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COMPARISON OF HORSE MACKEREL LENGTH FREQUENCIES OBTAINED FROM RESEARCH VESSELS AND COMMERCIAL MIDWATER TRAWLERS: IMPLICATIONS FOR BIOMASS ESTIMATION

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The validity of abundance estimates from hydroacoustic surveys relies, *inter alia*, on the ability of the fishing gear on the research vessel to sample non-selectively. This study compares the length frequencies of Cape horse mackerel *Trachurus trachurus capensis* taken in Namibian waters by the R.V. *Welwitchia* and commercial midwater trawlers. Results indicate that the length distributions of catches taken by the *Welwitchia* were significantly different from those from commercial trawlers, with a greater proportion of fish >25 cm being sampled by the latter. Also, the biomass estimated per length-class from hydroacoustic surveys over the period 1994–2000 was compared with those from annual landings of the commercial fishery. The length distribution of horse mackerel in purse-seine catches compares favourably with those from the research vessel. However, comparisons with the midwater trawl catches indicated that the length frequencies obtained from research vessels during the years 1994–1997 underestimated the number of large fish in the population and biased the biomass in those years. From 1998 to 2000 the bias was negligible. The magnitude of the error varied between years, but it remained fairly low. To compensate for this bias, length distribution data from midwater trawlers should be integrated into the acoustic biomass calculation procedure.

Key words: acoustic estimates, avoidance, horse mackerel, length frequencies, trawl catches

The Cape horse mackerel *Trachurus trachurus capensis* is the most abundant commercial species in the northern Benguela. Over the past four decades, it has contributed an average of about 300 000 tons to the fishing sector, which currently constitutes about 10% of Namibia's gross domestic product (Boyer and Hampton 2001). The horse mackerel stock in Namibian waters is utilized by two fisheries, midwater trawl and purse-seine. The midwater trawl fleet uses trawl nets of 60 mm mesh to target adults (17–48 cm), which occur offshore of the 200 m isobath, whereas the purse-seine fishery uses nets of 12 mm mesh to catch juvenile horse mackerel (6–20 cm) inshore of the same isobath.

Sound management requires reliable information on population size which, for horse mackerel off Namibia is estimated on hydroacoustic surveys that have been conducted annually since Namibia's Independence in 1990. From 1990 to 1998 the surveys were conducted using the Norwegian research vessel *Dr Fridtjof Nansen*; thereafter, the Namibian research vessel *Welwitchia* took over the surveys (Anon. 1994, 1998, 1999). Because of lack of accurate data on horse mackerel age and growth, results from most stock assessment models are considered unreliable. Therefore, advice on the annual Total Allowable Catch (*TAC*) has been generated by applying a constant proportion of 26% to the acoustic estimate in order to give a fishing mortality (*F*) of 0.3. Because the acoustic estimates are regarded as absolute in setting the *TAC*, it is clearly crucial that they be very accurate.

The number of fish in each length-class is estimated from

$$N_i = A * S_A * \frac{p_i}{\sum_{i=1}^{n} \sigma_i \rho_i} \quad , \qquad (1)$$

where N_i is the number of fish in length group *i*, *A* the area covered by the target population (square nautical miles), S_A the average area backscattering rate (m^2 nautical mile^{-2}), p_i the proportion of fish in length group *i* and σ_i the acoustic backscattering cross-section (m^2) of fish with length *i*. The parameter σ is the equivalent of the target strength (*TS*) in the linear domain and can be determined from the relationship

$$TS = 10 \log\left[\frac{\sigma}{4\pi}\right] \quad . \qquad (2)$$

The *TS* of a fish is proportional to its length; for horse mackerel it is defined as

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$$TS = 20\log L - 72 \quad . \qquad (3)$$

Hence σ is proportional to the square of the length.

Because of the length dependence of the acoustic energy reflected by a fish, the reliability of biomass estimated during acoustic surveys depends, *inter alia*, on the ability of the fishing gear used to sample non-selectively. On average the length distributions of horse mackerel obtained from the research vessels have consistently been smaller than those from commercial vessels. This is assumed to be a reflection of the inefficiency of the research vessels at catching larger horse mackerel (Anon. 1998, 1999), creating a bias in estimating the size of the population hydroacoustically. Therefore, in order to improve the abundance estimates, it is desirable to determine and hence to compensate for the bias introduced by trawl avoidance.

Horse mackerel is a very active species with a presumed high capacity for net-avoidance. The shape and muscle structure of the genus *Trachurus* enables it to attain high swimming speeds, placing it next to the fastest swimmers, the tunas (Hunter 1971, Hunter and Zweifel 1971, Bond 1996). Furthermore, avoidance reaction to fishing gear is generally size-dependent (Hunter 1971), larger fish being more capable than smaller ones of attaining and sustaining higher swimming speeds (Beamish 1966, He and Wardle 1988, He 1991).

