ICES Journal of Marine Science, 62: 424–429 (2005)
doi:10.1016/j.icesjms.2005.01.014

Analysis of size spectra off northwest Africa: a useful indicator in tropical areas?

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Stobberup, K. A., Inejih, C. A. O., Traoré, S., Monteiro, C., Amorim, P., and Erzini, K. 2005. Analysis of size spectra off northwest Africa: a useful indicator in tropical areas? – ICES Journal of Marine Science, 62: 424–429.

Changes in the size spectra of demersal fish communities off Cape Verde (1988, 1994), Guinea (1985–1995), and Mauritania (1987–2001) were studied. Intercepts and slopes showed opposite trends for Guinea and Mauritania, but were relatively stable in spite of a strong increase in landings per unit area. For Cape Verde, there were marked changes in size structure, seemingly inconsistent with the more moderate fishing pressure there. Changes in size structure do not seem to be suitable indicators of the effects of fishing in areas characterized by faster growth rates, small sizes, high species diversity, and complex interrelationships, such as the tropics.

Keywords: ecosystem indicators, fishing effects, northwest Africa, size spectra.

Received 1 April 2004; accepted 3 December 2004.

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Introduction

In recent years, several size-based indicators have been proposed as complementary management tools for monitoring the effects of fishing (e.g. Rice and Gislason, 1996; Haedrich and Barnes, 1997; Jennings *et al.*, 2002). One such metric is the slope of the size spectrum, which is constructed by plotting estimates of abundance against the body size of fish or invertebrates. The assumption is that exploitation leads to a steeper slope because fishing selectively removes larger individuals and reduces survival. Although results from tropical regions have been less conclusive than those from temperate regions owing to the absence of consistent time-series, similar trends have been observed (Gobert, 1994; Bianchi *et al.*, 2000). However, a recent study carried out off northwest Africa showed that intercepts and slopes of size spectra of trawl survey data collected off Senegal and Guinea were remarkably stable over time, despite a marked increase in fishing pressure (Thiam *et al.*, 2004).

We present three case studies for the Cape Verde Archipelago and the continental shelves of Guinea and Mauritania. The three areas are all located off northwest Africa, but differ in terms of resource exploitation and ecosystem productivity, representing three different tropical scenarios of fishing impacts over time. Off the continental coast, fishing pressure has increased markedly during the past two decades, which led to a large decrease (by an order of magnitude) of demersal fish biomass (of commercial species in particular; Christensen *et al.*, 2004; Gascuel *et al.*, 2004). Accordingly, our working hypothesis here is that the increased impact should be reflected in the size spectra. Specifically, we expected a steeper slope over time for both Guinea and Mauritania. Cape Verde represents a system where fishing pressure has remained relatively light, so there we expected a smaller (or no) change in slope over time. Therefore, the aim of this work was to address the utility of size spectra as a quantitative ecosystem indicator for monitoring and management purposes in tropical areas.

System characteristics

The Cape Verde ecosystem has strong links to the open oceanic ecosystem of the central Atlantic, and is

1054-3139/$30.00

characterized by relatively low primary production[1] (PP ≈ 675 mgC m^{-2} d^{-1}) and restricted shelf areas around the islands. The Guinean continental shelf is relatively wide, and coastal waters are highly productive because of a combination of strong tidal currents and strong river run-off (PP ≈ 1373 mgC m^{-2} d^{-1}). In Mauritanian waters, seasonal upwelling results in even greater productivity (PP ≈ 2541 mgC m^{-2} d^{-1}), which has sustained commercially important demersal and pelagic fisheries. The landings per unit area are supposed largely to reflect the evolution of effort (Figure 1).

There are clear differences in the demersal fish assemblages among the three systems. Species diversity is relatively low off Cape Verde, which may be related to the limited extent of available habitat, lesser productivity, and exposure to oceanic swells and currents, or a combination of the three factors. Demersal fish assemblages on the shelf areas off Cape Verde and Mauritania are dominated by subtropical species, especially sparids, whereas tropical species are more dominant in Guinean waters, specifically sciaenids in shallow waters (Longhurst and Pauly, 1987).

Material and methods

Data were derived from trawl surveys carried out with the general objective of assessing the demersal resources of the three areas. Because survey methodology varied over time, both in terms of sampling strategy and area coverage, a selection was made in order to obtain consistent time-series, taking into consideration vessel/gear combinations (Table 1).

