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The reproductive biology of the exploited razor clam, *Ensis siliqua*, in the Irish Sea, and potential effects of climate variability.

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Abstract

Knowledge of the reproductive cycle of a species is a prerequisite for long-term management of a fishery. The infaunal marine bivalve, *Ensis siliqua*, is a commercially important species in Europe, and is exploited in many countries, including Ireland, where it is sold by wet weight. Seasonal variations in the reproductive cycle of subtidal razor clams from the Skerries region of the Irish Sea, an important fisheries area, were examined between June 2010 and September 2011. It was noted that wet weight dropped significantly in the summer months of both years, immediately after the spawning period which may impact on the practicality of fishing for this species during this period. Histological examination revealed a female to male ratio of 1:1.12 and no hermaphrodites were observed in the samples collected. In the summer months of 2010 all female clams were either spent or in early development, with just a small percentage of males still spawning. The gonads of both sexes developed over the autumn and winter months of 2010, with the first spawning individuals recorded in January 2011. Spawning peaked in March 2011, but unlike in 2010, spawning continued through June and July with all animals spent in August 2011. The earlier and longer spawning period found in this species in 2011 compared to 2010 may have been due to the colder than normal temperature observed during the winter of 2010 plus the relatively warmer temperatures of Spring 2011, which could have affected the gametogenic development of *Ensis siliqua* in the Irish Sea. Timing of development and spawning is compared with other sites in the Irish Sea and elsewhere in Europe, including the Iberian Peninsula.

Key words: *Ensis siliqua*, bivalve, Ireland, gametogenesis, spawning.

1. Introduction

Ensis siliqua is a native species in Europe, and is distributed along the European Atlantic coast from the Norwegian Sea and the Baltic, south to the Mediterranean and along the Atlantic coast of Morocco (Costa et al., 2010; Darriba et al., 2005; Fernández-Tajes and Méndez, 2007; Gaspar and Monteiro, 1998; Varela et al., 2007). It is abundant in the British Isles, and widely distributed along the east coast of Ireland (Fahy, 1999). Commonly known as the razor clam or pod razor, *E. siliqua* inhabits fine sand, silt or muddy sediments along the coast of Europe, and can be found at depths ranging from 0 to 58m, though they are thought to be most abundant at 3-7m depth (Costa et al., 2010; Encyclopaedia of Life, 2010; Fahy, 1999; Gaspar and Monteiro, 1998). The valves of *E. siliqua* shells usually reach a maximum of 21 cm in length (Conchological, 2008; Encyclopaedia of Life, 2010; Holme, 1951), though larger individuals of up to 24cm have been recorded in Northern Europe (Muir and Moore, 2003). This clam species has a very large and powerful foot and is capable of rapid vertical burrowing in the fine sediments that it favours (Encyclopaedia of Life, 2010; Fahy and Carroll, 2007; Fernández-Tajes et al., 2007). Razor clams are usually found to have a sex ratio of 1:1, with a very low incidence of hermaphroditism (Gaspar and Monteiro, 1998; South Wales Sea Fisheries Committee, 1999).

Ensis siliqua is currently harvested by commercial fisheries in Spain, Portugal, and Ireland (Costa et al., 2010) and is regarded as an increasingly valuable fishery resource with potential for commercial aquaculture in many European countries (Arias-Pérez et al., 2011; Fernández-Tajes et al., 2007; Varela et al., 2007; Wootton et al., 2003). By 2004, the importation rates of razor clams were quite significant in Europe, representing a total value of €550 million, with Spain, Italy, France, Portugal and the Netherlands being the most significant importers (Fernández-Tajes and Méndez, 2007; Fernández-Tajes et al., 2007).

In 1997, a razor clam fishery began in the Republic of Ireland when a large bed of *Ensis* spp. which measured 21km^2, was discovered at Gormanstown, off the Meath coast (Fahy, 1999; Fahy and Carroll, 2007). In 1998, landings of *Ensis* were in the order of c. 500 tonnes and valued at €1,000,000 EU, making Ireland the largest supplier of *Ensis* in Europe in the space of two years (South Wales Sea Fisheries Committee, 1999). This continued until 2000, as the Republic of Ireland led the world in wild-caught landings (Hauton et al., 2007). Though official landing details of razor clams is unavailable for subsequent years, it is thought that the Irish fishery experienced problems in *Ensis* landings caused by over-fishing, poor recruitment and winter mortality in some beds (Hauton et al., 2007).

Between 2000 and 2005 the overall value of the Irish seafood market increased by 14%, the home market by 23% and exports by 7%, while seafood exports increased from €331 million to €354 million. Most seafood exports during this time were directed to EU markets such as France (23% of exports with a value of €82.1 million in 2005), Spain, Great Britain, Germany, Italy and Netherlands (BIM, 2006). More recently total shellfish exports from Ireland have increased in value by 18% to €135.5m, from 2009 to 2010. Exports of molluscs increased in volume by 10% from 2009 to 2010, and by another 15% from May 2010 to May 2011 (BIM, 2011). The OECD / FAO 2011-2010 outlook forecasts positive long term growth in the global seafood market, with aquaculture volumes predicted to grow at the rate of 2.8% per annum (BIM 2011). Of the three species of the genus *Ensis* that occur in Ireland – *E. siliqua, E. arcuatus* and *E. ensis* - *E. siliqua* makes up the vast bulk of landings (Fahy and Carroll, 2007). Because of the large global demand for shellfish, including *Ensis siliqua*, natural beds of this species are under pressure (Darriba et al., 2005; Hauton et al., 2007). The future commercial exploitation of these species will need careful management to ensure sustainability and avoid fishery over-depletion. To manage an exploited species, knowledge of the reproductive cycle of the species is essential, as it provides valuable data for recruitment, age and growth studies (Morsan and Kroeck, 2005). In particular, the effect of the gametogenic cycle on the weight of individuals would have an economic impact, as *E. siliqua* is currently sold by wet weight.

