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An evaluation of the bottom trawl surveys in the Benguela Current Large Marine Ecosystem

BJØRN ERIK AXELSEN*,† AND ESPEN JOHNSEN†

Institute of Marine Research, P.O. Box 1870 Nordnes, NO-5817, Bergen, Norway

ABSTRACT

Demersal fish, shrimp and cephalopod assemblages on the continental shelves and slopes off Angola, Namibia and the southern and western coasts of South Africa have been monitored in terms of fisheries-independent trawl surveys since the 1980s. The time series have provided vital input to stock assessments and are widely used in studies of ecology and biodiversity. The objectives of this study were to evaluate the technical specifications of the vessels and trawls used, to examine effects of modifications on catching efficiency, and to assess implications of these modifications over time. We find that the demersal trawl data collected in South Africa are not comparable with those of Namibia and Angola, and that the time series of Angola and Namibia contain inherent differences in terms of catchability of bottom dwellers. The introduction of smaller bobbins gear on the RV *Dr. Fridtjof Nansen* in 1994 increased the catchability of bottom-dwelling species, and catch rates of monkfish and sole were higher in surveys with commercial vessels than the RV *Dr. Fridtjof Nansen*. We recommend that temporal trends are interpreted with caution and that time series for the three countries are viewed in isolation.

Key words: abundance, Benguela Current Large Marine Ecosystem, bobbins, constraint rope, demersal, *Dr Fridtjof Nansen*, fish, tickler chain, time series, trawl

INTRODUCTION

The Benguela Current Large Marine Ecosystem (BCLME) is a wind-driven coastal upwelling system located along the southern and western coasts of southern Africa (Shannon, 1985; van der Lingen *et al.*, 2006), and is one of the most productive ecosystems in the world (Shannon, 1985; Hutchings *et al.*, 2009). The demersal fish, shrimp and cephalopod assemblages over the continental shelves and slopes of the BCLME have been monitored in terms of fisheries-independent trawl surveys since the 1980s. The first demersal trawl surveys with the RV *Dr. Fridtjof Nansen* off Angola and Namibia were performed in 1985 and 1990, respectively (Anon., 1986; Sætersdal *et al.*, 1999). In Angola the surveys were not carried out regularly during the early years, but annual surveys have been carried out in both countries since 1991. These time series represent vital input to national stock assessments of shrimp in Angola (Sætersdal *et al.*, 1999) and demersal fish in Namibia, Angola (Sætersdal *et al.*, 1999) and South Africa (Rademeyer *et al.*, 2008).

The data from these surveys have contributed significantly to our understanding of demersal assemblages in the region (Bianchi, 1992; Bianchi *et al.*, 2001, 2004; Hamukuaya *et al.*, 2001), and several analyses of the spatial dynamics, size and species structure of the commercially and ecologically important hake species (*Merluccius capensis* and *Merluccius paradoxus*) in Namibia (Burmeister, 2001, 2005; Johnsen, 2003; Johnsen and Kathena, 2012), and large-eye dentex (*Dentex macrophthalmus*) in Angola (Kilongo *et al.*, 2007) are based on these data. The time series data have also been used in environmental studies (Bartholomae and van der Plas, 2007), identification of marine biodiversity hotspots (Kirkman *et al.*, 2013) and assessments of changes in distribution and range shifts in demersal fish (Yemane *et al.*, 2014). Such studies presume constant sampling efficiencies for the target species throughout the time series (e.g., Bianchi *et al.*, 2004). This assumption is met in that the Gisund Super trawl has been used as a standard in all the surveys carried out by the two *Dr. Fridtjof Nansen* vessels (Sætersdal *et al.*, 1999; Jørgensen *et al.*, 2007). However, in the course of these investigations, several changes in vessels and trawl configuration have been implemented. These include change of trawl doors, modification to the ground gear, and introduction of tickler chains and constraint rope, as well as changes

**Correspondence*. e-mail: bjorna@imr.no †Equal authorship.

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to the survey design, all of which may have affected catching efficiency (Iqbal, 1993; Anon., 1995a; Maartens, 1999; Johnsen and Kathena, 2012).

The performance of demersal trawls is essentially determined by their geometry and bottom contact (Main and Sangster, 1983). Catching efficiency and selective properties are thus affected by a number of factors such as the design of the net sections and flotation, the type and configuration of ground gear and trawl doors, towing speed, bottom conditions (Main and Sangster, 1979) and noise emitted by the vessel and gear during operation (Main and Sangster, 1981; Ona and Godø, 1990; Engås, 1994). Efficiencies may thus differ between vessels, even when the same gear is used (Engås and Godø, 1989; Rose and Walters, 1990), and modifications in the gear can have profound effects on trawl performance. The catch process, i.e., from when the targets first are affected by the presence of the ship or trawl, through to being retained in the codend, can be divided into four stages: (i) in front of the doors, where targets may alter their behaviour in response to noise emitted by the ship or its propulsion system, the trawl wires or the ground gear; (ii) in the sweeping zone between the trawl doors and the wings, where targets may be herded towards the centre of the trawl path and enter the trawl mouth, or escape; (iii) in the trawl opening, where the targets may enter the trawl or escape beneath the fishing line or over the headline; (iv) inside the trawl, usually at the codend, where targets may escape through the meshes (mesh selection) (Wardle, 1986; Godø and Walsh, 1992; Godø, 1994). Modifying the configuration of trawls may influence their performance in any of the four stages of the catch process. Impacts may differ between species and size groups, and may be further modulated by environmental conditions such as ambient light, temperature and oxygen (Engås, 1994; Jørgensen *et al.*, 2007). Identifying and assessing effects on given species and size groups require dedicated comparative fishing trials (Pelletier, 1998), complicating the prediction of effects of a given modification.

This study focuses on the changes in the vessels and fishing gears used in the BCLME region, in order to identify the type of changes in catching efficiencies that should be expected, and when they are likely to occur. Specific objectives were: (i) to evaluate the technical specifications of the vessels and trawls used on the demersal surveys from 1985 until the present, (ii) to examine specific effects of modifications on catching efficiency of bottom dwelling species, and (iii) to assess trends in catch rates over time in light of concurrent methodological changes.

