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NOTE

Historic trawl data and recent information infers temporal change in the occurrence of squid in the diet of orange roughy (*Hoplostethus atlanticus* Collett) in New Zealand

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Abstract A review of historical trawl data for orange roughy on Chatham Rise and Challenger Plateau, New Zealand, between the years 1984 and 1996 infers a shift in this species' diet, with a progressive decline in the percentage occurrence of squid being apparent. On Chatham Rise, this decline in the percentage occurrence of squid appears to be compensated for by increases in the percentage occurrence of fish and crustaceans in orange roughy diet, whereas on Challenger Plateau, decreases in all of squid, fish and crustaceans are apparent. New orange roughy dietary data for 2004 from Chatham Rise is consistent with earlier data series, with further declines in the percentage occurrence of squid apparent. Declines in the occurrence of squid in the diet of orange roughy could be attributed to declines in the abundance of squid as a consequence of fisheries activity.

Keywords Orange roughy · Squid · Diet · Fisheries · New Zealand

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Introduction

A major fishery for orange roughy (*Hoplostethus atlanticus*, Collett), a species typical of slope waters from 750–1200 m, has developed around New Zealand since the 1970s. Initial Soviet catches on the north-eastern Chatham Rise were small (Robertson et al. 1984), but since 1978 larger fisheries have developed, particularly on Chatham Rise and Challenger Plateau — two submarine plateaux extending due East and West respectively of central New Zealand (Clark et al. 2000). The spawning-biomass of orange roughy has been dramatically reduced on both these plateaux. At ~3% virgin levels, the Challenger fishery was effectively closed in 2000 to allow stock to re-build, but with no subsequent data available it is unknown whether this closure has been successful. The Chatham Rise fishery continues to be exploited and spawning-biomass levels are thought to lie between ~10 and 30% virgin levels (Sullivan et al. 2005).

Trends in the reduction of orange roughy biomass since exploitation first began are typical of those seen in other deep-sea fisheries worldwide, with initial large catches and subsequent rapid declines (Branch 2001; Strutt 2001; Sullivan et al. 2005). Despite the importance of this fishery to the New Zealand economy, most research effort has been invested in determination of stock size and age estimation. Accordingly, biological data are limited or non-existent, and reasons for a fishery collapse are poorly understood; they might not be solely attributable to over-exploitation.

Long-term effects of fisheries on target species can include: decline in abundance of fished species; contraction of distribution or areas of high density; change in age and/or size structure, with fewer old, large fish, and a population dominated by new recruits; increase in growth rate of individuals, with a decrease in age for a given length; lower age and/or size at maturity; and possible change in species composition over time (Clark and Tracey 1994). A reduction in biomass, contraction in distribution, and reduction in size-at-maturity have been documented for male orange roughy on Challenger Plateau (Clark and Tracey *ibid*.).

A further, obvious effect of fishing activity is the change in diet resulting from removal or destruction of habitat, prey and associated species through trawl damage (Haedrich et al. 2001). This has been made apparent as a result of more holistic approaches to fisheries management being implemented in modern fisheries legislation, and a greater appreciation for the interconnectedness of marine systems (Mace 2001). Cascading effects on the target species are likely to include changes in its trophic level and associated changes in trophic dynamics of food webs (Wainright et al. 1993). However, despite the intuitive and obvious nature of trawl damage on both habitat and associated species (Kaiser et al. 2002, Cryer et al. 2002, Carbines et al. 2004), temporal shifts in the diet of species like orange roughy have yet to be documented. There are other more obvious changes, such as the decline in biomass of several bycatch species on northeast Chatham Rise (Clark et al. 2000).

Orange roughy from Challenger Plateau and Chatham Rise have a diet dominated by small, vertically migrating fish and crustaceans. Squid make up a small but important component (Rosecchi et al. 1988). Almost two decades after the work of Rossechi et al. (1988), the diet of orange roughy is revisited in this study. This short communication has two aims: firstly, to synthesize some little-known historical orange roughy dietary data out of 'grey literature' and secondly to comment on an inferred temporal shift in this species' diet: a decline in the percentage occurrence of squid in orange roughy taken from northeast Chatham Rise between 1984 and 2004.

Methods

Historical data reporting orange roughy diets from north–east Chatham Rise, 1984 and 1996, are sourced from accounts of Anderson and Fenaughty (1996), Clark et al. (2000) and Tracey et al. (1997). Data for the Challenger Plateau (1984–1990) are sourced from Clark and Tracey (1994). Numbers of orange roughy stomachs examined in these studies can be found in Table 1.

