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Exploring the effects of fishing on fish assemblages using Abundance Biomass Comparison (ABC) curves

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The possible effect of fishing on dominance patterns in the South African south coast demersal trawl fishery is assessed using Abundance Biomass Comparison (ABC) curves for the period 1986–2003. The ABC method compares the ranked distribution of abundance among species against the similar distribution of biomass among species. The temporal pattern in the ABC curves and the W-statistic for two depth groups (<100 m and 101–200 m), and for the whole area combined, shows a gradient of change in the demersal assemblages from neutral ($W \geq 0$) towards negative ($W < 0$), suggesting a disturbed or stressed condition. This corresponds to the onset of longline fishing effort in 1994, still ongoing in 2003, superimposed upon declining trawl effort in the same region. The ABC method shows promise as a guide for assessing the effects of fishing on fish communities, being based on established r- and k-selection theory. More modelling and comparative work is needed to establish acceptable ranges for the W-statistic, and their application in an ecosystem approach to fisheries management.

Keywords: ABC curves, effects of fishing, fish assemblages, r- and k- selection.

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Introduction

Heavy fishing is a major threat to the structural and functional organization of marine ecosystems. Such effects manifest themselves directly (as a spatial or temporal gradient in abundance of target species, habitat destruction, or decrease in mean size: Haedrich and Barnes, 1997; Jennings *et al.*, 2001), or indirectly (causing or enhancing changes in community structure or differential effects on functional groups; Greenstreet and Hall, 1996; Garrison and Link, 2000), and at different times. Despite the additional effects on fish assemblages and the environment, previous attempts to regulate the effects of fishing have focused mainly on the target species. Because of evidence for important indirect effects (Fogarty and Murawski, 1998; Pauly *et al.*, 1998) and of collapses of some fisheries, effort is currently being focused on understanding the wider effects of fishing, and measuring them. Many indicators have been proposed to capture such effects; all have their own merits and drawbacks based on available scoring criteria (Rice, 2000, 2003; Rochet and Trenkel, 2003; Rice and Rochet, 2005; Shin *et al.*, 2005).

Multivariate clustering methods, such as classification and ordination (Field *et al.*, 1982), are sensitive for detecting changes in community structure, but they do not show whether the changes are in the direction of a climax community (presumably positive), or attributable to natural or human-induced disturbance (presumably undesirable or negative). The Abundance Biomass Comparison (ABC) method was initially proposed by Warwick (1986) as a technique for monitoring disturbance (mainly pollution effects) on benthic invertebrate communities, by comparing dominance in terms of abundance with dominance in terms of biomass. Subsequently, it has been applied to marine benthic communities in different regions, and in most cases showed the expected changes in response to disturbance (Warwick *et al.*, 1987; Agard *et al.*, 1993).

ABC curves have a theoretical background in classical evolutionary theory of r- and k-selection. In undisturbed states, the community is supposed to be dominated by k-selected species (slow-growing, large, late maturing), and the biomass curve lies above the abundance curve. With increasing disturbance, slow-growing species cannot cope, and the system is increasingly dominated by r-selected species (fast-growing, small, opportunistic), and the biomass curve will be below the abundance curve (Figure 1). The difference between the two curves is given by the W-statistic, which represents the area between them. A negative sign indicates that the biomass curve lies below the abundance curve and suggests a disturbed community. The ABC method takes into account the number of species included in the analysis (Warwick and Clarke, 1994). An advantage of the method is that an appropriate data set for any area or time should allow the status of the community to be evaluated without the need for a spatial or a temporal control against which to compare the index obtained, because the biomass is compared with the abundance for the same time and place (Clarke and Warwick, 1994).

ABC curves have only recently been used in studies on fisheries. Bianchi *et al.* (2001) investigated whether there was evidence of disturbance in the Namibian demersal fish community. They found differences between the shelf and slope assemblages, but without a clear temporal trend. Blanchard *et al.* (2004) applied the ABC method along with other community and size-based indicators to assess the impact of fishing on invertebrate and fish communities in

