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Biology of Exploited Deep-water Sharks West of Ireland and Scotland

by

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Abstract

The biology and exploitation of deepwater sharks in the Rockall Trough and Porcupine Bank were studied by means of ten extensive trawl and longline surveys, in the depth range 300-2,800 m, supplemented by commercial landings data. Commercial exploitation concentrates on two species *Centrophorus squamosus* and *Centroscymnus coelolepis*, landings having risen from 340 t in 1990 to almost 6,000 t in 1998. Trawls and long-lines selected for significantly different size ranges of some species, though not others. Hook size was not an important selectivity parameter and longline was not found to be size-selective for sharks. The larger species attained sexual maturity at 75% to 85% of maximum length, while mean ovarian fecundity was low in the species examined (*Centrophorus squamosus* and *Deania calceus*, 8, *Centroscymnus coleolepis*, 13). Certain life-history stages were absent from the fishing grounds – smaller specimens of all species, gravid *Centrophorus squamosus* - though all reproductive stages of the other species were recorded. An age estimation procedure, based on sectioned dorsal spines, yielded estimates of 21-70 years (*Centrophorus squamosus*) and 11-35 years (*Deania calceus*). Empirical and von Bertalanffy data suggest that growth had slowed down or ceased before the onset of maturity. Discard levels were estimated for the main deepwater shark species. Sharks dominated discards from longliners. While ages were not validated, this study confirms that these species have conservative life-history strategies and are subject to increasing fishing pressures. The immediate challenge is to incorporate available data into assessment to support the management process.

Introduction

There are several fisheries for deepwater sharks in the northeast Atlantic, but most activity takes place in the Rockall Trough, and on the slopes of the Porcupine Bank. Two species of sharks are routinely landed for their flesh and livers; the leafscale gulper shark *Centrophorus squamosus* (Bonneterre, 1788) and the Portuguese dogfish *Centroscymnus coelolepis* (Bocage and Capello, 1864). These species are collectively called "siki" in French fishery records (Gordon, 1999), though they are marketed elsewhere under this name too. French vessels catch these species in the mixed-species trawl fishery, and landings have increased from 302 tons in 1991 to 3,284 tons in 1996, declining to 1,939 t in 1999 (ICES, 2000), see Table 1. Spanish longliners target deepwater sharks too (Pineiro.. 2001) but it is difficult to quantify landings as separate statistics for deepwater shark species are not collected from these vessels. More recently, longliners from Norway and trawlers and longliners from Scotland and Ireland are catching these species. Other, smaller species of deepwater sharks are now being landed, or in some cases livers or fins are retained and the carcasses discarded. These species are *Centroscyllium fabricii* (Reinardt, 1825) (Lorrance and Lespagnol, 2000), *Deania calceus* (Lowe, 1839) and *Centroscymnus crepidater* (Bocage and Capello, 1864). Apart from France no other country reports landings data for deepwater sharks, but rather for shelf and slope species combined.

Relatively few studies on these deepwater sharks exist in the scientific literature. However the majority deal with members of the Squalidae, reflecting their commercial importance. Two reproductive studies of *Centroscymnus coelolepis* and *Centrophorus squamosus* have been carried out in the northeast Atlantic. Girard and Du Buit (1999) present information on maturity, fecundity, size at birth and sexual segregation whilst Girard et al. (2000) conducted a detailed study of spermatogenesis and showed that there is no seasonal cycle in male reproduction. Much work on these two species has been carried out in Suruga Bay, Japan; An anatomical and morphological study of the reproductive tract of *Centroscymnus coelolepis* was carried out by Yano and Tanaka (1987), whilst Yano and Tanaka (1988) presented details of size at maturity, fecundity and segregation by depth for this species. Though some information on *Centrophorus squamosus* is presented by Yano and Tanaka (1983) there is little information on reproduction. Aspects of reproduction of *Deania calceus* have been studied by Clark and King (1989) and from New Zealand by Yano (1991) from Namibia. There are no published accounts of the biology of *Centroscymnus crepidater*.

This paper presents information on the biology of four of these exploited species; *Centroscymnus coelolepis*, *Centroscymnus crepidater*, *Centrophorus squamosus* and *Deania calceus*. Additional information on the reproductive segregations, based on extensive trawl and longline surveys of the continental slopes, is presented. The deficiencies in the knowledge base for these species are highlighted and the implications of sustained commercial exploitation are discussed.

Materials and Methods

This study is based on two trawl and four longline surveys of the Rockall Trough and Porcupine Bank, between 49°N and 58°N in the depth range 500 to 2,000 m (Table 2). Fishing was carried in eight fixed areas (Figure 1) of the continental slope in 200 m depth strata from 500 m to 1,300 m. Some deeper settings were made during longline surveys. Trawl surveys used a commercial "rock-hopper" trawl (Gundry's© Ltd.) with 105 mm mesh cod-end, with 25 mm liner, foot-rope length 23 m, with bobbins of 40 cm, the bridles comprised of 92 m of singles and 46 m of doubles. Hauls ranged in duration from 135 minutes to 380 minutes. Longlines consisted of main line of 9 mm or 11.5 mm, with Mustad© size 13/0 EZ, and smaller numbers of size 7/0 EZ hooks. Snoods were of 40-70 cm in length attached to the main line at 1.4 m intervals. Bait consisted of squid (60%) and mackerel (40%).

Specimens of sharks were identified according to Compagno (1984) and McEachran and Branstetter (1984). Total length (cm), taken as the length from the snout tip to the posterior tip of the caudal fin depressed along the anterior-posterior axis of the fish - was measured to the nearest centimetre below the actual length of the fish. Round weight (g) and sex were recorded. Spines were removed by cutting towards the notochord and preserved in 70% alcohol. The numbers of ripe ova in the each ovary and embryos in each uterus were counted. All specimens caught were measured and weighed except during the 1996 trawl survey, when the weight of a sub-sample was recorded, and using a raising factor the total weights for that haul of *Deania calceus* and *Centroscymnus crepidater* were estimated (Connolly and Kelly, 1996).

The discard rate was calculated as a percentage of the total catch for each haul and also as kg per tonne of target species. The latter rate enabled the estimation of the total weight discarded by raising the overall discard rate to the official reported landings of the target species. These target species were the commercially important species leafscale gulper shark *Centrophorus squamosus* and Portuguese dogfish *Centroscymnus coelolepis*. Since these are landed in gutted state, live weight landing weight was calculated using the following conversion factor of gutted to round weight for both commercial species combined.

$$\text{Round weight (g)} = 1.556 * \text{Gutted weight (g)} - 122.6$$

$$(\text{S.E. of regression} = 0.1974,\ r^2 = 0.924,\ n = 512).$$

Estimates of total weight discarded from trawlers were calculated from official landings data as reported to ICES (Anon., 2000). A conversion factor, using linear regression (SPSS, 1999) was used to convert from landed weights to live weight. Total numbers were calculated using this figure based on a mean weight of 2.612 kg.

The Kolmogorov-Smirnov (K.S.) Two Sample Test (Sokal and Rohlf, 1995) was used to test for significant differences in the length frequencies for sex and gear-type. The sex ratio (males: females) was calculated for each depth. The Chi-squared test (Zar, 1996) was used to examine the differences between observed sex ratios and the expected ratio of equal numbers of each sex. Maturity was assessed using the scale in Table 2, a modification of that devised for use in the EC FAIR deepwater research programme (Stehmann, 1998). The proportion of mature male and female fish per

1cm total length increment was calculated. Total length at 50% maturity for each species was determined using the Probit model (Sokal and Rohlf, 1995).

