CCAMLR Science, Vol. 18 (2011): 87–96

CAN TOOTHFISH CATCHES BE USED TO PREDICT THE PRESENCE OF VULNERABLE BENTHIC INVERTEBRATE TAXA?

S.J. Parker✉
National Institute of Water and
Atmospheric Research (NIWA) Ltd
PO Box 893
Nelson, New Zealand
Email – s.parker@niwa.co.nz

M.H. Smith
NIWA Ltd
PO Box 14901
Wellington, New Zealand

Abstract

Accurate estimation of the impact of bottom fishing on vulnerable marine ecosystems (VMEs) requires knowledge of the distribution of those communities relative to the fishing footprint. If high target species catch rates are associated with habitats where VMEs are found, impacts from fishing would be higher than if VMEs are distributed randomly with respect to fishing locations. This study used the catch of the six most common vulnerable invertebrate taxa reported by observers on New Zealand vessels during the 2009/10 Ross Sea longline fisheries to correlate toothfish catch rates and benthic invertebrate catch rates at the scale of a longline segment, ~1 200 m. Analysis of the data available showed no evidence that the presence of any of six VME indicator taxa was informative in predicting Antarctic toothfish (*Dissostichus mawsoni*) catch at the scale of a longline segment. This supports conclusions of previous work finding no relationship between aggregate VME indicator taxa weight and toothfish catch at the scale of a longline set, ~7 km. Further studies at intermediate scales (10–100 km) would be useful to determine if both toothfish and individual VME indicator taxa have regionally concentrated distributions, showing a high degree of spatial overlap with the fishery.

Keywords: bottom fishing, vulnerable marine ecosystem, VME, fishing footprint, longline, CCAMLR

Introduction

CCAMLR is charged with assessing the potential impact of fishing activities on vulnerable marine ecosystems (VMEs) within the Convention Area (CCAMLR, 2007; UNGA, 2007). However, the distributions of vulnerable invertebrate taxa in the Ross Sea are generally unknown and the fisheries-independent observations available are biased to waters shallower than where the fisheries occur. Few data are available describing the distribution of VME indicator taxa[1] in the Ross Sea region outside the spatial footprint of the fishery, but at similar depths.

The limited observations available suggest that individual taxa have large, but unique, spatial distributions in the Ross Sea region (Parker and Bowden, 2010), and that within their total range, vulnerable communities tend to occur in relatively small higher-density patches, often described as coral gardens (Hourigan et al., 2007; Parker et al., 2010). If vulnerable communities do occur in small patches spread over large areas relative to the distribution of fishing effort, the potential impact of spatially restricted fishing activities would be diminished. However, if they tend to occur where fishing effort is directed, then the potential impacts of fishing could be higher.

[1] 'VME taxa' refers to the list of taxonomic groups defined by the Commission in 2009 following the VME Workshop (SC-CAMLR, 2009) and listed in the CCAMLR VME Taxa Classification Guide 2009 (CCAMLR, 2009a). Data reported to CCAMLR as VME indicator units include all these groups.

Commercial fish species are often associated with bathymetric features, and fishermen often target areas with particular bathymetric characteristics. However, literature documenting a relationship between sessile invertebrates and targeted fish species is rare. Scientific observations of commercially exploited fish species in association with deep-sea coral and sponge communities suggest they often overlap in distribution (Brodeur, 2001; Heifetz, 2002; Krieger and Wing, 2002; Etnoyer and Warrenchuck, 2007; Hourigan et al., 2007), but this does not imply that fish abundance within those communities is higher than in other areas, or that those areas are important to the sustainability of associated fish populations (Auster, 2005). A positive relationship between relative fish abundance and coral-supporting habitats was shown experimentally in the North Atlantic by Husebo et al. (2002) by fishing for redfish (*Sebastes marinus*), tusk (*Brosme brosme*) and ling (*Molva molva*) inside and outside known coral habitats.