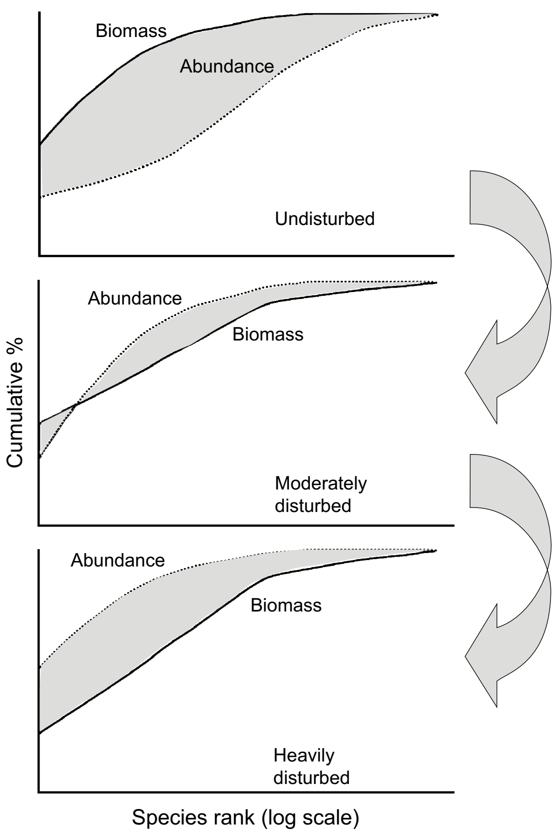

Figure 1. Theoretical ABC curves showing the pattern in the abundance and biomass of undisturbed, moderately disturbed, and heavily disturbed assemblages (modified from Clarke and Warwick, 1994).

the Bay of Biscay, France. They found that ABC curves showed the expected response to disturbance, lending support to the use of the method in a fisheries context.

We attempt here to assess the status of the South African south coast demersal fishery using ABC curves. The main hake-directed trawl fishery has been managed under a stock-rebuilding strategy since 1977, through input controls (regulating the number of vessels and mesh size) and output controls, such as total allowable catch (Rademeyer, 2003). The multispecies, multi-gear fishery involves inshore and offshore demersal otter trawling, a handline fishery and, recently, a longline fishery. The demersal trawl fisheries have operated since the early 1900s (Botha, 1985), but no baseline data are available for the period prior to trawling, to assess directly the impacts of trawling. One may assume that the greatest impact on the demersal communities was achieved when trawling intensified in the 1960s when the hake resource became known and more widely sought (Payne, 1995), and that more recent changes in impact may have only been comparatively small. However, the introduction of long-lining is likely to have introduced a new impact, and it might be possible to track the effects of this additional disturbance. Experimental longline fishing targeting kingklip (*Genypterus capensis*) was started in 1983, but it was stopped in 1990 because of its severe impact on the stock (Punt and Japp, 1994). Subsequently, experimental longline fishing directed at hake (*Merluccius capensis* and *M. paradoxus*) was started in 1994, and was formalized as a commercial fishery in 1998, targeting larger hake than does the trawl fishery (Rademeyer, 2003). As female hake grow faster and attain a larger size than males (Botha, 1971; Punt and Leslie, 1991), the longline catch consists primarily of large, highly fecund females. Apart from the direct effect on size distribution, the size-selective nature of the fishery may also have indirect effects: reduced reproductive output of the target species, and effects on the trophic structure of the system, the magnitude of which depends on the functional role of hake as a predator. Furthermore, the longline fishery can target fish on rough ground, where otter trawlers cannot operate.

Methods

The data for the analysis were collected during routine bottom-trawl biomass surveys, using the swept area method, conducted since 1986 (Table 1). Station selection follows a stratified-random sampling design where the number of stations allocated to a depth stratum is proportional to its area (Badenhorst and Smale, 1991). South coast surveys were generally conducted twice annually, in autumn (April−June) and spring (August−September).

Survey catch data were extracted for all species for which there was information on numbers and weight caught, corrected for subsampling factors, standardized to

Table 1. List of spring and autumn (italics) demersal surveys on the south coast of South Africa, with information on number of hauls and number of species included in the analysis.

Date	Depth range (m)	Number of stations by depth range (m)			Number of species
		0–100	101–200	201–500	
Sep. 1986	28–485	27	41	12	20
Sep. 1987	17–395	41	40	7	20
May 1988	*30–450*	*44*	*41*	*8*	*17*
May 1989	*32–185*	*31*	*31*		*22*
May 1990	*30–480*	*33*	*24*	*1*	*26*
Sep. 1990	24–224	43	29	1	30
Jun. 1991	*33–397*	*52*	*31*	*13*	*33*
Sep. 1991	31–289	55	20	1	31
Mar. 1992	*30–400*	*42*	*35*	*5*	*29*
Sep. 1992	25–124	60	27		33
Apr. 1993	*29–440*	*45*	*54*	*10*	*32*
Sep. 1993	29–186	71	34		40
Jun. 1994	*35–500*	*36*	*42*	*10*	*42*
Sep. 1994	30–200	64	28		46
Apr. 1995	*29–483*	*40*	*44*	*14*	*48*
Sep. 1995	28–193	66	30		51
Apr. 1996	*27–440*	*39*	*35*	*5*	*49*
Apr. 1997	*33–426*	*37*	*49*	*12*	*51*
Apr. 1999	*30–469*	*34*	*38*	*10*	*72*
Aug. 2001	35–384	32	41	7	38
Apr. 2003	*35–441*	*32*	*43*	*12*	*39*

