4 ON NAMIBIA'S MARINE FISH DIVERSITY

Gabriella Bianchi, Elizabeth Lundsør and Hashali Hamukuaya

Abstract

Conservation of marine diversity is a major challenge worldwide. Some of the difficulties reside in the paucity of baseline information on species diversity at the local level, and the lack of operational indices and reference points that may be useful for management purposes. In this study, various aspects of the diversity of Namibian demersal fish assemblages are explored, based on comprehensive datasets of fish occurrence and abundance obtained from bottom trawl surveys with the Norwegian research vessel Dr. Fridtjof Nansen. The study is meant to provide baseline information on Namibian demersal fish diversity that will hopefully represent a useful reference for future conservation efforts.

INTRODUCTION

Conservation of biological diversity has been high on the international political agenda since the 1992 United Nations Conference on Environment and Development (UNCED). The conference generated the Convention on Biological Diversity (CBD) that entered into force in 1993. Article 7 of the CBD deals with identification and protection of biodiversity, Article 10 deals with its sustainable use while Article 12 encourages the establishment of programmes for scientific research and education '...in measures for the identification, conservation and sustainable use of biological diversity... and provide support for such training and education for specific needs in developing countries'.

Implementing the CBD is a global challenge. Effective biodiversity management requires detailed information on biogeographic distribution of habitats and species and clearly defined objectives and performance indicators. Ten years since the CBD entered into force, this type of information is yet not available for most ecosystems. The challenge is greatest for marine habitats, given the difficulty in studying aquatic systems and the high costs of research on these systems. Although it may be argued that marine species are probably less vulnerable to local extinctions than terrestrial species, given that dispersal and new recruitment are easier than in terrestrial habitats, conservation of marine diversity should still be regarded as very important for the maintenance of ecosystem functions (Warwick and Clarke, 2001).

The only information available on fish diversity off Namibia is the type found in the FAO publications such as the Species Identification Sheets for Fishery Purposes (Fischer *et al.*, 1981), national field guides (Bianchi *et al.*, 1999) and species catalogues. These publications summarise published records of species occurrences and generalised charts are drawn based on these records. Table 1 presents an overview of the taxa included in the FAO national field guide for Namibia (Bianchi *et al.*, 1999), that includes the most comprehensive list of species recorded in this area. Similar information can also be found in FishBase, a global information system on fishes (Froese and Pauly, 2003). The information found in these works, however, does not have the level of detail needed for management purposes given that species distributions are indicated following broad biogeographic patterns and are not based on local habitat distribution. Also, monitoring diversity in a given area should take into account aspects of local abundance and dominance that can only be evaluated by sampling and comparing trends over time.

This study is meant to contribute to the description of biogeographic patterns of the diversity of demersal fish communities off Namibia. Furthermore, conventional and new indices of diversity will be applied to explore different aspects of fish diversity on the continental shelf and upper slope of Namibia.

MAIN BIOGEOGRAPHIC PATTERNS

Namibia's demersal assemblages have been described in Bianchi *et al.* (1999) and Hamukuaya *et al.* (2000). Major changes in the composition of the Namibian demersal fauna take place along the depth gradient and with latitude. A major faunal boundary is found at the shelf edge, between about 300 and 350 m depth, separating shelf from slope communities. Main patterns found

Table 1. Overview of recorded fish taxa, based on Bianchi *et al.* (1999).

Taxa	Agnatha	Elasmobranchs	Bony fishes
Orders	1	9	24
Families	1	25	129
Genera	2	47	296
Species	2	83	424

on the shelf are associated with latitude and a clear boundary is found at around 27°S, i.e. around the Lüderitz upwelling cell, and another at around 21°S. Main shelf assemblages are therefore three, each characterised by a distinctive species composition and associated with different environmental conditions. The northern shelf assemblage (from the Angolan border to about 21°S) is characterised by a number of tropical/subtropical species that reach here their southernmost distribution (e.g. *Dentex macrophthalmus, Synagrops microlepis* and *Pterothryssus belloci*). The central shelf area, between the latitudes of about 21 and 27 °S, is dominated by *Merluccius capensis* (Cape hake) and *Sufflogobius bibarbatus* (pelagic goby) and characterised by being the main oxygen-deficient area in the Benguela system. Near-bottom oxygen levels found here are very low, seldom > 0.5 ml l^{-1}. Diversity here should be expected to be lower and the species found here have special adaptations to withstand these extreme environmental conditions. South of Lüderitz and to the border with South Africa, the fish community is characterised by species that reach their northernmost limit, having their main distribution off South Africa. Near-bottom oxygen levels on this part of the shelf are usually above 2.5 ml l^{-1}. Dominating species are the hakes *Merluccius paradoxus* and *M. capensis, Lepidopus caudatus, Emmelichthys nitidus, Zeus capensis, Chelidonichthys capensis, Genypterus capensis, Thyrsites atun* and *Callorhinchus capensis.*

The upper slope assemblage (between 300 and 600 m depth) includes a few species also found on the shelf but also a number of deep-water benthic fishes. The deep-water hake *Merluccius paradoxus* is the dominating species, accompanied by several species of Macrouridae, *Helicolenus dactylopterus* and several species of deep-water sharks. Figure 1 shows the Namibian coast with the distribution of the main communities.

Demersal fish communities off Namibia have been intensively exploited since the early 1960s and, to the authors' knowledge, no comprehensive diversity studies were carried out at the early stages of exploitation. Bianchi *et al.* (2001) looked at trends in community diversity (richness, Shannon-Wiener and Simpson) and abundance/biomass comparisons (ABC plots) for the decade after Independence. The main feature that was revealed was an increase in diversity due to increased evenness during the study period in the upper slope area. An increase in richness was also observed but was attributed to improved survey protocols. Another important feature was the clear difference in richness and dominance (evenness) patterns between the shelf and the upper slope assemblages, with species richness and evenness increasing with depth.

