Ecosystem Approaches to Fisheries in the Southern Benguela
Afr. J. mar. Sci. 26: 115–139
2004

DISTRIBUTION PATTERNS OF KEY FISH SPECIES OF THE SOUTHERN BENGUELA ECOSYSTEM: AN APPROACH COMBINING FISHERY-DEPENDENT AND FISHERY-INDEPENDENT DATA

L. PECQUERIE, L. DRAPEAU*, P. FRÉON*, J. C. COETZEE†, R. W. LESLIE†*
and M. H. GRIFFITHS‡

Within the context of an ecosystem approach for fisheries, there is a need for quantitative information on distributions of key marine species. This information is valuable input for modelling species interactions in the southern Benguela ecosystem. In the present study, a method is described for mapping the density distribution of 15 key species: anchovy *Engraulis encrasicolus*, sardine *Sardinops sagax*, round herring *Etrumeus whiteheadi*, chub mackerel *Scomber japonicus*, horse mackerel *Trachurus trachurus capensis*, lanternfish *Lampanyctodes hectoris*, lightfish *Maurolicus muelleri*, albacore *Thunnus alalunga*, bigeye tuna *Thunnus obesus*, yellowfin tuna *Thunnus albacares*, silver kob *Argyrosomus inodorus*, snoek *Thyrsites atun*, Cape hake *Merluccius* spp., kingklip *Genypterus capensis* and chokka squid *Loligo vulgaris reynaudi*. The purpose was to make use of all available sources of data to extend the spatial and temporal coverage of the southern Benguela. Six sources of data were combined on a 10´ × 10´ cell grid in a Geographical Information System: acoustic and demersal surveys conducted by Marine and Coastal Management (MCM), and pelagic, demersal (including midwater trawl), hake-directed and tuna-directed longline commercial landings data collected by MCM. Comparisons of distributions between two periods (1980s and 1990s) and between two semesters (April–September and October–March) were conducted, but biases as a result of major differences in sampling strategy prevented detailed analysis for certain species. Maps of density distributions are nevertheless presented here and the method to determine them is discussed.

Key words: acoustic surveys, fisheries data, geographical distribution, GIS, trawl surveys

The Food and Agriculture Organization, in its Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem in 2001, emphasized the need for including ecosystem considerations in fisheries management (FAO 2003). Although the structure and functioning of the southern Benguela ecosystem are known in terms of trophic flows (Jarre-Teichmann *et al*. 1998, Shannon *et al*. 2003), there is a need for accurate and quantitative information on the geographical distribution of marine species to improve the modelling of the ecosystem and therefore its understanding.

The Benguela Current off the south-western coast of Africa (15–37°S) is one of the world's four major eastern-boundary current systems, along with the Humboldt Current off Peru and Chile (4–40°S), the Californian Current off the west coast of the USA (28–42°N) and the Canary Current off North-West Africa (12–25°N). In all these systems, large populations of pelagic and demersal fish are supported by strong coastal upwelling and intense plankton production (Carr 2002). However, in contrast to the other upwelling ecosystems, the southern part of the Benguela is influenced by the warm water of the Agulhas Current, which flows and meanders along the Agulhas Bank, invades part of the Bank and is partly retroflected along the west coast of South Africa through mesoscale processes (Harris *et al*. 1978, Lutjeharms 1981, Penven *et al*. 2001). For the purposes of the present study, the southern Benguela is assumed to extend seawards to the 2 000 m isobath (except for the high seas fisheries on tuna species), from 29°S (in the vicinity of the Orange River mouth) southwards along the west coast of South Africa and eastwards to 28°E (East London), covering an area of 360 000 km^2. It therefore incorporates the south and west coasts of South Africa and the Agulhas Bank (Shannon *et al*. 2003).

The important offshore fish resources of the southern Benguela spawn over various parts of the Agulhas Bank, and depend to a greater or lesser extent on the equatorward jet current between Cape Point and Cape Columbine to transport the early stages to the West Coast, where most recruitment takes place (Hutchings *et al.* 2002). Most pelagic recruits return to the Agulhas Bank in the poleward counter-current close to the coast. Species that become more demersal with age, such as Cape hake *Merluccius* spp. and horse mackerel *Trachurus trachurus capensis* tend to move into deeper

* Institut de Recherche pour le Développement, France, and Marine & Coastal Management, Department of Environmental Affairs and Tourism, Private Bag X2, Rogge Bay 8012, South Africa. E-mail: Laure.pecquerie@ifremer.fr
† Marine & Coastal Management
‡ Formerly Marine & Coastal Management; now Ministry of Fisheries, P.O. Box 1020, Wellington, New Zealand

Manuscript received September 2003; accepted March 2004

water as they move south, resulting in complex movements between the West and the South coasts (Barange *et al.* 1998).

The living marine resources of the southern Benguela form the basis of a fishing industry that supports almost 30 000 people in South Africa, mostly residing in the Western Cape. Some 90 hake trawlers and 97 purse-seiners currently account for >90% of the total commercial landed catch (Anon. 2001). Some 2 000 small inshore linefish vessels were licensed in the South African fleet in 2000. In addition, 18–70 Japanese and 19–26 Chinese-Taipei (Taiwanese) tuna longline vessels operated within the South African EEZ between 1996 and 2001. Small-scale fisheries include shoreline fishing, beach-seining, free-diving and shore-harvesting of shellfish, among others.

Purse-seine catches of anchovy *Engraulis encrasicolus* and sardine *Sardinops sagax* constitute the bulk of the catches of the pelagic fishery. They are the most important species in terms of mass, and round herring *Etrumeus whiteheadi*, juvenile horse mackerel and chub mackerel *Scomber japonicus* are valuable bycatch species of the purse-seine fishery (Anon. 2001). The major target species caught by the demersal trawl fishery are Cape hake and Agulhas sole *Austroglossus pectoralis*. Horse mackerel, kingklip *Genypterus capensis*, snoek *Thyrsites atun* and monkfish *Lophius vomerinus* are commercially important bycatch species of the hake-directed fishery (Anon. 2001). Although horse mackerel are caught as bycatch in both the pelagic purse-seine and demersal trawl fisheries, the majority of the landed catch is taken by a small midwater trawl fleet operating on the South Coast.

The handline fishery of the southern Benguela exploits a large number of species, including inshore reef-associated fish such as silver kob *Argyrosomus inodorus* on the South Coast, and migratory shoaling species such as snoek, by far the most important species caught commercially on the West Coast by this fishery. Offshore, large pelagic species, mostly yellowfin tuna *Thunnus albacares*, but also bigeye tuna *Thunnus obesus* and albacore *Thunnus alalunga*, are caught by pole and line vessels, as well as by Asian high-sea longliners (until 2002) and an experimental South African longline fishery (Marine and Coastal Management [MCM], unpublished data).

Data collected by MCM on these different fisheries, as well as data from their pelagic and demersal research surveys, were used to map the distribution range of different species of the southern Benguela, using a specifically designed Geographical Information System (GIS). These maps are useful for management purposes and could be used as inputs for trophodynamic models, such as the individual-based model OSMOSE (Shin 2000, Shin and Cury 2001). In all, 15 key species of intermediate trophic level were selected, small pelagic fish and tunas being located at the lowest and highest extremes of the range respectively. The species were: sardine, anchovy, round herring, chub mackerel, horse mackerel, lanternfish *Lampanyctodes hectoris*, lightfish *Maurolicus muelleri*, silver kob, snoek, albacore, bigeye tuna, yellowfin tuna, shallow-water Cape hake *Merluccius capensis* and deep-water Cape hake *Merluccius paradoxus* (combined), kingklip and chokka squid *Loligo vulgaris reynaudi*.

MATERIAL AND METHODS

Two main sources of data were used to map the distributions: (i) scientific surveys and (ii) commercial fisheries landings. The maps were compared with 10 distribution maps derived by Shin *et al.* (2004) according to a literature survey. Because the spatial extent used in the latter study was smaller than that used here, data outside their grid were not used for this comparison.

Survey data

Pelagic biomass surveys conducted by MCM are undertaken hydroacoustically and are designed to estimate annual spawner biomass and recruitment strength of the three small pelagic species (anchovy, sardine and round herring). The methods are detailed in Hampton (1987, 1992), Armstrong *et al*. (1987) and Barange *et al*. (1999). Acoustic recruitment surveys were initiated in May 1983 to assess the biomass and distribution of the recruiting anchovy and sardine, and are conducted within 50 nautical miles of the coast between the Orange River mouth (28°35´S) and Cape Infanta (21°E). Acoustic spawner biomass surveys, which estimate the size of the adult stock, have also been conducted annually since 1983. These surveys cover the entire continental shelf between Hondeklip Bay (30°30´S) and Port Alfred (27°S; Barange *et al*. 1999). Data collected between 1983 and 1987 were not used in this study because they were not available in a suitable computerized format. Since 1988, some 17 recruit surveys have been undertaken, mainly in May, and 17 spawner biomass surveys, mainly in November (Fig. 1a, Appendix 1). The surveys are conducted by day and night and consist of a series of stratified semi-random transects perpendicular to the coast. Oceanographic and plankton data are collected at stations positioned at 10 mile intervals along each transect. The density of each species of pelagic fish is estimated for each 10-mile segment and assigned to the midpoint of the segment (Jolly and Hampton 1990).

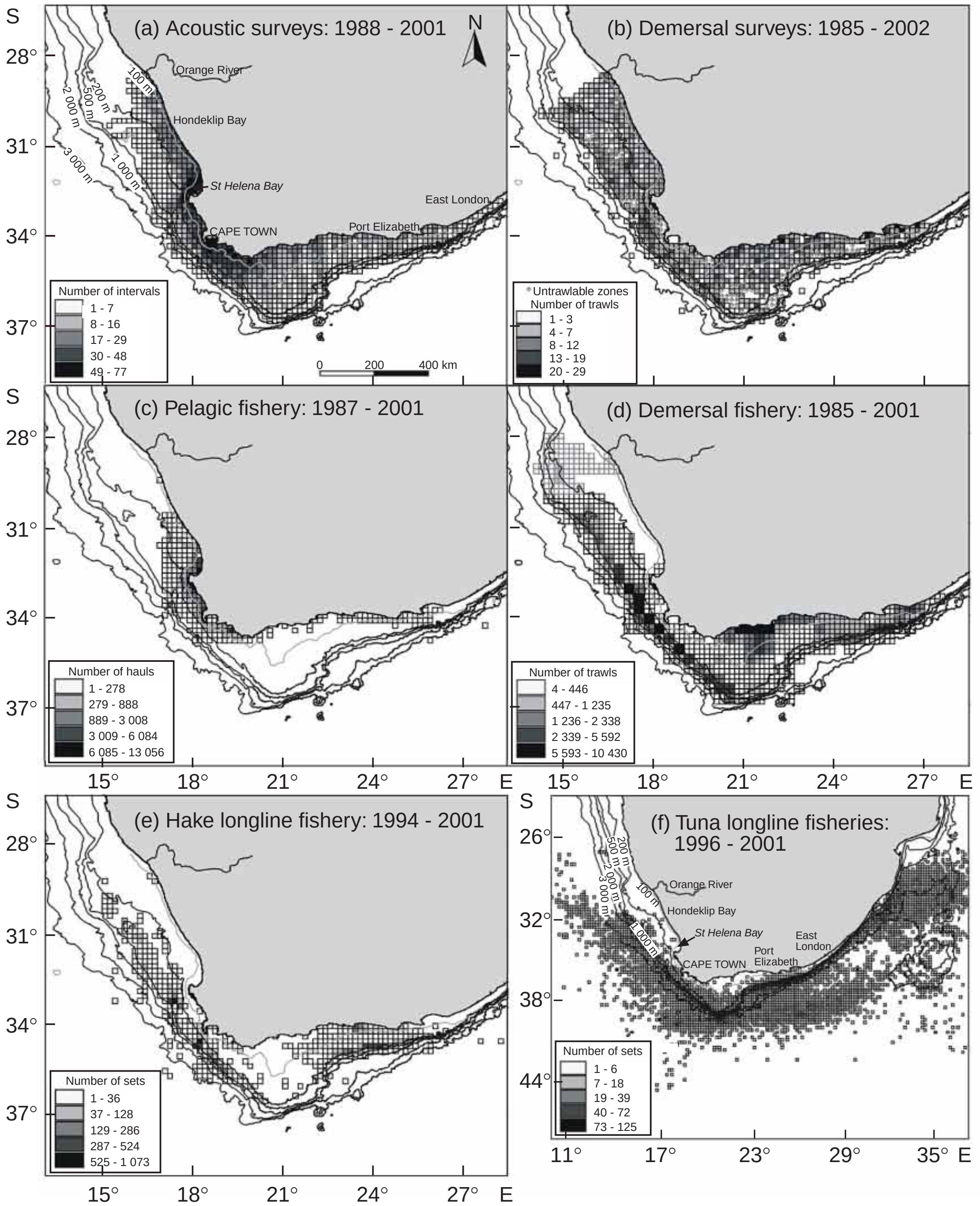

Fig. 1: Sample distribution of MCM databases for (a) acoustic surveys from 1988 to 2001, (b) demersal surveys from 1985 to 2002, (c) pelagic fishery from 1987 to 2001, (d) demersal fishery from 1985 to 2001 (note that the raw information is obtained on 20´ × 20´ grid cells), (e) hake-directed longline fishery from 1994 to 2001 and (f) tuna longline fisheries (foreign and South African) from 1996 to 2001

Demersal biomass surveys are based on the swept area method using a bottom trawl net with a codend of 35-mm mesh in the case of those conducted by the South African research vessel F.R.S. *Africana*, and with a codend of 8-mm mesh on for the Norwegian research vessel F.R.S. *Dr Fridtjof Nansen*. The surveys are designed to provide annual indices of biomass for the resources exploited by the South African hake-directed trawl fishery (Payne *et al.* 1985). The method is fully described by Badenhorst and Smale (1991). The surveys are subdivided into two areas: from the Namibian border to Cape Agulhas (West Coast) and from Cape Agulhas to Port Alfred (South Coast, Fig. 2b). Where possible, effective trawl duration is 30 minutes, although the nature of the seabed sometimes required trawls to be curtailed. Trawls shorter than 15 minutes are discarded and all others are standardized to 30 minutes. Since 1985, 45 surveys have been conducted by MCM, with an average of 93 trawls per survey (Fig. 1b, Appendices 2 and 3). Between 1985 and 1990, 6 winter and 6 summer cruises were undertaken on the West Coast and 3 autumn and 3 spring cruises on the South Coast. In 1991, winter surveys were stopped on the West Coast but since then 10 summer cruises were undertaken, whereas 10 autumn and 7 spring cruises were conducted on the South Coast.