In 2009, Parker and Mormede examined the catch of Antarctic toothfish (*Dissostichus mawsoni*) in relation to the aggregate weight of all VME indicator taxa per longline set and found no association, although these conclusions are likely to reflect the disproportionate influence of heavier taxa, such as sponges, and may mask relationships with other taxa. No known association of Antarctic toothfish abundance and benthic invertebrates, especially habitat-forming organisms, currently exists at small spatial scales.

The objective of this study is to use data collected by observers on New Zealand vessels from the Ross Sea Antarctic toothfish longline fisheries to look for evidence that toothfish catch may be correlated with the presence of individual VME indicator taxa.

Methods

Subject to management constraints and ice conditions, fishers target areas that they think will have the highest catch rates of the optimal size fish (in this fishery usually the larger fish), but a range of catch rates results because knowledge of where fish will be is imperfect. Catch-per-unit-effort (CPUE), defined as number of toothfish caught per 1 000 hooks, is typically distributed as a negative binomial with many more sets with low CPUE than high. Although a number of factors can influence CPUE, this analysis uses CPUE as a proxy to indicate areas with correspondingly low or high toothfish abundance.

In the 2010 fishing season (December 2009 to November 2010), vessels were required to report the total catch (in litres or kg) of VME indicator taxa for each segment[2] of longline fished as part of Conservation Measure 22-07 (CCAMLR, 2009b). Scientific observers on New Zealand vessels recorded which VME indicator taxa were captured on each observed segment, along with their weight and number. In cooperation with fishing vessel skippers, observers also recorded the numbers of toothfish captured per longline segment (instead of per longline set), allowing analysis to be conducted at the scale of longline segments. Weight of toothfish or numbers of other fish species were not recorded per segment. All vessels in the analysis used the integrated-weight autoline longlining method (see Fenaughty, 2006, for a detailed description).

Observer data were linked with catch and effort data from the CCAMLR Secretariat (extracted 10 May 2010), and used to correlate the presence or absence of VME indicator taxa with the catch of Antarctic toothfish (in numbers or presence) for each segment. VME indicator taxa weights were overdispersed with many zero catches, and the actual relationship between VME indicator taxon observed catch and density on the seafloor was unknown, so the response variable used was the presence or absence of each taxon. The presence of VME indicator taxa appears to be detectable because although each longline hook has a relatively small probability of capturing benthic organisms, longline segments contain many hooks, resulting in a significant overall probability of detecting presence (Parker et al., 2010).

To determine if VME indicator taxa by-catch was a predictable result of targeting areas believed to have high toothfish CPUE, a forward stepwise fitting of a binomial model with the response

[2] A longline segment means a 1 000-hook section of line or a 1 200 m section of line, whichever is the shorter, and for pot lines a 1 200 m section (Conservation Measure 22-07 in CCAMLR, 2009b). Typically, several segments make up a single set.

