Abstract.—The distribution and abundance of deep-sea sharks on Chatham Rise, New Zealand, are described. Sharks were collected as bycatch in two deep-water trawl fisheries at a total of 390 stations, which ranged in depth from 740 to 1503 m. Sixteen species of shark were caught; *Deania calcea, Centroscymnus crepidater, Etmopterus granulosus,* and *Centroscymnus owstoni* accounted for the largest portion of the shark catch. Species that would provide the highest yield of commercially important liver lipids were not abundant in trawls. All sharks combined formed only 4.2% of overall biomass captured in trawls. Depth is a major determinant of the composition of the shark assemblage; both density of sharks (kg/km^2) and species diversity were inversely proportional to depth. Distributional patterns of the shark community varied with location on Chatham Rise, and species composition of the shark catch varied with the species of teleost targeted in deep-water trawls.

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Assemblage of deep-sea sharks on Chatham Rise, New Zealand

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Sharks are common bycatch in deep water fisheries around the world, forming as much as 50% of the catch in deep-sea trawls in areas such as New Zealand and Australia (Deprez et al., 1990; Clark and King[1]). Most sharks captured in the New Zealand and Australian deep-water fisheries are dead by the time they are brought to the surface and are discarded, but some sharks are retained for their liver oil. In Japan and Australia, several species of deep-sea shark in the family Squalidae are targeted in fisheries and their liver oil is utilized. Although the short-term potential of fisheries directed towards deep-sea sharks has been investigated for a few species (Summers, 1987; Davenport and Deprez, 1989), little information on even basic biology is available for the species captured in these fisheries. Thus, the effects that deep-water fisheries have on shark populations that are either targeted directly or caught incidentally are unknown. Information on abundance, distribution, community structure, reproduction, and age and growth of deep-sea sharks would improve understanding of these effects.

Shark liver oil contains commercially important lipids, such as squalene and diacyl glycerol ether, which are used in cosmetic, pharmaceutical, and other industries (Deprez et al., 1990; Bakes and Nichols, 1995). The lipid composition of liver oil is quite variable among and within species, and consequently the most desirable sharks are those individuals and species that have the highest potential as a source for these valuable lipids (Davenport and Deprez, 1989; Bakes and Nichols, 1995). Therefore, understanding the distribution and abundance of different species of deep-sea shark, in conjunction with knowledge of the lipid composition of their liver oil, is important for optimal use of these resources.

Some deep-sea sharks prey upon commercially important teleosts (Clark et al., 1989; Clark and King[1]), but the impacts of shark predation on fish populations in terms of the overall economic impact on the fishery are unknown. Diet varies considerably among even closely related species of deep-sea shark (Compagno et al., 1991; Ebert et al., 1992), and the level of predation on commercially important species of teleost by sharks also varies among species (author's unpubl. data). Information on the distribution and abundance of deep-sea sharks, in conjunction with knowl-

[1] Clark, M. R., and K. J. King. 1989. Deep water fish resources off the North Island, New Zealand: results of a trawl survey, May 1985 to June 1986. New Zealand Fisheries Technical Report 11, 56 p. MAF Fisheries Research Center, P.O. Box 297, Wellington, New Zealand.

edge of their feeding habits, would improve our understanding of interactions between sharks and commercially important teleosts.

A variety of species of shark inhabit the deep water off New Zealand, where they form part of the bycatch of deep-sea fisheries that target teleosts such as orange roughy (*Hoplostethus atlanticus*) and smooth oreo (*Pseudocyttus maculatus*) (Clark and Tracey, 1994; Clark and King[1]). Access to this bycatch provided an opportunity to examine a multispecies complex of sharks, which might be termed an assemblage—"a group of co-occurring populations—not necessarily interacting" as defined by Crowder (1990). The purpose of this study was to investigate the abundance and distribution of sharks on Chatham Rise to increase understanding of the effects of fishing on shark populations, the potential of shark fisheries and utilization of bycatch, and interactions between sharks and commercially important teleosts.

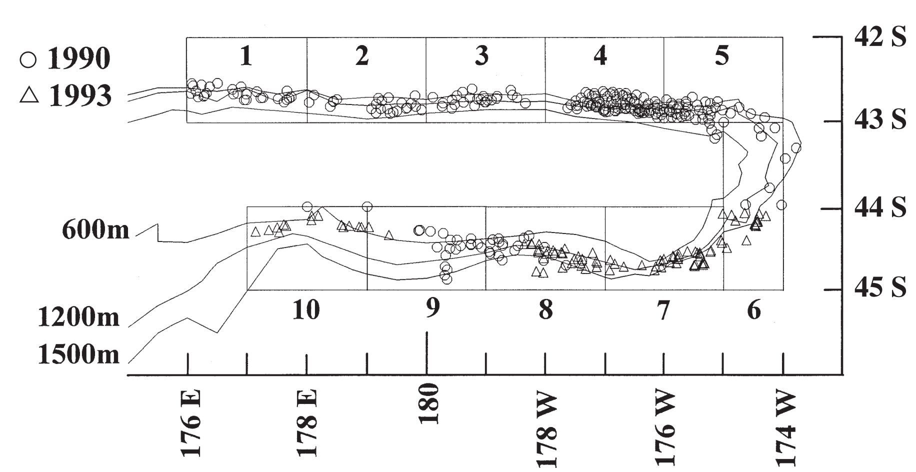

Figure 1

Map of Chatham Rise, New Zealand, showing depth contour lines and locations of trawls in a 1990 orange roughy survey and a 1993 smooth oreo survey. Trawls were grouped into 10 areas on the basis of major latitude and longitude meridians.

