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Reproduction and growth in the lesser-spotted dogfish *Scyliorhinus canicula* (Elasmobranchii; Scyliorhinidae), from the west coast of Ireland

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Abstract: The reproductive biology and von Bertalanffy growth parameters were investigated in lesser-spotted dogfish from the west coast of Ireland. The length at 50% maturity was similar for both sexes, occurring at 57.5 cm in males and at 58.1 cm in females. Age at maturity was estimated as six years. The number of oocytes displayed a marked seasonal cycle, which was lowest in March, and highest in November. Observations on maximum oocyte diameter indicate that ovulation occurs at 1.7 – 1.8 cm, and oocytes of this diameter were recorded throughout the study. Additionally, females with egg-cases *in utero* were also observed throughout the year, indicating a protracted breeding season, although peak egg-laying occurred in May, and was minimal in October. Gonad indices indicated that the male and female gonadal cycles were not synchronous, supporting the idea that females store spermatozoa. Based on this and previous studies, it appears that there are geographical variations in certain aspects of the reproductive biology. Vertebral bands were enhanced using an acid decalcification technique, and for the purpose of the study, bands were assumed to be annual in nature. The von Bertalanffy equation was estimated as $l_t = 82.7(1- e^{-0.15(t + 1.36)})$, and was similar to a length-frequency generated equation calculated for dogfish in Spanish waters.

Résumé : *Reproduction et croissance chez la roussette* Scyliorhinus canicula *(Elasmobranchii*; *Scyliorhinidae) de la côte ouest d'Irlande.* La biologie de la reproduction et les paramètres de croissance de von Bertalanffy ont été étudiés chez la roussette de la côte occidentale d'Irlande. La longueur à 50 % de maturité sexuelle était semblable pour les deux sexes, soit 57,5 cm chez les mâles et 58,1 cm chez les femelles. L'âge à la maturité sexuelle a été estimé à six ans. Le nombre d'ovocytes présentait un cycle saisonnier marqué, étant le plus faible en mars, et le plus élevé en novembre. Les observations sur le diamètre maximum des ovocytes montrent que l'ovulation se produit à 1,7 – 1,8 cm, des ovocytes de ce diamètre étant régulièrement observés au cours de notre étude. Des femelles avec des œufs encapsulés dans l'utérus ont été également observées tout au long de l'année, ce qui indique une saison de reproduction prolongée, bien que la ponte soit maximale en mai et minimale en octobre. La variation des indices gonadiques des mâles et des femelles montre que les cycles sexuels ne sont pas synchrones dans les deux sexes, ce qui renforce l'hypothèse d'une mise en réserve des spermatozoïdes par les femelles. Nos observations ainsi que des études précédentes, montrent qu'il y a des variations géographiques dans certains paramètres de la biologie de la reproduction. Des bandes vertébrales ont été mises en évidence grâce à une technique de décalcification, et dans notre étude, nous avons considéré ces bandes comme étant annuelles. L'équation de von Bertalanffy a été estimée comme étant $l_t = 82,7(1- e^{-0,15(t + 1,36)})$; elle était semblable à une équation de fréquence de taille calculée pour des rousettes dans les eaux espagnoles.

Keywords: Dogfish, ageing, reproduction, growth, Atlantic, Ireland.

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Introduction

The lesser-spotted dogfish *Scyliorhinus canicula* (L.) is a small bottom-dwelling scyliorhinid shark, which is common in the shelf waters of the North-eastern Atlantic, the Mediterranean, and the Adriatic Sea (Quéro, 1989). It is very common on all Irish coasts and is regularly taken in substantial numbers by the fishing industry. As it is of little economic value it is usually used as lobster-pot bait. Despite its abundance, little work has been conducted on the species in Irish waters, although recent studies have investigated the feeding habits (Henderson & Dunne, 1999) and parasite assemblage (Henderson & Dunne, 1998). Although its life-history has been described from both the north eastern Atlantic (Ford, 1921; Fauré-Fremiet, 1942; Sumpter & Dodd, 1979; Ellis & Shackley, 1997) and Mediterranean (Capapé 1977, 1978), most studies have found regional differences. Hence studies on *S. canicula* from Irish waters are desirable, especially as the west coast of Ireland presents the most westerly region of Europe. Supplementary information on the reproductive biology of *S. canicula* will increase our understanding of regional differences in its life-history.

Vertebral centra have proved the most useful structure in elasmobranch age determination, as the centra of a number of species have been shown to exhibit concentric rings similar to those found on teleost scales and otoliths (Cailliet et al. 1986). The vertebrae of *S. canicula*, however, are not known to show such markings, and the only prior study on age estimation for the species is based on length-frequency analysis (Rodriguez-Cabello et al., 1997). In an effort to address the problem of ageing small, deep-coned vertebrae, Correia & Figueiredo (1997) developed a decalcification technique for enhancing growth bands in the scyliorhinid shark *Galeus melastomus* Rafinesque. It was therefore decided to assess the applicability of this technique to *S. canicula*, and thereby construct the first growth model for the species based on incremental markings.

