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Bycatch and release of pelagic megafauna in industrial trawler fisheries off Northwest Africa

JaapJan Zeeberg[a,*], Ad Corten[a], Erik de Graaf[b]

[a] Netherlands Institute for Fisheries Research, Haringkade 1, IJmuiden, The Netherlands
[b] Maritiem Nets, Kalkbranderstraat 5, Katwijk, The Netherlands

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Abstract

The accidental capture of large animals such as sharks, manta rays, sea turtles, and dolphins in pelagic trawler fisheries remains controversial because it threatens biological diversity in many biogeographical regions, including the subtropical eastern North Atlantic. Bycatch rates observed during more than 1400 trawl sets off Mauritania, Northwest Africa, are shown to have been considerable during the past 4 years, with high animal abundance in Summer when the Northwest African shelf is occupied by subtropical water. We demonstrate the urgency for bycatch reduction and evaluate the use of species-selective gear, a conservation method immediately available and immediately effective in waters fished through international access agreements. A modification tested in commercial trawls during the observer program guides pelagic megafauna deflected by a filter to an escape tunnel along the bottom of the trawl. This "excluder" reduces bycatch mortality of the most vulnerable megafauna species by at least 40–100%.

Keywords: Bycatch; Sharks; Dolphins; Selective gear; Conservation management; Biodiversity; Mauritania

1. Introduction

European fisheries off Mauritania, Northwest Africa, are possible through international access agreements and private arrangements that enable between 40 and 70 foreign trawlers to exploit the potential of this highly productive upwelling system. Sardinella, sardine, and horsemackerel are the target species of the European (Dutch and Irish) pelagic fleet, which operates nearly year-round with five to ten freezer-trawlers. These boats are amongst the largest fishing vessels in the world with installed horse power for trawling and freezing between 9000 and 18,000 hp. In the Mauritanian Exclusive Economic Zone (EEZ, 200 n mi) they operate within miles of each other and are often accompanied by dozens of Russian, Lithuanian, and Icelandic trawlers, all together yielding more than 500,000 tons of small pelagic fish per year. With these figures the Northwest African shelf is fully exploited (FAO, in press) and ranks amongst the most productive and most intensively fished areas in the world.

Conservation of biodiversity is largely unregulated in waters of developing countries, depending on the capacity and willingness of the coastal state to monitor and limit the exploitation of its marine resources. The United Nations 1995 Code of Conduct for Responsible Fisheries (http://www.fao.org/fi) provides internationally accepted guidelines for the development and implementation of national fisheries policies, including the use of species-selective gear. From its side, the European Union has approved the UN Convention on Biodiversity (1992) and endorses the Johannesburg agreements (2002) to substantially reduce loss of biodiversity by 2010. This entails a commitment to ensure the sustainability of "external" fisheries, i.e. operating outside EU jurisdiction, by implementing science and instruments adopted for Community waters within the Common Fisheries Policy (Comm. 2002, 637, Chapter 3.1).

While European governments have successfully negotiated fisheries agreements – the agreement with Mauritania is

* Corresponding author. Tel.: +31 255 564 709; fax: +31 255 564 644.
E-mail address: jaapjan.zeeberg@wur.nl (J. Zeeberg).

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worth €430 million between 2001 and 2006 – there remains a need for concerted action to help implement protective measures in waters fished by the long-distance fleets. The accidental capture and mortality (bycatch) of larger non-target species has drawn both public and scientific attention. While public attention is commonly focused on cetacean mortality, fisheries have been demonstrated to constitute an immediate threat to the regional survival of many shark, sea turtle, and ray species, with no relief currently in sight (Brander, 1981; Spotila et al., 2000; Baum et al., 2003; Myers and Worm, 2003). The sheer size of the pelagic freezer-trawler fishery with net openings up to 90 m × 50 m invites speculation as to the amount of non-target animals killed and the effect on regional marine ecosystems. Elimination of the top predators will impact biodiversity by transforming natural species assemblages and ecosystem processes, and eventually this will jeopardize commercial fish stocks.

This paper presents pelagic megafauna bycatch rates observed during more than 1400 trawl sets off Mauritania, Northwest Africa, between October 2001 and May 2005 (Fig. 1). The monitoring program was part of an experiment to limit bycatch and improve fishing efficiency by using a simple gear adaptation, which enables large animals to escape alive and undamaged, in combination with satellite remote sensing to avoid areas preferentially sought by megafauna species. Protection of marine biodiversity from fisheries commonly focuses on closing off fishing areas ("marine reserves") or seasons, but this must be economically feasible, requiring broad political support and extensive monitoring of fishing activity. In contrast, gear modifications, such as the turtle excluder device (TED) used in USA shrimp fishery (Watson and Seidel 1980) and the Nordmøre-type grid used in Barents Sea shrimp fishery (Isaksen et al., 1990), provide immediate mitigation in areas that need it most. The urgency for bycatch-reducing measures off Northwest Africa remains debatable, due to a paucity of observations over the past ca. 40 years of industrial fishery, preventing the identification of stock trends, and because knowledge on the thresholds and dynamics of megafauna populations is sparse. However, the biological significance of the established take rates, and effects of animal removal at population level can be established for many of the species in this study by comparing with stock trends, abundance estimates, and conservation policies established elsewhere, e.g. in the western Atlantic Ocean.