Chatham Rise temporal data are augmented with new dietary information reported herein from a 2004 orange roughy trawl-survey on north–eastern Chatham Rise (Fig. 1), during which opportunistic collections of fisheries bycatch exceeding one ton were made (Anon 2004). Of the 96 orange roughy available from this

Table 1 The number of orange roughy stomachs containing food from the north–eastern Chatham Rise and Challenger Plateau from 1984–2004

Month/s	Year	ORH Stomachs with contents NE Chatham Rise (% containing squid)	ORH Stomachs with contents Challenger Plateau (% containing squid)
July	1984	360 (20.8)[a]	NR (14.5)[e]
July	1985	339 (12.4)[a]	NR (9.1)[e]
July	1986	346 (13.6)[a]	NR (13.6)[e]
June–August	1987	863 (17.8)[a]	NR (10.4)[e]
July–August	1988	446 (4.3)[a]	NR (10.6)[e]
July–August	1989	894 (10.9)[a]	NR (9.5)[e]
June–August	1990	912 (6.7)[a]	NR (7.7)[e]
June–July	1992	1473 (6.2)[a]	
July	1994	2050 (8.3)[b]	
July–August	1995	312 (6.4)[c]	
July	1996	NR (11)[d]	
July	2004	44 (6.7)	

[a] Anderson and Fenaughty 1996; [b] Tracey and Fenaughty 1997; [c] Tracey et al. 1997; [d] Clark et al. 2000; [e] Clark and Tracey 1994). Clark et al. (2000) report all trawl surveys occurring during winter (July), some sampling is known to have occurred during June and August (Anderson and Fenaughty 1996) (NR: not reported)

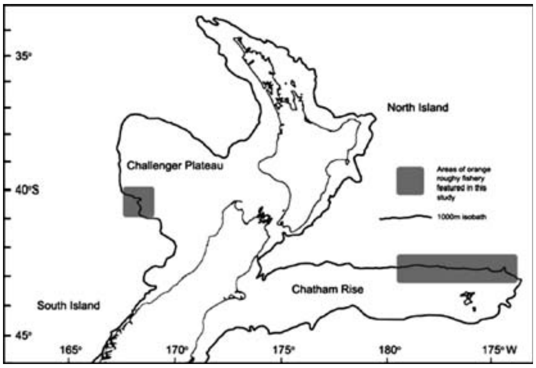

Fig. 1 Survey areas, Challenger plateau and north-east Chatham Rise

survey, 44 contained prey material in their stomachs and could be used for temporal comparison.

To compensate for reporting, personnel and identification inconsistencies between years in earlier reports, major prey groups are amalgamated into the higher taxonomic groupings of crustaceans (primarily natant decapods, euphausids and mysids), squid, and fish (with 'fish' and 'fish remains' treated collectively). Consistent with earlier reports, results are presented as percentage frequency (the number of prey items occurring as a percentage of the total number of stomachs containing prey). Results are plotted for Chatham Rise and Challenger Plateau separately.

Stock assessments for orange roughy traditionally occur during July on north–east Chatham Rise (Annala et al. 2004). At this time, orange roughy form large spawning aggregations. The locations of these spawning aggregations are known, and are targeted to provide consistent historical data (Sullivan et al. 2005). This dietary report focuses upon surveys during July only, as Liwoch and Linkowski (1986) and Rosecchi et al. (1988) report seasonal changes in orange roughy diet. Consequently, three historical accounts of diet for this species (1981, 1982 and 1988) have had to be excluded from this analysis. In the 1981 data Liwoch and Linkowski (1986) cite the percent frequency of squid in the diet of orange roughy as 18.8%, but it is unclear what period of time this figure represents, and whether this is an averaged figure throughout a year. The 1982 data, Robertson et al. (1984), report the percentage of squid in the diet of orange roughy from northeast Chatham Rise as 5%, but these findings are excluded as the survey was conducted a month later (August–September, with the bulk of the trawling occurring during September) than other research effort. A trawl survey undertaken during September–October 1988 (the second for that year) reported a percentage of squid in the diet of orange roughy of 8.2%; this has also been excluded for the same reason (Anderson and Fenaughty 1996). No dietary data were available for the period spanning 1997–2003.

