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Quantifying the relative intensity of fishing on New Zealand seamounts

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Abstract New Zealand seamounts support major fisheries for several deepwater fish species, including orange roughy (*Hoplostethus atlanticus*) and smooth oreo (*Pseudocyttus maculatus*). Although a high proportion of features in the depth range 500–1000 m have been fished, very little is known about the ecological impacts of bottom trawling on seamounts. The potential impact is likely to be influenced by the spatial extent and frequency of fishing. A new index is presented to assess the relative intensity of trawling on New Zealand seamounts. The fishing effects index (FEI) incorporates information on the density of fishing on the seamount as a proportion of the seabed area and also on tow direction. Detailed fisheries data from more than 250 000 tows were examined to calculate FEI for New Zealand seamounts. The most intensively fished seamounts were on the south Chatham Rise, an area characterised by a large number of relatively small features which were fished serially for orange roughy in the 1980s and 1990s. Other seamounts with high FEI were on the north Chatham Rise, Challenger Plateau, and off the east coast of the North Island. A range of sensitivity analyses indicated that the general rankings of seamounts were relatively robust to the choice of arbitrary thresholds used to assign tows to seamounts.

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Keywords impacts of trawling; deepwater fisheries; seamounts; fishing effort distribution; orange roughy

INTRODUCTION

Seamounts are important features of the New Zealand marine environment. About 800 seamounts with vertical elevation greater than 100 m above the surrounding sea floor have been identified in the general New Zealand region (Clark & O'Driscoll 2003). Seamounts are productive habitats for deepwater fish (Koslow 1997), and major fisheries for orange roughy (*Hoplostethus atlanticus*), oreos (black oreo *Allocyttus niger*, and smooth oreo *Pseudocyttus maculatus*), black cardinalfish (*Epigonus telescopus*), alfonsino (*Beryx splendens*), bluenose (*Hyperoglyphe antarctica*), and rubyfish (*Plagiogeneion rubiginosum*) occur on and around New Zealand seamounts (Clark & O'Driscoll 2003). They reported that nearly 80% of all known seamounts in the depth range 500–1000 m in the New Zealand region have been fished.

Although productive, seamounts are generally regarded as fragile habitats (Rogers 1994; Probert 1999). The environmental impact of fishing, especially bottom trawling, is the subject of growing public and political awareness (e.g., de Groot 1984; Hutchings 1990; Collie et al. 1997; Hall 1999; Koslow et al. 2001). The impacts of trawl gear have long been known, including gouging of the seabed, sediment resuspension and smothering, destruction of non-target benthic animals, and the dumping of processing wastes (see Jones 1992; Dayton et al. 1995). However, very little is known about the effects of fishing on the ecology of seamounts in the New Zealand region.

The ecological impact caused by fishing is influenced by the spatial extent and frequency of habitat disturbance (Thrush et al. 1998). One of the challenges facing researchers is how to quantify the intensity of trawling on individual seamounts. Simple measures, such as number of tows, may not adequately index fishing effort. For example, 100 tows on a very small seamount may represent a higher intensity of effort than 500 tows on a larger feature. The distribution of tows will also determine how much of the seamount area is affected by fishing. On some seamounts there is a "shotgun" type coverage with tows in all directions, whereas on others there appears to be a "trawl corridor" with most tows occurring in a single preferred direction.

Clark & O'Driscoll (2003) developed a fishing importance index (FII) which measured the effort, catch, consistency of fishing, and diversity of target species on each seamount. The FII was an attempt to quantify the relative importance of seamounts for the commercial fishery, but did not assess the likely impact of fishing on the seamounts. In this paper we describe a new measure, the fishing effects index (FEI), and use this to assess the relative intensity of trawling on New Zealand seamounts.

METHODS

Individual tow information, with location and estimated catch for each tow, have been recorded by most New Zealand deepwater fishing vessels since the early 1980s. Data are held in a database by the New Zealand Ministry of Fisheries, from which we extracted data for all tows which targeted orange roughy, oreos (black, smooth, and unspecified), black cardinalfish, alfonsino, bluenose, and rubyfish up to 30 September 2003. Orange roughy and oreo data extend back to the 1970s, but for the other species most of the fishing effort has occurred since 1989, and earlier data (collected under a slightly different system) were not included in the analysis. Positional data were less accurate before the introduction of global positioning systems (GPS) in about 1989. To assess the effect of this on the FEI, we also calculated indices excluding orange roughy and oreo data before 1989 as a sensitivity test. For all fisheries, some data were recorded on forms without detailed positional data, but these account for less than 10% of the total effort and were excluded from the analysis.

The start positions of tows were compared to the centre positions of over 800 seamounts on the NIWA database, which were determined from bathymetry and research surveys. The list of seamounts included all discrete hill-like structures with vertical elevation greater than 100 m above the sea floor (after Clark & O'Driscoll 2003).

The fishing effects index (FEI) for an individual seamount was defined as follows:

$$\mathrm{FEI} = \left(\frac{\sum \mathrm{L}}{\mathrm{A}}\right)\left(\frac{\mathrm{D}}{4}\right)$$

where $\sum$L is the summed tow length (in km) of all tows with start positions within 10 km of the seamount centre and tow length less than 5.6 km; A is the seamount area in square kilometres; and D is the number of tow directions (from 1 to 4) for each seamount that had more than 5 tows. The units of FEI are km^{-1}.