METHODS

Vessels and fishing gears

The *Dr. Fridtjof Nansen* research vessels have conducted annual demersal trawl surveys in Namibia and Angola as well as intermittent surveys in South Africa. The RV *Dr. Fridtjof Nansen* operated in the region from 1985 to 1993 and was replaced by the new *Dr. Fridtjof Nansen*, which is still in operation, in 1994. In Angola the time series were initiated by the old *Dr. Fridtjof Nansen* in 1985, while the new vessel took over in 1994. The time series in Namibia commenced with the old *Dr. Fridtjof Nansen* at independence (1990–1993) and continued with the new *Dr. Fridtjof Nansen* (1994–1999) until she was replaced by commercial trawlers from 2000 onwards. In South Africa the FRS *Africana* has been utilized throughout the time series (1984 until the present), with gaps in 1989, 2000, 2001 and 2008 due to technical problems with the vessel. The new *Dr. Fridtjof Nansen* replaced the *Africana* on the west coast surveys in 2000 and 2001. The technical specifications of the vessels and their respective periods of use in Angola, Namibia and South Africa are shown in Table 1.

In South Africa, the *Africana* utilized two different demersal trawls, a 2-panel Old German 180 in combination with WV demersal trawl doors and a chain and footrope ground gear (Atkinson *et al.*, 2011a), and a four-panel New German 180 trawl with Morgere 'Butterfly' combi doors and a modified rockhopper ground gear. On all surveys made by the old and the new *Dr. Fridtjof Nansen* vessels, a Gisund Super 2-panel demersal sampling trawl (Sætersdal *et al.*, 1999; Jørgensen *et al.*, 2007) was utilized, at first using Waco combi trawl doors (Angola 1985–1994, Namibia 1990–1995) and subsequently Thyborøn Type 7 combi doors. On the surveys in Namibia with commercial trawlers the same trawl and ground-gear configuration was used as for the surveys with the new *Dr. Fridtjof Nansen*, however, these vessels used Steinshamn V demersal trawl doors. Table 2 summarizes the technical specifications of the trawl configurations used. In the following we look closer into modifications within the time series in Angola and Namibia, where similar trawl configurations have been used. Detailed inventories of the trawl gear configurations for all surveys in Angola and Namibia are provided in Appendix 1 and 2, respectively.

Several modifications to the configuration of the Gisund Super demersal trawl used on the *Dr. Fridtjof Nansen* may have affected the time series for Angola and Namibia. The Gisund Super trawl was fitted with a rubber-bobbins ground gear (Fig. 1); however, with

Table 1. Vessels, technical specifications and periods of use for demersal trawl surveys in Angola, Namibia and South Africa (N/A, not available).

					Country		
Vessel	LOA (m)	Power (BHP)	GRT (tons)	Year built	Namibia	Angola	South Africa
Old *Dr. Fridtjof Nansen*	46.4	1500	491	1984	1990–93	1985–93	
New *Dr. Fridtjof Nansen*	56.8	2654	1444	1993	1994–99	1994–2013	2000–2001, 2008
Africana	77.9	2400	2471	1982			1984–2013
Katima	58.1	N/A	829	1973	1997		
Echelar	75.0	1798	2205	N/A	1997		
Oshakati	58.1	N/A	849	1974	1998, 2001		
Garoya	56.7	1739	1088	N/A	1998		
Ribadeo	68.1	2399	1508	N/A	1999		
Frans Aupa Indongo	61.4	N/A	820	1974	2000		
Blue Sea 1	73.5	N/A	1104	1977	2002–13		

Table 2. Trawl configurations for vessels (DFN: *Dr. Fridtjof Nansen*) by year. Bottom trawls include Gisund Super (GS) [2 panels, headline: 31 m, footrope: 47 m, wingspread: 21 m], Old German 180 (OG) [180 feet circumference, 2 panels] and New German 180 (NG) [180 feet, 4 panels]. Ground gears include large bobbins gear (LB) [500 mm discs], small bobbins gear (SB) [305 mm], chain and footrope (CF) and Rockhopper (RH). Vertical openings and sweep lengths are given in m. Sweep lengths are listed as bridles/sweeps/backstrop, and total sweep lengths in brackets. Codend mesh sizes (mm) are listed as stretched mesh sizes of the codend/inner liner. 'P' denotes partly, indicating that only the aft part of the codend was fitted with an inner liner. Trawl doors include Waco combi (WC), Thyborøn type 7 combi (TC), Steinshamn V demersal doors (SV), WV demersal doors (WV) and Morgere 'Butterfly' combi doors (MC). Surface area (m^2) and weight of the trawl doors in air (kg) are indicated.

	Trawl configuration								Country		
Vessel	Type	Opening	Sweeps	Meshes	Gear	Doors	Area	Weight	Angola	Namibia	South Africa
Old DFN	GS	4.5–5.0	40/0/11 (51)	20/10	LB	WC	6	1200	1985–93	1990–93	
New DFN	GS	4.5–5.0	40/0/11 (51)	20/10	SB	WC	6	1200	1994	1994–95	
	GS	4.5–5.0	40/0/11 (51)	20/10	SB	TC	7.41	1720	1995–2012	1996–99	2000–2001, 2008
Commercial	GS	4.5–5.0	40/0/11 (51)	20/10	SB	SV	7.1	1500		2000–12	
Africana	OG	1.5–2.0	30/55/8 (93)	120/40 P	CF	WV	7.5	1500			1985–88, 1990–99, 2002–2003, 2006, 2010
	NG	4.2–4.4	30/13/8 (51)	60/40	RH	MC	5.5	1500			2004–2005, 2007–2009, 2011

the change of vessels from the old to the new *Dr. Fridtjof Nansen* in 1994, the diameters of the bobbins and Danlenos were reduced from 500 to 305 mm, reducing the total clearance distance from the fish line to the bottom from an estimated 722 to 525 mm (Table 3).