Previous work on this species has outlined the reproductive cycle of *E. siliqua* but a maximum of only twelve months were examined in any area. In Southern Portugal 600 individuals were sampled between June 1992 and May 1993, and examined hisologically to determine the phases of gametogenic cycle present seasonally. Results described gametogenesis beginning in December with spawning individuals first observed in May and all individuals spent by July. Overall sex ratio did not differ significantly from 1:1 (Gaspar and Monteiro, 1998). In a shorter study running from February to August 1999 similar gonadal development and spawning times of *E. siliqua* were reported in razor clams sampled in the Gormanstown Bed of the Irish Sea by Fahy in 1999. The work was undertaken to establish factors relevant to a management strategy for the species two years after exploitation commenced in Ireland. Dredge samples, supplied by commercial vessels, provided 25 *E. siliqua* each month from February to August of 1999, and the reproductive cycle of the sampled clams was investigated using histological methods during these months only (Fahy, 1999). However, site specific variation in this cycle appears to exist, as 437 *E. siliqua* individuals from North western Spain were examined hisologically in 2000, to

determine the phase of gametogenic cycle present each month from June to November, supplying evidence of gametogenesis beginning in November and spawning taking place in April in razor clams from this area (Darriba et al., 2005) indicating that spawning might commence earlier at lower latitudes. In all of these studies the gametogenic cycle of this species was found to be annual, with a long sexual rest period during the summer and autumn months. Less detailed reports of *E. siliqua* spawning periods in March and April in Plymouth, United Kingdom (Lebour, 1938), and July and August in North Wales (Henderson and Richardson, 1994), and the Clyde Sea of Scotland (Muir and Moore, 2003) have also been recorded.

The effects of environmental conditions, including temperature, have been shown to influence the gametogenesis and spawning of a range of bivalve species such as *M. arenaria* (Brousseau, 1978; Cross et al., 2012; Gauthier-Clerc et al, 2002), *Crassostrea gigas* (Ruiz et al., 1992a), *Ostrea edulis* (Cano, 1997; Ruiz et al., 1992b), *Pecten maximus* (Pazos et al., 1997), *Pinna rugosa* (Ceballos-Vazquez et al., 2000), *Argopecten ventricosus* (Luna-Gonzalez et al., 2000), and *Ensis arcuatus* (Darriba et al., 2004) by affecting the timing and length of the spawning period, or causing a disparity between the spawning of either sex. In the Celtic/Biscay shelf, sea water temperatures are predicted to increase between 1.5 and 5°C over the next 100 years (Philipart et al., 2011), with global temperature hypothesized to increase 1.8 to 4°C by the end of the 21st century (Matozzo and Marin, 2011). Though lab-based work has been carried out to standardise techniques for hatchery reproduction of *E. siliqua* (Costa et al., 2010), the potential effect of changing waters temperatures, either seasonal or long-term, on the gametogenesis and spawning of the razor clam, *Ensis siliqua*, in Europe has not been previously addressed.

To allow for the on-going management and future exploitation of *E. siliqua* in Irish waters, the main objective of the present study was to determine the current reproductive cycle of this clam in the Irish Sea and examine any relationship between gametogenesis and temperature, on a monthly and seasonal scale.

2. Materials and Methods

2.1. Study Site

The Skerries region of the Irish Sea is located off the coast of Dublin city, in the region of N 52°13’06.9”, W 006°47’38.1”. Thirty live *Ensis siliqua*, which had been fished in the Skerries region were obtained monthly from June 2010 to September 2011, from a

commercial shellfish wholesaler on the east coast of Ireland. The clams were identified as *E. siliqua* using the method described by Fernandez-Tajes *et al* (2010), in which amplification of the internal transcribed spacer 1 (ITS-1) of razor clams is used to differentiate diverse species (Cross *et al, in prep*). No sample could be obtained in November 2010 due to severe weather conditions preventing trawling in the sampling area.

2.2. Histological Techniques

The total wet weight (g) and shell length (cm) of each individual clam was recorded. The soft tissue of each clam was dissected within 24 hours of collection. A section of the body of the animal was cut out, which contained the gonad, renal gland and digestive tract, and sections of the gill and mantle. The tissue was fixed in Davidson's solution for 48 hours and stored at 4°C. Slides were prepared using standard histological techniques, where tissues were dehydrated in alcohol, cleared in xylene, embedded in paraffin wax, sectioned at 7 µm, and stained with Harris' Hematoxylin and Eosin before being mounted (Porter, 1974). The prepared microscope slides were examined using 10X, 20X, and 40X magnifications, to determine sex and stage of reproductive development.

