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Comparisons of Trawl and Longline Catches of Deepwater Elasmobranchs West and North of Ireland

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Abstract

A comparison was made between catches from deepwater trawl and longline surveys (1993–2000) in the Northeast Atlantic. Longline catches were dominated by elasmobranchs, particularly squalid sharks and species numbers were low. Trawl catches had higher species numbers, with more teleosts, though elasmobranchs were still an important component. Species composition of the catch was depth dependent. Comparative trawl and longline surveys of the eastern and southern slopes of the Rockall Trough (west and north of Ireland) were used to examine size-selectivity. Trawls and longlines selected for significantly different size frequency distributions of *Centroscymnus coelolepis* and *Deania calceus*, though not for *Centrophorus squamosus*. These data highlight some important aspects of behavior of the species studying relation to fishing gears. Smaller *C. coelolepis* were selected by longlines than trawls, suggesting that smaller sharks were present at a considerable height above the seabed, out of reach of trawls, but attracted to baited hooks. In the case of *D. calceus*, larger females were selected by hooks, but were not present in trawl catches, possibly indicating their ability to escape towed gears. Trawl selectivity ogives were constructed for *D. calceus* and ogives for *C. coelolepis* and *C. squamosus* were simulated, using available data. Results suggest that longlines are not as selective for *C. coelolepis* as trawls. Selectivity ogives for *D. calceus* were similar in form, but longlines selected bigger individuals. Life history studies suggest that these species cannot sustain high fishing pressures. The implications of these results for the management of fisheries taking elasmobranchs are discussed.

Key words: catches, deepwater, longline, Ireland, shark, squalids, trawl

Introduction

In the Northeast Atlantic, deepwater elasmobranchs are taken in several deepwater fisheries. Most deepwater fishing activity occurs west and north of Ireland. Two species of sharks are routinely landed for their flesh and livers, the leafscale gulper shark (*Centrophorus squamosus*) and the Portuguese dogfish (*Centroscymnus coelolepis*). These species are collectively called "siki" in French fishery records (Gordon, 1999) though they are also marketed elsewhere under this name. French vessels catch these species in the mixed-species trawl fishery. Spanish longliners target deepwater sharks (Pineiro *et al*., 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 Ireland and trawlers 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. In addition to trawl and longline, there are fisheries for deepwater sharks using gillnets and tangle nets, but there are no catch or effort data available for these gear types. Smaller species include *Centroscyllium fabricii* and *Centroscymnus crepidater* (Lorance and Lespagnol, 2000). Considerable progress has been made by some countries in collecting deepwater shark data, though data are still incomplete. Table 1 presents landings data for large squalid deepwater sharks, mainly *C. squamosus* and *C. coelolepis* and other sharks, some of which are deepwater species.

Relatively few studies on deepwater elasmobranchs have been reported in the scientific literature. The majority deal with members of the Squalidae, but little attention has focussed on the impacts of fisheries on these species, despite their commercial importance in several regions of the world. The ICES Working Group on the Biology and Assessment of Deep-sea Fisheries Resources and Working Group on Elasmobranch Fish have run some preliminary assessments of these species since 2000 and the results to date are presented in Anon. (2000; 2002a; 2002b) and Clarke *et al.* (2003). Given these species are taken by several gears; it is prudent to examine the properties of each so that rational management decisions can be made concerning these fisheries. This paper presents information on catch composition, gear selectivity and comparative size distributions of some deepwater elasmobranchs taken by commercial trawls and longlines.

TABLE 1. Official landings data for deepwater sharks (tons) as reported to ICES (unpubl. data) for Sub-areas VI and VII. Data for deepwater sharks represents landings of *Centrophorus squamosus* and *Centroscymnus coelolepis*. Landings of other sharks include some deepwater species.

Year	*C. squamosus* and *C. coelolepis*		Various species	
	VI	VII	VI+VII	Total
1991	944	265	254	1 463
1992	1 953	878	639	3 470
1993	2 454	857	1 392	4 703
1994	2 198	1 363	1 864	5 425
1995	1 784	991	2 099	4 874
1996	2 374	754	2 176	5 304
1997	2 222	571	3 240	6 033
1998	2 081	673	3 023	5 777
1999	2 123	440	2 283	4 846
2000	3 040	621	737	4 398
2001	3 787	1 032	593	5 412
Total	24 960	8 445	18 300	51 705

Materials and Methods

The present study is based on three trawl and three longline surveys undertaken during 1993–2000 on the Rockall Trough and Porcupine Bank, between 50°N and 59°N in the depth range from 500 to 2 000 m (Table 2). Fishing was carried out in eight fixed areas (Fig. 1) of the continental slope from 500 m to 1 300 m. Some deeper settings were made during longline surveys. Commercial fishing gears were used in these surveys. Trawl surveys used a "bobbin" trawl (Gundry's© Ltd.) with a 105-mm mesh cod-end and 25 mm small-mesh liner. The foot-rope length was 23 m, with rubber discs of 40 cm. The bridles comprised of 92 m of singles and 46 m of doubles. Trawl hauls ranged in duration from 135 to 380 minutes. Longline surveys used the "Autoline" system with main lines of 9 mm or 11.5 mm diameter, with Mustad© size 13/O EZ and smaller numbers of size 7/O EZ hooks. Snoods were 40–70 cm in length attached to the main line at 1.4 m intervals. Bait consisted of squid (60%) and mackerel (40%).

Specimens were identified according to Compagno (1984) and McEachran and Branstetter (1984). Total length (cm), 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 lower than the actual length of the fish. All specimens caught were measured and weighed except during the 1996 trawl survey, when the weight of *Deania calceus* was estimated from a sub-sample and raising factor for each haul (Connolly and Kelly, 1996).

Catch rates expressed as kilograms per 1 000 hooks were calculated for *Centrophorus squamosus, Centroscymnus coelolepis* and *Deania calceus*, based on pooled data from the longline surveys.

The ratio of elasmobranchs to teleosts was calculated for each area. The percentage of total catch by 200 m depth-interval was calculated from comparative trawl and longline surveys of the eastern and southern slopes of the Rockall Trough in 1997.

Length-frequency distributions (5 cm groups), separated by sex, for *Centrophorus squamosus, Centroscymnus coelolepis* and *Deania calceus* were pooled by gear type (trawl, longline). The Kolmogorov-Smirnov Two Sample Test (Sokal and Rohlf, 1995) was used to test for significant differences between length frequencies from trawl and longline catches. This is a non-parametric test for ranked data. As such, it is robust to imbalance of sample size in the length frequencies compared. This analysis was performed for the 1997 trawl and longline survey data.