Tickler chains (Chittenden and Van Engel, 1972) were introduced on the *Dr. Fridtjof Nansen* in Angola as a standard from 1995 in response to trials carried out during the 1995 survey (Anon., 1995b). This was motivated by the assumption that they would stir up bottom-living species located on, or burrowed into, bottom sediments during trawling, and thereby reduce the likelihood of escapes under the fishing line (Engås and Godø, 1989; Jørgensen *et al.*, 2007). Tickler chains have been used on all subsequent surveys in this time series, apart from in 2002, when they were accidentally omitted. Tickler chains were used at all depths during the first survey in 1995, but only at depths greater than 300 m on the consecutive surveys, as their principal purpose was to increase catch rates of bottom dwellers such as monkfish (*Lophius* spp.), sole (*Austroglossus* spp., *Cynoglossus* spp. and *Dicologoglossa* spp.) and shrimp (*Aristeus varidens*, *Parapenaeus longirostris*) (Anon., 1995b). Tickler chains were not used

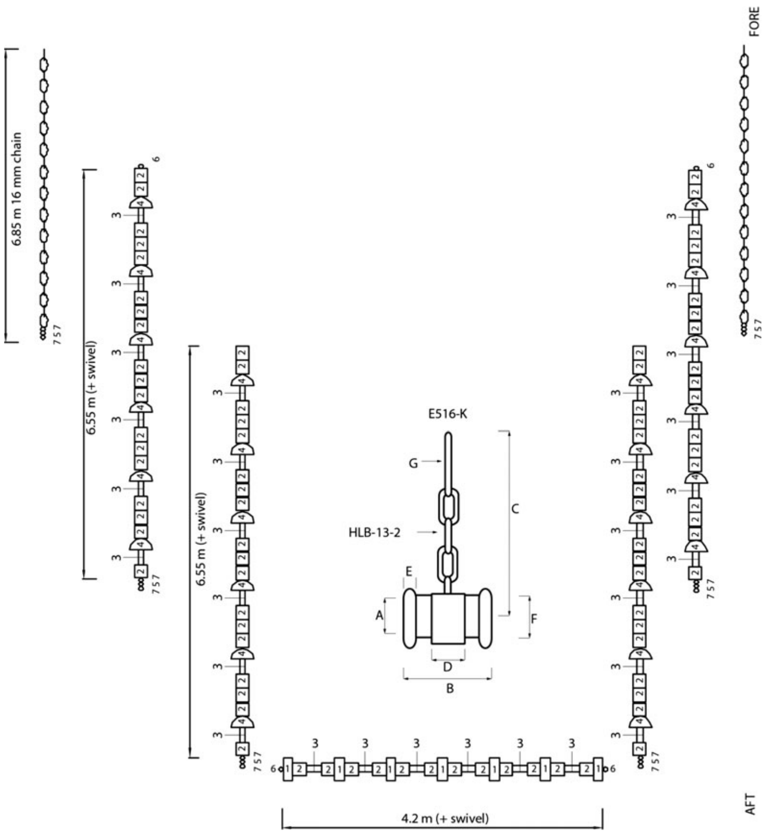


Figure 1. Schematic illustration of the bobbins roller gear of the new *Dr. Fridtjof Nansen*. 1: bobbin discs (Ø: 12″ = 305 mm); 2: spacer (Ø: 170 mm); 3: E516-K centre spacer (F) and chain (HLB-13-2) unit; 4: Danleno bunt bobbins (Ø: 305 mm); 5: swivel (19 mm); 6: chain (16 mm); 7: swivel-chain fixture. Dimensions of the E516-K spacer and chain unit: A: Ø = 65 mm; B: 200 mm; C: 360 mm; D: 60 mm; E: 19 mm; F: Ø = 83 mm (6.1 kg).

Table 3. Dimensions of the bobbins gears (illustration in Fig. 1) of the Gisund Super demersal sampling trawls utilized on the *Dr. Fridtjof Nansen* research vessels.

Specification	Old *Dr Fridtjof Nansen*	New *Dr Fridtjof Nansen*
Bobbins discs	500 mm	305 mm
Chain	460 mm	360 mm (C 12-125 STP)
Centre spacer	Ø: 83 mm (E 516)	Ø: 83 mm (E 516)
Fixture (fish line)	12 mm	12 mm
Clarence fish line-spacer	431 mm	414 mm
Clarence fish line-bobbins	222 mm	220 mm
Clarence fish line-bottom	722 mm	525 mm

in Namibia, apart from on one survey in 1995 when they were used experimentally in alternating tows.

A constraint rope mounted between the trawl warps (Godø and Engås, 1989) was introduced in Angola in 1995 and in Namibia in 1996. The constraint rope was about 9.5 m long, and was mounted at a distance of approximately 120 m from the doors, fixing the door spread at 50 ± 2 m. The constraint rope was only applied at depths greater than 80 m.

In the course of the time series there have been several advances in trawl monitoring technology, e.g., the development of wireless sensors mounted in the trawls that transmit trawl performance data in real time to the vessel operators. With the arrival of the new *Dr. Fridtjof Nansen* in 1994, a trawl monitoring system was introduced. The SCANMAR system is based on wireless sensors that among other things can record the depth, distance and clearance to the bottom *in situ*. This enabled far more precise estimates to be made of the starting time of trawl deployments as the trawl touched the bottom, improved the operators' ability to compensate for poor bottom contact, and reduced the risk of tearing the trawl during operations. The SCANMAR system was used routinely on all demersal surveys from 1994 onwards (Strømme and Iilende, 2001).

Survey design and onboard sampling

Angola. The first bottom trawl surveys with *Dr. Fridtjof Nansen* in Angolan waters was a series of four exploratory surveys conducted in 1985 (Anon., 1986;

Sætersdal *et al.*, 1999). The main purpose of this survey was to map the demersal resources and to obtain baseline estimates of their abundance (Sætersdal *et al.*, 1999). Between 1985 and 2001 the survey design was somewhat variable both in terms of coverage and season, as the main target species (shrimps *A. varidens*, *P. longirostris*, seabream *Dentex* spp. and hake *Merluccius* spp.) differed between surveys. During these years, the depth coverage also varied considerably, but trawl stations were consequently allocated along transects perpendicular to the coast. Since 2000, surveys have been standardized in the warm season (January–March) and transects have been fixed at approximately 15 nautical miles (nmi) apart, with sampling within pre-stratified depth bins (20–50 m, 50–100 m and 100-m bins from 100 to 800 m). This general design was in some cases modified somewhat in response to unsuitable bottom conditions or, in the northern part, to areas closed for fishing due to offshore petroleum activity. The trawl positions used in the 2000 survey were established as the standard for all subsequent surveys in the southern region (13°00′–17°15′S), while trawl positions used in the 2002 survey were established as the standard in the central and northern regions (06°00′–13°15′S) from 2003 onwards. Tow time was standardized to 30 min and towing speed over the bottom was standardized at 3 knots (3.0 ± 0.5 knots, 1 knot = 1.852 km h^{-1}).