A distance of 10 km from the seamount centre was chosen following Clark & O'Driscoll (2003). This threshold was arbitrary, but was chosen to encompass the likely maximum distance of a vessel away from a seamount while still fishing on that seamount. We investigated the sensitivity of the final results to this threshold by calculating indices using a threshold distance of 5 km. When a tow started less than 10 km from more than one seamount, it was assigned to the nearest seamount only. This approach may have introduced some degree of error where seamounts were close together and a vessel was fishing one seamount while its reported position was closer to a neighbouring one. However, this is a minor problem, as most seamounts are at least 5 km apart, so that tow start positions could be assigned to the correct feature.

Tow length was calculated as the product of tow duration in minutes and tow speed in knots. Mean tow speed was c. 3 knots, so that a tow length of 5.6 km was equivalent to a tow duration of 1 h. This threshold was also arbitrary, but was based on our experience that tows on seamounts seldom exceed 1 h (and are usually less than 30 min), whereas tows on surrounding flat areas are typically much longer. Again, the sensitivity of results to the choice of threshold was investigated by calculating indices with alternative thresholds of 3.7 and 9.3 km (2 and 5 nautical miles).

Tow direction was calculated from tow start and finish positions for tows that fulfilled both of the above criteria ("seamount tows") and additionally had tow lengths greater than 0.9 km (0.5 nautical miles). This additional threshold was introduced to reduce inaccuracies in directions resulting from positional rounding, as fishers generally only record tow positions to the nearest minute of a degree. For very short tows (<0.9 km), start and finish positions were almost always the same. Only tows from 1989

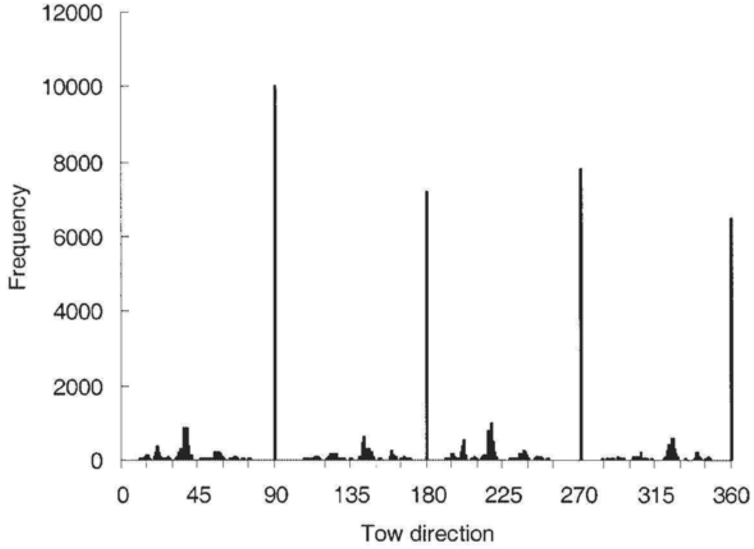

Fig. 1 Frequency of calculated tow directions for commercial tows (1989–2003) which started within 10 km of a seamount centre and were used in the analysis. On direction axis, 90 = east, 180 = south, 270 = west, 360 = north.

onwards had finish positions reported, so that tow direction could not be calculated for tows before 1989. Frequency histograms (Fig. 1) of reported tow directions indicated that fishers tended to preferentially report tows as being north, south, east, or west (i.e., latitude or longitude changed during the tow but usually not both). This directional bias was not a result of positional precision as the same pattern was apparent even for long tows (>5.6 km). To deal with this feature of the data, we categorised direction into four quadrants (north = 315°–45°, east = 45°–135°, south = 135°–225°, west = 225°–315°, where 0° = due north).

To test whether the direction of tows on an individual seamount x was non-random, we randomly took 1000 samples of size n_x from the total set of reported tow directions (Fig. 1), where n_x was the number of tows 0.9–5.6 km long where the tow start position was within 10 km of seamount x. We then compared the proportion of tows in each direction (north, south, east, or west) from the observed tows with the proportions from the random samples. The direction of trawling was considered to be non-random where there were fewer observed tows in one or more directions than in 95% of the random samples (i.e., one-sided test with $P = 0.05$).

Seamount areas (km^2) were only available for 138 of the 227 fished seamounts in the New Zealand region. Seamount area was estimated from the flat surface area of a polygon defined by the most complete depth contour that encircled the base of the seamount. This estimation did not account for differences in true surface area with elevation and steepness, but as most New Zealand seamounts have slopes of between 10° and 25° (NIWA unpubl. data), this was unlikely to be a major source of error. To calculate the FEI, we assigned the other 89 seamounts a nominal area of 1 km^2. This was reasonable because seamounts with no area information were known to be mostly small features.

The FEI incorporates data of the amount of fishing effort, tow direction, and seamount area. The index is essentially in two parts. The first part is a measure of the density of fishing on the seamount as a proportion of the seamount area. Summed tow length was used as a proxy for swept area because tow characteristics (doorspread and wingspread) were not reliably recorded. In general, orange roughy trawls have wingspread in the range 20–30 m, and doorspread of 100–200 m. The second part of the index is a scaling factor reflecting the proportion of tow directions in which the seamount was trawled. Seamounts have a high FEI if they have had a large amount of effort relative to their size and they have been towed in all directions.