Materials and methods

Data for this study were collected from deep-water bottom trawls during two cruises conducted by the Ministry of Agriculture and Fisheries on Chatham Rise, New Zealand (Fig. 1). The first survey (15 June to 5 August 1990) consisted of 281 trawls for orange roughy (*H. atlanticus*) and was conducted primarily on the north of Chatham Rise from the FV *Cordella*. The second survey (24 October to 9 November 1993) consisted of 109 trawls for smooth oreo (*P. maculatus*), primarily on the south of Chatham Rise from the RV *Tangaroa*. Fishing during both surveys was conducted at depths of 740–1503 m throughout the day and night (Fig. 2).

Each survey consisted of a stratified random trawl design intended to provide relative biomass estimates and to illustrate patterns of distribution of deep-water species on Chatham Rise. Six-panel bottom otter-trawls with cut-away lower wings were used in each survey. The door-spread was 75 m for orange roughy trawls and 119 m for smooth oreo trawls, and distance between the net wings for both trawls was approximately 26 m. Codend mesh sizes were 110 mm for orange roughy trawls and 100 mm for smooth oreo trawls. Towing speed for both vessels was approximately 3.0 kn. Orange roughy trawls were roughly 1 h in duration, and smooth oreo trawls ranged from several minutes to 45 min. For density estimates (kg shark/km^2) it was assumed that herding by, and escape from, nets were minimal, and that trawls sampled different species of shark with equal effort.

For each trawl, the catch was sorted into bins by species, and the total weight of each species caught at each station was recorded. Latitude, longitude, water temperature, minimum and maximum depth of fishing, towing speed, and start and end time were also recorded for each trawl. When the author was present on the research vessel (at all times other than from 15 June to 10 July 1990), all individuals of each species of shark were weighed and measured, except when large numbers of sharks were caught and a lack of time prevented examination of every shark. Because of size varied among species, an estimate of the total number of individuals captured in all fishing was derived by using the average weight for each species. Because there were differences in fishing methods (net characteristics, trawl duration) and time (season, year) between the two surveys, catch data from surveys were examined separately. When possible, comparisons were made between common areas fished during both surveys. For comparison of the composition of the shark community at different locations on Chatham Rise, ten areas were designated based on major latitude and longitude meridians (Fig. 1).

Consideration of sharks as an assemblage, which is separate from the rest of Chatham Rise community, is an artificial division. However, because the primary interest of this study was to describe the abundance and distribution of the sharks on Chatham Rise, several ecological indices were employed to compare different locations, depths, and species of shark. Abundance was expressed as density (kg shark/km^2) and was calculated for each species within each trawl based on the total weight of sharks caught, net width, towing speed, and trawl duration. Three features of distribution were examined for sharks: diversity, similarity, and randomness. Diversity was expressed as the number of species of sharks per trawl (Stephens et al. 1984; Garcia et al. 1998). The Bray-Curtis similarity index was used for comparisons among the ten areas on Chatham Rise, depth intervals, and between the two surveys:

$$S = 1 - \left(\sum_{i=1}^{s} \left| Y_{ij} - Y_{ik} \right| / \sum_{i=1}^{s} (Y_{ij} + Y_{ik}) \right),$$

where Y_{ij} = score for i^{th} species in the j^{th} sample; and
Y_{ik} = score for the i^{th} species in the k^{th} sample (Field et al. 1982; Sedberry and Van Dolah 1984).

This index ranges from 0 (no species in common) to 1 (identical species in each sample). Morisita's index of dispersion (I_d) was calculated for each species of shark as an indicator of the randomness of their distributions:

$$I_d = n\left(\sum X^2 - N / N(N-1)\right),$$

where n = number of plots;
N = total number of individuals counted in all n plots; and
ΣX^2 = squares of the number of individuals per plot summed over all plots.

If the dispersion is random, then I_d = 1.0; if perfectly uniform, I_d = 0; and if maximally aggregated (all individuals in the same trawl), I_d = the number of trawls (Brower and Zar, 1984). To minimize the dominant effect of anomalous catches, each value of shark density (kg/km^2) was converted to ln(x +1) prior to calculation of these ecological indices (Field et al., 1982; Bianchi, 1991) and comparisons of means were made by using either a two-tailed t-test or one-way ANOVA.