To enable comparisons between surveys, it has had to be assumed that no difference exists between trawled areas, and that orange roughy diet is consistent over area and depth. Given that all historical surveys have been carried out in a random stratified manner, variation attributable to area and depth are discounted. Furthermore, orange roughy diet was reported to be consistent between the Challenger Plateau and Chatham Rise, at least for prawns and squid (Rosecchi et al. 1988). Although the data-series are limited and comparisons between them must be treated with caution, additional historical information cannot be procured. Accordingly the following account of temporal change in the diet of orange roughy can only be inferred.

Results

Chatham Rise

From 1984 to 1996 there was an ~47% decrease in the percentage frequency of squid in the stomachs of orange roughy on Chatham Rise (Fig. 2). This represents a reduction from ~21% in 1984 to 11% in 1996, with data from the 2004 survey identifying a further reduction to ~7%: a total reduction of ~67% from 1984 levels. The percentage frequency of crustaceans and fish increased slightly in the diet of orange roughy on Chatham Rise over the same period.

Challenger Plateau

From 1984 to 1990, the percentage frequency of squid in the diet of orange roughy on Challenger

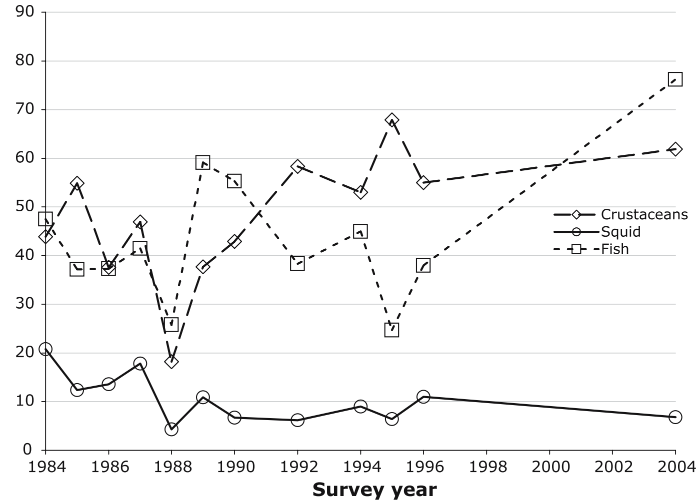

Fig. 2 The percentage frequency of crustaceans, fish and squid in the diet of orange roughy, from the north-east Chatham Rise, 1984–2004

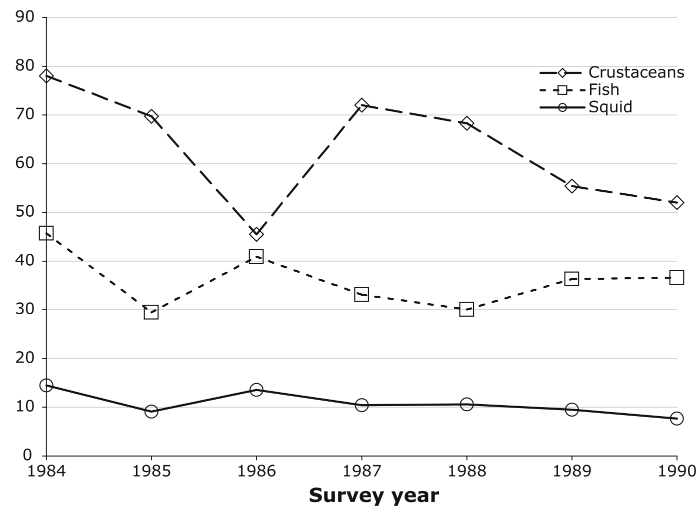

Fig. 3 The percentage frequency of crustaceans, fish and squid in the diet of orange roughy, from the Challenger Plateau, 1984–1990

Plateau decreased from ~15 to 8%, representing a ~47% reduction (Fig. 3); the percentage frequency of crustaceans and fish also decreased over the same period.

Discussion

One of the greatest challenges facing researchers endeavouring to reconstruct diet of deep-sea fish is accurate prey identification, especially when items are often fragmented or partially digested, and many prey items are poorly known or have yet to be described (Bulman et al. 2002). Consequently, prey species are often identified to Order. An example of this proves to be squid, which historically has not been well identified in orange roughy dietary studies, usually only to the level of the sub-class Coleoidea (Clark and Tracey 1994, Clark et al. 2000, Tracey et al. 1997). Of notable exception is the account of Rossechi et al. (1988), wherein squid are attributed to species in fourteen families.