RESULTS

More than 250 000 tows were extracted from the MFish database (Table 1). Of these, 84 793 tows (34%) fulfilled the criteria of occurring within 10 km

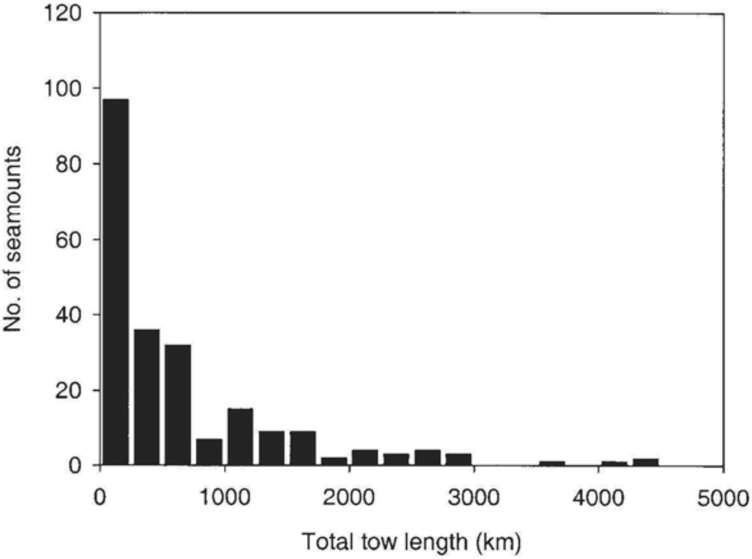

Fig. 2 Fishing effort (total tow length) on seamounts grouped into bins of 250 km. Two seamounts with 5500 and 10 500 km of tows are not graphed.

Table 1 Numbers of commercial tows included in analyses used in this paper. Directions were only calculated for tows occurring close to seamounts (–, not applicable).

Dataset	No. of tows	No. of tows with directions
All data	250 116	–
Base case	**84 793**	**54 922**
Sensitivity A	97 606	64 726
Sensitivity B	71 961	44 391
Sensitivity C	62 534	40 623
Sensitivity D	79 468	54 922

Base case: tow start <10 km from seamount centre, tow length <5.6 km
Sensitivity A: tow start <10 km from seamount centre, tow length <9.3 km
Sensitivity B: tow start <10 km from seamount centre, tow length <3.7 km
Sensitivity C: tow start <5 km from seamount centre, tow length <5.6 km
Sensitivity D: tow start <10 km from seamount centre, tow length <5.6 km, only data from 1989 (post-GPS)

of a seamount centre and being less than 5.6 km in length ("base case" in Table 1). Most of these seamount tows (76%) were targeted at orange roughy. The effect of varying the thresholds on the number of tows which were defined to be on seamounts is also shown in Table 1.

The total tow length on individual seamounts is shown in Fig. 2. The highest effort was on Hill 280 (NIWA seamounts database reference number) off the east coast of the North Island, which had over 10 000 km of tows. However, most seamounts had less than 750 km of tows. The median intensity of fishing was c. 130 km of tows per 1 km^2 of seamount area, although some seamounts had a much higher density of tows (Fig. 3).

The direction of tows was non-random for 81% of fished seamounts (Fig. 4). The pattern of tows on six example seamounts is shown in Fig. 5. On most seamounts, there were one or more clearly preferred tow directions. For example, on Hill 280, 88% of tows were north-northeast or south-southwest, whereas on Colville Knoll 77% of all tows were westwards (Fig. 5). On a few features, such as Mt Kiso, there was a shotgun-type coverage and the pattern of fishing was not distinguishable from random (Fig. 5).

The FEI results are shown in Fig. 6, with key data for the top 50 seamounts summarised in Table 2. Table 2 also shows the sensitivity of the ranking of seamounts to thresholds applied during the analyses.

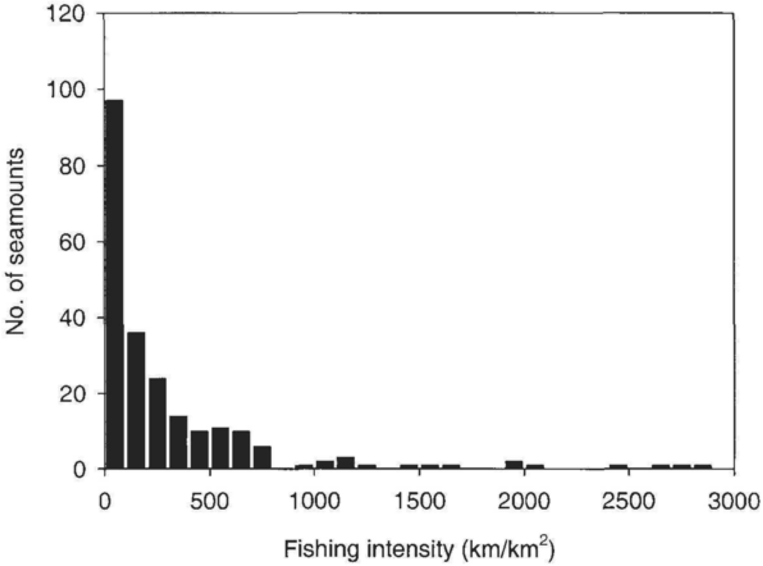

Fig. 3 Fishing intensity (tow length divided by seamount area) on seamounts grouped into bins of 100 km/km². Two seamounts with intensities of 3800 and 17 400 km of tows per km² are not graphed.