These conventional measures, however, have some drawbacks (Clarke and Warwick, 2001a) related to their dependence on sample size/effort. Furthermore, they lack a statistical framework to test whether and to what extent a sample departs from the expectation. Finally, they do not reflect phylogenetic diversity and therefore do not take into account to what extent species are taxonomically related. For these reasons Warwick and Clarke (1995) developed a set of indices that also take into account the taxonomic relatedness of the species present in a community. These indices have only been applied to fish communities in two works. Hall and Greenstreet (1998) compared the performance of these indices with conventional diversity indices based on species richness and evenness for a demersal fish commu-

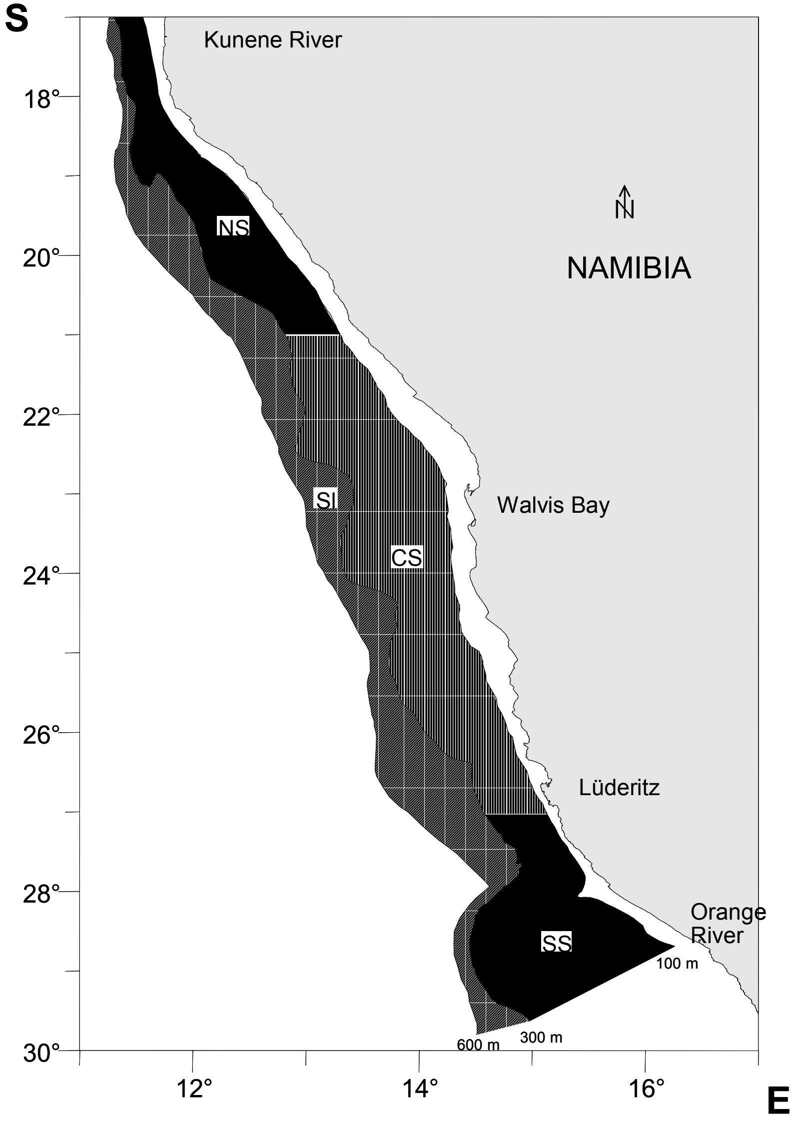

Figure 1. Namibia's shelf and upper slope area, showing the main habitats in this study. SL, Slope; NS, Northern Shelf; CS, Central Shelf; SS, Southern Shelf.

nity of the North Sea. They concluded that there was no difference in the observed trends between the conventional and the new 'taxonomic' indices but they argued that this was due to the fact that major changes had taken place in the community structure and that these were therefore well reflected in both types of indices.

Rogers *et al.* (1999) applied the new taxonomic indices on bottom-dwelling fish off NW Europe and found that greater resolution was achieved by using these indices as compared with conventional ones. They also noted that the taxonomic range, including both species redundancy and range of taxa with species fulfilling key functional roles, may be important for maintaining the ecosystem stability.

Materials and Methods

The data used in the current analysis were collected through bottom trawl surveys by the Norwegian research vessel Dr Fridtjof Nansen off Namibia, from 1990 to 2000 (Table 2). The stations were sampled randomly along transects perpendicular to the coast separated from each other by about 20 nautical miles and data collected from a total of 2309 stations were used for this analysis. The sampling gear was a high-opening shrimp and bottom fish trawl, with a headline of 31 m, footrope of 47 m, roller disks of 12 cm in diameter. The estimated headline height during towing was 5 m. The codend was lined with fine meshes of 20 mm. Towing lasted about 30 minutes at a speed of 3 knots.

Table 2. Overview of the surveys and number of trawl hauls used in the analysis. Project codes and station numbers, as used in the database from which the data were extracted, are also included.

Year	Start date	End date	Project code	St. Nr.	N Stations
1990	26/01	18/03	NA	2 - 242	241
1991	27/01	20/03	NA	501 - 710	210
1992	24/04	19/05	NA	1061 - 1225	165
1993	21/01	23/02	NA	1566 - 1759	194
1994	21/01	21/02	N1	1 - 152	152
1995	22/04	28/05	N1	920 - 1104	185
1996	14/01	17/02	N1	1185 - 1427	243
1997	12/01	19/02	N1	1857 - 2124	267
1998	13/01	20/02	N1	2229 - 2442	214
1999	13/01	18/02	NC	2600 - 2814	215
2000	17/01	22/02	NC	2815 - 3037	223

The catches were sampled and all species identified, on the basis of existing literature (Fischer *et al.*, 1981; Bianchi *et al.*, 1993; Smith and Heemstra, 1991). Each species was weighed and counted and catches standardised to catch per hour tow. Pelagic species belonging to the families Clupeidae, Engraulididae and Carangidae were not included in the analyses.

Data analysis

The continental shelf and upper slope of Namibia, between 100 and 600 m, were subdivided into four areas (Figure 1 and Table 3) based on Hamukuaya *et al.* (2000). For each area, analyses were performed both on individual samples and on the average catches over the whole sampling period.