Fecundity was determined by counting the number of ripe oocytes in stage 3 females and near-term embryos in stage 6 females. The changes in testis and ovary weight in relation to total weight were investigated using the gonadosomatic index (GSI) calculated as;

$$\text{Gonad Weight (g) / Total Weight (g)} * 100$$

for the changes in gonad weight throughout the process of maturation. Hepatosomatic Index (HSI) was calculated as;

$$\text{Liver Weight (g) / Total Weight (g)} * 100$$

HSI was calculated for each female maturity stage.

Dorsal spines of *Centrophorus squamosus* and *Deania calceus* were cleaned in a 4% hypochlorite solution for up to 12 hours, washed in running tap water and air-dried. Spines were sectioned using a Buehler © low speed jewellers saw with diamond blade. Sections were taken at a thickness of 500 µm at intervals of 2000 µm along the length of the external spine in order to make comparative counts. All bands (consisting of one translucent and opaque zone) present in the inner trunk layer (*sensu* Maisey, 1979) were included in age estimates. Maximum band count was found in those sections immediately proximal to the constriction of the central cavity, therefore age estimation was based on this region of the spine. Sections were cleared in xylene, air-dried before mounting on glass slides using resin C. Spine sections were read using a Wild Heerbrugge© binocular microscope using x 50 magnification and transmitted light. The dentinal layers were differentiated using a Leitz Biomed© compound microscope at x 40 magnification with transmitted light. Terminology for describing the spines and age estimation procedures follow Maisey, (1979) Wilson et al., (1983) and Guallart (1998).

The von Bertalanffy growth model was fitted to the combined data from the present study and that of Machado and Figueiredo (2000). The von Bertalanffy growth function can be described as;

$$L_t = L_\infty \left(1\text{-exp}^{-K(t-t_0)} \right)$$

Where: L_t = length at time t; L_∞ = asymptotic length, or mean maximum length; K = a rate constant with units of reciprocal time (years $^{-1}$) and t_0 = age of the fish at theoretical zero length. The von Bertalanffy growth function was fitted to length at estimated age for males and females separately by means of the Levenberg-Marquardt algorithm using the non-linear regression routine in SPSS *v*. 9.1 (SPSS, 1999).

Results

Depth distribution of the species is illustrated by catch rates in kg per 1,000 hooks, from longline surveys (Figure 2). The habitual depth range (300 m-1,800 m) of each species was sampled. *Centrophorus squamosus* and *Deania calceus* were most abundant between 700 m and 900 m. *Centroscymnus coleolepis* was more abundant deeper (1,300 m).

An important finding is the absence of smaller specimens of these species from the study area (Figure 3). Length range for *Centrophorus squamosus* was 71-122 cm for males and 74-145 cm for females. For *Deania calceus*, the range was 55-109 (males) and 52-117 for females, whilst for *Centroscymnus coleolepis* the range was 68-118 cm (males) and 70-121 for females. Small (7/0 EZ) hooks were deployed during the long-line surveys in 1997 and 1999 in an attempt to target small sharks but no smaller specimens were taken.

Interestingly, the modal lengths for male and female *Centroscymnus coleolepis* were widely separated though those for *Centrophorus squamosus* were not, even though there was an obvious tendency for females to grow larger in both cases. Gravid female *Centrophorus squamosus* were entirely absent from the study area, in contrast to *Centroscymnus coleolepis* where all maturity stages occurred. Evidently, larger mature *Centrophorus squamosus* are mainly absent from the study area. Furthermore, the size at 50% maturity (TL50) for females of this species (Table 3) is considerable greater than the modal length in the catch from these commercial gear-types.

Trawls and long-lines selected for significantly different (Kolmogorov-Smirnov two-sample test $p<0.05$) size ranges of *Centroscymnus coleolepis* and *Deania calceus*, though not *Centrophorus squamosus* (Figure 4). This is further evidence that the larger gravid *Centrophorus squamosus* are absent from the study area, and that gear selectivity is not the reason for their absence from samples. Longlines selected both larger and smaller *Centroscymnus coleolepis* than trawls. Large female *Deania calceus* were well represented in long-line catches, but almost totally absent from trawls, indicating that large, mature females can avoid these nets. Evidence for a more pelagic distribution of smaller specimens of the species under study may be found by comparison of length frequencies for trawl and long-line. Long-lines took smaller specimens of *Centroscymnus coelolepis* than trawls. This result suggests these smaller sharks occur at some distance from the seabed, out of the range of trawls (headline height around 4 m), but attracted to the baited hooks.

Discarding of *Deania calceus* from trawlers operating in ICES Sub-areas VII and VII in 1996 was estimated as 745 t, and the total number estimated to have been discarded in 1996 from trawlers was 285,322 individuals (Table 5). Based on the 1999 longline survey (Table 6) it can be seen that the percentage discard rate of these sharks depends on depth fished. The highest discarding occurred on the southern slopes of the Rockall Trough, where over 40% of the catch was *Deania calceus*. Indeed it accounted for over 30% of the total catch on the long-line survey of December 1999. However catch rates are depth dependent (Section 3.1.3). Thus long-lining in waters deeper than 1,200 caught only small amounts of *Deania calceus*. However when long-liners are targeting *Centrophorus squamosus*, *Mora moro* and *Phycis blennoides*, in waters less than 800 m, discarding may be higher. In the case of *Centroscymnus crepidater*, discards will be higher at depths around 1,200 m, as this species occurs deeper.

All species reached maturity at a large percentage of their total size (Table 4). This tendency was most marked in the case of *Centrophorus squamosus*, where females attained maturity at 88% of maximum size. Female TL_{50} estimated by length at maturity of *Centroscymnus coelolepis* was 102.5 cm (Figure 5, Table 3). In the case of males while the greatest proportion mature was reached at 91 cm, 100% maturity was not achieved at any length. Estimated TL_{50} was 86.4 cm for males. *Centrophorus squamosus*' TL_{50} estimates were 101.82 cm for males and 126.24 cm for females. For *Deania calceus* TL_{50} estimates of 85.16 cm for males and 105.03 cm for females were obtained. The larger value for females agrees with the greater lengths attained. Estimates of length at 50% maturity of *Deania calceus* are the first for that species and indicate that it attains sexual maturity only at large size. As for the other species, males mature at a smaller proportion of maximum length (78%) as opposed to females (86%). The size selectivity of the fishing gear has important implications for *Deania calceus*, large females of which are able to avoid trawls but are caught on long-line.

All the species have low ovarian and uterine fecundity. In the case of *Centrophorus squamosus*, no gravid specimens were ever recorded so the only fecundity information relates to ovarian ova counts. For *Deania calceus*, few gravid females were ever recorded and all were from the western slopes of the Porcupine Bank. Mean length of near term embryos of *Centroscymnus coelolepis* was 30.7 cm. Whilst gravid *Centrophorus squamosus* were absent a recent record of a near-term embryo from Madeira (Hareide and Stehmann, pers comm.) was 33 cm TL with external yolk sac. Mid-term *Deania calceus* embryos had a mean length of 24 cm. Based on these measurements it is clear that *Centroscymnus coleolepis* in the range 30- 68 cm are missing, with *Deania calceus* specimens from at least 24 cm to 55 cm also absent.