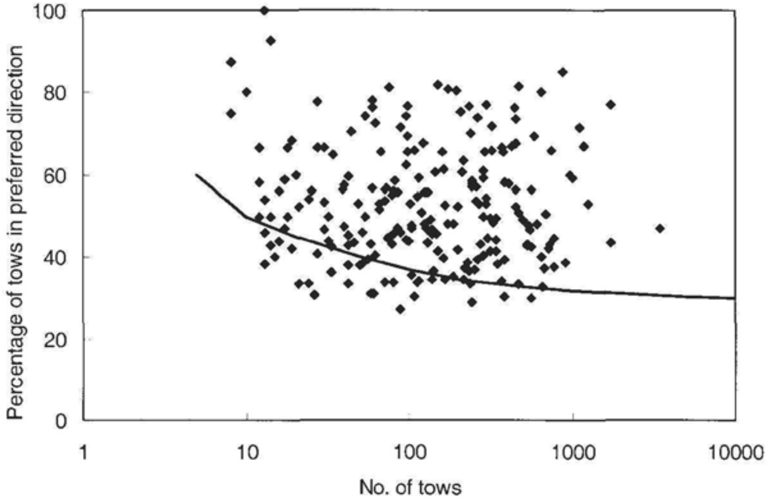

Fig. 4 Percentage of tows in preferred direction plotted as a function of total number of tows. Note $\log_{10}$ scale on x axis. Line shows the upper 95% confidence level for random tows from 1000 Monte Carlo simulations. Points above the line indicate seamounts which had significantly higher proportions of tows in the preferred direction than expected if the direction of trawling was random.

The most intensive fishing was on the south Chatham Rise, with 20 seamounts from this area ranking in the top 50 FEI (Table 2). The south Chatham Rise is characterised by a large number of relatively small features, which were fished serially for orange roughy in the 1980s and 1990s (Clark et al. 2000). Other seamounts with high FEI were on the north Chatham Rise (Crack, Zombie), Challenger Plateau (Northwest Pinnie, Spin Pinnie), and off the east coast of the North Island (Outer Castlepoint) (Fig. 6).

Changing the threshold criteria for seamount tows when calculating FEI caused small adjustments to the ranking of seamounts, but the general ordering was the same (Fig. 7). For example, the top 10 seamounts in Table 2 were ranked within the top 15 in all four sensitivities. Excluding data before 1989 (sensitivity D) had the smallest effect on the ranking of seamounts (Fig. 7), and we chose to include all available information for completeness in the base case. We also know that there was considerable fishing before 1989 on some seamounts (e.g., Crack, Mt Kiso, Trevs Pinni) (NIWA, unpubl. data).

There was only a weak relationship between the FEI and the fishing importance index (FII) as defined by Clark & O'Driscoll (2003) (Fig. 8). Some