Data were exported from the NANSIS database (Strømme, 1992) and matrices were generated with species abundance by sampling station, for each of the four areas over the whole study period. Another table was generated including pooled samples representing the average species abundance in each of the four areas described above. The former were used for calculating α- diversity while the latter would produce γ- diversity indices. α- diversity is the diversity at the local scale while γ- diversity describes diversity on a larger scale, here the total diversity of a given area (Whittaker, 1960).

All the calculations were done using the Primer-e programme (Clarke and Warwick, 2001b) for Windows.

Diversity indices

Since no single biodiversity index covers all aspects of biodiversity, a range is needed to describe marine communities (Jennings and Reynolds, 2000). In this work we have chosen to include the Shannon~Wiener index, species richness, Simpson's indices of dominance and evenness and newly developed indices for taxonomic diversity and distinctness. The higher taxa used for the analyses are based on the taxonomy presented by Moyle and Cech (1982), for the higher taxa (phylum to suborder) and Bianchi *et al.* (1999) for lower taxa (family to species). Fishbase (Froese and Pauly, 2003) was used for those species not included in Bianchi *et al.* (1999).

Table 3. Summary of spatial distribution of assemblages by latitude (Ang, border with Angola; SA, border with South Africa).

Area	Depth (m)	Latitude	N Stations
Upper slope	301-600	Ang-SA	1010
Northern shelf	100-300	Ang- 21°S	315
Central shelf	100-300	21- 27°S	513
Southern shelf	100-300	27°S-SA	180

The Shannon~Weiner index, H', is a commonly used index that expresses both species richness and evenness. It gives the share of N (individuals) per S (species).

$$H' = - \sum p_i \log p_i \tag{1}$$

where p_i is the percentage of species i in relation to the total number (S).

Species richness (S) is often given as total number of species. Richness is dependent on sample size so that it is important to show the relationship between the total number of species versus the number of samples or individuals sampled (rarefaction curves). We have chosen to display 'area plots' to show richness (cumulative number of species sampled) as a function of number of samples collected for each of the assemblages considered. For this purpose all samples taken in a given area have been used.

Simpson's indices, D and E, express dominance and evenness of species:

$$\text{Dominance: } D = \sum p_i^2 \tag{2a}$$

$$\text{Evenness: } E = 1 - D \tag{2b}$$

None of the above indices, however, includes the higher taxonomic relationship between species. They may therefore show the same diversity values for assemblages that comprise species closely related to each other as for assemblages where the species are taxonomically more distinct. Intuitively we would consider the latter case more diverse that the former. Warwick and Clarke (1995) developed biodiversity indices that express taxonomic diversity.

Average taxonomic diversity Δ can be considered as an extension of the Simpson diversity with the inclusion of taxonomic separation. It is described as the mean hierarchical path length between any randomly chosen individuals (x) (Jennings and Reynolds, 2000) while reflecting dominance patterns among species.

$$\Delta = [\sum\sum_{i<j} \omega_{ij} x_i x_j] / [N(N-1)/2] \tag{3}$$

where $N = \sum_i X_i$ i.e. all the individuals sampled and ω_{ij} is the taxonomic distances through the classification tree, between every pair of individuals.

Taxonomic distinctness Δ* is the expected taxonomic distance between two randomly chosen individuals under the condition that they represent two different species (Jennings and Reynolds, 2000). The dominance effect is reduced as compared with Δ. This is considered by far the most sensitive univariate measure of community structure by Warwick and Clarke (1995).

$$\Delta^* = [\sum\sum_{i<j} \omega_{ij} x_i x_j] / [\sum\sum_{i<j} x_i x_j] \tag{4}$$

Average taxonomic breadth Δ^+ is the taxonomic path length for presence/absence data and expresses the average taxonomic distinctness (Warwick and Clarke, 1995)

$$\Delta^+ = [\sum\sum_{i<j} \omega_{ij}] / [S(S-1)/2] \tag{5}$$

where S is the number of species in the sample.

Clarke and Warwick (1998) have shown that these indices are largely independent of sampling effort.

Weighing of samples

ω is the path length between two species. ω can be equal for each step in the taxonomic tree, (100/number of steps) or it can be based on taxon richness (Clarke and Warwick, 1999). The last approach was used in this study.

The values obtained in taxonomic breadth for samples within each community were tested against the average taxonomic breadth for all groundfish species sampled and identified during the study period, as described in Clarke and Warwick (2001b).

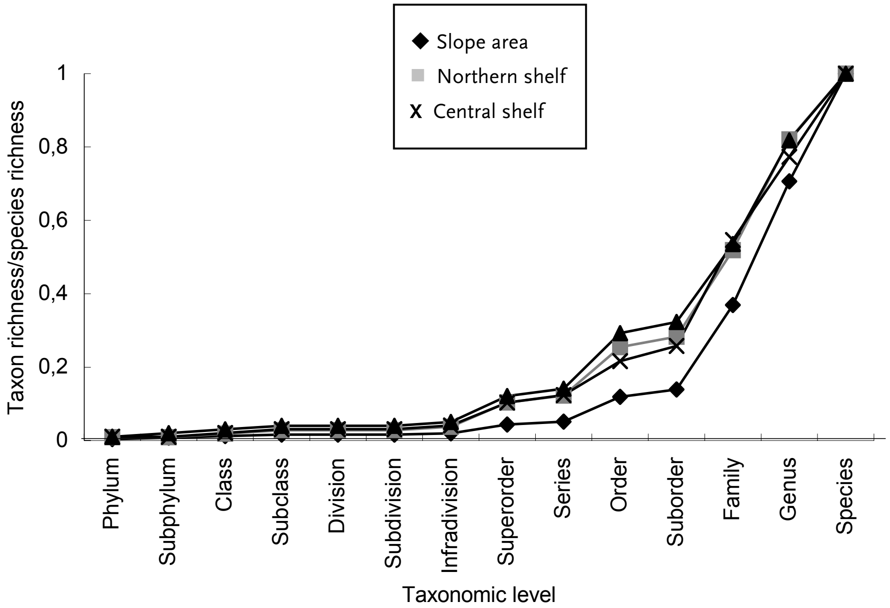

Figure 2. Profiles of ratios between richness at each taxonomic level and number of species in each community. Diamonds: Slope community; crosses: Southern shelf community; squares: Northern shelf community; triangles: Central shelf community.

