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By-catch of pelagic megafauna off Mauritania, Northwest Africa: observations and gear modifications. Final report.

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Summary

Trawl gear modification to exclude larger pelagic animals from the catch and to release them alive has been designed and tested during full scale commercial fishing off Mauritania, Northwest Africa, in 2001, 2002, and 2004 (5 missions, 92 days at sea). In a parallel program, more than 1500 hauls have been monitored for by-catch of pelagic megafauna, specifically sharks, bill fish, cetaceans, turtle, and sunfish, to provide by-catch rates that can be used to establish the mitigating effect of the 'excluder'. This excluder will replace the standard 'shark filter grid' in the first codend section of pelagic trawls. The prime objective in testing both the excluder and the cetacean grid was to determine potential negative effects on the geometry of the trawl and potential loss of target fish.

Experiments and underwater camera observations during peak commercial catches have demonstrated a 50 to 100% reduction in large animal by-catches without or with minor loss of target fish (sardinella and mackerel). The video footage shows that with a 400 meshes (circumference) excluder, target species were efficiently caught and only few commercial fish entered the escape tunnel entry. Five designs were tested and the outcome is a prototype excluder with a 600 diamond-shaped meshes (circumference) tunnel including a filter grid of 230 x 230 mm square meshes or 200x250 (rectangular mesh) and an adjacent horizontal panel of 400 mm diamond shaped meshes to separate non-targets from the catch.

In the proposed design, the grid panel is inclined 20° to guide larger non-target species downward to the entrance of an escape tunnel. In front of the filter grid attachment to the top panel, the excluder is provided with an exit to enable escape of reversing small cetaceans.

By-catch monitoring has demonstrated that captures are highly variable among the fleet with no apparent bias towards a single ship. Species that will be released by the proposed excluder include most if not all mature sharks, manta rays, most bill fish, and sea turtles. The majority of registered by-catch are juvenile hammerhead sharks of 0.50 (length-at-birth) to 1.30 m, which often pass through the grid with the target species and are only separated in the freezing factory below decks. To limit damage to the population it is paramount that the adult specimen can escape to reproduce, which the present excluder achieves. The proposed technique is foolproof and provides a low-cost measure to limit damage to the marine ecosystem.

The effects of the application of cetacean grid barrier (2 x 2 m meshes) rigged in the front part of a pelagic trawl could not be thoroughly tested. After a single experiment with a low catch research on this issue was cancelled by the ship's staff. Research is continued in the EU-funded research program Necessity; in this scheme a rope barrier was tested in a flumetank on a 1/32 scale in February 2005 and two types of full-scale barrier constructions will be tested on a research vessel in March 2005. In addition to a cetacean barrier, acoustic deterrents are under development to prevent these species from entering the trawl. Tests with commercially available 'pingers' demonstrate that these sounds are masked by the noise spectrum of larger Dutch freezer trawlers. There is no knowledge on the masking effect of the echo-location sonar by pinger sounds, which could increase the risk of by-catch of cetaceans at night. This basic issue will be investigated within the Necessity research program in a basin study in 2005. Preferably an inter-active acoustic deterrent device facilitating existing fish detection systems will be a more feasible approach as described in the I-Ping proposal offered to the Redersvereniging in 2004 (DdH).

All observations were made in the framework of three projects of the Netherlands Institute for Fisheries Research (RIVO B.V.) in the area, financed by the Dutch Ministry of Agriculture, Nature Management, and Food Safety (LNV) and partly by the Redersvereniging voor Zeevisserij: "Assessment of Sardinella and other small pelagics in West Africa" (313-1230001), "Application of remote sensing data to analyze the distribution and recruitment of sardinella" (313-1230002), and "Preventing by-catches of protected or endangered species in the pelagic trawl fishery in West Africa" (313-1230003).

1. Introduction

This is the final report of the RIVO project "Preventing by-catches of protected or endangered species in the pelagic trawl fishery in West Africa" (Contract 01.162, project 313-12300003). With a Remote Sensing project (Zeeberg 2005) and "Sardinella assessment", this work is part of a research program to analyse the variability in sardinella captures and by-catch off Mauritania, including the accidental by-catch of large species. All three projects in Mauritania cover a three-year period (2002-2004) and are jointly financed by the Dutch Ministry of Agriculture, Nature Management, and Food safety (LNV) and the Redersvereniging voor de Zeevisserij.

The reduction of catches of juvenile fish and non-target species became a focal point for ICES fishing technology working groups in the 1970s and 1980s. The ICES Gear and Behaviour Committee "agreed that member countries should be asked to pay closer attention to the development of fishing gears and equipment to safeguard the by-catch" (Walsh *et al.* 2000). Two species-selective technical devices have been successfully introduced in commercial fishing through legislation: the turtle excluder device (TED) used in shrimp fisheries in the USA (Watson and Seidel, 1980) and the "Nordmøre Grid" used in the Barents Sea shrimp fisheries to reduce catches of fin fishes (Isaksen *et al.* 1990). In 1996 an ICES study group reviewed sorting systems in different types of fisheries (ICES 1996). Many international studies were conducted aimed at improving species and size selectivity of pelagic targets such as Atlantic mackerel, horse mackerel and herring (van Marlen *et al.* 1995).

Most of the non-target fish species could theoretically be excluded from the catch using a Nordmøre type grid in the aft part of the trawl. However, the Nordmøre- and TED type of grid designs are rigid constructions and are mostly applied in smaller gear, like shrimp trawls or in mid-water trawls fished by slipway trawlers. These devices cannot assimilate massive catches of 70-200 tons, such as taken by the freezer trawlers in the Mauritanian EEZ. In contrast to their Russian counterparts, Dutch freezer trawlers are not equipped with slipway ramps, and cod ends containing rigid grids are not easily taken on board without damage to the trawl or the grid. Therefore, a flexible selection device made out of standard netting would be preferable in the Dutch pelagic fisheries.

Cetaceans need a different approach, because claustrophobia is a reaction observed among cetaceans in the purse seine fisheries for tuna, as well as under captive conditions in marine mammal parks. Cetaceans therefore are unlikely to be released alive passing a narrow release route in the cod end section. Other technical means to reduce cetacean by-catch include the application of acoustic deterrents and a net barrier in the front part of the trawl. A range of acoustic deterrent devices (pingers) is commercially available and efficiently used in reducing harbour porpoise by-catch in passive set gears. However, it is doubtful whether these devices can be successfully applied on towed gears to reduce Atlantic dolphin species. The success depend on the response of those species to those sounds as well as a number of other variables, like the spectra and levels of the background noise and the way the deterrent sound are masked by this noise.

Habituation to acoustic deterrents could contribute to by-catch when cetaceans exploit those sounds as beacons. Further research on the masking effects of available pingers offered for use in pelagic gears will be required for the Dutch pelagic fisheries. Also the sounds could hamper the dolphins' echo-location sonar sense. A cetacean barrier in the front part of the trawl, which does not produce sound but merely reflects the sonar signals of the dolphins and exploits their claustrophobia seems to be a more practical solution (de Haan 1998). Such an adaptation could also reduce the by-catch of other marine mammals, like pinnipeds. The influence of a cetacean barrier to the geometry of the trawl and the throughput of target fish are however to be investigated.

2. By-catch Observations between 2001 and 2005

From October 2001 until December 2004 we monitored 4 to 20 % of the monthly total fishing effort of the Dutch trawler fleet (Figure 1, Table 8) in months with the greatest likelihood of megafauna by-catch (May through December). In September, October, and November 2004, trawler crews assisted in the observation according to a provided manual (Annex 3) and up to 88% of the net hauls have been monitored. Due to a closure of the fishery over shallow water for two months, fishery was ca. 6 miles further off shore (20 nm limit) in September-October 2004. To prevent entering of large non target-animals with target fish into the cod end, sharks, dolphins and other megafauna are retained in a 'filter grid', which is a panel of 250 mm square meshes that allows target fish to pass. The grid is rigged in the tapered aft section of the trawl (Figs. 2 and 4) or in the first cod end section (about 50-70 m in front of the cod end). Depending on the amount and species thus captured, the grid may be emptied by releasing a zipper junction while the cod end is still in the water. During the observer missions, however, the grid is taken on board the vessel and the animals are identified up to species level (according to FAO determination guides), measured, and photographed.

In this 39 month period, a total of 1510 net hauls was monitored, during which more than 1000 animals were registered. In a separate observer program, which ran over 1999-2002 (ter Hofstede *et al.* 2004), large animals were recorded less systematically with 628 records. In both programs, hammerhead sharks (*Sphyrna lewini* and some *S. zygaena*) account for about 41% and turtles (leatherback and loggerhead) for 0.6% of the total number of large by-catch. By-catch registered by the monitoring program between 2001 and 2005 comprised for about 14% of sharks (other than hammerhead), 15% sunfish (*Mola mola*), 9% bill fish (marlin, sail fish, and spear fish), 12% rays (*Manta birostris* and skates), and 9% cetaceans (mostly common dolphin, *Delphinus delphis*). Extrapolation to (Dutch) fleet level can be done because the percentage of observed to total fishing days is accurately known and provides a factor for multiplication (Tables 6-8). Thus acquired numbers provide minimum estimates, based on 7 months observation per year. Observed and estimated by-catches by the Dutch fleet are a part (probably a smaller part) of the total number removed by the international trawlers, longlining, and artisanal gill-netting in the Mauritanian EEZ and around Northwest Africa.

The presence of (sub)tropical species (especially manta and hammerhead sharks) in the Mauritanian EEZ is minimal during Winter and Spring (November to June) when the region is dominated by trade-wind-induced upwellings and water temperatures drop from a summer maximum of 30°C to ca. 18°C (Figure 1). The estimated by-catch rates therefore are based on extrapolation per month, thus accounting for the substantial seasonal fluctuation in species composition. Furthermore, sardinella is a highly migratory species that appears to leave Mauritanian waters in Fall. Because of low sardinella abundance, the international trawler fleet between November and May targets sardine, horsemackerel, and mackerel in upwelling waters (Zeeberg 2004, 2005). By-catch in these fisheries is commonly restricted to the incidental blue shark and sunfish. During a mission in November-December 2003, in 63 hauls just ten large animals were registered, most of which occurred in vicinity of tropical water around 19°C (including one sea turtle), and two blue sharks (registered under "small sharks") in waters of 17°C. Summer missions involve trawling in shallow waters (water depth ca. 50 m), often hard against the 12 mile fishing limit around coral banks, with for instance, in September 2003 (28 hauls) high by-catch rates of bottom dwelling species, notably catfish (Arius heudelotii) and milk shark (Rhizoprionodron acutus). Extrapolations for dolphins and pilot whales have been done for capture of single specimen or small (2-5) pods, excluding the rare (once a year or less) capture of 'supergroups' of more than twenty (pilot whale) or fifty (dolphins) individuals. These numbers have been included in the "minimum" estimate (Table 7).

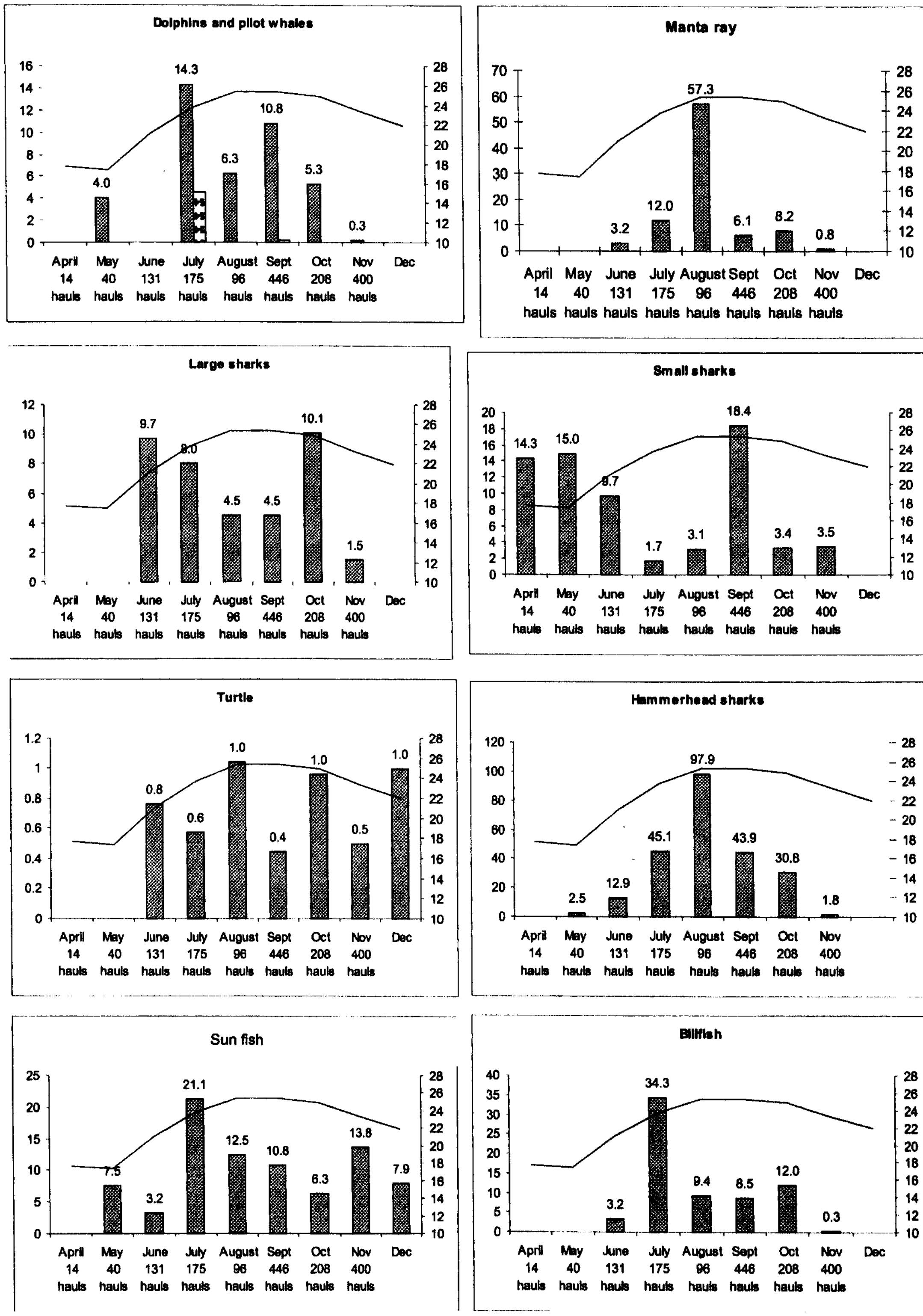

Figure 1. By-catch rates for species monitored in this study (Table 6), or number of animals taken in 100 net hauls (about 34 days on average). AVHRR Sea surface temperature is indicated on the right Y-axis (Zeeberg 2005); X-axis gives the total number of observed net hauls over the three year-period (2001-10 until 2004-12).