30-min trawl duration, and summarized according to depth category (Table 1). Smale *et al.* (1993) distinguished three demersal communities of fish and cephalopods on the south coast (an inshore community, a shelf community, and a shelf-edge or upper-slope community), so we summarized the catch data into the following depth categories: ≤100 m, 101–200 m, and 201–500 m. Epipelagic species such as anchovy (*Engraulis encrasicolus*), sardine (*Sardinops sagax*), and round herring (*Etrumeus whiteheadi*) were excluded from the analysis. The demersal assemblages include all teleosts, elasmobranchs, and cephalopods caught during the surveys.

ABC curves were constructed, and the W-statistic was calculated using PRIMER software (Clarke and Warwick, 1994) for the two lower depth categories separately, and for the aggregate over all depths. ABC plots were not constructed for the 201–500-m depth range, because of the lesser number of species with information on numbers and weight, but these data were included in the overall analysis. Autumn and spring data were not pooled to capture the potential influence of seasonal dynamics. Time-series of the W-statistic were assessed for significant trends using the non-parametric Spearman rank correlation coefficient (R_s; Zar, 1999).

Longline fishing effort data for the years 1984–1988 were obtained from Japp (1989). Information for the other years and for trawl effort was obtained from the database of Marine and Coastal Management (MCM), a part of the South African Department of Environmental Affairs and Tourism.

Results

Figure 2 shows the trend in fishing effort for South Africa's south coast demersal trawl and longline fisheries. Trawl effort was lowest in 1978, just after South Africa declared its 200-mile Exclusive Fishing Zone (1 November 1977) and the consequent exclusion from those waters of foreign distant-water fleets. It then peaked in the late 1980s and subsequently declined, with considerable annual variations. However, this decline may not be as marked as it appears, because potential changes in fishing power have not been taken into account in constructing the curve. Fishing effort in the longline fishery for kingklip increased between 1984 and 1986, but decreased substantially in 1988, before closing in 1990. The longline fishery was reinstated in 1994, this time targeting hake, with effort increasing substantially up to 2000.

Figure 3 shows the ABC curves for the autumn (April–June) surveys, and the 101–200-m depth range. There is a gentle gradient of change in the patterns of biomass and abundance dominance plots. For the period 1988–1993, the biomass curve lies above the abundance curve and has a positive W-statistic, but thereafter, the two curves cross once or twice, and the W-statistic is negative, except for 2003 (Figure 4b).

Figure 4 provides the temporal trends in the W-statistic by season and for the different depth ranges considered. Although the levels may differ between season (particularly evident for the 101–200-m depth range; Figure 4b), the temporal trends are consistent among seasons and depth ranges considered. All trends were significantly negatively correlated with year ($p < 0.05$), when values for seasons were pooled ($n = 21$), with the strongest effect for the 0–100-m depth range ($R_s = -0.68$; Figure 4a), followed by aggregated values over all depths ($R_s = -0.66$; Figure 4c), and the 101–200 m range ($R_s = -0.54$; Figure 4b).

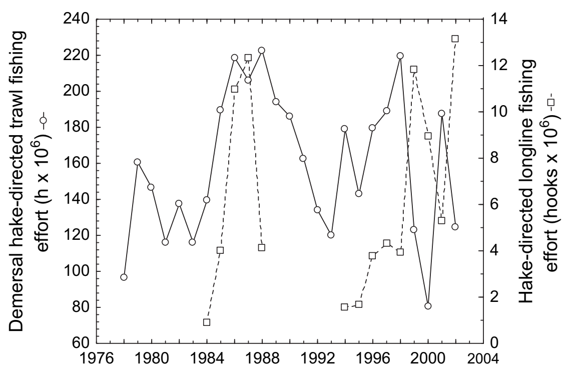

Figure 2. Long-term trend in the total fishing effort of the demersal trawl fishery and longline fishery (from MCM data, and Japp, 1989).