RESULTS

Appendix 1 shows the list of species and families of bottom-dwelling fishes caught in all trawl stations used in this study. Table 4 shows the number of taxa for each level of classification by main areas. The upper slope holds the highest number of species, genera and families, while at higher taxonomic levels the taxon richness values are comparable between the various communities/areas. In Figure 2 this is shown by comparing the ratio between taxon richness at all taxonomic levels used and the number of species in each area/community. The profiles show lower ratios for the slope community at higher taxonomic levels.

α- diversity

A measure of local species richness is provided by the average number of species caught per trawl haul (Figure 3). There are significant differences, with the upper slope area showing the highest value, followed by the southern shelf, while the central and northern shelves have the lowest values. Figure 3 also shows trends in dominance, with the shelf communities clearly characterised by higher dominance levels (lower evenness) and the upper slope with lower dominance (higher evenness).

Figure 4 shows means and variances for the Shannon~Wiener index (H'), average taxonomic diversity (Δ), distinctness (Δ^*) and average taxonomic breadth (Δ^+) for each of the communities at the α- diversity level. Two of the

Table 4. Number of groups in each taxonomic level, by main area.

	Slope	Northern shelf	Central shelf	Southern shelf
Phylum	1	1	1	1
Subphylum	2	1	2	1
Class	3	2	3	2
Subclass	4	3	4	3
Division	4	3	4	3
Subdivision	4	3	4	3
Infradivision	5	4	5	4
Superorder	11	11	12	10
Series	13	13	14	12
Order	30	27	29	21
Suborder	35	30	32	25
Family	93	55	53	53
Genus	178	87	81	75
Species	252	106	99	97

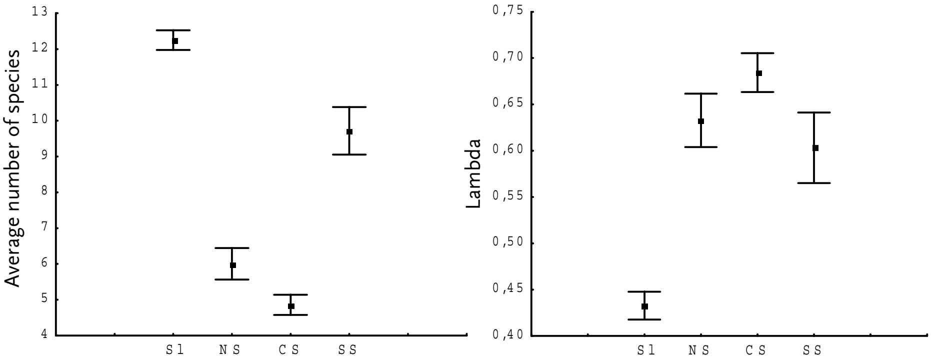

Figure 3. α – Diversity: Average species richness (left) and dominance (right). Sl, Slope; NS, Northern Shelf; CS, Central Shelf; SS, Southern Shelf. Mean ±0.95 Confidence Interval.

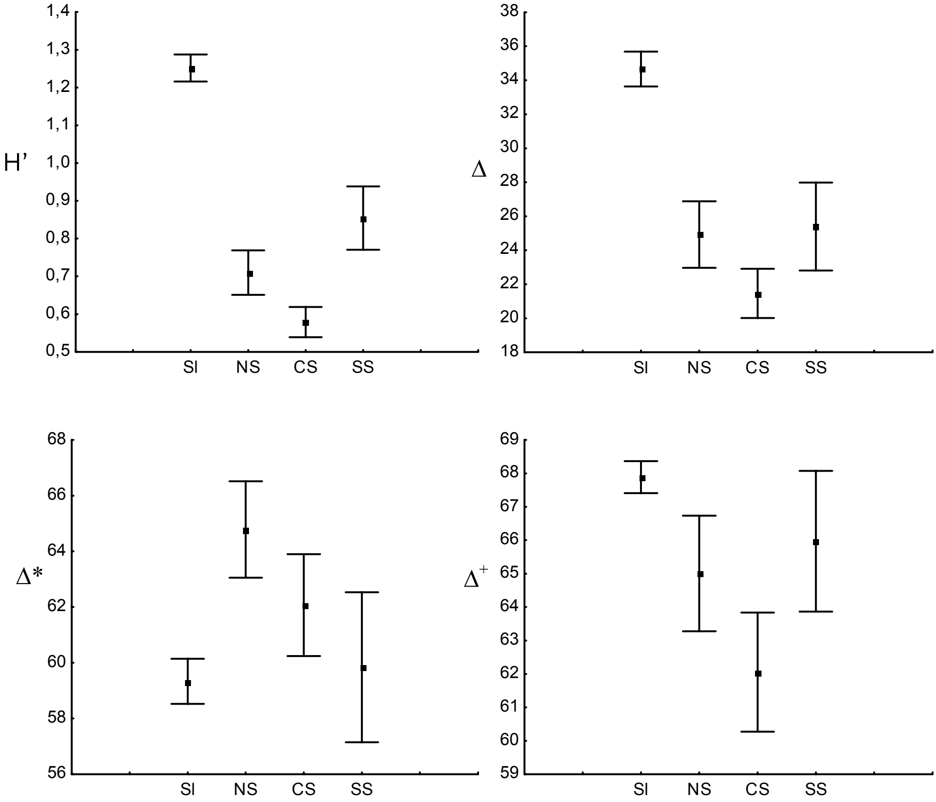

Figure 4. α – Diversity. Shannon~Wiener, H',(upper left); average taxonomic diversity, Δ (upper right); average taxonomic distinctness, Δ* (lower left); and average taxonomic breadth, Δ^+ (lower right). Sl, Slope; NS, Northern Shelf; CS, Central Shelf; SS, Southern Shelf. Mean ±0.95 Confidence Interval.

indices (H' and Δ) show a pattern of higher diversity in the upper slope area as compared with the shelf communities, with the central slope having the lowest diversity values. This result is consistent with the patterns in richness and dominance described above. As regards taxonomic indices where the dominance component has been removed (Δ^* and Δ^+), differences are not as marked and trends different. Remarkably, taxonomic distinctness is significantly higher in the northern and central shelves as compared with the slope community while taxonomic breadth is still highest in the slope area. The step lengths applied for the taxonomic indices are shown in Table 5.