2. Materials and methods

2.1. Megafauna bycatch rates

The objective of the bycatch-monitoring program was to assess monthly totals and establish whether these warrant mitigation. Bycatch has been identified when taken on board a trawler during the haul process. The bycatch is retained in a "filter grid" designed to prevent entering of large non target-animals into the cod end (Fig. 2). Few animals arrive on deck alive and most suffocate and succumb to water pressure while caught in the filter grid (Fig. 3). The grid is rigged with a zipper junction that enables emptying of the filter outside of the vessel, but the animals are often entangled and are commonly

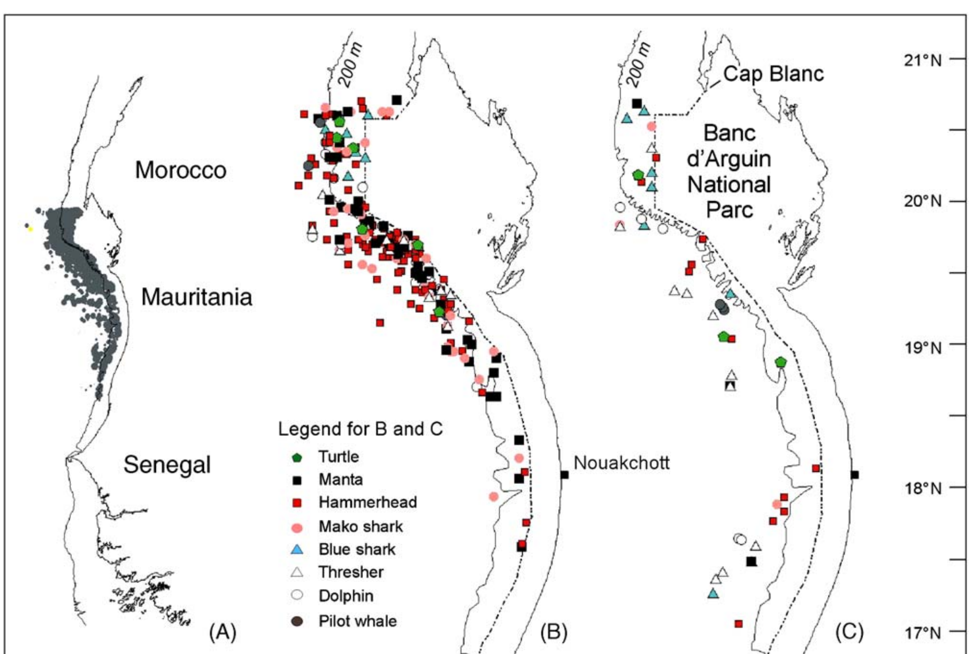

Fig. 1. (A) Fishing effort of one vessel in the Mauritanian EEZ between 2001 and 2005; (B) Megafauna bycatch off Mauritania, Northwest Africa during Summer (JASO) sets: with tropical species moving over the shelf (200 m bathymetry) into water with high primary productivity; and (C) Bycatch during Winter, with dolphins and oceanic sharks over deeper water. Broken line marks the extent of the 12–15 n mi fishing limit.

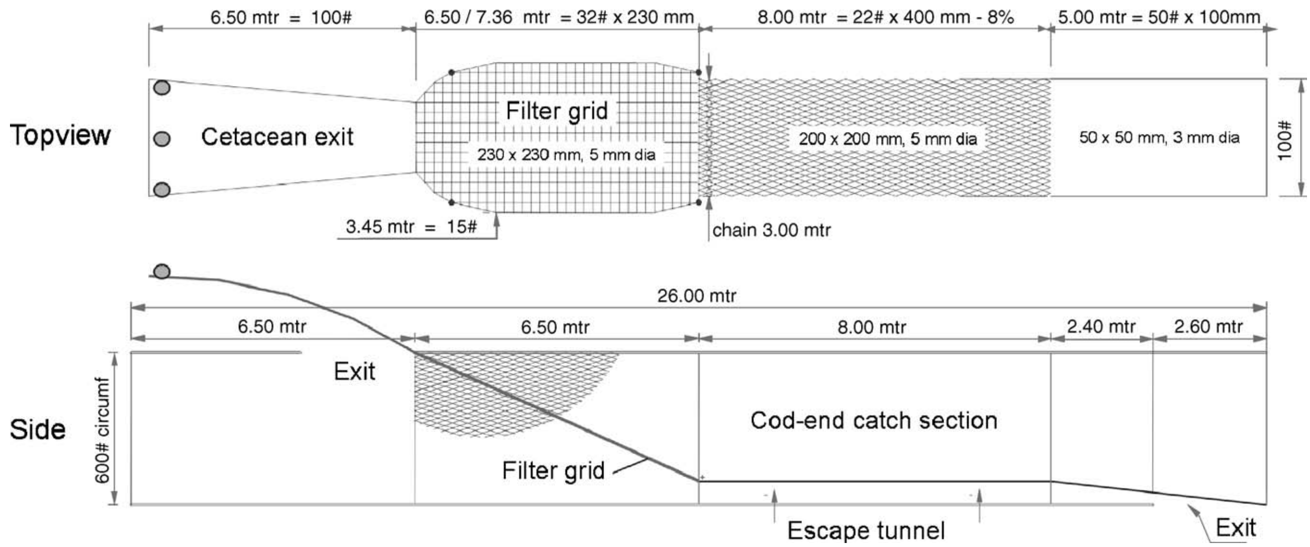

Fig. 2. Technical specifications of the aft section of a mid-water trawl (about 50–70 m in front of the cod end), showing the position of a filter grid connected to an escape tunnel. The filter grid slopes top-downwards with a ca. 20° inclination that forces larger non-targets downward to the tunnel entrance; before the grid is a cetacean exit.