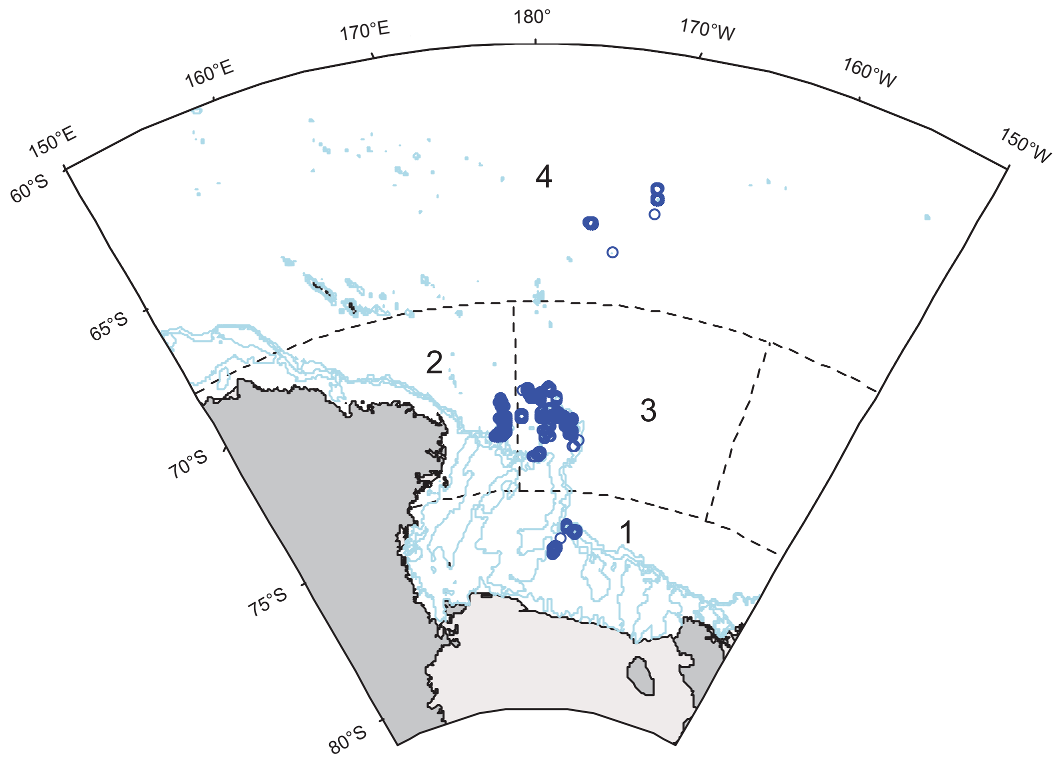

Figure 1: Ross Sea region indicating areas where segment-level toothfish and VME indicator taxa by-catch data were collected from New Zealand vessels during the 2009/10 Antarctic toothfish bottom longline fishery. These data were divided into four fishing regions (1–4) for spatial analysis.

variable as the presence/absence of each selected VME indicator taxon was carried out using the AIC criterion (Venables and Ripley, 2002).

Although depth, latitude and longitude were available for analysis, the primary objective was to determine if toothfish abundance could indicate the presence of VME indicator taxa. Reducing model deviance by incorporating other variables that may mask a correlation with VME indicator taxa could reduce the explanatory power of toothfish. These additional variables were fit in a subsequent analysis to test for differences in the correlation among areas.

The analysis was conducted in three steps. First, only toothfish variables (presence or abundance), were offered to the model. Second, in addition to the presence or absence of toothfish, *vessel* was offered to standardise catchability for the various VME indicator taxa (Table 1). Third, other variables (area, latitude, longitude, depth) were offered in addition to toothfish to develop the best predictive model from available data.

Data were available from sets on the continental shelf, slope and in the northern region (Figure 1). Following preliminary examination of the spatial distribution of the data, an area factor was assigned, splitting the slope into east and west areas, plus the northern and shelf areas.

Results

Data were available from New Zealand vessels from the 2010 season for the subset of line segments that was observed. A total of 1 332 segments with known toothfish catch was available (1 272 present and 60 absent), with 436 segments showing VME by-catch (Table 2). The locations of segments used in the analysis were distributed widely across the shelf, slope and northern regions of the Ross Sea and occurred in the main areas targeted by the fishery as a whole (Figure 1 in Hanchet et al., 2010).

Although the by-catch of VME indicator taxa was not rare (45% of hauls caught at least one VME taxon), many individual taxa were rarely observed (Table 2). Correlations of presence are sensitive to low sample sizes of positive observations.

Table 1: Explanatory variables offered to the forward stepwise fitting of a binomial model with response variable as presence/absence of the taxon using the AIC criterion. The 3rd order polynomial in toothfish count was not available for taxon ATX (anemones) or AXT (Stylasteridae) as it led to singularities in the model-fitting procedure.

