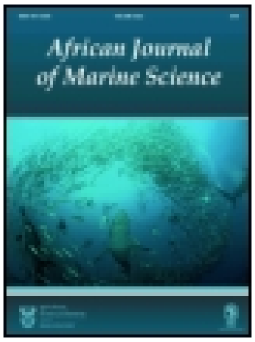

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Quantifying commercial catch and effort of monkfish *Lophius vomerinus* and *L. vaillanti* off Namibia

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QUANTIFYING COMMERCIAL CATCH AND EFFORT OF MONKFISH *LOPHIUS VOMERINUS* AND *L. VAILLANTI* OFF NAMIBIA

L. MAARTENS and A. J. BOOTH†*

Abundance and exploitation patterns of monkfish *Lophius vomerinus* and *L. vaillanti* were investigated for use as inputs into a stock assessment framework to be used for management of the Namibian monkfish resource. Total numbers of monkfish caught per size-class were estimated using industry records of tail products classified into six commercial categories. The proportions per category varied each year. Analysis of the commercial data suggests that large numbers of juvenile monkfish are harvested annually. Catch-per-unit-effort (*cpue*) data of vessels targeting monkfish and sole (the two species are combined in terms of Namibian fleet legislation) for the period 1991–1999 were analysed using two different methods to construct indices of abundance. Both indices, one standardized on vessel horsepower and the other standardized by means of a Generalized Linear Model, showed an increase in catch rate of monkfish from 1991 to 1994 and between 1996 and 1998, but a decline from 1994 to 1996 as well as during 1999. Conversion factors for landed or tail weight to whole weight for four different tail products of monkfish were estimated. Results obtained from the study suggest that the factor of 3.04 currently applied in Namibia to all tail-weight classes is not appropriate for the current fishery and needs to be amended. For management purposes it is also suggested that four different conversion factors, one for each monkfish tail product, be implemented.

Key words: catch per unit effort, Generalized Linear Model, *Lophius vaillanti, Lophius vomerinus,* monkfish, weight conversion factors

The fishery for monkfish *Lophius vomerinus* and *L. vaillanti* is an important component of the demersal fishery in Namibia, landings in 1998 totaling almost 17 000 tons and contributing N$119 million (= US$19.8 million in 1998) in export value (Ministry of Fisheries and Marine Resources, Namibia, unpublished data). *L. vomerinus* is the more abundant of the two species, contributing approximately 94% to the total Namibian landings of monkfish. The species extends from northern Namibia (21°S) to Durban, South Africa (30°S, 31°E; Leslie and Grant 1990). *L. vaillanti* is found north of Walvis Bay (23°S). Both are demersal species and inhabit areas from the subtidal zone to depths of more than 600 m (Fig. 1).

Catch statistics for Namibian monkfish date back to 1974. Total catches recorded for the various international fleets fishing off Namibia and published by the International Commission for the Southeast Atlantic Fisheries (ICSEAF) between 1974 and 1989 reveal a peak in excess of 14 000 tons (1981 and 1982), but then a decline to 6 000 tons in 1989. In view of the escalating commercial importance of monkfish, ICSEAF recommended in 1982 that efforts be made to collect data for stock assessment purposes (Anon. 1982a). Catch data reported for ICSEAF Divisions 1.4 (20–25°S) and 1.5 (25–30°S) were given as bycatch of the hake (*Merluccius* spp.) fishery (Anon. 1982b). In 1984, Spain reported catches of two species in their surveys, *L. upsicephalus, sensu lato L. vomerinus* in coastal waters 100–500 m deep and *L. vaillanti* in waters deeper than 400 m (Anon. 1982b).

Since Namibian Independence in 1990 and with the departure of foreign vessels from Namibian waters, annual monkfish catches initially decreased to approximately 1 500 tons in 1990, but then increased to >12 000 tons in 1994. Subsequently, monkfish catches decreased to around 10 000 tons during the period 1995–1997. Record catches of almost 17 000 tons were recorded during 1998, decreasing to 16 000 tons in 1999 (Fig. 2).

Historically, monkfish have contributed an important bycatch to the hake fishery. Because of increasing market demand and the subsequent escalation of its economic value, a monkfish-directed fishery developed. Fishing rights to catch monkfish and sole *Austroglossus microlepis* (the two species are combined in terms of Namibian fleet legislation) with a hake bycatch quota were implemented in 1994. The fishery for monkfish is currently managed through effort con-

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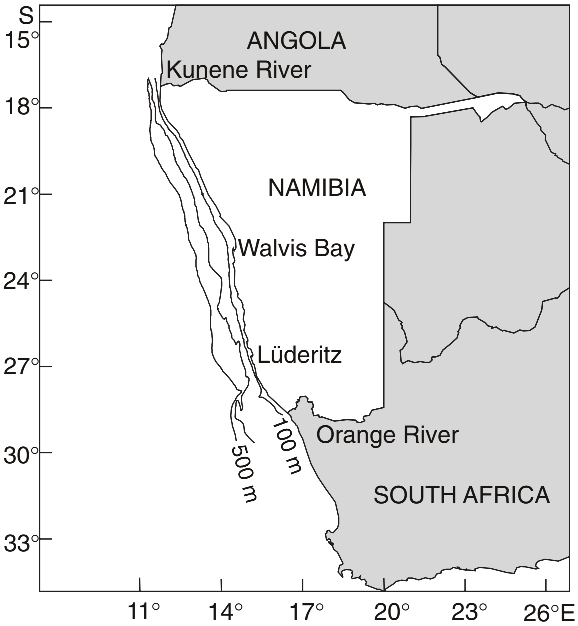

Fig. 1: Map of the study area. The distribution of monkfish off Namibia extends between the Kunene and Orange rivers from 100 to 700 m deep

trol, with limited access and a restriction of 800 h.p. on vessels. These rights expired at the end of the year 2000 for 13 vessels in the fleet, but five vessels can utilize the right until 2003. The number of licensed vessels fishing for monkfish and sole has remained fairly constant, ranging between 15 in 1991 and 18 in 1999 (Table I). Codend mesh sizes range between 75 and 110 mm.

Monkfish are still caught as a bycatch in the hake-directed fishery. The number of vessels in the demersal hake fleet has increased, but the percentage of monkfish caught as a bycatch relative to the total annual monkfish landings has remained more or less constant. In order to reduce the monkfish bycatch and to prevent occasional targeting of monkfish by hake vessels, the bycatch levies on monkfish were increased from N$2 000 to N$4 300 ton^{-1} in January 1998. During 1998 and 1999, hake vessels caught 17.8 and 22.3% of the total monkfish landed respectively (Table II), a substantial reduction from the 32.3% estimated between 1994 and 1997.

Even though an observer programme in which observers sample all commercially important species for length and sex while at sea was established in 1996, few length measurements of monkfish were made because the research priorities of the programme were elsewhere. Therefore, another source of length information for monkfish for use in length-based stock assessment modelling (Maartens 1999) was sought. This came in the form of size category data (monkfish tails sorted into different weight categories) obtained from the factories in Walvis Bay (Table III). Length frequency ranges were constructed within the different size categories and the annual numbers of fish per category were calculated for the period 1994–1999.

Catches of processed monkfish tails are scaled up to whole weight by applying a conversion factor; that currently in use in Namibia to convert tail or landed weight to whole or round weight for monkfish is 3.04 (Anon. 1993). The origin and accuracy of the data used to calculate this factor are, however, unknown. South Africa, to the immediate south of Namibia, uses a factor of 3.44 (Anon. 1998) to convert landed tail weight to whole weight (Chalmers 1978).