The external and internal morphologies of squalid fin spines have been described in detail by Maisey (1979). The spines of *Deania calceus* (Plate 1) and *Centrophorus squamosus* (Plate 2) displayed the same morphology as those described by Maisey and by *Gullart* (1998) for *Centrophorus granulosus*. While the cap tissues cover the anterior-lateral faces of the spines of *Squalus acanthias*, they are reduced to one or more ribs in the species in the present study and in other deepwater squalids *Centrophorus granulosus* (*Gullart*, 1998) and *Etmopterus spinax* (Maisey, 1979). Significant positive regressions of spine width and total length were found and the growth rates of first and second spines were not significantly different (ANCOVA, $p>0.5$). Estimates of 21-70 years (*Centrophorus squamosus*) and 11-35 years (*Deania calceus*) were obtained from cross-sections of first dorsal spines. Agreement within 1 year was found for more than 93 % of *Deania calceus* and 88 % of *Centrophorus squamosus* first and second spines. The present data for *Deania calceus* were combined with published data for small specimens of this species (Machado and Figueiredo, 2000) and allowed for the construction of von Bertalanffy growth models (Table 4 and Figure 6).

Discussion

Commercial fishing on the continental slopes seems set to continue. This study shows that these deepwater sharks have conservative reproductive strategies that suggest that they may not sustain intensive exploitation. Their differing bathymetric distributions and the segregation of maturity stages within the species have important implications for fisheries management. *Centrophorus squamosus* occurs shallower and was probably more heavily exploited at first. Fishing developed on the upper slopes, moving progressively deeper (Charuau *et al.*, 1995). However the gravid portion of the population is totally absent from the area of the fishery. Gravid *Centroscymnus coelolepis* tend to occur in shallower waters than most of the population. Thus these females are more vulnerable. However trawlers now fish to depths of as much as 1,500 m and longliners are not constrained by depth. *Centrophorus squamosus* has a lower reproductive output than *Centroscymnus coelolepis* and may be considered more susceptible to over-fishing, though a large part of its range is outside the area of exploitation. Maximum catch rates of *Deania calceus* are within the range of both trawlers and longliners. However in depths around 700 m this species dominates the catch on longline (Clarke, 1999) and fishermen tend to avoid this depth, since this species is not marketable – other than its livers and fins.

The absence of smaller *Centrophorus squamosus* and *Centroscymnus coelolepis* from west of Ireland and Britain was reported by Girard and DuBuit (1999). This papers shows that smaller *Deania calceus* and *Centroscymnus crepidater* are also absent. A possible explanation for this absence is that they are in fact present in the study area but not selected by the trawl or long-line gears employed. However, several aspects of the Marine Institute deepwater survey programme suggest that this is not so. Commercial (13/0) EZ hooks selected for greater lanternshark *Etmopterus princeps* of as small as 27 cm TL (Clarke *et al*., 1999), Thus commercial longlines can select the entire free-swimming range of the species under study. Yano and Tanaka (1984) also, unsuccessfully used smaller hooks to target smaller squalid sharks. Selectivity experiments conducted during the 1997 trawl survey showed that the 105 mm cod end retained roundnose grenadier *Coryphaenoides rupestris* as small as 3 cm pre anal fin length, even when the cod-end liner was not attached (Clarke *et al*., 1999). *Coryphaenoides rupestris* of 3 cm pre-caudal fin length so it seems unlikely that small sharks could escape through the meshes of the cod-end. The selectivity of the long-lines for small sharks and of the trawls for small *C. rupestris* suggest that the absence of smaller specimens cannot be explained by the selectivity of the fishing gears used.

Trawls and long-lines are fundamentally different fishing methods. Trawls herd fish into the opening of the net, but fish are attracted to long-lines by the smell of the bait. This results in both size and species selection (Hareide, 1995). Long-lines tend to select for larger teleost fish (Hareide, 1995; Jørgensen, 1995). The present study shows that longlines selected for size ranges of *Centroscymnus coleolepis,* and *Deania calceus* not taken on trawl. These results support Gordon's (1999) view that long-lines are not size-selective for squalid sharks and demonstrate that commercial longline gear selects for the entire free-swimming size-range of these exploited squalid sharks in the NE Atlantic.

The estimates of TL50 for *Deania calceus* and *Centroscymnus crepidater* are the first for these species. These results show that mature female *Deania calceus* are more vulnerable to longline, but largely avoid trawl nets. As for the two larger species, *Deania calceus* reaches maturity at a large proportion of maximum size. In contrast, the smaller *Centroscymnus crepidater* reaches maturity at a smaller proportion of the maximum size attained by that species. Estimates of TL_{50} of *Centroscymnus coleolepis* and male *Centrophorus squamosus* from the present study agreed with those of Girard and Du Buit (1999) within 1 cm. These authors estimate for female *Centrophorus squamosus* was slightly lower (124 cm) than that of the present study (128 cm). This may reflect a slight tendency for larger females to be attracted to baited hooks, since Girard and Du Buit's (1999) study was based exclusively on trawl samples. However the evidence suggests that mature females are largely absent and gravid females totally absent from the Rockall Trough and Porcupine Bank. Yano and Tanaka (1988) reported substantially lower lengths at 50% maturity from Suruga Bay, Japan than in the NE Atlantic. In Japan 50% of males and females were reported to be mature at 70 cm and 95 cm-99 cm respectively while in the present study the corresponding lengths were 86 cm and 102 cm. However maximum length in Suruga Bay, respectively 92 cm and 108 cm for males and females (Yano and Tanaka, 1984), was also less than observed in the present study, though in both cases 50% maturity was obtained at similar percentages of maximum length. Whether this is due to environmental differences (Girard and Du Buit, 1999) or other factors is unclear.

Length of gestation is unclear but it may be as long or longer than the 22-month period in the related species, spurdog *Squalus acanthias* (Ford, 1921, Templemann, 1944). Clark and King (1989) found only 25% of females in New Zealand in any stage of reproductive development and suggested a resting period of 4 years between reproductive episodes. In the present study only 10% of females showed signs reproduction (stages 3-6), though migration may be a reason for this. If the gestation period is of similar duration to that of *Squalus acanthias* and resting period as long as 4 years females may only produce one or two litters of around 11 pups in their entire life.