Comparative selectivity ogives for trawls and longlines were constructed for *Deania calceus, Centrophorus squamosus* and *Centroscymnus coelolepis*. Selectivity

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

Vessel	Type	No. of hauls	Month and Year	Depths (m)
Mary M	Trawl	26	November, 1995	740–1 400
Sea Sparkle	Longline	22	November/December 1995	542–1 332
Mary M	Trawl	26	September, 1996	560–1 102
Skarheim	Longline	32	August, 1997	292–2 925
Mary M	Trawl	22	October/November 1997	520–1 158
Loran	Longline	38	December, 1999	514–1 974

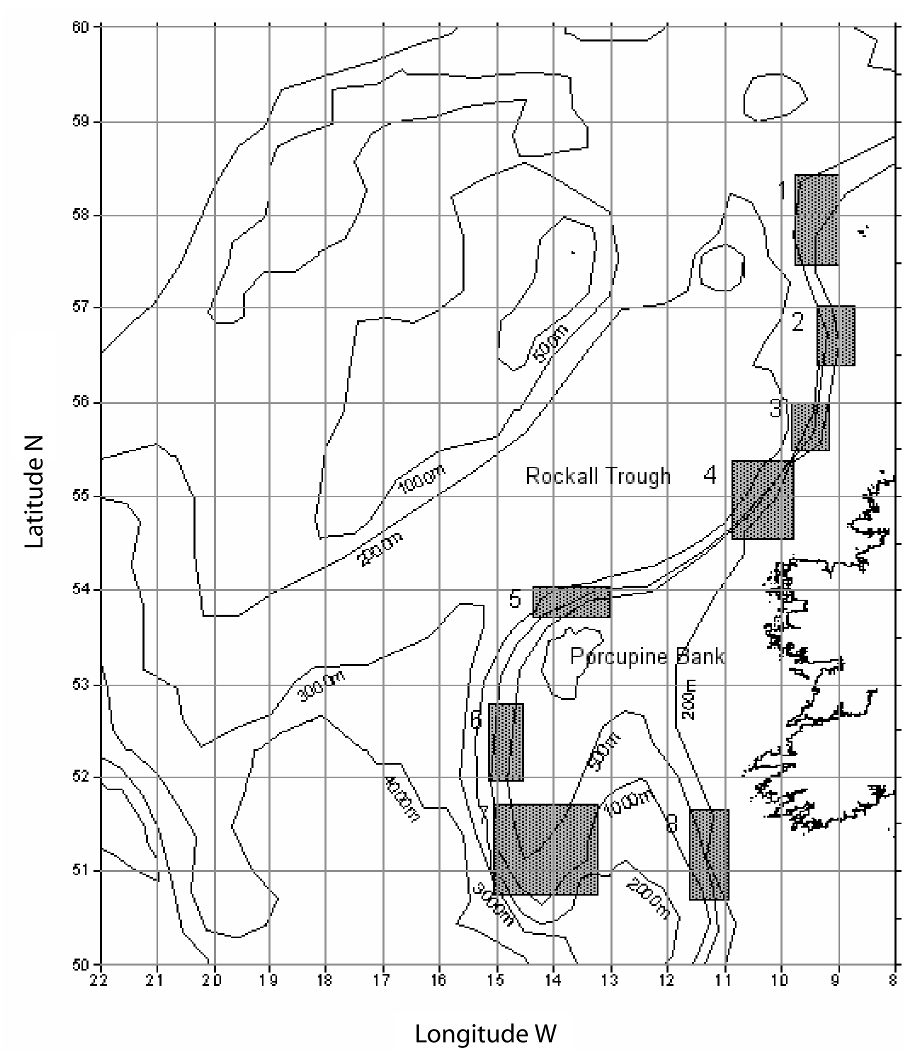

Fig. 1. The eight areas where stations were completed and shark sampling carried out. Areas 1–5 were in the Rockall Trough and areas 6–8 were in the Porcupine Bank area.

ogives were estimated using the method of Sparre *et al*. (1989) where the descending limb of a catch curve is extrapolated backwards to achieve an estimate of the non-fully selected age groups. The difference between these expected catch numbers and the observed values provide an estimate of the combined effect of recruitment and selectivity of the gear for these age groups. This approach assumes that mortality of fish not fully recruited to the fishery is the same as that estimated from the catch curve. This assumption is probably not valid in the case of sharks, where mortality of neonates and young juveniles is usually considered higher than mortality of the older age-classes. However, the approach offers a simple means to obtain first estimates of the selectivity patterns for these species. The logistic model was assumed to describe the selectivity pattern for each species. Input data for *D. calceus* were age based catch curves from the August 1997 trawl survey and the December 1999 longline survey. Initial runs displayed little difference between ogives for males and females, so data by sex were combined.

It was not possible to produce a catch curve for *Centroscymnus coelolepis* or *Centrophorus squamosus,* because von Bertalanffy growth parameters were not available. To simulate a selectivity ogive, length-frequency distributions from the 1997 trawl and longline surveys were used to produce length converted catch curves (Pauly, 1984). In the absence of parameters for the von Bertalanffy growth function, the following hypothetical parameters were chosen:

C. coelolepis $K = 0.09$, $t_0 = 0$, $L_\infty = 115$ cm
C. squamosus $K = 0.09$, $t_0 = 0$, $L_\infty = 136$ cm

Results

Depth distribution of the species is illustrated as catch rates in kilograms per 1 000 hooks, from longline surveys (Fig. 2). The habitual depth range (300–1 800 m) of each species was sampled. *Centrophorus squamosus* and *D. calceus* were most abundant between 700 m and 900 m. *Centroscymnus coleolepis* was more abundant deeper (1 300 m). Table 3 shows the relative proportions of elasmobranchs and teleosts in trawl and longline catches in each area (Fig. 1). In longline catches, the elasmobranchs outnumber teleosts in all areas, except 4, where shallower hauls took the dominant species (ling and tusk) shallower than 500 m, in large proportions. In trawl catches elasmobranchs were still well represented, but the ratio favoured teleosts. Clearly, the number of species is greater in trawls, and though elasmobranchs are present, they are a less important component of the catch. In longline catches, elasmobranchs dominate. There is also a trend for greater numbers of species in catches southwards.