removed on deck. Observers also requested that the animals would be kept on deck to be identified (to species level) and measured. In addition to the trawl lists that are submitted by the vessels on a regular basis, vessel crew has been requested in September–December 2004 to register, photograph, and measure bycatch. During this period, our 2–4 week observer missions did continue to provide independent reference.

The observed trawl sets represent 4–88% of the fishing effort of the Dutch freezer-trawlers in a particular month (Table 1). This percentage represents the days observed on a vessel per total days fished by the entire fleet (Table 2). The monthly probability of bycatch (Y) was modeled by fitting a generalized linear model (SAS genmod procedure):

$$Y = \alpha + \sin t + \cos t + \varepsilon$$

in this equation t denotes the time (time = month × $2\pi/12$), α is the average probability, and ε is a normally distributed error term. Input was 1 (bycatch) or 0 (no bycatch) and $0 < Y < 1$. The $\sin t + \cos t$ term fits a periodic regression with a period of 1 year. The monthly totals of sets monitored from 2001 to 2005 (grand total 1424) is 58 for March; 111 for April; May 35; June 32; July 187; August 91; September 367; October 225; November 262; December 56. The model calculates bycatch probability per haul at the 5% significance level ($p \ll 0.05$), assuming a more or less constant set duration. In Mauritania, trawl sets commonly last between 3 and 5 h, with an average of 3.2 sets in a day. Data modeling does not include large groups (20 and more) taken less than once a year of sun fish, manta rays, and dolphins, because a single event of very high bycatch has little statistical significance.

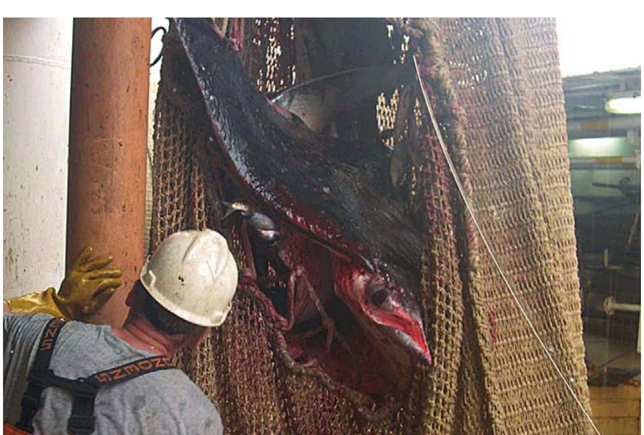

Fig. 3. Manta ray entangled in the filter grid after a regular (non-excluder) commercial set; note rope pulling the "zipper" junction that enables access inside the trawl.

2.2. Extrapolation to fleet-level

Observed bycatch rates are considered representative at fleet level because the trawlers monitored in this study employ similar effort and fishing tactics, and the chance to intercept megafauna in a particular month is equal for each trawler. The trawlers hunt sardinella with speeds of 5–6 knots and by circling in "spaghetti" trajectories, in order to keep the net outside the propeller wake and adapt to the fish evasions observed by sonar. Fishing activities often concentrate on temperature fronts, which are sought using sea surface temperature charts (Fig. 4). Bycatch rates fluctuate widely across the year parallel with seasonal oceanographic dynamics, but ocean conditions for a particular month vary little between the years (e.g. Mittelstaedt, 1991; Binet, 1997). Bycatch is therefore extrapolated and summed per month.

Extrapolation to fleet level (Tables 1 and 2) was done by multiplying the numbers taken in a month (catch) with

Table 1
Days and periods monitored by observers and trawler crews

	2001/2005			2002			2003			2004		
	Days fished	Period observed	Days observed	Days fished	Period observed	Days observed	Days fished	Period observed	Days observed	Days fished	Period observed	Days observed
Mar	31	3/24/05-	7 (23%)		–	–		–	–		–	–
April	30	4/13/05	13 (43%)	209	–	–	100	–	–	94	4/21–4/24	3 (3.2%)
May		–	–	227	–	–	233	–	–	165	5/6–5/14	8 (4.9%)
June		–	–	233	–	–	200	6/18–6/26	8 (4%)	163	–	–
July		–	–	214	07/10–07/29	26 (12.1%)	195	–	–	159	7/6–7/28	34 (21.4%)
August		–	–	185	08/23–08/31	8 (4.3%)	197	–	–	168	7/28–8/19	22 (13.1%)
September		–	–	206	09/10–10/01	21 (10.2%)	158	9/20–9/29	9 (5.7%)	141	09/01–09/30	124 (88%)
October	145	10/23–11/2/01	10 (6.9%)	141	10/20	7 (5%)	158	10/21–11/5	15 (9.5%)	101	10/01–10/18	36 (35.6%)
November		–	–	99	11/22	8 (8.1%)	73	11/20–12/6	16 (22%)	172	11/10–11/30	89 (51.7%)
December		–	–	20	–	–	58	–	–	84	12/01–12/12	30 (35.7%)

The "Days observed" percentage allows extrapolation of bycatch observations to fleet level per year (Table 2).