γ- diversity

Figure 5 shows the species-area plots by major assemblage while Figure 6 presents the species-area plot for the three shelf communities combined.

Number of stations varies from area to area but clearly species richness is higher on the upper slope than in any of the other regions. Despite the very high number of samples taken here (> 1000) the cumulative species curve does not seem to reach the asymptote, and therefore the total number of species may be expected to increase as sampling goes on. Comparison between shelf and upper slope (Figures 5, upper left and 6) shows how species richness is higher on the upper slope also when the three shelf communities are combined and number of samples is comparable between the two regions.

Table 5. Levels of classification used (k) and weights (step lengths) applied using the 'standard ' weighting scheme (ω_k) and an alternative scheme (ω_k^0) that uses an accumulation of the proportional decrease in taxon richness values (s_k).

k	Level	s_k	ω_k	ω_k^0
1	Species	308	7.14	6.02
2	Genus	232	14.29	18.88
3	Family	112	21.43	34.87
4	Suborder	40	28.57	38.03
5	Order	35	35.71	52.52
6	Series	15	42.86	56.04
7	Superorder	13	50	70.42
8	Infradivision	6	57.14	75.35
9	Subdivision	5	64.29	75.35
10	Division	5	71.43	75.35
11	Subclass	5	78.57	75.35
12	Class	5	85.71	87.68
13	Subphylum	2	92.86	100
14	Phylum	1	100	100

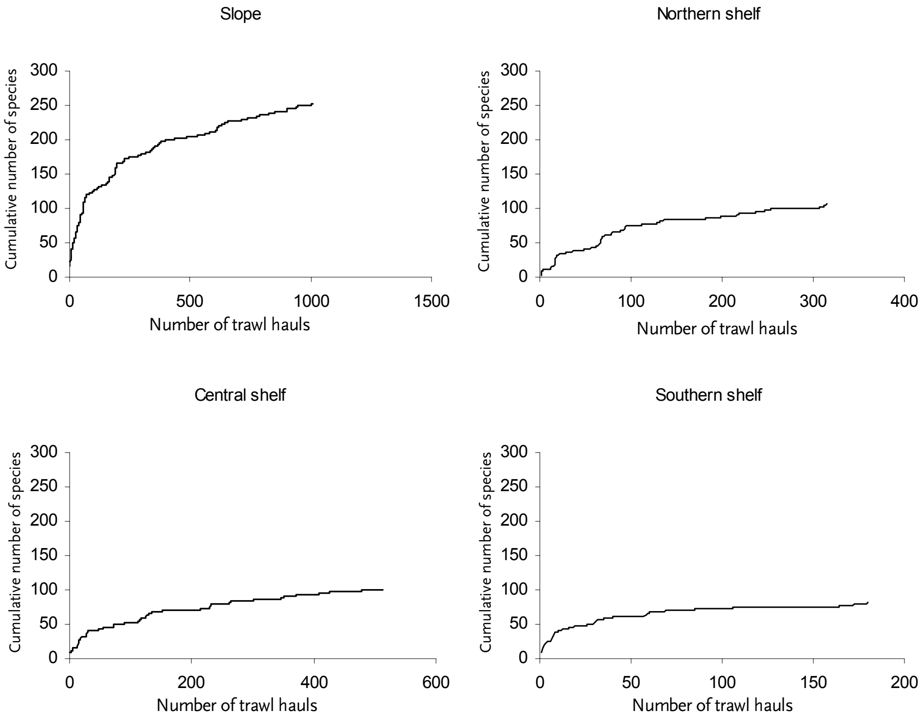

Figure 5. Species-area plot including all stations sampled during the study period, by main habitat type.

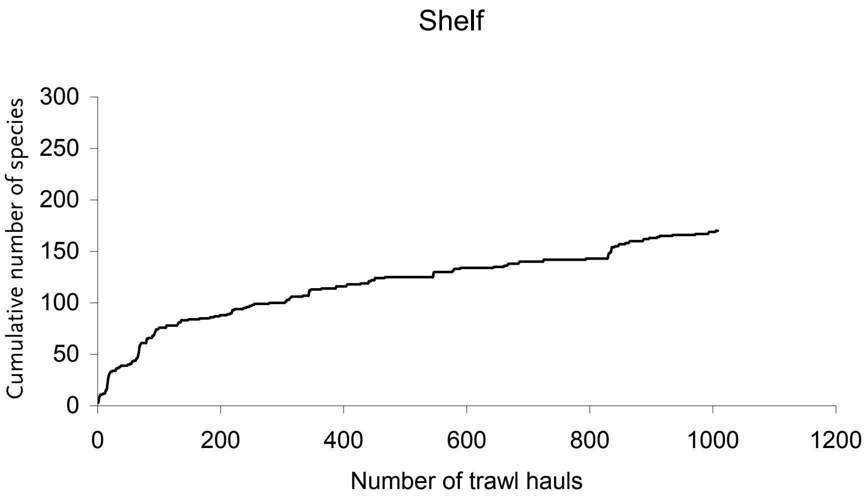

Figure 6. Species-area plot for the three shelf communities combined.

Table 6 shows a summary with the γ- diversity indices calculated for each of the assemblages and including all the stations sampled during the study period. These values provide therefore an average total diversity for the communities over a 10 year period.

γ- diversity calculated by the Shannon-Wiener index gives the highest value for the slope area and the lowest for the central shelf area. This correlates with a high dominance (lambda) on the central shelf and a high evenness on the upper slope and is consistent with the results obtained at the α-diversity level. The same pattern is shown in Δ, but for Δ^* the central shelf has the highest value and the three other areas are not significantly different from each other.

Figure 7 shows the 95% confidence intervals for the four regions of the mean taxonomic breadth. The mean is the theoretical mean from the overall value of Δ^+ for the global species list from the whole region while the variances are obtained by sampling a varying number of species (without replacement) from the total list of species. This produces an overall 'confidence funnel' that allows to check to what extent taxonomic breadth of a given set of samples falls within the expected values. The results show that most of the samples fall within the expected range but that most of them were below the expected mean.