Most studies of gear selectivity are concerned with selection in the codend (Wysokiński 1989, Dealteris and Riedel 1996, Bethke *et al*. 1999). To capture horse mackerel in the lower size ranges representatively, a small mesh is fitted in the codend of the net used on research vessels. Therefore, of concern in this study is the bias caused by the erroneously low prevalence or absence of large fish as a result of their behavioural reactions to the net.

The main objective of this study was to investigate whether the research vessels *Dr Fridtjof Nansen* and *Welwitchia* obtained size distributions of horse mackerel that represented the underlying population, and if not, to estimate the size of the bias and to find means of correcting for it.

MATERIAL AND METHODS

Three different datasets were used to investigate the problem at hand, data from the annual acoustic biomass surveys for horse mackerel from 1994 to 2000, length frequency data from commercial catches (midwater and purse-seine fleets) from 1994 to 2000, and data collected from experiments conducted during surveys in 1999 and 2000.

Acoustic surveys

In all, 11 surveys have been conducted to determine the biomass and to advise on appropriate *TAC*s for horse mackerel since Independence. From 1990 to 1993 the surveys were not targeted specifically on horse mackerel, but on a mixture of pelagic species, sardine *Sardinops sagax*, anchovy *Engraulis capensis*, red-eye round herring *Etrumeus whiteheadi* and juvenile horse mackerel, and hence were not considered in this analysis. After 1993, surveys were carried to target horse mackerel.

The surveys covered the assumed area of horse mackerel distribution, from the Lüderitz upwelling cell at 26°S into Angolan waters at about 16°S. The range in water depths covered varied between surveys, but was in general from 15 to 1 500 m. To facilitate interannual comparisons between biomass and catches, only data collected in Namibian waters (17°15´–26°00´S) were used for the analysis. The annual design of the surveys was in general similar, except in 1994 when zigzag instead of parallel transects were used in areas of low fish densities.

Standard procedures for determining length frequency were adopted (Anon. 1994, 1998, 1999). For large catches, a subsample of two baskets was taken from the catch and weighed. The mass of the total catch of horse mackerel was estimated from the number of baskets on deck and the species composition of the trawl. To determine the size distribution of the catch, a sample of at least 100 fish was measured for total length, to the nearest 0.5 cm (*Welwitchia*) or 1.0 cm (*Dr Fridtjof Nansen).*

When the total catch was small, it was sorted for species composition and all horse mackerel weighed and measured. To minimize the influence of unrepresentative trawls, all trawls were weighted (W_1) so that hauls containing few individuals (<100) were given proportionately low weighting and those with more than 100 fish equal weighting (= 1). The samples were further weighted by the S_A in the vicinity of the trawl, such that

$$p_i = \frac{n_{i1}}{\sum n}\left[w_1 \left(\frac{S_{A1}}{\sum S_A} \right) \right] \quad , \qquad (4)$$

where n_1 is the number of fish sampled in length group i in trawl 1, and S_{A1} is the average backscattering value for the area represented by trawl 1.

Length frequency sampling of commercial catches

From 1994 to 1996, length frequency data were collected at sea on an *ad hoc* basis from midwater

Table I: Hauls conducted by the R.V. *Welwitchia* and commercial trawlers for trawl comparisons in 1999 and 2000

Date	Start time	Vessel	Start position	End position	Duration (min)	Depth of headrope (m)
14/2/99	00:30	*Marshal Yakubovskiy*	17°50´S, 11°26´E	17°40´S, 11°24´E	90	30
14/2/99	16:34	*Welwitchia*	17°50´S, 11°15´E	17°51´S, 11°17´E	19	300
15/2/99	03:15	*Mars*	17°23´S, 11°23´E	17°25´S, 11°23´E	195	30
16/2/99	06:40	*Mars*	17°32´S, 11°25´E	17°18´S, 11°22´E	240	180
16/2/99	13:00	*Mars*	17°36´S, 11°26´E	17°26´S, 11°24´E	145	140
15/2/99	07:16	*Welwitchia*	17°30´S, 11°25´E	17°30´S, 11°26´E	13	66
16/2/99	16:36	*Welwitchia*	17°30´S, 11°25´E	17°33´S, 11°26´E	36	130
16/2/99	15:16	*Welwitchia*	17°27´S, 11°25´E	17°25´S, 11°24´E	21	202
16/2/99	18:50	*Welwitchia*	17°35´S, 11°26´E	17°39´S, 11°26´E	60	68
25/1/00	14:00	*Marshal Yakubovskiy*	18°31´S, 11°29´E	18°29´S, 11°31´E	390	180
25/1/00	08:55	*Northwind*	18°52´S, 11°28´E	18°35´S, 11°28´E	240	170
25/1/00	07:59	*Welwitchia*	18°30´S, 11°31´E	18°30´S, 11°30´E	30	154
25/1/00	11:17	*Welwitchia*	18°31´S, 11°28´E	18°29´S, 11°27´E	26	218

trawlers. Thereafter, the length frequency data were collected routinely on a daily basis at sea by trained observers. A random sample of 200 fish was taken from each haul, either from the deck or the conveyor belts. Length frequency measurements were made to the nearest 1.0 cm.