2.3. Staging of gonadal development

Clam reproductive maturity was categorised into six stages using a modification of the maturity scale described for *E. siliqua* by Gaspar and Monteiro (1998) who designated these stages as 'inactive, early active gametogenesis, late active gametogenesis, ripe, partially spawned and spent'. In the present study, these stages were renamed to 'Indeterminate, Early Development, Late Development, Ripe, Spawning and Spent' respectively, to reflect the stages observed, though the definition of each stage remained the same. The term 'inactive' was amended as the sexes of *E. siliqua* are difficult to distinguish during the sexual rest period, and it was decided that the term 'Indeterminate' would better describe this stage of gametogenesis. When more than one stage was present in a single individual, the maturity was scored based on the condition of the majority of each section (Table 1 and 2).

Table 1: Description of gametogenic stages of development in female *Ensis siliqua* (modified from Gaspar and Monteiro, 1998).

Stage	Description
Indeterminate	Sexes are indistinguishable microscopically due to the total absence of follicles and gametes.
Early Development	Initial stages of gametogenesis are present. The oocytes lie at the periphery of the alveolar walls and are attached to the basal membrane by a stalk.
Late Development	Interfollicular connective tissue is scarce, and the size of follicles is increased Most oocytes are free in the lumina while some are still attached to the basal membrane by a thin stalk.
Ripe	Follicles that are full of ripe gametes replace connective tissue. The oocytes take oval or polygonal shapes.
Spawning	Gametes are discharged. The follicle walls are broken and there are many empty spaces between and within the follicles.
Spent	An abundance of interfollicular connective tissue. Occasional residual oocytes present.

Table 2: Description of gametogenic stages of development in male *Ensis siliqua* (modified from Gaspar and Monteiro, 1998).

Stage	Description
Indeterminate	Sexes are indistinguishable microscopically due to the total absence of gametes.
Early Development	Spermatocytes proliferate toward the lumina.
Late Development	Sperm appears in the lumina and forms weak columns with tails orientated toward the centre.
Ripe	The lumina are packed with ripe spermatozoa.
Spawning	Gametes are discharged. The follicle walls are broken and there are many empty spaces between and within the follicles.
Spent	An abundance of interfollicular connective tissue. Occasional residual sperm present.

2.4. Environmental Parameters

The mean, minimum and maximum monthly seawater temperatures in the Skerries region, from January 2009 to December 2011, to cover the study period and the year prior to the study commencing were obtained from the Marine Institute (www.marine.ie).

3. Results

3.1. Wet Weight

Of the 450 individuals collected over 16 months from June 2010 to September 2011 the average wet weight of all *Ensis siliqua* individuals was 80.0±2g, with the lightest individual collected weighing 31.0g and the heaviest 153.0g. Over the study period, the mean monthly values of *E. siliqua* weight ranged from 40.68 ±0.9g in June 2011 to 117.2±2.4g in January 2011 (fig.1.). Razor clams sampled during the sexual rest period of June to August in 2010 and 2011 were statistically significantly lighter than those collected during the months of December to February 2011, when the spawning period began (T-test, t=0.1124, *df* = 4, p<0.1). The average weight of female *E. siliqua* was 80.4±4.0g while the average weight of sampled male *E. siliqua* was 80.5±3.0g

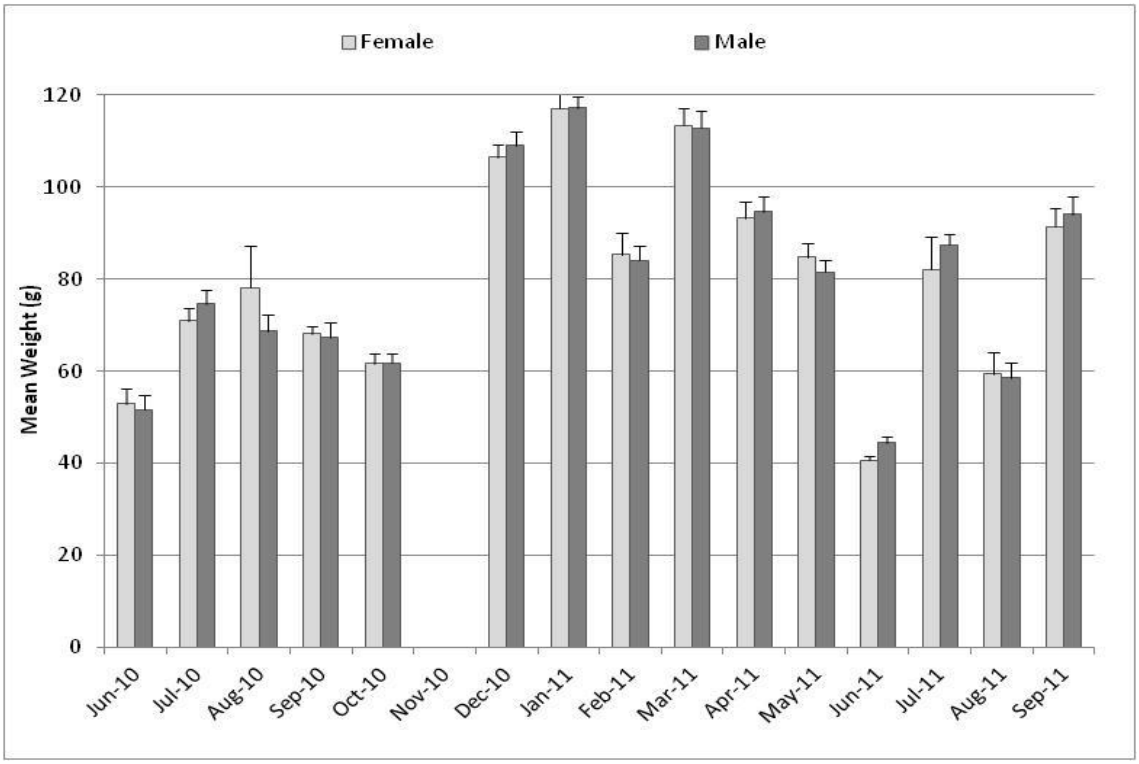

Figure 1: Mean weight (± S.E.) of female and male *Ensis siliqua* sampled at the Skerries region of the Irish Sea from June 2010 to September 2011.