DISCUSSION

Data limitations

Fish diversity studies have important limitations due to the difficulties of sampling a three-dimensional environment. Trawl gear, although among the least selective gears, can only sample a small fraction of the water column at the time, is size selective (but possibly this problem is less important on the RV Dr. Fridtjof Nansen, given that double lining in the codend and very small mesh sizes are used) and is species selective (some species living very close to the bottom might not be sampled properly). It is difficult to evaluate how this affects the various measures of diversity. It may be particularly im-

Table 6. γ-diversity with taxonomic diversity indices weighed for species richness.

Area	S	H'(loge)	Lambda	Δ	Δ^*	Δ^+
Slope	252	3.12	0.07	57.11	61.25	72.77
Northern shelf	106	2.01	0.17	50.91	61.65	71.21
Central shelf	99	1.19	0.40	41.83	69.45	72.34
Southern shelf	97	2.13	0.18	50.36	61.75	72.40

portant for the measures that have an equity component given that the relative abundance of species found in the catches does not necessarily reflect the actual relative abundance. These inaccuracies are further exacerbated by fish behaviour. Although the various species are described in the broad categories "demersal" or "pelagic", most carry out vertical diel migrations, more or less extensive depending on the species and/or the environmental conditions. Most of the species included in the analyses show this behaviour, but species that are mainly pelagic have been excluded from the analyses. For this reason, the study does not provide a comprehensive description of the total fish fauna found in the area.

Patterns of fish species diversity on the Namibian shelf and upper slope areas

The Namibian shelf and upper slope belong to the temperate South African region. Its northern limit coincides with the Angola~Benguela frontal area, situated off southern Angola where the tropical Eastern Atlantic zoogeographic region has its southern limit. This region is the poorest in fish species of all tropical regions, with 434 shore fishes (as compared, for example, with 900 on the other side of the Atlantic). The South African region, which includes both the Indian Ocean and Atlantic sides of southern Africa, has a higher number of species given the presence of warm currents that

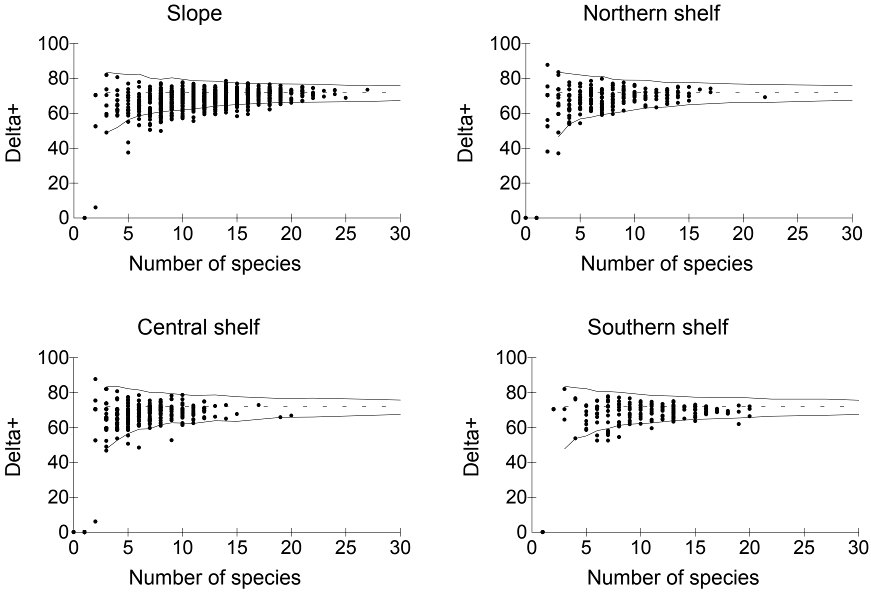

Figure 7. Funnel plots showing the average taxonomic distinctness of samples within each community, as compared with the 95% probability limits for Δ^+ and the mean taxonomic distinctness for the whole area.

extend the tropical Indo-Pacific fauna off the eastern and southern coasts of South Africa. Given its long isolation, this region has a high level of endemism. Namibia is part of the Southwestern Africa province (Briggs, 1974) that extends from southern Angola to the Cape of Good Hope.

Shelf diversity off Namibia is relatively low, with a total of 170 species recorded from 1008 trawl hauls. Only an average of 5 species per trawl haul is caught in the central shelf where near-bottom oxygen levels are lowest. Species richness at α-diversity level on the shelf reflects the poor ecological conditions in the central shelf, while the trends in the northern and southern shelves reflect the diversity of adjacent areas. Species richness measured as average number of species per trawl haul is highest on the slope. Both of the above trends seem to be in contrast with two accepted rules in marine zoogeography: 1) that fish richness increases with decreasing latitude and; 2) that richness decreases with depth. Macpherson and Duarte (1994) have shown for the Eastern Atlantic that species richness declines by about 1% for each degree of latitude. Obviously this seems not to apply locally for the Namibian marine fishes. Richness and dominance are negatively correlated (Figure 3), with high and low richness corresponding to low and high dominance, respectively. High dominance and low diversity are typical of 'stressful' environments and the low oxygen levels found in large parts of the shelf area off Namibia are likely the reason for the observed patterns. Other studies have shown how fish diversity is strongly affected by oxygen levels < 1 ml l^{-1}. (Bianchi 1991 and 1992).

Taxonomic indices showed similar trends to the species indices. In particular, the average taxonomic diversity (Δ) and the average taxonomic breadth (Δ^+) showed similar patterns to the Shannon~Wiener index, thus apparently not adding more information and insight, similarly to what was concluded by Hall and Greenstreet (1998) for patterns of change in the fish communities of the northern North Sea. However, taxonomic indices present a new aspect of diversity that seems worthwhile pursuing. Despite the higher species richness of the slope, its taxonomic range is similar to the shelf regions. Furthermore, diversity of higher taxa (expressed as ratio of number of higher taxa divided by the number of species in the assemblage) is in fact higher on the shelf than in the upper slope area (Figure 2). Two conclusions can be derived from this. The first is that relatively higher taxonomic diversity on the shelf may be related to higher ecological diversity. On the other hand, high taxonomic diversity associated with low species diversity at taxon level, may also result in ecologically unstable conditions. For example, the central shelf area holds relatively few species and has high levels of dominance. This may indicate the presence of (keystone?) fish species particularly well adapted to the given conditions but whose function in the ecosystem may be difficult to replace by other species in the case of population crashes due, for example, to overexploitation. In these cases of low species diversity in stressful environments, resilience of the system may be low and the precautionary approach to fisheries management should be more strongly emphasized.