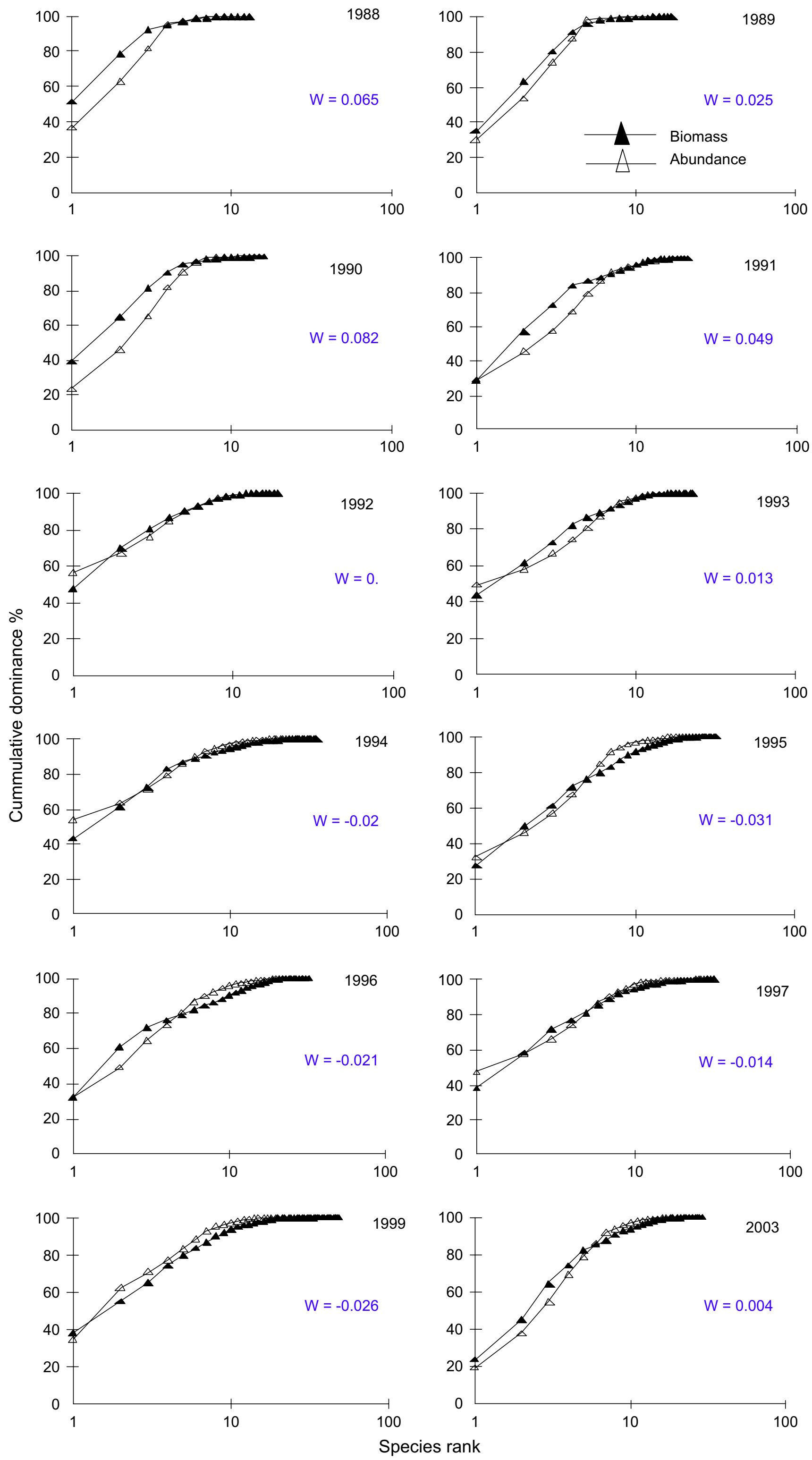

Figure 3. ABC curves for autumn survey data in the 101–200-m depth range, 1988–2003.