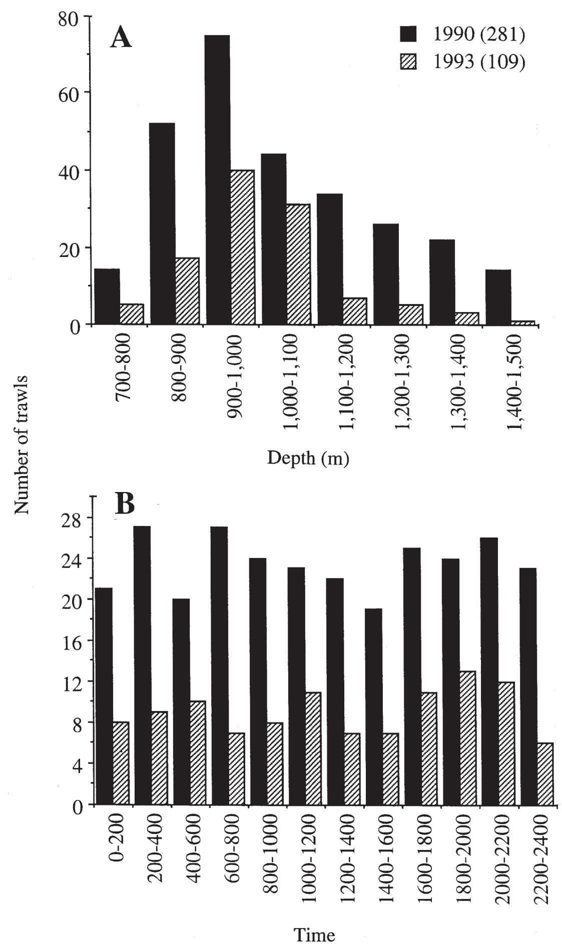

Figure 2

Number of trawls in a orange roughy survey (1990) and in a smooth oreo survey (1993) on Chatham Rise, New Zealand, at various intervals of (**A**) depth and (**B**) time of day. Numbers in parentheses are total trawls for each survey.

Results

Seven species of shark belonging to the family Squalidae and five undescribed species of catsharks in the genus *Apristurus* (family Scyliorhinidae) were regularly captured in deep-water trawls (Table 1). For the purpose of this study, all sharks of the genus *Apristurus* were treated as a single group. Several other species of shark were captured (*Chlamydoselachus anguineus*, *Centroscymnus coelolepis*, *Scymnodon squamulosus*, *Etmopterus lucifer*), but only one or two individuals of each species were captured and these are not discussed further. Although the composition of the catch varied throughout the day, there was no apparent correlation between density

Table 1

Catch data for eight taxa of sharks from trawls on Chatham Rise, New Zealand, 1990 (June–August, 281 trawls, depth range = 743–1503 m) and 1993 (November, 109 trawls, depth range = 780–1463 m). D.c. = *Deania calcea*, C.c. = *Centroscymnus crepidater*, E.g. = *Etmopterus granulosus*, C.o. = *Centroscymnus owstoni*, C.s. = *Centrophorus squamosus*, A.s. = *Apristurus* spp., S.p. = *Scymnodon plunketi*, D.l. = *Dalatias licha*. (SD = standard deviation).

	kg shark caught					% of total biomass			% of trawls			Avg. density (kg/km^2)			
Species	1990	1993	Total	Avg. wt. (kg)	Estimated no. of individuals	1990	1993	Total	1990	1993	Total	1990	1993	Total	SD
D.c.	6721.6	3618.7	10340.3	2.757	3750	1.38	2.10	1.57	65.7	50.5	61.5	172.5	343.5	220.3	590.3
C.c.	6058.0	351.3	6409.3	1.980	3237	1.25	0.20	0.97	58.6	39.2	53.2	151.2	61.8	126.2	266.5
E.g.	3072.2	2881.4	5953.6	1.416	4203	0.63	1.67	0.90	75.7	88.8	79.3	93.5	960.8	335.9	1624.5
C.o.	3731.9	25.5	3757.4	5.023	748	0.77	0.01	0.58	46.8	3.7	34.9	88.9	2.3	64.7	205.8
C.s.	181.0	81.7	262.7	8.209	32	0.04	0.05	0.04	7.1	7.5	7.2	4.7	33.1	12.6	115.2
A.s.	144.1	89.9	234.0	1.245	188	0.03	0.05	0.04	30.7	38.3	32.8	3.5	17.3	7.4	33.3
S.p.	128.7	105.8	234.5	9.770	24	0.03	0.06	0.04	5.0	6.5	5.4	3.0	23.0	8.6	88.9
D.l.	173.1	41.0	214.1	9.309	23	0.04	0.02	0.03	6.8	4.7	6.2	4.3	7.7	5.3	39.9
All sharks	22200.6	9188.3	27405.9		12205	4.15	4.17	4.16	90.3	97.2	92.2	521.8	1449.5	781.1	1786.6

and time of day for all sharks combined (ANOVA, $P=0.77$). Water temperature decreased linearly with depth ($r^2=0.61$) and ranged from 5.9° to 9.0°C.