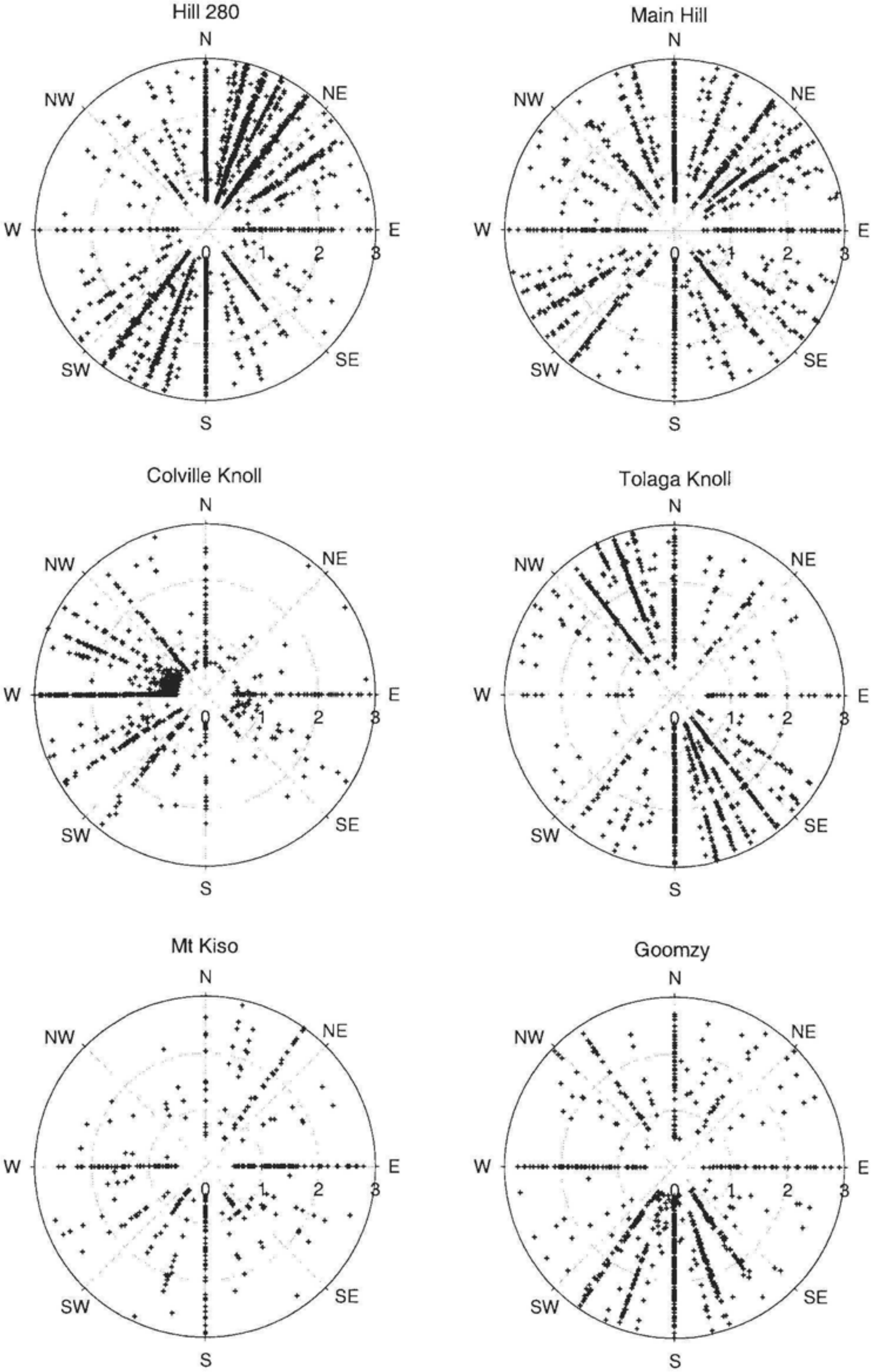

Fig. 5 Scatter plots showing the length (in nautical miles) and direction of tows on six New Zealand seamounts. Each point represents a single tow.

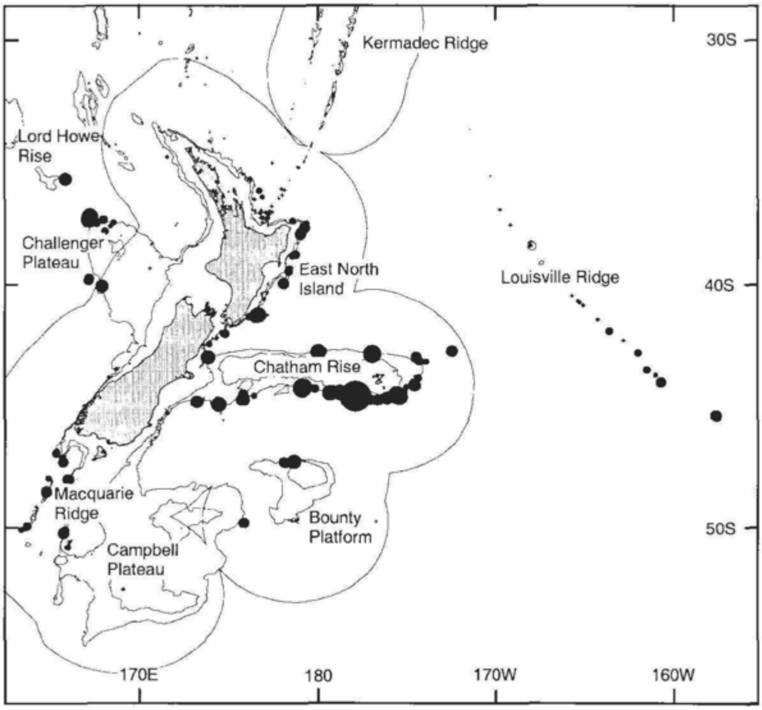

Fig. 6 Fishing effects indices (FEI) for New Zealand seamounts. Symbol area is proportional to the calculated FEI value. Data for the top 50 seamounts are given in Table 2.

seamounts (e.g., Hill 280), which had a lot of catch and effort, and therefore a high FII, had a low FEI because they were relatively large (see Table 2). Conversely, some small features (e.g., Hill 94, NIWA no. 668) which were of lower importance for the commercial fishery, had sustained a high intensity of effort, and so the FEI on these seamounts was high (see Table 2).

DISCUSSION

The FEI provided a measure of the relative intensity of trawling on seamounts. It allowed us to rank New Zealand seamounts on the basis of the density and direction of tows. Highest intensity of fishing was concentrated on small seamounts on the south Chatham Rise.

Most previous attempts to quantify the spatial intensity of trawling estimated trawl effort in a grid of cells over the fishing grounds (e.g., Piet et al. 2000; Pitcher et al. 2000; Cranfield et al. 2003). The choice of grid cell size is important because fishing effort is seldom homogeneously distributed over a wide area. For example, Rijnsdorp et al. (1998) found that in some of the most heavily fished areas of the North Sea, every square metre of the seabed within a 30 by 30 mile ICES rectangle was trawled 5–7 times a year on average. However, examination of the data at a much finer spatial resolution (1 by 1 mile squares) suggested that 5% of the area was trawled less than once in five years and 29% less than once a year. The FEI described here is an improvement on this grid approach because tows were assigned to individual seamounts rather than to arbitrary latitude-longitude cells, and tow direction was also incorporated.