Purse-seined horse mackerel samples fwere collected at the landing port of Walvis Bay during off-loading. The fish were collected at fixed intervals on the conveyor belt while being pumped into the factory. Samples were sorted to determine species composition and a random subsample of 50 fish was taken for length frequency analysis. Fish lengths were recorded to the nearest 0.5 cm and weights to the nearest 0.1 g.

A two-stage raising procedure was used to convert the length frequency samples from the commercial fleets to the total numbers of fish landed monthly. The length frequencies from individual samples were raised first to the weight of each catch, and then to the weight of the monthly landings. Because the weight of individual fish was not recorded (at sea) in the midwater samples, the length-weight relationship obtained during the acoustic surveys was used as the raising factor. After such correction, the monthly landings per length-class were summed (by simple addition) to produce a length distribution of the annual catch made by each fishery.

Parallel trawl comparison tests

Before replacing the *Dr Fridtjof Nansen* as research platform for the surveys, there was some doubt as to whether the *Welwitchia* would be able to catch horse mackerel, especially large fish. Therefore, during the first *Welwitchia* survey, several trawls were conducted in parallel with commercial trawlers to permit comparison of length distributions. This practice was repeated during the survey in 2000. The experiments were conducted randomly and neither the area nor the commercial vessels involved were selected *a priori*.

In 1999, comparisons were made with two commercial vessels, the *Marshal Yakubovskiy* and the *Mars*. Owing to time constraints, only one trawl comparison was made between the *Marshall Yakubovskiy* and the *Welwitchia*, the trawls by both vessels being conducted at 17°50´S, but that by the *Welwitchia* in shallower water (Table I). Also, by the time the *Welwitchia* got its trawl in the water, the fish had migrated into midwater, which explains the difference in trawl depth. Seven trawls, four by the *Welwitchia* and three by the *Mars*, were used in the comparison between those two vessels. The trawls were made within a small area bounded by latitudes 17°18´ and 17°36´S and longitudes 11°22´ and 11°26´E. Two of the trawls by the *Welwitchia* were conducted along the middle section of the *Mars* trawl path. The trawls were pooled by gear type and compared as if they were single samples.

During the survey in 2000, two trawl samples by the *Welwitchia* were compared with samples collected from two commercial vessels, the *Marshal Yakubovskiy* and the *Northwind*. The trawls were conducted around 18°30´S, 11°28´E, but that by the *Northwind* covered a longer longitudinal distance. The two trawls by the *Welwitchia* were combined.

A Kolmogorov-Smirnov test was used to compare the size distribution of fish in the midwater and sample trawls. The selection curve determined by De Villiers (1980) for a typical midwater net used on commercial trawlers was used to correct for selectivity differences attributable to a differing mesh size in the codend of the commercial and survey sample gear. The typical midwater trawl net described by De Villiers (1980) for horse mackerel has a retention rate at L_{50} of 23.5 cm and at L_{25} of 21.8 cm.