The most abundant shark (by weight) was the shovelnose dogfish (*Deania calcea*), which represented 32.5% of the shark catch in 1990, 50.5% in 1993, and 37.2% overall. The longnose velvet dogfish (*Centroscymnus crepidater*), southern lantern shark (*Etmopterus granulosus*), and Owston's dogfish (*Centroscymnus owstoni*) also formed large proportions of the shark catch (Table 1). The largest catch (by weight) for any species of shark in a single trawl was 850 kg for *D. calcea* (area 5), followed by 441 kg for *C. owstoni* (area 1). Although sharks dominated the catch in some trawls, they formed only 4.2% of total biomass collected in trawls. Even the most abundant species (*D. calcea*) accounted for only 1.6% of total biomass caught (Table 1). The highest estimate for number of individuals of any species of shark captured in a single trawl was 308 for *D. calcea*, followed by 194 for *E. granulosus*.

The most abundant shark in terms of number of individuals captured was *E. granulosus*, which was present in 79.3% of trawls (Table 1). *Deania calcea* and *C. crepidater* were also captured in large numbers and appeared in a high proportion of the trawls. For three of the larger species of squalids (the leafscale gulper shark, *Centrophorus squamosus*; the Plunket shark, *Scymnodon plunketi*; and the kitefin shark, *Dalatias licha*) few individuals were captured, and these species occurred in a low percentage of the trawls (Table 1). Preliminary examination of stomach contents revealed that orange roughy were most common in stomachs of *E. granulosus* and *C. owstoni*, but were also consumed by *C. squamosus* and *D. licha*.

Abundance

There was a significant difference between mean densities (kg/km^2) caught in the two surveys for *E. granulosus*, *C. owstoni*, *C. crepidater,* and *Apristurus* spp., but not for the other species (ANOVA, $P<0.01$). A comparison of common areas that were fished in both surveys (areas 6, 8, 9, and 10) showed that there was no significant difference between the densities of any of the species for the two surveys (t-test, $P>0.01$), and data from common areas for the two surveys were therefore combined. In the orange roughy survey, there was a significant difference among areas for densities of all species except *D. licha*, whereas in the oreo survey, significant differences were observed among areas for only two species, *C. crepidater* and *D. calcea* (ANOVA, $P<0.05$). The highest densities for all sharks combined were recorded at the eastern tip of Chatham Rise, in areas 5 and 6 (1003.4 and 2249.1 kg/km^2), and the lowest were in the southwestern areas 8 and 10 (257.7 and 254.4 kg/km^2).

Composition of the shark catch varied considerably with location fished. In areas on the north of Chatham Rise, closest to New Zealand (areas 1 and 2), the catch was dominated by *C. owstoni* and *C. crepidater*, which accounted for 84% of the shark catch by weight (Fig. 3). On the mid-north of Chatham Rise (area 3), *C. owstoni* and *C. crepidater* still formed the majority of the catch; however *D. calcea* was also abundant and all eight major taxa were recorded. The northeast of Chatham Rise included those areas (4 and 5) where the most trawls were conducted. Here, *C. crepidater* still formed a large