Figure 3 shows the percentage catch composition by species from comparable trawl and longline surveys of the continental slopes of the Rockall Trough in 1997. Squalid sharks dominate longline catches, deeper than 500 m, in this area. Elasmobranch dominance increases with depth,

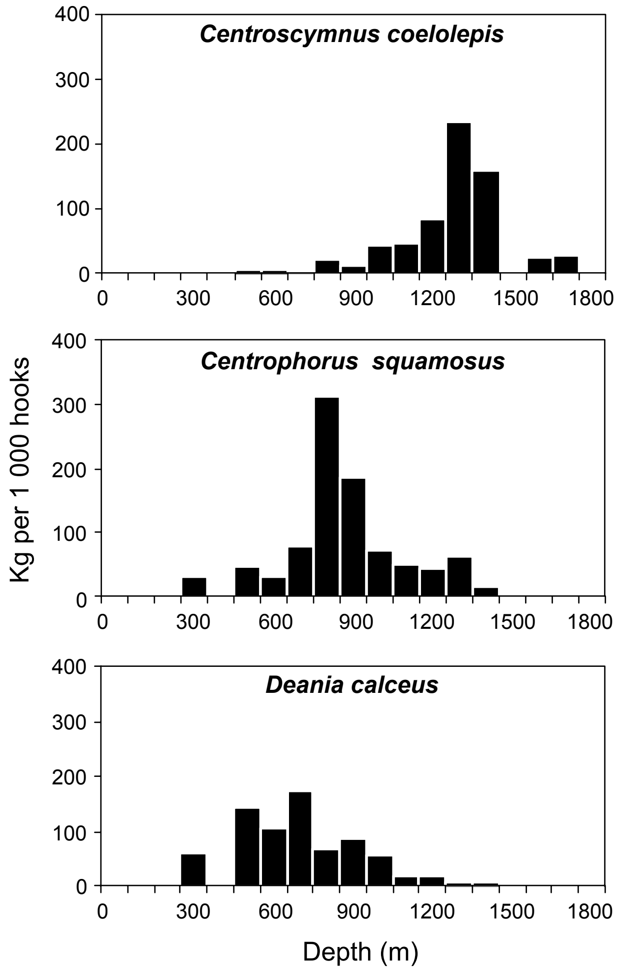

Fig. 2. Catch rates (kg/1 000 hooks) from longline surveys 1995–2000. Each 100 m interval indicated by its lower value.

with catches deeper than 1 300 m almost totally composed of squalid sharks (98%). The non-commercial species, *D. calceus*, is the largest component of the catch between 500 and 700 m and squalids are the dominant species at all depths in longline catches. In contrast, trawl catches display a greater diversity of species, with less dominance. The roundnose grenadier (*Coryphaenoides rupestris*), a teleost, dominated at depths greater than 700 m, but the remainder of catches at these depths comprised a diversity of species, both chondrichthyan and teleost. The large commercial squalids, *C. squamosus* and *C. coelolepis*, were the most abundant in trawl catches. Whereas teleosts comprise a higher component of trawl catches than elasmobranchs, it is clear that the latter group is well represented in catches from towed gears. The percentage species composition on the continental slopes of the Porcupine Bank, from longline catches, is illustrated in Fig. 4. The differing species composition in this more

TABLE 3. Relative numbers of elasmobranchs and teleosts from trawl and longline surveys of the same areas of the eastern and southern slopes of the Rockall Trough in 1997.

Gear	Area	No. of hauls	Depth	No. of elasmobranchs	No. of teleosts	Ratio elasmobranchs: teleosts
Longline	1	4	691–1 350	9	3	3.0
	2	4	684–1 166	10	8	1.3
	3	4	775–1 401	11	9	1.2
	4	9	353–1 357	12	13	0.9
	5	7	637–1 418	15	7	2.1
Trawl	1	4	654–1 159	5	14	0.4
	2	3	880–1 105	6	18	0.3
	3	4	550–1 150	7	28	0.3
	4	7	520–1 100	7	34	0.2
	5	3	1100–1 174	8	20	0.4

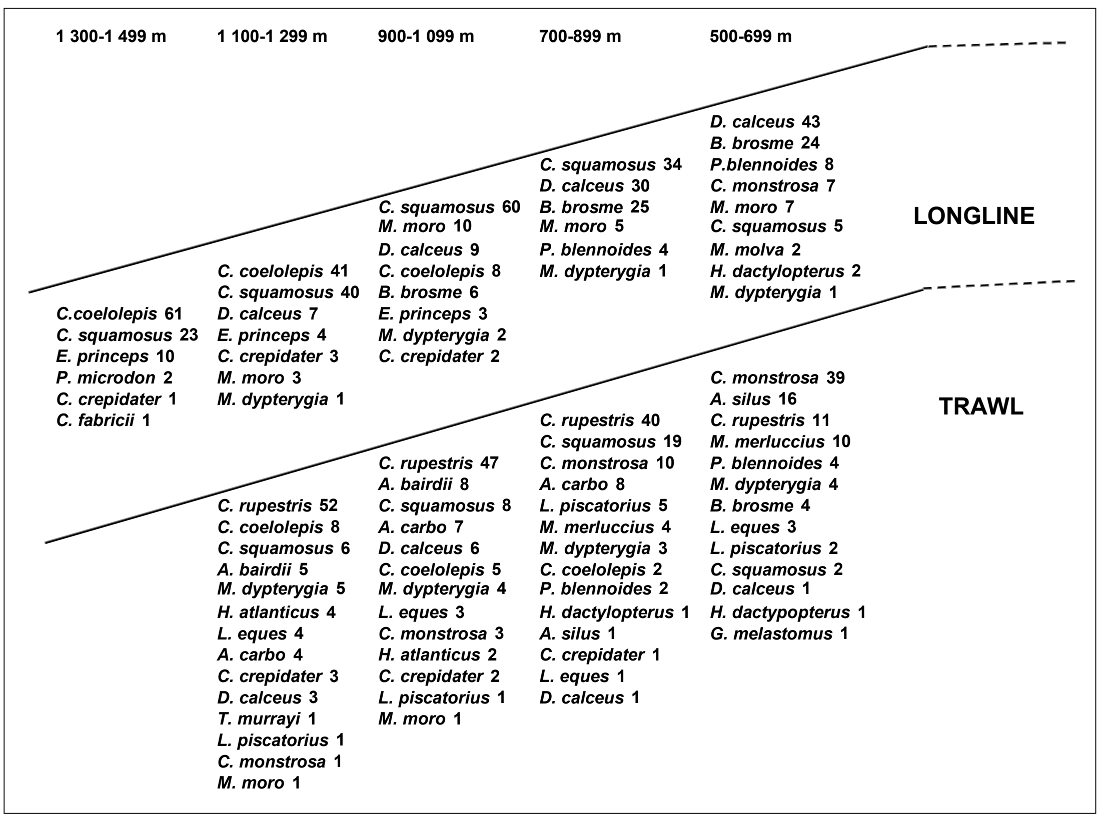

Fig. 3. Percentage composition of total catch by species in trawl and longline catches from the continental slopes of the Rockall Trough. Percentages rounded to nearest integer, and presented by 200 m depth interval.

southern region is evident. *D. calceus* is dominant over a range of depths here, comprising more than 60% of the catch between 700 and 900 m.