Catch per-unit-effort (*cpue*) data have often been used to provide information about changes in fish abundance (Swain and Sinclair 1994). Generally it is assumed that the relationship between commercial catch rate and stock abundance is linear, *cpue* being directly proportional to abundance (Hilborn and Walters 1992). This relationship can be derived from the catch equation that relates catch, fishing effort and stock abundance:

$$C = q\,N\,E \quad , \qquad (1)$$

where C is the catch, q the catchability coefficient, related to the efficiency of the gear, N the stock

Table I: Number of monkfish and sole vessels per category of horsepower between 1991 and 1999. Between 1994 and 1999, the total number of vessels licensed at any point in time was 18. A vessel count of more than 18 per year means that >18 vessels actually operated, despite only 18 being licensed, as a result of replacements during the year

Horsepower category	1991	1992	1993	1994	1995	1996	1997	1998	1999
200–399	8	8	10	10	9	8	7	4	4
400–599	4	4	5	5	5	5	10	8	6
600–799	3	3	3	3	5	6	6	8	10
All categories	15	15	18	18	19	19	23	20	20

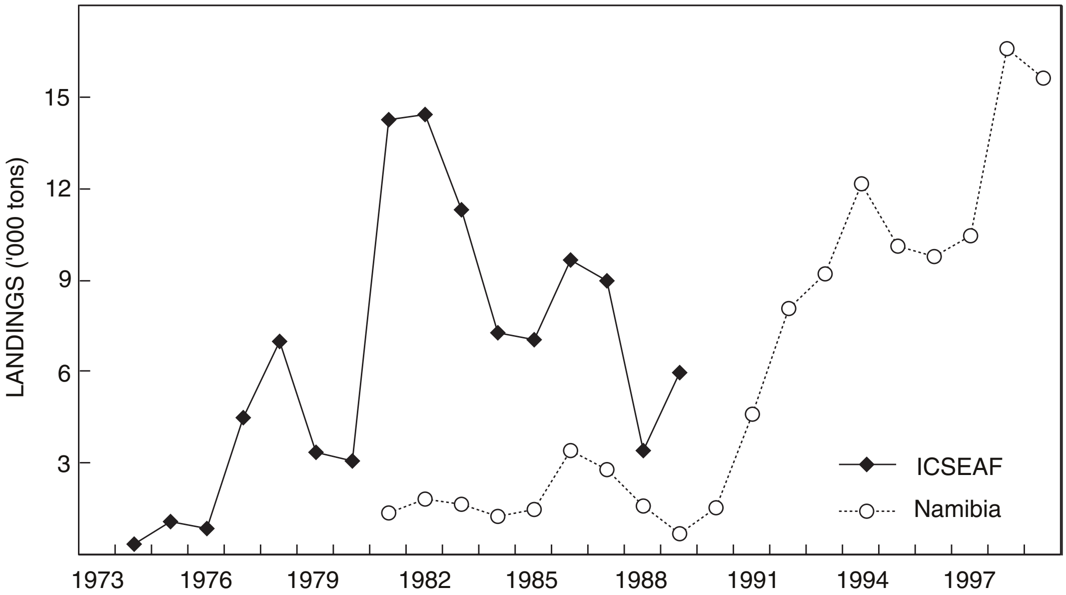

Fig. 2: Annual monkfish landings as recorded by ICSEAF, South Africa and the Namibian Ministry of Fisheries and Marine Resources. For the period 1981–1989, it is not known whether Namibian landings were incorporated into ICSEAF records

abundance and E is the fishing effort. Rearranging Equation (1) yields the following relationship between nominal *cpue* and stock abundance:

$$\frac{C}{E} = qN \quad . \tag{2}$$

The aim of this study was threefold: first, to analyse the size category data and calculate the numbers of monkfish caught per size category for the period 1994–1999; second, to standardize *cpue* by applying two independent methods, power factor analysis and

Table II: Namibian monkfish and hake landings by fleet and the percentage of monkfish landed by hake trawlers relative to the total annual monkfish landings and to the total annual landings of monkfish and hake

Fleet	Landings (tons)					
	1994	1995	1996	1997	1998	1999
			Monkfish			
Monkfish and sole fleet	8 809	6 476	6 158	7 237	13 479	10 484
Hake trawlers	3 349	3 654	3 590	3 022	2 950	3 483
Hake longliners	–	–	36	169	7	835
Experimental gillnet vessel*	–	–	–	–	134	823
All vessels	12 158	10 130	9 784	10 428	16 570	15 625
			Hake			
Hake trawlers	102 076	119 753	121 819	104 039	134 366	160 691
Landings			*Percentage of monkfish landed by hake trawlers*			
Total monkfish	27.5	36.1	36.7	29.0	17.8	22.3
Hake plus monkfish	3.2	3.0	2.9	2.8	2.1	2.1

*Monkfish were harvested by one experimental gillnet vessel during 1998 and 1999

Table III: Ranges of tail weights for the different size categories in which monkfish tails are landed. Data to obtain the total length range of monkfish in the different size categories were collected on board the M.F.V. *Loraine* during April 1996

Category	Tail weight range (g)	Total length range (cm)
Extra extra small (XXS)*	0–50	10–16
Extra small (XS)*	50–100	17–25
Small (S)	100–250	26–36
Medium (M)	250–500	37–48
Large (L)	500–1 000	49–59
Extra large (XL)	1 000+	60+

* Some vessels report XXS and XS as US

Generalized Linear Modelling (GLM). GLM was applied to the *cpue* data to account for the effects that annual, seasonal, vessel, area and depth differences may have on abundance trends. Hilborn and Walters (1992) suggested this method as the most appropriate to analyse catching power information and the best tool to calculate standardized catch rates. In addition, possible changes in fishing operations of the fleet directed at monkfish and sole in terms of depth, area and vessel size for the period 1991–1999 were investigated. Finally, it was considered appropriate to review the scaling factor currently used to convert landed/tail weight to whole weight owing to uncertainties as to its origin and accuracy. From that analysis it would be possible to assess the applicability of the conversion factor currently in use in the Namibian fishery for monkfish. Conversion factors for each of the tail products were calculated and their differences tested statistically. The *cpue* data pertain to both species, but data for *L. vomerinus* only were available to estimate conversion factors.

MATERIAL AND METHODS

Length composition data

Most monkfish caught by the fleet directed at monkfish and sole and by the hake fleet are headed and eviscerated at sea. The landed tails are either skin-on with or without caudal fins, or skinless with or without caudal fins, depending on market requirements. These tails are sorted into different size categories either at sea or at the factories after being landed (Table III). Size category data collected from the factories consist of monkfish tails in kilogrammes per size category per vessel on a monthly basis from 1989 to 1999 (for some vessels the data are not divided into categories, but are available on a monthly or annual basis). Data from some of the fishing vessels were not available, but the available data were considered to be a representative sample of the fleet. No size category data were attainable from the hake vessels for the period 1989–1993. Size category data from only two monkfish and sole vessels are available for the period 1989–1990, and for three vessels between 1991 and 1993. Owing to the small sample size, these data were excluded from the analysis yielding numbers of monkfish landed for the respective years.

The Namibian demersal fleet consists of hake trawlers, vessels directed at monkfish and sole, and hake longliners. The vessels directed at hake and at monkfish and sole can be divided into wetfish (WT) and freezer vessels (FT). Total catch per size category for the monkfish and sole fleet and for the hake-directed wetfish and freezer vessels for the six years of the study was estimated. Certain companies report catches in both the extra extra small (XXS) and extra small (XS) category, but other companies combine these two categories into an under-small (US) category. It was assumed that vessels with the US category land tails in both XXS and XS categories, an assumption based on observations made aboard the M.F.V. *Loraine* during April 1996 (Maartens 1999). The ratio of XXS to XS included in the US category was calculated from those vessels that recorded these categories separately; that ratio was then applied to the data from vessels that employed the US category. Furthermore, the proportion that each category contributed to the total catch was estimated from vessels that reported five or six categories. These percentages were used to allocate into categories the landed catch from vessels that only recorded one annual landing figure per year (Table IV). Finally, the estimated catch per size category was raised to total monkfish landings for the monkfish and sole fleet as well as hake freezer and wetfish vessels for the respective years.