Namibia. Between 1990 and 1996, trawl surveys were conducted in several seasons with some variation between years; since 1997 surveys have been standardized in the warm season (January–March). The main target species are hake (*M. capensis* and *M. paradoxus*). Trawl stations were distributed semi-randomly along transects located 20–25 nmi apart and oriented perpendicular to the coastline. Transect lengths ranged from 20 to 80 nmi, corresponding to a depth range of 90–600 m, with sampling within pre-stratified 100-m depth bins (Johnsen and Kathena, 2012). In shallow waters (<450 m bottom depth), trawls were hauled during the hours of daylight only, in order to reduce potential diel bias on catch rates (Walsh, 1991); waters deeper than 450 m were trawled both day and night (Johnsen and Iilende, 2007). Tow time was standardized to 30 min, apart from a few tows during the surveys in 1990 and 1991 where tow time was 60 min, presumably due to small catches being made. Towing speed was standardized at 3 knots.

South Africa. Trawl locations on the west coast surveys were sampled in January and February according to a stratified random sampling design. Survey lines were distributed randomly along the shelf within the depth range of 30–500 m, with sampling within pre-stratified 100-m depth bins (Leslie and Fairweather, 2008; Atkinson *et al.*, 2011a). Tow time and towing speeds were standardized to 30 min and 3 knots, respectively.

All catches are routinely sampled (or for large catches sub-sampled) for species composition by weight and numbers. Specialist taxonomists were invited to participate in some of the *Dr. Fridtjof Nansen* surveys. Sub-samples were analysed for length structures of the sampled fish. Total length was measured to the nearest 1 cm below from the tip of the snout to the longest lobe of the caudal fin, and carapace length to 1 mm below was recorded for shrimps (Sætersdal *et al.*, 1999). Sub-samples were also obtained for establishing length–weight relationships by measuring the total length to the nearest mm below and the total wet weight to the nearest 0.1 g below. Biological sampling (gender, gonad maturity) and morphometrics (otolith and scale samples) were performed for selected commercial species.

Comparative trawling trials

In Namibia, parallel trawling experiments were carried out between the new *Dr. Fridtjof Nansen* and commercial trawlers *Oshakati* (12–31 January 1998), *Garoya* (2–20 February 1998) and *Ribadeo* (11 January–21 February 1999) (Appendix 2) (Strømme and Iilende, 2001). The main motivation for these comparisons was to establish whether there were any systematic differences in catch rates of hake for intercalibration purposes (Strømme and Iilende, 2001). All vessels were equipped with the standard Gisund Super demersal trawl with equal configurations (small bobbins gear, constraint rope, no tickler chains), except that the commercial fishing vessels utilized Steinshamn V demersal trawl doors, whereas the *Dr. Fridtjof Nansen* used Thyborøn Type 7 Combi doors (Appendix 2). Here, these data have been reanalysed to investigate potential systematic vessel-related differences in catch rates of monkfish, sole and hake, and vessel-related differences in mean total lengths in hake. Zero catches were excluded, and data from both years were pooled in the comparisons for the catch rate analyses.

Two comparative studies were carried out with the new *Dr. Fridtjof Nansen* in 1995 to examine the effects of tickler chains mounted on the ground gear bobbins: alternate hauls in Namibia (Anon., 1995b), and pairwise comparison trials in Angola (Anon., 1995a). In both of these experiments the standard Gisund Super demersal trawl was used with equal configurations (Thyborøn doors, small bobbins gear, constraint rope) (Appendix 1). The tickler chains were used at all trawl depths. The species of primary concern in this regard were monkfish (*Lophius vomerinus*) and sole (*Austroglossus microlepis*) in Namibia, and monkfish (*Lophius vaillanti*), deep-sea red shrimp (*A. varidens*) and rose shrimp (*P. longirostris*) in Angola. To test the hypothesis that the introduction of tickler chains affected the performance of the trawl in Angola, catch rates (kg h^{-1}) of these species were compared between tows with and without the chain (N = 42). As the sampling during the Namibian experiment was not done in an alternating manner, mean catch rates of monkfish, hake and sole were calculated by nine depth-latitude strata (100–250 m, 251–400 m, 401–600 m, and 30–25°S, 25–21°S, 21–17°S) for stations with (N = 62) and without (N = 43) tickler chains and compared in a pairwise manner.

Only one trial comparing catches with the two trawl door types used on the new *Dr. Fridtjof Nansen* was performed, which was in Namibia in 1995 (Anon., 1995b). In this experiment the distance between the doors was approximately constant, as all tows were deployed at a bottom depth of about 300 m. The potential effect of the trawl door on hake and monk was examined here by comparing catch rates for tows using Waco and Thyborøn doors in a pairwise manner (N = 12).

All comparisons were done in a pairwise manner using the non-parametric Wilcoxon signed-rank two-sided test, using continuity corrections due to the heavily skewed distributions of the catch rates (Sheskin, 2011). The purpose of the comparisons was to determine whether predicted differences in catch rates of bottom-dwelling species were likely to be attributable to gear modifications. In this context, an alpha level of 0.05 was considered to indicate significant differences, and 0.10 to indicate probable differences.

Effects of gear changes over time

The reduction in bobbin disc size with the new *Dr. Fridtjof Nansen* reduced the clearance between the fish line and the bottom, which is expected to improve the catchability of bottom-dwelling species. We therefore predicted increased catch rates of bottom dwellers in Namibia in 1994. To evaluate this prediction, mean combined catch rates of monk and sole were calculated by nine depth–latitude strata (300–400 m, 401–500 m, 501–600 m, and 30–25°S, 25–21°S, 21–17°S) by survey, and plotted as a time series for the period from 1990 to 2008. The same prediction could not be made for Angola, as there were no surveys in the same season from 1990 to 1994, and in 1995 several gear modifications (trawl door type, tickler chains, constraint rope, trawl sensors) were introduced simultaneously (Appendix 1). From 1995 onwards, however, the trawl configuration in Angola has remained constant, apart from in 2002, when the tickler chains were omitted. We therefore predicted that combined catch rates of bottom dwellers monkfish and deep-sea red shrimp would drop in Angola in 2002. Mean catch rates were calculated for six latitude–depth strata (300–400 m, 401–500 m, 501–600 m, and 13–10°S, 10–6°S) by survey, and plotted as a time series for the period from 1986 to 2013. To avoid seasonal variation, only data from summer surveys (January–March) were examined.