Variable	Description
Toothfish count > 0	Presence/absence of toothfish. Factor with 2 levels TRUE or FALSE.
Toothfish count	Toothfish count. In 1st, 2nd and 3rd order polynomial terms.
Area	Factor with 4 levels. Defined in Figure 1. Three areas due for ATX.
Vessel	Factor with 4 levels.
Depth (m)	In 1st, 2nd and 3rd order polynomial terms.
Latitude	In 1st, 2nd and 3rd order polynomial terms.
Longitude	In 1st, 2nd, and 3rd order polynomial terms.

Table 2: Summary of number of longline sets, segments observed and the catch of toothfish and VME indicator taxa by vessel (A–D) in the New Zealand 2010 Ross Sea longline fishery. Note hauls and segments with VME indicator taxa indicate only observed hauls or segments where toothfish catch was also recorded. Vulnerable taxa not listed were not present on observed segments. AXT – Hydrocorals, ATX – Anemones, CSS – Scleractinians, GGW – Gorgonians, SSX – Ascidians, PFR – Sponges.

Vessel	A	B	C	D	Total
Sets	60	97	102	143	402
Segments	420	568	683	1101	2772
Segments with toothfish	146	91	45	990	1272
Sets with VME taxa	19	19	25	116	179
Segments with VME taxa	29	31	27	349	436
Segments with ATX	15	12	6	91	124
Segments with AXT	10	2	12	12	36
Segments with CSS	2	5	8	173	188
Segments with GGW	9	17	3	58	87
Segments with SSX	0	11	2	45	58
Segments with PFR	15	9	13	81	118
Segments with other taxa:					
Pennatulacea (NTW)	1	3	0	21	25
Euryalida (OEQ)	5	7	1	11	24
Cidaroidea (CVD)	1	0	0	11	12
Anthoathecate (AZN)	0	1	0	10	11
Zoanthid (ZOT)	0	1	0	9	10
Alcyonacea (AJZ)	1	0	0	5	6
Crinoid (CWD)	0	1	0	4	5
Bathylasmatidae (BWY)	0	0	0	3	3
Antipatharia (AQZ)	0	0	0	3	3
Bryozoan (BZN)	0	1	0	1	2
Serpulid (SZS)	0	1	0	0	1
Cnidarian (CNI)	0	1	0	0	1
Adamassium colbecki (DMK)	0	0	1	0	1
Brachipod (BRQ)	0	0	0	1	1

Therefore, this analysis used a natural break in frequency of taxa in the dataset between 35 and 25 total observations (Table 2) to restrict VME indicator taxa analysed to those with more than 35 observations of presence. Data from by-catch collections in 2010 indicated that observers could not reliably distinguish between demosponges and hexactinellid sponges (Tracey et al., 2010). Therefore, the two classes of sponges were aggregated and analysed as Porifera (PFR). For the analysis, the groups selected were anemones (ATX), stylasterid hydrocorals (AXT), gorgonians (GGW), scleractinians (CSS), ascidians (SSX) and sponges (PFR). Parker et al. (2009) also concluded that observers sometimes classified dead hydrocoral as scleractinian corals. Both Stylasteridae (AXT) and Scleractinia (CSS) were included here, though the CSS results should be interpreted with caution as they may be contaminated with AXT samples.

A coarse indicator of a correlation in occurrence can be observed if the proportion of observations with VME indicator taxa is dissimilar to the proportion of observations with toothfish (Friendly, 1994). The proportions of segments with each taxon present or absent relative to area or vessel showed no strong trend among factor levels (Table 3).

Toothfish presence or abundance (up to a third order polynomial) were not useful factors in predicting the occurrence of any of the six VME indicator taxa (Table 4) captured on individual longline segments. Toothfish catch never explained more than 4% of the null model deviance when forced into the model. Offering the remaining variables generally resulted in larger increases in R^2 than that gained when offering toothfish variables, but no model explained more than 25% of the null model deviance (Table 4). When additional variables were added, depth had the strongest effect for anemones and stony corals, and vessel was strongest for hydrocorals. Area did not explain more than 2% of the deviance for any VME indicator taxon and latitude explained 6% for sponges, but little for any other group.