The lack of systematic detail in historic data precludes detailed analysis, limiting the author to assessing temporal changes in the presence or absence of "squid". Nevertheless, using this simplified data, decreases in the percentage frequency of squids in the diet of orange roughy are apparent since 1984, and are cause for concern:

between 1984 and 1996, squid in the diet of orange roughy on north-east Chatham Rise declined ~47%. The stomachs of orange roughy examined in 2004 showed a decline in squid content of 67% from 1984 reported levels (Fig. 4). The 2004 data should be treated with caution; the sample size (n = 44) is much smaller than that of previous years (Table 1). Between 1984 and 1990 on Challenger Plateau, the decline was ~47% (Fig. 4).

The 44 orange roughy stomachs containing prey items examined in 2004 were from fish trawled from depths 1117 to 1196 m (Anon 2004), which is towards the deeper end of this species' depth distribution (Branch 2001). Orange roughy are thought to consume more squid with increasing depth (Rosecchi et al. 1988), and accordingly it could be assumed that this comparatively small sample would be likely to have a larger percentage occurrence of squid than previous samples taken over a broader depth range. This was not the case, with the percentage frequency of occurrence of squid in this sample being 6.7%, a figure consistent with the apparent downward trend inferred by data from earlier reports.

The reasons for the decrease in percentage occurrence of squid in the diet of orange roughy are unknown. Environmental factors such as temperature and salinity are thought to have been constant over the history on Chatham Rise (Clark et al. 2000), and are discounted from further consideration. However, one plausible explanation for the reduction of squid in the diet of orange roughy is a reduction in the availability of squid as prey. Hitchmough (2002) reports several deep-sea squid and octopus species found on Chatham Rise as 'endangered', suggesting a decrease in abundance of several cephalopod species.

Trawling can reduce squid biomass, either directly by the removal of species as bycatch, or the destruction of fragile free-floating gelatinous egg masses (O'Shea et al. 2004); squid biomass also can be indirectly affected by deterioration of seabed habitat quality (Rodrigues et al. 2001; Freese 2001; O'Driscoll and Clark 2005). The reproductive biology of only 16 out of 86 species of New Zealand squid has been described (O'Shea et al. 2004). Of the fourteen squid families described by Rossechi et al. (1988); only one, the Gonatidae is known to produce gelatinous egg masses (Seibel et al. 2005). However, as free-floating gelatinous egg masses are probably common to as many as 78 of the 86 species of squid that occur in New Zealand waters (O'Shea pers com.) the majority of these species stand to have their life history impacted by both midwater and bottom-trawl fishing operations at some time of the year. Life history of squid is much shorter than other animals such as fish (Jackson and Mladenov 1994); with orange roughy thought to be capable of living upwards of

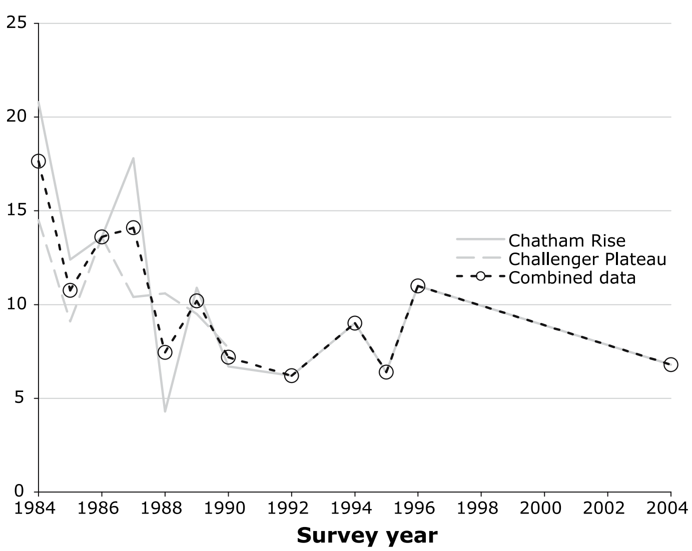

Fig. 4 The percentage frequency of squid, in the diet of orange roughy from the Chatham Rise (1984–2004) and Challenger Plateau (1984–1990). Data are combined for overlapping years

100 years (Tracey and Horn 1999); other abundant deep-water fishes such as warty oreo (George et al. 1998) and sharks (Clarke et al. 2002) are also thought to be long-lived. The consequences of the selective removal of squid by trawling or by the destruction of free-floating egg masses are unknown. Temporal regulation of trawling during time of release and development of egg-masses could be a possible solution; however this would require greater knowledge than currently exists regarding the reproductive biology of most New Zealand squid species.