RESULTS

Comparative trawling

In the parallel trawling trials between the new *Dr. Fridtjof Nansen* (using Thyborøn combi-doors) and commercial vessels (Steinshamn V doors) in Namibia in 1998 and 1999, the catch rates of the commercial vessels were on average 2.13 times higher for monkfish ($P \ll 0.01$, N = 163) and 1.44 times higher for sole (P = 0.09, N = 32) than those of the new *Dr. Fridtjof Nansen*, whereas no difference was found for hake (N = 365) (Fig. 2a). The hake (both *M. capensis* and *M. paradoxus*) caught by commercial vessels tended to be longer than those caught by the new *Dr. Fridtjof Nansen* (Fig. 3). Significant differences in length, however, were only found in *M. capensis* in 1998 (P = 0.04, N = 103) and *M. paradoxus* in 1999 ($P < 0.01$, N = 89).

In the alternate trawl deployments in Namibia in 1995, monkfish catch-rates were on average 2.74 times higher (P = 0.02) on tows with tickler chains than without. No differences in catch rates were found for sole and hake. In the pairwise comparisons in 1995, catch rates were an average of 1.48 times higher for deep-sea red shrimp in Angola (P = 0.03) (Fig. 2b) and 1.88 times higher for monkfish in Namibia (P = 0.02) with tickler chains than without (Fig. 2c). No differences in catch rates were found for monkfish or rose shrimp in Angola, or for sole or hake in Namibia.

The trawl comparisons between the Thyborøn and Waco trawl doors in Namibia in 1995 showed similar catching efficiencies for the two trawl door types for both monkfish and hake (Fig. 2d). No differences in catch rates were found.

Effects of gear changes

Figure 4 presents time series plots of combined catch rates of bottom-dwelling species for Angola (monkfish and deep-sea red shrimp) and Namibia (monkfish and sole). In Angola, the lowest median catch rate (2.1 kg h^{-1}) was obtained in 2002 (Fig. 4a). This is consistent with our prediction that catch rates of

Figure 2. Results of pairwise comparisons. (a) Catch rates for the new *Dr. Fridtjof Nansen* (grey boxes) and commercial vessels (white boxes) in Namibia in 1998 and 1999 for monkfish *Lophius* spp. (LS), sole *Austroglossus* spp., *Cynoglossus* spp., *Dicologoglossa* spp. (SO) and hake *Merluccius* spp. (MS). (b) Catch rates with (grey) and without (white) tickler chains in Angola in 1995 for deep-sea red shrimp (*Aristeus varidens*) (AV), monkfish (LS) and rose shrimp (*Parapenaeus longirostris*) (PL). (c) Catch rates with (grey) and without (white) tickler chains in Namibia in 1995 for hakes (MS), monkfish (LS) and sole (SO).; (d) Catch rates in hauls conducted with Thyborøn (white) and Waco (grey) trawl doors in Namibia in 1995 for hakes (MS) and monkfish (LS). Boxes span the first and third quartiles. Medians are indicated with thick lines. The whiskers represent 1.58× (interquartile range/√*n*). Outliers are indicated as points. Grey lines indicate paired values. (For hakes and monk in Fig. 2a, a random sample of 30 comparisons are depicted with grey lines).

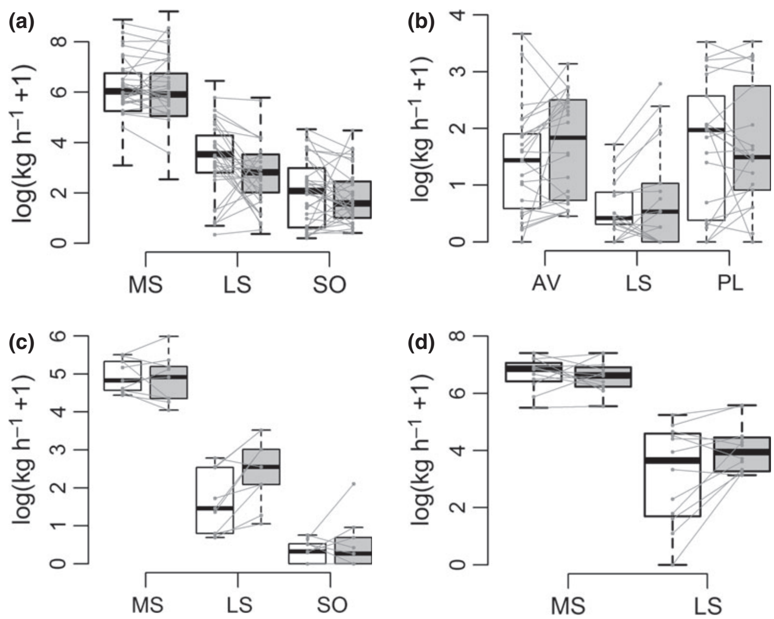
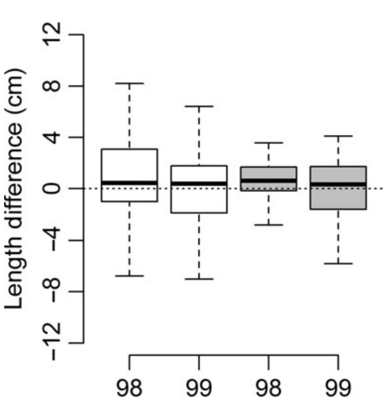


Figure 3. Size selection in hake *Merluccius capensis* (white boxes) and *Merluccius paradoxus* (grey) in Namibia in 1998 and 1999. Plotted values indicate the differences in the weighted mean total lengths (cm) between the new *Dr. Fridtjof Nansen* and commercial vessels *Oshakati*, *Garoya* (1998) and *Ribadeo* (1999). Positive values indicate higher weighted values for the commercial vessels. Boxes span the first and third quartiles. Medians are indicated by thick lines. The whiskers represent 1.58× (interquartile range/√*n*).



bottom dwellers would fall in Angola in 2002 due to the omission of tickler chains. In Namibia the three lowest catch rates in the time series were obtained using the old *Dr. Fridtjof Nansen* (1990, 1991 and 1993), with median values ranging from 1.2 to 2.8 kg h^{-1}, compared with 6.8 to 50.3 kg h^{-1} for the new *Dr. Fridtjof Nansen*, and 3.8 to 27.3 kg h^{-1} for the commercial vessels (Fig. 4b). This is consistent with our prediction that there would be a marked increase in catch rates of bottom dwellers with the introduction of the new bobbins gear in Namibia in 1994.