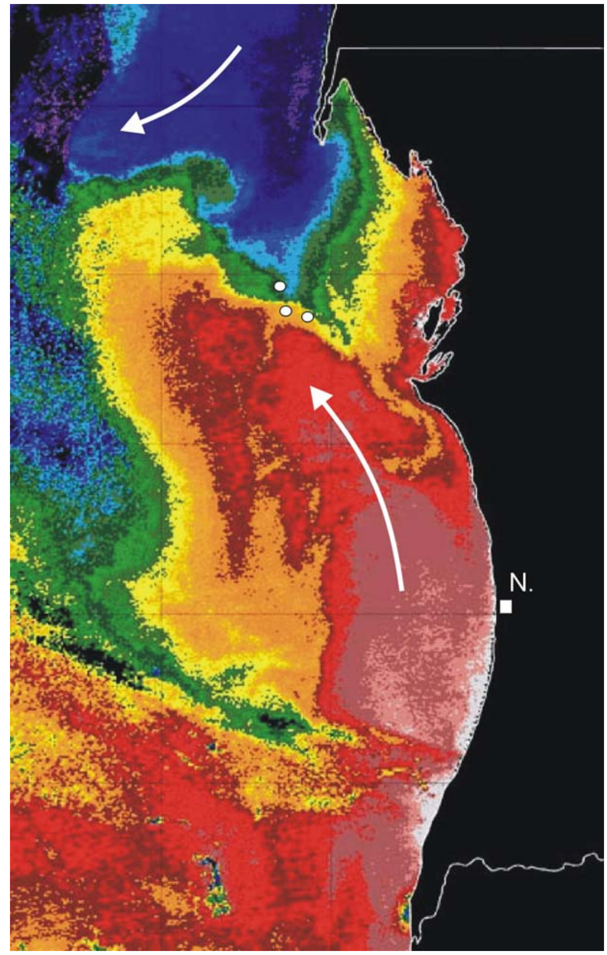

Fig. 4. Sea surface temperature chart from NOAA-AVHRR data on 21 July 2001, showing the first stage of the Summer temperature front between advecting tropical surface water and upwelled northern water. Color scale in 0.5 °C from 15.5 to 27 °C.

the monthly observation percentage (effort). These extrapolated monthly totals were summed to arrive at minimum (the lowest number of the series or 0-observation) and maximum annual totals removed by the freezer trawler fleet. This does not include the take of two Irish trawlers between 2001 and 2005 that have exerted similar effort as their Dutch colleagues. Overestimation of annual totals is unlikely because observations have concentrated on 5 months during Summer and Autumn and there is little data for the period December–June. The irregular sampling scheme and unpredictability of bycatch incidents prevents analysis of trends, or differences between seasons and species over the monitoring period.

3. Results

Megafauna bycatch off Northwest Africa commonly consists of larger predatory fishes, including the larger shark species, and less frequent sea turtles, manta rays, sun fish,

Table 2
Extrapolation table for the period July–November, showing bycatch registered by observers (*N*) between 2001 and 2005, with number of net hauls observed during a particular mission (*H*), the percentage of days observed (%), and the total mortality (*T*) thus extrapolated to fleet level