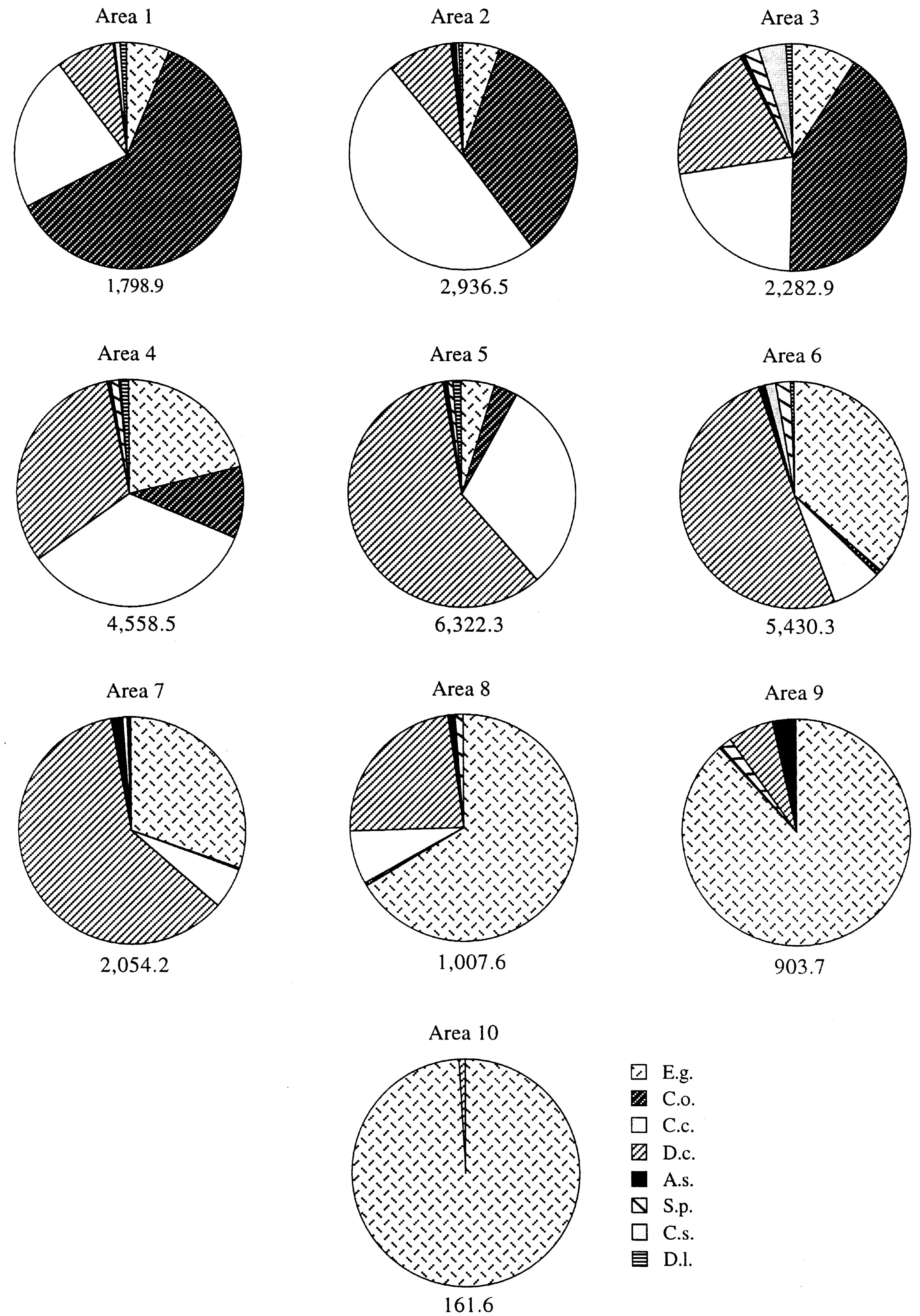

Figure 3

Species composition (as percent of total kg of shark caught) of the shark catch for both surveys combined in each of the 10 areas on Chatham Rise, New Zealand. Numbers below each area are the total weight (kg) of sharks caught in that area. E.g. = *Etmopterus granulosus*; C.o. = *Centroscymnus owstoni*; C.c. = *Centroscymnus crepidater*, D.c. = *Deania calcea*; A.s. = *Apristurus* spp.; S.p. = *Scymnodon plunketi*; C.s. = *Centrophorus squamosus;* and D.l. = *Dalatias licha*.

part of the catch, but the catch of *C. owstoni* declined substantially, and *D. calcea* began to dominate the shark catch. Along the eastern tip and southeast portion of Chatham Rise (areas 6 and 7), *D. calcea* accounted for the highest percentage of the catch, but *E. granulosus* was also prominent, and these two species formed over 85% of the shark catch by weight. *Etmopterus granulosus* dominated catches in areas along the south of Chatham Rise (areas 8–10); the proportion of the total catch increased with proximity to New Zealand (Fig. 3). The three large squalids (*C. squamosus*, *S. plunketi*, *D. licha*) were sporadically caught in areas 1–8, each with a peak density in area 6, but no squalids were recorded from the southwest of Chatham Rise (areas 9 and 10). *Apristurus* spp. were caught in small numbers throughout Chatham Rise, but their presence was more dependent upon depth than location (Fig. 3).

Composition of the catch also varied with depth (Fig. 4) and several natural divisions were apparent. The three large squalids (*C. squamosus*, *S. plunketi*, *D. licha*) appeared to have shallow distributions, and were not captured deeper than 1100 m (with the exception of one *S. plunketi* caught at 1170 m, and one *C. squamosus* at 1201 m). Densities (kg/km^2) of the other species were fairly high at depths of 700–1200 m, although *D. calcea* was most abundant at depths of less than 1000 m, *E. granulosus* peaked at 900–1200 m, and *Apristurus* spp. densities were highest at depths greater than 1000 m (Fig. 4). At depths greater than 1200 m, *Apristurus* spp. were the only sharks regularly caught in the trawls. There was a significant difference among three depth intervals (700–1000 m, 1000–1300 m, and 1300+ m) for mean densities (kg/km^2) of each species in the orange roughy survey, but only for the three most abundant species (*D. calcea*, *C. crepidater,* and *E. granulosus*) in the oreo survey (ANOVA, $P<0.05$). Density (kg/km^2) for all sharks combined gradually declined with depth between 700 and 1200 m, but was low at depths greater than 1200 m (Fig. 5).