DISCUSSION

The *Dr. Fridtjof Nansen* time series provide valuable information about the state of the living marine resources in the BCLME region in southern Africa (FAO, 2010). These investigations were initially exploratory in nature, focusing on mapping of poorly explored resources, but gradually shifted towards monitoring temporal changes (trends) in the abundance of commercial resources. A growing number of studies

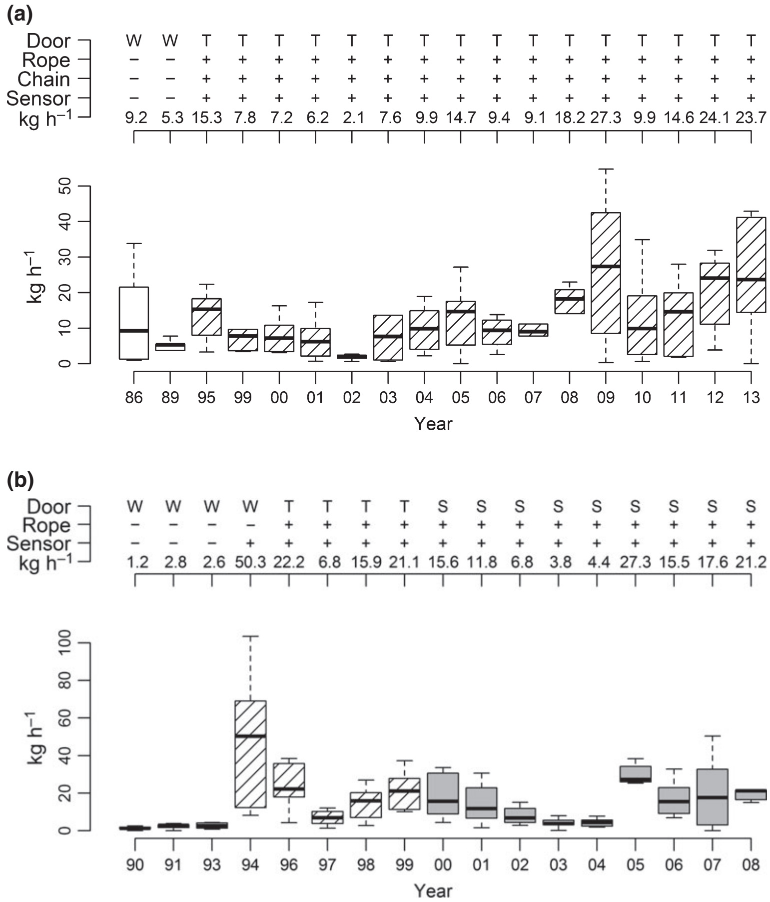


Figure 4. Time series of catch rates of bottom-dwelling species obtained with the Gisund Super demersal sampling trawl on the old *Dr. Fridtjof Nansen* (white boxes), the new *Dr. Fridtjof Nansen* (striped) and commercial (grey) vessels. Top panel: trawl door types used, including Waco (W), Thyborøn (T), Steinshamn (S); presence (+) or absence (−) of constraint rope, tickler chains and SCANMAR sensors; and median catch rates in kg h^{-1}. Bottom panel: (a) Combined catch rates of monkfish *Lophius* spp. and deep-sea red shrimp *Aristeus varidens* in Angola between 6°S and 13°S in 1989–2013. (b) Combined catch rates of monkfish and sole *Austroglossus* spp., *Cynoglossus* spp. and *Dicologoglossa* spp. in Namibia in 1990–2008. Only tows made in the depth range of 300–600 m are included. Boxes span the first and third quartiles. Medians are indicated by thick lines. The whiskers represent 1.58× (interquartile range/√*n*).

have explored the BCLME time series in new contexts such as environmental studies (Bartholomae and van der Plas, 2007), identification of marine biodiversity hotspots (Kirkman *et al.*, 2013), and assessments of changes in distribution and range shifts in demersal fish (Yemane *et al.*, 2014). However, some caution should be exercised when the time series data are being explored for trends in species groups other than those that the survey methodology was designed for, in particular with regard to changes in methodology. Unfortunately, the technical specifications of the Gisund Super trawl configurations are frequently incorrectly referred in survey reports and the peer-review literature, and modifications to trawl configurations are unfamiliar to several authors. Both Bianchi *et al.* (2001) and Hamukuaya *et al.* (2001) state that the sampling gear used by the *Dr. Fridtjof Nansen* has been constant between surveys. The bobbins used on the old *Dr. Fridtjof Nansen* have been commonly reported to be 305 mm in diameter (e.g., Sætersdal *et al.*, 1999), but the correct diameter is 500 mm (Iqbal, 1993), which has been verified by internal IMR documents. The use of bigger bobbins on the old than the new *Dr. Fridtjof Nansen* was also noted by Maartens (1999), but to the best of the authors' knowledge, this has not been reported elsewhere. The bobbins of the new *Dr. Fridtjof Nansen* were incorrectly reported to be 12 cm in diameter by Bianchi *et al.* (2001, 2004) and Hamukuaya *et al.* (2001). The area (7.41 m^2) and weight (1720 kg) of the Thyborøn trawl doors are also often inaccurately reported, e.g., 7.8 m^2 and 1670 kg, respectively, in some survey reports (e.g., Anon., 1994), and 7.9 m^2 and 2200 kg in Jørgensen *et al.* (2007).