During April 1996, a commercial sampling survey was conducted aboard the monkfish freezer trawler *Loraine*. Length ranges were obtained for the different size categories (see Table III). In addition, a factor was obtained to convert tail length to total length for the two monkfish species and, by applying the length-weight relationship $W = 0.0347\ L^{2.7714}$, the total weight (kg) of each fish was calculated per cm length-class.

The mean tail weight per category was calculated in two different ways, first from

$$\textit{Mean tail weight per category} = \left[\frac{\sum (W \times n)}{\sum n}\right] / \, 3.04 \ , \qquad (3)$$

where W is the weight per cm length-class, n the

Table IV: Conversion statistics used to obtain the total catch of monkfish per size category for the monkfish and sole fleet and hake freezer and wetfish trawlers, 1994–1999. The number of vessels' data to which these statistics were applied is shown in parenthesis

Parameter	Value					
	1994	1995	1996	1997	1998	1999
Monkfish and sole fleet						
% US ratio (XXS:XS)	13.5:86.5	20.8:79.2	16.1:83.9	16.9:83.1	14.5:85.5	18.2:81.8
Number of vessels	8 (8)	8 (9)	10 (7)	9 (6)	9 (11)	9 (10)
XXS (%)	2.1	2.9	–	–	–	–
XS (%)	12.0	9.5	–	–	–	–
S (%)	27.5	29.0	–	–	–	–
M (%)	29.6	29.4	–	–	–	–
L (%)	23.6	22.5	–	–	–	–
XL (%)	5.3	6.8	–	–	–	–
Number of vessels	8 (2)	8 (2)				
Hake freezer trawlers						
XXS (%)	–	–	0.2	–	–	–
XS (%)	–	–	1.2	–	–	–
S (%)	–	–	8.3	–	–	–
M (%)	–	–	31.5	–	–	–
L (%)	–	–	38.7	–	–	–
XL (%)	–	–	20.0	–	–	–
Number of vessels	8	4	2 (4)	2		
Hake wetfish trawlers						
% US ratio (XXS:XS)	–	–	–	2.4:97.6	–	–
Number of vessels				4 (3)		
XXS (%)	–	–	0.2	–	2.0	1.4
XS (%)	7.0	25.8	2.2	–	14.8	7.0
S (%)	27.9	35.3	21.7	–	37.2	34.8
M (%)	35.8	26.3	36.9	–	27.8	30.8
L (%)	18.8	10.8	23.9	–	14.8	19.1
XL (%)	10.6	1.9	15.1	–	3.4	6.8
Number of vessels	6 (13)	2 (14)	7 (19)		3 (11)	4 (9)

number of monkfish measured and 3.04 is the conversion factor to convert tail weight to total weight. Second, the mean tail weight per category was obtained from samples of monkfish tails (boxes) that were weighed and the number of tails per box recorded, where

$$Mean\ weight\ per\ category = \frac{\sum tail\ weights\ per\ category}{\sum number\ of\ tails} \ . \quad (4)$$

The mean tail weight per category was used to obtain numbers of fish per category for the fleets directed at monkfish and sole as well as at hake for the period 1994–1999.

Catch-per-unit-effort data and standardization

Cpue data were obtained from the Ministry of Fisheries and Marine Resources' database and consisted of the following: license number, vessel name, date fished, geographical trawl position or grid number, duration of trawling (h), number of trawls, depth of trawling (m) and total weight of the catch (kg). The skippers of the vessels directed at monkfish and sole provided the *cpue* data. Only data from the monkfish and sole fleet were included in the analysis of *cpue* data, because monkfish is the target species and not a bycatch, as in the hake-directed fishery. The catch was converted from headed and gutted (HG) weight or tail weight by applying the factor 3.04 to whole round (WR) weight (Anon. 1998).

In January 1997, revised daily catch logs were introduced; these included a request for additional trawl information, such as geographical trawl position, start and end time of each trawl, seabed and trawl depth for each trawl, and target species. Records containing obvious reporting errors (i.e. depth and geographical trawl position) were excluded from the analysis. A number of records had zero total catch

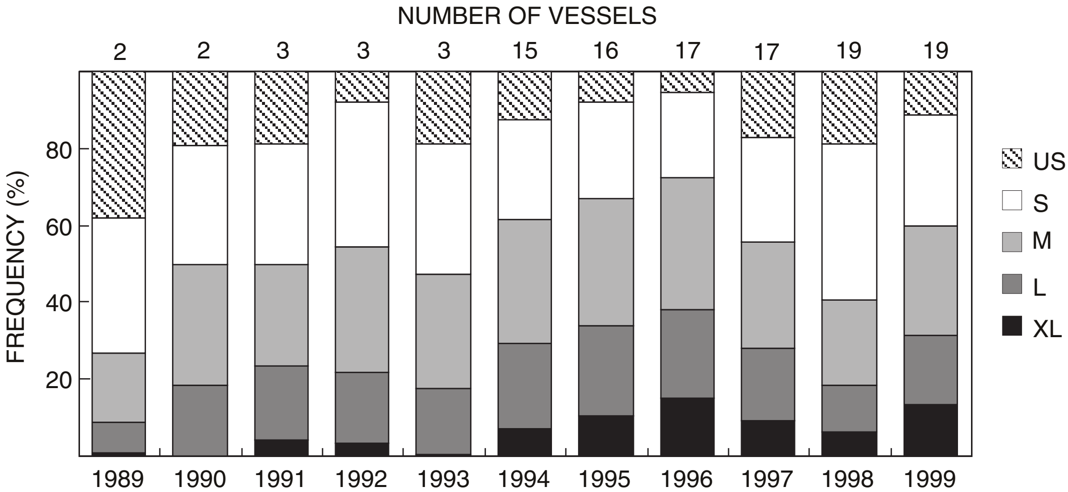

Fig. 3: Percentage frequency of monkfish tails (by weight) landed per size category by vessels directed at monkfish and sole, 1989–1999

and these were also excluded from the analysis. In addition, only records for which monkfish were recorded as the target species were considered.

The fishing operations of the fleet directed at monkfish and sole at various depths, for various categories of horsepower and in different areas of operation, were compared for the period 1991–1999.

Standardization was carried out by two methods, power factor analysis and Generalized Linear Modelling (GLM).

POWER FACTOR ANALYSIS

The vessels directed at monkfish and sole were categorized into three categories of horsepower, 200–399, 400–599 and 600–799 h.p. Examination of residual plots of the log-transformed *cpue* data (difference of each individual point from the mean) showed that the data were normally distributed, so the quarterly *cpue* from the commercial fleet between 1991 and 1999 could be calculated easily.

In order to standardize effort for all three categories of horsepower, statistical tests (i.e. single factor Analysis of Variance, ANOVA, and Tukey's-test for contrasts; Zar 1996) were carried out to determine if the datasets differed significantly, and which datasets could be combined, if not. The relative fishing power (FP) was calculated through division of the annual catch rate of one category of horsepower by that of another (the standard). The observed effort of a specific category of horsepower was then standardized when multiplied by its relative fishing power. *Cpue* for each year, using the total catch for that year and the standardized effort, was then calculated.

GENERALIZED LINEAR MODELLING

A GLM was fitted to the *cpue* data from the commercial monkfish and sole fleet to investigate the effect of certain factors on the estimate of *cpue* between 1991 and 1999. The computer package SPSS 7.5 (SPSS 1997) was used.