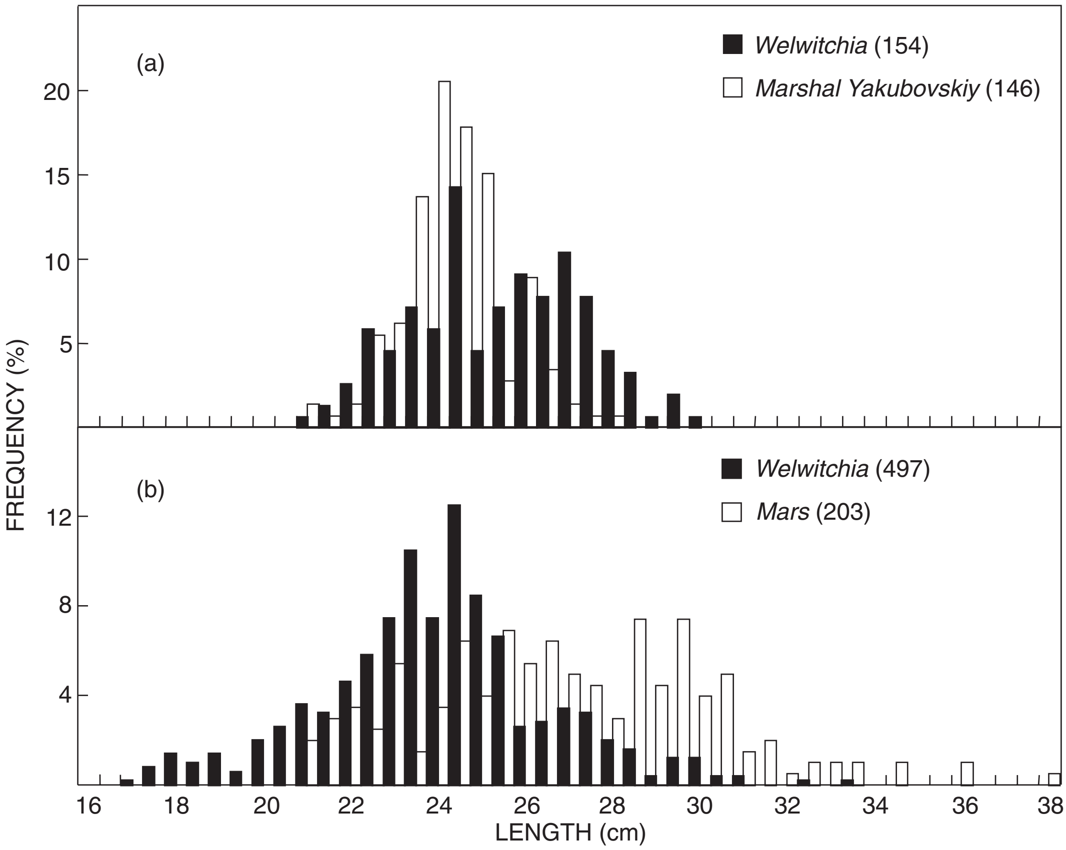

Fig. 1: Length frequency distributions of fish sampled from (a) the *Welwitchia* and the *Marshal Yakubovskiy*, and (b) the *Welwitchia* and the *Mars* in 1999. Numbers in parenthesis represent sample sizes

Comparison between acoustic estimates and catches

To estimate the bias attributable to sample trawl avoidance, it was assumed that the acoustic index would be proportional to the total number of fish in the population each year.

The raised annual catches by length-class from the two fisheries were pooled and used in this analysis. The underestimate of biomass (B_u) was obtained by subtracting the total number of fish in each length-class in the commercial catches (C_l) from the corresponding length group estimated acoustically (A_l). The difference (in numbers) in each length-class was converted to weight using a length-weight relationship (W_l) from each of the surveys. All length-classes where the catch exceeded the acoustic estimate (mostly lengths >25 cm) were summed as an indication of B_u, i.e.

$$B_u = \sum_{l=25}^{l=n} \left[\left(A_l - C_l \right) W_l \right] \quad . \qquad (5)$$

RESULTS

The results of the trawl comparisons between the *Welwitchia* and the *Marshall Yakubovskiy* in 1999 are presented in Figure 1a. The length distribution of fish caught by the *Welwitchia* differed significantly from that of the *Marshal Yakubovskiy* ($p < 0.05$). Although the distributions of fish by the two vessels were similar, 21–30 cm for the former and 21–28 cm for the latter, the *Welwitchia* caught a higher proportion of large fish (>27 cm). The modal length of the fish in both

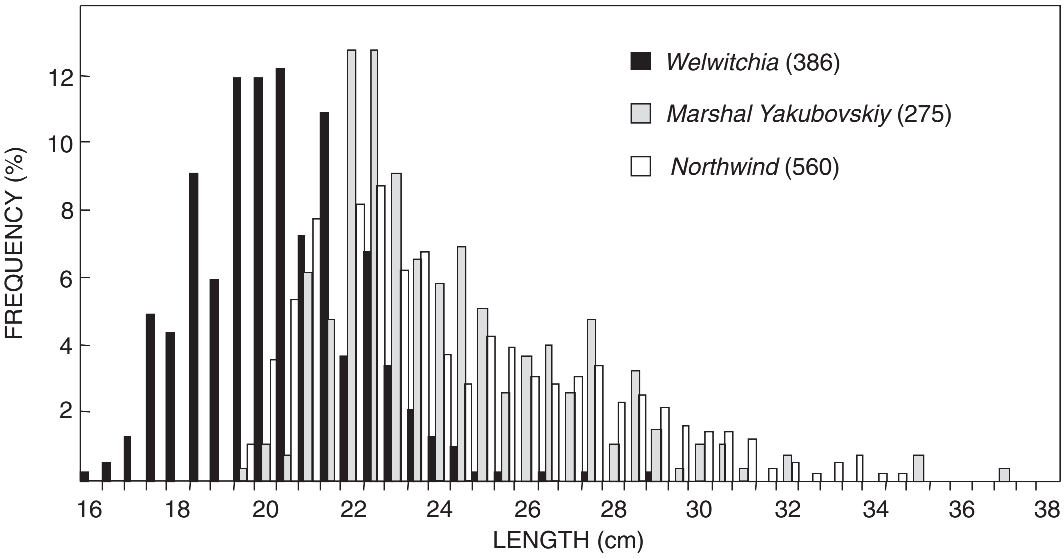

Fig. 2: Length frequency distributions of fish sampled from the *Welwitchia*, the *Marshal Yakubovskiy* and the *Northwind* in 2000. Numbers in parenthesis represent sample sizes

samples was also approximately the same.