Here we document historical changes in the use of vessels, trawls and their configuration during the bottom trawl surveys in the BCLME region. For Angola and Namibia, the demersal trawl time series are consistent in terms of trawls used (Gisund Super). However, changes in both vessels and gear configurations have taken place, particularly with regard to the ground gear and trawl doors used, and the introduction of tickler chains. Unfortunately, such modifications are commonly associated with concurrent changes in catching efficiency of bottom-dwelling species (Main and Sangster, 1983). For Angola, the time series is reasonably robust with regard to gear changes, at least from 1999 onwards. By then, the *Dr. Fridtjof Nansen* had come into operation, survey design and trawl configuration were largely standardized, and surveys were carried out annually at the same time of year (February–March). For Namibia, however, alternations of vessels and trawl configurations have probably resulted in changes in sampling efficiencies in terms of both species and size selectivity. From 1995 onwards, the use of tickler chains in Angola but not in Namibia, further precludes comparisons between Angola and Namibia in terms of bottom-dwelling species in waters deeper than 300 m.

The demersal trawls used in South Africa, i.e., the old and new German 180 (Atkinson *et al.*, 2011a), are structurally different from each other and from the Gisund Super trawls used in Namibia and Angola. The Old German 180 had a much lower vertical opening (1.5–2.0 m) than the Gisund Super (4.5–5.0 m), much larger meshes (120 mm in the fore section of the codend and an only partly covering 40 mm inner liner, versus 20-mm codend meshes with a fully covering 10-mm inner liner for the Gisund Super), and was operated with different trawl doors (WV doors versus Thyborøn) and ground gear (chain and footrope versus bobbin roller gear) (Table 2). Atkinson *et al.* (2011a) note that the changes in the trawl gear of the *Africana* resulted in a greater portion of the water column being sampled, reduced herding and reduced sampling of flatfish and batoids as a result of the modified footrope. Consequently, catch rates and size distributions obtained with these two trawl systems are not directly comparable, in particular for bottom-dwelling species (Engås and Godø, 1989). Although the *Dr. Fridtjof Nansen* replaced the *Africana* on the demersal surveys in 2000 and 2001 due to technical problems with the latter vessel, the data from these years are frequently disregarded in time series analyses (Atkinson *et al.*, 2011b) due to these differences in sampling gear (Leslie and Fairweather, 2008; Atkinson *et al.*, 2011a).

The present study therefore placed special emphasis on the potential effects of modifications to the configuration of the Gisund Super sampling trawls used on the surveys in Angola and Namibia. The analyses provide no evidence of significant temporal changes in the catchability of hake, either in Angola or Namibia (Fig. 2a) (Strømme and Iilende, 2001). The results demonstrate, however, that the mean total lengths of hake caught with commercial trawlers tended to be higher than those taken by the new *Dr. Fridtjof Nansen* (Fig. 3). Commercial trawler catch rates of the bottom dwellers monkfish and sole were higher than those made by the new *Dr. Fridtjof Nansen* in Namibia, suggesting that the commercial vessels have better bottom contact and thus better herded the fish into the trawl than the research vessel (Gordoa and Hightower, 1991). Vessels may also affect their own trawl performance differently through the noise patterns they emit during the capture process (Main and Sangster, 1981; Engås and Godø, 1989; Ona and Godø, 1990; Engås, 1994). Although time series of hake may still be largely comparable between Angola (*Merluccius polli* and *M. capensis*) and Namibia (*M. capensis* and *M. paradoxus*), these experiments demonstrate that this may not be the case for more sea bed-oriented species groups. Our tests focused on monkfish and sole, but similar effects are to be expected for other sea bed-oriented fish such as certain rays (e.g., *Raja* spp., *Rhinobatos albomaculatus*¸ *Cruriraja parcomaculata*), flounders (e.g., *Citharus linguatula*) and Atlantic batfish (*Dibranchus atlanticus*).

The high catch rates of bottom dwellers by commercial trawlers in Namibia may be due to ship effects, or their use of demersal trawl doors as opposed to the combi-doors used by the *Dr. Fridtjof Nansen* (Table 2). The change of doors on the *Dr. Fridtjof Nansen* in Angola (1995) and Namibia (1996) may also have affected the performance of the Gisund Super demersal trawl; however, the comparative trawl door trials in Namibia revealed no significant differences there (Fig. 2d). Irrespective of the significance of trawl door effects, the introduction of commercial vessels with demersal trawl doors in Namibia from 2000 onwards has probably led to a significant increase in sampling efficiency of sea bed-oriented species (Fig. 2a) and possibly to altered sampled length structures of hake (Fig. 3).

We document that the introduction of tickler chains on the bobbins roller gear on the new *Dr. Fridtjof Nansen* in 1995 increased deep-sea red shrimp catch rates in Angola by 48% (Fig. 2b), and that the use of tickler chains on experimental trials in Namibia led to a near three-fold increase in mean catch rates of monkfish (Fig. 2c) (Maartens, 1999). The use of tickler chains in Angola (from 1995), but not in Namibia, may similarly have affected the catch rates of other bottom-dwelling species there (Fig. 2b) (Anon., 1995b), and thereby also their estimated abundance.

Finally, we have established that the new *Dr. Fridtjof Nansen* took considerably higher catches of bottom dwellers than the old *Dr. Fridtjof Nansen* (Fig. 4b). This is the most significant change in terms of trawl configuration and is very probably caused by the reduction in bobbin size from 500 to 305 mm with the change of vessels (Iqbal, 1993; Maartens, 1999), corresponding to a reduction of the fish line to bottom distance by approximately 197 mm, or 27% (Table 3). We hypothesized that this would cause a marked rise in the catch rates of bottom dwellers in Namibia in 1994, which was in accordance with our time series analysis showing that the catch rates of monkfish and deep-sea red shrimp increased by a factor of almost 20 in that year (Fig. 4b). As this change coincided with the change of vessels from the old to the new *Dr. Fridtjof Nansen*, vessel effects may also have contributed. However, tow speed and all other gear factors remained constant in this period, and it seems unlikely that the larger, more powerful new *Dr. Fridtjof Nansen* (Table 1) would cause less intense avoidance reactions than the old *Dr. Fridtjof Nansen*. The reduced gap may also have reduced escapes of species, such as hake, which are known to flee under the fishing line (Jørgensen *et al.*, 2007). In their study, escapement of *M. capensis* were generally below 5%, whereas for *M. paradoxus* they ranged from 10 to 20% in 2002, and in 2003 from 10% in deep waters (570 m) to more than 50% in shallow waters (Jørgensen *et al.*, 2007).