Materials and methods

Specimen collection

Dogfish were collected on-board commercial otter-board trawlers, operating in the Galway Bay and Dingle Bay areas (Fig. 1), on a monthly basis (where possible), between October 1997 and October 1998. Because of adverse weather conditions, and also seasonal changes in the type of fishing gear employed by vessels, sample material was available for only eight months of the study. In addition to samples taken for detailed examination, total length and clasper length/nidamental-gland width measurements were taken from a random sub-sample of the dogfish remaining on deck, to supplement studies on maturity. Information was collected from a total of 560 dogfish, of which 258 were subjected to a full examination (Table 1).

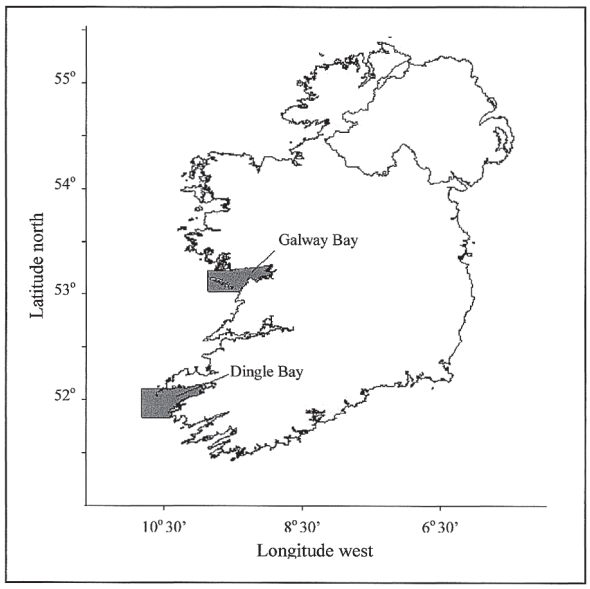

Figure 1. Areas of sample collection.
Figure 1. Zones de récolte des spécimens étudiés sur la côte occidentale de l'Irlande.

Table 1. Specimens dissected each month.
Tableau 1. Nombre de spécimens disséqués chaque mois.

Month	male	female
March	10	21
April	15	25
May	17	18
July	16	25
September	13	18
October	20	21
November	10	10
December	13	17

Specimen processing

The total length (L_T) and weight of dogfish were recorded, and the internal clasper length was also measured for males. The liver was removed and weighed to the nearest 0.1 g, and the digestive tract removed to allow visual examination of the reproductive system. A qualitative assessment of maturity was made, based on the condition of the gonad/duct system, and the width of the nidamental-gland of females was measured to the nearest 1 mm. Gonads were removed and weighed to the nearest 0.1 g, and ovaries fixed in a 4% formalin solution for at least two months, to allow

hardening of oocytes prior to examination. When present, egg-cases were removed from the uteri and the length (dorso-ventral mid-line) and width (at the widest point) were measured. Partially formed egg-cases were also noted, but no measurements were taken. The remaining viscera were removed from the body cavity, and the eviscerated weight recorded to the nearest 0.1 g. Fixed ovaries were rinsed in running tap water overnight, and the number of mature/developing ova (i.e. those greater than 0.5 cm) were counted. The gonadal index employed was Gonad Index (gonad weight/L_T^3 x 10^8) (Cailliet et al. 1986), so as to limit the use of at-sea weight measurements as much as possible. The same equation was used to calculate an Hepatic Index, substituting liver weight for gonad weight.

A section of vertebral column was removed from the post-pectoral region of 50 male and 50 female dogfish. Vertebrae were cleaned in a solution of 10.0 g of trypsin and 5.0 g of sodium carbonate per litre of water (at 37° C for 24 hours) and processed following Correia & Figueiredo (1997), although a longer soaking time (~15 minutes) was used to satisfactorily decalcify the vertebrae.

Results

Reproduction

The length-frequency distributions of dogfish examined are presented in Fig. 2. Size at first maturity was 52 and 53 cm (L_T) for females and males respectively (Fig. 3). The largest immature female occurred at 64 cm, and 50% female maturity was at approximately 58.1 cm. Extrapolating from the von Bertalanffy equation (see next section), these lengths indicated first maturity at just under five years of age, and 50% maturity occurred at six years. The relationship between nidamental-gland width and total length (Fig. 4) indicated an increase in gland width at the 52 cm L_T, coinciding with the first mature individuals. Furthermore, minimum gland width increased sharply at 66 cm, closely coinciding with 100% maturity. These increases in gland width were closely mirrored by increases in ovarian weight (Fig. 5).