3.2. Length

The average length of all razor clams collected was 17.5±0.2cm. Individuals collected measured from 12.8cm to 21.4cm in length, with mean monthly lengths ranging from 14.5±0.1cm to 19.4±0.1cm (fig. 2). Unlike wet weight values, the average length of individuals did not significantly differ between seasons. The average length of female *E. siliqua* was 17.5±0.3cm, and the average length of male clams was 17.6±0.2cm.

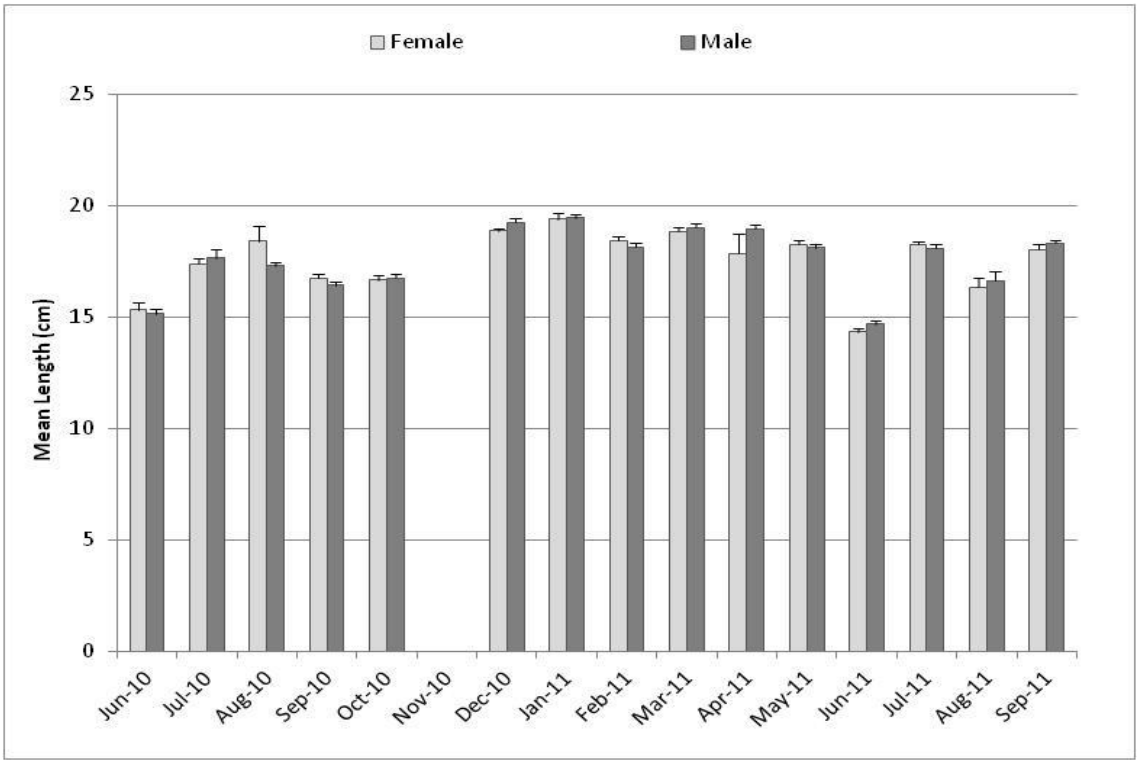

Figure 2: Mean length (± S.E.) of female and male *Ensis siliqua* sampled at the Skerries region from June 2010 to September 2011.

3.3. Histology

3.3.1. Sex Ratio

Of the 450 individuals sampled for histological analysis, 169 (38%) were female and 202 (44%) were male, with 79 (18%) termed "Inactive" (fig. 3). A Chi-squared (χ^2) with Yates correction was used to analyse sex ratios. The overall female: male sex ratio of 1:1.12 did not show a significant divergence from a 1:1 ratio (χ^2= 2.94, *df*= 1, $P < 0.05$), nor was there a statistically significant divergence within months, though the closest to showing a

significant divergence was the May 2011 sample, with 10 female and 20 male *E. siliqua.* No hermaphrodite individuals were recorded in the sampled *E. siliqua*.