The two components of the FEI were tow density and tow direction. Because tow duration was reported to the nearest minute and tow speeds are usually constant, the calculated tow length is probably an accurate indicator of the swept area. The major uncertainty in quantifying tow density was the seamount area, for which data were not available for many of the smaller seamounts. FEI will be underestimated if the actual seamount area was less than the nominal area of 1 km^2 assigned to these features. Data on tow direction were more problematic. Originally we had intended to consider this component of the effect of fishing in more detail by examining distribution of tow directions on a seamount at higher resolution (e.g., 10° angular bins), but the quality of the data did not allow this approach. Positions were reported to the nearest

Table 2 Details of the 50 seamounts with the highest fishing effects indices (FEI) derived from the base case analysis in this paper. NIWA no. is the NIWA seamounts database reference number. Region, latitude (lat), longitude (long), depth and area refer to the location and physical characteristics of the seamount. Effort is an estimate of the total distance towed on the seamount. Tow direction gives the percentage of tows in each direction (N, north; E, east; S, south; W, west). The rank of the FEI index is compared to the rank of the fishing importance index (FII) which is a measure of the relative importance of the seamount to the commercial fishery (after Clark & O'Driscoll 2003). Ranks of FEI are also given for four sensitivity tests which used different data selection criteria (see Table 1).

	NIWA	Lat	Long		Depth	Area	Effort	Tow direction (%)				FEI	FEI	FII	Sensitivity ranks			
Region	no.	(S)	(E)	Name	(m)	(km^2)	(km)	N	E	S	W	(km^{-1})	rank	rank	A	B	C	D
Chatham Rise	654	–44.6	182.2	The Pimple	942	0.1	872	2	61	13	24	17 442	1	35	1	1	1	1
Chatham Rise	649	–44.2	179.2	Fletchers Pinnie	907	0.3	1143	5	76	12	7	3810	2	21	3	2	5	5
Chatham Rise	668	–44.5	184.5	Hill 94	588	0.4	1129	3	4	44	49	2821	3	63	5	6	9	2
Chatham Rise	608	–42.8	183.1	Crack (Mt Muck)	700	1.0	2796	30	39	7	24	2796	4	1	2	5	6	12
Challenger Plateau	563	–37.3	167.3	Spin Pinnie	578	*	2638	7	6	85	1	2638	5	38	8	4	3	3
Challenger Plateau	576	–37.2	167.3	NW Pinnie	606	*	2494	5	80	9	6	2494	6	42	4	9	2	4
East North Island	760	–41.2	176.7	Outer Castlepoint	764	*	2032	16	7	68	9	2032	7	40	7	11	8	8
Chatham Rise	651	–44.5	180.7	Trevs Pinnie	878	1.4	2750	6	77	9	7	1965	8	4	6	10	7	22
Chatham Rise	587	–42.8	180.1	Zombie	891	0.8	1566	20	66	2	12	1958	9	22	14	3	4	6
Chatham Rise	688	–44.9	174.5	Courtney Place	–	*	1699	12	30	30	28	1699	10	6	11	8	36	7
Chatham Rise	652	–44.4	181.3	Mt Kiso	630	2.7	4248	15	31	34	21	1573	11	2	9	12	10	45
East South Island	769	–43.0	173.9	Mernoo Gap Hill	900	*	1492	70	7	19	4	1492	12	29	10	28	22	16
East North Island	764	–41.3	176.6	S. Castlepoint Hill	732	*	1224	37	31	16	16	1224	13	62	12	44	25	14
Bounty Platform	791	–47.3	178.7	Pinky	–	*	1168	66	20	1	14	1168	14	64	13	14	73	9
Chatham Rise	664	–44.7	183.9	Featherlite	952	0.3	344	32	46	6	16	1146	15	84	19	7	14	10
Chatham Rise	695	–44.8	173.3	–	1 011	*	1 101	25	30	20	24	1101	16	18	18	13	41	11
Challenger Plateau	579	–40.1	168.0	Twin Tits	790	2.0	2173	44	16	30	9	1086	17	7	15	23	11	48
Lord Howe Rise	557	–35.7	166.0	Pinnie	772	*	1016	8	33	49	10	1016	18	105	20	15	17	13
Challenger Plateau	578	–40.1	168.0	Mega Brick	833	3.0	2968	26	18	50	6	989	19	5	17	37	13	69
Lord Howe Rise	556	–35.7	166.0	Pinnie	780	*	796	15	18	53	14	796	20	116	22	25	12	15
Chatham Rise	632	–44.7	184.8	Big Chief	795	3.0	2206	12	60	16	13	735	21	8	36	16	15	17
Challenger Plateau	561	–37.2	167.3	Ayers Rock	606	*	735	29	9	57	5	735	22	108	31	22	21	18
East North Island	506	–37.9	179.1	Snake	914	1.7	1241	8	26	10	57	721	23	78	28	39	24	19
Chatham Rise	776	–42.7	187.6	Ho Chi Minh	1236	0.6	428	48	7	6	39	714	24	81	37	17	32	20
Chatham Rise	684	–44.8	175.9	Willies	869	*	705	2	3	54	41	705	25	73	40	31	16	21
Chatham Rise	690	–44.8	173.4	–	–	*	684	17	33	29	21	684	26	25	24	36	55	30
Chatham Rise	638	–44.7	184.7	Cooks	770	1.0	678	26	43	17	14	678	27	50	45	18	18	23
Chatham Rise	656	–44.7	182.9	Pinnie	–	*	670	4	42	40	15	670	28	66	23	49	86	47
East North Island	503	–37.7	179.3	Hill 5	960	1.0	690	15	16	37	32	668	29	110	26	46	20	24
Chatham Rise	659	–44.8	183.4	Dolly Parton	923	*	664	7	66	8	19	664	30	36	46	20	23	26
Chatham Rise	672	–44.7	175.8	Pinnie	891	*	661	7	6	33	54	661	31	98	39	27	30	25
Campbell Plateau	743	–50.2	165.9	AK47	859	1.0	659	7	41	13	39	659	32	58	41	19	19	27
Louisville Ridge	–	–45.4	202.4	–	540	*	657	20	5	16	58	657	33	111	42	34	59	28
Chatham Rise	640	–44.6	184.2	Condoms	860	1.5	967	9	28	29	34	645	34	28	43	26	37	29
Challenger Plateau	562	–37.3	167.3	North Dork	822	*	617	13	27	53	7	617	35	85	16	69	78	31