The largest immature male occurred at 61 cm (Fig. 3), and the size at 50% maturity was 57.5 cm, slightly smaller than females. Clasper length increased at 53 cm L_T, coinciding with first maturity, and increased to 62 cm L_T, coinciding with 100% maturity (Fig. 6). The relationship between testis weight and total length (Fig. 5), followed a similar pattern.

The number of oocytes was highly variable, and a partial correlation (controlling for sample month) determined that fecundity increased with increasing female length ($P < 0.05$). Monthly variation in oocyte number (Fig. 7) indicated a marked seasonal cycle, with lowest values in

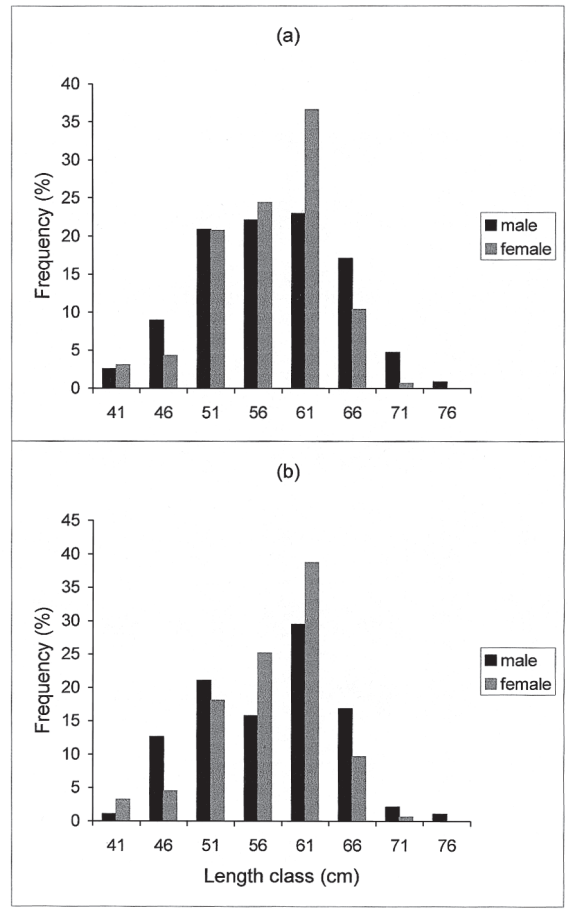

Figure 2. Length-frequency distribution of dogfish examined from the west-coast of Ireland (a = all specimens, b = dissected specimens).

Figure 2. Distribution des fréquences de taille des spécimens de roussette récoltés sur la côte occidentale de l'Irlande (a = tous les spécimens, b = spécimens disséqués).

March, and a peak in November. Observations on maximum ovum diameter indicated that oocytes were ovulated at 1.7 – 1.8 cm, and the majority of mature individuals contained ova of this diameter in all sample months.

Monthly changes in the gonad index of female fish (Fig. 8b), indicated a peak in May, after which it declined, with a second smaller peak in December. Monthly changes in the gonad index of males followed a similar trend up to and including April (Fig. 8a). However, male values reached a minimum later in the year, during October, and peak in November and December.

Females were observed to carry egg-cases throughout the year, although the proportion with egg-cases was variable. Peak egg-laying occurred in May and was minimal in October (Fig. 9). Egg-case length did not display a significant relationship with female length (Spearman-rank

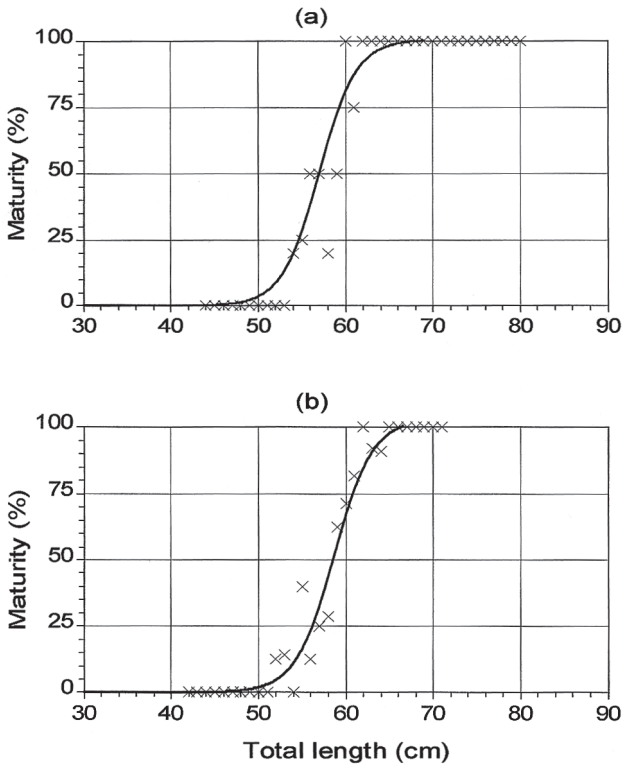

Figure 3. Percentage maturity of (**a**) male, and (**b**) female dogfish at each length.