Gravid female *Centrophorus squamosus*, absent from west of Ireland and Scotland have been recorded in Madeira (Hareide and Stehmann, pers. comm.) and Portugal (Figueiredo, pers. comm.). However the present study did not record any gravid females from west of Ireland or Scotland despite intensive sampling. This finding agrees with that of Girard and Du Buit (1999). Furthermore, less than 30% of female *Centrophorus squamosus* in that study were mature. Analysis of uterine widths of *Centrophorus squamosus* show that a small proportion of the females west of Ireland and Scotland had indeed already carried pups (Clarke *et al. in press*). Similarly, small *Deania calceus* not present west of Ireland are found off Portugal (Machado and Figueiredo, 2000). Clark and King (1989) found that smallest *Deania calceus* associated with large females in waters to about 800 m, and a progressive increase in their numbers moving west to east around North Island New Zealand. This finding may indicate a cyclical migration with small sharks present in localised areas. This indicates a migration linked to the reproductive cycle. Migration was suggested by Girard and Du Buit (1999) to explain the absence of smaller specimens of these species from west of Ireland and Scotland and it was suggested that they might be present on the Mid Atlantic Ridge. Whilst migration does explain the absence of gravid *Centrophorus squamosus* from west of Ireland and Britain, one of the few studies of the Mid-Atlantic Ridge (Hareide and Thomsen, 1997) did not record smaller specimens of these species there. The likelihood that many deepwater species are highly migratory underlines the necessity for co-operative international research and future investigations of these species should encompass as wide a geographic range as possible.

Limited information on the combined landings of *Centrophorus squamosus* and *Centroscymnus coelolepis* are available (Anon, 2000). But in the case of *Deania calceus* and *Centroscymnus crepidater*, that are mainly discarded it is difficult to quantify catch levels. Connolly and Kelly (1996) provided the first estimates of the tonnage of *Deania calceus* discarded in the Rockall Trough. The estimate of discarding from the present study (745 t) for the Rockall Trough and the slopes of the Porcupine Bank was lower than Connolly and Kelly's (1996) estimate for the Rockall Trough. Connolly and Kelly (1996) estimated discard rates for *Deania calceus* using roundnose grenadier *Coryphaenoides rupestris* as the target species.

Despite their wide usage in ageing of elasmobranchs (Cailliet, 1990), vertebral centra did not prove useful for the species under study. This finding agrees with previous work on the squalid shark *Squalus acanthias* (Cailliet *et al*., 1983; Polat and Gumus, 1995; Soldat, 1982). Maisey (1979) provided a detailed structural study of squalid spines. The spines of these species shared the morphology of those species described by Maisey (1979) and by Guallart (1998) for *Centrophorus granulosus*. Dorsal spines appear to offer the only means of age estimation of squalid sharks. The present study provides a method for estimating age of *Centrophorus squamosus*. The age estimates for the species under study are based on the assumption that each band was formed annually and after birth. Guallart (1998) used width measurements of the inner trunk layer of full-term embryos to estimate the extent of embryonic growth in the spines he used for age estimation of *Centrophorus granulosus*. This appears to be the only means by which to adjust age estimates for embryonic growth. However in the present study this is not possible due to the lack of full term embryos. The von Bertalanffy growth parameters presented in this work are the first for Deania caleus. Indeed the Guallart (1998) presents the only other published growth information for a squalid sharks – other than *Squalus acanthias*.

As stated by Beamish and McFarlane (1983) validation of age should be carried out. However this was not possible in the present study. McFarlane and Beamish (1987) noted that the mark visible in cross section was also annual. However, they did not use these annuli for ageing, citing the difficulty in processing, the cap providing a much easier method, and because of the loss of bands due to wear at the tip. The age estimates obtained from cross-sections in the present study, can be considered as conservative because each band was counted and no complete marks were eliminated. Further work on age estimation is required, before the process described by Cailliet *et al*. (1986) is complete. In order to complete this task, validation of age (Beamish and McFarlane, 1983) will be required. Validation of age by means of a tissue-marking dye (McFarlane and Beamish, 1987) is likely to be very difficult to achieve for species that occur in depths of more than 500 m. However Yano and Tanaka (1986) successfully attached transmitter-tags to specimens of *Centrophorus acus*, which then returned to their normal depth ranges. Therefore tagging experiments of this and other species of deepwater sharks may be possible.

Concerns about the sustainability of fisheries, in particular for sharks, have prompted the FAO to recommend that national management plans be formulated. Such plans may be hampered by lack of scientific information. However in view of the rapid development and diversification of the fisheries the best available data should be employed. The current work and other studies of have produced life history information on squalid sharks. However considerable uncertainty exists in a number of critical data and parameters important for assessment and management of the northeast Atlantic deepwater fishery. Chief among these are estimates of total catch by species, validation of age and a characterisation of the distribution of juveniles. Models incorporating known life history parameters, such as life tables seem to offer the best option and should be applied to target and by-catch species alike. The prominence of squalid sharks in the multi-species deepwater ecosystem, the effects of increased mortality on deepwater stocks and a lack of understanding of the impact these sharks have on other important species constitute strong justification for the immediate implementation of a management plan. The immediate challenge is to ensure that the available international data is collated, assessed and promptly incorporated into a management regime for the deepwater fishery.

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Table 1. Official landings (tons) of sharks in ICES Sub-Areas VI and VII by country. Only France provides data for deepwater species (*Centrophorus squamosus* and *Centroscymnus coelolepis*). Data for other countries include continental-shelf species.

	Faroes	France	Germany	Spain	Norway	England/Wales	Scotland	Total
1988						19	0	19
1989						32	8	40
1990		302				38	5	345
1991		1,184				201	53	1,438
1992	3	2,802				503	133	3,441
1993		3,426	124			821	447	4,818
1994		3,609	395			742	727	5,473
1995		3,417	2			1,315	782	5,516
1996		3,284	276			1,345	555	5,460
1997		2,984	66	152		2,721	301	6,224
1998		2,567	65	645		1,812	501	5,590
1999		1,839	189	199	13	1,403		3,743

Table 2. Details of surveys from which samples and information for this study were obtained.

Vessel	No. Hauls	Date	Areas	Depth Range (m)
Mary M	26	September, 1996	1 - 8	560 - 1,102
Skarheim	32	August, 1997	1 - 5	292 - 2,925
Mary M	22	October/November 1997	1 - 5	520 - 1,158
Loran	38	December, 1999	5 – 8	514 - 1,974
An Capall Bán	19	August, 2000	5 and 13	171 – 1,316
An Capall Bán	28	September, 2000	5	170 – 1,800

Table 3. Results of Probit analysis of maturity showing estimated length (cm) at 50 % maturity (TL_{50}). Maximum length is given in each case and the ratio of length at 50 % maturity to the maximum. Ovarian fecundity (above) and uterine fecundity (below) presented for each species

Species	Sex	TL_{50}	95 % C. I. Lower	95 % C. I. Upper	Maximum Length	Ratio	Fecundity
Centroscymnus coleolepis	female	102.5	97.79	105.73	121	0.85	13 (10-21) 13 (8-21)
Centroscymnus coleolepis	male	86.4	82.48	88.44	109	0.79	
Deania calceus	female	105.03	102	109.54	119	0.86	13 (6-14) 8, 14
Deania calceus	male	85.16	83.86	86.74	109	0.78	
Centrophorus squamosus	female	128.27	126.2	130.7	145	0.88	8 (6-11) No data
Centrophorus squamosus	male	101.82	100.2	103.14	122	0.83	
Centroscymnus crepidater	female	68.13	62.10	71.37	99	0.69	
Centroscymnus crepidater	male	51.89			92	0.56	

Table 4. Estimates of the parameters of the von Bertalanffy growth model for *Deania calceus* based on age estimation data from the first dorsal spine in the present study and from empirical growth data presented by Machado and Figueiredo (2000).