Commercial data

Data from the pelagic fishery consisted of total catch per set (or haul) of the purse-seiner, located on a 10´ × 10´ cell grid from 1987 to 2001 (Fig. 1c, Appendix 4). Two sources of data were used to allocate the catches to given cells on the grid: (i) logbooks, in which estimates of each species and per set are recorded by the skipper, and (ii) the total landings per species and per trip for each boat as reported by fisheries inspectors operating at landing sites. When catches of one trip were taken in different cells, the skipper's estimates by cell are corrected by the estimated ratio of the landed catch taken in each cell, and the catch composition by cell is either estimated from single set trip(s) by other boat(s), or more often considered the same in each cell visited by the boat (most of the time these cells are adjacent).

The data provided by the inshore and offshore hake-directed trawl fisheries covered the period 1985–2001 (Fig. 1d, Appendix 5). Data provided by foreign vessels fishing in South African waters are also recorded in the demersal commercial database and represent 3% of the trawls. Catch and effort (trawl duration) are reported for 20´ × 20´ cells on a trawl-by-trawl basis, using the start position of the trawl (Punt and Japp 1994). Skippers' estimates of catch per species per trawl, recorded in the demersal logbook, are used to apportion the total landed catch among individual trawls. For this study, trawls completed in the same grid block were summed to give an estimate of the landed catch for each 20´ × 20´ cell. The two species of hake are not separated at sea and are recorded as one species. There are seven species pre-printed on the trawl logsheets: Cape hake, sole, horse mackerel, kingklip, monkfish, snoek and chokka squid, and data on those species only were used in the current study. The trawl sector targets three species, Cape hake, horse mackerel and Agulhas sole. Catches are declared at a drag level according to the target species, and distribution information per grid cell can be deduced accordingly. For all other species, landed catches are apportioned among trawls in the ratio of the hake catch. It was not possible to declare any other target species, and hake was taken as the default. Discarded fish are generally not recorded.

Three different longline fisheries operated off South Africa during the study period (Fig. 1e, f, Appendices 6, 7 and 8). Two experimental longline fisheries, hake-directed and tuna-directed, were introduced off South Africa in 1994 and 1998 respectively. The 80 or so foreign tuna-longliners operating in the South African EEZ between 1996 and 2002 were required to provide catch and effort data to MCM on a monthly basis. Longliners, both foreign and South African, report their catch and effort on a per-line-set-per-day basis, indicating the position at the start of the line deployment. In the case of the hake-directed fishery, no distinction is made between the two species.

Construction of single-species distribution maps

Because the different sources of data were of heterogeneous origin and therefore covered different areas (Fig. 2), all data were combined to determine the best possible estimates of the distribution of each species using the widest sampled area of the southern Benguela. This task is complicated, if the requirement is more than just presence/absence mapping, which would inevitably overestimate the significant/core distribution of the species. A four-step process was developed which permitted mapping of the distributions of the 15 key species within the sampled area: (i) data validation, (ii) choice of spatial and temporal resolution, (iii) computation of an index of relative abundance for a given spatial and temporal resolution and (iv) intercalibration and combination of the datasets. The GIS software Arcview 3.2a was used to build these maps.

DATA VALIDATION

The GIS helped to identify some errors where the-catch position was incorrectly recorded or captured, e.g. when the given location was inland or outside the area covered by fishing vessels and surveys. Obvious

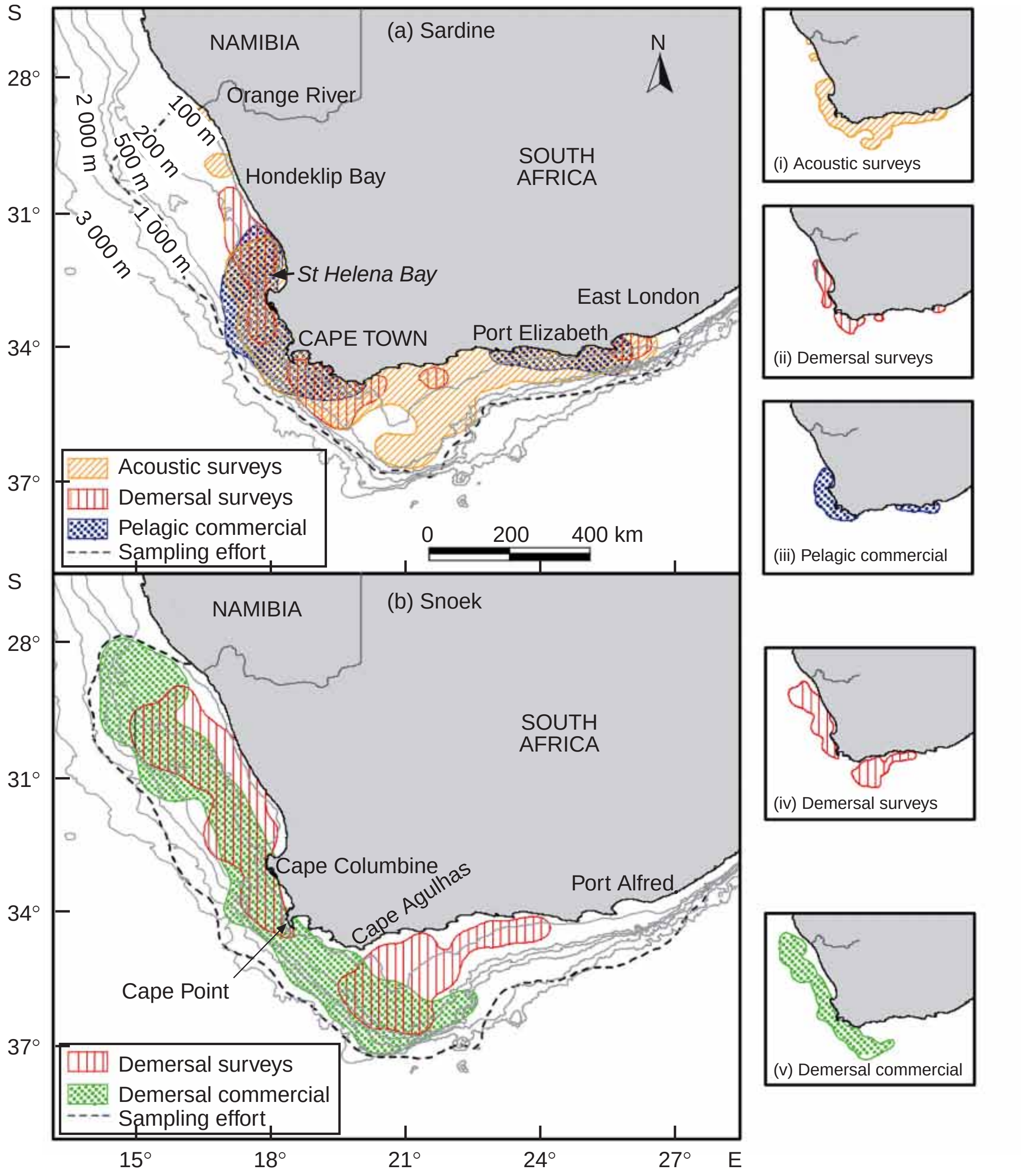

Fig. 2: Example of combination between different sources of data for mapping the distribution of fish species and the spatial extension of combined sampling efforts (offshore limit given by the dotted line) of (a) distribution of sardine from (i) acoustic surveys, (ii) demersal surveys, (iii) pelagic commercial fisheries and (b) distribution of snoek from (iv) demersal surveys and (v) demersal commercial fisheries

typing errors were corrected by tracking daily boat activity. When this was not possible, records were rejected. In addition, some source-specific data constraints/filters were applied.

- Every density estimate of the *acoustic surveys* of pelagic fish was considered. From the *demersal surveys* database, only trawls made south of the Orange River, with durations greater than 15 minutes, were

Table I: Summary of the different databases used to map the species distribution

Database	Time-series	Type and number of temporal units	Total number of samples used	Unit of abundance	Spatial resolution
Acoustic surveys	1988–2001	34 cruises	10 732 intervals	g m^{-2}	Latitude–longitude
Demersal surveys	1985–2002	45 cruises	3 920 trawls	kg 30 min^{-1}	5´ × 5´ cell
Pelagic commercial	1987–2001	15 years	102 974 sets	kg set^{-1}	10´ × 10´ cell
Demersal commercial	1985–2001	17 years	905 371 trawls	kg $hour^{-1}$	20´ × 20´ cell
Foreign tuna longline	1996–2001	6 years	17 569 sets	kg 1 000 $hooks^{-1}$	Latitude–longitude
South African tuna longline	1998–2001	4 years	2 318 sets	kg 1 000 $hooks^{-1}$	Latitude–longitude
Hake longline	1994–2001	8 years	11 404 sets	kg 1 000 $hooks^{-1}$	Latitude–longitude
Literature survey	–	–	–	Presence/absence	18´ × 15´ cell

considered. This threshold was applied to ensure that the gear was fully open and operational long enough to provide a representative sample. As a result of the exclusion of trawls north of the Orange River and trawls of short duration (<15 minutes), 87% of the demersal survey database could be used. Demersal catches of pelagic species (e.g. sardine and round herring) were included to increase temporal and spatial coverage for these species. In order for the survey data to be comparable with those from commercial fisheries (longline and trawl), it was necessary to pool data for the two hake species.

- For *pelagic commercial* data, given the patchiness of pelagic species distributions (Fréon and Misund 1999), the catch composition of adjacent grid-cells is not necessarily similar, as assumed in the current raw data processing by MCM. Because catch per species is recorded per trip (and not per set), it was necessary to select only those trips in which all set(s) were performed within a single grid cell. Extracted data constituted 58% of the pelagic commercial database.
- Different criteria were used to select data from the *demersal commercial* database. Trips north of the Orange River were not included in the dataset. Trawl duration had to be in the range 15–720 minutes (12 h) to avoid errors attributable to inconsistency of "am" and "pm" usage. The conservative cut-off limit of 720 minutes was chosen to be consistent with GLM analysis (Glazer 1999). Trawls were rejected when the total mass of the species under study was greater than the total catch or when the total catch was greater than 99 tons, which is the maximum capacity of the biggest trawl recorded in the database plus 10%, and also when the total catch per trawl was greater than the maximum capacity of the trawl for each boat plus 30%. To limit misrepresentation of relative abundance from catches, cells with >15 trawls were selected and cells were not considered where the average depth of the trawls was greater than the mean depth of the cells estimated from ETOPO2 (http://www.ngdc.noaa.gov/

Table II: Summary of the databases used for each species. Mean density and *cpue* are computed as the average of the mean *cpue* per grid cell, including zero values and considering the whole fished area, regardless of the distribution of the species

Group	Species	Acoustic surveys (mean density in g m^{-2})	Demersal surveys (mean *cpue* in kg h^{-1})	Pelagic commercial (mean catch in tons $year^{-1}$)	Demersal commercial (mean *cpue* in kg h^{-1})	Longline commercial (mean *cpue* in kg 1000 $hooks^{-1}$)	Literature survey (presence/ absence)
Small pelagic fish	Anchovy	15.5	6.5	150 000			x
	Sardine	11.8	62	42 000			x
	Round herring	9.5	72	32 000			x
	Chub mackerel		24	750			x
	Horse mackerel		345	4 500	128		x
Mesopelagic fish	Lanternfish		1	600			x
	Lightfish		0.5				x
Large pelagic fish	Albacore					80	
	Bigeye tuna					100	
	Yellowfin tuna					175	
	Silver kob		20.5				
	Snoek		37		47		x
Demersal fish	Cape hake		600		795	350	x
	Kingklip		18		22	19	x
Cephalopod	Chokka squid		10		3.3		

mgg/fliers/01mgg04.html) plus 1 000 m. As a result, 82% of the demersal commercial database was used.