Figure 3. Pourcentage de maturité chez les roussettes (**a**) mâles, (**b**) femelles, en fonction de la taille.

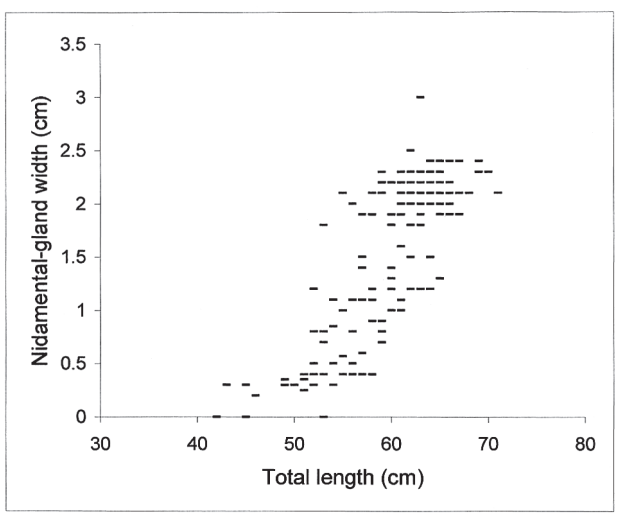

Figure 4. Relationship between nidamental-gland width and total length, of female dogfish from the west coast of Ireland.

Figure 4. Largeur de la glande nidamentaire en fonction de la longueur totale du corps chez les roussettes femelles de la côte occidentale d'Irlande.

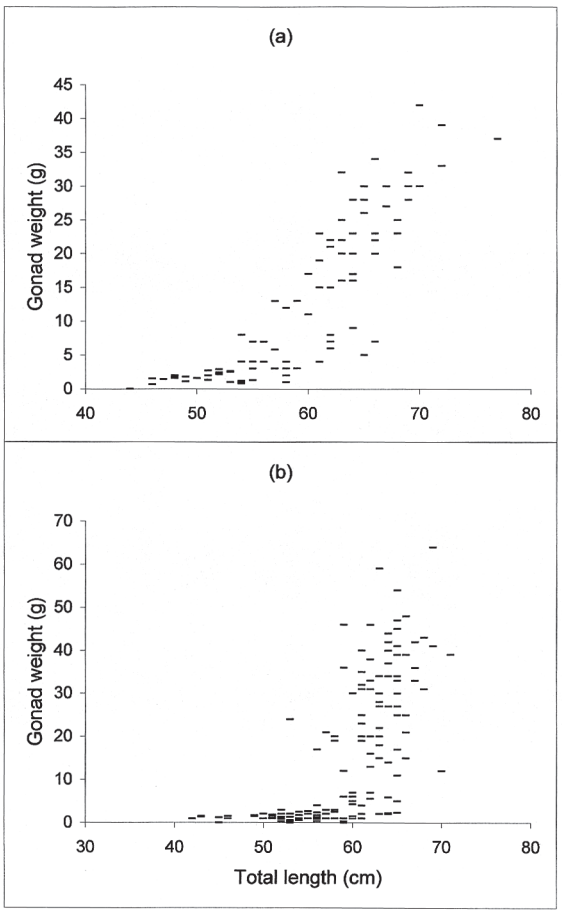

Figure 5. Relationship between gonad weight and total length, in (**a**) male, and (**b**) female dogfish from the west coast of Ireland.

Figure 5. Poids des gonades en fonction de la longueur totale, chez les roussettes (**a**) mâles, et (**b**) femelles de la côte occidentale d'Irlande.

correlation, $P > 0.05$), however, in the case of egg-case width, a significant relationship was found (Spearman-rank correlation, $P < 0.05$).

Age and growth

Of the 100 specimens processed for ageing, a total of 67 displayed readable centrum markings, of which 59% were female, and 41% were male. Vertebrae which did not display obvious banding patterns were distributed randomly throughout the sample, no relationship being found between readability and centrum diameter (ANOVA, $P > 0.05$). For the purpose of this study, vertebral bands were assumed to be annual, in lieu of verification studies. Figure 10 presents the frequency of occurrence of the various age classes. The minimum age recorded was the same for both sexes, and as such indicated that dogfish enter this fishery at approximately three years of age. An Anderson-Darling test determined that the age distributions of both sexes were