A description of the model is:

$$\ell n\,(cpue + \delta) = \mu + \alpha_{year} + \beta_{month} + \gamma_{vessel} + \kappa_{area} + \lambda_{depth} + \phi_{year \times month} + \omega_{year \times area} + \eta_{year \times vessel} + \varepsilon \qquad (5)$$

where μ is the intercept, α_{year} the year effect, where year is a factor with nine levels, β_{month} the month effect, where month is a factor with 12 levels, γ_{vessel} is the vessel effect pertaining to each individual vessel fishing in the monkfish and sole fishery, κ_{area} the area effect, where area is a factor with 13 degrees of latitude (17–29°S), λ_{depth} the depth effect, where depth is a factor with five levels ("150" for depths ≤199 m, "250" for depths of 200–299 m, "350" for depths of 300–399 m, "450" for depths of 400–499 m and "550" for depths of 500–599 m), $\phi_{year \times month}$ the interaction between year and month, $\omega_{year \times area}$ the interaction between year and area, $\eta_{year \times vessel}$ the interaction between year and vessel, ε the error term assumed to be normally distributed, and δ is 50% of the mean of the *cpue* values.

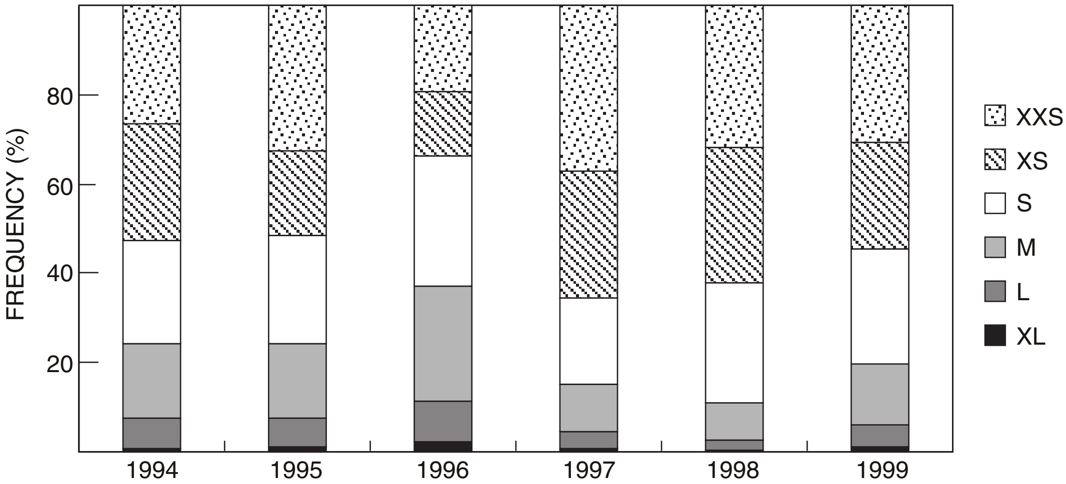

Fig. 4: Percentage frequency of monkfish tails (in numbers) landed per size category by vessels directed at monkfish and sole, 1994–1999

The log-transformed (*cpue* + δ) produced symmetric residuals with a stable variance. This technique is consistent with the GLM analysis applied to catch-rate data for South African hake (Brown *et al*. 1995).

A standardized *cpue* time-series is obtained as follows:

$$Cpue_y = \exp\left[\mu + \alpha_{year} + \bar{\beta} + \bar{\gamma} + \bar{\kappa} + \bar{\lambda}\right] - \delta \quad , \quad (6)$$

where

$\bar{\beta} = \left(\sum \beta_{month}\right) /$ *number of months*,
$\bar{\gamma} = \left(\sum \gamma_{vessel}\right) /$ *number of vessel factors*,
$\bar{\kappa} = \left(\sum \kappa_{area}\right) /$ *number of latitude factors*, and
$\bar{\lambda} = \left(\sum \lambda_{depth}\right) /$ *number of depth factors*.

However, due to the interactions, the standardized *cpue* series is obtained from

$$Cpue_y = \left[\left[\Sigma_{month}\left(\exp\begin{pmatrix}\mu + \alpha_{year} + \beta_{month} \\ +\gamma_{vessel} + \kappa_{area} \\ +\lambda_{depth} + \phi_{year\times month} \\ +\omega_{year\times area} \\ +\eta_{year\times vessel}\end{pmatrix}\right)\right] / 12\right] - \delta \quad . \quad (7)$$

Conversion factors

Data were collected from a hake trawler during March 1998 at one of the factories in Walvis Bay (fresh fish on ice) and during April 1999 aboard the commercial hake vessel *Katima* (fresh fish) during a monkfish selectivity experiment. In all, 159 monkfish (total length 19.4–67.6 cm) were sampled at the factory and another 762 (11.0–102.5 cm) on board the commercial vessel. All fish were weighed (g) and measured (mm total length *TL*) before being headed and eviscerated by hand, as is the custom of commercial fishers. The process involves removal of the head by severing the body as close to the anterior end of the vertebral column as possible. Each tail was weighed (g) as a skin-on tail with the caudal fin intact, after which the skin and caudal fin were removed to obtain the weight of skin-on tails with caudal fins, skinless tails with caudal fins and skinless tails without caudal fins respectively. Fin weight was calculated to obtain the weight of skin-on tails without caudal fins.

Whole round weight was regressed against tail product weight to obtain a conversion factor for each tail product. The slope of the linear least-squares regression provided an estimate of the conversion factor for each tail product. Statistical differences between the slopes (each representing a conversion factor for a specific tail product) were assessed using Analysis of Covariance, ANCOVA (Snedecor and Cochran 1967). A single factor Analysis of Variance (ANOVA) was used to compare the mean weights of the tail products for all four tail products.

The percentage weight loss for each of the four product stages was calculated for each fish. In addition, the percentage weight loss from whole round fish to skin-on tails with caudal fins was regressed against fish length to test for an increase in the percentage

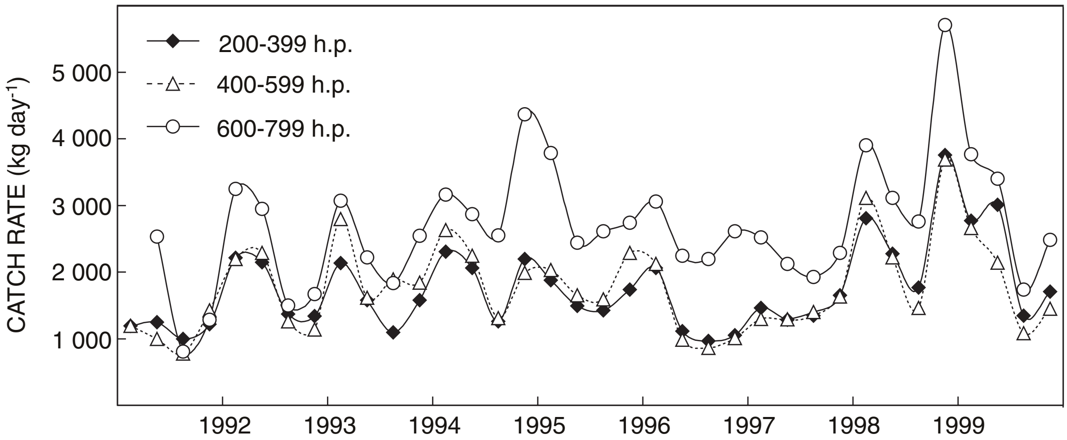

Fig. 5: Quarterly *cpue* from vessels directed at monkfish and sole per category of horsepower, 1991–1999

weight loss with increasing size. An ANOVA was used to compare the weight loss among fish lengths grouped into classes of 10 cm, with differences between length groups determined using a Tukey's multiple test for contrasts (Zar 1996).

RESULTS

Length composition data

Analysis of the data to convert tail length to total length (*TL*) resulted in the linear relationship

$$TL = 1.45 \times Tail\ length - 0.64\ (r^2 = 0.99, n = 505)\ . \quad (8)$$

The results of the analysis to calculate mean tail weight per category are summarized in Table V. The average values obtained from the results of the two methods (Equations 3 and 4) were used to obtain numbers of monkfish per size category for the period 1994–1999 (see Fig. 4).