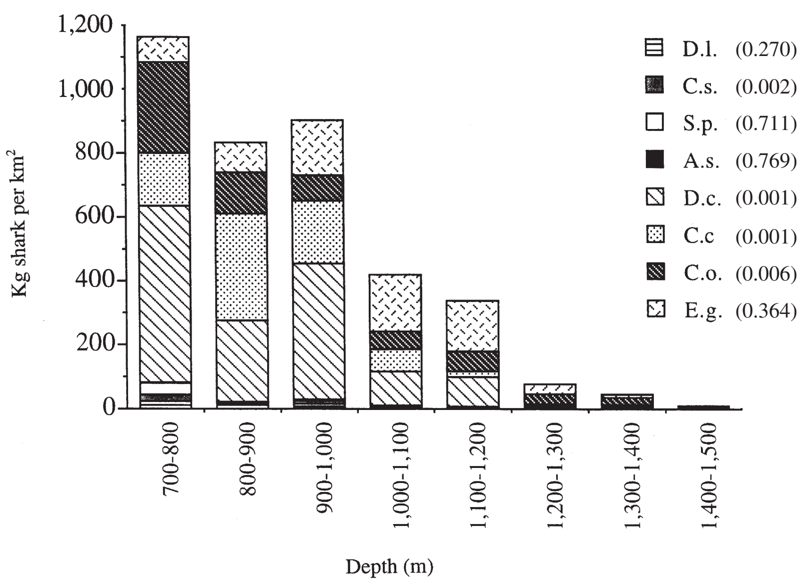

Figure 4

Density (kg/km^2) of sharks collected at all locations on Chatham Rise, New Zealand, at various depth intervals for both surveys combined. For abbreviations of species see Figure 3. For each species, *P* -values are given in parentheses for ANOVA comparisons of densities among depth intervals.

Distribution

Diversity (number of species per trawl) was significantly higher for the orange roughy survey than for the oreo survey (*t*-test, $P=0.0003$), but diversity in areas common to both surveys (areas 6, 8, 9, 10) did not differ (*t*-test, $P=0.14$, 0.77, 0.81, and 0.63 respectively). There was a significant difference among areas for mean diversity values in both surveys (ANOVA, $P<0.01$). Area 3 had the highest mean diversity value (4.2, SD=1.6) and area 10 had the lowest value (1.1, SD=0.9). Diversity differed significantly among the three major depth intervals (700–1000 m, 1000–1300 m, 1300+ m) for the oreo survey (ANOVA, $P=0.007$), but not for the orange roughy survey (ANOVA, $P=0.50$). The total number of species of shark caught in trawls was inversely proportional to depth, and declined by half from a maximum of ten (800–900 m) to only five species at depths of 1200–1300 m (Fig. 5).

The index of similarity (S) between the two surveys was high (0.89), and for each survey there was a high degree of similarity between areas, except for those most distant from each other, particularly between area 10 and other areas (Table 2). Indices of similarity between depth intervals were very similar for both surveys: high (0.80 for the orange roughy survey and 0.81 for the oreo survey) for the two shallowest depth intervals (700–1000 m versus 1000–1300 m), moderate (0.57 and 0.63) for the 1000–1300 m vs 1300+ m intervals, and much lower (0.42 and 0.47) for

700–1000 m versus 1300+ m intervals.

Morisita's index of dispersion (I_d) indicated that all species of sharks tended to be aggregated on Chatham Rise to some degree. The three large squalid sharks were the most aggregated: *S. plunketi* (I_d=104.5), *C. squamosus* (82.4), *D. licha* (55.4), followed by *E. granulosus* (24.3), *Apristurus* spp. (21.2), *C. owstoni* (10.9), *D. calcea* (8.2), and the most randomly distributed was *C. crepidater* (I_d=5.4).

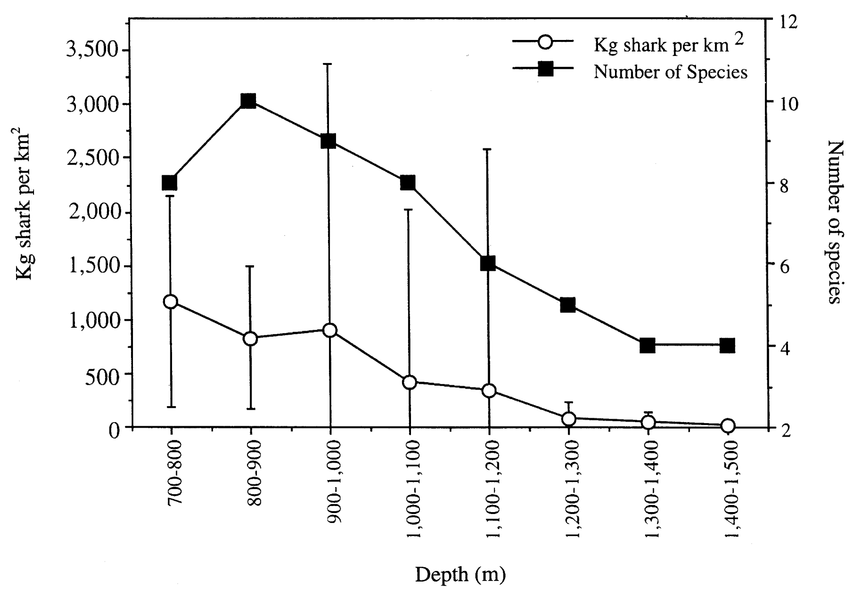

Figure 5

Average density (kg/km² ±SD) of all sharks combined and number of species captured within various depth intervals on Chatham Rise, New Zealand, for both surveys combined. For comparison of mean densities among intervals with ANOVA, P = 0.011, df = 389.