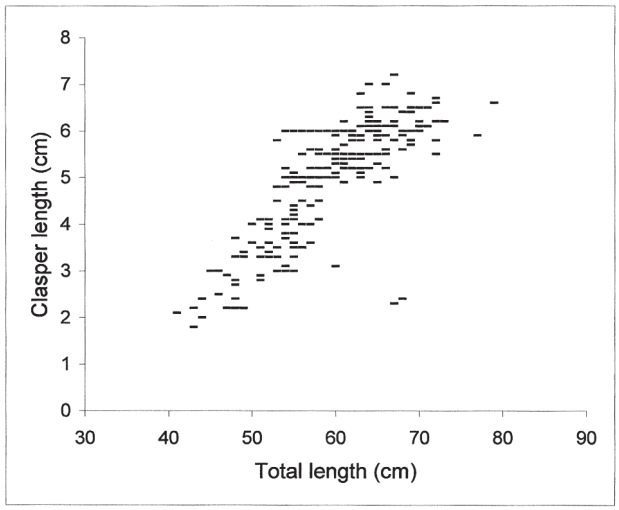

Figure 6. Relationship between internal clasper length and total length, in male dogfish from the west coast of Ireland.

Figure 6. Longueur interne du clasper en fonction de la longueur totale, chez les roussettes mâles de la côte occidentale d'Irlande.

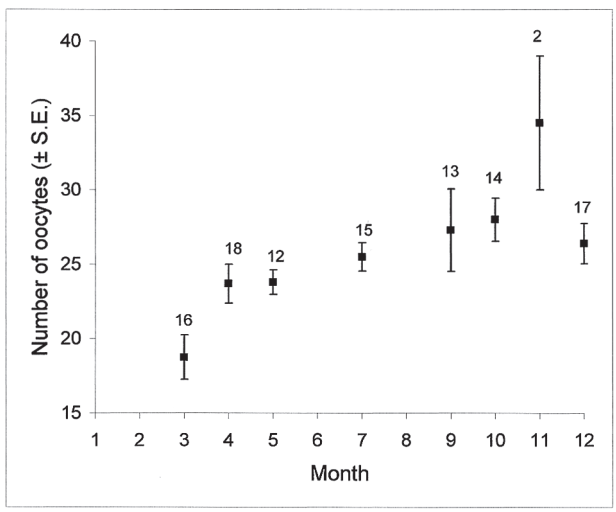

Figure 7. Number of oocytes in mature female dogfish in each sample month.

Figure 7. Nombre d'ovocytes chez les roussettes mûres au cours des différents mois de l'année.

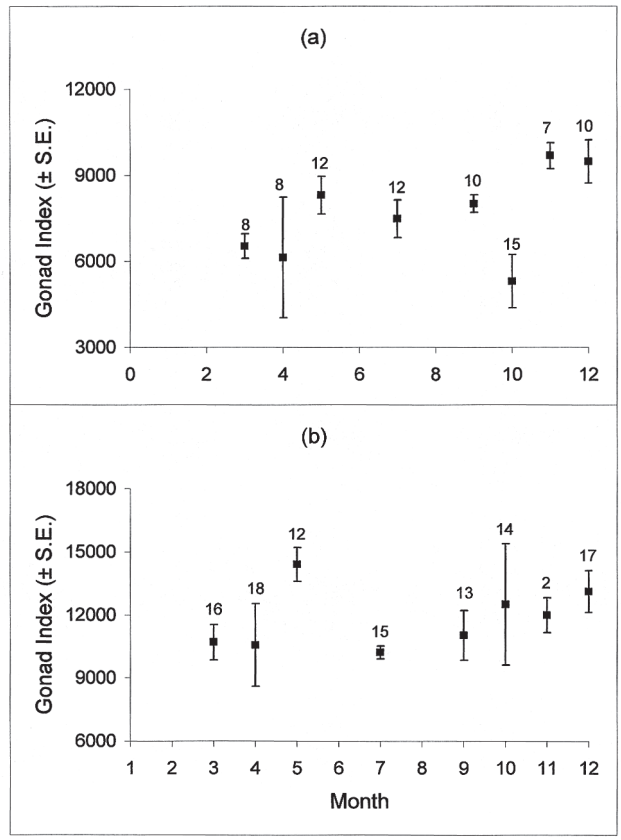

Figure 8. Range in gonad index for mature (a) male, and (b) female dogfish in each sample month.

Figure 8. Variation de l'index gonadique chez les roussettes (a) mâles, (b) femelles, au cours des différents mois de l'année.

normal ($P < 0.05$), and a t test determined that the age composition of the sexes differed significantly ($P < 0.01$).

The relationship between centrum diameter and age was found to be linear for both sexes (ANOVA, $P < 0.001$), and a t test deemed that this relationship did not differ significantly between the sexes ($P > 0.05$) (Fig. 11). The relationship between centrum diameter and total length was also found to be linear in both sexes (ANOVA, $P < 0.001$) (y = 84.002 x + 16.942, where y is total length (cm) and x is centrum diameter (cm), and again, the relationship did not differ significantly between the sexes (t test $P > 0.05$).