There was a significant difference ($p < 0.05$) between the relative size frequency of fish caught by the *Mars* and the *Welwitchia* in 1999 (Fig. 1b). The size of fish caught by the *Welwitchia* ranged between 16 and 34 cm (modal length 24 cm), whereas the *Mars* caught fish between 21 and 40 cm, with a peak at 27 cm, indicating that the research vessel sampled horse mackerel that were on average smaller than those caught by the *Mars.*

The sample from the *Welwitchia* was also significantly different ($p < 0.05$) from that of the commercial trawlers in 2000 (Fig. 2). However, the differences were more pronounced in 2000 than in 1999. Although there was some overlap in the length distributions obtained with the *Welwitchia* and the two commercial vessels (19–24 cm), the *Welwitchia* caught more small fish. The fish caught by the *Welwitchia* ranged in size from 16 to 25 cm, but most fish were <20 cm. The length distributions of horse mackerel caught by the two trawlers were similar, with a modal fish length of about 23 cm.

Figures 3 and 4 reflect the relative length frequencies and the absolute numbers of horse mackerel per length-class >20 cm obtained from surveys and the midwater fishery from 1994 to 2000. Figure 3 is included to show the complete relative length distribution of fish caught by the research vessels in comparison with those made by the commercial vessels. Figure 4 only shows length-classes >20 cm, because it was in the larger size-classes that the number of fish estimated in the catch exceeded those estimated acoustically.

The shape of the distribution curves of fish from the purse-seine fishery compared favourably with those from the research vessels and hence will not be

Table II: Total acoustic biomass, annual catch, underestimate of biomass (B_u) and the relative difference between the underestimate and the acoustic estimate for Cape horse mackerel off Namibia, 1994–2000

Parameter	1994	1995	1996	1997	1998	1999	2000
Acoustic estimate (tons)	1 444 193	1 407 210	974 016	781 590	1 914 700	1 860 000	1 470 000
Annual catch (tons)	364 000	310 000	320 000	300 000	311 000	321 000	350 000
B_u	159 553	18 575	30 348	27 580	70	7 011	1 511
% difference	11.0	1.3	3.1	3.5	0.0	0.4	0.1