Discussion

Any spatial correlation in the distribution of toothfish and VME indicator taxa at the scale of the fishing event would be important to recognise and incorporate into the management strategy to prevent significant adverse impacts to VMEs. However, with the data available, toothfish catch was not a useful factor in predicting the occurrence of any of six VME indicator taxa by-catch at the scale of longline segments (~1 200 m).

The relationships fitted in this study should be treated with caution as several assumptions were made which constrain robust conclusions. Most importantly, segments were treated as independent samples, which they likely were not as some correlation is likely to exist between adjacent segments on a line or between segments spatially located very near to each other. This correlation would tend to increase the standard errors associated with the fitted parameter estimates.

There are only a few potential scenarios where a strong association between toothfish distribution and VME indicator taxon distributions could exist, but not be detectable in catch data. One scenario is if the fishing locations are close enough to VMEs to attract toothfish to the baits, but far enough away that VME indicator taxon do not consistently occur. This is unlikely because it requires that fishers can identify, target and successfully deploy longline gear to be consistently near, but not contact, VME indicator taxa. Factors such as fishing in deep water, lateral drift with currents, the length of a set (typically greater than 6 km), and constraints of using sonar to identify features, make the exclusive targeting of areas near VME habitats unfeasible.

A second scenario could be that the catchabilities of the associated VME indicator taxa are so low and inconsistent as to be essentially random. This variation would obscure any consistent signal that VME indicator taxa existed in that area. However, evidence is emerging from densely sampled areas that the determination of presence, for at least several of these taxa, is consistent. For example, several risk areas have now been designated within a few kilometres of each other all by the same taxonomic group (SC-CAMLR, 2010). In addition, by-catch consistently occurs in areas where these taxa are known to occur (Parker et al., 2010). Both observations indicate that, at least for some taxa, longlines may be reliable sampling tools. Analysis required to show this for all vulnerable taxa awaits further data collection.

Third, the ability to detect a correlation will also rely on the taxonomic levels analysed. A strong correlation could exist between toothfish and a

Table 3: Cross-tabulated proportions of longline segment observations of the presence (P) or absence (A) of each modelled VME indicator taxon and corresponding Antarctic toothfish (TOA) catch, presence in each area, or observed on each vessel. AXT – Hydrocorals, ATX – Anemones, CSS – Scleractinians, GGW – Gorgonians, SSX – Ascidians, PFR – Sponges.

TOA	AXT		ATX		CSS		GGW		SSX		PFR		Total
	A	P	A	P	A	P	A	P	A	P	A	P	
A	0.041	0.004	0.044	0.002	0.043	0.002	0.042	0.003	0.044	0.001	0.043	0.002	60
P	0.866	0.089	0.929	0.026	0.816	0.139	0.893	0.062	0.912	0.043	0.869	0.086	1272
Area													
1	0.688	0.313	0.875	0.125	0.953	0.047	0.734	0.266	0.875	0.125	0.688	0.313	64
2	0.938	0.062	0.993	0.007	0.897	0.103	0.945	0.055	0.942	0.058	0.945	0.055	417
3	0.876	0.124	0.973	0.027	0.781	0.219	0.976	0.024	0.965	0.035	0.906	0.094	629
4	1.000	0.000	0.964	0.036	0.982	0.018	0.856	0.144	0.982	0.018	0.928	0.072	222
Vessel													
1	0.900	0.100	0.933	0.067	0.987	0.013	0.940	0.060	1.000	0.000	0.900	0.100	150
2	0.872	0.128	0.979	0.021	0.947	0.053	0.819	0.181	0.883	0.117	0.904	0.096	94
3	0.875	0.125	0.750	0.250	0.833	0.167	0.938	0.063	0.958	0.042	0.729	0.271	48
4	0.913	0.088	0.988	0.012	0.834	0.166	0.944	0.056	0.957	0.043	0.922	0.078	1040
Total	1208	124	1296	36	1144	188	1245	87	1274	58	1214	118	1332

Note: Vessel 4 provided observations on almost 100% of segments.