- In terms of *longline commercial* information for hake, data were selected in which the number of hooks was equal to the number of baskets multiplied by the number of hooks per basket ±15%, in order to eliminate misreported or wrongly captured effort data. A catch per unit of effort (*cpue*) for hake and kingklip was calculated as kg 1 000 hooks^{-1}. Data with a *cpue* >15 000 kg 1 000 hooks^{-1} for hake and >1 000 kg 1 000 hooks^{-1} for kingklip were discarded. These arbitrary thresholds were chosen according to the maximum weight of hake and the fact that the kingklip *cpue* is lower than that of hake. Two types of location are provided in the hake longline data, the latitude and longitude at the start of the line, and the code of the cell of the demersal trawl commercial grid. Data were eliminated when these two locations did not match. Data that had obviously incorrect latitude and longitude from the tuna longline commercial database were also discarded. Tables I and II summarize the information provided by each database and the sources of data that were used for each species.

SPATIAL AND TEMPORAL RESOLUTION

For all databases, data were combined by month and by cell. The data could be conveniently divided into two semesters: April–September (Semester 1) and October–March (Semester 2) for almost all the databases, except for the demersal survey data. From 1991, demersal surveys only covered the West Coast during Semester 1, so species distribution of the two semesters for each data source were therefore compared individually. Two periods of study were chosen: pre-1989 (included) as Period 1 and post-1989 as Period 2. In order to overcome the bias related to changes in the sampling area over time, only the common sampled area (intersection) was used when comparing the two periods or semesters.

The temporal resolution was selected in order to provide satisfactory spatial coverage of the southern Benguela. Lower resolutions (quarterly and monthly) were envisaged, but they generated bias because the areas sampled were too small. The specific semesters were chosen to limit the effect of migration of juvenile pelagic fish in the southern Benguela, mostly during September and October (Crawford 1981a, b, c, Hampton 1987, Armstrong *et al*. 1991, Barange *et al*. 1999). The two periods were selected to correspond to those proposed by Shannon *et al*. (2003): the 1980s, characterized by a very high abundance of anchovy, and the 1990s, a period of increasing abundance of sardine.

As shown in Table I, the spatial units of the different data are not consistent. Therefore, all data were displayed on a 10´ × 10´ cell grid to allow for comparisons between the different sources of data. For each cell, the mean of the data located in it was aggregated for acoustic and demersal surveys. In order to obtain disaggregated 10´ × 10´ cells that were compatible with the other databases, each 20´ × 20´ grid-cell of the demersal commercial data grid was artificially split into four.

INDICES OF RELATIVE ABUNDANCE

The following method was applied for every database and every species: for each cell, an index I_j, which was considered to be an index of relative abundance for a given cell j, was calculated for the temporal resolution chosen. Each data component was weighted by the average value of each temporal unit (e.g. one experimental survey or one semester of commercial data) in order to give each temporal unit the same weight:

$$I_j = \frac{\sum_{i=1}^{p} \left(\frac{\bar{x}_{ij.}}{\bar{\bar{x}}_{i..}} \right)}{\sum_{i=1}^{p} n_{ij}} \tag{1}$$

with $$\bar{\bar{x}}_{i..} = \frac{\sum_{j=1}^{q} \bar{x}_{ij.}}{\sum_{j=1}^{q} n_{ij}}$$

and $$\bar{x}_{ij.} = \frac{\sum_{k=1}^{n_{ij}} x_{ijk}}{n_{ij}} ,$$

where x_{ijk} is the k^{th} *cpue* of year i and cell j, and n_{ij} is the number of observations for year i in cell j.

To prevent overestimating the spatial distribution of each species because of out-of-range or unusual catches, the observations were ranked by I_j, and records corresponding to 5% of the biomass in very low abundance areas were discarded. The different distributions obtained by different datasets for every species and temporal resolution were then displayed on the map.

INTERCALIBRATION AND COMBINATION OF THE DATASETS

Intercalibration of the different datasets was performed to obtain a general pattern of the spatial density of the different species. A reference source by species was initially chosen. Intersections between the reference dataset and all non-reference datasets were used to calibrate the indices of abundance of each species (Fig. 2). Among the common cells, those in which sampling effort was greater than the sampling median of each data source were selected (e.g. 10 intervals for acoustic surveys and 35 sets for pelagic commercial data). A proportional coefficient F between these relative abundance indices was computed using a regressive approach:

$$F = \frac{\bar{I}_{ref}}{\bar{I}_{non-ref}} \qquad (2)$$

where $\bar{I}_{ref}$ and $\bar{I}_{non-ref}$ are the means of abundance indices of the reference source and the non-reference source respectively.

Data of the non-reference sources were scaled by F. Data by species were weighted to keep their sum equal to 0.95 (taking into account that 95% of the total biomass by species was represented). The distributions of the biomass of each species, combining all data sources, were then mapped. The calibration factors used by species and data source are listed in Appendix 9.

In order to reflect the medium level of precision provided by the method described here, quartiles of the relative abundance of each species on the distribution maps were displayed, after several trials. Initially, a table was derived of frequency distribution of the cumulated relative abundance sorted in decreasing order. Four classes were then constructed: (i) high densities (0–25%), (ii) medium densities (25–50%), (iii) low densities (50–75%) and (iv) very low densities (75–95%), given that 95% of the biomass was represented.

The total area of distribution per species was calculated by summing the area of the cells where the species was present (junction). Because the relationship between latitude and distance is constant (1´ latitude = 1 nautical mile = 1.852 km), whereas that of longitude varies with the cosine of latitude (Raisz 1948) – 1´ longitude = 1´ latitude × cos(latitude) – the latitude of the centroid of a 10´ × 10´ cell was used to calculate its area A in km^2:

$$A = 18.52 \times (18.52 \times \cos \text{latitude}) \quad . \qquad (3)$$

RESULTS

The results of this study show that each source of information provides relevant, but incomplete, information on the distribution of a species. It is therefore necessary to combine different sources of data to obtain a realistic distributional range for each species (Fig. 3).

Comparison between Periods 1 and 2

The number of grid of cells sampled by pelagic and demersal commercial fisheries within the intersection sampled area remained constant over the two periods, but those sampled by acoustic and demersal surveys increased substantially (72 and 33% respectively, Table III). This was not because of any appreciable increase in sampling intensity per year, but rather to the fewer years and therefore surveys in Period 1; owing to the randomness of the sampling scheme, more surveys mean more sampled cells on the grid. Therefore, variations between the two periods have to be interpreted cautiously.

Data analysis on small pelagic species such as anchovy, anchovy, sardine and round herring suggest a subtantial

Table III: Variation between Period 1 (1985–1989) and Period 2 (1990–2002) of the surface (in %) of the sampling effort and the distribution ranges (limited to the common sampled area of the two periods) by database for 12 species from the southern Benguela

Group	Effort and species	Acoustic surveys	Demersal surveys	Pelagic commercial	Demersal commercial
	Effort	+71.6	+32.9	+4.0	0
Small pelagic fish	Anchovy	+84.4	+126.4	+1.6	
	Sardine	+193.1	+125.2	+60.3	
	Round herring	+122.9	+95.2	+72.1	
	Chub mackerel		+65.7	–38.4	
	Horse mackerel		+40.1	+34.2	+31.6
Mesopelagic fish	Lanternfish		+7.5	+148.2	
	Lightfish		–43.0		
Large pelagic fish	Silver kob		–3.3		
	Snoek		–14.0		+0.2
Demersal fish	Cape hake		+7.7		+6.2
	Kingklip		+39.0		+2.6
Cephalopod	Chokka squid		–2.1		–10.6

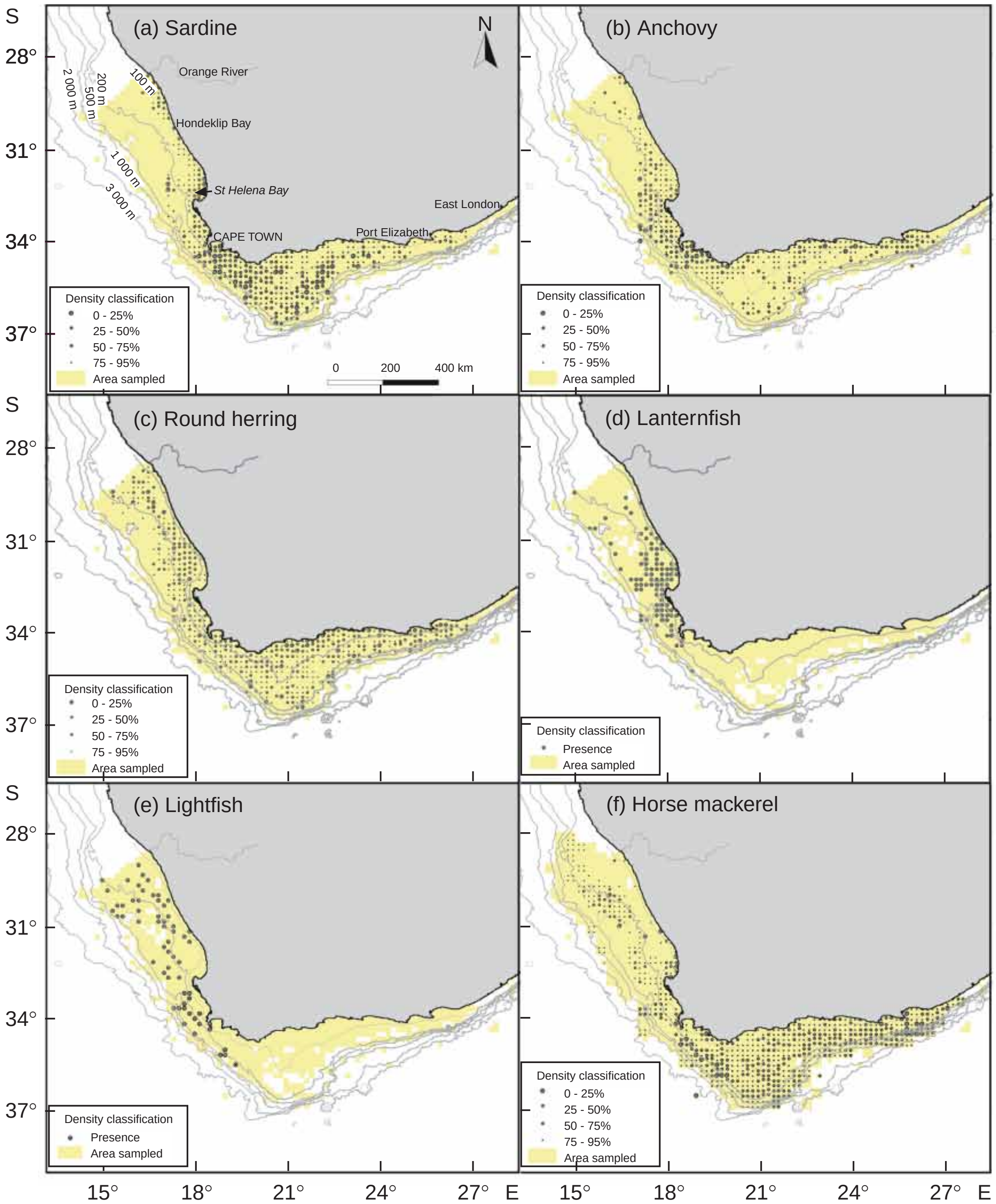

Fig. 3: Distribution maps of (a) sardine, (b) anchovy, (c) round herring, (d) lanternfish (presence/absence only), (e) lightfish (presence/absence only), (f) horse mackerel, (g) chub mackerel, (h) chokka squid, (i) kingklip, (j) hake, (k) silver kob, (l) snoek, (m) albacore, (n) bigeye tuna, (o) yellowfin tuna after combination of all data sources and represented by class (high densities (0–25% of the total biomass), medium densities (25–50%), low densities (50–75%) and very low densities (75–95%), given that 95% of the biomass has been represented. The sampled areas are also shown