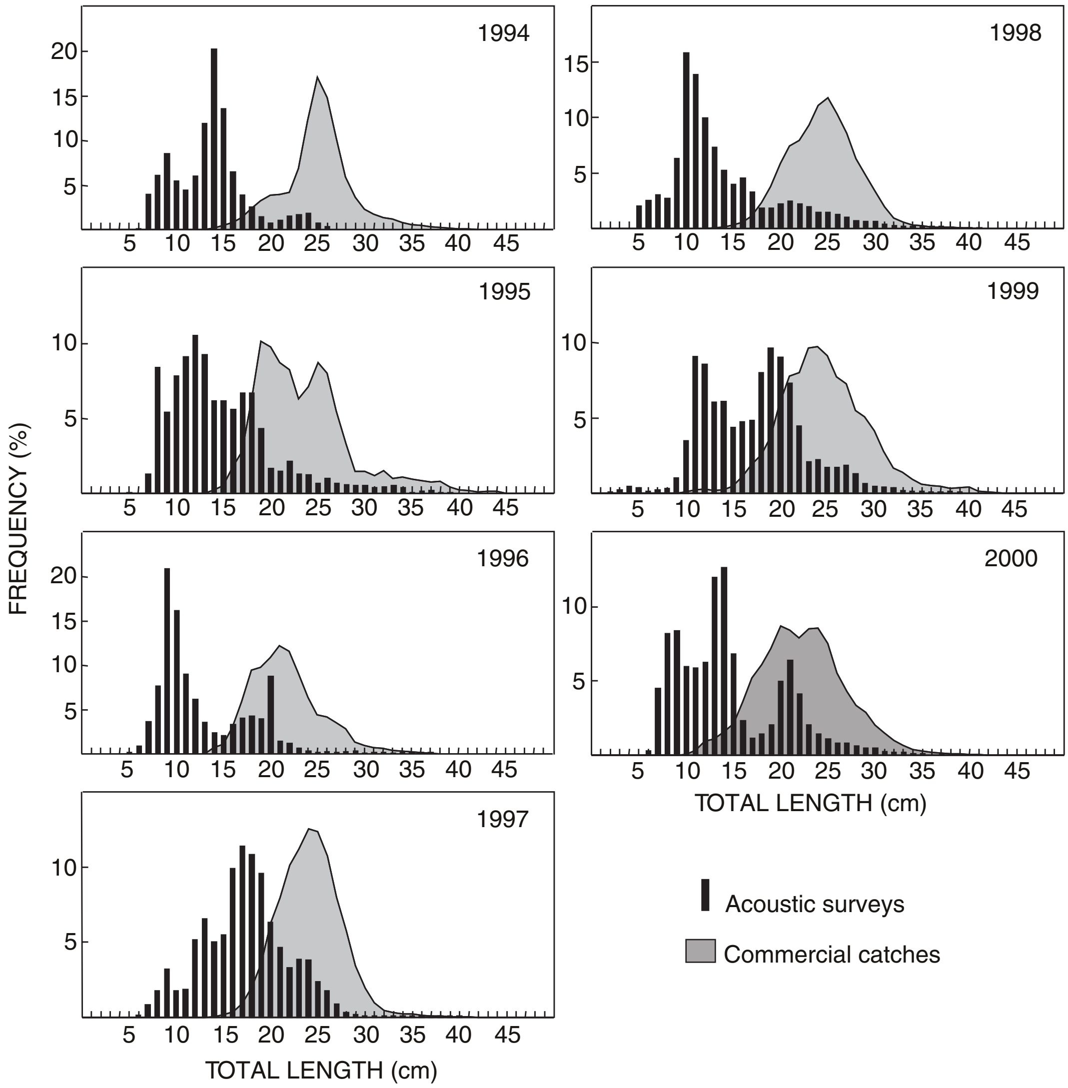

Fig. 3: Length frequencies of horse mackerel obtained during acoustic surveys and from commercial midwater trawl catches, 1994–2000

discussed further. However, the midwater trawlers caught fish as large as 45 cm, whereas the maximum length of fish sampled during the acoustic surveys was 38 cm (Fig. 3). Most of the fish caught by the midwater trawlers were about 25 cm long, but adult fish in acoustic samples varied between 20 and 23 cm. In all the surveys, horse mackerel <25 cm constituted 95% of the total estimated biomass.

The absolute numbers of fish determined acoustically were higher than those in the catches up to the 25 cm length-class. From that length onwards, with the exception of 1998, the commercial catch numbers exceeded the numbers estimated acoustically (Fig. 4).

The underestimates of biomass and the relative difference each year are given in Table II. In 1994, 159 000 tons or ~11% of horse mackerel were missing from the acoustic biomass estimates. In the period 1995–1997, the difference was smaller, respectively 1.3, 3.1 and 3.5%. Thereafter, the difference was negligible.

It must be stressed that the fishery only harvests a

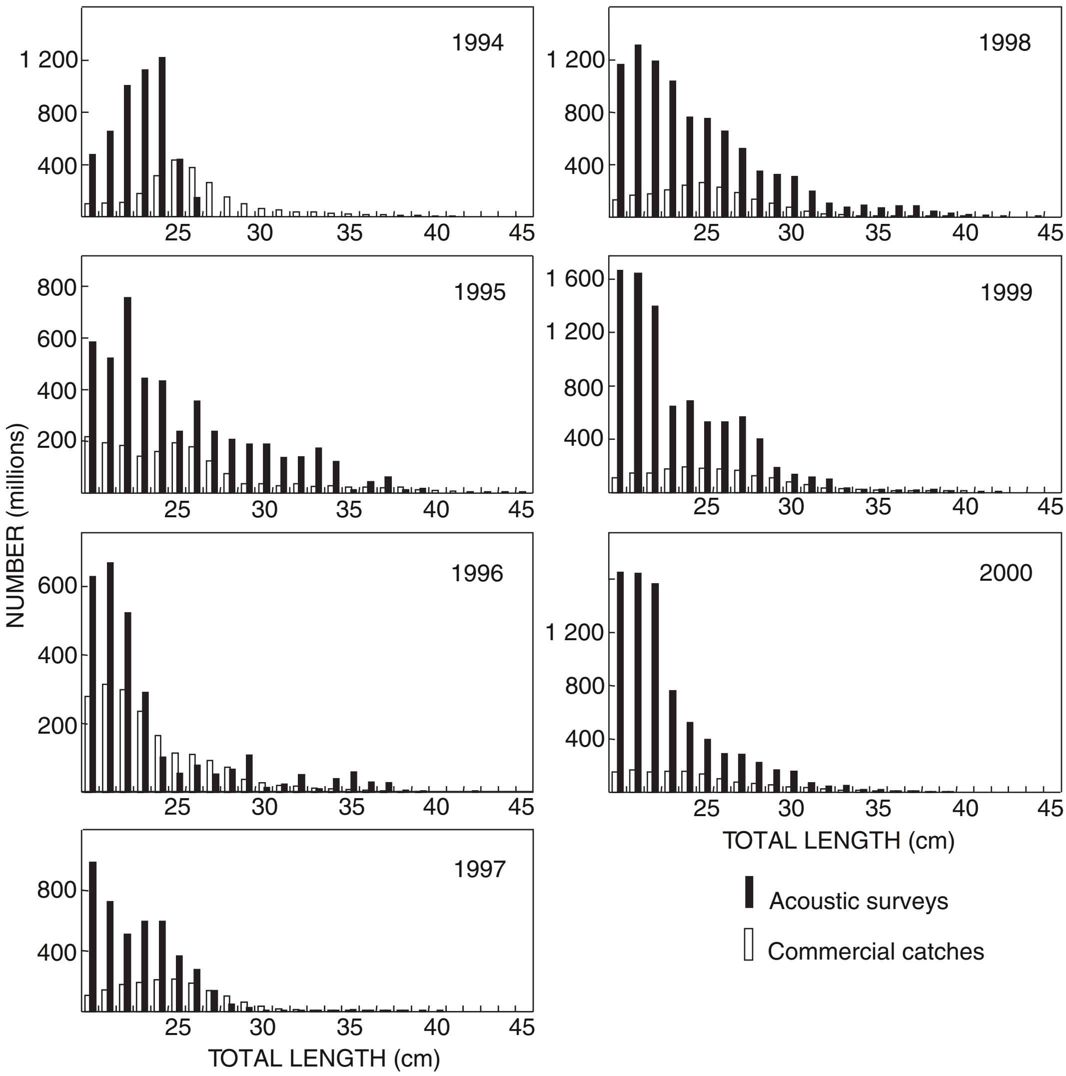

Fig. 4: Absolute number of fish per length-class estimated hydroacoustically and in the commercial catches, 1994–2000