Table 4: Analysis of deviance tables for models of the presence of each VME indicator as a function of toothfish catch and other variables. First, the 3rd order polynomial of toothfish counts was added to the models, then the variables depth, area, latitude and longitude were added in the order according to the AIC criterion. The cumulative R^2 after sequentially adding the term indicates explanatory power of the model. For polynomial variables, the order is given in parentheses.

Taxon/variable	Df	Deviance	Resid. Df	Resid. Dev.	R^2
ATX – Anemones					
NULL	NA	NA	1331	824.87	NA
Toothfish (3rd)	3	8.07	1328	816.80	0.01
Depth (2nd)	2	72.64	1326	744.15	0.10
Latitude (3rd)	3	22.91	1323	721.24	0.13
Area	2	19.61	1321	701.64	0.15
AXT – Hydrocorals					
NULL	NA	NA	1331	331.00	NA
Toothfish (3rd)	3	7.97	1328	323.04	0.02
Vessel	3	55.74	1325	267.29	0.19
CSS – Stony corals					
NULL	NA	NA	1331	1084.33	NA
Toothfish (3rd)	3	39.92	1328	1044.40	0.04
Depth (3rd, 3)	3	170.95	1325	873.45	0.19
Vessel	3	43.33	1322	830.11	0.23
Latitude (3rd)	3	19.36	1319	810.76	0.25
GGW – Gorgonians					
NULL	NA	NA	1331	642.95	NA
Toothfish (3rd)	3	5.62	1328	637.34	0.01
Latitude (2nd)	2	72.20	1326	565.14	0.12
Depth (3rd, 3)	3	20.98	1323	544.16	0.15
Longitude (2nd)	2	6.55	1321	537.61	0.16
PFR – Sponges					
NULL	NA	NA	1331	797.23	NA
Toothfish (3rd)	3	12.05	1328	785.17	0.02
Latitude (3rd)	3	50.07	1325	735.10	0.08
Vessel	3	52.46	1322	682.64	0.14
Longitude (2nd)	2	19.35	1320	663.29	0.17
Depth (2nd)	2	4.75	1318	658.54	0.17
SSX – Anemones					
NULL	NA	NA	1331	476.98	NA
Toothfish (3rd)	3	2.39	1328	474.59	0.01
Vessel	3	22.84	1325	451.75	0.05
Area	3	12.44	1322	439.31	0.08
Longitude (1st)	1	4.28	1321	435.02	0.09
Latitude (1st)	1	2.53	1320	432.50	0.09

single species, genus, or family of VME taxa, but not be detectable at the order, class or phylum levels. This scenario is possible in theory, but higher-resolution taxonomic data will be required to conduct those analyses. In a similar way, a correlation may exist between other by-catch species or juvenile toothfish and VME indicator taxa distributions, as juvenile toothfish have been shown to be negatively buoyant and more likely to exploit benthic habitats (Near et al., 2003).

If toothfish actively seek out habitats with VME indicator taxa, and the fishery is effective at targeting toothfish concentrations at the scale of those features, then fishing effort and VMEs would quickly become highly spatially correlated at that scale. The present analysis found no correlation at the fine scale of a longline segment, approximately 1 200 m. Parker and Mormede (2009) analysed longline sets, finding no correlation between aggregate VME indicator taxa weight and toothfish catch at a small scale (~7 km). At the scale that fishers target toothfish with individual sets (1–10 km), the available data indicate no correlation in distribution for these taxa with toothfish. At scales smaller than 1 km, fishing effort becomes essentially untargeted and is finer than the resolution of segment-level data (Sharp, 2010).