By calculating by-catch rates at fleet level it is assumed that the 'samples' are drawn from a homogenous seasonal population. The chance to intercept (a shoal of) megafauna in a particular month is equal for each trawler because of similar effort and fishing tactics. The trawlers usually operate in close vicinity, often within five miles of each other, circling in 'spaghetti' trajectories with speeds of 5-6 knots and using the same gear riggings. Table 1 illustrates that in 2002 at deep water the larger trawls were commonly used. Trawls with a larger circumference have a larger net opening and the greater extension of their rigging parts (bridles and doors) likely provides a more significant herding effect. In 2003 and 2004, the fleet preferably used the smaller 4300 meshes trawl, which has a flatter profile and is more easily maneuvered in shallow coastal waters.

The high variance of the by-catch rates reflects the incidental nature of megafauna captures. By-catches are highly variable among the fleet with no apparent bias per ship. Simultaneous observations on two ships, as has been done in July and November 2004, may yield no or low by-catch on one vessel and high by-catch on the other. Generally, when sardinella abundance is low, by-catch of non-target species increases because of random trawling while searching for the target species. During the evening and night, when pelagic fish disperse and occur scattered, the boats do not target specific shoals and by-catch is greater than during the day. The number taken from a species is variable between years, however, certain regularities can be seen (Figure 1, Tables 6 and 7); e.g. the capture of blue sharks (under small sharks) in cold water and the arrival of hammerhead with tropical water. In 2004 we registered a remarkable number of manta ray, with one record of 26 mature individuals in a single haul. The manta arrived on deck alive, but died in the 20-30 minutes it took to process the catch. The only way to discard manta dead or alive is to pierce one of the wings and hoist the animals from deck by crane. Survival of these heavy (up to 1 ton) fish therefore depends on release mechanisms in the water.

Table 1. Size and dimension of pelagic gear during experiment and observation periods. Trawl openings have been measured using the trawl sonar system. The length displayed in the second column is the total length of head and foot rope and both side ropes. Values of columns 5-8 are averages over the observed number of hauls. Thy stands for Thyboron type of fishing door.

Circumference		Doors	Weights	Warps	Bridles	Water depth	Trawl opening		Period
# meshes	m	m²	kg	m	m		H	V	
4300	522	Thy 13	1375	385	38	1060	68	31	2002-07
4300	522	Nets 12.25	1750	421	30	151	79	27	2004-07
5300	734.4	Nets 12.25	1500	293	50	53	70	31	2004-11
6900	893.8	Thy 13	1562	378	48	534	101	30	2002-07
7200	1440	Nets 12.25	1500	325	50	53	96	50	2004-11
9300	1245	Thy 13	1500	360	50	1060	105	30	2002-07

3. Gear Modification: Methods

A net adaptation to exclude larger non-targets from the catch and to release them alive has been developed in cooperation with Maritiem trawl manufacturing company, Katwijk (The Netherlands). Based on first experiments in October 2001 (de Haan 2003), net development and experiments on board trawlers continued in 2002 and 2004. During missions in July (de Haan 2002a) and September 2002 (de Haan 2002b), and July and November 2004 the settings and rigging of the excluder design have been progressively improved. The following overview illustrates the schedule and number of operations, the excluder designs and the pelagic trawls with which the adaptations were tested. Fishing gear used for the selectivity experiments was rigged according the normal standard commercial operation and towed in a GPS speed range between 4.7 and 6.5 knots.

Table 2. Experiments in 2002 and 2004

Period	Days	Hauls observed and % filmed		Water depth	Excluder model	Trawl opening (meshes)
2002-07	13	21	79.1	1060	400 #	4300 6900 9300
2002-09	12	23	74.6	534	400 #	4800 6900
2004-07	6	9	77.7	151	a) 600 # b) cetacean barrier	4300
2004-11	16	16	53.5	53	600 # 400 #	5300

3.1. Progress and evaluation of the net adaptations

The basic design (Figure 2) of the excluder consists of a top downwards-sloped filter grid with a mesh size big enough to allow commercial fish to pass, while larger non-target species are forced downward to the bottom part. The filter grid is left open on the bottom panel, providing the entrance of separated route for larger non-target fish leading to an escape hatch in the bottom panel.

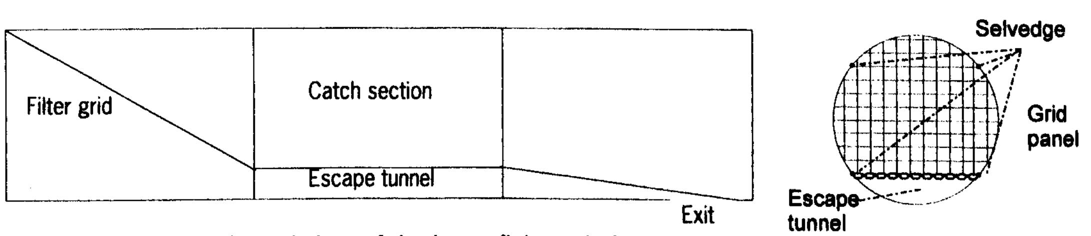

Figure 2. Side and frontal view of the large fish excluder

The excluder replaced the conventional section with the shark- blocking grid and was positioned directly behind the tapered aft section of the trawl, approximately 70 m in front of the codend.

In the research period this basic design has been evaluated in four different designs (Annex 1.1). An overview of specifications tested during each mission is given in Table 3.

The first experiments in 2001 showed that larger non-targets could be efficiently filtered and released from the net, however, opportunities to investigate the response of target fish were few. The experiments in 2002 were continued in summer when sardinella catches peaked and more effort was put in optimizing the design to the filtering of target fish and finding a new balance in the filtering of larger non-targets.

Table 3. Overview of main excluder design parameters

	2001-10	2002-07	2002-09	2004-07	2004-11
Tunnel specifications					
Rigging mesh type	Double twined diamond shaped	Double twined diamond shaped	Double twined diamond shaped	Square 25x25 mm	a) 25 x 25 mm b) Conventional
Circumference (# meshes)	400	400	400	600	a) 600 b) 400
Diameter (m)	2.5 m	2.5 m	2.5 m	4.5 m	a) 4.5 b) 2.5
Escape tunnel opening (m)	1.8 x 0.4	1.8 x 0.4	1.8 x 0.4	3.1 x 0.6	a) 3.1 x 0.6 b) 1.8 x 0.4
Filter grid					
Mesh size (mm), square and hexagonal (b)	250x250	a) 200x200 b) 250x150 x250	250x250	200x200	200x200
Twine thickness (mm) and material	12, nylon	a) 6, nylon b) 12, elastic	12 mm nylon	5, *Dyneema*	5, *Dyneema*
# meshes	31 x 12	31 x 12	31 x 10	45 x 15	37 x 13
Separation panel between tunnel and catch section					
Length (m)	12.5 m	a) 9 b) 9	a) 4.5 b) 4.5	4 m	a) 4 b) 4.4
Mesh type	Diamond	Diamond	a) Diamond b) Square	Square	a) Square b) Diamond
Mesh length (mm, stretched)	500	400	500 250x250	25x25	a) 25x25 b) 400
# meshes	30 x 18	18 x 18	10x18	160 x 120	11 x 16
Twine	6 mm nylon	6 mm nylon	12 mm nylon	5 mm *Dyneema*	a) 5, *Dyneema* b) 6, nylon
Length of chain weight					
Chain length at 9 kg/m	2.2 m	2.2 m	2.2 m	3.25 m	2.2 m

On the 2002-07 trial a provisional netting barrier was rigged on the bottom panel close to the lower part of the grid to divert target fish away from the escape tunnel (Annex 1.1.1.). Other changes were the mesh size and twine diameter of the filter grid (200 x 200 mm, 6 mm nylon twine), which reduced the influence of the water flow to the grid and the smaller mesh would reduce the length of filtered non-targets from the catch. The 400 and 500 mm (stretched length) meshes of both separation panels (type a & b) were set to the selvedge to an opening of 10% of the stretched length, which is an increase of 5 % compared to the 2001 design. The vertical height in the escape route was also reduced by lead cord weights. As sharks became entangled in the escape tunnel the next design tested in 2002-09 had a shorter escape tunnel and a larger filter grid mesh (250 x 250 mm). To cope with a larger number of bigger non-targets the nylon twine of the filter grid and separation panel was increased to 12 mm. Also the barrier height in front of the grid was increased from 30 to 50 meshes (Annex 1.1.3. and 1.1.4.). One of the outcomes of the 2002-09 trial was the relation found between the barrier in front of the grid and the poorer performance of the escape tunnel rigging, which could not spread to the required size (Figure 5 in Annex 2). To improve the release of manta a tunnel of 25 mm square meshes circumference was built (2004-07, Annex 1.1.5.) with a filter grid of 200 mm square meshes built of 5 mm *Dyneema* twine to reduce the drag and so minimize negative effects on the vertical escape tunnel opening and improve the durability. A net barrier in front of the filter grid was omitted to observe the behavior of target fish to this new design. The separation panel was built of 25 mm square meshes to avoid entanglements and to observe the losses of target fish.

In spite of all measures, like kites attached to the side panels at the front and backside of the excluder and progressive enlargement of the filter grid and separation panel width from 3.05 m to 4.05 m the escape tunnel of the 600 square meshes design did not reach the required horizontal opening. The reduced spread is attributed to the higher water flow through the square-mesh tunnel panels, which lowered the water pressure inside the excluder and thus the spreading of the tunnel section. Other design factors, which contributed to losses of target fish were the rigging of the filter grid (2 different angles), which guided target fish towards the escape tunnel entrance and the higher volume underneath the lowest part of the filter grid did not force smaller amounts of target fish to pass through these meshes. This behavior was also observed when the lowest part of the filter grid was rigged fully horizontally along the selvedge.

Because the performance of the 600 meshes design was unsatisfactory, a provisional 400 meshes excluder was built on board with the type of filter grid of the 600 meshes design, rigged as on the 2002-07 trial, but with a separation panel built of larger diamond shaped meshes, similar to those tested in the 2002-07a design (Annex 1.1.6.). The experiment showed a chain weight of 2.2 m attached to the junction of filter grid and separation panel reduced escape changes of target fish (Figure 13 in Annex 2).

3.2. Cetacean net barrier

An experiment with a vertical barrier built of ropes in the front part of a 5600 meshes trawl showed that the vertical opening was slightly reduced, but that an adaptation on this scale was technically feasible (de Haan 1998). Any results on the effects on the fishing efficiency were not obtained. Instead of vertical ropes a more symmetrical design of 2 m square meshes with a possibility for bi-directional escapes through upper as well as lower panel was made available by the netting company Maritiem, Katwijk (Annex 1.5.). As the hydro-dynamic effects to the vertical trawl opening were thought high and grid meshes could become jammed between trawl panel meshes, this barrier grid was build of a smaller 8 mm nylon twine. The grid panel was positioned in the 7.20 m meshes of a 4300 meshes trawl (distance from head and foot rope is 49 m).

3.3. Acoustic experiments

The emitted sound spectra and levels of commercial available pelagic pingers were measured in a tank in 2004 and the outcome showed that a number of parameters did not match the manufacturer's specification. Especially the specified low frequency spectrum of SaveWave pingers was not confirmed by the analysis. Also the manufacturer's strategy to rig SaveWave pingers to a pelagic trawl is doubtful and inefficient. It shows there is also a lack of knowledge about the operation of pelagic gears. The recommendation of rigging the deterrents to the bridles and doors in Mauritanian waters could lead to the increase of by-catch as dolphins once arriving between the bridles cannot escape sideways or upward and the only way to escape would be a full reverse, which is unlikely. A better approach would be to mount the pingers around the circumference of front-side large meshes or to aim at a single deterrent instead of multiple devices, which is a time consuming matter. The proposed (DdH) I-Ping interactive acoustic deterrent system aims using standard fish detection equipment on board as deterrent including a cetacean listening function to alert the ship's staff and activate acoustic deterrents on ship and trawl.

As the contribution to the background noise of tonal signals of fish detection systems on board of Dutch trawlers is under estimated an inventory was started of the standard acoustic fish detection equipment installed on board of Dutch freezing trawlers. To conclude whether commercial available pingers are technically feasible a representative Dutch pelagic trawler (November 2004), the background noise levels, spectra and the masking effects were measured on a pelagic fishing tow with 2 SaveWave pingers on the fishing doors and one on the selvedge 4 m behind the junction of the 9–8 m meshes. The measurement took place in November 2004 under excellent weather conditions.

3.4. Underwater video observations

To monitor gear experiments we used autonomous underwater video equipment, which consisted of:

- an underwater camera Multi-Seacam1050 (0.27 lux at f 2.8, DeepSea Power & Light);
- a Multi-Seacam1060 (0.01 lux at f 2.8, DeepSea Power & Light);
- a DV video recorder (Sony, GV-D 300);
- a backup Digital-8 video recorder (Sony, GV-D 200).

Underwater video recordings were stored on Maxwell DVM 80SE tapes and Sony Digital-8 tapes (type N8-90P2), which allowed a recording period of respectively 120 and 135 minutes in long-play mode. Observations could therefore only cover 50 to 80% of a trawling period, which typically lasts three to four hours. Underwater video recordings were analysed using a Sony GV-D 1000 mini DV recorder/monitor and a desktop computer and reviewed in a record list for each haul with the start time of the recorder as time reference. Video clips were captured and in case they were sufficiently relevant, stored on a USB mass storage device (Maxtor 160 Gb) for post-processing to MPEG-2 video clips. The geometry of the trawl opening and the detection of target fish and the travel time of target fish towards the excluder were observed using the ship's trawl sonar. Trawl sonar images were recorded at the start of the haul, during the haul when fish detections were made and at the end of haul and stored on mini DV cassette tape using a VGA splitter with S-VHS video output (AverKey Pro converter) connected to a Sony GV-D 1000 video recorder. Deck shots illustrating by-catches as aid to their identification, technical materials, modifications to net adaptations on board the vessels were recorded using a Sony Digital-8 DCR-TRV 140E camcorder.