In the case of the Cape Verde Archipelago, only areas that were sampled consistently in 1988 and 1994 were selected. Data from earlier surveys were rejected because sampling methods differed. For Guinea, a time-series of shallow-water stations (5–40 m) spanning the years 1985–1995, carried out by the same vessel, was available. For Mauritania, data from 39 surveys were selected, covering the period 1987–2001 (Table 1). Earlier surveys appear to have selectively sampled commercial species, so were not included, along with the data from a few surveys that either targeted cephalopod species specifically or covered a restricted area. Data were standardized by calculating catches by weight and number per 30 min fished (1 h for Cape Verde), and applying correction factors based on the mean number of hauls per stratum, because sampling intensity varied in time and space (Table 1). Invalid hauls and those with incomplete information were excluded, and only demersal species were included in the analysis.

The large differences in the extent of the continental shelves of each country are reflected in the approximate area covered by the trawl surveys (Table 1). Sampling intensity in terms of the number of hauls per unit area was roughly comparable among areas, so the number of species caught was assumed to reflect system characteristics rather than sampling deficiencies. Efforts at species identification appear to have been greater in the Mauritanian surveys, but this should have no effect on size spectrum analysis. The species included in the analysis represent a major proportion of the biomass available on trawlable grounds in each area, and were classified as commercial or non-commercial depending on whether they had a market value in each country.

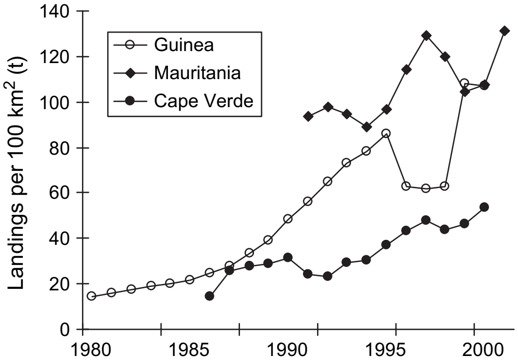

Figure 1. Landings of demersal fish in Cape Verde (INDP, 2001), Guinea (FAO, 2002), and Mauritania (IMROP, 2002).

Size spectra (log-transformed biomass by $\log_2$ body-mass classes) were constructed for pre-defined strata (year, season, depth, zone; Table 1), and for commercial and non-commercial species separately. They were normalized by dividing the biomass in a given class by the width of the class interval, as suggested by Jennings *et al.* (2002). The objective was to linearize the size spectra so as to obtain an approximate normal error distribution and homogeneous variance (Figure 2). We consider this to be a statistically more elegant method than the procedure used by Bianchi *et al.* (2000), although the objective of linear transformation is the same.

Generalized Linear Models (GLMs; McCullagh and Nelder, 1992) were used to obtain annual estimates of the intercepts and slopes over time, taking into account the effect of the other pre-defined strata (factors). The model is described in the Appendix.

Results

The GLM models fitted to the size spectra in each case study were highly significant, explaining between 62% and 79% of the variability (r^2; Table 2). Intercepts and slopes of the size spectra varied considerably over time (Figure 3).

For Mauritania, slopes tended to decrease (become steeper) and intercepts to increase for commercial species, as might be expected from the increasing exploitation of demersal fish over time. This trend depends predominantly,

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[1] See: www.seaaroundus.org.

Table 1. Summary information for demersal trawl surveys used for the analysis of size spectra in Cape Verde, Guinea, and Mauritania, including the definition of strata by year, season, zone, and depth used.

Parameter	Cape Verde	Guinea	Mauritania
Time period	1988, 1994	1985–1995	1987–2001
Number of surveys	2	26	39
Season strata	Warm (Jul.–Nov.)	Dry (Dec.–Apr.) Wet (May–Nov.)	Warm (Jun.–Oct.) Cool (Nov.–May)
Zone strata (limits)	Boavista/Maio Island Sal Island	N (≥ 10.2°N) C (≥ 9.5°N) S (<9.5°N)	N (≥ 19.25°N) S (<19.25°N)
Depth strata (limits, m)	2 (<50, >50)	1 (5–40)	4 (20 m, 50 m, 100 m)
Area covered (km^2)	3400	35000	31600
Number of hauls	133	1493	3683
Mean number of hauls per stratum	14.0	28.7	18.8
Range (hauls)	1–32	7–71	1–65
Number of commercial species	49	109	93
Number of non-commercial species	106	136	261