Species	Year	July				August				September				October				November			
		N	*H*	%	*T*	*N*	*H*	%	*T*	*N*	*H*	%	*T*	*N*	*H*	%	*T*	*N*	*H*	%	*T*
Turtle	2001													0	30	7	0				
	2002	0	88	12	0	0	22	4	0	0	87	10	0	1	20	5	20	0	18	8	0
	2003									0	28	6	0	1	57	10	11	1	63	22	4.6
	2004	1	87	21	4.7	1	74	13	7.64	_2_*	331	88	2.28	_0_*	111	36	0	1	319	52	1.9
Hammerhead sharks	2001													7	30	7	101				
	2002	33	88	12	273	12	22	4	279	44	87	10	431	5	20	5	100	0	18	8	0
	2003									50	28	6	877	12	57	10	126	1	63	22	4.6
	2004	46	87	21	215	82	74	13	626	_102_*	331	88	116	_40_*	111	36	112	_6_*	319	63	9.6
Mako/thresher sharks	2001													0	30	7	0				
	2002	3	88	12	25	1	22	4	23.3	8	87	10	78.4	2	20	5	40	0	18	8	0
	2003									0	28	6	0	1	57	10	11	1	63	22	4.6
	2004	11	87	21	51					_12_*	331	88	13.7	_18_*	111	36	51	5	319	52	9.7
Milk/blue sharks	2001													2	30	7	29				
	2002	2	88	12	17	0	22	4	0	3	87	10	29.4	3	20	5	60	4	18	8	49
	2003									50	28	6	877	2	57	10	21	6	63	22	27
	2004	1	87	21	4.7	3	74	13	22.9	_29_*	331	88	33	_0_*	111	36	0	4	319	52	7.7
Bill fish	2001													10	30	7	145				
	2002	1	88	12	8.3	1	22	4	23.3	1	87	10	9.8	2	20	5	40	0	18	8	0
	2003									2	28	6	35.1	5	57	10	53	0	63	22	0
	2004	59	87	21	276	8	74	13	61.1	_35_*	331	88	39.8	_8_*	101	36	22	_1_*	319	52	1.9
Sun fish	2001													0	30	7	0				
	2002	33	88	12	273	1	22	4	23.3	25	87	10	245	4	20	5	80	3	18	8	37
	2003									1	28	6	17.5	3	57	10	32	0	63	22	0
	2004	4	87	21	19	11	74	13	84	_22_*	331	88	25	_6_*	111	36	17	_52_*	319	52	101
Manta rays	2001													4	30	7	58				
	2002	0	88	12	0	2	22	4	46.5	2	87	10	19.6	0	20	5	0	0	18	8	0
	2003									0	28	6	0	3	57	10	32	1	63	22	4.6
	2004	21	87	21	98	53	74	13	405	_25_*	331	88	28.4	_10_*	101	36	28	2	319	52	3.9
Dolphins	2001													0	30	7	0				
	2002	20	88	12	165	0	22	4	0	43	87	10	422	4	20	5	80	1	18	8	12
	2003									0	28	6	0	1	57	10	11	0	63	22	0
	2004	5	87	21	23	6	74	13	45.8	_5_*	331	88	5.69	_6_*	111	36	17	_0_*	319	52	0
Pilot whales	2001													0	30	7	0				
	2002	8	88	12	na	0	22	4	0	1	87	10	9.8	0	20	5	0	0	18	8	0
	2003									0	28	6	0	0	57	10	0	0	63	22	0
	2004	0	87	21	0					_0_*	331	88	0	_0_*	111	36	0	_0_*	319	52	0

* Italics numbers include observations by trawler crews and taken from vessel logs.