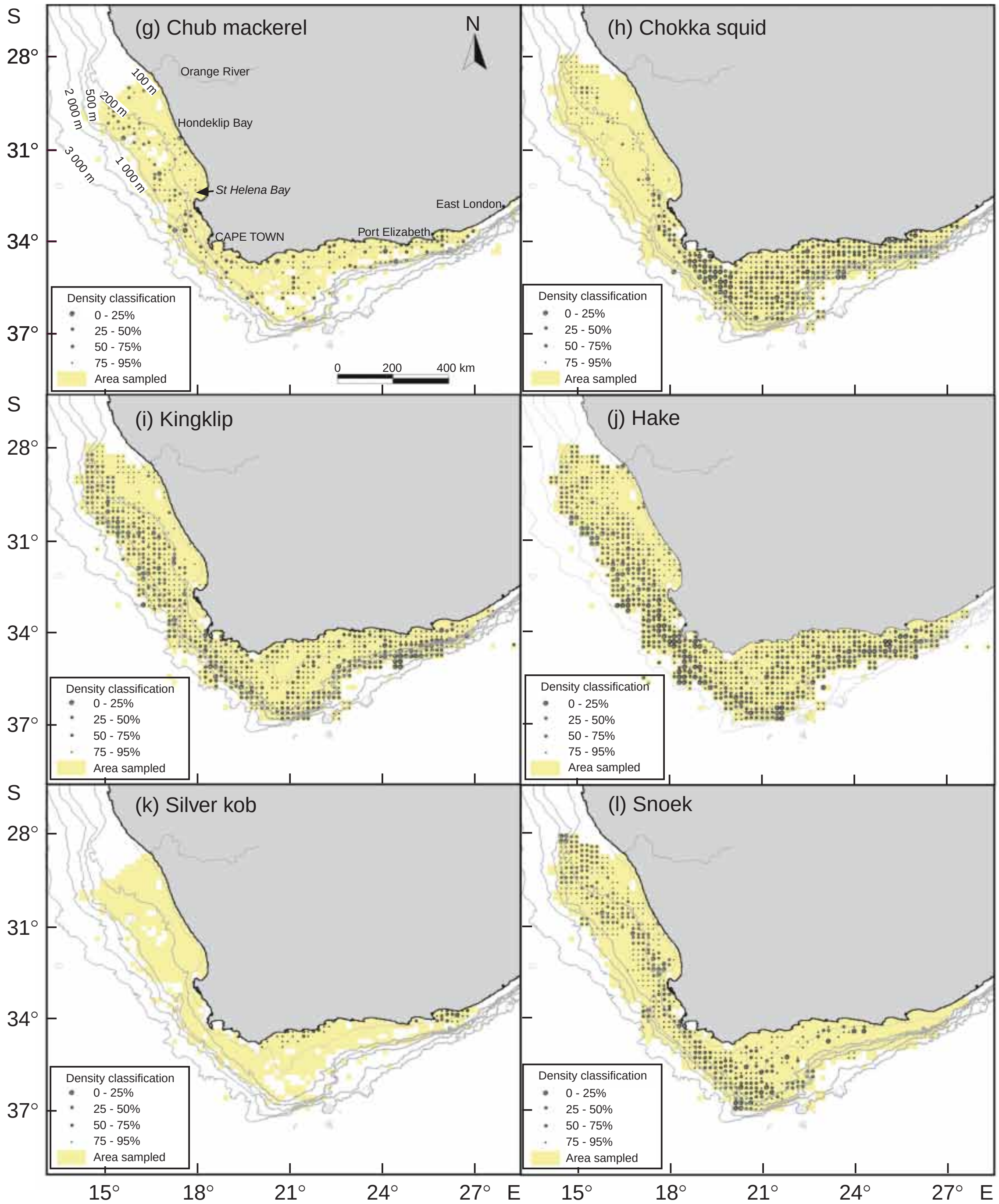

Fig. 3: *(continued)*

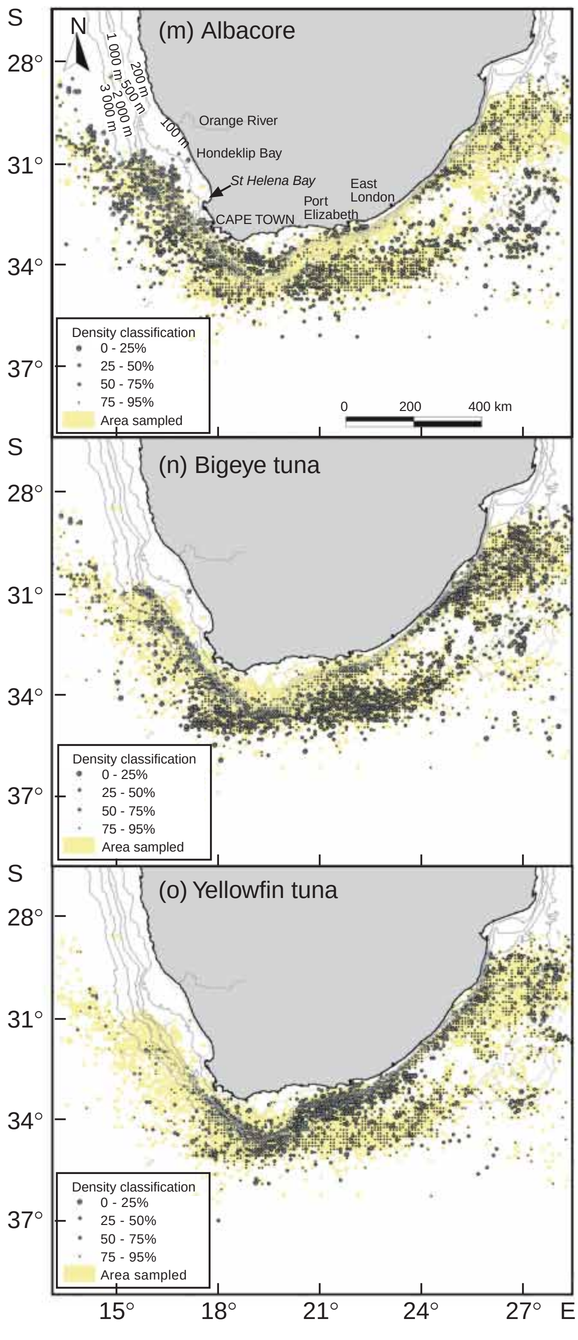

Fig. 3: *(continued)*

increase in distribution ranges between Periods 1 and 2 for acoustic and demersal surveys (Table III), a result confirmed by the pelagic commercial data for sardine and round herring, but not for anchovy. Horse mackerel distribution appears to have increased by about 35% between the two periods. Demersal survey and commercial data suggest that there was only a small decrease in snoek and chokka squid distribution and a small increase in hake distribution between the two periods. There is a large increase in area of distribution between the two periods for kingklip, but it is only indicated by the demersal survey database (Table III).

Comparison between Semesters 1 and 2

The number of grid cells sampled by the pelagic and demersal fisheries (within the intersection sampled area) and, to a lesser extent, by the hake longline fishery are comparable between the two semesters. In contrast, from Semester 1 to Semester 2 the number of grid cells sampled by the tuna longline commercial data is halved, and that of the acoustic surveys increased by 74%. This is mainly because of the difference in areas covered by the May recruitment survey (coastal only) and the more extensive November spawner biomass survey. It was therefore difficult to quantify the real differences between the two semesters for those two databases.

Both acoustic survey and pelagic commercial data show a consistent decrease within their common sampled areas between Semesters 1 and 2 for anchovy and sardine (Table IV). Tuna longline and demersal commercial data also show a substantial decrease of tuna and snoek distribution ranges respectively between the two semesters. For horse mackerel, the pelagic fishery data indicate a substantial decrease in distributional range between the two semesters. This decrease, however, is not confirmed by the demersal fishery data, which suggest a small increase.

Both acoustic survey and pelagic commercial data show a consistent broadening of round herring distribution within their common sampled areas between the semesters. Pelagic and demersal commercial data indicate a substantial increase in the distributional range of lanternfish and chokka squid respectively. The pelagic commercial data show a large increase in chub mackerel distributional range (Table IV).

Comparison with maps derived from a literature survey

Comparison between maps drawn from the literature and indicating presence/absence of a species (Shin *et*

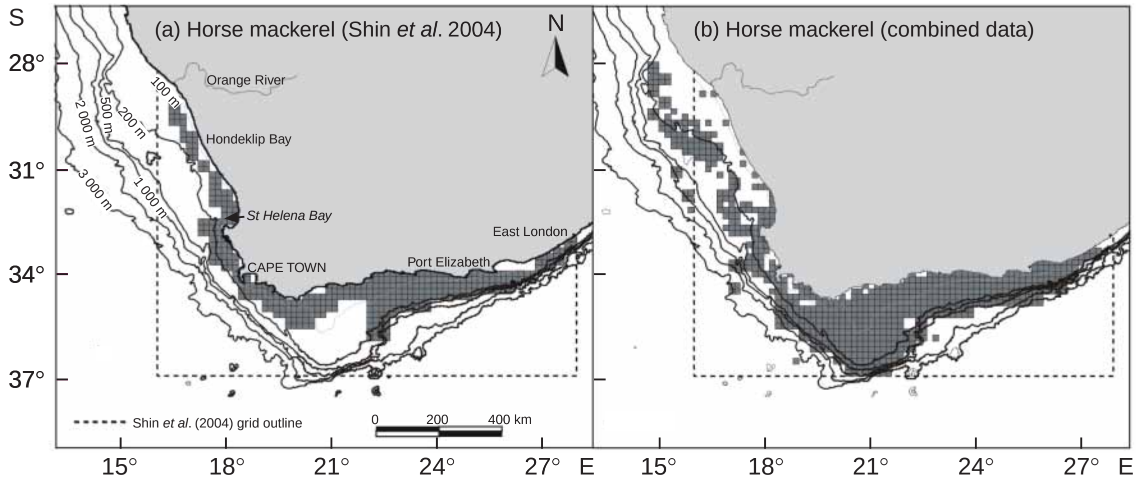

Fig. 4: Distribution of horse mackerel from (a) literature survey (Shin *et al.* 2004) and (b) after combination of all data sources

al. 2004) and those drawn from other databases allow validation of the current method. This comparison (Table V) shows that there is a good match between these two types of maps, especially regarding small pelagic and demersal species. However, the distribution maps resulting from a combination of different databases show a generally broader distribution of the species than those derived from the literature survey (Fig. 4). The only exceptions are for the two mesopelagic species, for which there is no satisfactory database covering their distribution.

DISCUSSION

Heterogeneity and effectiveness of data sources

Research surveys provide accurate data to estimate the spatial and density distributions of most abundant commercial species, notably because their spatial coverage is relatively good and the data are calibrated to reflect actual biomass. In contrast, the spatial coverage of commercial landings data is patchy and being

Table IV: Variation between Semester 1 (April–September) and Semester 2 (October–March) of the surface (in %) of the sampling effort and the distribution ranges (limited to the common sampled area of the two semesters) by database for 14 species from the southern Benguela

Group	Effort and species	Acoustic surveys	Pelagic commercial	Demersal commercial	Tuna longline	Hake longline
	Effort	+73.7	–5.2	0	–53.2	+24.4
Small pelagic fish	Anchovy	–1.7	–14.2			
	Sardine	–4.2	–11.6			
	Round herring	+14.1	+11.2			
	Chub mackerel		+114.1			
	Horse mackerel		–34.8	+2.8		
Mesopelagic fish	Lanternfish		+22.6			
Large pelagic fish	Albacore				–27.2	
	Bigeye tuna				–20.2	
	Yellowfin tuna				–18.8	
	Silver kob					
	Snoek			–12.5		
Demersal fish	Cape hake			+4.5		+2.0
	Kingklip			–14.5		+3.5
Cephalopod	Chokka squid			+22.3		

Table V: Comparison between maps obtained from a literature survey (Shin *et al.* 2004) and from the combination of surveys and commercial data (MCM databases). Data outside the literature survey grid were not consider here

Species	Literature survey/ combined data (%)	Comments
Anchovy	83	Good matching. Combined data show a more inshore distribution on the West Coast, a more offshore distribution over the Agulhas Bank and a farther east distribution on the South Coast
Sardine	112	Good matching. Combined data show a gap over the central part of the Agulhas Bank
Round herring	99	Very good matching
Chub mackerel	134	Combined data show a more offshore patchy distribution and a larger but still patchy distribution all along the South Coast
Horse mackerel	61	Combined data indicate a more extended distribution over the Agulhas Bank
Lanternfish	387	Very few survey or commercial data
Lightfish	474	Very few survey or commercial data
Snoek	64	Combined data indicate a more extended distribution northwards and over the Agulhas Bank
Cape hake	73	Good matching. Combined data indicate a more extended distribution northwards and eastwards
Kingklip	77	Good global matching despite local discrepancies, combined data indicate a more extended distribution over the shelf edge

uncalibrated, do not reflect true biomass. The principal limitation for the use of survey data is the limited number of surveys carried out per year. Also, in terms of the South African acoustic surveys, upgrading of the Simrad EK400 echo-sounder system, which was used to estimate acoustic back-scattering strength up to 1997, to the EK500 echo-sounder, had consequences for the measurement of pelagic fish density. An intercalibration study showed that, owing to receiver saturation in the EK400 system, the density of most pelagic schools would have been underestimated prior to 1997 (Barange *et al*. 1999). This saturation effect was much larger for sardine schools than for those of anchovy and round herring. Nonetheless, the method used in the present study should not be too sensitive to those changes because the same weighting was given to every survey.