The spatial extent of fisheries research conducted throughout New Zealand waters is depicted in Gordon (2000), wherein the distribution of some 24,000 bottom trawls around New Zealand is illustrated. These research bottom trawls have been undertaken over a 40-year period for the purposes of ascertaining fish stock resources in New Zealand waters; mid-water trawls are specifically excluded. The impact of fisheries research on the seabed is only a fraction of that of commercial fishing effort, with over 250,000 deep-water tows recorded between 1989 and 2003 (O'Driscoll and Clark 2005).

The data from Chatham Rise infer an apparent shift in the diet of orange roughy over a 20-year period: a decrease in squid and a corresponding increase in crustaceans and fish. However, the Challenger Plateau data show the occurrence of all of crustaceans, fish and cephalopods as declining, so the situation is unclear. Forced shifts in diet, and hence trophic feeding level, have been linked to other exploited species, such as haddock on Georges Bank, feeding 2/3 of one trophic level lower in 1987 than in 1929 (Wainright et al. 1993). Additionally, sperm whales (*Physeter macrocephalus*), known predators of orange roughy in New Zealand waters (Gaskin and Cawthorn 1967), locally appear to no longer consume fish of any variety; moreover, there also appears to be a decline in the number of locally-occurring squid species in the diet of this species (Gomez-Villota 2006). It is likely that sperm whale diet reflects changes in abundance of both fish and squid in New Zealand waters, and it is within reason to expect the same applies to orange roughy diet.

Data used for these analyses were collected during fisheries research trawl surveys tailored to assess orange roughy stock size, rather than to reconstruct the species life history or diet. These trawl surveys usually occur in July, during which time this species aggregates in spawning plumes; this time proves to be the easiest to assess orange roughy biomass (Sullivan et al. 2005). These plumes are also the primary target of commercial fishers (Clark et al. 2000). However, orange roughy feed least during spawning (Liwoch and Linkowski 1986; Rosecchi et al. 1988), so dietary analyses conducted during spawning periods are probably the least informative of all, rendering the dataset reviewed here quite limited in rigor. Future research needs to bear in mind that although it is convenient to combine stock assessment research effort with biological considerations, it does not always generate the most useful of data. Nonetheless, these are the only data available for these two fisheries, and despite obvious limitations, they do enable broad temporal comparisons to be made. The 2004 sample was arbitrarily collected and of small size compared with earlier surveys; future investigations would benefit from larger random sample sizes and better prey identifications.

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References

Anderson OF, Fenaughty JM (1996) Trawl surveys of orange roughy on the Chatham Rise, 1984–1992. New Zealand Fisheries Assessment Report No. 81. 56pp

Annala JH, Sullivan KJ, Smith NW.McL, Griffiths MH, Todd PR, Mace PM, Connell AM (2004) Report from the Fishery Assessment Plenary, May 2004: Stock assessments and yield estimates, Ministry of Fisheries. 690pp

Anon (2004) Estimation of the abundance of orange roughy in Northeast Chatham Rise, 2004. *Tangaroa* (TAN0408) and *Tasman Viking* (TVI0401). Unpublished NIWA Report, 18pp

Branch TA (2001) A review of orange roughy *Hoplostethus atlanticus* fisheries, estimation methods, marine biology and stock structure. S Afr J Mar Sci 23:181–203

Bulman CM, He X, Koslow JA (2002) Trophic ecology of the mid-slope demersal fish community off southern Tasmania, Australia. Mar Freshw Res 53:59–72

Carbines G, Jiang W, Beentjes MP (2004) The impact of oyster dredging on the growth of blue cod, *Parapercis colias*, in Foveaux Strait, New Zealand. Aquat Conserv 14:491–504

Clark MR, Tracey DM (1994) Changes in a population of orange roughy, *Hoplostethus atlanticus*, with commercial exploitation on the Challenger Plateau, New Zealand. Fish B 92:236–253

Clark MR, Anderson OF, Francis RICC, Tracey DM (2000) The effects of commercial exploitation on orange roughy (*Hoplostethus atlanticus*) from the continental slope of the Chatham Rise, New Zealand, from 1979 to 1997. Fish Res 45:217–238

Clarke MW, Connolly PL, Bracken JJ (2002) Catch, discarding, age estimation, growth and maturity of the squalid shark *Deania calceus* west and north of Ireland. Fish Res 56:139–153