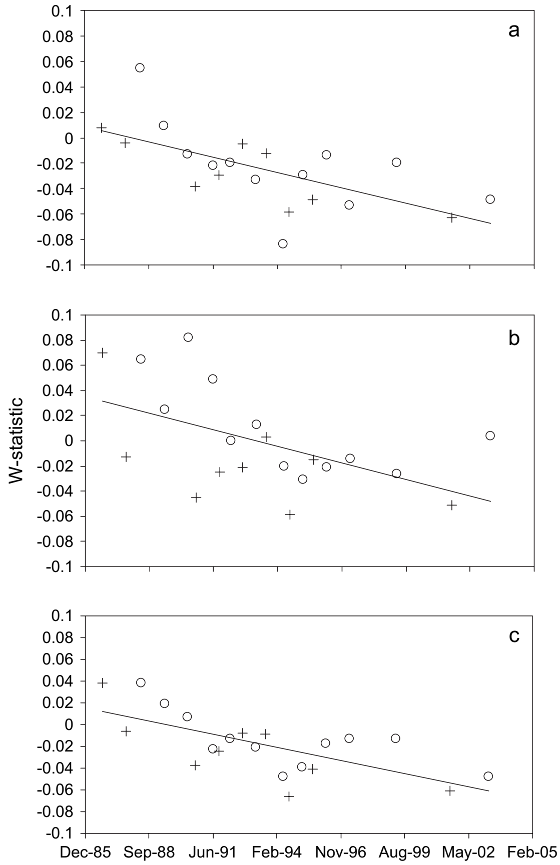

Figure 4. Trend in the W-statistic for (a) the <100-m, (b) the 101–200-m depth range, and (c) the aggregated data over all depths for autumn surveys (circles) and spring surveys (crosses), 1986–2003. Linear regressions have been fitted to the data for both seasons together using the method of least squares to indicate the trend (n = 21 in each case).

Discussion

The results of the ABC curves and their corresponding W-statistic for the communities by depth category, separately and for the aggregated community over all depths, suggest that South Africa's south coast demersal fish and cephalopod assemblages have become increasingly stressed, according to the classification developed by Warwick (1986). This gradient of community change from a less disturbed towards a more disturbed state can be deduced from the temporal trend in the W-statistic. Based on trawl effort data, one might expect a decreasing stress from 1988 onwards, but there may be delay effects caused by the increase in effort just before that year. An alternative explanation could be that the newly introduced and extremely size-selective demersal longline fishery (Japp, 1989) caused marked additional stress that outweighed the impact caused by trawling. Overall, we cannot rule out the possible impact of chronic environmental damage affecting demersal assemblages over a much longer period.

The results of ABC analysis may be biased by a large influx of recruits of dominant species. However, this seems unlikely to be the case here, because the trend continues over the entire period, even though recruitment variations may cause annual variations in the W-statistic. Complementary analyses for either taxonomic or ataxonomic indicators would help confirm the interpretation. According to Warwick and Clarke (1994), the ABC response for the benthic community is mainly due to shifts in phyletic proportions and changes in the relative proportion of abundance and biomass of polychaete species. In a demersal fisheries context, ABC plots may reflect changes in the relative abundance of large and small species in assemblages, and/or changes in size composition. The work of Blanchard *et al.* (2004) appears to confirm this.

The application of the ABC method to the management of multispecies fisheries might be better justified if it were tested in simulations of theoretical fish communities, with different life history traits of its members, and subjected to different fishing and environmental perturbations. Application of the method to different communities around the world with different histories of fishing could also help in understanding the response to this type of stress, and in establishing a "safe" range of the W-statistic within its theoretical range from −1 to +1. Nevertheless, the results suggest that the ABC method may provide a useful underpinning guide to an ecosystem approach to fisheries management, having a sound theoretical basis in r- and k-selection, and requiring only abundance and biomas data that are available routinely from surveys such as those used here.

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References

Agard, J. B. R., Gobin, J., and Warwick, R. M. 1993. Analysis of marine macrobenthic community structure in relation to pollution, natural oil seepage and seasonal disturbance in a tropical environment (Trinidad, West Indies). Marine Ecology Progress Series, 92: 233–243.

Badenhorst, A., and Smale, M. J. 1991. The distribution and abundance of seven commercial trawl fish from the Cape south coast of South Africa, 1986–1990. South African Journal of Marine Science, 11: 377–393.

Bianchi, G., Hamukuaya, H., and Alvheim, O. 2001. On the dynamics of demersal fish assemblages off Namibia in the 1990s. South African Journal of Marine Science, 23: 419–428.

Blanchard, F., LeLoc'h, F., Hily, C., and Boucher, J. 2004. Fishing effects on diversity, size and community structure of the benthic invertebrate and fish megafauna on the Bay of Biscay coast of France. Marine Ecology Progress Series, 280: 249–260.