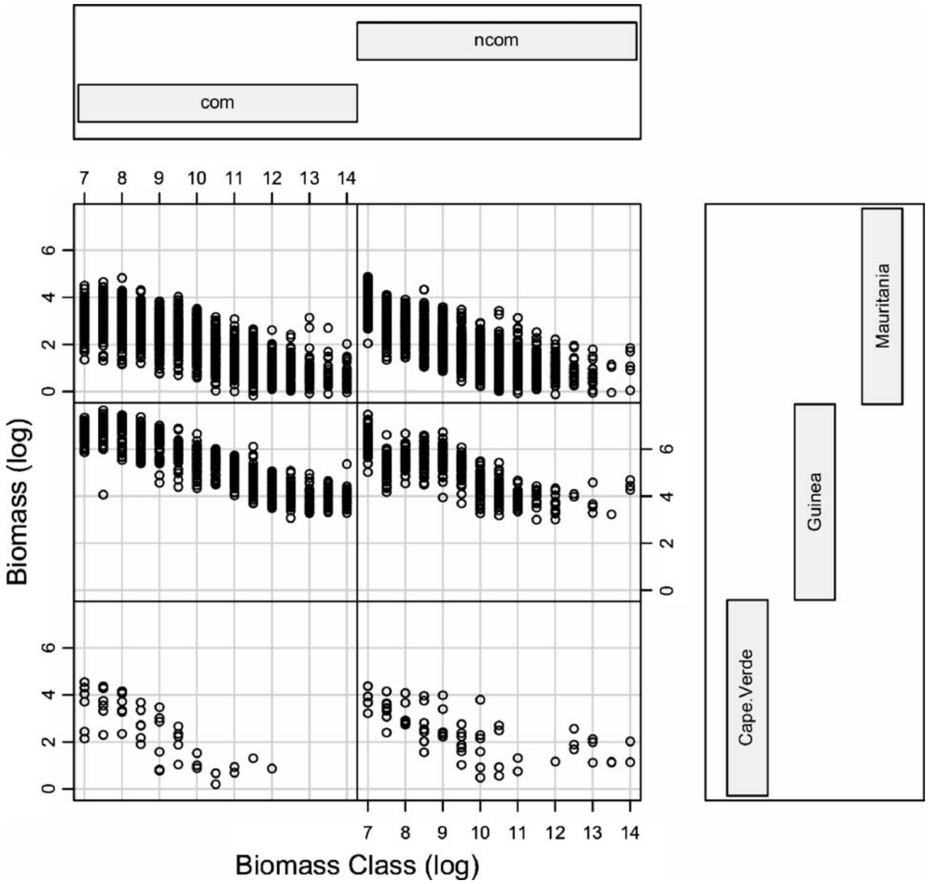

Figure 2. Scatter in the size spectra constructed for all individual, pre-defined strata by species group (com, commercial; ncom, non-commercial) by area.

Table 2. General results of the GLM models applied in the three case studies; Cape Verde, Guinea, and Mauritania. Coefficients of the regression analysis are given in the Appendix.

Area	F-statistic	d.f.	Adjusted r^2	p-value
Cape Verde	20.6	97	0.62	0.000
Guinea	98.0	1 086	0.79	0.000
Mauritania	137.6	3 656	0.70	0.000

however, on a few significantly lower and higher points at the beginning and at the end of the time-series, respectively (Appendix), but judging from the significance of the year coefficients, including interaction terms, the trends of decreasing slopes and increasing intercepts were not significant. In contrast, non-commercial species exhibit the opposite pattern, with increasing slopes and decreasing intercepts. The values of both slopes and intercepts for the two groups cross over in recent years, indicating that the trends cancel each other out.

For Guinea, the patterns were less clear. Intercepts appear to have increased for non-commercial species and to have decreased for commercial ones, opposite to the pattern observed off Mauritania. Slopes varied with no apparent trend, despite a substantial increase in landings over the period investigated (Figure 1). Again, the year coefficients and interaction terms were generally not significant, indicating that the trends were not significant (Appendix).

For Cape Verde, there is a marked change in size structure (increase in intercept; decrease in slope) between 1988 and 1994 (Figure 3), even though official statistics indicate only a moderate increase in fishing intensity during that period (INDP, 2001). The changes were even more pronounced for non-commercial species than for commercial ones, but the year coefficients were not significant and the observed change in size structure can be attributed to zone and depth effects (Appendix). This change in size structure could be traced to catches of some 20 large fish in 1988, which had a great influence on the regression (cf. Figure 2).