The percentage catch rate of *D. calceus* is presented in Table 4. The highest proportion of *D. calceus* in the catches occurred on the southern slopes of the Rockall

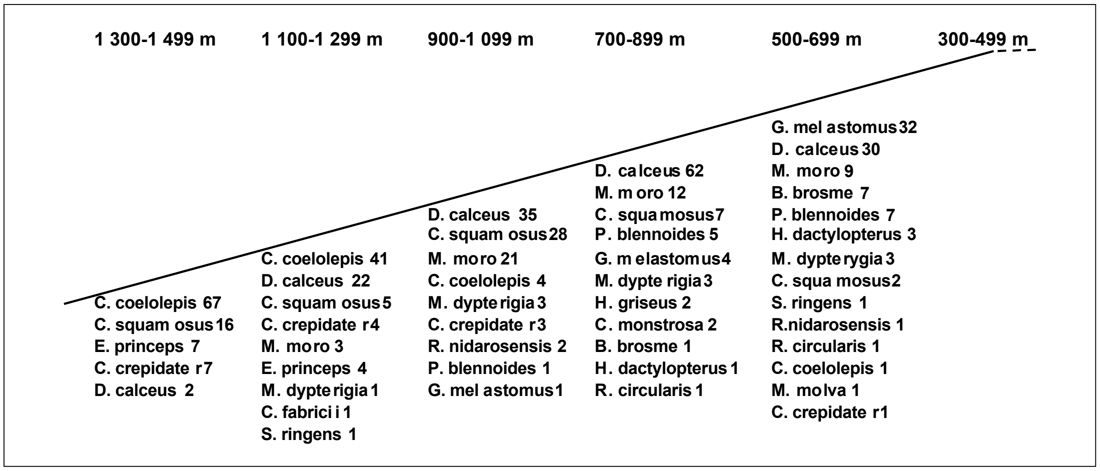

Fig. 4. Percentage composition of total catch by species longline catches from the continental slopes of the Porcupine Bank. Percentages rounded to nearest integer, and presented by 200 m depth interval.

Trough (Area 5), where it comprised more than 60% of the catch. It accounted for more than 30% of the total catch on the longline survey of December 1999. However catch rates are depth dependent and longlining in waters deeper than 1 200 caught only small amounts of *D. calceus*. However, when longliners targeted *C. squamosus*, *Mora moro* and *Phycis blennoides*, in waters less than 800 m, catch rates of non-commercial sharks were higher.

Length frequencies show the absence of smaller specimens of these species from the study area (Fig. 5). These length frequencies are based on trawl and longline surveys spanning all the areas. Trawls and longlines selected for significantly different (Kolmogorov-Smirnov two-sample test $P<0.05$) size ranges of *C. coelolepis* and *D. calceus*, though not *C. squamosus* (Fig. 5). Large female *D. calceus* were well represented in longline catches, but less well represented in trawls, indicating that large, mature females can avoid these nets.

Selectivity ogives for the three species studies are presented in Fig. 6, 7 and 8. Selectivity ogives for *D. calceus* (Fig. 6) display similar shapes for both gears and sexes. The model predicts that longlines select for older (larger) sharks than trawls. Age_{50} was estimated at 11 years for trawls and 15 years for longlines. Results of the simulated ogive analysis for *C. coelolepis* (Fig. 7) suggest different selectivity patterns between trawl and longline. For females, longline appears to be less selective than trawls for younger (smaller) sharks. The ogive for longline caught females displayed a lower $Age_{50,}$ and only slight increases in proportions selected with increasing age. In contrast the trawl ogive for females displayed a sudden increase in proportion selected around age 25. This suggests that longlines are less selective for female *C. coelolepis* than males, and take a higher proportion of smaller sharks. This effect is also illustrated in the comparative length frequencies (Fig. 5), smaller females being selected by hooks, but absent from the towed gear. There is less difference in the ogives for male *C. coelolepis*, for which longlines did not attract greater numbers (Fig. 5). When combined for both sexes, the differences were masked, however, the longline ogive is slightly less steep than that of the trawl. For *C. squamosus,* trawls selected smaller individuals than longlines (Fig. 8). The shapes of the selectivity ogives are however similar.

Discussion

The present study illustrates some important differences between trawls and longlines with respect to catches of deepwater elasmobranchs (see Table 5 for taxonomic groups). Clearly, the catch composition of deepwater sharks is depth dependent, as also described by Gordon (1999). The present data show the composition of elasmobranch species in the total catch for commercial gears, by depth. Of the two commercial species, *C. squamosus* has a shallower, distribution between 800 and 1 000 m and *C. coelolepis* is deeper and the dominant species in longline catches deeper than 1 100 m. *D. calceus* is not commercially exploited, but dominates longline catches in intermediate depths on the slopes of the Porcupine Bank; it is slightly less important a component further north in the Rockall Trough. Because this species tends to occupy hooks that could otherwise attract commercially valuable species, longline fishermen tend to avoid these depths. Therefore two completely separate longline fisheries can be defined in this area, one on the upper slopes targeting

TABLE 4. Percentage of total catch during longline surveys in August 1997 (Areas 1–5) and December 1999 (Areas 5–8) of *Deania calceus*.

1997			1999		
Area	Depth (m)	%	Area	Depth (m)	%
1	1 044	1.9	5	988	47.4
1	762	2.3	5	748	54.8
			5	557	47.8
2	1 288	2.0	5	1 277	19.3
2	1 143	3.1	5	745	62.6
2	905	0.8			
			6	585	3.7
3	1 300	0.5	6	765	60.1
3	1 099	0.9	6	944	34.1
3	954	0.9	6	1 097	39.8
3	775	4.2	6	1 304	2.5
			6	1 378	1.8
4	1 275	3.1			
4	969	5.4	7	1 227	6.6
4	723	4.2	7	1 038	26.6
4	1 218	5.3	7	907	34.0
4	902	18.1	7	1 403	1.2
4	740	40.8	7	695	1.4
4	545	11.7	7	1 209	7.1
5	1 404	1.2	8	1 251	51.2
5	1 134	17.0	8	610	57.7
5	806	28.5	8	883	75.8
5	637	75.2	8	1 444	7.0
5	1 178	8.4	8	1 032	15.0
5	968	36.5	8	849	5.7
5	688	40.7	8	995	10.6
			8	988	30.4
			8	1 105	38.4
			8	1 071	14.3
			8	1 071	24.0
			8	1 125	48.9

ling (*Molva molva*) and tusk (*Brosme brosme*) with by-catches of greater forkbeard (*Phycis blennoides*), mora (*Mora moro*) and blue ling (*Molva dypterygia*). Deeper than 1 000 m there is a target fishery mainly for the two commercially important large sharks *C. squamosus* and *C. coelolepis*.