4. Results: Observation of target species behaviour and filtering efficiency

4.1. Target Species Behaviour

4.1.1. Sardinella

Underwater camera observations demonstrate that the tested designs had no adverse effect on sardinella behavior and that fishing during the hydrodynamic tests was efficient in all situations. In the 2002-07 design few sardinella were observed in the escape tunnel (Figure 4 in Annex 2) and the barriers in front of the filter grid forced the fish to pass through the higher regions of the grid. Both sardinella species (*Sardinella aurita* and *S. maderensis*) were filtered efficiently with the 2002-07, 2004-07 designs. The fish showed a frantic behavior with individual attempts to investigate escape possibilities, with physical contacts with tunnel panels. After a short haul of one hour a significant catch of 70 ton sardinella (2002-07) was efficiently separated from the release route, none were observed escaping through the escape tunnel. The fish remained swimming for more than 1 hour and showed a pendulum behavior swimming forward and falling backwards. The final clue was therefore difficult to establish. Although the 600 meshes circumference excluder performed not stable and the required horizontal opening could not be established, the vertical wave action contributed in herding sardinella through the filter grid meshes. The filtering efficiency of larger quantities in the 400 as well 600 meshes excluder models reached the required commercial level (Figure 8 in Annex 2). In smaller quantities, however, the fish dived and stayed close to the escape tunnel entrance (2004-07, 2004-11), probably those small amounts of fish were lost. The 400 meshes excluder (2002-07) was commercially fished for a period of six days involving 23 hauls. Figure 3 shows that this result matched a series of conventional hauls without the excluder of an adjacent time period with the same 6900 trawl (the average excluder catch was 57.65 tons, while the catch with the conventional rigged cod end was 55.53 tons).

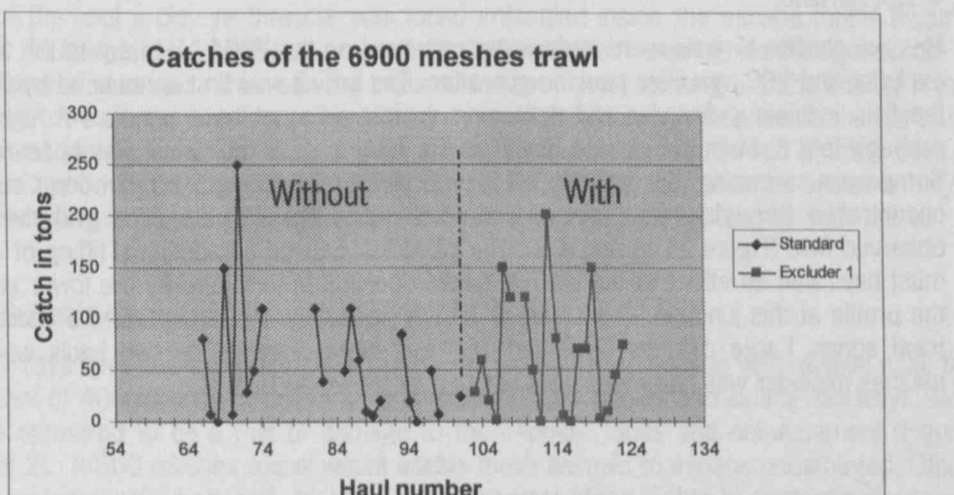

Figure 3. Sardinella catches (6900 trawl) with (23 hauls) and without the excluder (30 hauls)

Also the final observation haul of 2004-07 showed that a catch of 60 tons was obtained and that this catch matched the readings of the trawl sonar system. Smaller amounts of arriving fish maintained a stationary position inside the escape tunnel entrance, but these fishes showed a pendulum swimming behaviour (backward-forward) and penetrated finally through the lower part of the grid. Some smaller amount of fish was observed escaping from the 600 meshes excluder (2004-11), observations outside the trawl (2004-07) showed their numbers were irrelevant. With this result it seemed possible to omit the additional netting ramps in front of the grid to sweep up target fish more upwards, which simplified the design.

When haul period was <2 hours the hauling stage was underwater observed in a few cases (2002-07), showing sardinella reversed through the filter grid as soon as the fishing doors were heaved in and the relative speed reduced to about 1.5 knots. This phenomenon was observed from the moment the fishing doors were disconnected until heaving of the trawl onto the trawl winch, which on average took about 15 minutes in total. Probably a significant share of the catch is lost under this condition, which is also illustrated by sardinella falling on deck through the 200 mm meshes of the aft section of the trawl. While hauling the trawl, the chain weight rigged across the escape entrance closed the tunnel entrance and lowered the separation panel towards the bottom panel, reducing escape opportunities for target fish swimming in sections before filter grid and excluder. It appeared that fish detections on the trawl sonar do not automatically mean that sardinella will arrive in the cod end section as was proved by the underwater observations (2002-07). Before this evidence was recorded it was feared that these detected fish were lost in the excluder on similar occasions.

4.1.2. Mackerel

Mackerel remained swimming stationary over a long period of time. In the 2001-10 design the filtering with 250x250 mm meshes operated efficiently, however, larger fish did not easily penetrate the 200x200 meshes of the 2004-07 and of both the 2004-11 designs (Table 3). They kept position underneath the 200 mm filter grid on the level of the escape tunnel entrance. Smaller number of specimen penetrated the grid meshes. A single observation on the first haul of the 2004-11 trial showed that a number of fish were entangled with the gills onto the bars of the 200 mm grid meshes indicating passing through these meshes was not easy and not always successful (Figure 10 in Annex 2).

4.1.3. Sardine

Massive sardine arrivals were underwater observed on the 2004-11 trial with the 600 meshes excluder and 200 mm filter panel in operation. The arrival was first announced by the scales of the fish, indicating disorder and collapsing against adjacent trawl panels. A high share was probably lost through the escape tunnel as the lower part of the tunnel was obscured with fish. Some were swimming, the majority could not maintain swimming and arrived in disorder. In this uncontrolled throughput fish became gilled in many bars of the filter grid meshes in the observed field (Figure 11 in Annex 2). The gilled fish caused an additional lifting of the grid and must have had an effect to the vertical tunnel opening as indicated by the lower selvedge and the profile at this junction. The catch of 70 ton was below the expected level indicated by the trawl sonar. Large catches (150 and 160 ton) were obtained on two hauls when the 400 meshes excluder was commercially employed on the 2004-11 trial.

4.1.4. Horsemackerel

A significant amount of horsemackerel was observed diving towards the escape tunnel in the 600 meshes excluder with 200 x 200 mm mesh grid panel (2004-07, haul 1). A large number of these entered the escape tunnel and the majority escaped (Figure 9 in Annex 2). Small numbers of horsemackerel were observed in the escape tunnel of the 2002-07, 2004-07 and 2004-11 design. The fish maintained a stationary swimming behaviour for longer periods of time, small amounts of fish inside the escape tunnel may have escaped.

4.1.5. Hairtail

On the 2004-11 trial a large amount of hairtail (*Trichiurus lepturus*) was observed diving in front of the 200 mm filter grid towards the escape tunnel entrance. Many were seen entering the tunnel entrance. Hair tail fish becomes easily entangled in the interior meshes. Because of the extremely sharp teeth the entanglements and their remainders damaged nylon mesh material (2002-07). This was one of the motives to build the filter grid and separation panel of a more durable twine like the *Dyneema* type.

4.2. Filtering efficiency of Non-targets

4.2.1. Billfish

Like target fish, marlins and other bill fish tried to maintain a stationary position in the water flow in front of the grid panel with accelerations forward. They get entangled in the grid with their spears or tails while reversing. Much energy is spent in cases of entanglements, in most cases caused by the spear and in some cases by the tail in meshes of the separation panel and filter grid. Chances of releases were highest when individuals arrived exhausted and proceeded through the escape tunnel passively (Figure 7 in Annex 2). Two fishes with a length of 1.80-1.90 m were able to penetrate a 250 mm square mesh (2001-10).

4.2.2. Hammerhead shark

The results are based on observations made of 2001-10 and 2002-07. On most of the occasions hammerhead sharks were able to escape. The fish is not maintaining position in the water flow, but slowly swimming the escape route without accelerations (Figure 1 in Annex 2). The lower efficiency in the 2002-07 trial was caused by the lower vertical height in the escape route compared to the design tested in 2001-10. After this experiment the number of observations reduced to zero, mainly due to the shallow water fishing area. On the 2002-07 trial a hammerhead shark and an unidentified shark were observed entering the tunnel, at the end of the haul a big-eye thresher was found entangled inside the escape tunnel (Figure 6 in Annex 2). As the entanglements occurred mostly in a certain area the lead weight on the tunnel panel in that area was removed. The reduced escape tunnel opening and the energy it took for the fish to reach the hatch was expressed on a single observation on which the hammerhead remained stationary on the bottom panel for about 1 minute, after which it came back to life and escaped. During the constant day-and night fishing operation with the excluder only a few small sharks were by-caught, while other ships in close range caught significantly more.

4.2.3. Manta rays, rays, and skates

Manta rays have been observed in 2001-10 and were seen to escape with relative ease through a tunnel of 400 meshes circumference by rotating their bodies and exiting sideways. However there appeared to be a risk of damage to the cephalic lobes and entanglement (Figure 2 in Annex 2). A 600 meshes tunnel would enable these animals to escape undamaged. Other rays (mature individuals) frequently by-caught off Northwest Africa (Table 5) were observed escaping with ease.

4.2.4. Sunfish

Observations showed that when these fishes arrive in front of the filter grid they loose control of vertical swimming and are blown by the water current against the filter grid meshes. On such an event the vertical tunnel opening is increased due to the increased drag and lifting force of the panel, with increasing chances of target fish to escape (Figure 3 in Annex 2). Also entanglements of smaller sunfish inside the tunnel did occur, which reduce release chances of other non-target species. After the addition of a barrier in front of the filter grid (2002-07/09) the number of grid collisions reduced and in stead most of these fishes were caught in the front of the barrier where they did not affect the efficiency to target fish. However, the results of the 600 meshes excluder design showed releases of sunfish did occur. In two occasions (2004-11) single specimen observed against the filter grid meshes were not actually caught and could have been released during hauling.

4.2.5. Pilot whales

On the daytime experiment of the 2002-07 trial a catch of a group of 6-10 pilot whales was underwater observed with the second design with a flexible filter grid in operation. Some animals damaged the flexible filter grid meshes and forced themselves through, a number of five animals became jammed in the tunnel perpendicular to the water flow. The observation clearly demonstrated that the excluder dimensions were too small to release marine mammals of that size and numbers. In this observed disorder animals drowning produced heavy tail beats that hampered other animals to find the escape route. An important observation was that most animals were still alive when they reached the excluder, and that the last drowning was observed 12 minutes after the arrival of the animals at the excluder. As the by-catch was too heavy to be hoisted on deck the corpses were released with the cod end opened over the stern, without being able to examine the by-catch.

4.2.6. Turtles

In November 2004 a small turtle (ca. 0.6 m) was filmed escaping (Figure 12 in Annex 2). After having being clamped for awhile against the filter grid panel of the 2004-11a design (Table 2) the animal climbed downwards using its wings, swam towards the escape tunnel entrance and escaped.

Tabel 4. Observed by-catch releases (R) and captures in the excluder (C) during experiments.

Mission	2001-10		2002-07		2002-09		2004-07		2004-11	
Species	R	C	R	C	R	C	R	C	R	C
Bill fish	4	6					2	3		
Hammerhead	5	2	2	4						
Shark (other)		2	1	1		1				
Manta ray	3	1								
Ray							4		2	
Sunfish				20		7		3	2	8
Pilot whale				6-10						
Turtle									1	

5. Prototype design and considerations for further research

5.1. Filter grid

To improve filtering of small sharks and juvenile megafauna, an experimental 200 mm square mesh filter grid was introduced instead of the standard 250 mm square mesh. With the 200 mm panel in position, sardinella were caught efficiently, but mackerel and sardine were obstructed by the finer grid. Based on these observations it is recommended to adjust the filter grid mesh to a size of 230 x 230 mm. A grid with rectangular meshes of 200 x 250 mm (longest bar vertical) may improve filtering and still let target fish pass unobstructed. Compared to the 230 x 230 mm mesh, the 200 x 250 mm mesh has a 20 mm shorter circumference and will reduce drag i.e. lift forces, which benefits the vertical escape tunnel opening.

The filter grid is inclined under an angle of about 28 °, and constructed of 5 mm *Dyneema*. To lower the vertical escape entrance and close it during hauling, a chain weight of 3 m long (9 kg/m) is added at the junction of the filter grid and separation panel. The present inclination of the filter panel improves the throughput of mackerel and sardine, while maintaining full release efficiency of non-target species.

5.2. Tunnel dimension

The 400 meshes circumference tunnel (diameter 2.5 m) is too narrow to release manta rays without risks of damage to the cephalic lobes and therefore a 600 traditional mesh tunnel is preferred. Assuming a mesh opening of 30% a tunnel diameter of 3.6 m can be reached. The traditional diamond-shaped double twined meshes do provide the required hydrodynamic stability and connect well to the adjacent sections with the same mesh type.

5.3. Escape tunnel and exit

The separation panel design with 400 mm (stretched length) diamond shaped meshes of 5 mm Dyneema is proposed for the prototype excluder. The length of this section will be extended from 4 to 8 m to match the scale enlargement from the 400 to 600-meshes tunnel circumference. To minimize instability effects on the rigging of the bottom panel, the exit of the tunnel is cut in a triangular shape along the mesh bars (Figure 4). The length of the 100 mm hatch cover will be equal to the 2002-07 and 2004-11 design.

Recent observations of cetacean behaviour in pelagic pair trawls fishing for sea bass (Northridge, personal communication 2005) have demonstrated that common dolphins search for escape possibilities along the roof of the trawl. An exit in the top panel, in front of the filter grid, is therefore added to increase the escape chances of small cetaceans. The position and slope of the filter grid enables the cetaceans to reverse and accelerate.