Sex	Estimate	S.E.	95 % confidence limits	
Females				
K	0.077	0.0126	0.052	0.102
t_0	-0.933	0.6809	-2.289	0.422
L_∞	119.303	6.6700	106.024	132.582
Males				
K	0.135	0.0190	0.098	0.173
t_0	0.165	0.5433	-0.917	1.247
L_∞	93.516	2.8231	87.895	99.138

Table 5. Estimates of total discards from trawlers of *Deania calceus* in the Rockall trough and Porcupine slopes in 1996.

Fleet	Discard Rate Kg / tonne target species	Landings t gutted	Landings t round	Discard t	Discard numbers
French and Scottish	138.86	3,339	5,367	745	285,322

Table 6. Percentage discard rates during long-line survey in December 1999 for *Deania calceus and Centroscymnus crepidater*.

Area	Haul	Depth m	Total Catch kg	*Deania calceus* kg	*Deania calceus* %	*Centroscymnus crepidater* kg	*Centroscymnus crepidater* %
5	1	988	2555	1210	47.4	123.1	4.8
5	2	748	1401	768	54.8		
5	3	557	1087	520	47.8		
5	4	1277	480	93	19.3	47.8	10.0
5	6	745	1644	1029	62.6		
6	8	585	604	22	3.7		
6	9	765	856	514	60.1		
6	10	944	1572	535	34.1	30.6	1.9
6	11	1097	2491	990	39.8	7.2	0.3
6	12	1304	935	23	2.5	22.9	2.4
6	13	1378	1049	19	1.8	82.3	7.8
7	14	1227	1002	67	6.6	73.8	7.4
7	15	1038	653	174	26.6	35.2	5.4
7	16	907	1333	453	34	10.9	0.8
7	17	1403	867	10	1.2	75.2	8.7
7	18	695	640	9	1.4	15.9	2.5
7	19	1209	983	70	7.1	23.4	2.4
8	20	1251	694	356	51.2	18.5	2.7
8	21	610	1041	600	57.7	6.7	0.6
8	22	883	1124	852	75.8		
8	28	1444	312	22	7	37.0	11.9
8	30	1032	155	23	15	2.1	1.4
8	31	849	102	6	5.7		
8	32	995	204	22	10.6	11.7	5.7
8	33	988	435	132	30.4	8.8	2.0
8	34	1105	351	135	38.4	14.6	4.1
8	35	1071	742	106	14.3	11.7	1.6
8	36	1071	527	127	24	26.3	5.0
8	38	1125	264	129	48.9	10.9	4.1

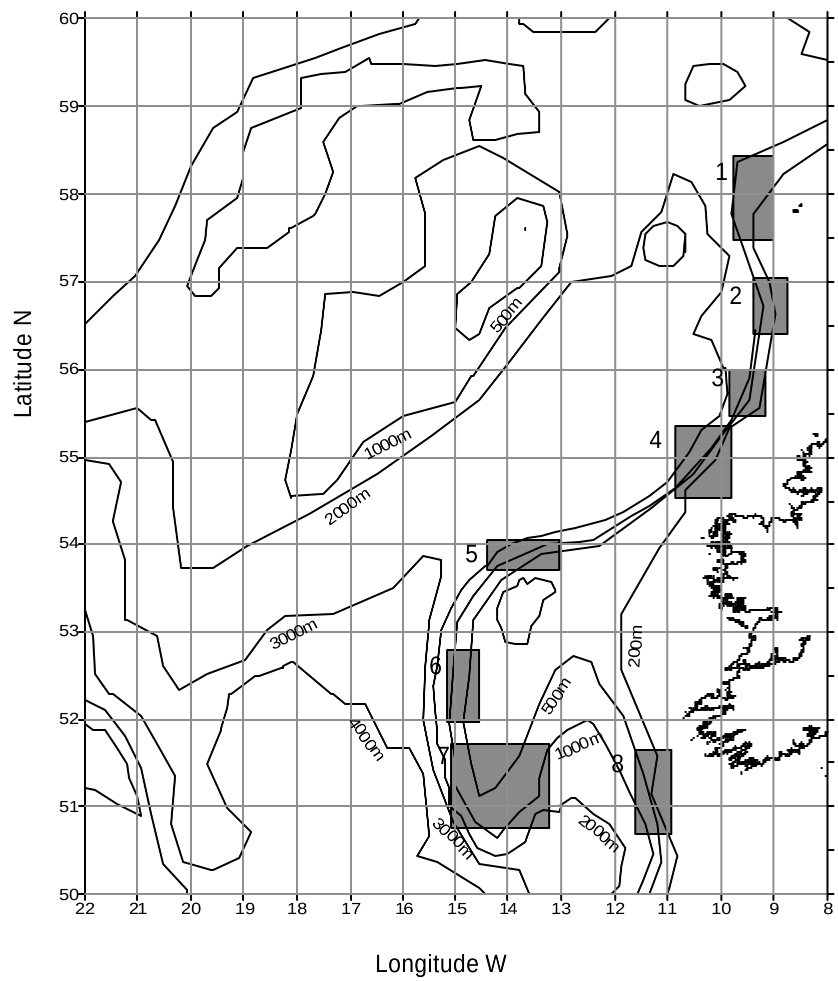


Figure 1. The 8 areas where stations were completed and shark sampling carried out.