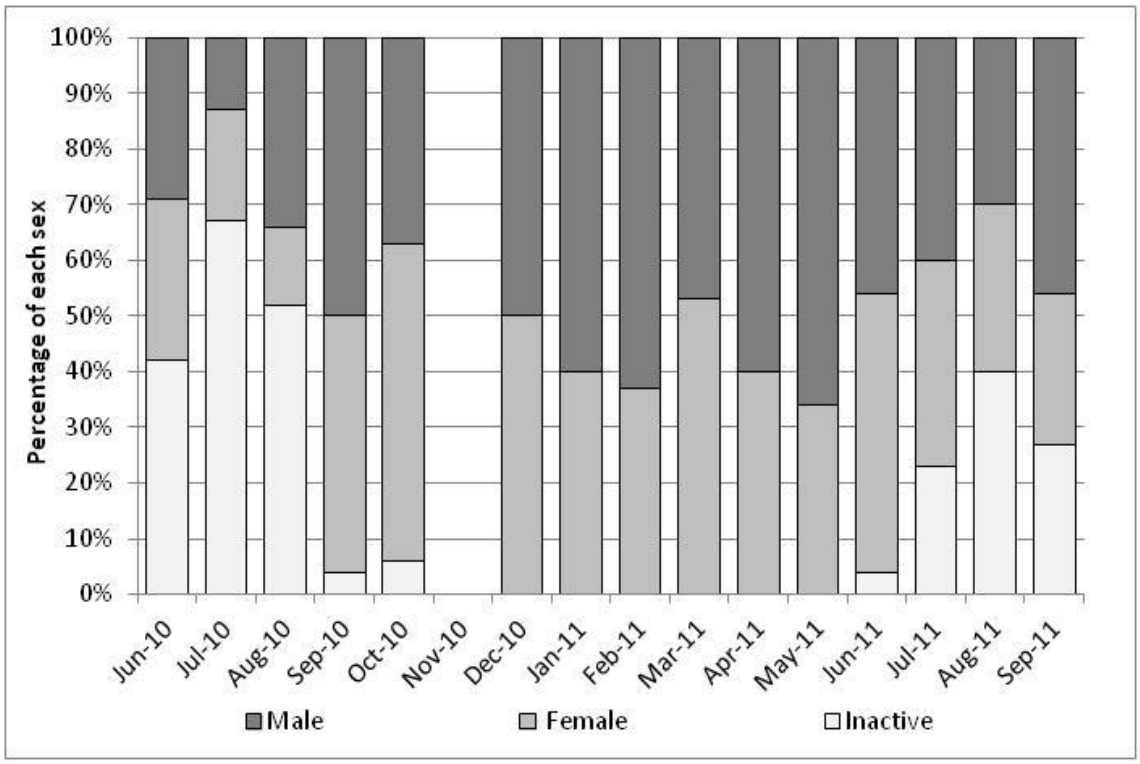

Figure 3: Sex ratio of *Ensis siliqua* sampled at The Skerries region over study period.

3.3.2. Sexual Cycle

3.3.2.1. Females

During the course of the sampling period all six of the stages of gametogenesis described by Gasper and Monteiro (1998) were observed (fig. 4 and 5). In the first month of sampling, in June 2010, all of the female *Ensis siliqua* were spent. However, in July, 67% of females were spent and 33% were in the early developing stage. Early development rose to 75% in August, and all females sampled were identified as early developing by September 2010. The first late developing (41%) and ripe (35%) female individuals were recorded in October 2010, with most females (73%) in the late developing stage by December. The first spawning individuals (17%) were present in the January 2011 sample. This increased to 75% of female individuals spawning in March, and stayed at a high percentage (73%) until June 2011, when the first spent females were identified (20%). In July and August of 2011 female *Ensis siliqua* were mostly in the spent stage of gametogenesis at 82% and 100% respectively, with the final spawning individuals recorded at 18% of the sample in July 2011. Therefore, in

2011 spawning continued in June and July, while in the previous year all females were either spent or in early development by June 2010. All individuals sampled in September 2011 were in the early development stage (fig. 4).