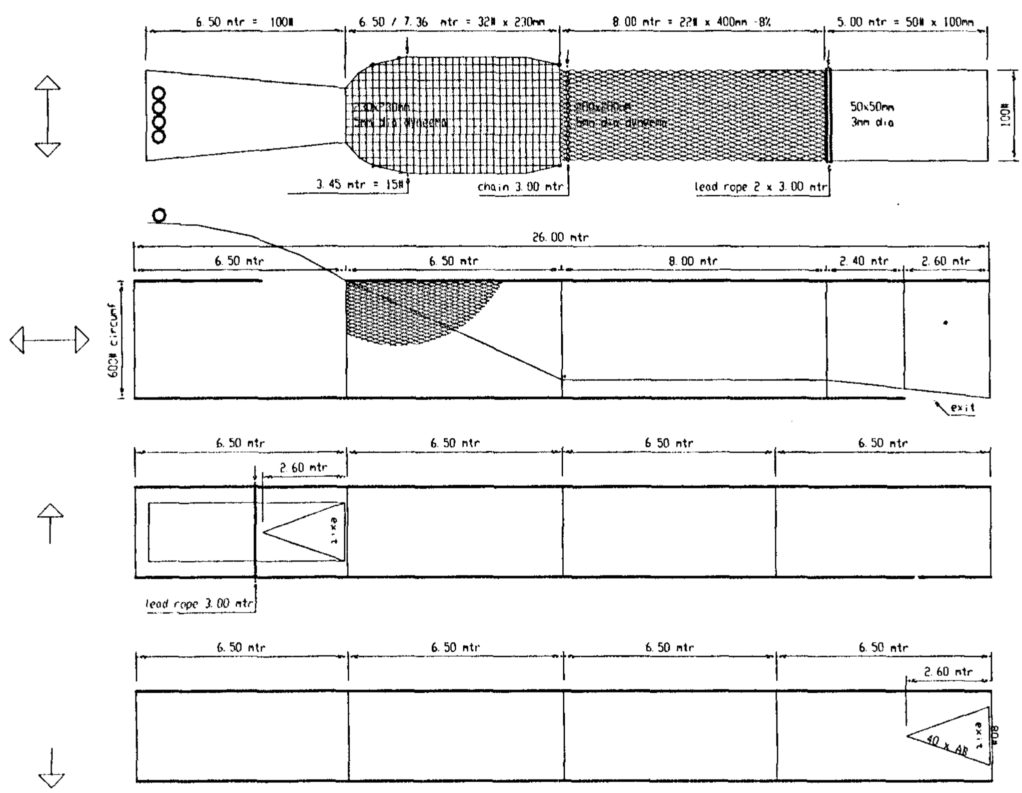

Figure 4. Prototype excluder with 600 traditional mesh tunnel, courtesy E. de Graaf, Maritiem Katwijk. Top: top view with (left to right) cetacean exit, filter grid, separation panel, and exit cover. Below that are the side view, then the top panel, and (bottom) bottom panel of the tunnel (see also Annex 1.5.).

5.4. Underwater video observations

The coverage of the complete haul by underwater video footage and the expansion to a dual camera system to be able to observe different position at a time is foreseen and the technical modification ongoing. A real-time wireless video system first used on the first experiments in 2001 is being improved to suit the purpose. This system will cover a haul duration of 7 hours. Low power recording material to extend the 120 minutes is not available on the market yet, future development will aim on low power windows embedded controller with flash-card as storage medium.

5.5. Cetacean grid barrier and future acoustic experiments

The single experiment with the cetacean grid barrier (2 x 2 m meshes) showed that the cooperation of crew on board commercial trawlers with this type of net adaptations is below the desired level. It will be recommended to consider the application of research vessels for the exclusion experiments of larger non-targets and to continue research on target fish on commercial trawlers. Further experiments were cancelled by the ship's staff, fearing that a panel in the trawl opening would prevent target species from entering.

The research on the application of acoustic deterrents showed that presently available pingers offered for use on pelagic trawlers do not suit the purpose and that the sound pressure levels of these devices have to be reconsidered. It will be recommended to follow the route described in the I-Ping proposal offered to the Redersvereniging in 2004 (DdH).

6. Discussion: variation in animal prevalence and how to estimate the excluder's mitigating effect

6.1. Seasonal variations

Megafauna by-catch increases sharply when springtime winds decrease and warm (>21°C) tropical water invades the region, on average early May in southern Mauritania (17°N) and two months later around Cap Blanc at 20°45'N (Zeeberg 2005). Cetaceans were rarely encountered during line-transect counts in relation with an acoustic survey for the "Sardinella assessment" project between 16 and 28 April 2004 (Tulp & Leopold 2004). In total, ten groups or singles were observed during 91.5 hours of counts over water depths <500 m, too few even for animal abundance estimates (Buckland *et al.* 2001; Borchers *et al.* 2002; Griffin & Griffin 2003). In May and during summer, however, very large groups are frequently spotted during acoustic fish stock surveys and by trawler crew on the southern Mauritanian shelf and adjacent oceanic waters (E. Winter, in: Zeeberg 2005; K. Goudswaard, personal communication 2005; Laptikhovskii 2001). The dolphins and pilot whales (short-finned, G. macrorynchus) are possibly chasing the returning sardinella and trawlers incidentally capture pods of 10-20 pilot whale or groups of 5 to 30 dolphin. More than 200 decomposing dolphins (and many sea turtles) were discovered on beaches south of Mauritania's capital Nouakhott in June 2003 (www.iucn.org) and again in June 2004 (Nouakchott Info, 13 June 2004). Similar strandings in the Nouakchott area in the fall of 1995 are attributed to bottom set gill nets, which occur along much of the Mauritanian coast (Nieri et al. 1999). Thus, with the arrival of the animals in the region, by-catch rates increase sharply in all types of fishery.

6.2. Expected mitigating effect of the excluder

Species that will be released alive and undamaged by the proposed excluder (600 meshes tunnel and 230 mm square mesh filter grid) include most if not all mature sharks, most bill fish, and sea turtles. The majority of by-caught hammerheads are juveniles of 0.50 (length-at-birth) to 1.30 m, which often pass through the grid with the target species and are only separated in the freezing factory below decks. Hammerheads spawn year round, producing litters of 20-30 pups (Hazin *et al.* 2001), and to prevent damage to the population it is paramount that the adult specimen can escape to reproduce. The 250 x 250 mm shark grid currently in standard use blocks hammerhead sharks with lengths >1.50 m and other fish with lengths ca. >1.80 m. The smaller 230 mesh (and also the 200 x 250 mm mesh) will further limit by-catch of juvenile megafauna and other unwanted by-catch such as dolphinfish (*Coryphaena hippurus*), longfin pompano (*Trachinotus ovatus*), meager (*Argyrosmus regius*), and low resilience fishes such as sea catfish (*Arius heudeloti*). Reduction of the bycatch rate (Figure 1, bycatch per measure of fishing effort) in the coming year(s) may provide an estimate of the mitigating effect of the excluder.

Although the subtropical eastern North Atlantic ranks with the world's most productive oceans, there is cause for concern because Northwest African stocks are likely threatened or depleted as described under national and international conventions (e.g. the US Endangered Species Act). Next to the sea turtles, which are listed by the IUCN Red List (www.redlist.org) as critically endangered (Spotila *et al.* 2000; Ferraroli *et al.* 2004), *Manta birostris* seems to be the species primarily threatened by trawler fisheries off Northwest Africa. The species inhabits tropical shelf waters and because it produces just one pup every two or three years, rapid population declines have been observed where target fishing has taken place (cf. Red List inventory). Comparison of cetacean by-catch rates with Potential Biological Removal (PBR) levels set for US waters provides the rough indication that takes off Northwest Africa may exceed safe limits. For short-finned pilot whale off California, Oregon, and Washington (also an eastern boundary current upwelling system), a PBR level is set of one (1.19) animal per year; and 182 white-sided dolphins can be caught off the US Northeast (Federal Register 69, 231, 2 December 2004).

At present there exists no solution to filter or deter cetaceans from the net opening. A barrier of vertical ropes in the front part of the trawl will be further tested, utilizing the animals' claustrophobic nature. In addition to the cetacean barrier, acoustic deterrents are under development to prevent these species from entering the net opening, or guide them out during hauling. Tests with commercially available 'pingers', effective to deter shallow seas species such as porpoises from static gear, demonstrate that in towed fishing gear the pinger sounds are masked by the noise spectrum of the trawler.

The most practical application to reduce cetacean by-catch, however, is an exit in the top panel (roof) of the trawl, in front of the filter panel attachment, to enable escape of reversing cetaceans. The majority of cetaceans captured in pelagic trawler fisheries are the smaller, surface-bound oceanic dolphins, notably short-beaked common dolphins (*Delphinus delphis*), bottlenose dolphins (*Tursiops truncates*), and (along the European shelf margin) white sided dolphins (*Lagenorhynchus acutus*; see Couperus 1997). Common dolphins are the most abundant of all cetaceans and are usually caught in groups of 2 to 5. Individuals could potentially escape using the 600 meshes tunnel. Cetacean by-catch is seen to occur almost exclusively during night trawls, indicating the additional need for behavioural and ethological studies, including interaction of the cetaceans with seabirds during day-time. The potential for release of mature individuals by the proposed excluder is indicated by species in Table 5. Of the most vulnerable species: turtle, manta ray, and mature (hammerhead) sharks, most, if not all individuals will be released.

Table 5: Species observed as by-catch between 2001 and 2005 (adopted from ter Hofstede *et al.* 2004), and potential for release of mature individuals by the excluder device.

Group	Family	Species	Common name	Released
sunfishes	*Molidae*	*Mola mola*	Ocean sunfish	Some
billfishes	*Istiophoridae*	*Xiphias gladius*	Swordfish	Some
		Istiophorus albicans	Atlantic sailfish	Some
		Maikara nigricans	Atlantic blue marlin	Some
rays	*Dasyatidae*	*Dasyatis centroura*	Roughtail stingray	Some
	Myliobatidae	*Manta birostius*	Atlantic manta	Most
		Mobula spec.	devil ray	Some
	Rajidae	*Raja miraletus*	Brown ray	Most
		Rajidae	skates	Most
	Torpediniformes	*Torpedo torpedo*	Common torpedo	Most
		Torpinidae	electric ray	Most
sharks	*Carcharhinidae*	*Carcharhinidae*	requiem shark	Most
		Carcharhinus limbatus	Blacktip shark	Most
		Carcharhinus obscurus	Dusky shark	Most
		Prionace glauca	Blue shark	Some
		Rhizoprionodron acutus	Milk shark	No
	Leptocharidae	*Leptocharias smithii*	Barbeled houndshark	No
	Triakidae	*Mustelus mustelus*	Smooth-hound	No
		Heptranchias spec.	sevengill shark	Most
		Hexancheus griseus	sixgill shark	Most
	Alopiidae	*Alopias profundus*	Bigeye tresher	Most
	Lamnidae	*Isurus oxyrinchus*	Shorfin mako	Most
	Squaliformes	*Scymnodon obscurus*	velvet dogfish	No
Hammer-head sharks	*Sphyrnidae*	*Sphyrna lewini*	Scalloped hammerhead	Most
		Sphyrna mokarran	Great hammerhead	Most
		Sphyrna zygaena	Smooth hammerhead	Most
Sea turtles	*Dermochelyidae*	*Dermochelys coriacea*	Leatherback turtle	Most
	Cheloniidae	*Caretta caretta*	Loggerhead turtle	Most
	Cheloniidae	*Eretmochelys imbricata*	Hawksbill turtle	Most
cetacea	*Delphinidae*	*Delphinus delphis*	Common dolphin	Some
		Globicephala spec.	Pilot Whale	No
		Grampus griseus	Risso's dolphin	No
		Stenella coeruleoalba	Striped dolphin	Some
		Tursiops truncates	Bottlenose dolphin	No

7. Conclusions and recommendations

- Gear modification to exclude larger non-targets from the catch and to release them alive has been designed and tested during full scale commercial trawling in 2001, 2002, and 2004 (5 missions, 92 days at sea). In a parallel program, more than 1500 hauls have been monitored for by-catch of pelagic megafauna, specifically sharks, bill fish, cetaceans, turtle, and sunfish.

- Experiments with a 400 meshes circumference tunnel and a filter grid with 250 x 250 mm meshes have demonstrated a 50 to 100% reduction in large animal by-catches. However, the filter panel with 200 x 200 mm mesh size with double inclination angles was seen to obstruct and deflect target species, which then were observed diving to the escape tunnel entry. Based on observations of the 2002-07 trial a large share of these fish would probably still enter the catch section through the 400 mm diamond-shaped meshes separation panel with an increased length of 8 m. The instable action of the 600 meshes tunnel build of 25 mm meshes also had a positive side, the vertical wave action herded sardinella through the filter grid meshes.

- Hammerhead sharks have shown to escape easily due to the slow action of the flexible cartilage back bone structure. The fish slowly swim the escape route without accelerations. Manta require a horizontal escape tunnel opening of at least 3 m, this can be achieved by applying a tunnel with a diameter of 3.6 m build of traditional diamond-shaped double twined meshes. With the increased tunnel diameter and so the higher vertical opening at the center of the tunnel, sharks and billfish will have improved escape opportunities compared to the 400 meshes circumference design. Sunfish releases seem to increase with the tunnel diameter. Entanglements of sunfish in the filter grid reduce the efficiency to the catch of target fish.

- The recommended excluder design is a 600 meshes tunnel (traditional, double-twined diamond-shaped meshes). This traditional tunnel design will facilitate an escape tunnel entrance of 3 m with increased escape changes for manta and the highest possible effort for target fish catches. The filter grid is build of a 230 mm square mesh and connected to a separation panel of 400 mm diamond shaped meshes. An optional 200 x 250 mm rectangular filter grid mesh is considered as alternative for the 230 mm square mesh as the rectangular mesh reduces the total twine length and so the overall drag. The filter grid as well as the separation panel are built of a highly durable 5 mm *Dyneema* twine. The steeper inclination of the filter grid (17 to 28°) and larger mesh size provides optimal through flow of the target species into the cod end and reduces the gilling of mackerel and sardine. These changes will not affect the diversion of the commonly encountered non-targets.

- The chain weight on the junction of the filter grid and separation panel will reduce the vertical opening of the escape tunnel entrance and closes the tunnel completely during hauling. As a result the 100 mm netting will cover the exit window and reduces losses of target fish during hauling.

- The new excluder design is equipped with an additional exit in the top panel in front of the filter grid. The larger codend tunnel diameter (3.6 m) could enable small numbers of small cetaceans, like common dolphins and striped dolphins, to escape through this exit, however, dolphins usually arrive in pods, mitigation of dolphin by-catch focuses on keeping these groups out of the trawl and away from the net opening.

- The prototype is recommended for testing, as permanent part of the pelagic trawl, during two months (May-June) in 2005. In this period the final filter grid construction will be evaluated. After this period, the prototype should be introduced as standard rigging on at least three ships for a three month evaluation.