Commercial data provide large quantities of daily data over the entire year. The presence of uncalibrated data was the main problem encountered in this study. Filtration of the commercial data resulted in substantial elimination of data and there was difficulty in selecting objective thresholds for effort, maximum weight and maximum *cpue*. Furthermore, data from the midwater trawl fishery are recorded in the same database as the bottom trawl fishery, because a trawler can easily switch between the two types of gear, and the same vessels (and companies) are involved in both fisheries. Therefore, no distinction was made between these two gear types in the analysis.

Spatial coverage of the commercial pelagic fishery was also problematic, because vessels fish on aggregations closest to their home ports to save fuel and to lower costs. The major commercial species (in terms of mass) is anchovy, so purse-seiners may have to travel farther to catch that species if they are not available close to port. Quotas for sardine were limited during most of the study period, so the absence of catches from an area cannot be interpreted as indicative of an absence of sardine. A vessel may simply have steamed past the sardine if it had no sardine quota. Therefore, commercial catches and effort reflect neither the full geographical range of the species nor the areas of highest abundance. The demersal fishery, however, operates all along the South African coast, although effort is obviously concentrated where demersal species are most abundant and trawling grounds are more clement.

The distribution of anchovy, sardine and round herring were mapped by combining three sources of data; densities (acoustic surveys), mean *cpue* (demersal surveys) and mean catches per set (commercial data). Demersal survey data were useful for sardine and round herring (mean *cpue* was relatively high at 62 and 72 kg h^{-1} respectively; Table II, Appendix 3), because this might provide information on the distribution of large fish located close to the seabed. Nonetheless, some of these pelagic species were possibly caught while the trawl was being retrieved and when the net meshes collapsed on the surface. Furthermore, extrusion through the meshes when the nets are distended and before they are masked by bigger catches of larger fish may well have resulted in an undersample of pelagic species in the demersal survey data.

Horse mackerel is a target species of both demersal and pelagic fisheries. For this species, it was therefore useful to employ demersal commercial and survey data that had relatively similar mean *cpue* (Table II, Appendices 3 and 5) and pelagic commercial data that provided inshore information to obtain the widest sampled area. The maps are likely to underestimate the distributions of chub mackerel and round herring, which are known to range offshore beyond the area sampled by the pelagic fishery and scientific surveys.

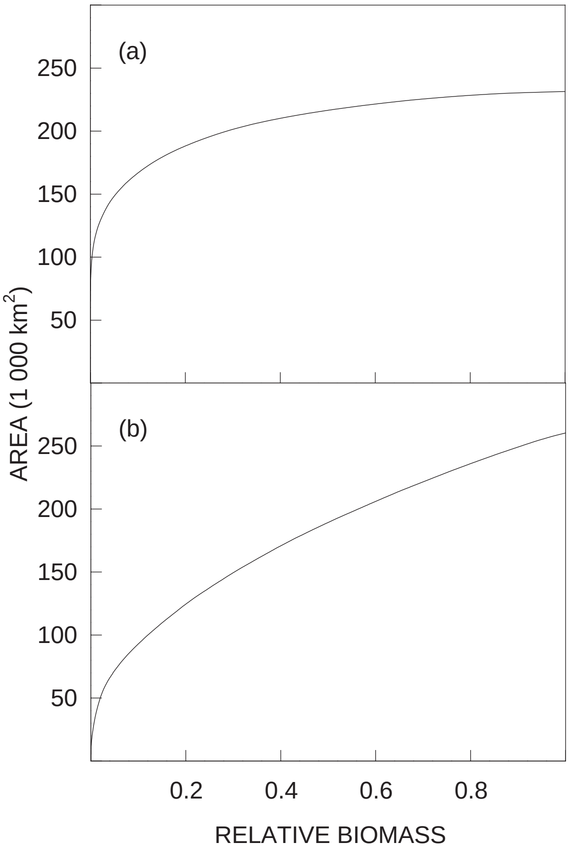

Fig. 5: Area of distribution as a function of the relative biomass of (a) sardine and (b) hake, derived from MCM acoustic surveys and the demersal commercial database

It appears that neither the demersal surveys nor the pelagic fishery provide representative geographical distributions for mesopelagic lanternfish and lightfish, because these small species escape through the codend used during demersal surveys and are not targeted by the pelagic fishery. Indeed, their mean *cpue* on demersal surveys was <1 kg h^{-1}, with the exception of one cruise in 2000 by a vessel using a small (8 mm) mesh codend (Table II, Appendices 2 and 3). Furthermore, the pelagic fishery caught <600 tons year^{-1} of lanternfish during the period 1987–2001 (Appendix 4), whereas its biomass was estimated to be in the order of one million tons during the same period (Shannon *et al*. 2003).

Foreign and experimental tuna longline fisheries yielded comparable mean *cpue*s for each of the three tuna species (Appendices 7 and 8). Consequently, the two datasets were combined to provide average *cpue* values of 175, 100 and 80 kg 1 000 hooks^{-1} for yellowfin tuna, bigeye tuna and albacore respectively. Demersal commercial and survey data were useful in mapping the distribution of snoek, because their mean *cpue*s were similar. Despite snoek being an important species in the handline fishery (Griffiths 2002), data for that fishery were not available, nor were they for the chokka squid and jig fisheries. Such data would be expected to improve the accuracy of the distribution maps for snoek and chokka squid, but for inshore only. According to Griffiths (1996, 1997, 2000a), there are three stocks of silver kob along the South Coast. The demersal survey data facilitated representation of the distribution of two of them (Fig. 3k), the third one being located in an untrawlable zone in False Bay.

Demersal survey and commercial data yielded similar mean *cpue*s for hake (795 and 600 kg h^{-1} respectively) and for kingklip (22 and 18 kg h^{-1}; Appendices 3 and 5). Longline catch rates of kingklip were low (19 kg 1 000 hooks^{-1} vs 350 kg 1 000^{-1} hooks for hake; Appendix 6). Longline fisheries data are very useful, because they are not influenced by rough seabed, as is the case for trawl fishing, and they map the distributions of larger hake.

In conclusion, none of the available data sources covered the whole distribution of any species, so it was necessary to combine data sources. Nevertheless, given the variability in accuracy and precision of the different data series and in some cases their limited coverage in space and time, there is still some uncertainty associated with the distribution ranges determined.

Methodology

Ideally, the spatial resolution selected should be related to the temporal resolution: the appropriate spatial resolution should match the mean area covered by the movements of an individual of the most mobile of the 15 species during a single unit of time. This was not possible here for practical reasons and because fish behaviour was largely ignored for most of the species under study.

The indices of abundance used are affected by biases in space and time owing to fish behaviour, fisher strategy, technological improvements, etc. (Fréon and Misund 1999). For example, the catch per set is an index of school size that only partly reflects abundance. Major differences in catchability among species might influence the distribution maps presented as well as the calculation of abundance indices. For instance, Age 0 fish may, depending on the species, be poorly represented relative to their absolute abundance

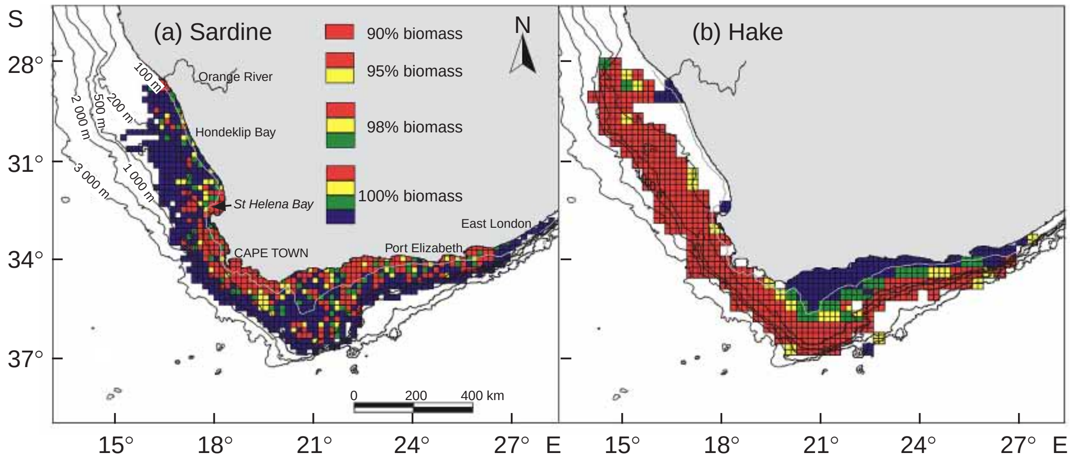

Fig. 6: Distribution of (a) sardine (using MCM acoustic surveys only) and (b) hake (using demersal commercial database only) according to the percentage of biomass represented

(Murawski and Finn 1988). Furthermore, the data are not standardized in all commercial data-bases.

To obtain a representative distribution for a species, it was decided early on not to map 100% of the biomass. However, it was not possible to determine a threshold beyond which the distribution area was not significantly modified. Furthermore, the situation varies markedly among the different species. For example, pelagic species such as sardine showed a plateau in the area versus biomass relationship (Fig. 5a), whereas the relationship was more linear for hake (Fig. 5b), suggesting the use of a lower threshold than for sardine. The choice to represent 95% of the biomass was arbitrary and this threshold may therefore be too conservative. Perhaps future work should consider 98 or 99% of the biomass as a threshold (Fig. 6) and, for different purposes, analyse the distribution of the remaining 1 or 2% of outliers. Some of them are obviously the consequence of misreporting or misidentification of species, but in some cases, fish may have been carried beyond their normal range by exceptional environmental conditions that might result in mortality.

The number of common cells used to calculate the coefficient F between two databases was selected arbitrarily, but a significant relationship could not be found between the two databases considered. Owing to time constraints, preliminary attempts to use a General Linear Model to calibrate the data were not pursued. Nonetheless, this preliminary work showed a linear (but insignificant) relationship between the different indices of abundance provided by the different data sources. The mean ratio F was used to intercalibrate the different databases and so to combine them, because the error on F was expected to be <2 and therefore to have a limited impact on the distributions. It was assumed that the classification of these data by quartile reflected this level of error.

Despite these limitations, the results clearly indicate that, for nearly all species, more realistic distribution maps were obtained by combining several databases than by using a single database. Of course, it may be argued that a major assumption of the survey technique is that the entire population is contained within the surveyed region and therefore that there is no need to combine survey data with commercial data, which only represent the higher concentrations or the fishable biomass closest to port. To counter that argument, three points need to be made. First, commercial data can increase the quality of the coverage within the main area of a species' distribution without causing an overestimation of the density within fishing areas resulting from the method used. Second, the use of different fishing gears (purse-seine, midwater trawl, bottom trawl, longline) limits the bias attributable to selectivity in overlapping areas between the coverage of different databases. Third, a potential bias may result from considering only survey data when there are fish outside the fishing grounds and when some cells are undersampled or not properly sampled (gear selectivity) by the surveys in those regions. Therefore, any resulting distorted distribution will still be more accurate than if only surveys are used. A method to address the problem of undersampled areas is to perform kriging on the maps. That was not carried out for this study because such data manipulation is highly sensitive to the parameterization through which gaps could be filled in areas where there were actually no fish (e.g. sardine in the central part of the Agulhas Bank).

Interpretation

CHANGES BETWEEN THE TWO PERIODS

Shannon *et al*. (2003) compared the functioning of the southern Benguela in the 1980s and the period 1990–1997 using trophic flows, comparing the anchovy-dominated system of the 1980s with that of the 1990s when sardine biomass and, to a lesser extent, round herring and horse mackerel biomass, was increasing. The present study has demonstrated an extended distribution for sardine, round herring, horse mackerel and hake, concurring with conclusions of Shannon *et al*. (2003) as well as MCM acoustic survey data. However, the results here show an increase in anchovy distribution range, which coincides with the increase in anchovy biomass in the late 1990s. Barange *et al*. (1999) concluded that a decrease in anchovy biomass was related to a decrease in its distribution, but that for sardine it may be reflected in the densities of the schools. However, for the current study the two periods (1980s and 1990s) were unbalanced in terms of data availability, more acoustic and demersal survey data being available for the second period. Because the distribution of pelagic fish is very patchy, the probability of recording pelagic fish in a particular cell increases with increasing numbers of acoustic transects or trawls passing through that cell. Therefore, the broader distribution recorded here for the second period could partly be the result of the increased number of acoustic and demersal surveys undertaken then. Use of a larger spatial scale would be more appropriate in that case, a choice also justified by the high mobility of pelagic species.

However, changes in the distribution between the two periods shown by the pelagic commercial data are in agreement with survey data for sardine, round herring and horse mackerel, although the first dataset does not suffer from the same bias as survey data, because the sampled area did not change much between the two periods (Table III). The extension to the sardine distribution during Period 2, shown by both surveys and commercial data, could be related to the generally perceived increase in sardine abundance then (Barange *et al*. 1999, Beckley and van der Lingen 1999, Shannon *et al*. 2003). Nonetheless, the commercial data might suffer from two opposing biases when used to estimate the distribution area. The increase in quotas for this species from the mid 1980s is likely to favour extension of targeted effort on the South Coast, whereas during that period of high abundance, the commercial fleet would likely find fishable quantities closer to their home port. Therefore, one would expect a decrease in sardine distribution estimated from commercial datasets compared with the previous period, when sardine were scarce and the vessels would have had to search farther from port. However, because the survey data indicate a larger increase in sardine distribution between the two periods than the commercial data do, the second bias may be small. For anchovy, the fact that the total area fished did not change between the two periods may indicate that the range of this species did not change much.