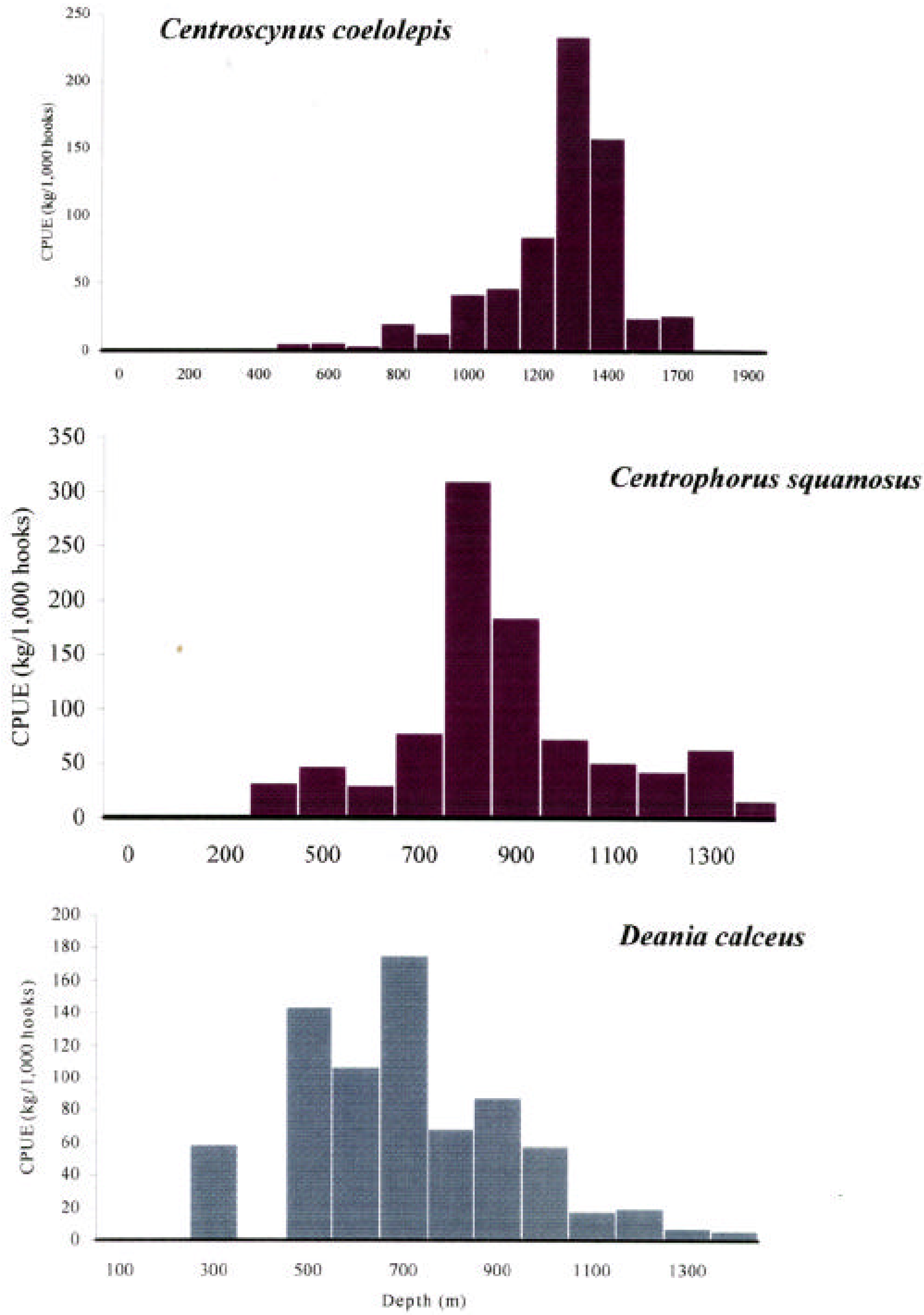


Figure 2. Catch rates (kg/1,000 hooks) from longline surveys 1995-2000. Each 100 m interval indicated by its lower value.

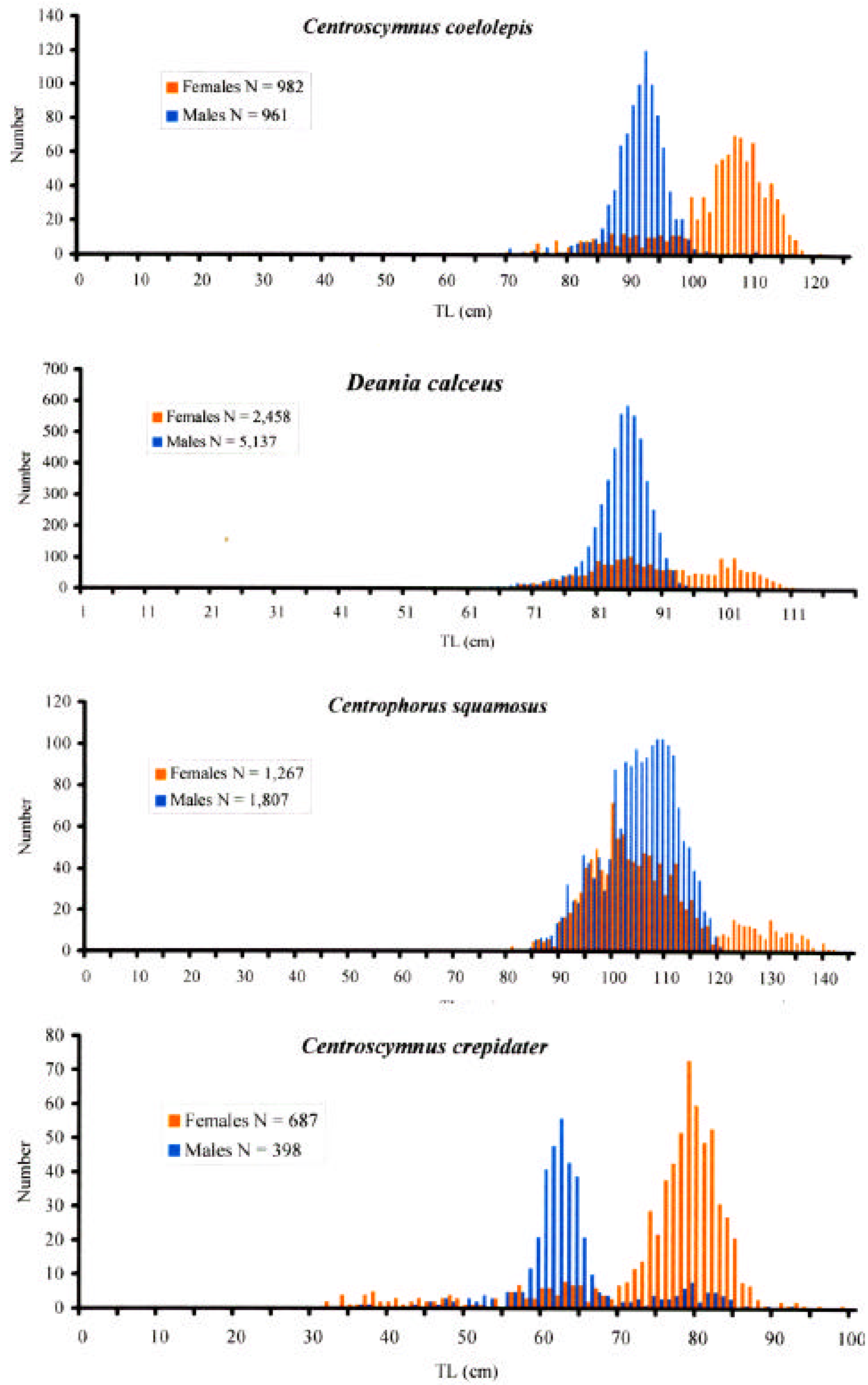


Figure 3. Length frequencies of deepwater sharks from Irish Marine Institute deepwater surveys 1996-2000 of the eastern slopes of the Rockall Trough and Porcupine Bank.