Macquarie Ridge	783	–48.5	164.9	Spastic Spider	–	*	588	5	66	4	25	588	36	72	50	24	35	32
Macquarie Ridge	784	–48.0	166.1	Doghill	–	*	581	4	42	35	19	581	37	74	53	21	26	33
East North Island	280	–40.0	178.1	Hill 280	500	18.2	10 539	47	8	41	4	579	38	3	27	52	57	34
Louisville Ridge	–	–44.0	199.3	–	740	*	552	4	63	26	7	552	39	95	54	30	49	35
Lord Howe Rise	558	–35.6	166.0	Pinnie	807	*	547	10	34	48	8	547	40	142	35	48	27	36
Chatham Rise	685	–44.7	175.9	Neow	888	*	538	10	5	33	52	538	41	103	51	42	29	37
Chatham Rise	642	–44.6	184.8	Lucky	957	1.8	966	2	81	10	7	537	42	26	55	29	28	38
Bounty Platform	790	–47.3	178.2	Mars Bar	–	*	524	9	14	11	66	524	43	101	33	59	52	39
Campbell Plateau	756	–49.8	175.9	Barbaras Blaze	865	*	516	5	11	36	48	516	44	49	56	32	31	40
Chatham Rise	778	–42.7	187.5	Ho Whyte	983	*	513	29	27	34	10	513	45	80	58	33	34	41
East North Island	763	–41.3	176.6	S. Castlepoint Hill	739	*	507	61	5	27	7	507	46	128	29	75	33	42
Chatham Rise	655	–44.6	182.2	Amaltal Pinnie	900	*	494	6	66	20	8	494	47	47	21	64	68	58
Chatham Rise	610	–43.0	185.6	Smiths City	894	3.0	1450	33	14	33	21	483	48	13	61	35	42	43
Chatham Rise	648	–44.7	184.8	Little Chief	738	0.7	335	15	32	9	44	479	49	121	59	51	38	44
Macquarie Ridge	785	–47.3	165.8	Hang_10	–	*	474	10	58	5	27	474	50	90	57	38	39	46

– No data available.

* Area assumed to be 1.0 km^2.

minute of a degree and there was an apparent tendency of fishers to change only one coordinate (latitude or longitude) between tow start and finish positions, leading to an overwhelming bias in calculated tow directions. This forced us to crudely categorise direction into quadrants.

There is an additional risk of bias in tow directions if some sectors of a seamount are steep, meaning all tows were short (less than the 0.9 km threshold) so that direction could not be calculated. This would mean that trawling occurred in a quadrant but was not detected in this analysis. However, we found that almost all seamounts had at least some tows in all four directions, so that this potential bias was unlikely to have had a major impact on the FEI.

Even though directional data had low precision, it was apparent that the direction of trawling was non-random on most (81%) fished seamounts. This has led to suggestions by commercial fishers that the impact of fishing will be restricted to the "trawl corridor" (preferred tow path) whereas adjacent areas on the same seamount are unaffected. Within the constraints mentioned above, our analysis did not support this hypothesis. Although most seamounts had one or more preferred tow directions, there was usually some trawling in all four quadrants. Even a small number of tows may lead to significant impact. For example, Pitcher et al. (2000) reported that each tow removed roughly 5–20% of the available biomass of sessile epibenthos on the Great Barrier Reef. A single trawl can sweep the sea floor over a width of 100–200 m (doorspread), and on a small seamount the threshold level of five tows in a given direction may represent a significant fraction of the total seabed area.

Many of the decisions made and thresholds used in this analysis were arbitrary. For example, a threshold distance of 10 km from the nearest seamount and maximum tow length of 5.6 km almost certainly included some tows on the flat close to the base of an adjacent seamount where the features are small. However, the range of sensitivity analyses indicated that the general rankings of seamounts were relatively robust to the choice of thresholds.