Other changes may also have influenced catch rates. The introduction of the trawl monitoring system (SCANMAR) in 1994 reduced the risk of the trawl lifting off the bottom during deployments, and may thereby have contributed to improved trawl performance. However, this factor could not by itself explain the extent of the increase in catch rates of bottom dwellers in Namibia in 1994, as Fig. 4b shows. The introduction of a constraint rope reduced door spread and thus served to maintain a more fixed trawl geometry (width and vertical opening) (Engås and Godø, 1986; Koeller, 1991) and bottom contact at depth (Godø and Engås, 1989), and has probably improved the catchability of bottom-dwelling species in deep deployments through reduced escapes under the ground gear. Other potential effects that could not be examined quantitatively here include potential creeping effects of improved trawl monitoring and winch control technology, increased sampling intensity, experience and learning effects, and the irregular participation of experienced taxonomic experts on the surveys. Although they may have improved the identification of tricky species and provided valuable training for technicians and scientists onboard, particularly for Angola due to the high diversity of the demersal communities there, their irregular presence on the surveys may have introduced some bias in favour of exotic species. The combined effects of all these factors may have contributed to the somewhat irregular pattern of catch rates seen in Fig. 4, which also seems to be characterized by undulating trends consistent with cyclic variations in abundance.

CONCLUSIONS

- The demersal trawl data collected with the FRS *Africana* in South Africa are not comparable with those of the RV *Dr. Fridtjof Nansen* in South Africa, Angola or Namibia, due to fundamental structural differences in the trawls used.
- The time series for Angola and Namibia contain inherent differences in terms of catchability of bottom-dwelling species, due to the use of commercial trawlers in Namibia and the use of tickler chains in Angola.
- The introduction of the smaller bobbins gear with the new *Dr. Fridtjof Nansen* in 1994 increased the catchability of bottom-dwelling species.
- There is no evidence to suggest that the introduction of commercial trawlers in Namibia in 2000 caused significant changes to the catchability of hake. However, catch rates of monkfish and sole were found to be significantly higher on surveys with commercial vessels than the new *Dr. Fridtjof Nansen*, and commercial vessels tended to catch larger hake.
- The time series in Angola appear to be the most robust in the region, certainly with the new *Dr. Fridtjof Nansen* from 1999 onwards. However, the omission of tickler chains in 2002 did cause an artefactual drop in catch rates of bottom-dwelling species in that year.
- Overall changes include intermittent alternation of trawls, doors and ground gears used on the *Africana* in South Africa, whereas in Angola and Namibia there have been changes in vessels, change of trawl doors, reduction in bobbin size, and introduction of a constraint rope and tickler chains. These changes to the trawl configurations have likely affected the catchability of bottom-dwelling species. Temporal trends should therefore be interpreted with caution, particularly for South Africa and Namibia, and the time series for each country should be viewed in isolation.

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APPENDIX

Appendix 1. Summary of trawl specifications by survey for Angola. Tickler chains and constraint rope were used for stations deeper than 300 and 80 m, respectively. ‘Trawl sensors’ denotes the use of the SCANMAR wireless trawl monitoring system.

	Year	1985				86		89			91		92	93	94	95		96	97		98–11	02	03–13
Factor	Survey/year	1	2	3	4	1	2	1	2	3	1	2	1	1	1	1	2	1	1	2	1	1	1
Vesse[1]	Old DFN	X	X	X	X	X	X	X	X	X	X	X	X	X									
	New DFN														X	X	X	X	X	X	X	X	X
Doors	Waco	X	X	X	X	X	X	X	X	X	X	X	X	X	X								
	Thyborøn															X	X	X	X	X	X	X	X
Ground gear	500 mm discs	X	X	X	X	X	X	X	X	X	X	X	X	X									
	305 mm discs														X	X	X	X	X	X	X	X	X
Tickler chain	Used															X[1]	X	X	X	X	X		X
Constraint rope	Used															X	X	X	X	X	X	X	X
Tow duration[2]	Minutes										30	30	30	30	30	30	30	30	30	30	30	30	30
Trawl sensors	Used														X	X	X	X	X	X	X	X	X

[1]Tickler chains used at all depths in this survey.
[2]Blank cells denote that tow duration was not standardized as some tows were aborted prior to 30-min tow time due to large catches.

Appendix 2. Summary of trawl specifications by survey for Namibia. A constraint rope was used for stations deeper than 80 m. Trawl duration is given in minutes. 'Trawl sensors' denotes the use of the SCANMAR wireless trawl monitoring system.

	Year	1990		91		92		93		94			95	96		97			98			99		00	01	02–12
Factor	Survey/year	1	2	1	2	1	2	1	2	1	2	3	1	1	2	1	2	3	1	2	3	1	2	1	1	1
Vessel	Old DFN	X	X	X	X	X	X	X	X																	
	New DFN									X	X	X	X	X	X	X			X			X				
	Commercial																A	B		C	D		E	F	C	G
Doors	Waco	X	X	X	X	X	X	X	X	X	X	X	X													
	Thyborøn													X	X	X			X			X				
	Steinshamn																X	X		X	X		X	X	X	X
Ground gear	500 mm discs	X	X	X	X	X	X	X	X																	
	305 mm discs									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tickler chain	Used												X[1]													
Constraint rope	Used													X	X	X	X	X	X	X	X	X	X	X	X	X
Tow duration	Minutes	30[2]	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Trawl sensors	Used									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

A: Comparative fishing with *Katima*: 2–5 February 1997; B: Comparative fishing with *Echelar*: 1-day trial in 1997; C: Comparative fishing with *Oshakati*: 12–31 January 1998; D: Comparative fishing with *Garoya*: 2–20 February 1998; E: Comparative fishing with *Ribadeo*: 11 January–21 February 1999; F: *Frans Aupa Indongo*: 2000; G: Bl*ue* Sea: 2002–2012.

[1]Tickler chains used alternately between tows.

[2]Some stations in this survey were of 60-min duration.