The percentage frequency of monkfish tails landed per size category by the monkfish and sole fleet between 1989 and 1999 (by weight) and between 1994 and 1999 (in numbers) is illustrated in Figures 3 and 4. It is clear that large numbers of monkfish ≤36 cm *TL* are landed (Fig. 4). Between 1994 and 1996, catches of monkfish in the US and S categories combined decreased (from 38 to 28%), whereas catches in the other categories (M, L and XL) increased (from 62 to 72%). However, catches between 1996 and 1998 increased from 28 to 59% in the US and S categories and decreased from 72 to 41% for the M, L and XL categories combined. Catches of monkfish in the US and S categories decreased from 59 to 40%, and catches in the other categories (M, L and XL) increased from 41 to 60% between 1998 and 1999 (Fig. 3).

Catch-per-unit-effort data

POWER FACTOR ANALYSIS

The observed quarterly *cpue* from the monkfish and sole vessels for the period 1991–1999 is illustrated in Figure 5. Investigation of the data highlighted a pattern of fluctuating seasonal availability of monkfish.

Catches of monkfish by the fleet directed at monkfish and sole and the days spent at sea for the period 1991–1999 are illustrated in Figure 6 (note that data obtained from the catch logs are shown and not the

Table V: Mean tail weight (kg) of monkfish per size category obtained using two methods

Size category	Mean tail weight (kg) (Method 1: Equation 3)	Mean tail weight (kg) (Method 2: Equation 4)	Mean of the two methods
XXS	0.011	0.010	0.011
XS	0.063	0.070	0.067
S	0.172	0.210	0.191
M	0.331	0.370	0.351
L	0.649	0.670	0.659
XL	1.655	1.850	1.752

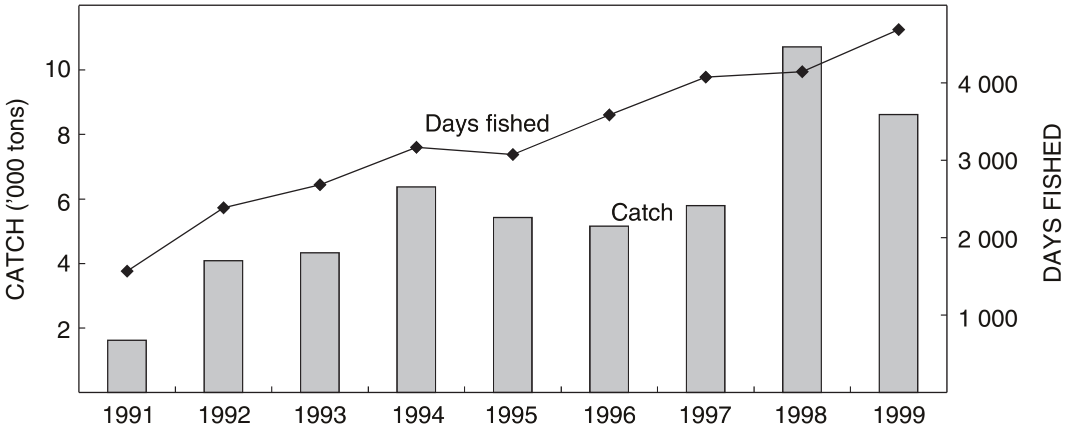

Fig. 6: Catch and the total number of days fished by the Namibian fleet directed at monkfish and sole, 1991–1999

total annual monkfish landings). The effort or days spent at sea were similar during 1997 and 1998, but catches increased considerably. However, during 1999, there was a 13.1% increase in the number of days spent at sea whereas monkfish catches decreased. Overall, the days spent at sea increased by 198.9% between 1991 and 1999.

Highly significant differences in *cpue* were detected between the different categories of horsepower ($p < 0.001$) through applying the ANOVA. A Tukey test for contrasts indicated that data from the 200–399 and 400–599 h.p. categories could, however, be combined, because they were statistically similar. Fishing powers calculated for the 600–799 h.p. category relative to the 200–599 h.p. category were: 1.1 (1991), 1.3 (1992), 1.4 (1993), 1.7 (1994 and 1995), 1.9 (1996), 1.6 (1997), 1.5 (1998) and 1.4 (1999). The standardized *cpue* from all three categories of horsepower combined between 1991 and 1999 is shown in Figure 7.

GENERALIZED LINEAR MODELLING

The results from the GLM analysis are summarized in Table VI. The model accounts for 48.6% of the total variation of monkfish *cpue* and all effects have a significant effect on the *cpue* ($p < 0.001$).

The standardized *cpue* indices obtained from both the GLM and the power factor analyses are illustrated in Figure 7. The two indices exhibit a similar pattern over time, but the estimates of abundance obtained

Table VI: Results from the GLM applied to the *cpue* of the fleet directed at monkfish and sole with the factors used in the analysis (R^2 = 0.494; Adjusted R^2 = 0.486)

Source of variation	Type III sum of squares	Degrees of freedom	Mean square	*F*-ratio	Significance
Corrected model	2 231.17	349.00	6.39	62.29	0.00
Error	2 282.00	22 236.00	0.10		
Total	1 438 328.58	22 586.00			
Corrected total	4 513.17	22 585.00			
Intercept	4 453.63	1.00	4 453.63	43 396.51	0.00
Year	10.32	8.00	1.29	12.57	0.00
Month	193.10	11.00	17.55	171.05	0.00
Area	89.86	12.00	7.49	72.97	0.00
Number	376.99	33.00	11.42	111.32	0.00
Depth	7.17	4.00	1.79	17.47	0.00
Year × month	259.78	88.00	2.95	28.76	0.00
Year × area	108.81	70.00	1.55	15.15	0.00
Year × number	183.71	123.00	1.49	14.55	0.00

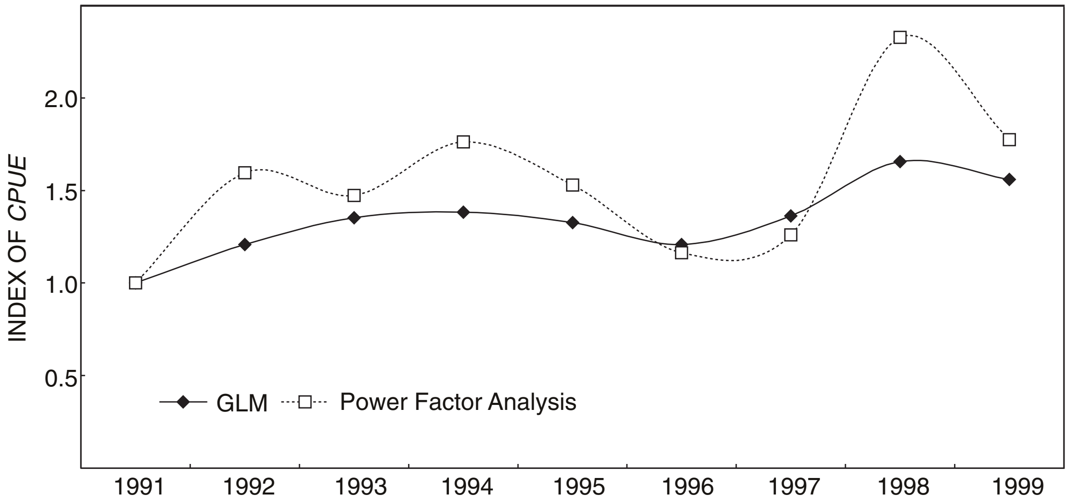

Fig. 7: Power-factor- and GLM-standardized estimated monkfish *cpue* of vessels directed at monkfish and sole, 1991–1999

from the GLM are lower (apart from those of 1996 and 1997) than those obtained from the power factor analysis. This may be explained by the fact that the index derived from power factor analysis only takes into account the vessel effect at a crude level, whereas the GLM adjusts for additional effects, such as year, month, area and depth, and it also allows for interactions.