fraction of the total stock and hence these underestimates of biomass should be regarded as minimum.

DISCUSSION

Length distribution samples are indispensable in the conversion of echo-integration values to number of fish and biomass. The acoustic backscattering area is proportional to the square of the total fish length (MacLennan and Simmonds 1992). Because sigma increases with fish length, the number of fish will be overestimated when mean length is underestimated. However, because the weight of the fish increases with fish length according to the formula

$$W = aL^b \quad , \tag{6}$$

where a ~ 0.01 and b ~ 3, total biomass (B) will be underestimated. The extent of the error will depend on the length-weight relationship of the population

Table III: Comparisons of vessel size and trawl gear used by the research vessels and a typical midwater trawler

Parameter	*Welwitchia*	*Dr Fridtjof Nansen*	Midwater trawler (Meridien type)
Tonnage (grt)	490	1 444	2 500–4 407
Length (m)	47.28	56.75	104
Width (m)	8.3	13	16
Horsepower (bhp)	1 400	2 400	7 000
Tow duration	<30 min	<30 min	Average 4 h
Towing speed (knots)	3.5–5	3–4	>5
Gear type	Engels 308	2 Åkrehamn 320 and 486	Mostly Russian manufactured trawls
Codend mesh size (mm)	12	20	>60
Trawl doors	Polyice	Tyboroen	Unknown
Area (m^2)	4.2	7.8	10
Weight (kg)	900	1 670	2 200
~ Vertical opening (m)*	10–12	10–20	60–80
~ Horizontal opening (m)*	30	41.2 and 58	120
~ Door distance (m)*	60–70	60–110	150–180

* Dependent on trawl speed, sweep length and wire length

and hence will vary seasonally and annually. If the actual average sigma is $\bar{\sigma}$, then the actual number of fish insonified will correspond to

$$\rho_A = \frac{S_A}{\bar{\sigma}} \quad . \tag{7}$$

The difference between the estimated and the actual number of insonified fish ($\Delta\rho_A$) will, therefore, be

$$\Delta\rho_A = \hat{\rho}_A - \rho_A = \frac{S_A * A\left(\bar{\sigma} - \hat{\sigma}\right)}{\left(\bar{\sigma} * \hat{\sigma}\right)} \quad . \tag{8}$$

This number will be positive when the mean length of the population is underestimated and negative when the mean length is overestimated. The error in biomass (ΔB) will hence be

$$\Delta B = \hat{B} - B = \hat{\rho}_A * \hat{w} - \rho_A * \overline{w} \quad , \tag{9}$$

where $\hat{B}$ is the estimated biomass, B the actual biomass, $\hat{w}$ the estimated mean weight and w the actual mean weight. This figure will, however, be negative when the mean length of the population is underestimated and positive when the mean length is overestimated.

Results of the current study suggest that the length distribution of horse mackerel obtained during acoustic surveys results in an underestimate of total biomass. Although individual trawls may yield large horse mackerel, the *Welwitchia* in general is not efficient at catching large horse mackerel, particularly fish >25 cm. Apart from one trawl, during the comparisons in 1999, when the *Welwitchia* landed a bigger proportion of large fish, the research vessel consistently oversampled smaller fish. In that particular instance the trawling speed (speed over ground) was unusually high, 5.3 knots compared to 3.3–4.2 knots for most other trawls, perhaps providing the reason for the anomaly.

Avoidance by large horse mackerel of *Welwitchia* trawl gear is perhaps better reflected by the comparisons made for 2000 (Fig. 2). It is noteworthy that, in this set of comparisons, the disparity between the length distributions occurred despite one of the trawls by the research vessel having been made at about the same time and depth, and along the same trail of fish. The two variables during this trawl were the speed, which for the *Welwitchia* was 4.2 knots and for the commercial vessel about 6 knots, and tow duration (Table I).

Differences in biomass between the acoustic estimates and the catches further support the contention that the research vessel is unable to catch larger horse mackerel representatively (Fig. 4). As mentioned already, the acoustic index is currently assumed to be an absolute estimate of horse mackerel population size off Namibia. It should, therefore, be higher than the commercial catches. However, in this exercise, the midwater commercial catches from 1994 to 1997 contained more fish >25 cm. Although the dimensions of the net used on the *Dr Fridtjof Nansen* are somewhat different from those on the *Welwitchia* (Table III), the two appear to have similar selective properties, because the size distribution of horse mackerel from the two research vessels is similar. The high losses experienced in 1994 can be explained by the survey design that year, which was restricted to a maximum depth of 350 m, so not covering the entire stock (Table II). Therefore, the trends in biomass can be regarded as comparable and, in relative terms, to be reflecting changes in the population over time.