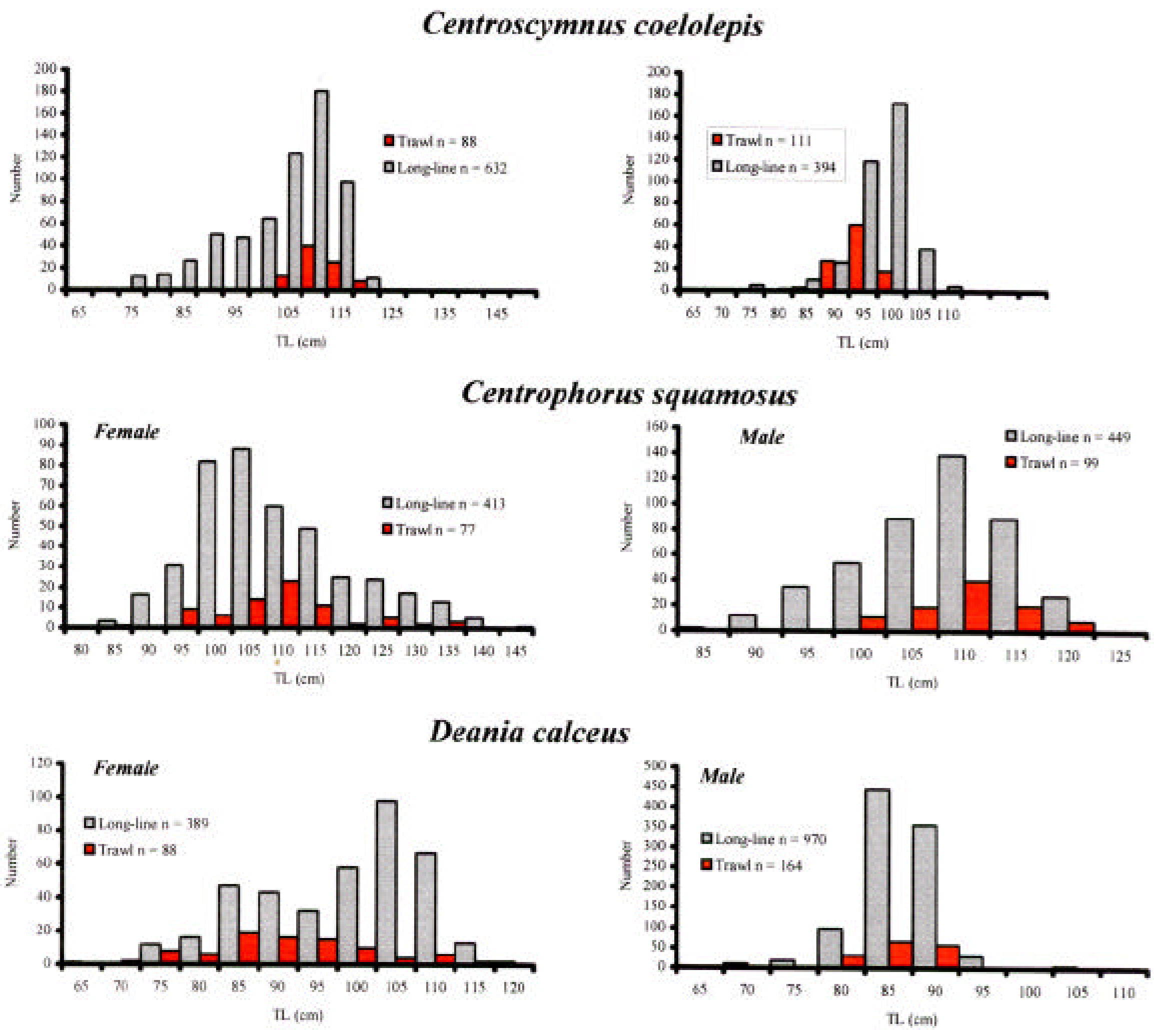


Figure 4. Comparison of length frequencies from trawl and longline surveys of the Rockall Trough in 1997.

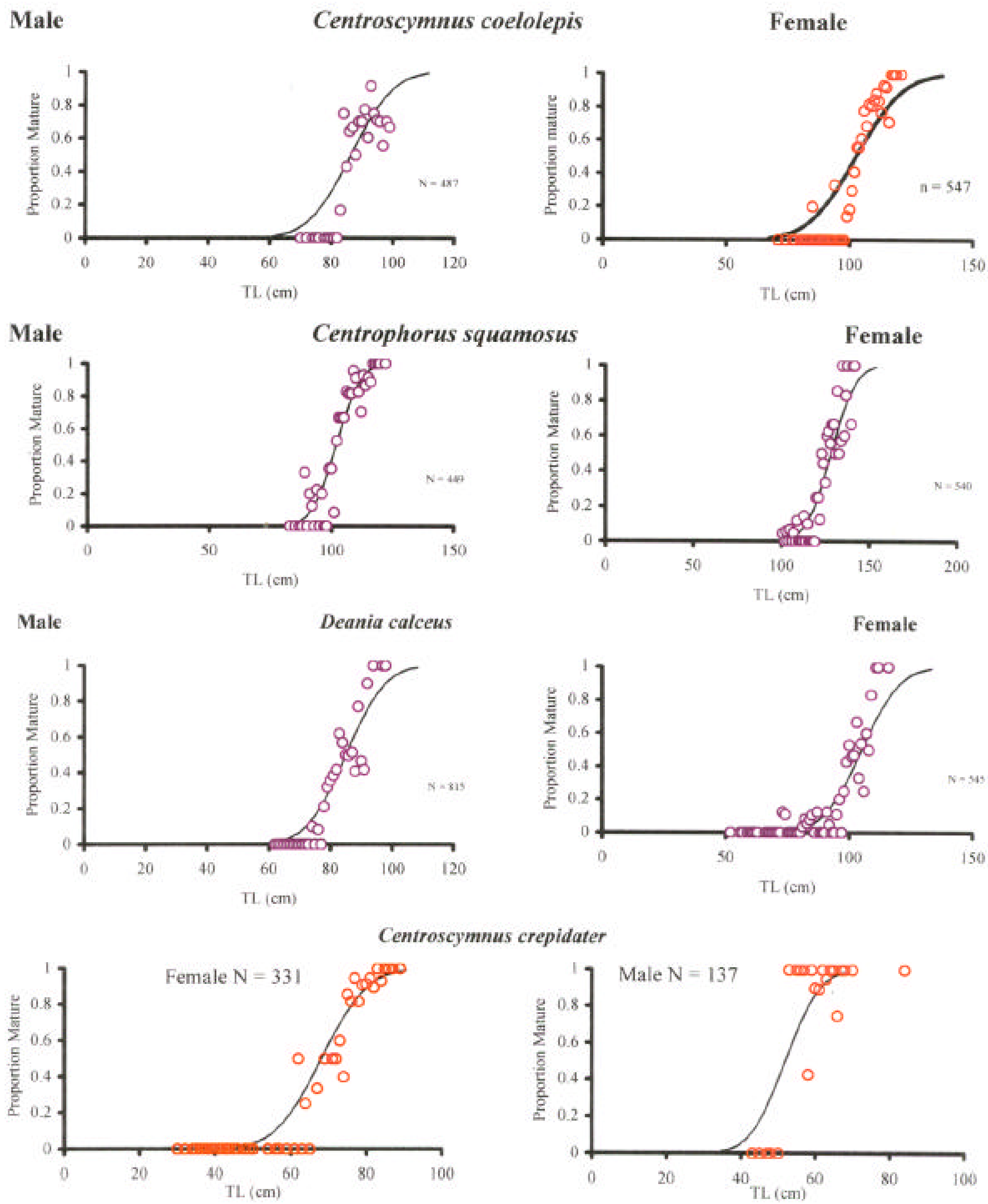
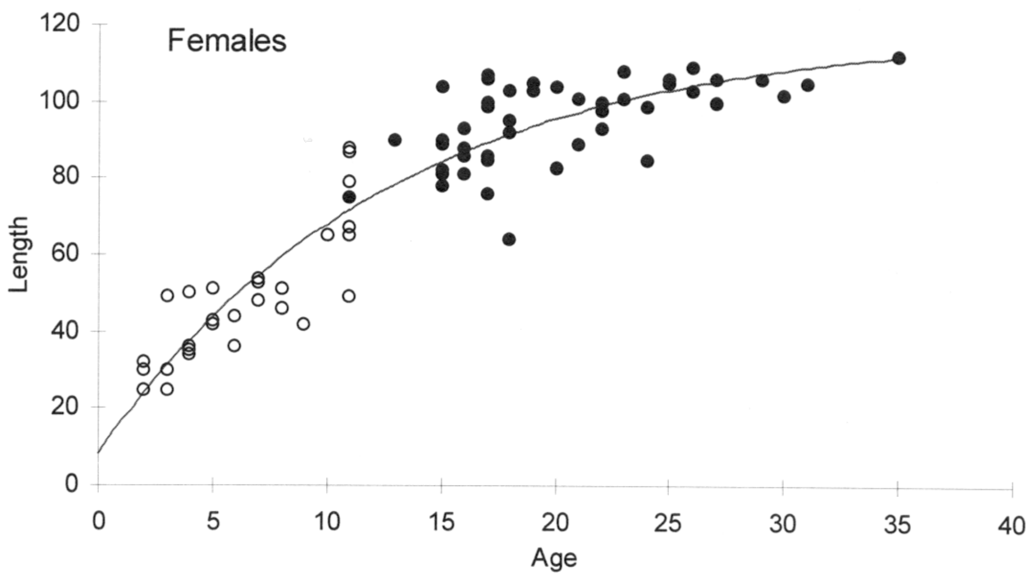