- The majority of cetaceans captured in pelagic trawler fisheries are the smaller, surface-bound oceanic dolphins, notably short-beaked common dolphins (*Delphinus delphis*), bottlenose dolphins (*Tursiops truncates*), and (along the European shelf margin) white sided dolphins (*Lagenorhynchus acutus*; see Couperus 1997). Common dolphins are the most abundant of all cetaceans and are usually caught in groups of 2 to 5. Individuals could potentially escape using the 600 meshes tunnel. Cetacean by-catch is seen to occur almost exclusively during night hauls, indicating the additional need for behavioural and ethological studies, including interaction of the cetaceans with seabirds during day-time.

- Another interaction possibly related to cetacean by-catch is the observation of sardinella escaping from the catch section during hauling and probably escaping through the 200-400 mm meshes of the tapered aft section of the trawl. Cetaceans are capable of relating these events to the different underwater sound pattern of the hauling operation (cavitation noise reduced to practically zero and exchanged for tonal noises from the main winch) and could be attracted to the trawl and alerted over longer distance. As a result of these observations commercial codend sections were adapted by trawl manufacturer companies to hamper the fish in codend sections from reversing towards frontal trawl sections.

- At present there is no proven solution to avoid cetaceans from entering the trawl. The effects of the application of cetacean grid barrier (2 x 2 m meshes) rigged in the front part of a pelagic trawl was not thoroughly tested. After a single experiment with a low catch research on this issue was cancelled by the ship's staff. Research is continued in the EU-funded research program Necessity; in this scheme a rope barrier was tested in a flumetank on a 1/32 scale in February 2005 and two types of full-scale barrier constructions will be tested on a research vessel in March 2005.

- In addition to a cetacean barrier, acoustic deterrents are under development to prevent these species from entering the trawl. Tests with commercially available 'pingers' demonstrate that these sounds are masked by the noise spectrum of larger Dutch freezer trawlers. There is no knowledge on the masking effect of the echo-location sonar by pinger sounds, which could increase the risk of by-catch of cetaceans at night. This basic issue will be investigated within the Necessity research program in a basin study in 2005. Preferably an inter-active acoustic deterrent device facilitating existing fish detection systems will be a more feasible approach as described in the I-Ping proposal offered to the Redersvereniging in 2004 (DdH).

- In the last three trials not a single observation could be made of behavior of a hammerhead or manta, leaving the exclusion efficiency not thoroughly tested. It will be recommended to conduct the final prototype experiment on larger non-targets also in areas along the shelf margin (water depth 200 m) and to consider the exploitation of research vessels when fishing in deeper areas cannot be established or guaranteed.

- A filter grid of 230 x 230 mm meshes would not obstruct target species and provide optimal filtering of large non-targets, including juvenile megafauna. The 20° inclination of the filter panel provides optimal through flow of the commonly encountered non-targets while fully facilitating entry of the target species into the cod end.

- Reduction of the by-catch rate in the coming year(s) in comparison with present observations may provide an estimate of the mitigating effect of the excluder. Registration of by-catch should occur on a regular basis, on deck and in the factory, by trawler crew and observers. Guides to identify and measure have been provided (Annex 3) and are available in French for Mauritanian observers. Photography of the by-catch is encouraged to facilitate accurate identification. Sampling and measurement of by-catch provides extra workload for crew and the observers have to be able to motivate and work with the deck crew.

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Species	year	Apr			May				June				July				August				September				October				November				Dec	
		N	H	%	N	H	%	T	N	H	%	T	N	H	%	T	N	H	%	T	N	H	%	T	N	H	%	T	N	H	%	T	N	H
turtle (loggerhead and leather)	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	31	4	0									0	28	6	0	1	57	10	11	1	63	22	4.57		
	2004	0	14	3	0	40	5	0	1	100			1	87	21	4.7	1	74	13	7.64	2	331	88	2.28	0	111	36	0	1	319	52	1.93	1	100
hammerhead shark (lewini and zygaena)	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								4	31	4	100									50	28	6	877	12	57	10	126	1	63	22	4.57		
	2004	0	14	3	1	40	5	20.8					46	87	21	215	82	74	13	626	102	331	88	116	40	111	36	112	6	319	63	9.57	0	36
mako and thresher sharks (large 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								3	31	4	75									0	28	6	0	1	57	10	11	1	63	22	4.57		
	2004	0	14	3	0	14	5	0					11	87	21	51					12	331	88	13.7	18	111	36	51	5	319	52	9.66	0	36
small sharks (milk and 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	49.4		
	2003								3	31	4	75									50	28	6	877	2	57	10	21	6	63	22	27.4		
	2004	2	14	3	6	40	5	125					1	87	21	4.7	3	74	13	22.9	29	331	88	33	0	111	36	0	4	319	52	7.73	0	36
bill fish (marlin, sailfish, spearfish)	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								1	31	4	25									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	1.93	0	36
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	31	4	25									1	28	6	17.5	3	57	10	32	0	63	22	0		
	2004	0	14	3	3	40	5	62.5					4	87	21	19	11	74	13	84	22	331	88	25	6	111	36	17	52	319	52	101	3	36
manta ray	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								1	31	4	25									0	28	6	0	3	57	10	32	1	63	22	4.57		
	2004												21	87	21	98	53	74	13	405	25	331	88	28.4	10	101	36	28	2	319	52	3.87	0	36
dolphins (all common species)	2001																								0	30	7	0						
	2002	21		na									20	88	12	165	0	22	4	0	43	87	10	422	4	20	5	80	1	18	8	12.3		
	2003								0	31	4	0									0	28	6	0	1	57	10	11	0	63	22	0		
	2004				4	100	na	na					5	87	21	23	6	74	13	45.8	5	331	88	5.69	6	111	36	17	0	319	52	0	0	36
short-finned 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	31	4	0									0	28	6	0	0	57	10	0	0	63	22	0		
	2004	25	100	na									0	87	21	0					0	331	88	0	0	111	36	0	0	319	52	0	0	36

Table 6. By-catch registered by project observers between 2001 and 2005 (N), with number of net hauls observed during a particular mission (H), the percentage of days observed to days fished (fleet level, Table 8), and the total mortality (T) extrapolated to fleet level. Highlighted numbers include observations taken from vessel logs and (September, October, November 2004) observations by crew (Table 8 and Annex 3).

Table 7. Annual catches of megafauna off Mauritania at Dutch fleet level estimated from observations on board the trawlers between 2001 and 2005. Shaded area indicates months for which "no data" exist, either because no observations have been made or because the record is incidental and cannot be extrapolated to a maximum.

	turtle		hammerhead		large sharks		small sharks		billfish		sunfish		manta ray		dolphins		pilot whale	
	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
January	n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.	n.d
February	n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.	n.d
March	n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.	n.d
April	n.d.		n.d.		n.d.		2	n.d.	n.d.		n.d.		n.d.		21	n.d.	25	n.d
May	n.d.		1	21	n.d.		6	125	n.d.		3	63	n.d.		4	n.d.	0	n.d
June	0	n.d.	4	100	3	75	3	75	1	25	1	25	1	25	0	n.d.	0	n.d
July	0	5	215	273	25	51	5	17	8	276	19	273	21	98	23	165	8	n.d
August	0	8	279	626	1	23	3	23	23	61	23	84	47	405	6	46	0	n.d
September	0	2	116	877	14	78	30	877	10	40	25	245	20	28	6	422	1	10
October	11	20	100	126	11	47	21	60	21	145	16	80	26	58	11	80	0	n.d
November	2	5	5	10	5	10	8	49	1	2	37	101	4	5	1	12	0	n.d
December	1	n.d.	n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.		n.d.	n.d
	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
totals	**14**	**40**	**720**	**2033**	**59**	**284**	**78**	**1226**	**64**	**549**	**124**	**871**	**119**	**619**	**72**	**725**	**34**	**44**

	2001			2002			2003			2004		
	Fish Days	Obs	Perc	Fish Days	Obs	Perc	Fish Days	Obs	Perc	Fish Days	Obs	Perc
Jan		0			0			0			0	
Feb		0			0			0			0	
Mar		0			0			0			0	
April		0			0			0		94	3	3.2
May		0			0			0		165	8	4.8
June		0			0		200	8	4.0		0	
July		0		214	26	12.1		0		159	34	21.4
August		0		185	8	4.3		0		168	22	13.1
Sept		0		206	21	10.2	158	9	5.7	141	124	87.9
Oct	145	10	6.9	141	7	5.0	158	15	9.5	101	36	35.6
Nov		0		99	8	8.1	73	16	21.9	172	89	51.7
Dec		0		20	0		58	0		84	30	35.7

	2001				2002				2003				2004			
	Obs_S	Obs_e	Days		Ob_S	Ob_e	Days		Ob_s	Ob_e	Days		Ob_S	Ob_E	Days	
Jan			0				0				0				0	
Feb			0				0				0				0	
Mar			0				0				0				0	
April			0				0				0		21-Apr-04	24-Apr-04	3	RE1
May			0				0				0		6-May-04	14-May-04	8	RE1
June			0				0		18-Jun-03	26-Jun-03	8	RE1			0	
July			0		10-Jul-02	29-Jul-02	19	PB1			0		6-Jul-04	28-Jul-04	22	RE2
					4-Jul-02	11-Jul-02	7	RE1					28-Jul-04	9-Aug-04	12	PB1
August			0		23-Aug-02	31-Aug-02	8	RE2			0		28-Jul-04	19-Aug-04	22	RE3
Sept			0		10-Sep-02	1-Oct-02	21	PB2	20-Sep-03	29-Sep-03	9	RE2	1-Sep-04	30-Sep-04	124	own
Oct	23-Oct-01	2-Nov-01	10	PB0	13-Oct-02	20-Oct-02	7	RE3	21-Oct-03	5-Nov-03	15	OB8	1-Oct-04	15-Oct-04	36	own
Nov			0		14-Nov-02	22-Nov-02	8	RE4	20-Nov-03	6-Dec-03	16	RE3	10-Nov-04	23-Nov-04	13	RE4
													25-Oct-04	26-Nov-04	76	own
Dec			0				0				0		12-Nov-04	12-Dec-04	30	PB2

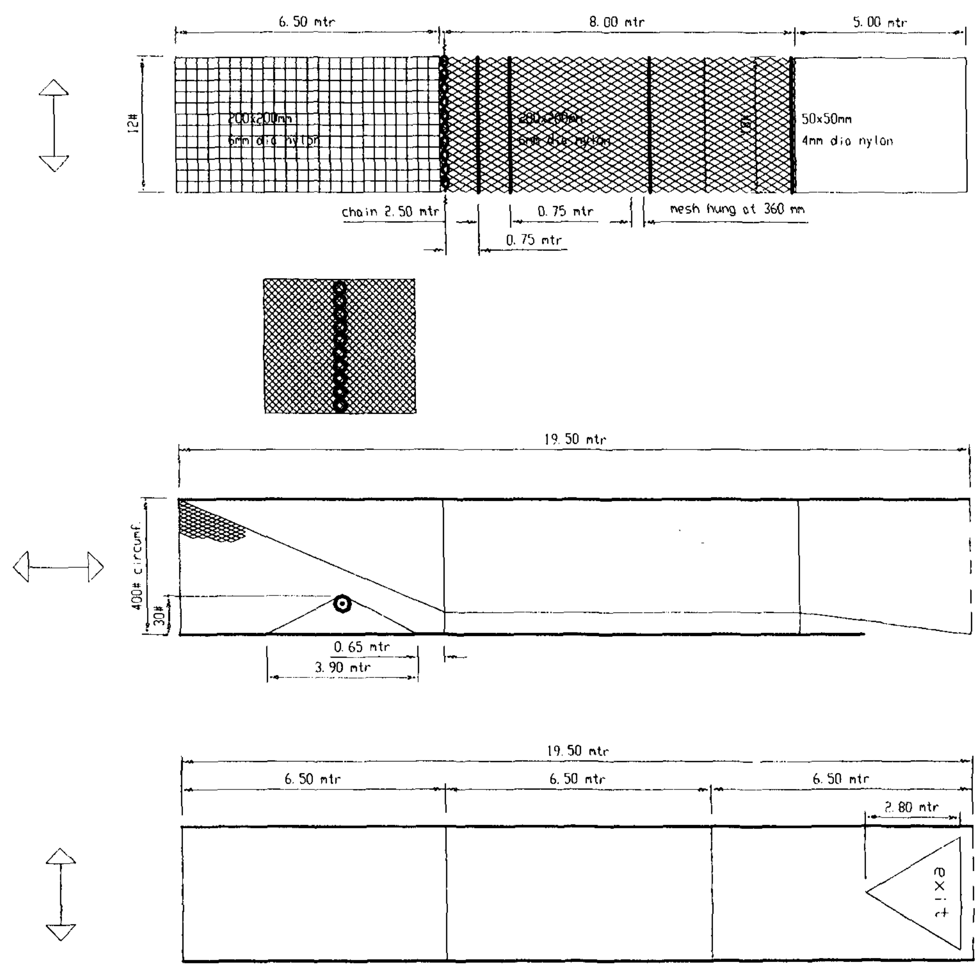
Table 8. Research missions (bottom), including crew observations ("own" – multiple ships); total (Dutch) fishing days (top), and percentage of those observed.