Due to limited data, a von Bertalanffy equation was estimated for the sexes combined:

$$l_t = 82.7\ (1 - e^{-0.15(t + 1.36)})$$

Using this equation total length at hatching was estimated to be 15.2 cm. The relationship between total length and somatic weight did not differ between the sexes (t test, $P > 0.05$), and was described by the equation $W = 0.0018L^{3.1168}$, ($r^2 = 0.92$).

The hepatic index (HI) displayed a marked variation between seasons in both male and female dogfish, being minimal in autumn and maximal in winter in both cases (Fig. 12). However, little can be inferred from this as (a) a partial correlation controlling for season determined that there was a significant relationship between HI and total length ($P < 0.001$), and (b) an analysis of variance

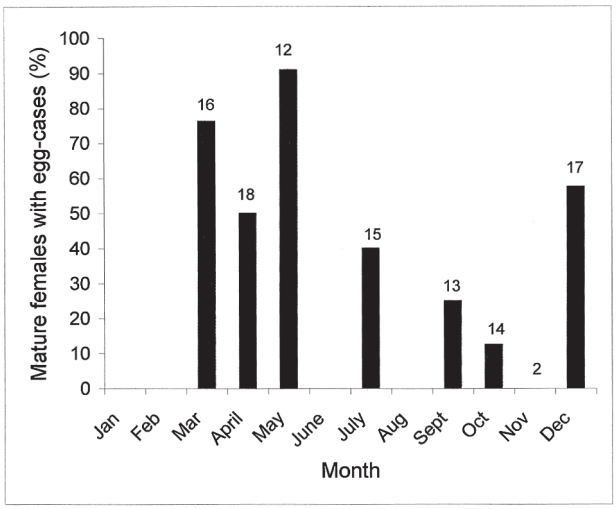

Figure 9. Percentage of mature female dogfish in each sample month, with either fully or partially formed egg-cases.

Figure 9. Pourcentage de roussettes femelles contenant des œufs encapsulés au cours des différents mois de l'année.

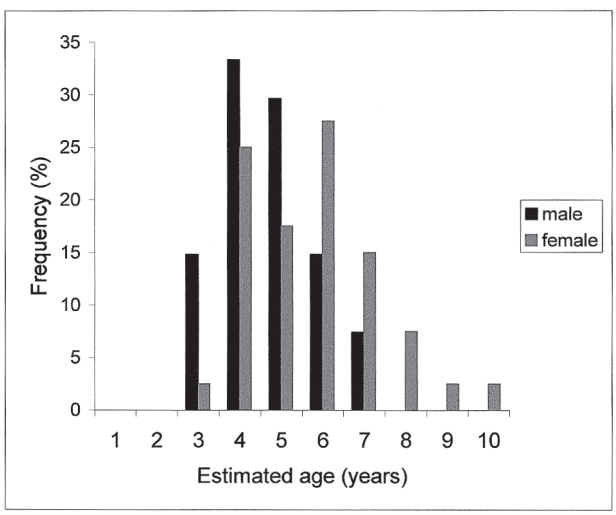

Figure 10. Age-distribution of dogfish examined during the present study, based on the Correia & Figueiredo (1997) technique of enhancing vertebral growth bands.

Figure 10. Fréquence des âges estimés d'après la technique de Correia & Figueiredo (1997) de mise en évidence des anneaux de croissance vertébrale, pour l'ensemble des spécimens de roussettes de cette étude.

determined that there was a significant difference between seasons, with regard to L_T composition ($P < 0.001$).

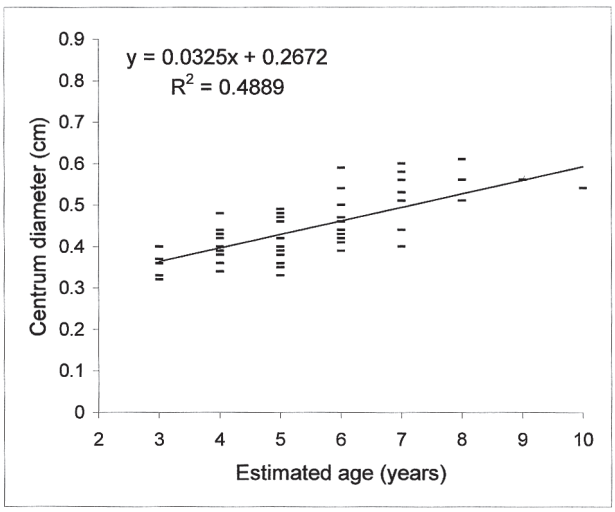

Figure 11. Relationship between centrum diameter and estimated age, of dogfish from the west coast of Ireland.