Fig. 5. Maturity ogives for sharks species based on probit analysis of proportions mature by 1 cm length increment.



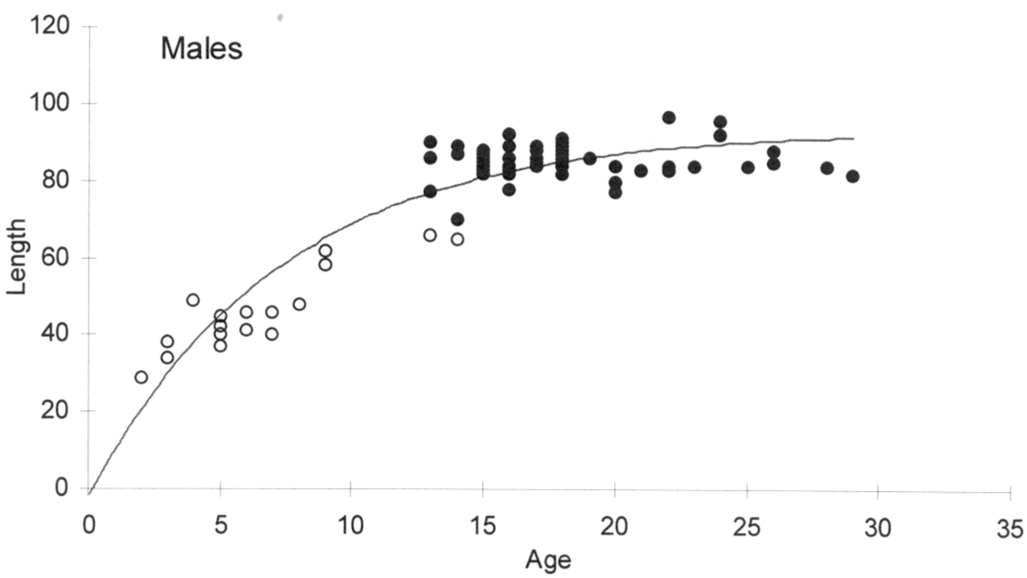


Fig. 6. Von Bertalanffy growth models for *Deania calceus* based on age estimate data from the current study – closed circles – and frompublished work by Machado and Figueiredo (2000) – open circles.

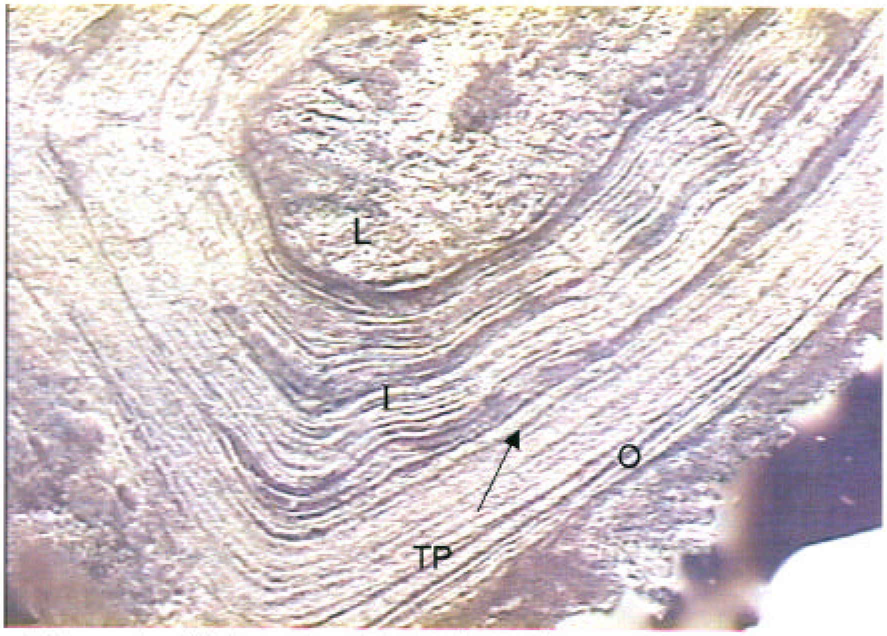


Plate 1: Cross section of 1st dorsal spine of *Deania calceus*. I , inner trunk layer, TP, trunk primordium, O, outer trunk layer, L, lumen

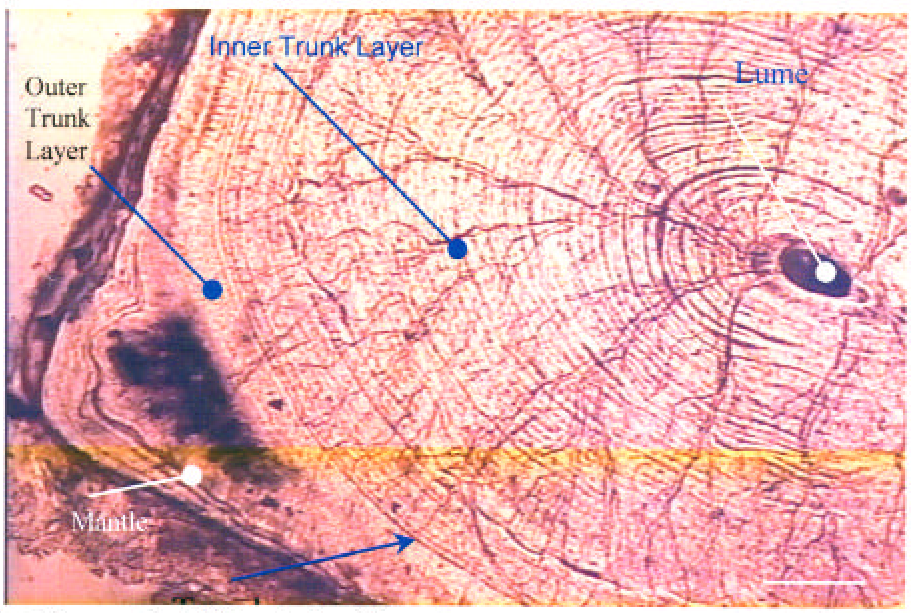


Plate 2: Cross section of 1st dorsal spine of *Centrophorus squamosus*.