ANNEX 1 Net adaptations

All drawings courtesy E. de Graaf, Maritiem Katwijk

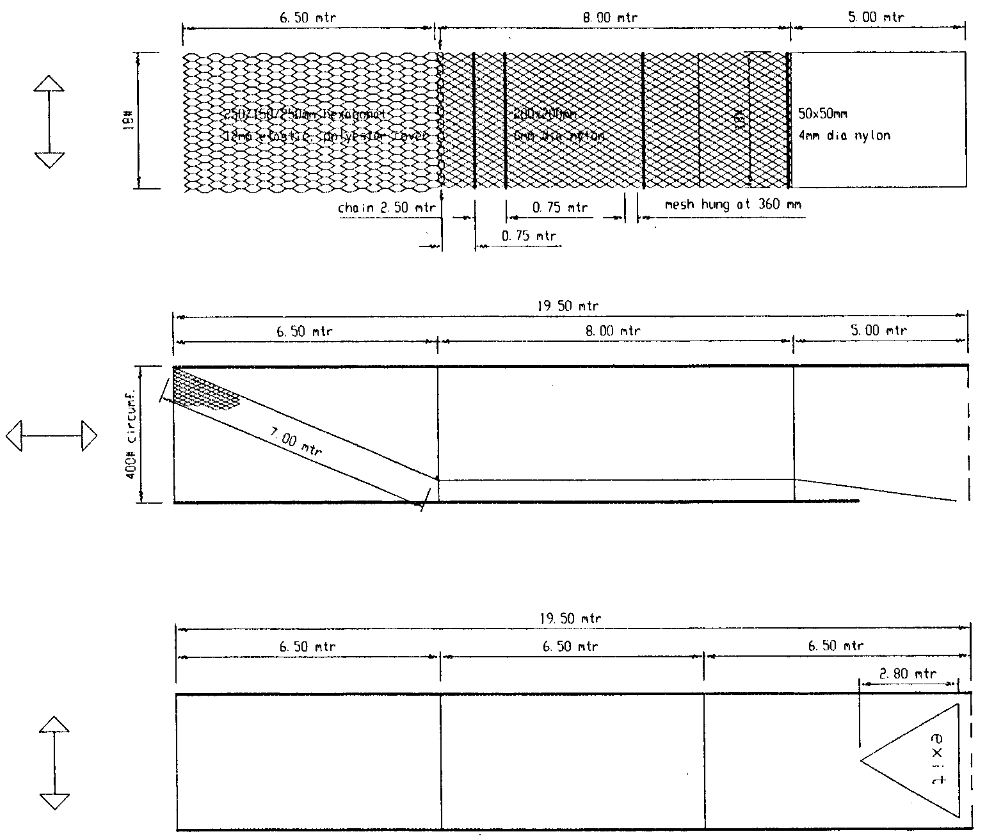
1.1. Large fish excluder design

1.1.1. Excluder 400 design 2002-07a



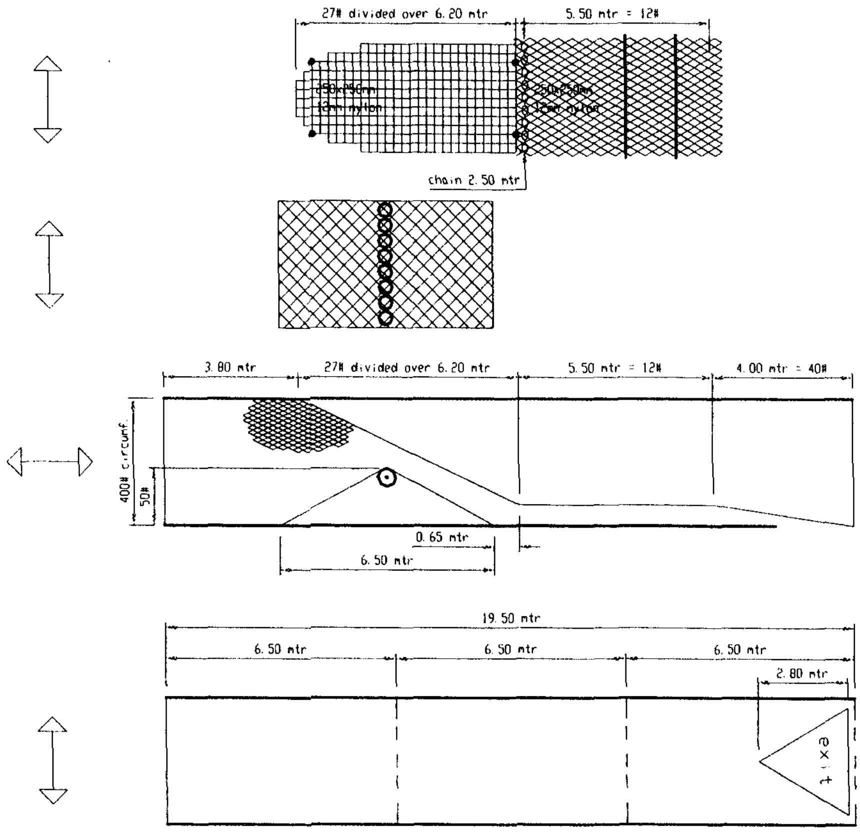
Improvements to the first design (de Haan, 2002) were the mesh size of the filter grid (200 mm square mesh) and the twine diameter (reduced from 12-6 mm nylon). This would reduce the filtered length of larger non-targets and the drag of the filter grid and so the vertical height of the escape tunnel entrance. Two larger fish excluders (type a & b) were developed each built in three traditional (double twined diamond shaped meshes 68 mm stretched length) codend sections each 100 meshes long. Assuming a mesh opening of 30 % the tunnel could reach a diameter of 2.3 m. On the 2002-07 trial a provisional netting barrier, made of traditional tunnel netting, was rigged on the bottom panel close to the lower part of the grid to divert target fish away from the escape tunnel. The barrier was 30 tunnel meshes high and 60 meshes long and the final rigging contained 10 floats (8 inch/4 litres).

1.1.2. Excluder 400 design 2002-07b



Basic differences between both designs were the mesh shape and the mesh material of the interior. The hexagonal filter grid meshes (650 mm stretched length (250-150-250 mm) of design "b" were made of 12 mm elastic core with a polyester jacket. The length of the diamond-shaped separation mesh of the design "b" was increased to 500 mm stretched length to fit a length of 8 m with 18 meshes in width. Across the entrance of the escape tunnel a chain weight and four pieces of 2.5 m lead cord of 26 mm diameter (weight of 3 kg/m) were attached to the separation panel. The rigging of lead cord-weights was equal for both designs. The rigging angle of the filter grid was equal to the version tested in 2001-10. The 400 mm (stretched length) meshes of the separation panel (type a) were set to the selvedge to an opening of 10 % of the stretched length, which is an increase of 5 % of the 2001 design. The hatch cover of 100 mm netting was extended towards the front to reduce entanglements of non-targets and escapes of target fish.

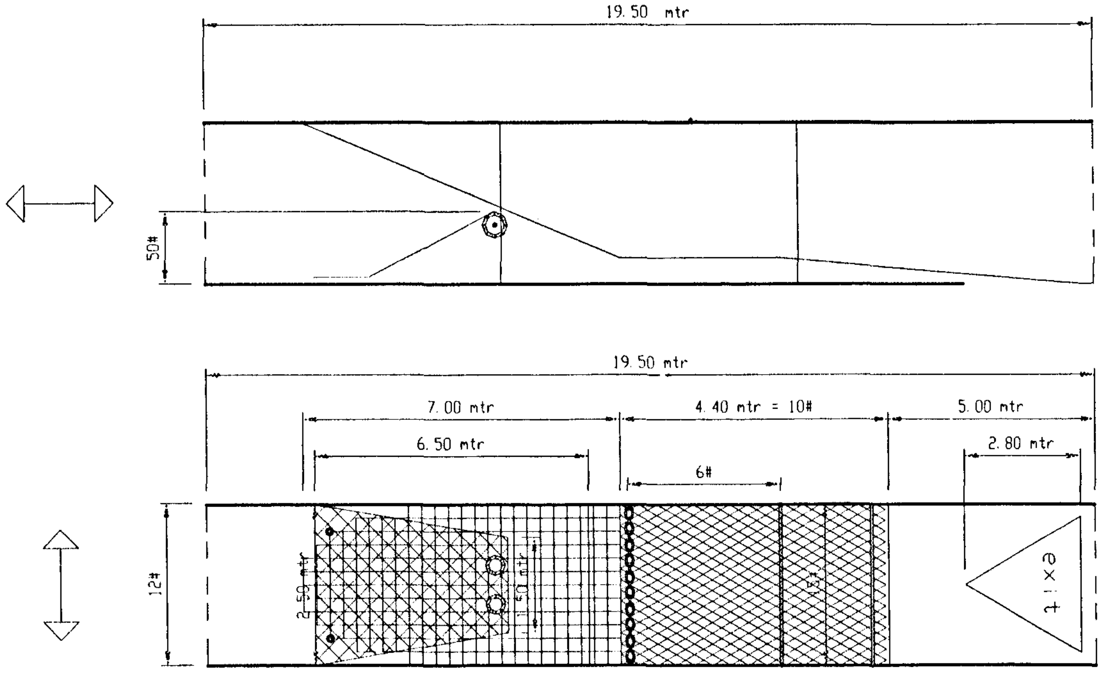
1.1.3. Excluder 400 design 2002-09a



This design slightly differed from the version tested in 2002-07a. The main changes were the increase of the increased height of the net barrier (from 30 to 50 meshes high); the filter grid mesh (250 mm square mesh) with an increased twine diameter (12 mm) as a result of the catch of larger numbers of bigger non-targets and the shape of the grid panel, which was cut elliptically at the top to equally divide the tension forces over the meshes and to minimize the effect to the vertical opening of the escape entrance. A lead enforced twine thinner twine was foreseen, but could not be accomplished. The barrier was attached to the bottom panel 2.95 m in front and behind of the highest point of the barrier (measured length on the selvedge). The back part of the barrier was attached 4 meshes in front of escape tunnel entrance. The floatation of the barrier was reduced from 12 to 8 floats. A chain weight with a length of 2.2 m was attached to the separation panel entrance. The lead weight across the entrance (a double twine of 2.05 m was taken out after the reduction of the chain weight to 1.80 m.

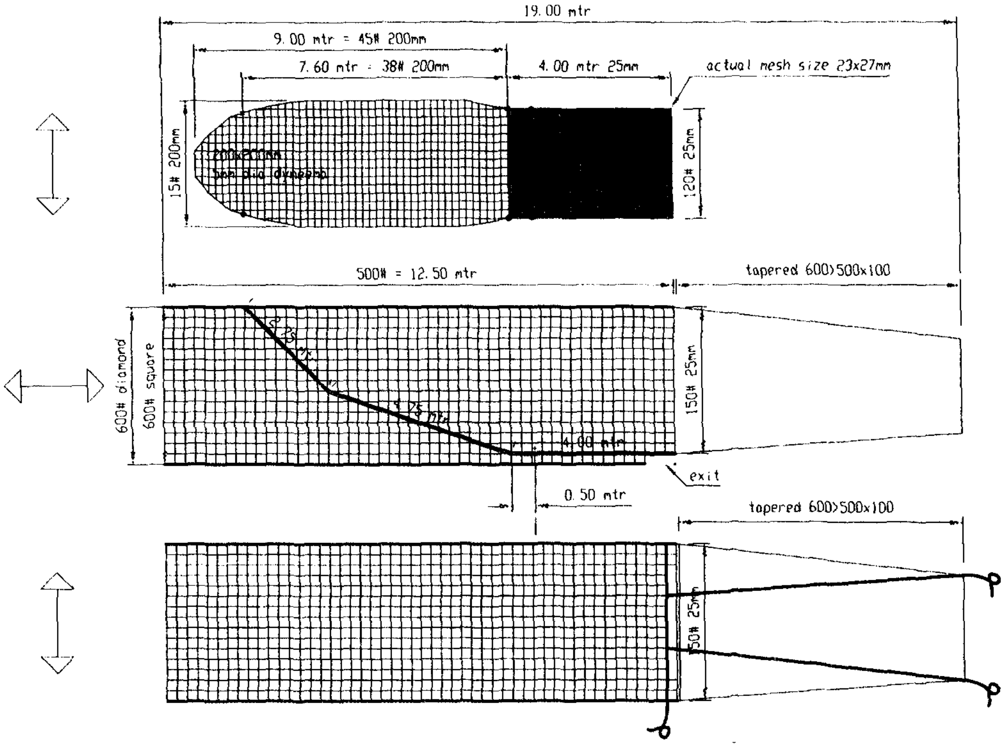
The maximum spread of the lower selvedge was set to 2.0 m (8 meshes of 250 mm). The length of the separation panel was reduced from 9 m (2002-07) to 4.40 m and was built of 10 meshes of 470 mm (stretched length) lengthwise and 15 meshes in width. The 470 mm meshes were set to the selvedge to an opening of 10 % of the stretched length. On the sixth mesh behind junction 1-2 a lead cord was attached across the panel and another to the junction of the 470-100 meshes.

1.1.4. Excluder 400 design 2002-09b



The filter grid of was equal to that of the 9a design. In the 9b design the barrier in front of the filter grid was made of a tapered panel of traditional tunnel meshes, which is attached to the lower selvedge starting at the front part of the excluder with the last 30 meshes built upwards along the sides of the tunnel to create the actual barrier. The panel is tapered from 90 meshes at the front to 60 meshes at the end, reducing the width to 1.5 m, which will create a belly in the bottom panel and thus increasing the vertical opening of the escape tunnel with increased changes for larger fish to escape. The separation panel was build of the same square mesh (250 mm) as the filter grid and was built 8 meshes in width. To prevent the lifting of the escape tunnel entrance two lead cords (2.67 kg/m each) and a chain weight (9 kg/m) were attached across the junction of the filter grid- and separation panel.

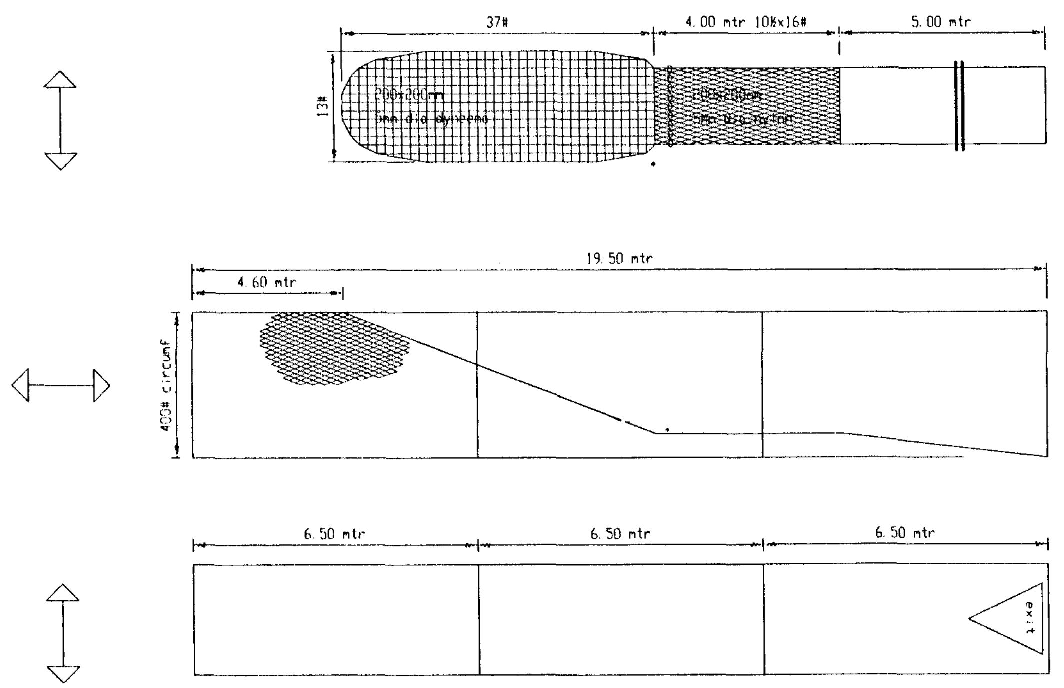
1.1.5. Excluder 600 design 2004-07



The tunnel of the excluder was built of knotless single-twined 25 mm square meshes, 600 meshes circumference (560 clear meshes, tunnel diameter 4.5 m).