The FEI does not directly assess the impact of fishing on seamounts. Other studies have shown that the type of bottom trawl gear used in New Zealand seamount fisheries has a marked impact on the bottom, with removal of benthic fauna (Probert et al. 1997; Koslow et al. 2001). However, the impact will depend on substrate type and community composition, as well as intensity of fishing (van

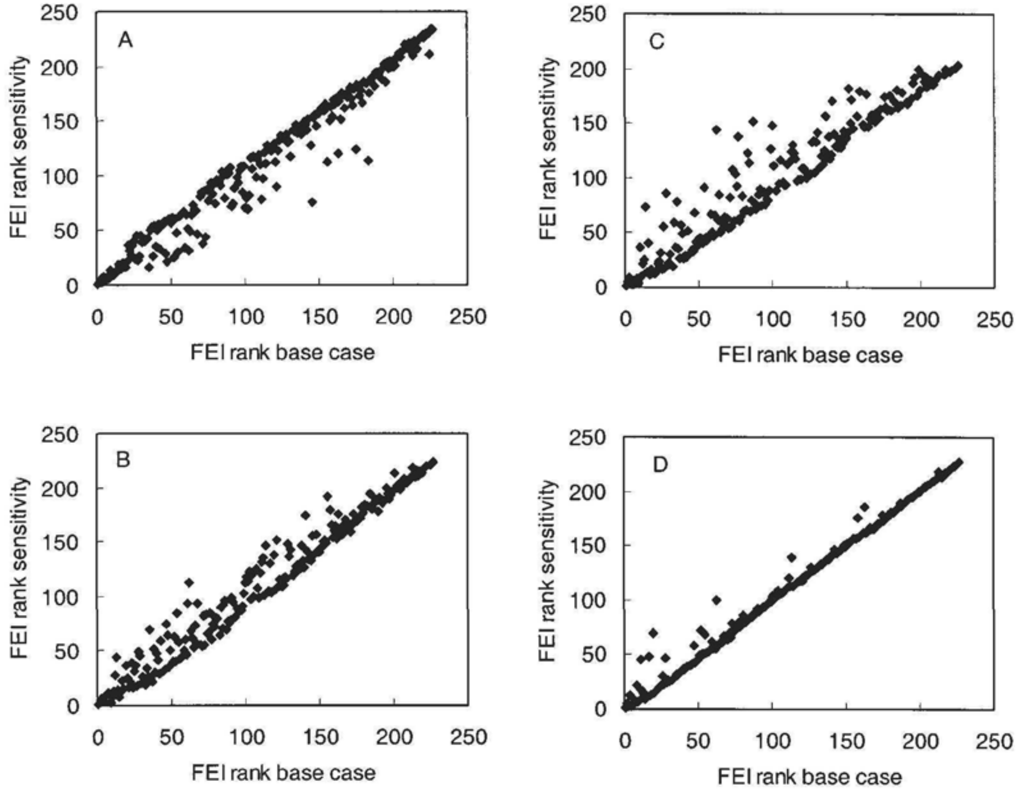

Fig. 7 Sensitivity of fishing effects index (FEI) rankings to changes in thresholds used in the analyses: **A**, maximum tow length = 9.3 km; **B**, maximum tow length = 3.7 km; **C**, maximum distance from seamount centre = 5 km; **D**, only data from 1989 (post GPS). The distance from the 1:1 line indicates how much the new rank (*y* axis) changed from the base case (*x* axis).

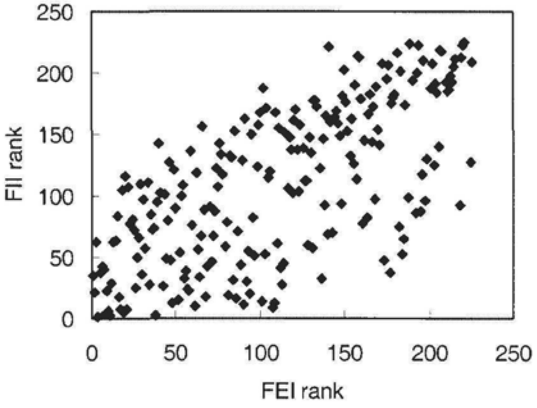

Fig. 8 Relationship between rankings of fishing effects index (FEI) and fishing importance index (FII). FII was updated from Clark & O'Driscoll (2003) to include data up to 2003.

Dolah et al. 1987; Freese et al. 1999; Pitcher et al. 2000). The coral cover present on many seamounts is fragile, and easily damaged by bottom trawl gear (Clark & O'Driscoll 2003), whereas the same intensity of trawling may have a smaller impact on a softer substrate (e.g., Sanchez et al. 2000).

Few data are available from New Zealand seamounts to evaluate the biological meaning of the FEI (i.e., to "ground truth" the index). One area where a comparison can be made between the FEI and measured biological impacts of trawling is on the Graveyard complex on the northern Chatham Rise. Clark & O'Driscoll (2003) presented data (summarised in Table 3) from a photographic survey showing the distribution of coral on four seamounts with varying levels of fishing intensity (Graveyard, Morgue, Diabolical, and Gothic). Table 3 shows that seamounts with higher FEI (Graveyard and Morgue) had lower occurrence and abundance of live habitat-forming coral than seamounts with lower FEI

Table 3 Occurrence and abundance of live habitat-forming coral (*Solenosmilia variabilis* and *Madrepora oculata*) on four seamounts on the northern Chatham Rise with different fishing effects indices (FEI). Coral data are from photographic transects (after Clark & O'Driscoll 2003). N is the number of camera stations.

Seamount	FEI (km^{-1})	FEI rank	N	Occurrence (% of images)	Abundance (mean % cover)
Graveyard	228	79	70	1.4	0.03
Morgue	94	123	55	1.8	0.04
Gothic	23	167	62	44	21
Diabolical	0	–	42	21	12

(Gothic and Diabolical). However the sample size is small, and, because these four seamounts are close together, there may have been errors assigning some tows to seamounts when calculating the FEI (see Methods). Further research is required to relate the intensity of fishing to observed impacts on the fauna of New Zealand seamounts.

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