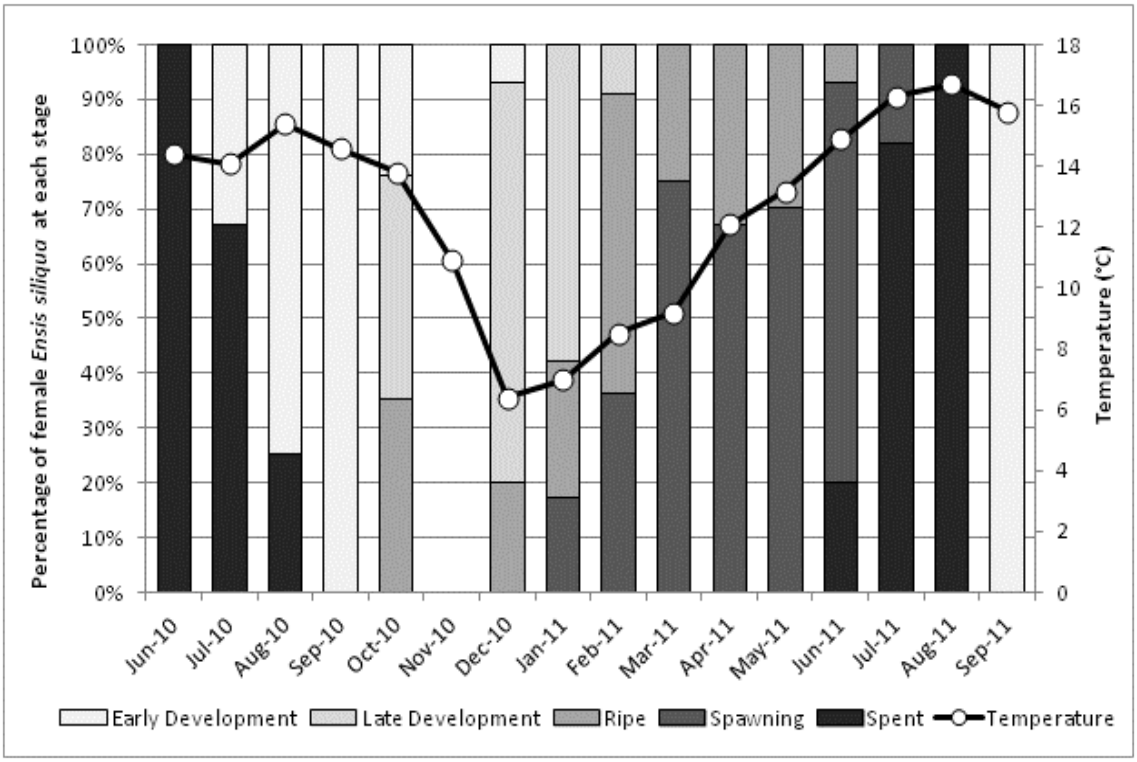

Figure 4: Stages of gametogenesis observed in female *Ensis siliqua* over the study period, with average monthly water temperatures shown.

3.3.2.2. Males

In the first samples collected in June 2010, only 11% of the male *Ensis siliqua* were still spawning, with 89% spent. The first male individuals in the early development stage were recorded in July (25%) with all males sampled in this stage in August and September 2010. 45% of male individuals were in the late development stage in October, when the first ripe male clams (10%) were recorded. By December 2010, 80% were in late development and 20% ripe, and the first spawning individuals were recorded in January 2011 (57%). All male *Ensis siliqua* sampled were spawning in March, with males either ripe or spawning until June 2011, when the first spent male clams were identified (8%). The majority of males were spent in July and August, with the final spawning males recorded in July 2011 (25%). As with female *E. siliqua*, 100% of male individuals were in the early development stage in September 2011(fig. 5).

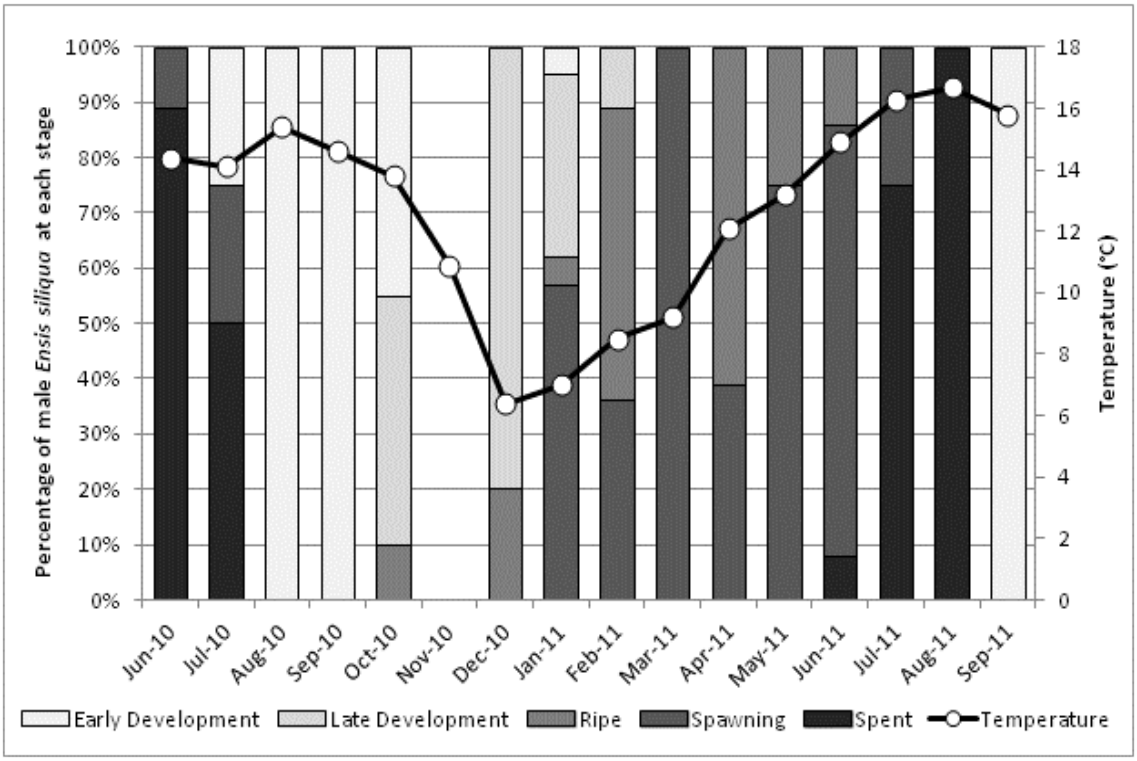

Figure 5: Stages of gametogenesis observed in male *Ensis siliqua* over the study period, with average monthly water temperatures shown.

3.4. Temperature

The mean monthly seawater temperature in the Skerries region was consistently higher in 2011 than 2009 and 2010, having the highest minimum and maximum temperatures recorded in the three years (fig. 6). The lowest mean monthly temperature reached during the sampling period was in December 2010, at 6°C, with a minimum temperature of 3.6°C recorded during that month. The highest mean temperature reached during the sampling period was in July 2011, at 16.7°C, with a maximum temperature of 17.9°C reached in July 2010, and in July and August 2011 (fig.6).