Botha, L. 1971. Growth and otolith morphology of the Cape hakes *Merluccius capensis* Cast. and *M. paradoxus* Franca. Investigational Report, Division of Sea Fisheries, South Africa, 97. 32 pp.

Botha, L. 1985. Occurrence and distribution of Cape hakes *Merluccius capensis* Cast. and *Merluccius paradoxus* Franca in the Cape of Good Hope area. South African Journal of Marine Science, 9: 327–357.

Clarke, K. R., and Warwick, R. M. 1994. Changes in Marine Communities: an Approach to Statistical Analysis and Interpretation. Plymouth Marine Laboratory, Plymouth. 144 pp.

Field, J. G., Clarke, K. R., and Warwick, R. M. 1982. A practical strategy for analysing multispecies distribution patterns. Marine Ecology Progress Series, 8: 37–52.

Fogarty, M. J., and Murawski, S. A. 1998. Large scale disturbance and structure of marine systems: fishery impacts on Georges Bank. Ecological Applications, 8: S6–S22.

Garrison, L. P., and Link, J. S. 2000. Fishing effects on spatial distribution and trophic guild structure of the fish community in the Georges Bank region. ICES Journal of Marine Science, 57: 723–730.

Greenstreet, S. P. R., and Hall, S. J. 1996. Fishing and the groundfish assemblage structure in the northwestern North Sea: an analysis of long-term and spatial trends. Journal of Animal Ecology, 65: 577–598.

Haedrich, R. L., and Barnes, S. M. 1997. Changes over time of the size structure in an exploited shelf fish community. Fisheries Research, 31: 229–239.

Japp, D. W. 1989. An assessment of the South African longline fishery with emphasis on stock integrity of kingklip, *Genypterus capensis* (Pisces: Ophidiidae). MSc thesis, Rhodes University. 138 pp.

Jennings, S., Kaiser, M. J., and Reynolds, J. D. 2001. Marine Fisheries Ecology. Blackwell Science, Oxford. 417 pp.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F. 1998. Fishing down marine food webs. Science, 279: 860–863.

Payne, A. I. L. 1995. Cape hakes. *In* Oceans of Life off Southern Africa, 2nd edn, pp. 136–147. Ed. by A. I. L. Payne, and R. J. M. Crawford. Vlaeberg, Cape Town. 380 pp.

Punt, A. E., and Japp, D. W. 1994. Stock assessment of the kingklip *Genypterus capensis* off South Africa. South African Journal of Marine Science, 14: 133–149.

Punt, A. E., and Leslie, R. W. 1991. Estimates of some biological parameters for the Cape hakes off the South African west coast. South African Journal of Marine Science, 10: 271–284.

Rademeyer, R. A. 2003. Assessment and management procedures for the hake stocks off southern Africa. MSc thesis, Department of Mathematics and Applied Mathematics, University of Cape Town.

Rice, J., and Rochet, M-J. 2005. A framework for selecting a suite of indicators for fisheries management. ICES Journal of Marine Science, 62: 516–527.

Rice, J. C. 2000. Evaluating fishery impacts using metrics of community structure. ICES Journal of Marine Science, 57: 682–688.

Rice, J. C. 2003. Environmental health indicators. Ocean and Coastal Management, 46: 235–259.

Rochet, M-J., and Trenkel, V. M. 2003. Which community indicator can measure the impact of fishing? A review and proposal. Canadian Journal of Fisheries and Aquatic Sciences, 60: 86–99.

Shin, Y-J., Rochet, M-J., Jennings, S., Field, J. G., and Gislason, H. 2005. Using size-based indicators to evaluate the ecosystem effects of fishing. ICES Journal of Marine Science, 62: 384–396.

Smale, M. J., Roel, B. A., Badenhorst, A., and Field, J. G. 1993. Analysis of the demersal community of fish and cephalopods on the Agulhas Bank, South Africa. Journal of Fish Biology, 43: 169–191.

Warwick, R. M. 1986. A new method for detecting pollution effects on marine macrobenthic communities. Marine Biology, 92: 557–562.

Warwick, R. M., and Clarke, K. R. 1994. Relearning the ABC: taxonomic changes and abundance/biomass relationships in disturbed benthic communities. Marine Biology, 118: 739–744.

Warwick, R. M., Pearson, T. H., and Ruswahyuni. 1987. Detection of pollution effects on marine macrobenthos: further evaluation of the species abundance/biomass method. Marine Biology, 95: 193–200.

Zar, J. H. 1999. Biostatistical Analysis. Prentice Hall, New Jersey. 663 pp.