The interior consisted of a top downwards-sloped filter grid of square meshes of 200x200 mm of 5 mm *Dyneema* twine connected to a knotless square mesh (25 mm, nylon, type 210/180, diameter 3 mm). The filter grid had an elliptical shape at the top to match the circular tunnel profile and to avoid the lifting of the tunnel entrance by the centre meshes of the grid. The filter grid was not fixed to the bottom panel, providing the entrance of the escape tunnel. The width of the separation was progressively increased from 2.60 m at the start of trial 2004-07 to 4.05 m at the end the 2004-11 trial. The lower meshes of the filter grid were set accordingly to these changes. The angle of the grid panel was for the first 2.75 m 45° and 20° for the remaining length (4.75 m). The hatch in the lower panel was an open junction in the bottom panel over the full width. To avoid instable actions of the bottom panel two ropes were connecting the bottom panel to the adjacent tapered section.
The front-side of the excluder was connected to a tapered section built of 90° rotated diamond-shaped 72 mm (stretched length) meshes (knotted, double-twined mesh of 3 mm nylon). This tapered section (200 meshes long, □ 12 m) reduced the 800 meshes circumference to 600 meshes at the front side of the excluder. The 90° rotation of the diamond-shaped meshes would have a positive effect to the water flow and thus the throughput of fish. The tapered back part was build of traditional codend meshes of double-twined diamond shaped 68 mm meshes, connecting the ship's standard tapered 500-400 # section (100 meshes, 72 mm stretched length).

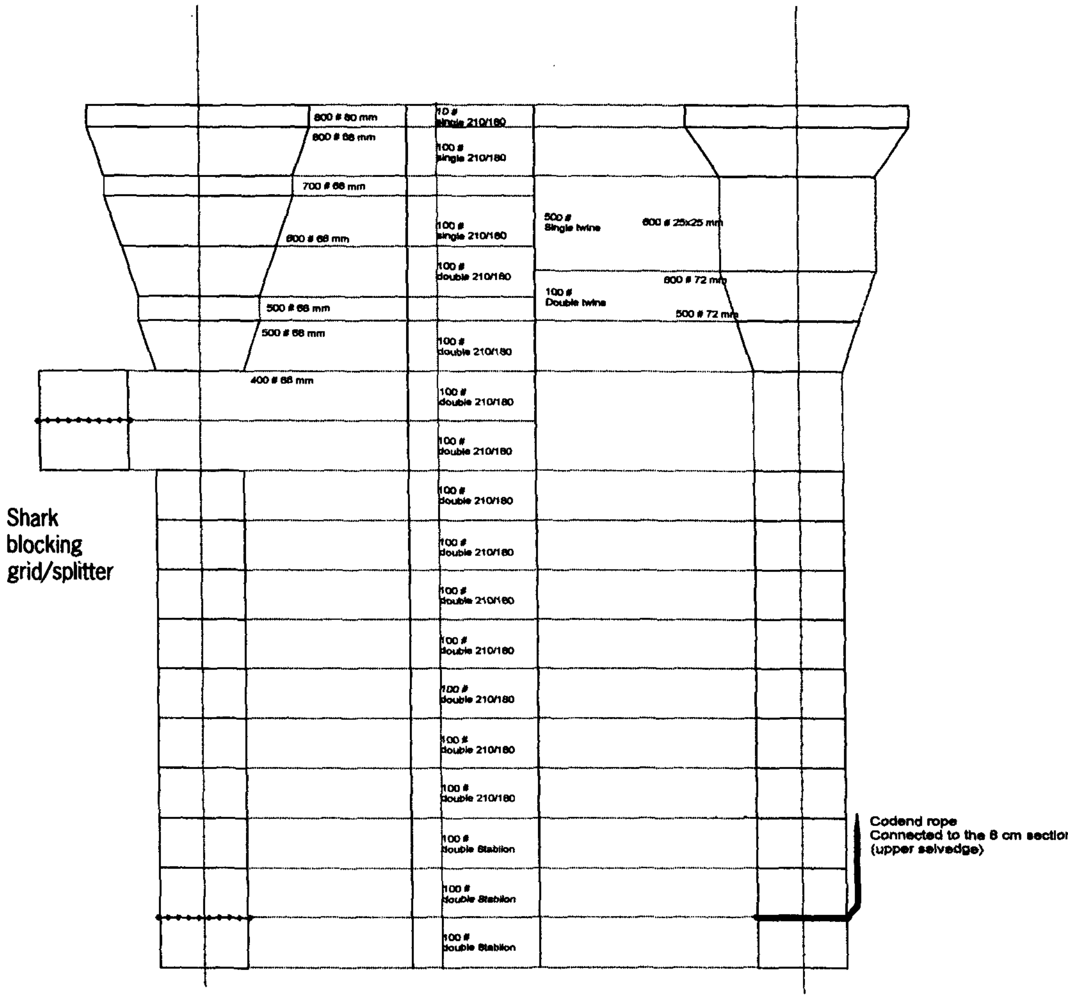
1.1.6. Excluder 400 design 2004-11



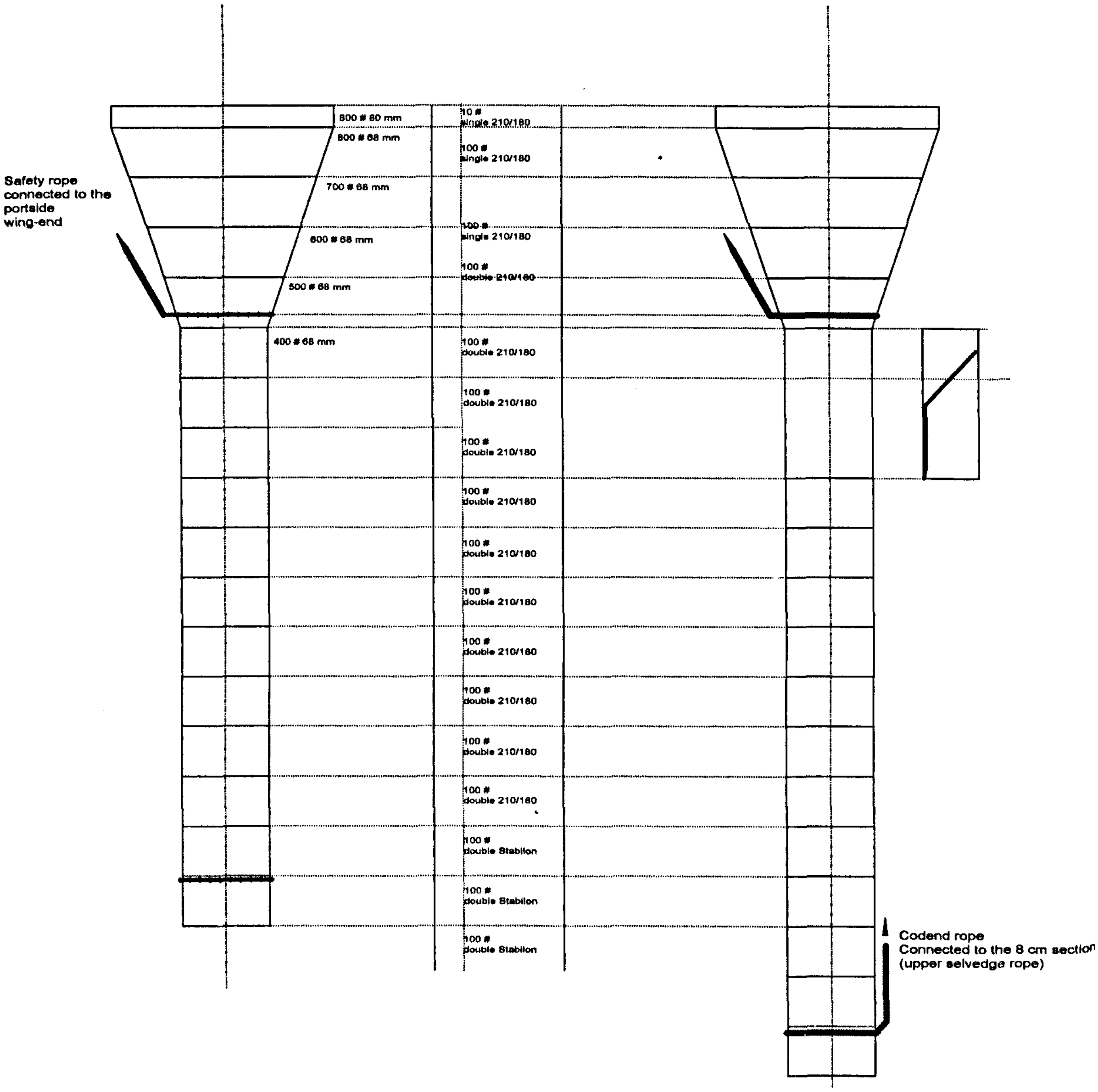
The 400 meshes tunnel section (360 clear meshes), used on the 2002-09 trial (built of traditional double-twined diamond shaped meshes, 68 mm stretched length) was provided with a provisional interior build on the 2004-11 trial. The theoretical tunnel diameter would be 2.3 m, assuming a mesh opening of 30 %. The material and mesh size of the filter grid was equal to the grid of the 600 # design. The grid panel had an elliptical shape at the top to match the circular tunnel profile and to avoid the lifting of the tunnel entrance by the centre meshes. The filter grid was built along the bars of the tunnel meshes and was not fixed to the bottom panel, providing the entrance of the escape tunnel. The junction of the grid to the separation panel was set to a width of 2.20 m (11 filter grid meshes). Across the junction of the grid and separation panel a chain weight of 2.20 m was attached. The separation panel consisted of 400 mm meshes (diamond-shaped meshes, stretched length, built of 6 mm nylon) 10.5 mesh long and 16 meshes in width. The 400 mm meshes were set to the selvedge to an opening of 10 % of the stretched length. The separation panel was extended with 100 mm netting (stretched length, diamond-shaped meshes, 35 meshes long and 65 meshes in width, length along the selvedge ropes 4.0 m. The front of the exit relative to the junction of 400-100 mm meshes was 13 (100 mm) meshes behind this junction.

The dimensions of the exit in the bottom panel was 39 meshes long (2.53 m) and 80 meshes at the base (1.60 m), equal to the design tested in 2002-09. The exit was cut in the centre of the bottom tunnel panel, with the base at the aft junction of the excluder to the adjacent codend section (5 meshes were left in width on either sides of the base of the exit, assuming a total of 10 meshes of the bottom panel were taken into the selvedge). Two lead cords (2.67 kg/m each) were positioned across the 100 mm netting just in front of the hatch to hamper losses of target.

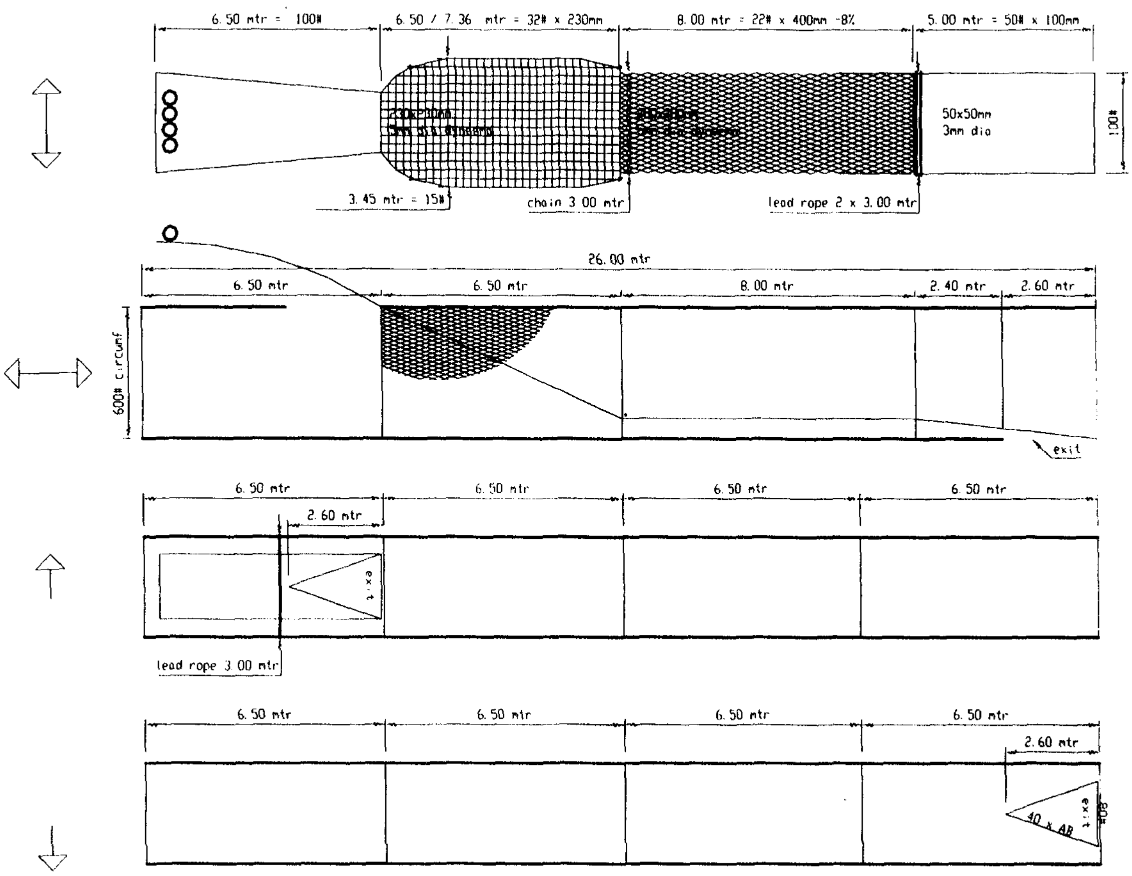
1.2. Position of the 600 mesh excluder design (2004-11) and adaptation of cod-end sections