Trawl catches are not dominated by elasmobranchs. On the slopes of the Rockall Trough, roundnose grenadier dominates trawl catches from 700 m and deeper. However, deepwater sharks are the next most important species in terms of weight, after this teleost. Discards from trawling in this region are high, and are composed of up to 30 different species, while species diversity of discards from longlining is lower, but dominated by sharks (Connolly and Kelly, 1996). Trawl discards are composed of small individuals of commercial species such as *Coryphaenoides rupestris, Molva dypterygia* and *Phycis blennoides*. Some teleost species are taken mainly on longline, being mainly absent from trawls, notably *M. moro* and *B. brosme*. Small specimens of the squalid sharks are not present in this region (see below). Trawl discards are also composed of a large range of non-commercial species, such as blue antimora (*Lepidion eques*), Murray's longsnout grenadier (*Trachyrhynchus murrayi*) and Baird's smoothhead (*Alepocephalus bairdii*). In contrast, longline discards are mainly composed of non-commercial shark species such as blackmouth dogfish

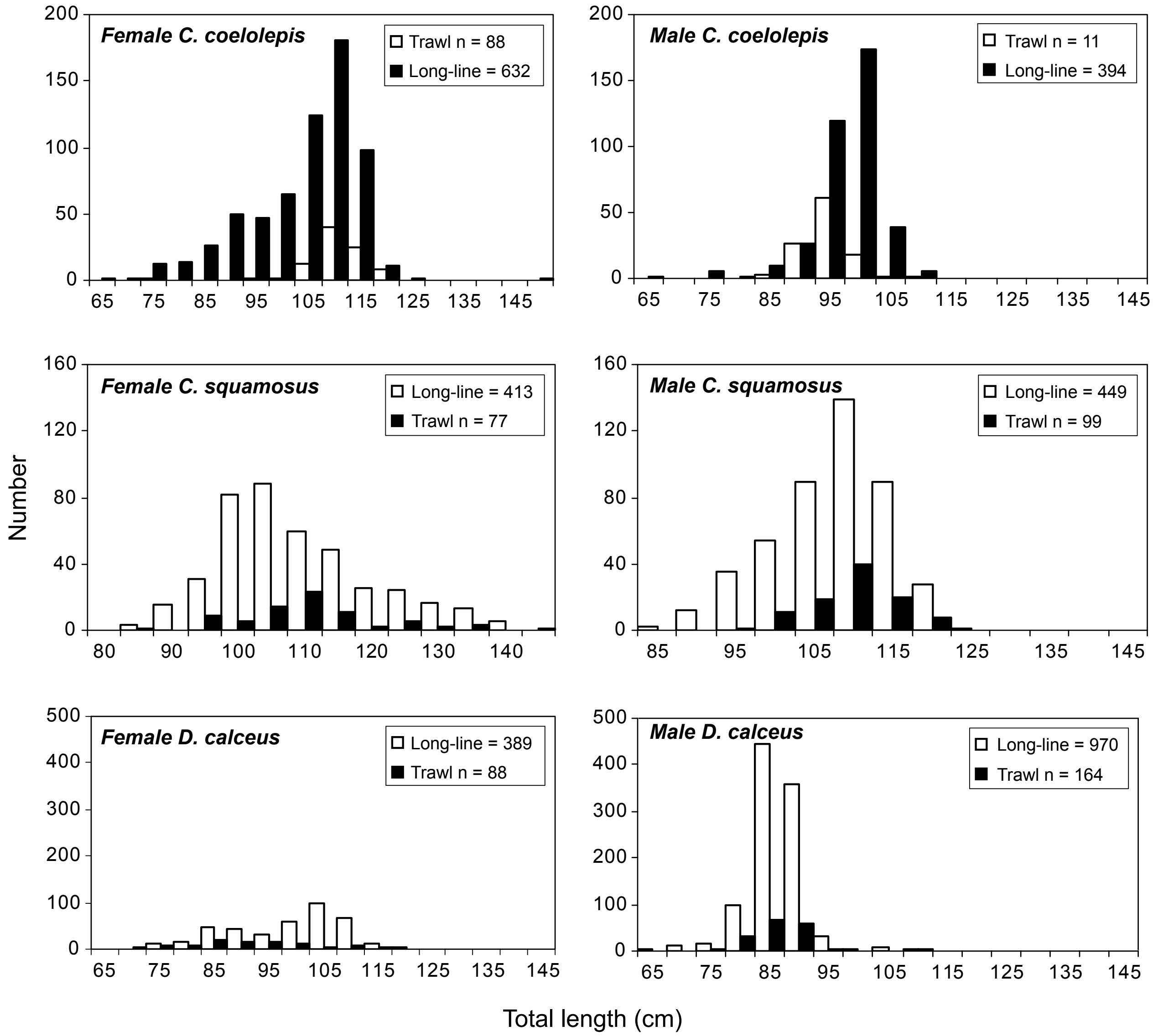

Fig. 5. Comparison of length frequencies from trawl and longline surveys of the Rockall Trough in 1997.

(*Galeus melastomus*), greater lanternshark (*Etmopterus princeps*), *D. calceus* and *C. crepidater*. Few small teleosts are taken on longline, less than 5% of the catch of ling or blue ling below legal minimum landing size were caught on a subsequent longline survey (Clarke and Moore, 2002). In contrast, longlines take many small shark species, and smaller specimens of some of the larger species of shark than the trawls.

An estimated 533 tons of *D. calceus* was discarded during trawling operations in the Rockall Trough and slopes of the Porcupine Bank in 1996 (corresponding to ICES Sub-areas VI and VII) were provided by Clarke *et al*. (2002b). It is more difficult to estimate discarding levels from longlining, because landings data are less complete. However, from the species composition data it can be seen that non-commercial sharks will dominate the discards. In shallower longline settings the main species are *D. calceus* and *G. melastomus*, whereas in the deepest settings (commercial viability decreases below 1 500 m) *Centroscymnus crepidater* and *E. princeps* are most important. Markets for *D. calceus* and other non-commercial species may become available in the future, which would lead to increased exploitation of these sharks.