Of the three taxonomic indices used in this study (Δ, Δ^* and Δ^+), Δ^* has been difficult to interpret. It displays a quite different pattern as compared with all the other indices, but is consistent with the analysis of diversity of higher taxa shown in Figure 2.

Visualization of trends of taxonomic breadth within each community as compared with the theoretical mean is indicative of a lower local taxonomic breadth at community level as compared with the total. This confirms the distinctness of the four regions. It is suggested that diversity studies in a given geographic area should be preceded by analyses that test the homogeneity of the area, by, for example, multivariate analyses. Correlation with environmental variables leads to the definition of habitats, thus allowing separation of environmental effects from anthropogenic effects in understanding patterns of diversity.

Demersal fish diversity and fisheries management - A pragmatic approach toward monitoring fish diversity

Clearly diversity has many facets and can hardly be represented by a single index. The question still remains as to which indices should be used to indicate ecosystem health as related to possible effects of fishing, and what are the reference points for these measures that fisheries management should aim at. Based on the experience made through the work of the SCOR working group on ecosystem effects of fishing (ICES, 2000) and the present study, the following is an outline for a pragmatic approach to monitoring demersal marine fish diversity.

Bottom trawl surveys, usually carried out under controlled conditions and with appropriate sampling schemes, are performed in areas exploited by the industrial fisheries. This type of data could be used to study diversity patterns in space and time, according to the following analytical steps:

- Stratification of a given area into communities by multivariate analyses and habitat definition (by, for example, main environmental variables). This would provide a definition of ecological and management units.
- Analysis of community properties as regards diversity, taking into account species richness, dominance and measures of taxonomic diversity.
- Monitoring trends over time. Development of reference points should be done in an adaptive way, at least to start with.

Methods should be standardized so that experiences gained in a given area could more easily be compared. Standardization of methods is a key issue and should be sought for all the analytical steps. For example, when looking at taxonomic indices, it is essential that the number of taxonomic levels and the type of taxa utilized are the same given that the choice of number and type of taxa affects the taxonomic index. Furthermore, there are other features of diversity that may be important to evaluate (e.g. functional diversity) and studies should be carried out to find which of the indices are most informative in relation to assessing ecosystem health.

It is recommended that international (e.g. FAO) and regional fisheries organizations should take the lead as regards promoting the standardization of methods for describing and monitoring marine fish diversity.

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APPENDIX 1. List of fish families and species collected by bottom trawl by the RV DR. F. Nansen (1990-2000).

Family	Species
HAGFISHES	
Myxinidae	
	Myxine capensis
CARTILAGINEOUS FISHES	
Lamnidae	
	Isurus oxyrinchus
	Apristurus sp.
	Apristurus saldanha
	Galeus polli
Scyliorhinidae	
	Holohalaelurus regani
	Scyliorhinus capensis
	Galeorhinus galeus
Triakidae	
	Mustelus palumbes
	Mustelus mustelus
Carcharhinidae	
	Carcharhinus signatus
	Prionace glauca
Chlamydoselachidae	
	Chlamydoselachus anguineus
	Heptranchias perlo
Hexanchidae	
	Hexanchus griseus
Echinorhinidae	
	Echinorhinus brucus
Dalatiidae	
	Etmopterus sp.
	Etmopterus pusillus
	Etmopterus lucifer
	Etmopterus spinax
	Etmopterus brachyurus
	Centroscymnus crepidater
	Centroscymnus coelolepis
	Centroscyllium fabricii
	Scymnodon squamulosus
	Isistius brasiliensis
	Oxynotus centrina
Centrophoridae	
	Centrophorus sp.
	Centrophorus uyato
	Centrophorus granulosus
	Centrophorus squamosus
	Deania profundorum
	Deania calcea
	Deania quadrispinosum
Squalidae	
	Squalus blainvillei
	Squalus megalops
	Squalus acanthias
	Squalus mitsukurii
Rajidae	
	Raja sp.
	Raja miraletus
	Raja caudaspinosa
	Raja alba
	Raja straeleni
	Raja wallacei
	Raja clavata
	Raja stenorhyncus
	Raja leopardus
	Raja confundens
	Raja doutrei
	Raja pullopunctata
	Raja springeri
	Raja spinacidermis
	Cruriraja parcomaculata
	Bathyraja smithii
Torpedinidae	
	Torpedo nobiliana
Dasyatidae	
	Dasyatis sp.

Family	Species
Myliobatidae	
	Myliobatis aquila
Callorhinchidae	
	Callorhinchus capensis
Rhinochimaeridae	
	Neoharriotta pinnata
Chimaeridae	
	Hydrolagus sp.
	Hydrolagus mirabilis
BONY FISHES	
Albulidae	
	Pterothrissus belloci
Colocongridae	
	Coloconger cadenati
Muraenidae	
	Uropterygius wheeleri
Ophichthidae	
	Mystriophis rostellatus
	Ophisurus serpens
Nemichthyidae	
	Nemichthys scolopaceus
	Nemichthys curvirostris
Congridae	
	Bathyuroconger vicinus
Nettastomatidae	
	Venefica proboscidea
Synaphobranchidae	
	Synaphobranchus kaupii
Halosauridae	
	Halosaurus ovenii
Notacanthidae	
	Notacanthus sexspinis
Microstomatidae	
	Nansenia sp.
Bathylagidae	
	Bathylagus glacilis
Alepocephalidae	
	Alepocephalus sp.
	Alepocephalus rostratus
	Xenodermichthys copei
Platytroctidae	
	Maulisia microlepis
Gonostomatidae	
	Diplophos sp.
	Diplophos maderensis
	Triplophos sp.
	Triplophos hemingi
Sternoptychidae	
	Argyropelecus aculeatus
	Argyropelecus affinis
	Maurolicus muelleri
Phosichthyidae	
	Phosichthys sp.
	Phosichthys argenteus
	Yarrella blackfordi
Stomiidae	
	Melanostomias sp.
	Odontostomias micropogon
	Photonectes braueri
	Stomias boa boa
	Astronesthes sp.
	Bassanago albescens
Ateleopodidae	
	Guentherus altivela
Chlorophthalmidae	
	Chlorophthalmus atlanticus
	Chlorophthalmus agassizi
	Chlorophthalmus punctatus
Notosudidae	
	Scopelosaurus meadi
Paralepididae	
	Lestidium atlanticum
	Lestrolepis intermedia
	Lestidiops sp.
	Macroparalepis macrogeneion
	Macroparalepis affinis