Changes in fishing operations related to area, depth and vessel horsepower

Figure 8 illustrates the fishing operations of the monkfish and sole fleet in terms of area, depth of operation and horsepower category. During the period 1991–1999, fishing intensity was greatest in the central region (21°–24°59´S). Fishing operations by the fleet, however, decreased slightly between 1991 and 1996 (Fig. 8a) and doubled between 1996 and 1998. The extent of fishing in the south (25°–29°30´S) more than doubled between 1991 and 1997, but it then decreased in 1998. Fishing in the north (17°–20°59´S) peaked in 1996, after which it decreased to levels similar to those experienced in 1991. Between 1998 and 1999, fishing activities in the central region increased by 30%, whereas in the north and south it almost halved.

Analysis of fishing depth data illustrates a shift in the mean depth of fishing between 1991 and 1999 (Fig. 8b). In 1991, most fishing took place in depths of 200–299 m. From 1992 to 1995, fishing intensity between 300 and 399 m increased and in 1996 some 10.6% of the fishing activity was in depths of 400–499 m. There was a noticeable shift in mean fishing depth during 1997, when the level of fishing activity between 200 and 299 m was similar to that between 300 and 399 m. During 1998, fishing was most concentrated between 300 and 399 m, but in 1999, 15.4% of all fishing operations took place between 400 and 499 m.

A comparison of the amount of fishing exerted by the various horsepower categories between 1991 and 1999 is illustrated in Figure 8c. Fishing operations of the 200–399 h.p. category declined between 1994 and 1999, but there was an increase in fishing activities within the 400–599 h.p. category between 1994 and 1997 and in the 600–799 h.p. category between 1995 and 1999.

Conversion factors

Factors to convert tail weight to total weight for each of the four tail products obtained from data collected on board the *Katima* are illustrated in Figure 9. Highly significant differences were noted between the four products for both the factory ($F_{(3.632)} = 2.62$; $p <$ 0.0001) and commercial vessel ($F_{(3.3044)} = 2.61$; $p <$ 0.0001) datasets, and between the slopes of the four product regressions for the factory ($F_{(6.627)} = 3.18$; p 0.01) and commercial vessel data ($F_{(6.3040)} = 200.3$; $p < 0.001$) respectively. A comparison of the slopes

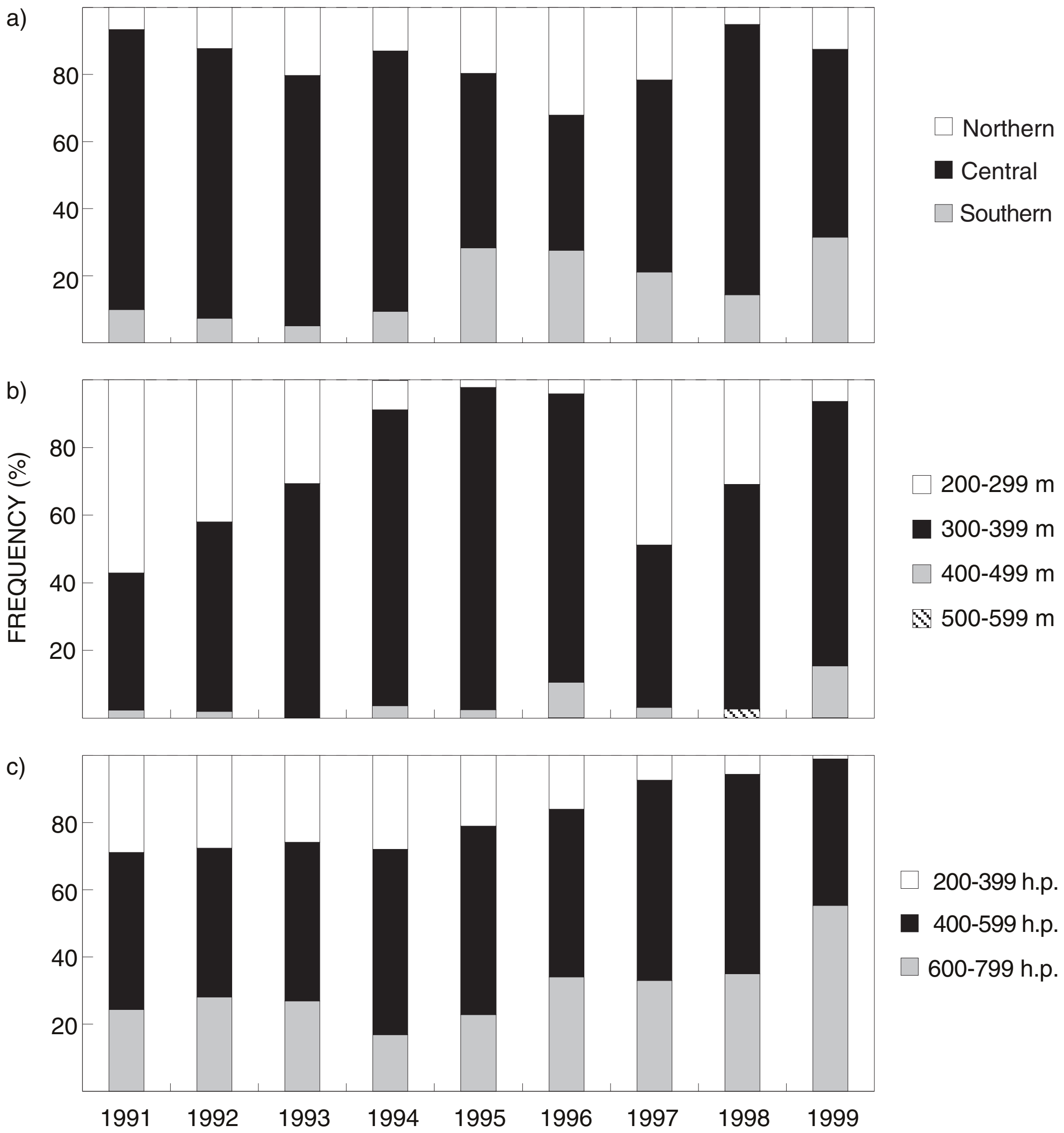

Fig. 8: Frequency with which the fleet directed at monkfish and sole operated (a) in the northern (17°–20°59´S), central (21°–4°59´S) and southern (25°–29°30´S) regions off Namibia, (b) at various depths, and (c) in each category of horsepower, 1991–1999

(conversion factors) obtained from the data collected in 1998 and 1999 revealed that the conversion factors collected in 1999 aboard the commercial vessel were significantly lower for all tail products ($F_{(2,917)} = 6.32$; $p < 0.001$). As a consequence, data collected at the factory and aboard the commercial vessel were not pooled to obtain combined commercial conversion factors. The sample size at the Walvis Bay factory during March 1998 was small (159 fish) compared to numbers in the April 1999 sample (762 fish) taken aboard the *Katima*; they also incorporated a narrower size range (19–67 cm v. 11–102 cm) of fish. A summary of the