Figure 11. Relation entre le diamètre du centrum vertébral et l'âge estimé des roussettes de la côte occidentale d'Irlande.

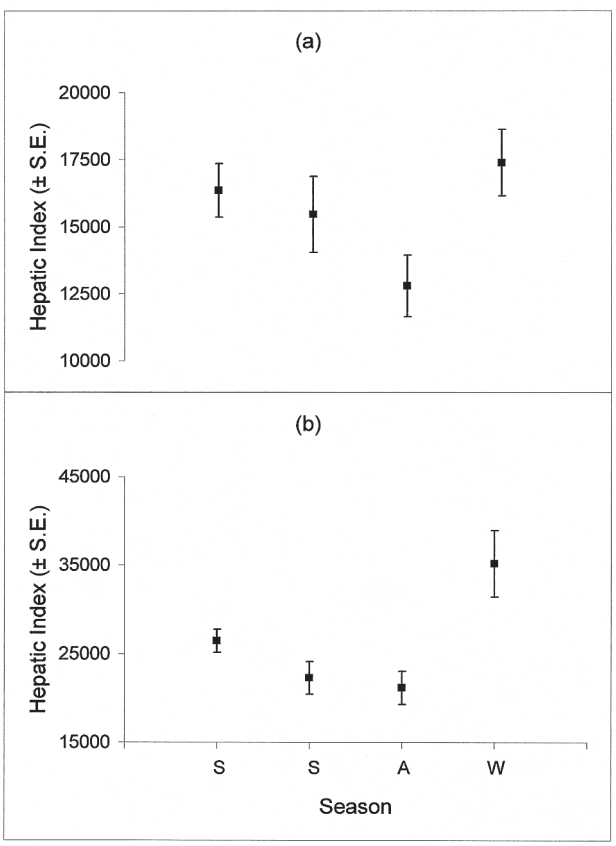

Figure 12. Relationship between hepatic index and season (W, winter = Dec.- Feb.; S, spring = Mar.- May; S, summer = June - Aug.; A, autumn = Sept.- Nov.) in (a) male, and (b) female dogfish from the west coast of Ireland.

Figure 12. Variation de l'index hépatique chez les roussettes (a) mâles, (b) femelles, au cours des différentes saisons (W = hiver, S = printemps, S = été, A = automne) sur la côte occidentale d'Irlande.

Discussion

The range in length at which female dogfish were found to mature is almost exactly the same as that determined by Ellis & Shackley (1997) for dogfish in the Bristol Channel, and is very similar to that reported from the Atlantic coast of France (Fauré-Fremiet, 1942), and from the south coast of England (Ford, 1921). Ellis & Shackley (1997) estimated the size at 50% female maturity to be 55 cm, which is approximately 3 cm smaller than that reported here. However, this difference is only slight, and is possibly due to variability between studies, rather than actual geographic differences. Reports on maturity in male dogfish are, however, slightly more variable. Ellis & Shackley (1997) estimate 50% male maturity at 52 cm, which is again smaller than the size determined here, but more importantly Ellis & Shackley's (1997) size at 50% maturity does not even fall within the range in which maturity was found to occur in males during the present study. This is especially interesting when one considers that the size at 50% maturity determined here is almost identical to that estimated for male dogfish in the French Atlantic (Leloup & Olivereau, 1951). While inter-study variability cannot be ruled out, the magnitude of the differences in the size at maturity suggests that there may be geographic differences in the size at which male dogfish mature. The results of the present study are in complete agreement with Ellis & Shackley (1997), in that both clasper length and nidamental-gland width increase dramatically between the range in length at maturity determined by the qualitative method.

The monthly trend in female gonad index (GI) determined here is similar to the female gonosomatic index (I_G) reported by Ellis & Shackley (1997) for dogfish in the Bristol Channel. However, while both studies agree that female GI/I_G peaks in May, lowest mean value occurred in July during the present study, preceding Ellis & Shackley's (1997) lowest mean value by three months. This is possibly a manifestation of the fact that relatively few mature female dogfish were captured in July, however, the fact that the trend thereafter closely follows that of Ellis & Shackley (1997) from November onwards, suggests otherwise. Furthermore, a similar trend to that of the present study was found by Sumpter & Dodd (1979) for dogfish in Caernarvon Bay, who also found that lowest mean relative ovary weight occurred in July. However, on the south coast of England they determined a trend more closely resembling that of Ellis & Shackley (1997), with the lowest mean value occurring in October. Taking all of these results into consideration, it therefore appears that there is a temporal difference in the occurrence of minimum GI/I_G, possibly based on latitude. Variations in the timing of peak GI/I_G are not so easily explained. While the timing of lowest mean relative ovarian weight determined here is in agreement with Sumpter & Dodd's (1979) findings for dogfish in Caernarvon Bay, they also determined that mean relative ovary weight peaked earlier in the year relative to that of dogfish in the Bristol Channel, or from the south Coast of England, a result not found in the present study. The reason for this difference is unclear.