Discussion

Our study has placed emphasis on the effect of time (year) on the intercepts and slopes of the size spectra, adjusting for the effects of depth and zone in the region, the effects of which have previously been shown to be significant (Thiam *et al.*, 2004). Similar results were found (Appendix) with significant effects of depth and zone on the intercepts of the size spectra (only shallow depths were considered for Guinea). Depth and zone appear to be more important than year for all three areas. Seasonal effects were not significant in the case of Guinea and Mauritania, and were therefore omitted from the models. Off Cape Verde, the surveys were carried out only during the warm season.

The overall effect of time on the intercepts (year coefficient) was highly significant for Guinea ($p < 0.001$) and Mauritania ($p < 0.001$), but not significant for Cape Verde. In relation to the slopes, coefficients of the "log.cl:y" interaction term are the most interesting, because they determine the year effects on the slope of size spectra for commercial species. They were highly significant for Mauritania ($p < 0.001$) and Cape Verde ($p = 0.002$), but not significant off Guinea. More important than significance levels, however, is whether consistent patterns of increase or decrease in intercepts and slopes are observed in response to exploitation. Both intercepts and slopes showed opposite responses for Guinea and Mauritania, despite marked increases in landings per unit area in

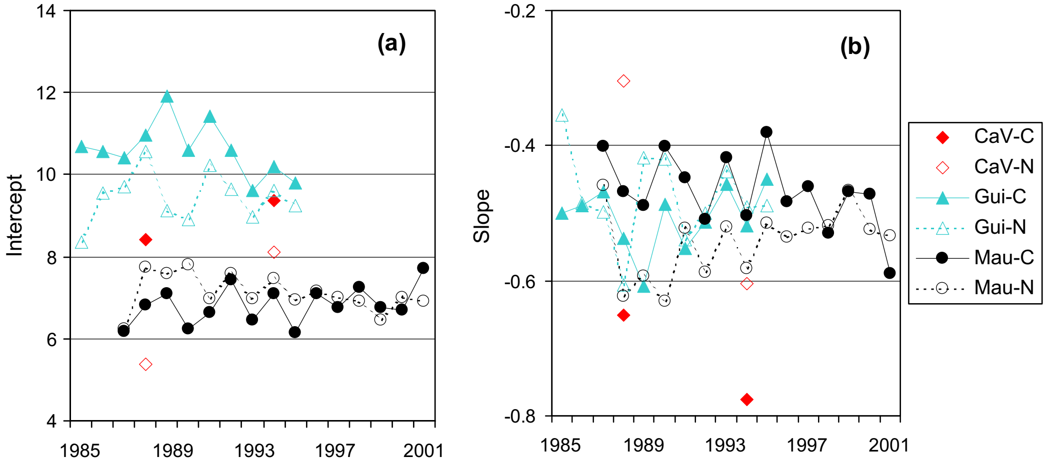

Figure 3. (a) Intercepts and (b) slopes of size spectra by year, commercial value (C, commercial; N, non-commercial), and area (CaV, Cape Verde; Gui, Guinea; Mau, Mauritania), corrected for mean effects of zone and depth (based on coefficients presented in the Appendix).

both regions. Only a few of the year coefficients and interaction terms were significant, and there was no consistent increase or decrease, indicating that the trends were not significant (Appendix). The relative stability over time also reaffirmed previous findings by Thiam *et al.* (2004), based on Guinean and Senegalese data, that spectra were relatively insensitive to the level of exploitation.

When comparing commercial and non-commercial species, an expectation of more pronounced changes in the spectra of the commercial species was confirmed for Mauritania only. Size spectra may not be expected to be the same for commercial and non-commercial species, because this would depend on market conditions, which differ between countries. Also, size spectra cannot be compared directly between surveys, because of differences in sampling gear and methods. However, even with all things being equal, size spectra would be expected to differ among ecosystems, particularly in terms of the intercept, owing to differences in productivity (Bianchi *et al.*, 2000).

A possible explanation for the lack of a consistent response to fishing in the three areas investigated is that the rate of change of the slope is inversely proportional to a weighted average of the von Bertalanffy growth parameter (K) of the constituent species (Gislason and Lassen, 1997). As values of K tend to be higher in tropical regions (Pauly, 1998), the slope would be expected to be less sensitive to changes in fishing (Bianchi *et al.*, 2000).

Another explanation may be that fisheries in productive tropical areas exploit a relatively small proportion of the available biomass of demersal stocks, which should make the system more resilient to exploitation. For Mauritania, the pattern of decreasing slopes and increasing intercepts in the size spectra of commercial species was largely compensated by an opposite trend in that of non-commercial species, suggesting an adjustment at an ecosystem level as well as resilience of the system to exploitation.