Cryer M, Hartill B, O'Shea S (2002) Modification of marine benthos by trawling: toward a generalization for the deep ocean? Ecol Appl 12(6):1824–1839

Freese JL (2001) Trawl-induced damage to sponges observed from a research submersible. Mar Fish Rev 63:7–13

Gaskin DE, Cawthorn MW (1967) Diet and feeding habits of the Sperm Whale (*Physeter catadon* L.) in the Cook Strait region of New Zealand. New Zeal J Mar Freshw Res 2:156–179

George MJA, Jackson GD, Green CP, Robertson SG (1998) Preliminary estimates of the age and growth of immature smooth oreo *Pseudocyttus maculatus* Gilchrist 1906 (Oreosomatidae) in the Falkland Islands region of the South Atlantic. Polar Biol 19:330–335

Gomez-Villota, F (2006) Sperm whale diet in New Zealand. Unpublished MAppSc thesis, Division of Applied Sciences, Auckland University of Technology. 231pp

Gordon DPG (2000) The Pacific Ocean and global OBIS: a New Zealand perspective. Oceanography 13(3):41–47

Haedrich RL, Merrett NR, O'Dea NR (2001) Can ecological knowledge catch up with deep-water fishing? A North Atlantic perspective. Fish Res 51:113–122

Hitchmough R (comp.) (2002) New Zealand threat classification lists. Department of conservation threatened species occasional publication 23:210

Jackson GD, Mladenov PV (1994) Terminal spawning in the deepwater squid *Moroteuthis ingens* (Cephalopoda: Onychoteuthidae). J Zool Lon 234:189–201

Kaiser MJ, Collie JS, Hall SJ, Jennings S, Poiner IR (2002) Modification of marine habitats by trawling activities: prognosis and solutions. Fish and Fisheries 3:114–136

Liwoch M, Linkowski TB (1986) Some biological features of orange roughy *Hoplostethus atlanticus* (Trachichthyidae) from New Zealand waters. Reports of the Sea Fisheries Institute 21:28–41

Mace P (2001) A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. Fish and Fisheries 2:2–32

O'Driscoll RL, Clark MR (2005) Quantifying the relative intensity of fishing on New Zealand seamounts. New Zeal J Mar Freshw Res 39:389–850

O'Shea S, Bolstad KS, Ritchie PA (2004) First records of egg masses of *Nototodarus gouldi* McCoy, 1888 (Mollusca: Cephalopoda: Ommastrephidae), with comments on egg-mass susceptibility to damage by fisheries trawl. New Zeal J Zool 31:161–166

Robertson DA, Grimes PJ, McMillan PJ (1984) Orange roughy on Chatham Rise: results of a trawl survey August–September 1982. Fisheries Research Division Occasional Publication No. 46. 27pp

Rodrigues N, Sharma R, Nath BN (2001) Impact of benthic disturbance on megafauna in Central Indian Basin. Deep-Sea Res II 48:3411–3426

Rosecchi E, Tracey D, Webber WR (1988) Diet of orange roughy, *Hoplostethus atlanticus* (Pisces: Trachichthyidae) on the Challenger Plateau, New Zealand. Mar Biol 99:293–306

Seibel BA, Robinson BH, Haddock SHD (2005) Post-spawning egg care by a squid. Nature 438:929

Strutt I (2001) Fleet Flops on seamounts: mountains of debt from Indian Ocean. Fish News Int 41(1):1

Sullivan KJ, Mace PM, Smith NW.McL, Griffiths MH, Todd PR, Livingston ME, Harley SJ, Key JM, Connell AM (Comps.) (2005) Report from the Fishery Assessment Plenary, May 2005: Stock assessments and yield estimates, Ministry of Fisheries. 792pp

Tracey DM, Anderson OF, Clark MR (1997) A two-vessel survey of orange roughy in the Chatham Rise ''Spawning box'' July-August 1995. New Zealand Fisheries Technical Report No. 49. 18pp

Tracey DM, Fenaughty JM (1997) Distribution and relative abundance of orange roughy on the Chatham Rise, May-July 1994. New Zealand Fisheries Technical Report No 44. 44pp

Tracey DM, Horn PL (1999) Background and aging of orange roughy (*Hoplostethus atlanticus*, Trachichthyidae) from New Zealand and elsewhere. New Zeal J Mar Freshw Res 33:67-86

Wainright SC, Fogarty MJ, Greenfield RC, Fry B (1993) Long-term changes in the Georges Bank food web: trends in stable isotopic compositions of fish scales. Mar Biol 115:481–493