At very large spatial scales, including areas outside the current fishing footprint, strong correlations are likely to exist between where the toothfish fishery takes place and where VMEs occur, simply because each group may be found in broadly similar areas (e.g. similar depth ranges), but these correlations would have no predictive value at the scale of the fishing event and would not be detectable using fishery-dependent data, due to the highly non-random distribution of fishing effort (i.e. exclusively targeting areas of perceived toothfish habitat).

Little analysis of VME indicator taxa distributions or toothfish catch has been conducted at intermediate scales of 10–100 km. No appropriate data exist to compare VME indicator taxa densities inside and outside the fishing footprint at these scales. Comparing the distributions of VME indicator taxa inside and outside the fishing footprint will require fishery-independent data or a simulation approach to identify the potential impacts of spatial association.

Conclusions

Comparisons within the fishing footprint require dense fishing effort at small to intermediate spatial scales (i.e. scales that the fishery operates on). Evidence of spatial aggregation or dispersion for taxa such as sponges and gorgonians has been reported at this scale (Parker et al., 2010), but this has not included a corresponding analysis of toothfish distribution. Because of the low numbers of by-catch observations for these taxa and the large areas within the fishing footprint containing little recent effort, conclusions about correlation at these intermediate scales are limited. Studies at intermediate scales (10–100 km) would be useful to determine if both toothfish and individual VME indicator taxa have regionally concentrated distributions showing a high degree of spatial overlap.

Acknowledgements

Thanks are due to the science staff, scientific observers and fishing crew who collected the data used for this analysis. The New Zealand Antarctic Fisheries Working Group provided helpful discussions and input into this paper. David Ramm and Eric Appleyard provided the data extracts from the CCAMLR Secretariat. The CCAMLR Working Group on Ecosystem Monitoring and Management also provided helpful discussions on this paper. The paper was also improved by the comments of two reviewers. This project was funded by the New Zealand Ministry of Fisheries under project ANT2009/01.

References

Auster, P.J. 2005. Are deep-water corals important habitats for fishes? In: Freiwald, A. and J.M. Roberts (Eds). *Cold-Water Corals and Ecosystems.* Springer-Verlag, Berlin-Heidelberg: 747–760.

Brodeur, R.D. 2001. Habitat-specific distribution of Pacific ocean perch (*Sebastes alutus*) in Pribilof Canyon, Bering Sea. *Cont. Shelf Res.*, 21: 207−224.

CCAMLR. 2007. *Report of the Twenty-sixth Meeting of the Commission (CCAMLR-XXVI)*. CCAMLR, Hobart, Australia: 219 pp.

CCAMLR. 2009a. CCAMLR VME Taxa Classification Guide. CCAMLR, Hobart, Tasmania, Australia: 4 pp. Available at www.ccamlr.org/pu/e/e_pubs/VME_guide.pdf.

CCAMLR. 2009b. *Schedule of Conservation Measures in Force, 2009/10*. CCAMLR, Hobart, Australia: 223 pp.

Etnoyer, P. and J. Warrenchuk. 2007. A catshark nursery in a deep gorgonian field in the Mississippi Canyon, Gulf of Mexico. *Bull. Mar. Sci*., 81 (3): 553–559.

Fenaughty, J.M. 2006. Geographical differences in the condition, reproductive development, sex ratio and length distribution of Antarctic toothfish (*Dissostichus mawsoni*) from the Ross Sea, Antarctica (CCAMLR Statistical Subarea 88.1). *CCAMLR Science*, 13: 27–45.

Friendly, M. 1994. Mosaic displays for multi-way contingency tables. *J. Amer. Stat. Assoc*., 89: 190–200.

Hanchet, S.M., M.L. Stevenson and A. Dunn. 2010. A characterisation of the toothfish fishery in Subareas 88.1 and 88.2 from 1997/1998 to 2009/2010. Document *WS-FSA-10/23*. CCAMLR, Hobart, Australia: 31 pp.

