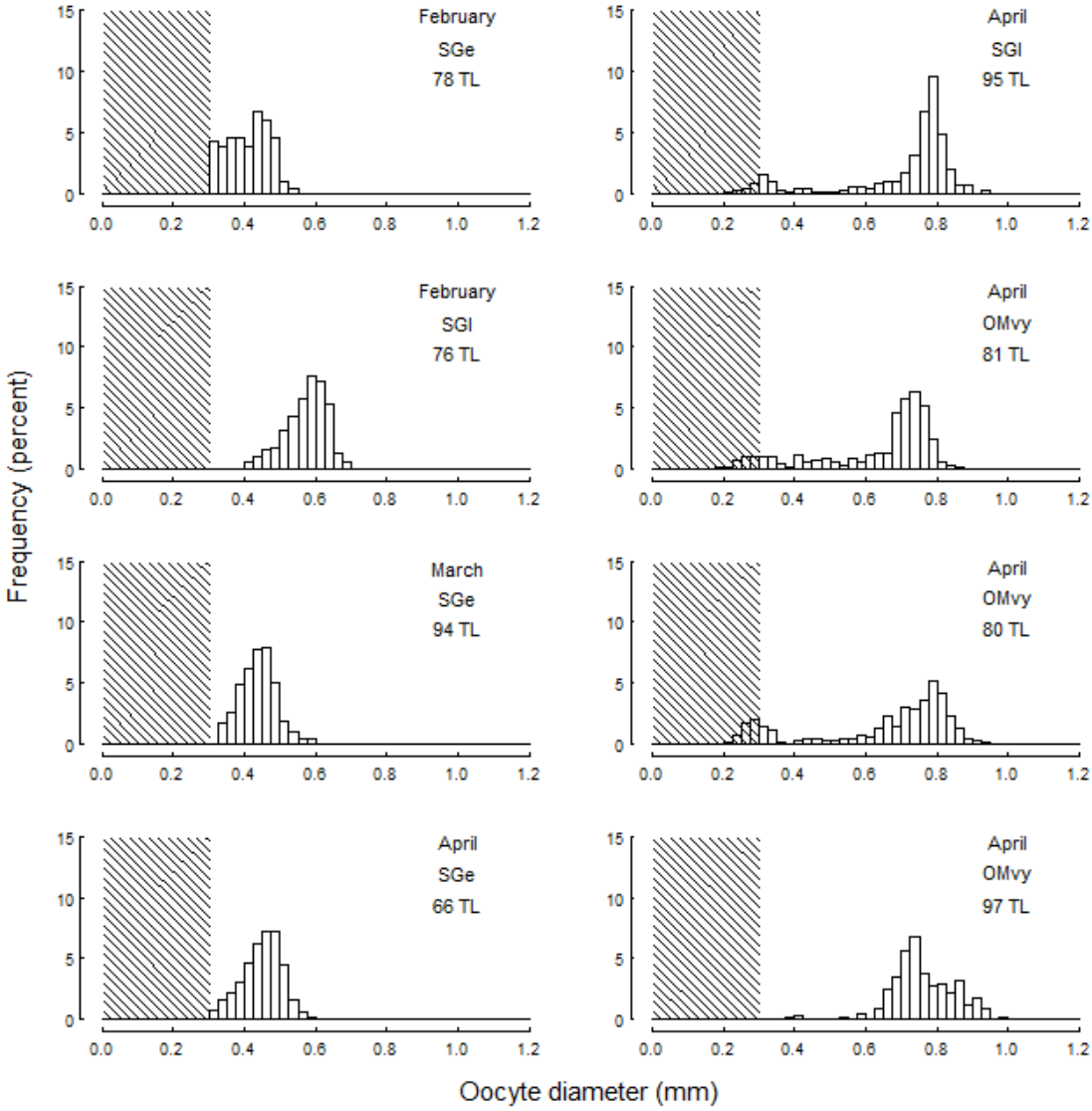

Fig. 10. Whole oocyte diameter frequencies for eight females with post-ovulatory follicles, suggesting these individuals had spawned already and were preparing to spawn again in the same season. Measurements and labels are as in Fig. 9.