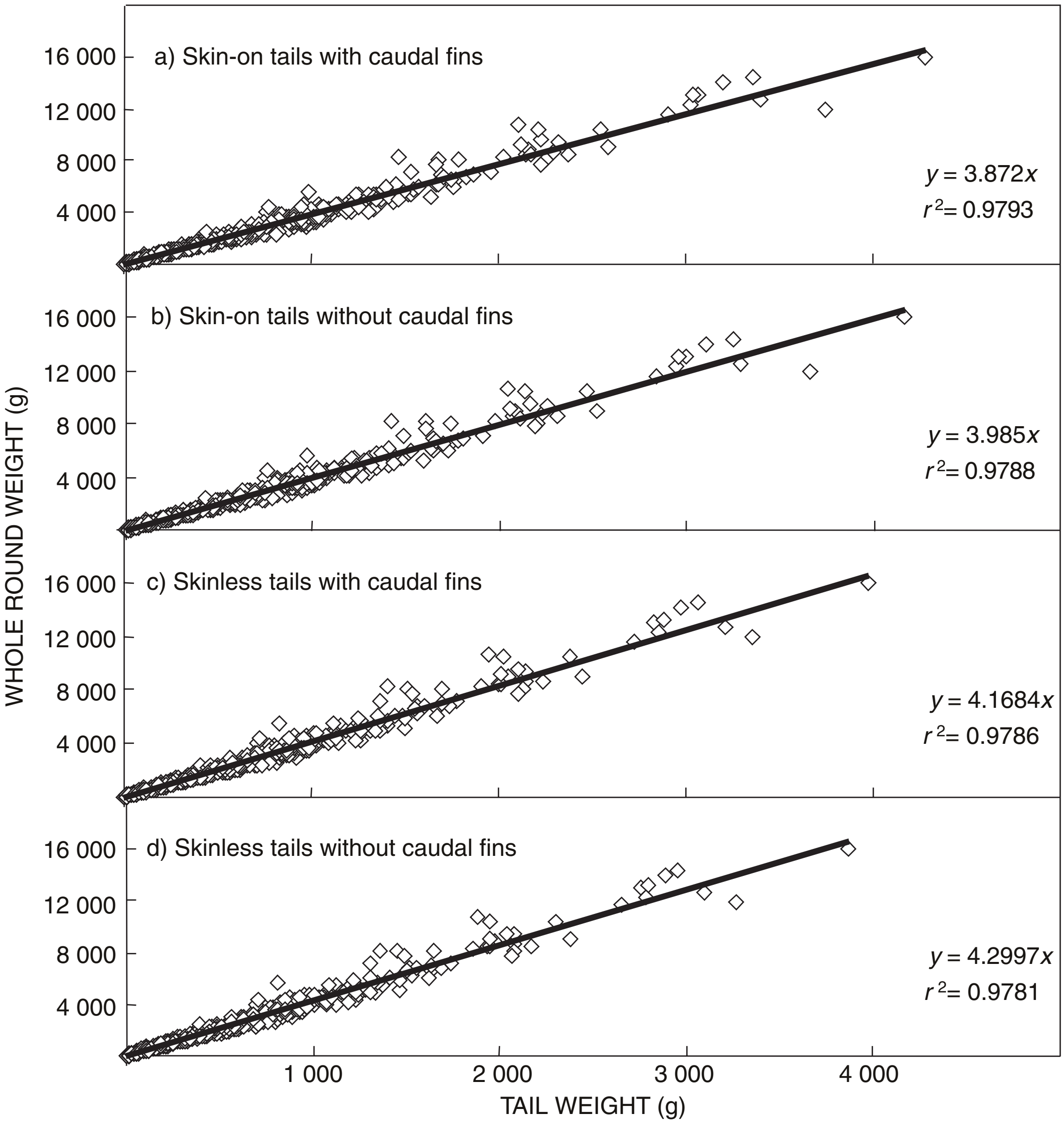

Fig. 9: Relationship between tail weight (g) of skin-on or skinless, with or without caudal fins, and whole round weight (g) for *Lophius vomerinus* from samples collected aboard the M.F.V. *Katima* during April 1999 ($n = 762$)

Table VII: Average weight loss per tail product, weight range and standard deviation (*SD*) obtained for the different *L. vomerinus* tail products sampled aboard the M.F.V. *Katima* during April 1999 ($n = 762$)

Tail product	Average weight loss (%)	Weight range (g)	*SD*
Skin-on with caudal fin	25.39	15.03–33.96	3.05
Skin-on without caudal fin	24.66	14.38–33.05	3.01
Skinless with caudal fin	23.44	13.07–31.19	2.96
Skinless without caudal fin	22.70	12.42–30.35	2.91

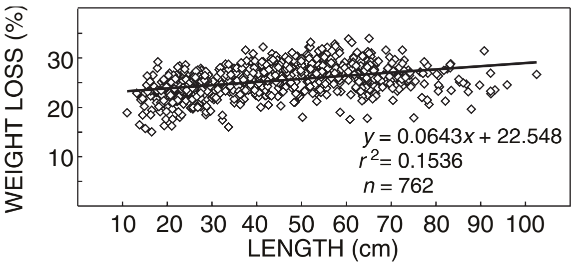

Fig. 10: Change in weight of individual *Lophius vomerinus* per centimetre length-class obtained from samples collected aboard the M.F.V. *Katima* during April 1999

findings per product type on the *Katima* is given in Table VII. Sample collection on board the *Katima* took place during a monkfish selectivity experiment. An "Albatross" monkfish trawl with tickler chains and 110-mm mesh codend were used and trawling took place on a known fishing ground for the species (Maartens 1999). The gear used and area of operation explains why smaller monkfish as well as a bigger size range were obtained on board the *Katima* (v. the commercial hake vessel with different gear), resulting in positively biased size-selective fishing practices, not representative of the fishery. Considering that the fishery for monkfish operating off Namibia typically lands fish ranging in size from 10 to 102 cm *TL* (Maartens 1999) and that conversion factors need to be unbiased to provide a representative estimate of catch, conversion factors were only calculated from the April 1999 commercial sample.

The number of monkfish and mean length per 10 cm length-class, together with the mean weight and conversion factor per tail product, are summarized in Table VIII. Overall, factors to convert skin-on tails with caudal fins to whole round weight ranged between 3.67 (50–59.9 cm length-class) and 4.48 (10–19.9 cm).

The linear regression of percentage weight loss from whole round fish to skin-on tails with caudal fins against fish length is illustrated in Figure 10. Single factor ANOVA indicated a highly significant difference in weight loss among fish lengths grouped into 10-cm length-classes ($F_{(9,751)} = 1.89$; $p < 0.0001$). The Tukey test for contrasts indicated that length-classes 10–29, 30–39 and 40+ cm were significantly different from each other ($p < 0.001$), illustrating a significant increase in percentage weight loss with increasing size.

DISCUSSION

Length composition data

It is evident from the analysis of size category data that large numbers of juvenile monkfish (Figs 3, 4) are harvested, perhaps leading to growth overfishing (Hilborn and Walters 1992). It would, therefore, be advisable to reduce the capture of these juvenile fish. In order to address this concern, several experimental research cruises have been undertaken since November 1998 to find a suitable grid design to release juvenile monkfish below a certain size (Maartens 1999). The implementation of a rigid sorting grid may be a possible solution to increase the length-at-first-capture of monkfish and to ensure the harvesting of mainly adults.

The percentage frequency of US (XXS + XS) monkfish tails landed during 1997 and 1998 increased over those for the period 1994–1996 (Figs 3, 4). A possible explanation is that a large proportion of monkfish in the 100–299 m depth zone during 1998 were juvenile. Another explanation is that a notice-

Table VIII: Summary statistics and conversion factor (in parenthesis) for each 10 cm length-class of monkfish obtained from data collected aboard the M.F.V. *Katima* during April 1999