Discussion

Sharks are abundant and widely distributed on Chatham Rise. Even though sharks form a relatively small percentage of the overall catch in deep-water trawls they are frequently caught by the hundreds and occasionally dominate catches. The most abundant shark (by weight) on Chatham Rise, *D. calcea*, was often caught in large numbers, which suggests the presence of large aggregations. However, this species was caught in a high percentage of trawls and was widely distributed on Chatham Rise, which resulted in a fairly low index of dispersion (I_d). *D. calcea* is abundant elsewhere in New Zealand waters, accounting for as much as 70% of the shark catch off the North Island (Clark and King[1]). Kobayashi (1986) reported that *D. calcea* was one of the most common sharks in deep-water catches from Japan as well. The most ubiquitous shark in terms of presence at nearly all depths and locations on Chatham Rise was *E. granulosus*, although this species may have a fairly limited distribution outside of New Zealand and southeast Australia. Tachikawa et al. (1989) synonymized the New Zealand lantern shark, *E. baxteri*, with the widely-distributed southern lantern shark, *E. granulosus*; however, there may be several species within the *E. granulosus* group and *E. baxteri* may well be a valid species (Compagno et al., 1991; Wetherbee, 1996).

Catsharks captured in trawls were keyed out to five undescribed species (A–E) belonging to the genus *Apristurus* (Paulin et al., 1989). That several hundred specimens of these undescribed sharks were collected, underscores the paucity of information on deep-sea sharks. This genus also contains many undescribed species in other locations, such as Australia (Last and Stevens, 1994), and may eventually be recognized as one of the most speciose genera of sharks.

Table 2

Bray-Curtis index of similarity between geographical areas on Chatham Rise, New Zealand for a 1990 orange roughy survey and a 1993 smooth oreo survey. For location of areas see Figure 1.

Orange roughy survey Area	2	3	4	5	6	7	9	10
1	0.87	0.84	0.84	0.74	0.69	0.71	0.56	0.38
2		0.89	0.87	0.85	0.78	0.71	0.56	0.36
3			0.84	0.82	0.82	0.68	0.53	0.34
4				0.87	0.85	0.75	0.61	0.42
5					0.89	0.65	0.58	0.36
6						0.72	0.64	0.42
8							0.81	0.60
9								0.71

Oreo survey Area	7	8	9	10
6	0.76	0.71	0.35	0.32
7		0.76	0.47	0.37
8			0.57	0.53
9				0.85

Very few individuals of three species of relatively large squalid sharks (*Centrophorus squamosus*, *Scymnodon plunketi*, and *Dalatias licha*) were captured on Chatham Rise. These three species also happen to have liver oil that is high in squalene, or that has a high diacyl glycerol ether to triglycerol ratio, and the liver oil of these sharks is thus of high quality for industrial purposes (Bakes and Nichols, 1995; Wetherbee, 1998). Because each of these species formed less than 1% of the total shark catch in all fishing, targeting of any of these species by commercial fisheries on Chatham Rise does not appear to be practical. However, these species have been captured in greater numbers in fishing that was conducted at shallower depths and that targeted different fishes at locations other than Chatham Rise in New Zealand (Clark and King[1]).

The consistency in catch rate, regardless of time of day, indicates that there are few changes in the distribution of the deep-sea shark community on a diurnal basis. However, capture in a trawl may not provide information on activity patterns or feeding periodicity. For example, Kobayashi (1986) found that capture rate of sharks was higher at night than during the day in deep-sea fishing with baited lines. The present study was conducted over a three-month period and does not provide much information on seasonal differences in the distribution of deep-sea sharks. Some studies have suggested that there is continual movement of reproductive groups, or age classes, out of a particular area (Yano, 1991; Wetherbee, 1996). Other studies have maintained that community structure, temperature, and salinity of the deep-sea environment vary little throughout the year (Kobayashi, 1986; Clark and King[1]).

Orange roughy appear to be common prey of two species of sharks (*E. granulosus* and *C. owstoni*) and are also consumed by two of the less common, large squalids (*C. squamosus* and *D. licha*). *Centroscymnus owstoni* may exert the greatest predation pressure on orange roughy populations because both species are found in large numbers on the north of Chatham Rise. An expanded investigation of the feeding habits of sharks would provide more information on the relationship between sharks and commercially important teleosts on Chatham Rise.

Abundance

Differences in abundance of sharks between the orange roughy and oreo surveys appear to be attributable to the location at which fishing was concentrated in each survey. For the oreo survey, fishing was restricted to the south of Chatham Rise, and during the orange roughy survey, fishing was concentrated on the north of Chatham Rise (although trawls were made throughout Chatham Rise). The observation that there were no significant differences between the catches in areas common to both surveys indicates that overall differences between the surveys were probably not due to differences in fishing methods (duration of trawls and net specifications) or time (season or year). The contribution of sharks to total biomass of each survey was also remarkably similar.