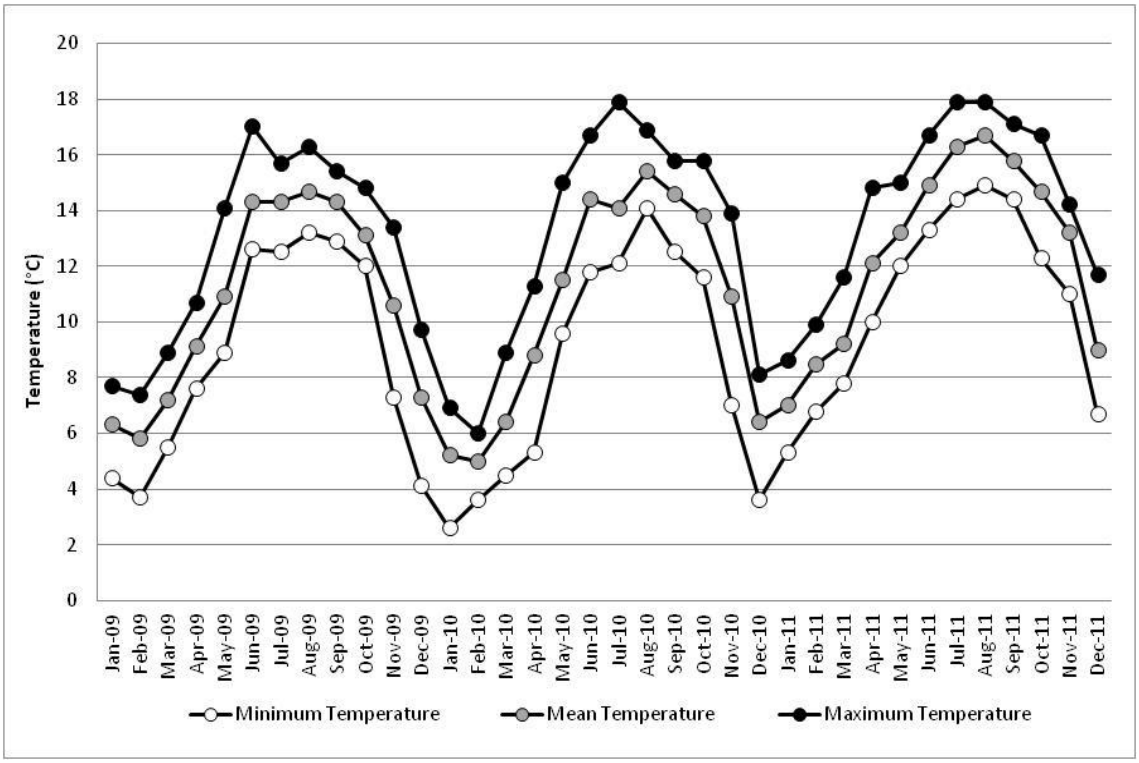

Figure 6: Water temperature readings for The Skerries region, from January 2009 to December 2011, showing mean, minimum and maximum temperatures recorded for each month.

4. Discussion

The *Ensis siliqua* sampled in the present study were both longer (average length: 17.5±0.2cm), and heavier (average wet weight: 80.0±2.0g), than in previous work in North-western Spain (Darriba et al., 2005), while similar to the mean length (17.19cm) of animals recorded in the Gormanstown bed in 1999 (Fahy, 1999). The size and weight data of the present study could be affected by the fact that *E. siliqua* were obtained from a fishery, where only clams of a certain size are landed, while the Spanish clams were randomly collected from a clam bed by diving in the subtidal zone of Sardiñeiro Beach, Galicia. Past work on *E. siliqua* dredged in the Gormanstown fishing area in the Irish Sea (Fahy, 1999) revealed that male *E. siliqua* were both larger and more numerous than females. This contrasts with data in the present study, as the average length and weight of female *E. siliqua* are very similar and not significantly different to that of male individuals.

Ensis siliqua of the Skerries region were significantly lighter in the summer months of June to August 2010 and 2011, than the winter months of December 2010 to February 2011,

though the average length of individuals did not significantly differ between the seasons. This is probably due to the clams spawning or being spent. Heavier weights outside this period are probably due to the increased presence of ripe gonads in both sexes. This phenomenon has not been previously recorded in research of razor clams. *Ensis siliqua* fisheries are carried out year-round in Ireland and other European countries. This differs from the fishing of other bivalve species (e.g. *Mytilus edulis* and *Ostrea edulis*), when fisheries are closed during the spawning period. As *Ensis siliqua* are currently sold by weight, and are significantly lighter in the sexual rest period of the summer months, the economic benefits of fishing during the months of June to August should be considered. From an ecological point of view decreased fishing during the sexual rest period of *E. siliqua* would potentially allow for increased recruitment, and reduce the possibility of pathogenic load and diminished condition during this stressful time.

The female to male sex ratio of 1:1.12 in the present study was not significantly different from the 1:1 ratio previously described in southern Portugal (Gaspar and Monteiro, 1998) and northwest Spain (Darriba et al., 2005). There was no evidence of hermaphroditism in the present study, in keeping with low incidences of hermaphroditism in past studies (Darriba et al, 2005; Fahy, 1999; Gaspar and Monteiro, 1998; South Wales Sea Fisheries Committee, 1999).

Six stages of maturation have previously been recognised in the gonadal cycle of *Ensis siliqua,* including a resting stage, during which the sexes are not distinguishable (Fahy, 1999; Gaspar and Monteiro, 1998). In the present study all of these six stages of gametogenesis were observed in Irish Sea *E. siliqua* at some time, and there was a distinct seasonal cycle in development. *Ensis siliqua* matured over the autumn and winter months of 2010, with all individuals either ripe or spawning from March to May 2011. This species has previously been described as gonochoric, with the sexes undergoing synchronous development and spawning (Darriba et al., 2005; Fahy, 1999; Gaspar and Monteiro, 1998). The data of the present study supports this theory, with female and male clams both beginning gametogenic development in July 2010, and the presence of spawning female and male individuals observed from January to July 2011.