The absence of small specimens of the large squalid sharks from west of Ireland and Britain has been well documented (Clarke *et al*., 2002a; Girard and DuBuit, 1999).

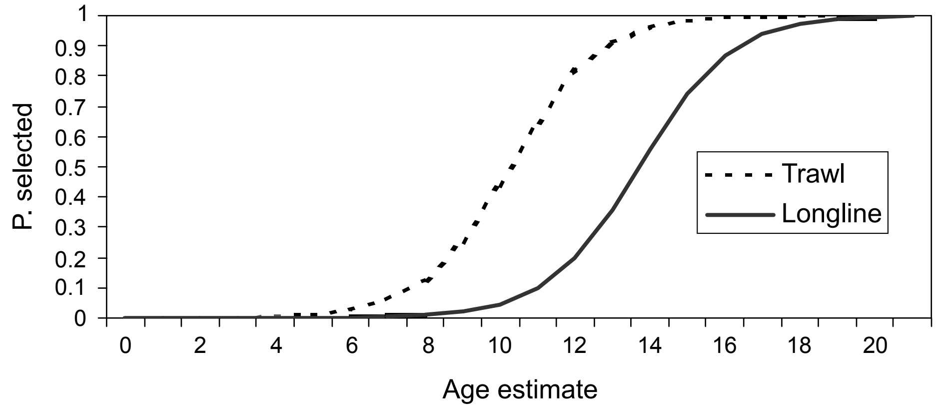

Fig. 6. Estimated selectivity ogives for *Deania calceus*, sexes combined, derived from catch curve analyses. Estimated Age_{50} (trawl) = 11 and Age_{50} (longline) = 15.

In the case of *D. calceus* and *C. squamosus* this is probably explained by migratory behaviour. Smaller *D. calceus*, absent from the area west of Ireland, are present off continental Portugal (Machado and Figueiredo, 2000). Gravid *C. squamosus*, totally absent from west of Ireland, are found in Madeira and off Portugal (N. R. Hareide and G. Garnes, pers. comm.; M. J. Figueiredo, pers. comm.). Interestingly, neither gear selected for *C. squamosus* larger than 122–145 cm (Fig. 5). This provides further evidence that the larger gravid *C. squamosus* are absent from the study area and that gear selectivity is not the reason for their absence from samples. It seems clear that smaller sizes of these species do not escape through the cod-end of trawls. Nor is it likely that the baited hooks used do not select the smaller specimens, since small specimens of *E. princeps* (27 cm TL) were taken in these surveys (Connolly *et al*., 1999).

Certain aspects of the behaviour of these species are highlighted by comparison of the size-frequencies from trawl and longline. The greater numbers of large female *D. calceus* taken on longline may suggest that this species is capable of making quick movements that allow it to escape towed gears.

Evidence for a more pelagic distribution of smaller specimens of *C. coelolepis* may be found by comparison of length frequencies for trawl and longline. Longlines took smaller specimens of *C. coelolepis* than trawls. This result suggests these smaller sharks occur at some distance from the seabed, out of the range of trawls (headline height ~4 m), but attracted to the baited hooks. It also known that gravid females of this species are found in shallower waters (Clarke *et al*., 2001; Yano and Tanaka, 1988). This is an important factor in considering the impact of fishing in waters shallower than 1 000 m on *C. coelolepis*, as mainly mature and gravid females are taken.

In the present study, the logistic model was considered to represent both trawl and longline selectivity. This model is widely used for trawls (Millar and Fryer, 1999). However, authors are divided on whether it can be applied to longlines. Very little is known about longline selectivity. Some authors consider that longlines have bell-shaped functions, like gillnets (Sparre *et al*., 1989). This type of curve would imply that the largest size classes must escape the gear after contact. However, given the typical scarcity of large fish in commercial fisheries it is difficult to estimate the right hand limb of such a curve (Millar and Fryer, 1999). While there may be some tendency for reduced selectivity of the largest, most powerful sharks, it is not possible to quantify this at present. The choice of the logistic model for hook selectivity in the present study was based on the need to describe the left-hand limb of the curve to investigate the effects of selectivity and recruitment to the fishery. A recent selectivity study for deepwater fish, off continental Portugal, reported the logistic to be a versatile model, which adequately described the pattern observed (Sousa *et al*., 1999).

Millar and Fryer (1999) define three categories of size selection in fish:

1) Population selection: The probability that a fish of a given length is captured from the population.
2) Available selection: The probability that a fish of given length is captured given that it is available to the gear.

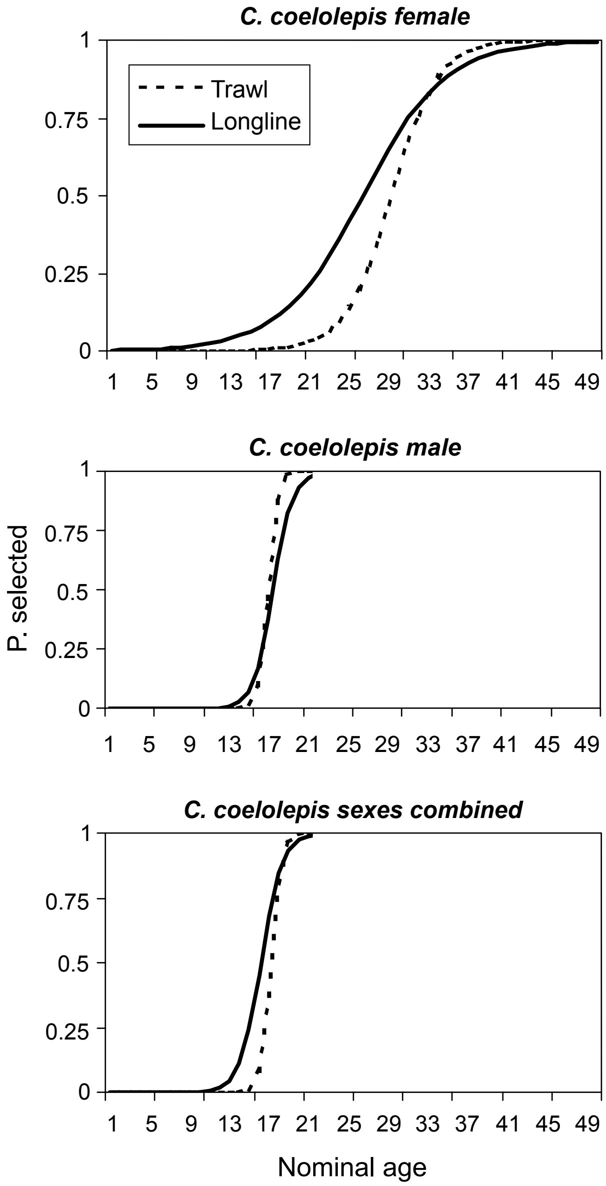

Fig. 7. Estimated selectivity ogives for *Centroscymnus coelolepis*, derived from length-converted catch curves developed with hypothetical von Bertalanffy growth parameters.