Heifetz, J. 2002. Coral in Alaska: distribution, abundance, and species associations. *Hydrobiologia*, 471: 19–28.

Hourigan, T.F., S.E. Lumsden, G. Dorr, A.W. Bruckner, S. Brooke and R.P Stone. 2007. Deep coral ecosystems of the United States: introduction and national overview. In: Lumsden, S.E., T.F. Hourigan, A.W. Bruckner and G. Dorr (Eds). *The State of Deep Coral Ecosystems of the United States*. *NOAA Technical Memorandum CRCP-3*. Silver Spring, MD: 1–64.

Husebo, A., L. Nottestad, J.H. Fossa, D.M. Furevik and S.B. Jorgensen. 2002. Distribution and abundance of fish in deep-sea coral habitats. *Hydrobiologia*, 471: 91–99.

Krieger, K.J. and B.L. Wing. 2002. Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. *Hydrobiologia*, 471: 83–90.

Near, T.J., S.E. Russo, C.D. Jones and A.L. DeVries. 2003. Ontogenetic shift in buoyancy and habitat in the Antarctic toothfish, *Dissostichus mawsoni* (Perciformes: Nototheniidae). *Polar Biol*., 26 (2): 124–128.

Parker, S.J. and S. Mormede. 2009. Is the by-catch of vulnerable invertebrate taxa associated with high catch rates of fish in the Ross Sea longline fisheries? Document *WS-VME-09/7*. CCAMLR, Hobart, Australia: 11 pp.

Parker, S.J. and D.A. Bowden. 2010. Identifying taxonomic groups vulnerable to bottom longline fishing gear in the Ross Sea region. *CCAMLR Science*, 17: 105–127.

Parker, S.J., S. Mormede, D.M. Tracey and M. Carter. 2009. Evaluation of VME taxa monitoring by observers from five vessels in the Ross Sea region Antarctic toothfish longline fisheries during the 2008/09 season. Document *TASO-09/8*. CCAMLR, Hobart, Australia: 13 pp.

Parker, S.J., R.G. Cole and S.M. Hanchet. 2010. Spatial scales of benthic invertebrate habitats from fishery by-catch and video transect data in the Ross Sea region. Document *WG-EMM-10/28*. CCAMLR, Hobart, Australia: 18 pp.

SC-CAMLR. 2009. Report of the Workshop on Vulnerable Marine Ecosystems. In: *Report of the Twenty-eighth Meeting of the Scientific Committee (SC-CAMLR-XXVIII)*, Annex 10. CCAMLR, Hobart, Australia: 537–571.

SC-CAMLR. 2010. Report of the Working Group on Ecosystem Monitoring and Management. In: *Report of the Twenty-ninth Meeting of the Scientific Committee (SC-CAMLR-XXIX)*, Annex 6. CCAMLR, Hobart, Australia: 196–198.

Sharp, B.R. 2010. Revised impact assessment framework to estimate the cumulative footprint and impact on VME taxa of New Zealand bottom longline fisheries in the Ross Sea region. Document *WG-SAM-10/20*. CCAMLR, Hobart, Australia: 22 pp.

Tracey, D.M., M.E. Carter and S.J. Parker. 2010. Evaluation of VME taxa classification by scientific observers from New Zealand vessels in the Ross Sea Antarctic toothfish longline fishery during the 2009/10 season. Document *TASO-10/10*. CCAMLR, Hobart, Australia: 16 pp.

UNGA. 2007. Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments. Document *UNGA A/RES/61/105*. UNGA, New York: 21 pp. Available at: www.un.org/Depts/los/general_assembly/general_assembly_reports.htm.

Venables, W.N. and B.D. Ripley. 2002. *Modern Applied Statistics with S*. Fourth edition. Springer, New York: 495 pp.