Length-class (cm)	Number of fish	Mean length (cm)	Mean tail weight (g) and conversion factor			
			Skin-on with caudal fin	Skin-on without caudal fin	Skinless with caudal fin	Skinless without caudal fin
10–19.9	50	16.85	22.04 (4.48)	21.21 (4.66)	19.52 (5.05)	18.70 (5.27)
20–29.9	187	24.80	23.64 (4.17)	22.99 (4.28)	21.82 (4.53)	21.17 (4.67)
30–39.9	95	35.52	25.14 (3.95)	24.44 (4.06)	23.27 (4.26)	22.57 (4.39)
40–49.9	140	44.48	26.51 (3.76)	25.77 (3.87)	24.50 (4.07)	23.76 (4.19)
50–59.9	107	54.60	27.34 (3.67)	26.53 (3.78)	25.33 (3.95)	24.52 (4.08)
60–69.9	112	64.54	26.58 (3.79)	25.82 (3.90)	24.63 (4.09)	23.87 (4.22)
70–79.9	45	73.45	25.87 (3.91)	25.13 (4.02)	24.00 (4.21)	23.26 (4.34)
80–89.9	19	83.71	25.18 (4.01)	24.45 (4.13)	23.51 (4.29)	22.78 (4.42)
90–99.9	6	92.77	25.40 (3.93)	24.71 (4.05)	23.47 (4.27)	22.77 (4.40)
100–109.9	1	102.50	26.64 (–)	25.99 (–)	24.77 (–)	24.12 (–)

Table IX: Factors for converting tail weight to total weight for various *Lophius* species and similar tail products

Species	Country	Conversion factor	Year	Source
*L. piscatorius**	South Africa	3.44	1971	Chalmers (1978)
L. vomerinus	Namibia	3.04	?	Anon. (1993)
L. americanus	Canada	3.50	1985	Anon. (1992)
L. budegassa	Spain	2.54	1998	Quincoces *et al.* (1998a)
L. piscatorius	U.K.	3.45	1986	Bedford *et al.* (1986)
L. piscatorius	France	3.07	1988	Anon. (1992)
L. piscatorius	Germany	3.25	1988	Anon. (1992)
L. piscatorius	Norway	2.80	1988	Anon. (1992)
L. piscatorius	Sweden	2.86	1988	Anon. (1992)
L. piscatorius	U.K.	3.00	1988	Anon. (1992)
L. piscatorius	Spain	2.79	1998	Quincoces *et al.* (1998b)
Mixed species†	U.K.	3.07	1985	Elson *et al.* (1989)

* Refers to *L. upsicephalus* (later taxonomically revised as *L. vomerinus*)
† *L. piscatorius* and *L. budegassa*

able shift in the mean depth of fishing (increased fishing operations between 200 and 299 m) took place during 1997 and 1998. Considering that one of the identified recruitment areas is between 23 and 25°S (Anon. 1984, 1985) and that there was increased fishing activity in the central area (21°–24°59´S) during 1997 and 1998, it is not surprising that the vessels were harvesting more juvenile fish.

Catch-per-unit-effort data

A distinctly seasonal pattern emerged from the nominal catch rates on a quarterly basis. It may be assumed that these seasonal patterns are instigated by environmental factors because no market forces and/or fishing seasons could be identified. Environment-driven forces may also explain the decline in *cpue* between 1994 and 1996, as well as the increase in subsequent years. Macpherson and Gordoa (1992) note that environmental factors responsible for changes in species distribution and availability are not entirely clear. Changes have been related to sea surface temperature, persistence of upwelling and concentration of dissolved oxygen at the bottom. Horizontal migration of fish could be another possible cause. Jean (1965) suggested that *L. americanus* undertake seasonal migrations and Azevedo (1996) found that small *L. budegassa* prefer shallow water and move to deeper water as they grow. No definitive information is, however, yet available on possible migration of the two *Lophius* spp. in Namibian waters.

The increase in the number of landings by the monkfish and sole fleet from 1991 to 1994 is thought to be a result of an improvement in the efficiency of the fleet in combination with an increase in the number of vessels in 1993 (Table I). As a consequence, increases in *cpue* of 39.6 and 11.7% were observed in the standardized power factor analysis (excluding 1993) and GLM *cpue* indices respectively. However, there was an overall decrease in monkfish catches between 1994 and 1996. The standardized *cpue* determined by power factor analysis decreased on average by 18.6% between 1994 and 1996 (Fig. 7). There was a similar trend in the GLM-standardized *cpue*, i.e. a decline of 6.5% in catch rates between 1994 and 1996. The question is therefore whether the decline in *cpue* between 1994 and 1996 is an indication of continuous depletion of the resource or a reflection of complex dynamics that coincide with adjustments of the resource to changes in fishing patterns after 1991. Unfavourable environmental conditions prevailed during 1994 and 1995. These consisted of low concentrations of dissolved oxygen during 1994 and a warm-water event in 1995. As a result, declining abundance trends until 1997 were evident in most commercially important stocks, including both hake species (O'Toole and Bartholomae 1998). It is possible that these conditions had a similar effect on the monkfish resource.

Between 1996 and 1998, the standardized power factor and GLM *cpue* indices increased on average by 46.5 and 17.1% respectively (Fig. 7). Days spent at sea (effort) between 1997 and 1998 increased by a mere 1.7%, indicating an increase in catchability/availability of monkfish during 1998. The overall effective fishing effort did increase during 1998 (see Fig. 8c), but not enough to account for the increase in monkfish catches by the fleet directed at monkfish and sole. During 1999, the standardized power factor and GLM *cpue* indices decreased by 23.8 and 5.8% respectively.

Conversion factors

Monkfish tail products in the Namibian fishery are classified into categories, the landed catch consisting of varying proportions. Further tail products have also been developed, and these changes need to be incorporated into updated conversion factors to ensure accurate landing estimates. If accurate estimates of total landed catch were to be obtained, reliable conversion factors would ideally be required for the different tail products and the sizes of fish used to produce the products.

There were statistically different conversion factors between tail products, indicating that, for management purposes, four conversion factors would need to be implemented within the monkfish fishery, one for each tail product. Ignoring these differences would result in dramatic differences in estimates of landed catch. For example, skin-on tails with caudal fins and skinless tails with and without caudal fins made up 42.5, 16.0 and 41.5% of the total landed weight of monkfish by commercial monkfish and sole vessels during 1998 (LM unpublished data). If the tail-product-specific conversion factors (3.87, 4.17 and 4.30) obtained during this study were applied, as opposed to the factor used currently, there would be a 34.8% increase in landed weight of Namibian monkfish. This has serious implications for stock assessments that rely on historical catch data and/or *cpue* data series. Size category data split into different tail products are available for the period 1998–1999 and, once suitable and realistic conversion factors have been estimated, updated abundance indices can be calculated.

Overall, the conversion factor of 3.04 currently used by Namibia is 13% lower than that used by South Africa (Table IX) and 27% lower than that calculated in this study for skin-on tails with caudal fins. Clearly this factor is not representative (factors of 3.87–4.30 for the different tail products) of the Namibian fishery for monkfish.

Chalmers (1978) commented that variation should be expected when calculating conversion factors. Sources of variation include factors of a biological and technical nature, such as food availability and variation in the cleaning and gutting techniques. Bedford *et al*. (1986) noted that biological and environmental factors such as fish size, sex, area of origin and seasonal variation in body condition may have significant effects on the relationship between landed and whole weight. Müller and Ernst (1995) similarly noted that gonad development caused differences in the conversion factor (landed to live weight) for Baltic cod between the first and second half of the year and, on a spatial scale, different stocks of *Lophius* have been shown to have different conversion factors (Table IX). Nevertheless, suitable and realistic conversion factors can be calculated to reduce total landed catch error if all sources of variability are understood and future estimation procedures for conversion factors modified.

THE FUTURE

The collection of size information will continue to ensure that an accurate, long-term abundance index is available. However, the collection of monkfish length frequency data by observers at sea should be encouraged in an attempt to halt the use of broad size categories in length-based assessment models. Such data would provide more accurate conversion factors to be used in the estimation of total annual catch.

Examination of commercial nominal *cpue* data revealed a distinctly seasonal pattern, in all probability instigated by environmental factors beyond the scope of this study. The GLM, however, could be refined to take at least some environmental effects into account.

The conversion factors estimated during this study seem to be an improvement on the existing 3.04. However, data for monkfish conversion factor studies should be collected for each quarter of the year for the complete length range of fish being caught and for both sexes equally before Namibian fisheries management authorities implement an amended factor.

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