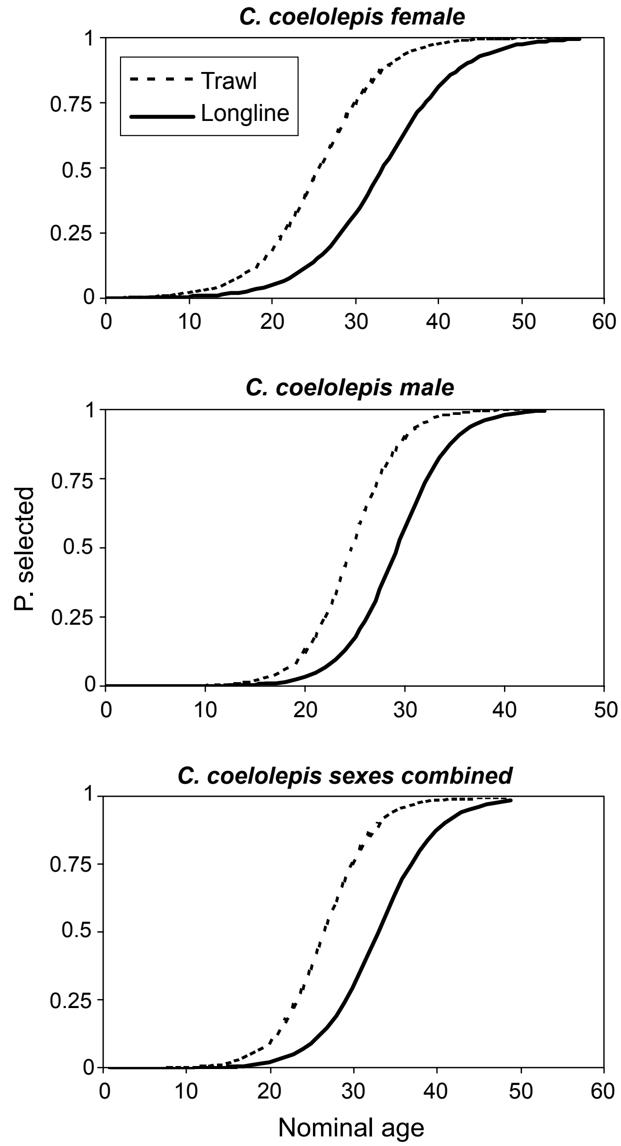

Fig. 8. Estimated selectivity ogives for *Centrophorus squamosus*, derived from length-converted catch curves developed with hypothetical von Bertalanffy growth parameters.

3) Contact selection: The probability that a fish of given length is captured given that it contacted the gear.

It seems reasonable to assume that contact selectivity of trawls for these sharks is unity, since they are very unlikely to escape through the meshes. Trawls are selective for these sharks in the sense that some sharks avoid trawls and a part of the population of these sharks is beyond the range of the trawl. It seems clear from comparisons of length frequencies from trawl and longline in the present study that some sharks (probably larger specimens) can avoid trawls. It also appears some size ranges are not present in the area where they would be vulnerable to trawls. From the composition of elasmobranchs in trawl catches, it can be seen that there is considerable mortality of small sharks from trawling (Clarke *et al*., 2002b; Connolly and Kelly, 1996).

Longlines may be selective for sharks in the sense that some sharks may take the bait, but subsequently break the hook or snood and escape. Observations on-board show

TABLE 5. Scientific names and taxonomic group of species mentioned in the text.

Scientific name	Group	Scientific name	Group
Centroscymnus coelolepis	Elasmobranch	*Coryphaenoides rupestris*	Teleost
Centrophorus squamosus	Elasmobranch	*Alepocephalus bairdii*	Teleost
Etmopterus princeps	Elasmobranch	*Hoplostethus atlanticus*	Teleost
Pseudotriakis microdon	Elasmobranch	*Lepidion eques*	Teleost
Centroscymnus crepidater	Elasmobranch	*Aphanopus carbo*	Teleost
Centroscyllium fabricii	Elasmobranch	*Trachyrynchus murrayi*	Teleost
Deania calceus	Elasmobranch	*Lophius piscatorius*	Teleost
Mora moro	Teleost	*Merluccius merluccius*	Teleost
Molva dypterygia	Teleost	*Argentina silus*	Teleost
Brosme brosme	Teleost	*Galeus melastomus*	Elasmobranch
Phycis blennoides	Teleost	*Scymnodon ringens*	Elasmobranch
Chimaera monstrosa	Chimaera	*Raja nidarosiensis*	Elasmobranch
Helicolenus dactylopterus	Teleost	*Raja circularis*	Elasmobranch
Molva molva	Teleost	*Hexanchus griseus*	Elasmobranch

that this does occur but it is difficult to quantify the extent to which this takes place. Thus, there may be some contact selection, though the small number of broken snoods on these surveys suggests that this is not common. Longlines may also display population selection, in that smaller sharks may be out-competed by large sharks for available hooks. However, this will only take effect over the size ranges of the sharks that are present in the region, since smaller sharks appear to be totally absent. In contrast to trawls, available selection is likely to be unity, since it is unlikely that a shark, being available to a bait, would actually or fail to take it. It is possible that gravid female *C. squamosus* are not attracted to longlines. This effect has been well documented for spawning teleosts. However, the presence of gravid *C. coelolepis* and *D. calceus* suggests that if pregnant *C. squamosus* were present, they would be caught by longlines.