Darriba *et al.* (2005) referred to the possibility of geographical differences in the reproductive pattern of *E. siliqua* caused by variations in environmental conditions. Brousseau (1995) stated that the duration of spawning in *Crassostrea virginica* populations along the Atlantic coast varies geographically, increasing as latitude decreases (Brousseau,

1995), while environmental conditions including food availability and temperature have been shown to affect gametogenesis and spawning of *M. arenaria* on the western Atlantic coast (Brousseau, 1978). The first *E. siliqua* in a stage of early gametogenic development in both sexes were identified in the present study in July 2010, in comparison to November and December in Portugal and Spain (Darriba et al, 2005; Gaspar and Monteiro, 1998). Average daily water temperatures for the Skerries region were recorded at 14.3°C in June and July of 2010, while seawater temperatures recorded in November and December in Portugal, and Spain average at 16.5°C and 14.5°C respectively (Sousa-Pinto and Araujo, 1998).

Ripe individuals were first present in October 2010 in the Skerries sample, when the monthly average water temperature was 13.8°C, with the majority of ripe clams present in February (8.5°C) and April (12.1°C) of 2011. These data correlate with the reproductive cycle of *Ensis siliqua* in Portugal and Spain, where ripe individuals were present in March and April (seawater temperature average of 16°C in Portugal, and 13.5°C in Spain). The single spawning period observed in razor clams of the Skerries region, from March to June, is similar in timing to that of other European sites such as Portugal, Spain, Scotland and Plymouth (Darriba et al., 2005; Gaspar and Monteiro, 1998; Lebour, 1938; Muir and Moore, 2003), though most of these spawning periods are of a shorter duration than that of the Skerries razor clams. In contrast, *Ensis siliqua* of north Wales were reported to spawn in July and August of 1999, (South Wales Sea Fisheries Committee, 1999), when the average monthly sea temperature reached 16.5°C (Norris, 2001), while Fahy observed a spawning period from mid-May to mid-August in the Gormanstown bed of *E. siliqua*, which is adjacent to the Skerries region of the Irish Sea (Fahy, 1999). Water temperatures recorded from May to August at the Gormanstown bed in 1999 averaged at 13.14°C, which is cooler than the average water temperature of 15.27°C recorded in the present study in 2010. This variance in the timing of spawning periods could be due, in part, to differing environmental conditions such as water temperature and food availability, between sampling years and geographical sites.

Past work has indicated that annual seawater temperatures may rise in European, including Irish, waters in the future (Hiscock et al., 2004; Christensen et al., 2007). In the present study mean monthly data showed an increase in water temperature from 2009 and 2010 to 2011. The mean monthly water temperatures of 2011 were all 2°C warmer, on average, than those of 2010. The effect of environmental parameters on the reproductive process of bivalves is well documented in previous studies (Cano et al., 1997; Ceballos-

Vazquez et al., 2000; Gaspar and Monteiro, 1999; Luna-Gonzalez et al., 2000, Pazos et al., 1997). Of these parameters, temperature is thought to be one of the most important (Darriba et al., 2004), as it is considered the main environmental cue for induction of gametogenesis and spawning in temperate regions (Grant and Creese, 1995; Harvey and Vincent, 1989). In July 2010, early development of *E. siliqua* began, and continued into August and September. In comparison, in 2011 the first *E. siliqua* in the early development stage of gametogenesis were only recorded in September, two months later than the previous year, and more similar in timing to *E. siliqua* in the warmer climes of Portugal and Spain (Darriba et al., 2005; Gaspar and Monteiro, 1998). Also, the spawning period extended for a longer time in the Skerries region in 2011, with 73% of individuals spawning in June, compared to 3% in June 2010. This extension of the spawning period, and delay in the first stages of the subsequent reproductive cycle could be due to the warmer seawater temperatures experienced in the summer months of 2011, and would have resulted in a greater number of *Ensis siliqua* gametes released over a relatively longer period of time in the spawning period of 2011. Previous research on the reproductive cycle of *Mya arenaria* recorded a similar increase of 2°C in the winter months of 1974 compared to 1973 in Massachusetts, U.S.A. Consequently, gametogenesis of the soft shell clam began a month earlier then in 1973 (Brousseau, 1978). Past work on *Macoma balthica* in the Wadden Sea has indicated that rising seawater temperatures could affect the stocks of this bivalve by lowering the reproductive output, with an earlier spawning period resulting in food availability during the pelagic phase being reduced (Philipart et al., 2003). If future climate change predictions come about, the effects of a longer spawning period on the health, growth, development and recruitment of *E. siliqua* will need to be considered in future management of this species in the Irish Sea.

In the present study, *E. siliqua* was chosen as a model species in which to examine the effects of changing water temperatures on the general biology of a commercially important bivalve in the Irish Sea. With more dependence on aquaculture rather than fisheries in the future in Ireland (BIM, 2011), the need for the modelling and subsequent management of this and other commercial shellfish species under various climate change scenarios is necessary. Further studies examining the potential effects of climate variability are essential to allow the long term fisheries management of this species.

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