Family	Species
Neoscopelidae	
	Neoscopelus macrolepidotus
Myctophidae	
	Diaphus sp.
	Diaphus dumerili
	Diaphus hudsoni
	Lampadena sp.
	Lampadena pontifex
	Lampanyctodes hectoris
	Lampanyctus australis
	Symbolophorus boops
Ophidiidae	
	Ophidion sp.
	Dicrolene intronigra
	Brotula barbata
	Genypterus capensis
	Lamprogrammus exutus
	Selachophidium guentheri
Macrouridae	
	Coelorinchus sp.
	Coelorinchus fasciatus
	Coelorinchus coelorhinc. poll
	Coelorinchus braueri
	Coelorinchus matamua
	Coelorinchus acanthiger
	Hymenocephalus italicus
	Malacocephalus laevis
	Malacocephalus occidentalis
	Nezumia sp.
	Nezumia aequalis
	Nezumia leonis
	Nezumia milleri
	Nezumia micronychodon
	Trachyrincus scabrus
	Gadella imberbis
	Laemonema laureysi
Moridae	
	Lepidion capensis
	Physiculus capensis
	Tripterophycis gilchristi
Bregmacerotidae	
	Bregmaceros sp.
	Merluccius sp.
	Merluccius polli
	Merluccius capensis
Merlucciidae	
	Merluccius paradoxus
	Lyconus pinnatus
Batrachoididae	
	Batrachoides sp.
	Chatrabus melanurus
	Perulibatrachus rossignoli
Lophiidae	
	Lophius piscatorius
	Lophius vaillanti
	Lophius vomerinus
Chaunacidae	
	Chaunax pictus
Ogcocephalidae	
	Dibranchus atlanticus
Melanocetidae	
	Melanocetus johnsoni
Diceratiidae	
	Phrynichthys wedli
Ceratiidae	
	Ceratias holboelli
	Cryptopsaras couesii
Scomberesocidae	
	Scomberesox saurus
Trachipteridae	
	Trachipterus trachypterus
	Trachipterus jacksonensis
	Zu elongatus
Regalecidae	
	Regalecus glesne
Trachichthyidae	
	Hoplostethus cadenati
	Hoplostethus mediterraneus

Family	**Species**
	Hoplostethus atlanticus
	Hoplostethus melanopus
Berycidae	
	Beryx splendens
Barbourisiidae	
	Barbourisia rufa
	Cyttus traversi
Zeidae	
	Zeus faber
	Zeus capensis
	Zenopsis conchifer
Oreosomatidae	
	Allocyttus verrucosus
	Neocyttus rhomboidalis
	Oreosoma atlanticum
Grammicolepididae	
	Xenolepidichthys dagleishi
Centriscidae	
	Macrorhamphosus scolopax
	Notopogon macrosolen
Congiopodidae	
	Congiopodus spinifer
	Congiopodus torvus
Liparidae	
	Careproctus griseldea
Scorpaenidae	
	Scorpaena sp.
Psychrolutidae	
	Ebinania costaecanarie
	Psychrolutes macrocephalus
Setarchidae	
	Ectreposebastes imus
Sebastidae	
	Helicolenus dactylopterus
	Sebastes capensis
	Trachyscorpia capensis
Triglidae	
	Chelidonichthys capensis
	Chelidonichthys queketti
	Trigla lyra

Family	**Species**
Acropomatidae	
	Synagrops microlepis
Polyprionidae	
	Polyprion americanus
Callanthiidae	
	Callanthias legras
Serranidae	
	Anthias anthias
Epigonidae	
	Epigonus sp.
	Epigonus telescopus
	Epigonus pandionis
	Epigonus denticulatus
Bramidae	
	Brama brama
	Taractichthys longipinnis
	Taractes sp.
Caristiidae	
	Caristius groenlandicus
Emmelichthyidae	
	Emmelichthys nitidus
Sparidae	
	Dentex macrophthalmus
	Spondyliosoma cantharus
	Argyrosomus hololepidotus
Sciaenidae	
	Umbrina canariensis
	Atractoscion aequidens
Percophidae	
	Bembrops heterurus
Callionymidae	
	Paracallionymus costatus
Gobiidae	
	Sufflogobius bibarbatus
Sphyraenidae	
	Sphyraena guachancho
Gempylidae	
	Paradiplospinus gracilis
	Ruvettus pretiosus
	Thyrsites atun

Family	Species
Trichiuridae	
	Aphanopus sp.
	Benthodesmus tenuis
	Lepidopus caudatus
	Trichiurus sp.
	Trichiurus lepturus
	Scomber japonicus
Scombridae	
	Allothunnus fallai
Centrolophidae	
	Centrolophus niger
	Hyperoglyphe moselii
	Schedophilus pemarco
	Schedophilus huttoni
	Schedophilus ovalis
Nomeidae	
	Cubiceps caeruleus
Tetragonuridae	
	Tetragonurus cuvieri
	Tetragonurus atlanticus
Bothidae	
	Arnoglossus imperialis
	Arnoglossus capensis
	Monolene microstoma
Soleidae	
	Austroglossus microlepis
	Austroglossus pectoralis
	Dicologoglossa cuneata
	Synaptura kleini
Cynoglossidae	
	Cynoglossus capensis
	Cynoglossus zanzibarensis
Diodontidae	
	Chilomycterus reticulatus