DIFFERENCES BETWEEN THE TWO SEMESTERS

The area surveyed acoustically and sampled by the pelagic fishery in both semesters is inshore, mainly on the West Coast. The decrease of anchovy and sardine distribution (limited to the common area sampled during the two semesters) could be attributable to the southward migration of juvenile pelagic fish between the two semesters (Crawford 1981a, b, Hampton 1987, Armstrong *et al*. 1991, Barange *et al*. 1999). This is not the case for round herring, however, although juveniles also migrate southwards (Crawford 1981c). Such lack of change for round herring is likely because the pelagic fishery targets mainly adult round herring, almost exclusively on the West Coast between Cape Point and Cape Columbine.

The seasonal differences in horse mackerel distribution observed in the pelagic and commercial fisheries (Table IV) likely occur because the pelagic fishery takes mainly 0-year old fish at the start of the season, mostly on the West Coast as a bycatch in the anchovy fishery, whereas the demersal fishery takes adults, which do not display such strongly seasonal migratory patterns (Barange *et al*. 1998).

The decrease in tuna distribution between Semesters 1 and 2 could also be interpreted as a northward spawning migration of pre-adults and adults; they spawn during summer in tropical waters (Colette and Nauen 1983, Kroese 2000a, b, c). The same fishing gear delimits different distribution areas around southern Africa for albacore, bigeye tuna and yellowfin tuna. These distribution patterns generally agree with studies on worldwide distributions of the same species based on longline gear (Fonteneau 1997).

Although handline catch and effort data for snoek were not available for this study, the broader Semester 1 distribution depicted by the trawl databases is believed to be realistic, because snoek move offshore (200–450 m depth) to spawn in July and remain there until October (Griffiths 2000b, 2002), i.e. three months in Semester 1 and one month in Semester 2.

No appreciable changes were found in the distribution of demersal species between the two semesters, in accordance with the statement of Payne (1995), who found no evidence of longshore migration patterns for demersal species such as Cape hake off South Africa. The present findings, however, could be a result of the lack of discrimination between adults and juveniles in the datasets. Le Clus *et al*. (2002) proposed a migration of *M. capensis* between the West and South coasts, based on different size-classes of *M. capensis* examined from demersal surveys. Furthermore, *M. paradoxus* occurs off Namibia apparently as a non-spawning population (Burmeister in press), indicating that most of the spawning of that species takes place on the Agulhas Bank. This would infer alongshore spawning migration by this species.

COMPARISON WITH LITERATURE SURVEY MAPS

Many fish studies have been conducted in the southern Benguela (Moloney *et al*. 2004), and it is possible to find detailed information on the distribution of some key species. The comparison between literature survey maps and combined data maps limited to the cell grid domain used by Shin *et al.* (2004) showed that usually the same features are found in both types of map. However, except for mesopelagic fish and chub mackerel, the present results showed more extended distributions.

Some of the differences between these maps are the result of the low spatial resolution of the demersal commercial data (20´ × 20´), which in turn are limited by the length of an individual trawl track (10.5 miles for a tow of 3 h). The continental shelf on the West Coast is narrow and some cells cover the entire shelf edge (500 – 2 000 m). As a result, the distribution areas of the species caught in those cells will be extended over the 2 000 m isobath and will thus often be overestimated.

Mesopelagic fish populations on the West Coast, although only lightly exploited, play an important role in the foodweb of the southern Benguela, particularly as a link between zooplankton and Cape hake (Jarre-Teichman *et al*. 1998). It was not possible to draw a representative distribution of these species, which are distributed widely in the southern Benguela (Prosch 1986, Prosch *et al*. 1995), because of a lack of relevant data. For snoek, the combined data map indicates that its real distribution could extend southwards and offshore, as described by Griffiths (2002): snoek are found as far east as Algoa Bay, near Port Elizabeth, from the surface to 550 m deep. The distributions of demersal species extended farther northwards for the combined data than for the literature survey, indicating that the stocks could be contiguous with stocks in Namibian waters. This may result from low densities not being represented in literature survey maps.

The method used in this study has interesting prospects for the determination of density distributions of marine species by combining both commercial and survey data in a GIS. Using the distribution maps for 15 key species of the southern Benguela with quantitative data is the first step of a species interactions study that includes a spatial dimension. The study will help to identify and describe interactions among species (Drapeau *et al*. 2004), which is one of the priorities in building a scientific basis for incorporating ecosystem considerations into fisheries management (FAO 2003).

ACKNOWLEDGEMENTS

This work is a contribution to the joint South – African/ French programme IDYLE, which involves the Institut de Recherche pour le Développement, France, Marine and Coastal Management (MCM), and the University of Cape Town. We specially thank the following MCM staff members: Lynne Shannon and Carl van der Lingen for their enormous help in the interpretation of the data; Dagmar Merckle, Mark Prowse, Johan Rademan and Jan van der Westhuizen who provided access to the pelagic survey and commercial databases; Jean Glazer and Frances Le Clus for information from the demersal database; Liesl Janson and Chris Wilke for handline and tuna database information; Pheby Mullins for hake longline database information and Leroux Kloppers for numerous extractions of the demersal commercial databases. We also thank Alieya Haider and Adrienne Melzer from the MCM library, Cathy Boucher, Tony van Dalsen, Megan Terry and Million Ghirmay for their assistance, and Larry Hutchings for his valuable comments on an early version of the manuscript.

LITERATURE CITED

ANON. 2001 — *Fishing Industry Handbook. South Africa, Namibia and Moçambique*, 29th ed. Cape Town; George Warman: 448 pp.

ARMSTRONG, M. J., BERRUTI, A. and J. COLCLOUGH 1987 — Pilchard distribution in South African waters, 1983–1985. In *The Benguela and Comparable Ecosystems*. Payne, A. I. L., Gulland, J. A. and K. H. Brink (Eds). *S. Afr. J. mar. Sci.* **5**: 871–886.

ARMSTRONG, M. J., JAMES, A. G. and E. S. VALDÉS SZEIN-

FELD 1991 — Estimates of annual consumption of food by anchovy and other pelagic fish species off South Africa during the period 1984–1988. *S. Afr. J. mar. Sci.* **11**: 251–266.

BADENHORST, A. and M. J. SMALE 1991 — The distribution and abundance of seven commercial trawlfish from the Cape south coast of South Africa, 1986–1990. *S. Afr. J. mar. Sci.* **11**: 377–393.

BARANGE, M., HAMPTON, I. and B. A. ROEL 1999 — Trends in the abundance and distribution of anchovy and sardine on the South African continental shelf in the 1990s, deduced from acoustic surveys. *S. Afr. J. mar. Sci.* **21**: 367–391.

BARANGE, M., PILLAR, S. C. and I. HAMPTON 1998 — Distribution patterns, stock size and life-history strategies of Cape horse mackerel *Trachurus trachurus capensis*, based on bottom trawl and acoustic surveys. In *Benguela Dynamics: Impact of Variability on Shelf-Sea Environments and their Living Resources*. Pillar, S. C., Moloney, C. L., Payne, A. I. L. and F. A. Shillington (Eds). *S. Afr. J. mar. Sci.* **19**: 433–447.

BECKLEY, L. E. and C. D. VAN DER LINGEN 1999 — Biology, fishery and management of sardines (*Sardinops sagax*) in southern African waters. *Mar. Freshwat. Res.* **50**: 955–978.

BURMEISTER, L. (in press) — Is there one stock of *Merluccius paradoxus* in the Benguela region? *Afr. J. mar. Sci.* **27**.

CARR, M-E. 2002 — Estimation of potential productivity in eastern boundary currents using remote sensing. *Deep-Sea Res.* **49**: 59–80.

COLLETTE, B. B. and C. E. NAUEN 1983 — F.A.O. species catalogue. 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. *FAO Fish. Synop.* **125**: 137 pp.

CRAWFORD, R. J. M. 1981a — Distribution, availability and movements of anchovy *Engraulis capensis* off South Africa, 1964–1976. *Fish. Bull. S. Afr.* **14**: 51–94.

CRAWFORD, R. J. M. 1981b — Distribution, availability and movements of pilchard *Sardinops ocellata* off South Africa, 1964–1976. *Fish. Bull. S. Afr.* **14**: 1–46.

CRAWFORD, R. J. M. 1981c — Distribution, availability and movements of round herring *Etrumeus teres* off South Africa, 1964–1976. *Fish. Bull. S. Afr.* **14**: 141–181.

DRAPEAU, L., PECQUERIE, L., FRÉON, P. and L. J. SHANNON 2004 — Quantification and representation of potential spatial interactions in the southern Benguela ecosystem. In *Ecosystem Approaches to Fisheries in the Southern Benguela*. Shannon, L. J., Cochrane, K. L. and S. C. Pillar (Eds). *Afr. J. mar. Sci.* **26**: 141–159.

FAO 2003 — Fisheries Management 2. The ecosystem approach to fisheries. *FAO Technical Guideline for Responsible Fisheries.* **4**(Suppl. 2). Rome; FAO: 112 pp.

FRÉON, P. and O. A. MISUND 1999 — *Dynamics of Pelagic Fish Distribution and Behaviour: Effects on Fisheries and Stock Assessment*. Oxford; Fishing News Books: 348 pp.

FONTENEAU, A. 1997 — *Atlas of Tropical Tuna Fisheries: World Catches and Environment*. Paris; ORSTOM Editions: 192 pp.

GLAZER, J. P. 1999 — The application of general linear modelling methods to estimate trends in abundance of the hake and rock lobster stocks off South Africa. M.Sc. thesis, University of Cape Town: 329 pp.

GRIFFITHS, M. H. 1996 — Age and growth of South African silver kob *Argyrosomus inodorus* (Sciaenidae), with evidence for separate stocks. *S. Afr. J. mar. Sci.* **17**: 37–48.

GRIFFITHS, M. H. 1997 — The life history and stock separation of silver kob, *Argyrosomus inodorus*, in South African waters. *Fishery Bull., Wash.* **95**(1): 47–67.

GRIFFITHS, M. H. 2000a — *Argyrosomus inodorus.* In *Southern African Marine Linefish Status Reports.* Mann, B. Q. (Ed.). *Spec. Publ. Oceanogr. Res. Inst. S. Afr.* **7**: 77–78.

GRIFFITHS, M. H. 2000b — *Thyrsites atun.* In *Southern African Marine Linefish Status Reports.* Mann, B. Q. (Ed.). *Spec. Publ. Oceanogr. Res. Inst. S. Afr.* **7**: 40–41.

GRIFFITHS, M. H. 2002 — Life history of South African snoek *Thyrsites atun* (Pisces: Gempylidae): a pelagic predator of the Benguela ecosystem. *Fishery Bull., Wash.* **100**: 690–710.

HAMPTON, I. 1987 — Acoustic study on the abundance and distribution of anchovy spawners and recruits in South African waters. In *The Benguela and Comparable Ecosystems*. Payne, A. I. L., Gulland, J. A. and K. H. Brink (Eds). *S. Afr. J. mar. Sci.* **5**: 901–917.

HAMPTON, I. 1992 — The role of acoustic surveys in the assessment of pelagic fish resources on the South African continental shelf. In *Benguela Trophic Functioning*. Payne, A. I. L., Brink, K. H., Mann, K. H. and R. Hilborn (Eds). *S. Afr. J. mar. Sci.* **12**: 1031–1050.

HARRIS, T. F. W., LEGECKIS, R. and D. VAN FORE[E]ST 1978 — Satellite infra-red images in the Agulhas Current system. *Deep-Sea Res.* **25**(6): 543–548.

HUTCHINGS, L., BECKLEY, L. E., GRIFFITHS, M. H., ROBERTS, M. J., SUNDBY, S. and C. VAN DER LINGEN 2002 — Spawning on the edge: spawning grounds and nursery areas around the southern African coastline. *Mar. Freshwat. Res.* **53**: 307–318.

JARRE-TEICHMANN, A., SHANNON, L. J., MOLONEY, C. L. and P. A. WICKENS 1998 — Comparing trophic flows in the southern Benguela to those in other upwelling ecosystems. In *Benguela Dynamics: Impacts of Variability on Shelf-Sea Environments and their Living Resources*. Pillar, S. C., Moloney, C. L., Payne, A. I. L. and F. A. Shillington (Eds). *S. Afr. J. mar. Sci.* **19**: 391–414.

JOLLY, G. M. and I. HAMPTON 1990 — A stratified random transect design for acoustic surveys of fish stocks. *Can. J. Fish. aquat. Sci.* **47**(7): 1282–1291.

KROESE, M. 2000a — *Thunnus alalunga.* In *Southern African Marine Linefish Status Reports.* Mann, B. Q. (Ed.). *Spec. Publ. Oceanogr. Res. Inst. S. Afr.* **7**: 103–104.