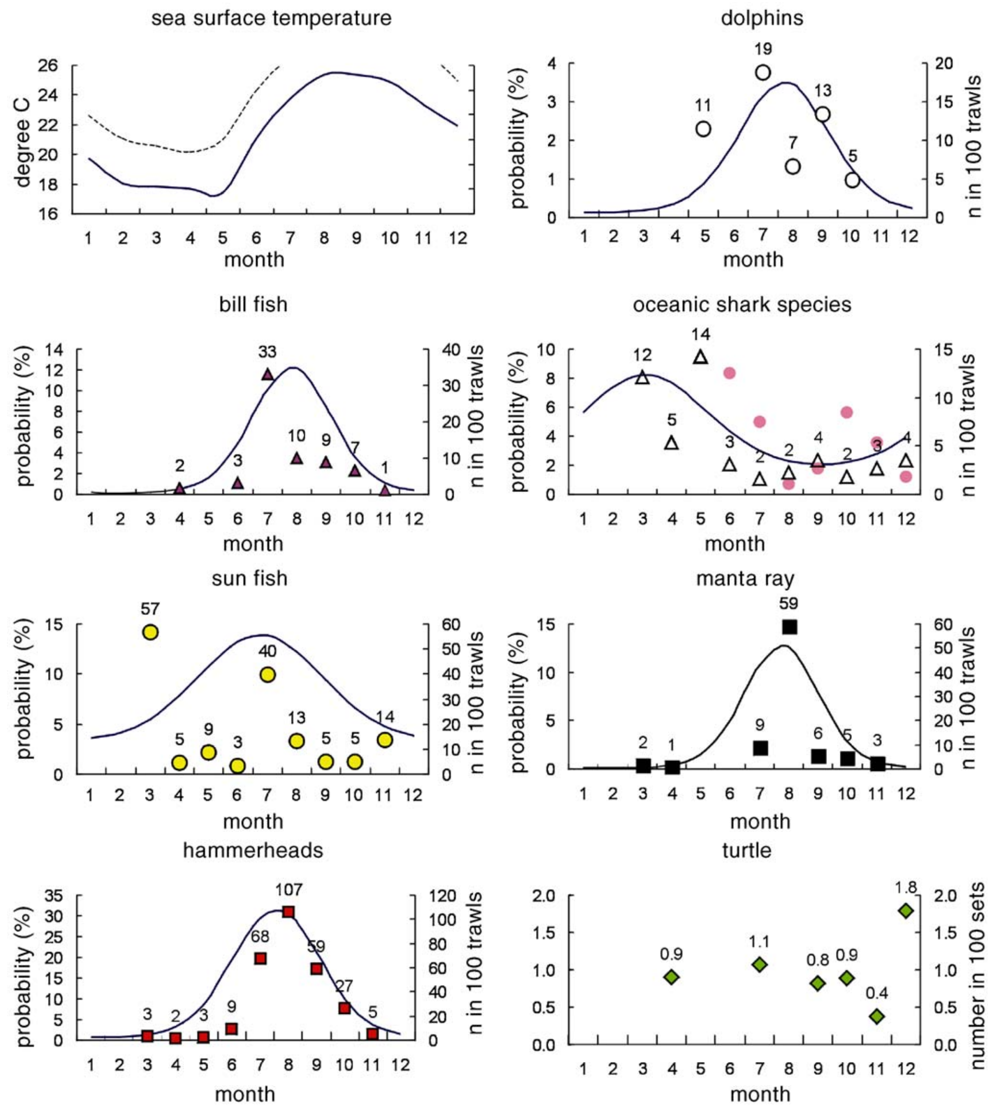

Fig. 5. Bycatch for each month, summed per 100 trawl sets, or about 31 days on average (right axis); and modeled probability (left axis), taking into account all trawl sets in a particular month. The box "oceanic sharks" has makos (dots) plotted with modeled thresher and blue sharks. Turtle bycatch of ca. 1 per month cannot be fitted with the model. AVHRR-derived sea surface temperature for 19°30′N, 17°W, and 16°30′N, 16°30W (broken line) is shown top-left, indicating the annual cycle of the trade wind-driven upwelling (2001–2003 average).

and dolphins (Table 3). Bycatch rates and composition show substantial seasonal variation. The bycatch probability of (sub)tropical species (manta, hammerhead sharks, bill fish) in the Mauritanian EEZ is minimal during the Winter and Spring (December to June) when, under the influence of trade wind-induced upwellings, sea surface temperatures drop from a summer maximum of 30 °C to ca. 18 °C (Fig. 5). Trawlers, fish and fish predators appear to congregate along the thermal oceanic fronts that develop above the shelf (water depths 40-200 m) towards the end of Spring, when the strength of the trade winds decreases (Fig. 4). This occurs on average early May in southern Mauritania (17°N) and 2 months later around Cap Blanc at 20°45′N. The seasonal cycle of this system is well represented by the model fit, which is significant ($p \ll 0.05$), except for sea turtle bycatch (Fig. 5).

Table 3
Pelagic megafauna bycatch retained in the filter grid during commercial trawl sets, and releases through a tunnel "excluder" tested and developed within this program (De Haan and Zeeberg, 2005)

Species	% bycatch	% released
Bill fish (*Maikara, Xiphias, Istiophorus* sp.)	10	40
Hammerhead (*Sphyrna lewini, zygaena, mokarran*)	42	55
Shark (*Isurus, Alopias, Carcharinus, Prionace* sp.)	9	20
Manta ray (*Manta birostris*)	9	75
Ray (*Dasyatidae, Rajidae* sp.)	5	100
Sunfish (*Mola mola*)	16	5–20
Cetaceans (see text)	8	0
Turtle (*Dermochelys, Eretmochelys, Caretta* sp.)	1	100

The column "released" includes the results of first tests and because of progressive improvements in the design, represents minimum values.

Sardinella (*Sardinella aurita* and *Sardinella maderensis*) is a highly migratory species that appears to leave Mauritanian waters in Autumn. Between November and May the international trawler fleet targets sardine, horsemackerel, and mackerel in upwelling waters. These fisheries are relatively "clean" with the incidental oceanic shark (blue sharks and thresher sharks), sunfish, or turtle. From the monitoring program on board the freezer-trawlers it appears that in summers or years with low sardinella abundance, bycatch of non-target species increases because the vessels continue to trawl while searching for the target species. As observed on radar, the international fleet frequently lines-up along the thermal front, providing for a highly concentrated, intensive fishery. Search efforts also concentrate around bathymetric features such as coral banks in shallow water marginal to the 12–15 n mi fishing limit (Fig. 1). During the evening and night, when pelagic fish disperse and occur scattered, the boats are unable to target specific shoals and while searching for fish may also collect greater bycatch than during the day. Cetacean bycatch is seen to occur almost exclusively during night trawls, indicating the additional need for behavioral and ethological studies, including interaction of the cetaceans with seabirds foraging on discards during day-time (B. Couperus, personal communication).

4. Discussion

4.1. Are the established bycatch rates typical for the freezer-trawlers?

Capture of the larger animals is incidental and as a result bycatch rates vary widely between vessels at any given time. Nevertheless, the observed rates are considered representative at fleet level because the trawlers monitored in this study employ similar effort and fishing tactics. In 2003 and 2004, the fleet preferably used the smaller 4300 (circumference) meshes trawl (70 m × 30 m net opening), which is more easily maneuvered in shallow waters above the shelf. Trawls with a larger circumference have a larger net opening and the greater extension of their rigging parts (bridles and doors) likely provides a significant herding effect. In comparison, the frequent hauls and concomitant trawl entrance collapses during maneuverings of the smaller Russian, Lithuanian, and Icelandic trawlers do appear to promote cetacean bycatch (cf. Fertl and Leatherwood, 1997).