In the specific case of the northwest African shelf, intercepts and slopes do not seem to provide suitable indicators, although other effects of fishing over the past two or three decades have been relatively well documented using various other approaches (Christensen *et al.*, 2004; Gascuel *et al.*, 2004). The failing response of size-based indicators to exploitation may reflect a more general feature of ecosystems characterized by faster growth rates, small sizes, high species diversity, and complex interrelationships, such as in the tropics. Moreover, the plots of intercepts and slopes suggest considerable short-term variability in the system, indicating possible effects of environmental factors.

Acknowledgements

We thank Didier Gascuel and Daniel Pauly for advice and suggestions, and the European Commission for funding the "Fisheries Information and Analysis System (FIAS/SIAP)" project, which made the study possible.

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Appendix

GLM models fitted to size spectra for Cape Verde, Guinea, and Mauritania and the estimated coefficients

The model fitted had the following general form:

$$\begin{aligned}\log(\mathrm{B}) = {} & \mathrm{a}(\text{intercept}) + \mathrm{b}(\text{log.cl}) + \mathrm{c}_1(\mathrm{y}) + \mathrm{c}_2(\text{seas}) \\ & + \mathrm{c}_3(\text{d.str}) + \mathrm{c}_4(\text{zone}) + \mathrm{c}_5(\text{c.val}) + \mathrm{i}_1(\text{log.cl} : \mathrm{y}) \\ & + \mathrm{i}_2(\text{log.cl} : \text{c.val}) + \mathrm{i}_3(\mathrm{y} : \text{c.val}) \\ & + \mathrm{i}_4(\text{log.cl} : \mathrm{y} : \text{c.val}) \qquad (1)\end{aligned}$$

where B is the biomass, log.cl the log(size class), y the year, seas the season, d.str the depth, c.val refers to commercial or non-commercial species, a the intercept, b the slope, c the coefficients of the factor terms, and i refers to the interaction terms. The term i_1 is a yearly additive term on the slope for commercial species, i_2 and i_4 are additive terms on the slope for non-commercial species, and i_3 is a yearly additive term on the intercept for commercial species (see Table 1 for other definitions). Seasonal effects were not significant and have been excluded. Factor coefficients express the difference between each level of the factors and first level (contrast treatment). The table below lists only significant terms (*** <0.001; ** <0.01; * <0.05).

	Estimate	s.e.	t-value	p
Cape Verde				
(intercept)	8.24	0.93	8.90	***
log.cl	−0.65	0.10	−6.25	***
zone_SAL	0.65	0.15	4.48	***
d.strata_B	−0.32	0.14	−2.32	*
c.val_ncom	−3.02	1.03	−2.93	**
log.cl:c.val_ncom	0.35	0.12	3.01	**
Guinea				
(intercept)	10.63	0.27	39.24	***
log.cl	−0.50	0.03	−19.33	***
y_1989	1.24	0.46	2.70	**
y_1993	−1.09	0.42	−2.58	*
c.val_ncom	−2.33	0.51	−4.57	***
zone_South	0.11	0.04	3.01	**
log.cl:y_1989	−0.11	0.04	−2.48	*
log.cl:c.val_ncom	0.15	0.05	2.67	**
y_1988:c.val_ncom	1.94	0.79	2.45	*
y_1993:c.val_ncom	1.70	0.74	2.30	*
log.cl:y_1988:c.val_ncom	−0.22	0.09	−2.49	*
Mauritania				
(intercept)	6.388	0.242	26.41	***
log.cl	−0.40	0.03	−16.23	***
y_1988	0.67	0.33	2.04	*
y_1989	0.93	0.32	2.89	**
y_1992	1.26	0.38	3.35	***
y_1994	0.92	0.34	2.69	**
y_1996	0.92	0.38	2.43	*
y_1998	1.10	0.36	3.06	**
y_2001	1.55	0.37	4.20	***
d.str_D2	−0.28	0.02	−11.59	***
d.str_D3	−0.46	0.03	−18.46	***
d.str_D4	−0.22	0.03	−7.93	***
log.cl:y_1988	−0.07	0.03	−2.00	*
log.cl:y_1989	−0.09	0.03	−2.65	**
log.cl:y_1992	−0.11	0.04	−2.83	**
log.cl:y_1994	−0.10	0.04	−2.86	**
log.cl:y_1996	−0.08	0.04	−2.11	*
log.cl:y_1998	−0.13	0.04	−3.43	***
y_1990:c.val_ncom	1.51	0.68	2.21	*
log.cl:y_1990:c.val_ncom	−0.17	0.07	−2.34	*