KROESE, M. 2000b — *Thunnus albacares.* In *Southern African Marine Linefish Status Reports.* Mann, B. Q. (Ed.). *Spec. Publ. Oceanogr. Res. Inst. S. Afr.* **7**: 105–106.

KROESE, M. 2000c — *Thunnus obesus.* In *Southern African Marine Linefish Status Reports.* Mann, B. Q. (Ed.). *Spec. Publ. Oceanogr. Res. Inst. S. Afr.* **7**: 107–108.

LE CLUS, F., LESLIE, R. W and R. F. OSBORNE 2002 — Spatial and temporal trends in length-dependent distribution of shallow-water Hake, *Merluccius capensis*, based on bottom trawl surveys. *Abstracts of the Southern African Marine Science Symposium, July 2002, Swakopmund, Namibia*: p. 55.

LUTJEHARMS, J. R. E. 1981 — Features of the southern Agulhas Current circulation from satellite remote sensing. *S. Afr. J. Sci.* **77**(5): 231–236.

MOLONEY, C. L., VAN DER LINGEN, C. D., HUTCHINGS, L. and J. G. FIELD 2004 — Contributions of the Benguela Ecology Programme to pelagic fisheries management in South Africa. In *Ecosystem Approaches to Fisheries in the Southern Benguela*. Shannon, L. J., Cochrane, K. L. and S. C. Pillar (Eds). *Afr. J. mar. Sci.* **26**: 37–51.

MURAWSKI, S. A. and J. T. FINN 1988 — Biological bases for mixed-species fisheries: species co-distribution in relation to environmental and biotic variables. *Can. J. Fish. aquat. Sci.* **45**: 1720–1735.

PAYNE, A. I. L. 1995 — Cape hakes. In *Oceans of Life off Southern Africa*, 2nd ed. Payne, A. I. L. and R. J. M. Crawford (Eds). Cape Town; Vlaeberg: 136–147.

PAYNE, A. I. L., AUGUSTYN, C. J. and R. W. LESLIE 1985 —

Biomass index and catch of Cape hake from random stratified sampling cruises in Division 1.6 during 1984. *Colln scient. Pap. int. Commn SE. Atl. Fish.* **12**(2): 99–123.

PENVEN, P., ROY, C., BRUNDRIT, G. B., COLIN de VERDIÈRE, A., FRÉON, P., JOHNSON, A. S., LUTJEHARMS, J. R. E. and F. A. SHILLINGTON 2001 — A regional hydrodynamic model of upwelling in the southern Benguela. *S. Afr. J. Sci.* **97**: 472–475.

PROSCH, R. M. 1986 — The biology, distribution and ecology of *Lampanyctodes hectoris* and *Maurolicus muelleri* along the South-African coast. M.Sc. thesis, University of Cape Town: viii + 197 pp.

PROSCH, R. M., HULLEY, P. A. and R. A. CRUICKSHANK 1995 — Mesopelagic fish and some other forage species. In *Oceans of Life off Southern Africa*, 2nd ed. Payne, A. I. L. and R. J. M. Crawford (Eds). Cape Town; Vlaeberg: 130–135.

PUNT, A. E. and D. W. JAPP 1994 — Stock assessment of the kingklip *Genypterus capensis* off South Africa. *S. Afr. J. mar. Sci*. **14**: 133–149.

RAISZ, E. 1948 — *General Cartography*. New York; McGraw–Hill: 54–62.

SHANNON, L. J., MOLONEY, C. L., JARRE, A. and J. G. FIELD 2003 — Trophic flows in the southern Benguela during the 1980s and the 1990s. *J. mar. Syst.* **39**: 83–116.

SHIN, Y-J. 2000 — Interactions trophiques et dynamiques des populations dans les écosystèmes marins exploités. Approche par modélisation individus-centrée. Ph. D. thesis, Université Denis Diderot, Paris: 245 pp.

SHIN, Y-J., SHANNON, L. J. and P. M. CURY 2004 — Simulations of fishing effects on the southern Benguela fish community using an individual-based model: learning from a comparison with ECOSIM. In *Ecosystem Approaches to Fisheries in the Southern Benguela*. Shannon, L. J., Cochrane, K. L. and S. C. Pillar (Eds). *Afr. J. mar. Sci.* **26**: 95-114.

SHIN, Y-J. and P. CURY 2001 — Exploring fish community dynamics through size-dependent trophic interactions using a spatialized individual-based model. *Aquat. Living Resour.* **14**: 65–80.

APPENDIX 1

Description of the acoustic surveys, 1988–2001 (MCM, unpublished data)

Cruise	Year	Start	End	Region	Start Location	End Location	Survey name
Afr 065	1988	27 Jun.	18 Jul.	West Coast	Cape Frio	Cape Agulhas	Anchovy recruitment
Afr 068	1988	18 Nov.	13 Dec.	Entire coast	Hondeklip Bay	Port Elizabeth	Anchovy/sardine spawner stock
Afr 073	1989	8 Jun.	22 Jun.	West Coast	Lüderitz	Cape Agulhas	RSA anchovy recruitment
Afr 078	1989	7 Nov.	30 Nov.	Entire coast	West Coast (31°N)	Port Alfred	Pelagic fish biomass
Afr 081	1990	5 May	15 May	West Coast	West Coast	Cape Agulhas	Early anchovy recruitment
Afr 083	1990	21 Jun.	4 Jul.	West Coast	Orange River	Cape Agulhas	Anchovy recruitment
Afr 087	1990	6 Nov.	30 Nov.	Entire coast	West Coast (30°N)	Port Alfred	Pelagic fish biomass
Afr 090	1991	6 Mar.	18 Mar.	West Coast	Orange River	Cape Columbine	Pelagic pre-recruit and mesopelagic
Afr 092	1991	7 May	24 May	West Coast	Orange River	Cape Infanta	anchovy/sardine recruitmant
Afr 097	1991	7 Nov.	3 Dec.	Entire coast	West Coast (32°N)	Port Elizabeth	Pelagic fish biomass
Afr 103	1992	12 May	28 May	West Coast	Orange River	Cape Infanta	Anchovy/sardine recruitment
Afr 108	1992	5 Nov.	2 Dec.	Entire coast	Hondeklip Bay	Port Elizabeth	Pelagic spawner biomass
Afr 112	1993	18 May	3 Jun.	West Coast	Orange River	Cape Infanta	Anchovy/sardine recruitment
Alg 002	1993	6 Aug.	18 Aug.	West Coast	27´30°S (North of Lüderitz)	Cape Point	Anchovy/sardine recruitment
Afr 117	1993	9 Nov.	3 Dec.	South Coast	Cape Columbine	Port Alfred	Pelagic spawner biomass
Afr 121	1994	3 May	27 May	West Coast	Lüderitz	Cape Infanta	Anchovy/sardine recruitment
Afr 126	1994	11 Nov.	7 Dec.	South Coast	Cape Columbine	Port Alfred	Pelagic spawner biomass
Alg 023	1995	2 Jun.	23 Jun.	Entire coast	Orange River	Port Alfred	Anchovy/sardine recruitment
Alg 030	1995	20 Oct.	1 Nov.	Entire coast	Hondeklip Bay	Cape Point	Pre-spawner biomass
Afr 132	1995	13 Nov.	4 Dec.	South Coast	Cape Point	Port Alfred	Pelagic spawner biomass
Alg 039	1996	3 Jun.	25 Jun.	Entire coast	Orange River	Port Elizabeth	Anchovy/sardine recruitment
Alg 044	1996	17 Oct.	28 Oct.	West Coast	Hondeklip Bay	Cape Point	Pre-spawner biomass
Afr 137	1996	21 Oct.	3 Nov.	South Coast	Cape Point	Mossel Bay	South Coast spawner biomass
Alg 045	1996	3 Nov.	16 Nov.	South Coast	Mossel Bay	Port Alfred	South Coast spawner biomass
Afr 145	1997	15 May	31 May	West Coast	Orange River	Cape Infanta	Anchovy/sardine recruitment
Afr 148	1997	28 Oct.	6 Dec.	Entire coast	Hondeklip Bay	Port Alfred	Pelagic spawner biomass
Alg 056	1998	18 May	10 June	Entire coast	Orange River	Port Alfred	Anchovy/sardine recruitment
Alg 060	1998	3 Nov.	7 Dec.	Entire coast	Hondeklip Bay	Mossel Bay	Pelagic spawner biomass
Afr 153	1999	7 May	2 Jun.	Entire coast	Orange River	Port Alfred	Anchovy/sardine recruitment
Alg 068	1999	1 Nov.	6 Dec.	Entire coast	Hondeklip Bay	Port Alfred	Pelagic spawner biomass
Alg 074	2000	4 May	30 May	Entire coast	Orange River	Port Alfred	Anchovy/sardine recruitment
Alg 087	2000	1 Nov.	6 Dec.	Entire coast	Hondeklip Bay	Port Alfred	Pelagic spawner biomass
Alg 095	2001	3 May	30 May	Entire coast	Orange River	Port Alfred	Anchovy/sardine recruitment
Alg 099	2001	19 Oct.	31 Oct.	Entire coast	Hondeklip Bay	Cape Point	Pelagic spawner biomass

APPENDIX 2

Description of the demersal surveys, 1985–2002 (MCM, unpublished data). The survey NAN04 is not included in the table and was not taken into account owing to a different encoding system in the database

Cruise	Year	Start	End	Region	Survey name
A028	1985	7 Jan.	30 Jan.	West Coast	Demersal biomass
A033	1985	1 Jul.	21 Jul.	West Coast	Demersal biomass
A039	1986	8 Jan.	5 Feb.	West Coast	Demersal biomass
A046	1986	1 Jul.	24 Jul.	West Coast	Demersal biomass
A048	1986	12 Sep.	3 Oct.	South Coast	Demersal biomass
A050	1987	6 Jan.	31 Jan.	West Coast	Demersal biomass
A054	1987	16 Jun.	10 Jul.	West Coast	Demersal biomass
A056	1987	8 Sep.	5 Oct.	South Coast	Demersal biomass
A059	1988	2 Feb.	24 Feb.	West Coast	Demersal biomass
A063	1988	10 May	3 Jun.	South Coast	Demersal biomass
A066	1988	1 Aug.	26 Aug.	West Coast	Demersal biomass
A069	1989	5 Jan.	6 Feb.	West Coast	Demersal biomass
A072	1989	10 May	31 May	South Coast	Demersal biomass
A075	1989	14 Jul.	16 Aug.	West Coast	Demersal biomass
A079	1990	5 Jan.	28 Jan.	West Coast	Demersal biomass
A082	1990	23 May	13 Jun.	South Coast	Demersal biomass
A084	1990	11 Jul.	6 Aug.	West Coast	Demersal biomass
A086	1990	7 Sep.	2 Oct.	South Coast	Demersal biomass
A088	1991	7 Jan.	28 Jan.	West Coast	Demersal biomass
A093	1991	7 Jun.	1 Jul.	South Coast	Demersal biomass
A095	1991	12 Sep.	3 Oct.	South Coast	Demersal biomass
A096	1991	14 Oct.	28 Oct.	South Coast	Pilot horse mackerel
A100	1992	v6 Feb.	3 Mar.	West Coast	Demersal biomass
A102	1992	31 Mar.	22 Apr.	South Coast	Demersal biomass
A106	1992	2 Sep.	24 Sep.	South Coast	Demersal biomass
A109	1993	19 Jan.	12 Feb.	West Coast	Demersal biomass
A111	1993	15 Apr.	12 May	South Coast	Demersal biomass
A116	1993	1 Sep.	30 Sep.	South Coast	Inshore biomass and horse mackerel
A118	1994	4 Jan.	26 Jan.	West Coast	Demersal biomass
A122	1994	6 Jun.	5 Jul.	South Coast	Demersal biomass
A125	1994	21 Sep.	18 Oct.	South Coast	Inshore biomass and horse mackerel
A127	1995	6 Jan.	3 Feb.	West Coast	Demersal biomass
A129	1995	22 Apr.	19 May	South Coast	Demersal biomass
C131	1995	28 Sep.	19 Oct.	South Coast	Demersal biomass
C133	1996	12 Jan.	4 Feb.	West Coast	Demersal biomass
C135	1996	10 Apr.	2 May	South Coast	Demersal biomass
C139	1997	8 Jan.	3 Feb.	West Coast	Demersal biomass
C144	1997	14 Apr.	8 May	South Coast	Demersal biomass
C150	1999	11 Jan.	3 Feb.	West Coast	Demersal biomass
C152	1999	8 Apr.	8 Apr.	South Coast	Demersal biomass
NAN01	2000	19 Jan.	15 Feb.	West Coast	Demersal biomass
NAN03	2000	28 Apr.	17 May	West Coast	Gear trials
C160	2001	27 Aug.	21 Sep.	South Coast	Demersal biomass
C165	2002	7 Jan.	7 Feb.	West Coast	Demersal biomass

APPENDIX 3

Average *cpue* by species and by demersal survey, 1985–2002 (MCM, unpublished and filtered data)