Several factors, including the dimensions of the gear, fishing operations, fish behaviour and availability, may have caused the differences in the size of fish caught by the two research and the commercial vessels (Wileman *et al*. 1996, Winger *et al*. 1999). Generally, bigger trawls are more effective at sampling large fish (Wileman *et al.* 1996, Bethke *et al.* 1999). The vertical opening of the net on the research vessels is about 10 m compared to >60 m on the commercial vessels (Table III). Therefore, more fish, especially larger active fish, would be expected to escape from the front of the research vessel's net.

The behaviour of horse mackerel in reaction to the trawl plays an important role in their capture. Cape horse mackerel *Trachurus t. capensis* reacted to nets by diving, shown by a drop in the target strength measured during trawling (Barange and Hampton 1994). It is, however, not possible to draw inferences from that study as to whether diving enhances or decreases the chances of vertical escape from the path of the net.

The divergence in the size distributions of the two types of vessels can also be related to the duration of the trawling operation on commercial vessels, an average of 4 h compared to about 30 minutes for the research vessels. In other studies, direct observations of the swimming performance of species such as saithe *Pollachius virens*, cod *Gadus morhua*, sprat *Sprattus sprattus*, sandeel *Ammodytes* spp. and haddock *Melanogrammus aeglifinus* at the mouth of a trawl indicated that larger fish swim for very long periods before being captured (Wardle 1993). Given that horse mackerel can swim aerobically for at least 80 minutes (Wardle *et al.* 1996), a number of fish effectively herded in front of the sample trawl are expected to escape when the net is retrieved. Lengthening the tow duration might yield bigger catches but would not necessarily result in larger catches of big fish, because at high fish densities the net on the research vessel often becomes saturated within a few minutes.

Furthermore, the speed of trawling on research vessels is slower than on commercial vessels. In demersal trawls, for example, fish are effectively herded into the trawl path when the speed of the sweeps is equal to or greater than the swimming speed of the fish (Winger *et al*. 1999). If the same applies to pelagic trawls, then higher speeds of tow may be required to capture horse mackerel effectively. Assuming that the minimum swimming speed of Cape horse mackerel is similar to that demonstrated for *Trachurus symmetricus* by Hunter (1971), a towing speed >3.5 knots would be required to catch horse mackerel >23 cm long representatively. According to Hunter and Zweifel's (1971) derivation, horse mackerel 19 and 36 cm long have minimum swimming speeds of 1.0 and 3.0 m s^{-1} respectively. On average the research vessels tow at 1.8 m s^{-1} (3.5) knots and thus can only effectively catch horse mackerel <23 cm. Conversely, commercial trawlers tow at a minimum speed of about 2.6 m s^{-1} (5 knots) and should effectively catch fish up to 31 cm long. This is in accordance with the overall length distributions obtained during the annual acoustic surveys and the commercial midwater catches (Fig. 3). However, results of the parallel trawl comparisons were inconclusive. For example, two trawls by the *Welwitchia* that targeted the same aggregation of fish contained fish with different modal lengths (25 and 28 cm), despite being conducted at the same speed. Therefore, the results obtained from the trawl comparisons in this study should be interpreted with caution, because the number of hauls made was not large enough to eliminate the effect of haul-to-haul variability. Moreover, the experiment did not properly address conditions such as stock composition, distribution and density, trawling speed, direction and time, and similarity of catch rates, all of which could have had a significant effect on the results.

The small codend used to increase the retention of small fish on the research vessel creates a dilemma, because it reduces the maximum towing speed. Flow resistance and the resulting drag increases with smaller meshes. In other words, there is seemingly a trade-off between catching small and large fish effectively.

THE FUTURE

It is evident that trawl avoidance does affect biomass estimates of horse mackerel, but the bias is relatively small (Table II). The bias does not seem to be explained by differences in research vessels and trawl gear.

Considering that the bias introduced by the use of a non-representative length distribution is small compared to others identified for horse mackerel in Namibia, such as the use of a *TS* for a different species, S_v threshold, effect of bubbles, vertical migratory behaviour and impartial coverage of the stock, it is suggested that future research focus on quantifying some of those aspects mentioned. To compensate for the loss of big fish as a result of avoidance, a more pragmatic approach would perhaps be to integrate commercial samples obtained during the survey period into the biomass calculation process. Ways to combine length distribution from the midwater catches with those from surveys to produce a true size distribution of the population should be investigated. Alternatively, ways to improve the catchability of large fish on the research vessel, such as with a larger net and towing faster for longer periods, as well as the use of commercial vessels to identify acoustic targets, could be attempted.

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