The selective properties of trawl and longline for deepwater fish have been discussed by several authors. They are fundamentally different fishing methods, trawls herd fish into the opening of the net whereas longlines attract fish from a wide area by the odour of the baits (Hareide, 1995). This difference explains why longlines have been found to capture larger fish than trawls. According to Bjordal and Lokkeborg (1996) the swimming speed of a fish is proportional to its body size; larger fish being able to swim faster than smaller ones. In addition, bigger fish often frighten smaller fish from bait. The consequence of these differences is that the exploitation patterns of the two gears will be different. For teleosts, this effect has been illustrated by yield-per-recruit analyses. Jorgensen (1995) showed that for Greenland halibut (*Reinhardtius hippoglossoides*), maximum yield-per-recruit and yield-per-recruit corresponding to $F_{0.1}$ are reached at lower rates of fishing mortality for longlines than trawls. Jorgensen (1995) concluded that longline offered a better means of exploiting this teleost species, since a larger biomass will remain in the sea if a given quota is fished with longlines. Moreover, a given tonnage of this species taken by longline will consist of fewer, larger individuals than trawl. Heavy exploitation of a stock of fish by longline may result in damage to the spawning stock, though this will usually involve less risk of over-exploitation than fishing of younger age groups according to Hareide (1995). Longlines have other advantages too; they are less destructive of benthic habitats, longline vessels have lower energy consumption rates, they produce fish of higher market value, and there is little effect of ghost fishing (Bjordal and Lokkeborg, 1995). However, these authors point out that longlines do have the propensity to select for smaller fish, if there are few large fish on a fishing ground.

The present study provides the first comparisons of selectivity of trawls and longlines for deepwater sharks. The results show that longlines select for larger *D. calceus* and *C. squamosus* than trawls. These results are in agreement with those found for *Reinhardtius hippoglossoides*. However, results of the simulations for female *C. coelolepis* suggest that longlines are not always more selective that trawl. Indeed, trawl displayed almost "knife-edge" selectivity for females of this species. These differences highlight an important property of longlining. This method can capture fish from a wider area than trawls, resulting in differing size distributions. This simulation predicts that exploitation of a stock of *C. coelolepis* by longlines will involve the removal of greater numbers of smaller females than exploitation by trawl. This suggests that longlines may be less size-selective for some deepwater sharks. This effect would suggest that a fishery for deepwater sharks, prosecuted solely by longline could result in greater removals of younger sharks, opposite to what has been observed for teleosts.

The results of the present study allow several conclusions to be made about trawl and longline fishing for deepwater elasmobranchs. Longlines are more effective at catching sharks and shark species dominate in longline catches deeper than 500 m. Small elasmobranchs dominate the discarded fraction of the catch from longlines, but not trawls. Therefore, in general, elasmobranchs are more vulnerable to longlines than to trawls. For some species, longline selects larger specimens. In theory, this means that exploitation of these species by longline will result in more of the biomass being left in the sea. However, for *C. coelolepis*, longlines actually select for smaller females. This implies that targeting of this species by longline will remove more of the spawning stock than trawling. Therefore, *C. coelolepis* is especially vulnerable to exploitation in the area west and north of Ireland, because all stages of its reproductive cycle are found in this area. In contrast, mature and gravid *C. squamosus* are totally absent, and those stages of *Deania calceus* are largely absent. This implies that these two species are somewhat less vulnerable to fishing in this area.

Studies of the life history parameters of these species suggest that they are slow growing, mature relatively late in life and have low fecundities (Clarke *et al*., 2001; Clarke *et al*., 2002a, 2002b; Girard and DuBuit, 1999). These characteristics imply that they cannot sustain high levels of fishing pressure. Yet they are subject to considerable, and increasing exploitation in the Northeast Atlantic. The present study presents some properties of the two main gear types used to exploit these species. There are also gill-net fisheries for deepwater sharks, but there are no data available on these activities. There has been great debate both within ICES and European fisheries management agencies on appropriate management measures for deepwater species. In June 2002, the Council of the European Union agreed a series of TACs for a limited number of species, not including sharks. It remains unclear whether a single management measure such as this would be successful and the ICES Advisory Committee on Fisheries Management has advised that a range of management measures may be required. However, the Council of the European Union also introduced an effort control regime on a wider range of deepwater species. The debate is now being carried to the Northeast Atlantic Fisheries Commission (NEAFC), which deals with management of fisheries outside coastal jurisdictions in the region.

The species interactions in the deepwater fisheries west of Ireland are illustrated in Fig. 9. It can be seen from this that there are several separate fleets. It would be useful for managers of fisheries, to consider the characteristics of the gear types involved in deepwater fisheries, in terms of fleet profile, gear used and time spent targeting deepwater species. Then the biological characteristics of the various species should be considered, and the most recent management advice. The next step might be to take account of the species that are caught by more than one gear type so that knowledge of technical interactions can be incorporated into management measures. Reliable reports from the fishery show that the average autoline longliner can catch 3–6 tons of commercial squalid sharks per day, in comparison to 1–2 tons for an average trawler. This confirms that longlines are more efficient at catching sharks than trawl.

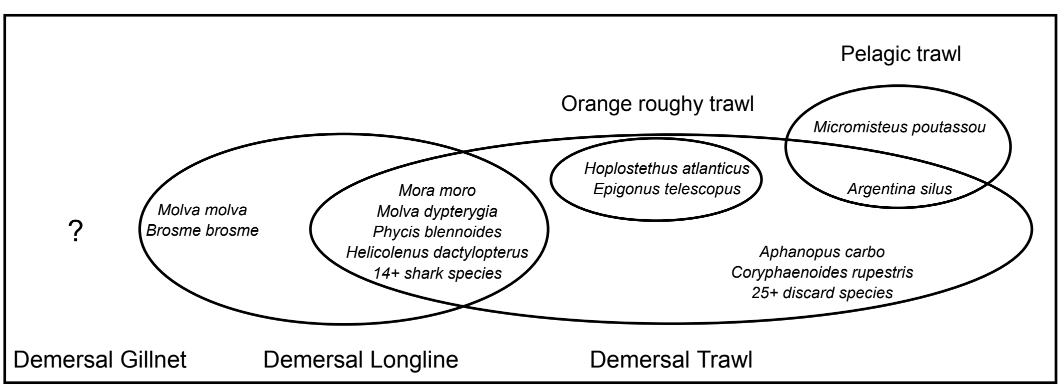

Fig. 9. Schematic representation of the interactions between the main deepwater fishing gear types in the area west of Ireland and Britain. Some species are caught by more than one gear. Data on by-catch in the pelagic trawl fishery for greater argentine *Argentina silus* are lacking. No data are available for gillnet fisheries.

This information suggests that days at sea may provide a simple means of regulating the relative fishing capacities of the various gear-types in the deepwater fleet. Based on a life history approach, the deepwater squalid sharks were found to be the most vulnerable to overexploitation, with lowest predicted recovery rates (Anon., 2001; Clarke *et al*., 2003). These sharks are taken by all demersal deepwater gear-types in the area, and given their vulnerability, it would seem prudent to incorporate what is known about their biology, life history, and the technical aspects of the fisheries that capture them, into a unified management regime for deepwater fishing. Such an approach should be implemented as quickly as possible.

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