Monthly variations in male GI were also apparent. This parameter peaked in November, preceded by the lowest mean value in October. Taking into account the months for which no mature male samples were available, the monthly trend in relative testis weight follows a broadly similar trend to that of Ellis & Shackley (1997) for the first half of the year. It is unfortunate that there were no male dogfish available for examination during August, as this is the month in which Ellis & Shackley (1997) determined that testis weight peaked. However, it is clear that testis weight peaked later in the year during the present study, during November and December. As in the case of female GI, it therefore appears that there are geographical differences in the male parameter. While the GI of both sexes follows a similar seasonal trend, female GI increased in autumn, while male GI continued to decrease. This suggests that male gonadal activity is at a minimum during autumn, which is not synchronous with minimum female gonadal activity. This situation was also observed by Ellis & Shackley (1997), but as female dogfish are thought to store spermatozoa in the nidamental-gland (Metten, 1939), the testicular cycle need not be synchronous with the ovarian cycle. The peak in testicular activity in winter suggests that mating occurs during this season.

The percentage of gravid females recorded early in the year during the present study is greater than that reported by Ellis & Shackley (1997), although it is interesting to note that the pattern of increase/decrease is similar between the two studies. The higher percentages reported here may possibly be explained by the fact that only mature females were plotted for this study, while Ellis & Shackley (1997) include all females greater than the size at 50% maturity, thus also including immature individuals. It is interesting to note that egg-laying rates differed between studies, peaking in May presently, but not until June/July in Bristol Channel (Ellis & Shackley, 1997). It is also interesting to note that they did not record any egg-cases in August and September, and while there were no samples available for August here, 25% of mature females examined in September were gravid. As the gap in egg-laying reported by Ellis & Shackley (1997) is well documented in British waters (Craik, 1978; Sumpter & Dodd, 1979), it is evident that dogfish from the west of Ireland differ in this respect. The minimum egg-laying months during the present study were October and November, and while no egg-cases were recorded during November this is no doubt due to the fact that only two mature females were examined. Egg-laying therefore

appears to occur year-round off the west coast of Ireland, peaking in Spring.

When assessed on a seasonal basis, GI and the percentage of gravid females follow a similar trend, peaking in spring and decreasing through summer to a minimum in autumn, after which they both increase during winter. Fecundity, however, followed this trend inversely, rising from a minimum in spring to a maximum in autumn, after which it decreased slightly. This suggests that, during spring, ovaries consist of a greater proportion of well-developed ova, which are gradually replaced by ova in the early stages of development as the breeding cycle proceeds. Thus, in autumn, ovaries would contain a greater number of developing ova, of which a relatively small proportion is in the latter stages of development. During winter, an increasing proportion of these ova mature (increasing GI) and are ovulated/laid, thus decreasing fecundity and increasing the proportion of gravid females.

The von Bertalanffy growth parameters estimated here are very similar to those estimated by Rodriguez-Cabello et al. (1997), who employed length-frequency analysis on dogfish from the Cantabrian Sea. It therefore seems likely that the method of age estimation employed here is a reliable one, although verification studies are obviously desirable. However, the size at birth estimated by both this study and that of Rodriguez-Cabello et al. (1997) is clearly overestimated, as the size at birth for this species is now well established at around 9–10 cm (Compagno, 1984; Ellis & Shackley, 1997). This can be explained by the poor ability of the von Bertalanffy in describing embryonic growth.

Collenot (1966) studied the development of dogfish in a captive environment up to the age of four, and determined a length of 15 cm at one-year old, 20 – 25 cm at two years, 30 – 35 cm at three years, and 45 cm at four years. The lengths observed by Collenot (1966) for the first three years of life are slightly smaller than calculated in the present study, but by the fourth year the results of both studies are very similar. Again, this might possibly be due to the poor performance of the von Bertalanffy in the early stages of life, but the limited data of the present study must also be considered. Furthermore, the fact that Collenot's (1966) specimens were reared in a captive environment may have had an effect on their growth patterns.

There are reports of this species attaining lengths of up to 100 cm in the Northeast Atlantic (Kennedy, 1969; Compagno, 1984), but these reports are possibly in error, specimens being confused with the larger congener *Scyliorhinus stellaris*, as specimens of *S. canicula* exceeding 80 cm are rarely observed (Kennedy, 1969; Vas, 1991; Rodriguez-Cabello et al., 1997). The asymptotic length, $L\infty$, determined here, would therefore appear to be a satisfactory estimate.

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