The majority of cetaceans captured in pelagic trawler fisheries are the smaller dolphins that live near the sea surface (as opposed to larger, diving dolphin species): short-beaked common dolphins (*Delphinus delphis*), bottlenose dolphins (*Tursiops truncates*), and (along the European shelf margin) white-sided dolphins (*Lagenorhynchus acutus*; see Couperus, 1997). Trawlers, and the Mauritanian research vessel *Al Awam* during its fish stock surveys, rarely encounter cetaceans at the onset of Spring. In May and during Summer, however, very large groups are frequently spotted on the southern Mauritanian shelf and adjacent ocean waters (see also Laptikhovskii, 2001). The dolphins and pilot whales (short-finned, *Globicephala macrorynchus*) are possibly chasing the returning sardinella. Trawlers in Spring incidentally capture pods of 10–20 pilot whales or groups of 5–30 dolphins, while mass dolphin strandings may occur on beaches south of Mauritania's capital Nouakchott. Strandings in the Autumn of 1995 are attributed to bottom set gill nets, which have been placed along much of the Mauritanian coast (Nieri et al., 1999). The IUCN documented more than 200 decomposing dolphins (and many sea turtles) in June 2003 (IUCN, 2003). A mass stranding incident was also reported by Mauritanian authorities in June 2004 (Nouakchott Info Daily, 13 June 2004, pp. 1 and 5). The transit of sardinella through the region appears to up megafauna bycatch rates in all types of fishery, with the combined international trawler fleet (40–70 vessels) accounting for a substantial part of the larger, oceanic animals.

4.2. Need for megafauna bycatch mitigation

Present observations placed into the context of national and international conventions (e.g. the US Endangered Species or Marine Mammal Protection Act) do suggest that pelagic megafauna stocks at Northwest Africa qualify as "threatened". Captured animals include the turtle species leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), and hawksbill (*Eretmochelys imbricata*). Sea turtles are listed as critically endangered (Spotila et al., 2000; Ferraroli et al., 2004; see also http://www.redlist.org) and annual bycatch by the freezer-trawlers of up to 50 turtles seems unsustainable. With the turtles, *Manta birostris* may be the species primarily threatened by trawler fisheries. Manta ray inhabit tropical shelf waters and because each mature female produces just one pup every 2 or 3 years, rapid population declines have been observed where target fishing has taken place (http://www.redlist.org). Extrapolation from our observations (Table 2) indicates annual removal of between 120 and 620 mature mantas, which is unlikely to be sustainable. Freezer-trawler bycatch in the Mauritanian EEZ of 70–720 dolphins, mostly common dolphins (*Delphinus delphis*), is considerable, but comparable to bycatch in European waters (Morizur et al., 1999) and probably less than international moratoria of 1–1.7% of the relevant abundance estimates.

Bill fish and shark populations on a global scale are at "lower risk", but within biogeographical ranges they are depleted and often on the verge of collapsing. Hammerheads and blue sharks are by-caught or targeted as commercial species in all (sub)tropical seas. Based on longliner catch data, hammerhead numbers are shown to have plummeted 90% in 10 years over subtropical shelf regions in the western North Atlantic (Baum et al., 2003; Myers and Worm, 2003). Because the longline fleets in the subtropical eastern North Atlantic exert comparable fishing effort, and effort is seen to shift from western to eastern Atlantic waters (Buencuerpo

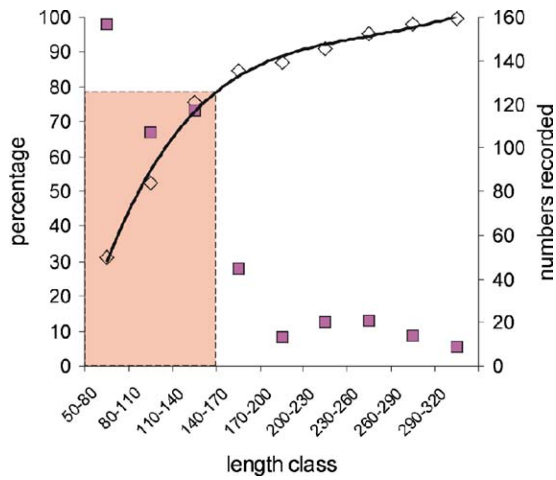

Fig. 6. Cumulative frequency distribution of hammerhead bycatch (trend line) and recorded totals for each length class (squares). The ogive is consistent with random sampling from a normally distributed, homogenous seasonal population. Shaded area marks hammerheads not separated by the filter grid, which are juveniles <140 cm comprising ca. 75% of the bycatch.

et al., 1998; Serafy et al., 2004), the recorded pattern is considered to be representative for the Northwest African region. Bill fish frequently captured and discarded by the Dutch freezer-trawlers are swordfish (*Xiphias gladius*), sailfish (*Istiophorus albicans*), and Atlantic marlin (*Makaira nigricans*), a species that is considered depleted (Serafy et al., 2004).

The annual removal by the European trawlers of 1000–2000 sharks is considered to be high and unsustainable. The majority of these are hammerhead sharks (*Sphyrna lewini, Sphyrna zygaena, Sphyrna mokarran*), followed by variable numbers of *Carcharhinidae*, mako (*Isurus* sp.), tresher (*Alopias* sp.), and blue sharks (*Prionace glauca)*. The low fecundity of sharks and slow recovery of shark stocks underscore the necessity to control directed shark fishery and fisheries in which sharks constitute a significant bycatch. As such, the proposed excluder fits in the International Plan of Action (IPOA) for conservation and management of shark stocks proposed by the UN FAO. The 250 mm × 250 mm shark filter grid currently in standard use blocks hammerhead sharks with lengths >1.40 m and other fish with lengths ca. >1.80 m. Although this grid removes only 25% of the hammerheads, these include all the mature specimens (Fig. 6). The majority (ca. 75%) of hammerheads caught by the freezer-trawlers are juveniles of 0.50 (length-at-birth) to 1.40 m, which often pass through the filter grid with the target species and are only separated in the freezing factory below decks. Hammerheads spawn year round, producing litters of up to 30 pups (Hazin et al., 2003), and to prevent damage to the population it is paramount that mature animals can escape to reproduce.