The composition of the shark community was dependent upon the area of Chatham Rise that was sampled. Moving from west to east on the north of Chatham Rise, the dominant species in trawls changed from *C. owstoni* to *D. calcea*. Fishing areas at the eastern tip of Chatham Rise were the most diverse. There, the highest densities (kg/km^2) were recorded for six of the eight species of sharks and for all sharks combined. *Etmopterus granulosus* was the most abundant shark on the south of Chatham Rise, completely dominating the catch in the westernmost areas. Variation in the composition of the deep-sea shark community with location has been observed in other areas off New Zealand, and also in Japan and southern Africa (Kobayashi, 1986; King and Clark, 1987; Compagno et al., 1991). In several studies, the community of deep-sea sharks was thought to vary with latitude (Merrett and Marshall, 1981; Nakaya and Shirai, 1992; Yano and Kugai, 1993). The distribution of sharks on Chatham Rise may be influenced by a number of physical and biological factors. However, the lack of information on the deep-sea environment in this area precluded examination of the relationship between shark abundance and either biotic or abiotic factors; in contrast to other studies (Graham and Hastings, 1984; Bianchi, 1991; 1992; Garcia et al., 1998). Large portions of Chatham Rise are as shallow as 500 m, and sharks with fairly deep distributions might not move freely between the north and south slopes. Thus, the patterns of distribution observed for several species of sharks near Chatham Rise may be related to this physical barrier.

In this study, shark abundance also varied with depth. The depth range at which maximum shark density was recorded in the present study (700–800 m) was deeper than that reported by Kobayashi (1986) (300–500 m), and shallower than that found by Yano and Kugai (1993) (1100–1200 m). Depth distributions of sharks caught on Chatham Rise are characterized by several patterns. Some of the larger species were rare at depths greater than 1100 m, which may approximate their maximum depth of occurrence. The density of other species declined abruptly beyond 1200 m, and the proportion of *Apris-*

turus spp. in the catch increased at depths greater than 1200 m. The depths fished in the present study did not appear to reveal the minimum depth of occurrence for any species of shark. Compagno et al. (1991) noted the importance of determining minimum depth of occurrence describing the depth distribution of a particular species.

On Chatham Rise, density (kg/km^2) of all sharks combined was fairly constant up to about 1200 m but dropped drastically beyond this depth. Nakaya and Shirai (1992) observed a similar dramatic decrease in shark density at 500 m, and Merrett and Marshall (1981) at 1000–1100 m. An inverse relation between shark abundance and depth has been described for a number of species in other regions of New Zealand, and in other parts of the world (Merrett and Marshall, 1981; Kobayashi, 1986; King and Clark, 1987; Yano and Kugai, 1993).

Distribution

Diversity (species of shark/trawl) was higher for the orange roughy surveys than for the oreo surveys, but there was no significant difference in mean diversity between areas common to both surveys. These observations support the contention that differences in the shark catch between surveys are related to sampling location, rather than to temporal or methodological differences between surveys. However, there were generally more trawls within each area during the orange roughy survey than for the oreo survey, which may have increased the total number of species caught on the north of Chatham Rise. Hill (1973) predicated that as the size of a sample is increased, so almost without limit will the diversity. Diversity also declined with increased depth on Chatham Rise, and Crowder (1990) suggested that such a decline in species diversity might be due to changes in the level of competition, predation, or environmental homogeneity.

In this study, only 16 species of shark were caught, although many more species of deep-sea shark have been captured in New Zealand (Paulin et al., 1989). The total of only 16 species caught in the present study is also low in comparison to numbers (>30) of species caught in deep-water surveys in other parts of the world (Kobayashi, 1986; Compagno et al., 1991; Nakaya and Shirai, 1992; Yano and Kugai, 1993). Much of the fishing on Chatham Rise was conducted at depths of greater than 1000 m, which may be beyond the depth limit of a number of species of squalid sharks found in New Zealand waters (Yano, 1985; Compagno et al., 1991).

The index of similarity between the orange roughy and oreo surveys was high, again suggesting that differences introduced as a result of variable fishing methods or time were probably not substantial. The nearly identical indices of similarity between depth intervals for each survey also support this conclusion. The high indices of similarity between areas for most species, along with the fairly low indices of dispersion, indicate that although their abundance is variable, most species have fairly wide distributions on Chatham Rise.

Sharks within the genera *Etmopterus* and *Centrophorus* are thought to segregate by species in Japanese waters (Kobayashi, 1986; Baba et al., 1987; Yano and Tanaka, 1983). In the present study there was little evidence to suggest that any two species displayed such segregation. Compagno et al. (1991) found that *Centroscymnus* spp. were sympatric but had very different food habits. An examination of dietary overlap among sharks common on Chatham Rise may reveal whether these sympatric species compete for the same food resources.

Although the sharks captured during this study were incidental to commercially important fishes, such as orange roughy and smooth oreo, the data collected from these trawls have provided information on the abundance and distribution of a number of species of deep-sea shark on Chatham Rise. Distributional patterns of sharks vary among species, and the composition of the deep-sea shark community varies with depth and location. Therefore, the overall impact of deep-water trawl fisheries on shark populations would be expected to vary among species and to depend on the particular fishery, which in turn influences the location and depth where fishing is concentrated.

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