Cruise	Number of trawls	Average *cpue* (kg h^{-1})												
		Anchovy	Sardine	Round herring	Chub mackerel	Horse mackerel	Lantern-fish	Light-fish	Silver kob	Snoek	Deep-water hake	Shallow-water hake	Kingklip	Chokka squid
A028	96	0	1.1	177.2	2.5	40.6	6.0	4.0		26.8	304.0	172.7	28.6	10.6
A033	77	0	0.8	31.3	18.8	90.2		1.2		68.1	363.6	231.2	13.2	11.2
A039	91	28.5	0.3	45.6	34.9	21.9	3.2	0.7		50.5	385.8	189.2	10.2	10.4
A046	85	0.4	3.4	10.0	16.3	56.1	0.5	0.3		65.9	318.0	207.2	8.8	5.9
A048	80	0.1	1.4	1.6	20.1	181.3			19.7	19.0	132.8	210.6	35.5	8.7
A050	90	0.2	0.4	32.9	13.4	44.2	1.0	0.3		33.0	478.7	131.3	6.2	8.3
A054	75	2.0	7.7	59.4	81.0	122.6	0.2	0.2		44.0	361.1	141.4	15.2	4.8
A056	88	1.5	76.1	8.8	45.8	613.3			28.9	15.1	196.3	247.0	17.4	13.5
A059	91	11.8	0.7	61.8	2.2	87.3	4.5	0.8		39.2	217.6	100.0	13.8	8.0
A063	93	24.8	2.8	38.9	10.6	267.0			6.0	6.2	265.6	284.3	12.3	7.2
A066	86	4.2	186.1	35.2	12.7	75.1	0.3	0.1		52.5	370.0	78.0	5.1	2.7
A069	27	4.0	0.2	92.3	7.7	56.5	0.9	0.1		109.6	1 309.9	305.3	32.0	3.4
A072	62	0.8	10.1	52.3	17.0	352.2			15.2	25.5	24.5	329.7	18.1	17.2
A075	86	0	38.2	197.0	30.3	73.6	1.0	0.2		41.2	710.0	358.1	4.7	5.6
A079	83	3.6	0.6	91.2	6.2	111.2	1.8	0.4		18.2	533.9	512.2	10.3	5.7
A082	58	1.3	0.7	7.3	0.9	253.2			29.0	8.2	332.3	451.6	15.6	7.1
A084	89	0.2	79.6	82.4	2.6	169.6	0.9	0.2		61.7	464.2	244.3	5.2	11.6
A086	78	2.0	91.6	19.8	5.2	1 008.8			22.0	24.9	245.7	352.7	4.0	15.4
A088	111	1.0	0.7	165.5	7.6	82.9	1.0	0.5		38.7	557.8	120.7	8.9	4.6
A093	89	0.1	2.3	23.0	4.1	772.2	0		45.0	75.7	194.6	447.8	15.9	18.5
A095	75	0.2	1.0	3.0	5.2	1 092.6			14.3	11.8	0	205.1	6.6	25.5
A096	6	0				0					0	0		
A100	105	59.0	1.0	110.3	1.4	129.4	1.0	0.3		24.2	395.7	149.6	17.5	2.9
A102	84	14.2	23.3	108.6	11.4	602.5		0	29.4		231.3	233.5	7.8	13.1
A106	87	13.8	90.7	28.6	27.2	771.8			18.0	6.3	0	250.9	7.6	12.4
A109	87	7.9	6.3	107.3	17.6	385.8	1.1	0.1		14.6	419.1	106.0	23.2	2.5
A111	111	24.7	19.7	209.8	24.4	670.6	0	0	10.9	0.6	703.4	104.1	29.0	20.0
A116	107	2.8	1.4	39.5	9.8	602.5			29.7	23.8	93.0	110.2	10.6	19.4
A118	104	1.2	1.1	65.7	3.3	311.3	0.6	0.1		81.2	270.1	92.2	18.7	4.7
A122	87	2.1	0.9	25.5	69.1	611.3	0		27.6	239.6	431.9	111.9	107.3	18.7
A125	95	0.6	103.5	6.3	23.0	804.8			23.9	18.2	842.0	146.6	5.7	15.2
A127	124	1.3	50.8	382.4	21.0	224.9	1.2	0		41.4	484.1	219.6	17.7	2.6
A129	94	1.3	33.1	23.0	150.6	362.9			22.2	2.8	252.9	181.0	46.6	16.2
C131	96	2.3	276.9	89.7	27.9	518.7			41.2	16.5	43.6	195.8	4.7	17.4
C133	96	0.1	23.7	60.5	11.6	486.9	0.4	0.1		22.3	522.1	101.3	23.0	10.1
C135	78	30.4	12.6	40.8	153.5	534.9			1.8	6.9	288.8	174.9	7.8	18.8
C139	97	0	0.6	36.5	6.2	148.2	0.9	0.1		38.9	742.8	269.4	13.9	5.0
C144	101	5.0	142.2	32.7	40.4	435.6			4.4	4.9	719.8	148.1	15.5	7.4
C150	89	0	1.2	19.7	8.2	208.1	2.3	0.1		72.9	637.9	239.0	25.3	5.5
C152	82	1.5	104.6	107.3	42.5	640.8			10.0	0.6	1 883.4	235.3	29.8	14.4
NAN01	102	1.2	64.7	167.1	3.5	38.0	181.7	2.8		21.9	335.6	261.4	21.3	2.5
NAN03	87	21.5	26.6	35.1	35.1	470.7		0.1	11.9	8.9	70.0	180.0	18.2	7.6
C160	85	8.0	1 172.1	13.5	3.0	511.8			20.4	23.4	100.7	208.9	7.3	8.7
C165	110	8.9	1.3	154.1	8.4	180.7	0.5			39.8	436.7	168.2	22.9	8.1
Total or mean	3 824	6.5	61.9	72.1	24.3	346.0	8.4	0.5	20.5	36.8	392.7	204.6	17.9	10.2

APPENDIX 4

Catches of the pelagic commercial purse-seine fleet, 1987–2001 (MCM, unpublished and filtered data)

Year	Number of boats	Number of sets	Catch (thousand tons)					
			Anchovy	Sardine	Round herring	Chub mackerel	Horse mackerel	Lanternfish
1987	88	11 111	354.40	15.23	23.29	0.53	1.74	0.01
1988	102	13 630	362.19	17.56	46.01	0.20	4.35	0.07
1989	105	7 206	182.00	15.32	28.87	0.20	15.53	2.96
1990	105	4 308	83.75	20.60	26.08	0.01	2.64	0.23
1991	93	4 327	94.91	19.23	19.63	4.68	0.33	0.23
1992	87	7 788	205.93	18.46	28.33	0.15	1.05	0.46
1993	88	6 219	135.43	18.24	34.67	0.16	4.81	0.63
1994	87	4 858	87.58	35.60	31.39	1.11	4.43	0.63
1995	85	6 778	102.92	57.24	46.31	1.27	0.66	0.53
1996	87	3 770	22.71	47.23	25.72	0.44	9.17	0.02
1997	84	5 041	34.44	60.59	52.75	2.16	4.90	0.09
1998	85	5 044	58.58	66.21	31.67	0.03	13.03	3.16
1999	96	6 637	110.45	66.24	31.41	0.26	1.09	0.12
2000	95	7 159	176.95	66.70	20.98	0.01	2.80	0.20
2001	93	9 098	182.93	109.18	32.54	0.08	0.64	0.04
Total or mean	92	102 974	146.34	42.24	31.98	0.75	4.48	0.62

APPENDIX 5

Average *cpue* of the demersal commercial fleet, 1985–2001 (MCM, unpublished and filtered data)

Year	Number of trawls	Average depth per trawl (m)	Average duration per trawl (minutes)	*Cpue* (kg h^{-1})				
				Horse mackerel	Snoek	Cape hake	Kingklip	Chokka squid
1985	40 685	237	185	70.86	34.15	958.17	26.09	5.41
1986	60 607	227	190	103.71	35.53	759.17	18.45	4.42
1987	45 733	250	187	123.49	45.24	796.38	16.92	3.87
1988	58 471	213	188	120.9	67.01	640.59	12.59	4.71
1989	52 572	216	183	95.37	66.34	800.92	15.41	7.15
1990	54 359	213	181	173.69	73.59	757.52	10.98	4.06
1991	56 286	232	169	216.06	84.28	836.65	14.57	3.68
1992	57 529	231	173	235.52	60.97	741.38	15.45	1.96
1993	57 393	242	172	209.42	61.94	830.44	18.33	2.67
1994	57 306	238	168	107.35	41.22	794.88	19.16	3.53
1995	55 333	243	167	80.45	47.76	845.67	30.43	0.00
1996	56 819	255	171	106.62	31.83	871.34	26.09	0.04
1997	61 508	259	167	95.45	41.34	697.36	20.84	2.67
1998	57 243	254	164	108.87	46.91	781.86	24.33	3.61
1999	47 913	268	166	105.79	31.65	841.48	32.62	3.65
2000	42 633	262	170	129.43	6.93	759.38	28.95	2.25
2001	42 981	279	172	98.89	19.52	784.72	34.46	2.26
Total or mean	905 371	242	175	128.35	46.84	793.99	21.51	3.29

APPENDIX 6

Average *cpue* of the hake-directed longline fishery, 1994–2001 (MCM, unpublished and filtered data)

Year	Number of sets	Average number of hooks	*Cpue* (kg 1 000 hooks^{-1})	
			Hake	Kingklip
1994	746	6 300	257.3	24.0
1995	446	5 600	289.2	34.8
1996	1 639	5 800	400.6	20.7
1997	2 105	5 600	314.0	19.5
1998	703	7 700	399.3	22.1
1999	2 139	6 800	440.9	17.6
2000	1 935	8 200	404.5	15.1
2001	1 691	8 800	359.8	11.5
Total or mean	11 404	7 000	349.5	19.3

APPENDIX 7

Average *cpue* of the foreign tuna longline fleet fishing in South African waters, 1996–2001 (MCM, unpublished and filtered data)

Year	Number of boats	Number of sets	Average hooks number	*Cpue* (kg 1 000 hooks^{-1})		
				Albacore	Yellowfin	Bigeye
1996	38	779	2 800	161.8	96.9	78.6
1997	93	3 848	2 600	90.4	130.0	125.4
1998	91	4 218	2 700	96.0	124.5	117.3
1999	83	2 673	2 600	62.8	299.7	67.2
2000	91	4 057	2 700	69.9	149.7	95.1
2001	63	1 994	2 900	107.8	148.5	98.0
Total or mean	77.5	17 569	2 700	98.1	158.2	96.9

APPENDIX 8

Average *cpue* of the South African experimental tuna longline fishery, 1998–2001 (MCM, unpublished and filtered data)

Year	Number of boats	Number of sets	Average hooks number	*Cpue* (kg 1 000 hooks^{-1})		
				Albacore	Yellowfin	Bigeye
1998	17	266	880	14.0	135.4	90.9
1999	15	335	1 300	38.2	224.7	79.2
2000	19	901	1 600	94.3	268.5	168.1
2001	20	816	1 300	106.2	130.1	70.9
Total or mean	17.8	2 318	1 270	63.2	189.7	102.3

APPENDIX 9

Calibration factors used to combine all data sources by species

Species	Reference data	Median	Calibrated data	Median	Cells in common	Cells selected	Calibration factor *F*
Anchovy	Acoustic surveys	10 stations	Demersal surveys	5 trawls	36	25	0.121
Anchovy	Acoustic surveys	10 stations	Pelagic commercial	35 sets	74	63	0.319
Sardine	Acoustic surveys	10 stations	Pelagic commercial	35 sets	113	73	0.745
Sardine	Acoustic surveys	10 stations	Demersal surveys	5 trawls	49	34	0.220
Round herring	Acoustic surveys	10 stations	Pelagic commercial	35 sets	63	53	0.278
Round herring	Acoustic surveys	10 stations	Demersal surveys	5 trawls	135	73	0.587
Chub mackerel	Demersal surveys	5 trawls	Pelagic commercial	35 sets	13	9	0.159
Horse mackerel	Demersal surveys	5 trawls	Pelagic commercial	35 sets	9	5	0.388
Horse mackerel	Demersal surveys	5 trawls	Demersal commercial	175 trawls	195	91	1.567
Lanternfish	Demersal surveys	5 trawls	Pelagic commercial	35 sets	10	7	2.615
Snoek	Demersal surveys	5 trawls	Demersal commercial	175 trawls	111	23	1.549
Cape hake	Demersal surveys	5 trawls	Demersal commercial	175 trawls	257	88	1.636
Cape hake	Demersal surveys	5 trawls	Hake longline	3 sets	170	64	0.845
Kingklip	Demersal surveys	5 trawls	Hake longline	3 sets	95	43	1.002
Kingklip	Demersal surveys	5 trawls	Demersal commercial	175 trawls	189	70	2.182
Chokka squid	Demersal surveys	5 trawls	Demersal commercial	175 trawls	201	95	1.156