The biological significance of the established take rates and need for bycatch-reducing measures remains ambiguous, because the effects of megafauna mortality in trawler fisheries cannot be quantified at population level. The urgency for mitigation can, however, be deduced from the fishery statistics for Northwest Africa. While the non-European annual fishing effort (pelagics) has remained constant at about 8000 fishing days in the past 10 years, EU standardized fishing days have increased by about 50% to ca. 2200 days in the past 5 years (FAO, 2003, in press). The Mauritanian upwelling region is yet seen to have rich megafauna diversity, which seems to have persisted through ca. 40 years of industrial fishing, possibly deriving from tropical regions further south. However, as effort and bycatch are intrinsically linked, and present bycatch levels appear to be at the limit of sustainability, accumulating fishing pressure increases the likelihood that species will be pushed into regional, ecological extinction.

4.3. Development of a species selective sorting system

Management measures leading to marine reserves or closed seasons, or adaptive, bycatch-limiting trawling habits are long in coming and difficult to implement, especially for a nation that derives 25% of its state budget from fisheries agreements, with fish products accounting for 50% of export revenues. Unless bycatch can be prevented altogether, survival of sharks, manta, and other large bycatch depends on a mechanism in the water that will filter and subsequently release non-targets from the catch, directly after the animals have entered the trawl. Such a mechanism exists for shrimp trawls (e.g. Watson and Seidel, 1980; Isaksen et al., 1990) and is currently being developed within several research programs for the much larger pelagic trawls.

Trawl-gear modification to exclude larger pelagic animals from the catch is a trade off between megafauna-filtering efficiency and catch—with full processing of 50–200 tons of small pelagic fish commonly taken in a set. The gear designed under this program guides pelagic megafauna deflected by a filter to an escape route along the bottom of the trawl (Fig. 2). To ensure acceptance by the fishing industry, experiments were aimed to achieve zero loss of target fish with at least a halving of the bycatch rate. First tests in fully commercial trawl sets with this "tunnel excluder" have been promising and a prototype is presently in experimental use by the Dutch trawlers off Northwest Africa (Fig. 2). Underwater video recordings have demonstrated the functionality and rigging performance of the prototype, showing manta rays, hammerheads, and turtles exiting with ease. Improvements have focused on the diameter and stability of the tunnel opening, minimizing loss of target fish, and reduction of entanglements of sharks, manta rays, and bill fish. The inclination of the filter grid at ca. 20° balances the throughput of fish and the deflection of especially sun fish (*Mola mola*), which tend to be immobilized against the grid. (Gear modifications are detailed in De Haan and Zeeberg (2005)). The present prototype achieves a 40–100% reduction of the bycatch of the most vulnerable species (Table 3).

Although individual dolphins could potentially escape using a tunnel, cetaceans are less likely to enter such a narrow

(3–4 m) release route because of claustrophobia, which has been observed among cetaceans in marine mammal parks and purse seine fishery for tuna. At present there exists no solution to filter or deter cetaceans from the net opening. In addition to several types of cetacean "barriers" (i.e. vertical ropes in the front part of the trawl), acoustic deterrents are under development to prevent dolphins from entering the net opening, or guide them out during hauling. In the noise-saturated environment of a pelagic trawler, the effect of "pingers" has not yet been demonstrated. The most practical way to reduce cetacean bycatch, then, is to have an exit in the net's top panel (cf. Defra, 2003, p. 18). Dolphins are observed to seek an exit in the upper part of the trawl and the position and slope of the filter grid in the present design enables the cetaceans to reverse and accelerate upwards to reach the water surface (Fig. 2).

5. Conclusions

- Bycatch observations on board freezer-trawlers in the Mauritanian EEZ demonstrate considerable bycatch of especially hammerhead sharks, manta rays, and sea turtles.
- The biological significance of the established take rates and need for bycatch reducing measures remains ambiguous, because the effects of megafauna mortality in trawler fisheries cannot be quantified at population level. However, comparison with stock trends, abundance estimates, and conservation policies established elsewhere, suggests that bycatch rates off Northwest Africa are at the limit of sustainability. Because effort and bycatch are intrinsically linked, the urgency for mitigation is further deduced from a 50% increase of pelagic fishing pressure off Northwest Africa in the past 5 years.
- Experiments in Mauritania have concentrated on the identification of bycatch seasonality and, at least during months of high animal abundance (June–September), application of a "tunnel excluder": a simple gear adaptation that enables large animals to escape. Species that will be released alive and undamaged by this excluder include most if not all mature sharks, most bill fish, rays, and sea turtles. The most practical way to reduce cetacean bycatch is to have an exit in the net's top panel.
- Management measures leading to marine reserves or closed seasons, or adaptive, bycatch limiting trawling habits are difficult to implement, while gear adaptation may achieve immediate results at low cost. To ensure the sustainability of trawler fisheries, excluders should be standard rigging on pelagic trawlers, especially in months with maximum animal abundance.

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