1.3. Position of the 400 # design 2004-11b and adaptation of codend sections



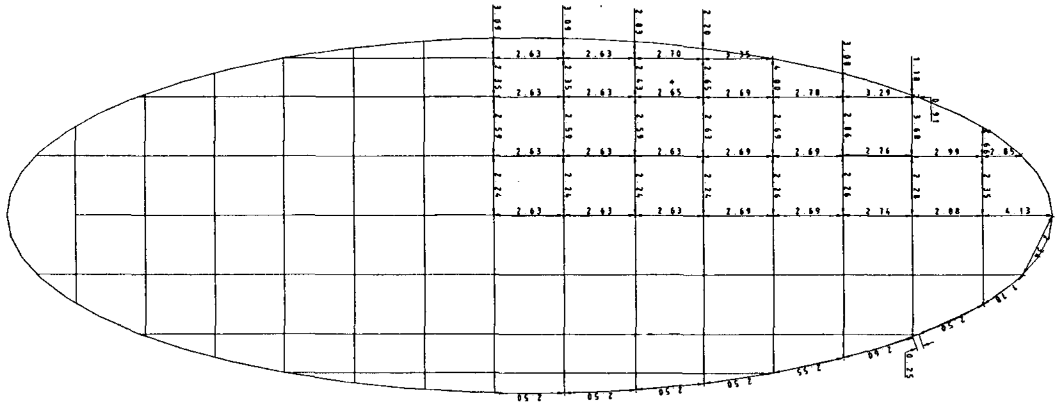
1.4. Prototype excluder 600 traditional mesh circumference

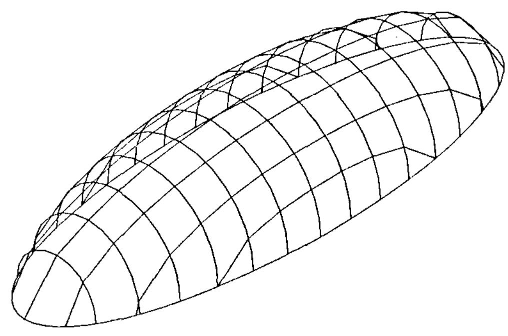


A filter grid of 230 mm square meshes and an adjacent separation panel of 400 mm (stretched length diamond-shaped meshes) will be built in three traditional tunnel sections each 100 meshes long and of 600 meshes circumference (560 clear meshes, built of traditional double-twined diamond shaped meshes, 68 mm stretched length). The theoretical tunnel diameter would be 3.6 m, assuming a mesh opening of 30 %.
The filter grid is built of 5 mm *Dyneema* and had an elliptical shape at the top to match the circular tunnel profile and to avoid the lifting of the tunnel entrance. The inclination of the filter grid is set at 28 ° (tunnel mesh ratio of 10 (base) :14 (up)) and not fixed to the bottom panel, providing the entrance of the escape tunnel. The junction of the grid to the separation panel is set to a width of 3.0 m (13 filter grid meshes). Across the junction of the grid and separation panel a chain weight of 3.0 m is attached (with PU overall jacket). The separation panel is enlarged to a length of 8 m and consisted of 400 mm meshes (diamond-shaped meshes, stretched length, built of 5 mm *Dyneema*) 22 mesh long and 22 meshes in width. The 400 mm meshes were set to the selvedge to an opening of 8 % of the stretched length. The separation panel was extended with 100 mm netting (stretched length, diamond-shaped meshes, 50 meshes long and 100 meshes in width, length along the selvedge ropes 5.0 m. The front of the exit relative to the junction of 400-100 mm meshes was 13 (100 mm) meshes behind this junction. The dimensions of the exit in the bottom panel is 39 meshes long (2.53 m) and 80 meshes at the base (1.60 m), equal to the design tested in 2002-09. The exit is cut in the centre of the bottom tunnel panel, with the base at the aft junction of the excluder to the adjacent codend section (5 meshes were left in width on either sides of the base of the exit, assuming a total of 10 meshes of the bottom panel were taken into the selvedge). Two lead cords (2.67 kg/m each) were positioned across the junction of the 400-100 mm meshes to hamper escapes of target fish.

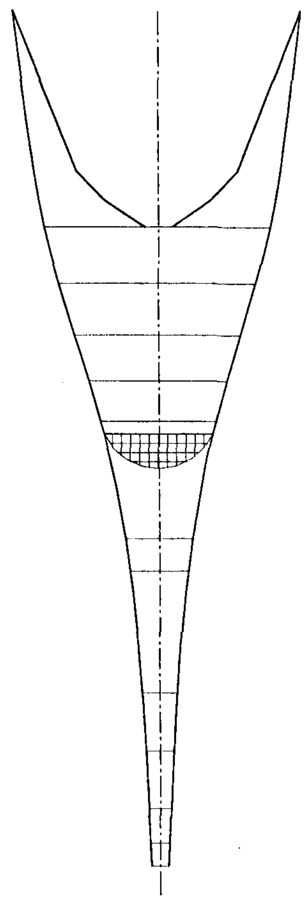
1.5. Cetacean grid barrier

Design of a square mesh grid barrier and position In a 4300 meshes trawl





garen rug/buik	garen zijde	# mazen	maas-wijdte
15mm		7½	
	12mm	2	10000
		2	9000
12mm		2	8000
		2	7000
		2	6000
		1	5400
210/864	210/864	6	3600
210/864	210/864	7	1800
210/408	210/408	50	800
210/408	210/408	50	400
210/180	210/180	100	200
210/180	210/180	100	120
210/180	210/240	100	80



Annex 2 Underwater video recordings

Figure 2.1 Hammerhead on it's way to the exit (2001-10)

Figure 2.2 Manta (2001-10) proceeding with a 90° body rotation towards the escape hatch while tipping the 400 mm meshes with the cephalic lobes

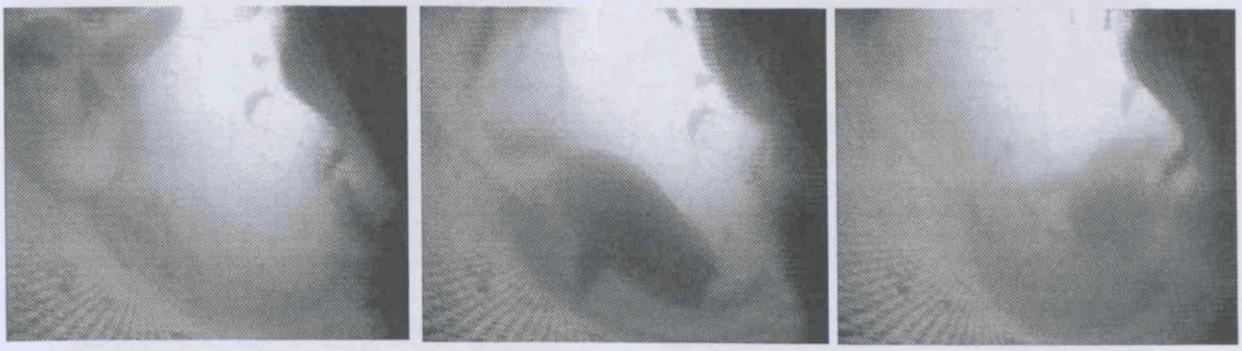


Figure 2.3 Sunfish arriving vertically at the filter grid (2002-07), on the moment the fish changes to a horizontal body angle the fish is blown by the water flow against the filter grid,. Increasing the vertical opening of the escape tunnel.

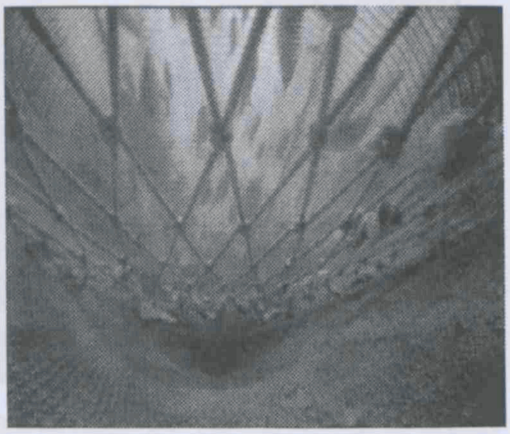
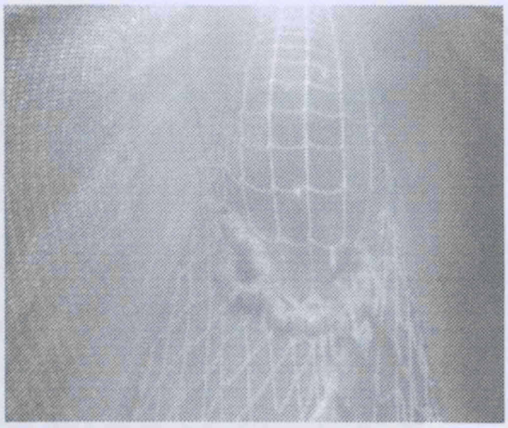


Figure 2.4 Escape tunnel of the 2002-07 design with target fish in the catch section. Position of view is 1 m in front of the junction of 400-100 mm meshes.



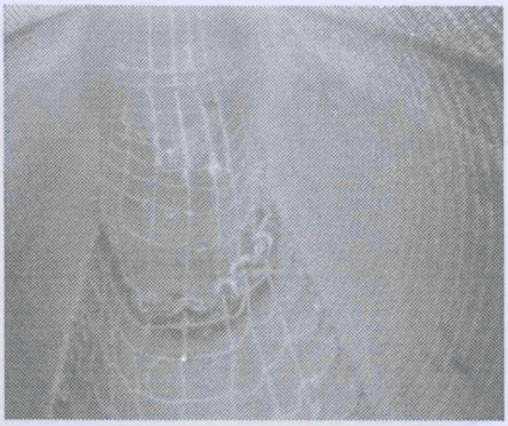


Figure 2.5 Overview of the 2002-09a and b designs illustrating the reduced horizontal tunnel spread

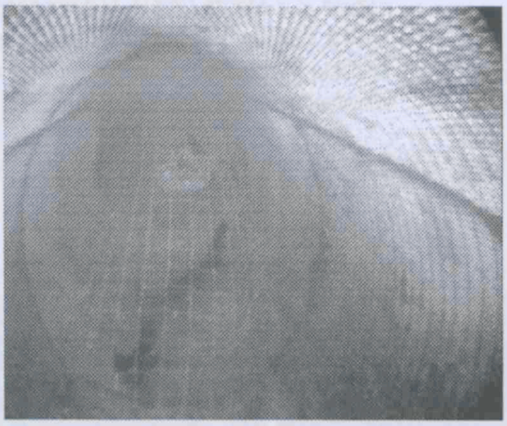


Figure 2.6 Hammerhead entering the escape tunnel and sunfish against the filter grid (2002–07)

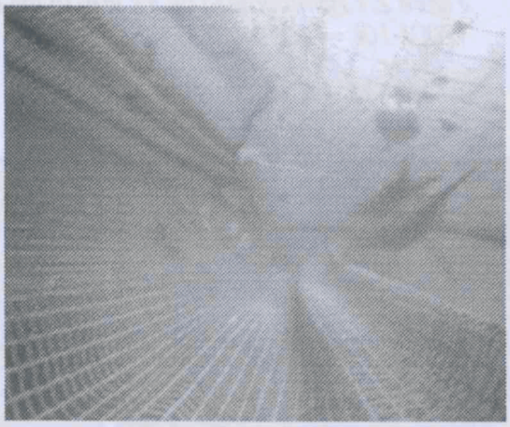


Figure 2.7 Billfish in front of the escape tunnel of the 600 # square mesh tunnel (2004-07)

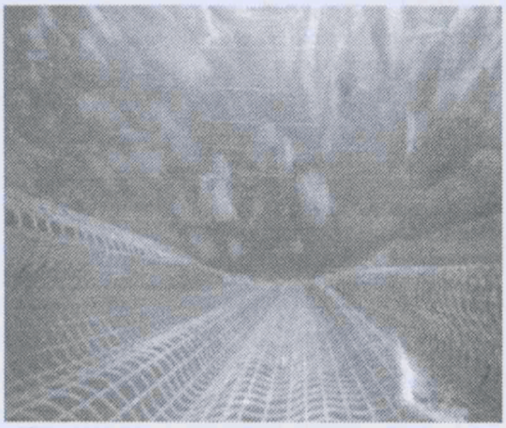


Figure 2.8 Majority of sardinella in the catch section of the 600 # square mesh tunnel (2004-07)

Figure 2.9 Majority of horsemackerel diving towards the escape tunnel (2004-11)

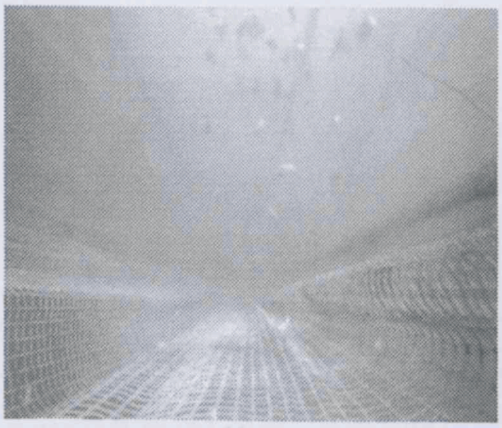


Figure 2.10 Mackerel gilled in the filter grid meshes of the 600 # square mesh tunnel (2004-11)

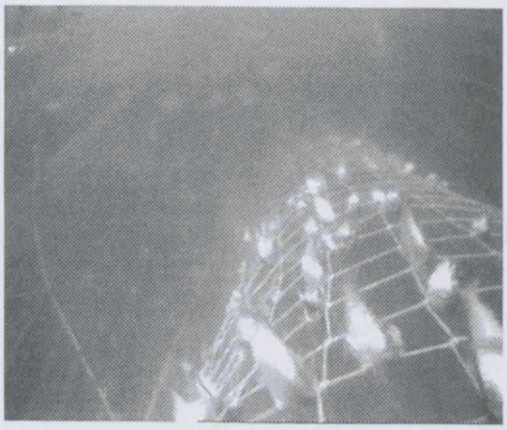
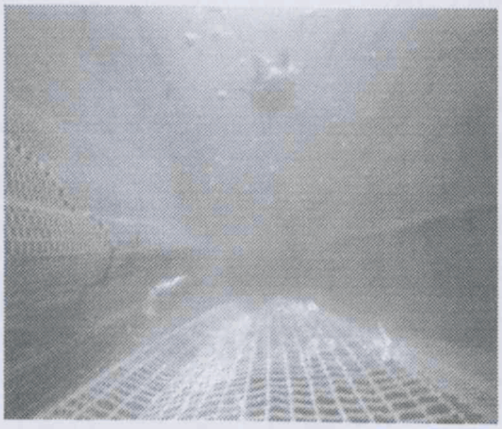


Figure 2.11 Sardine gilled in the meshes of the filter grid (2004-11)



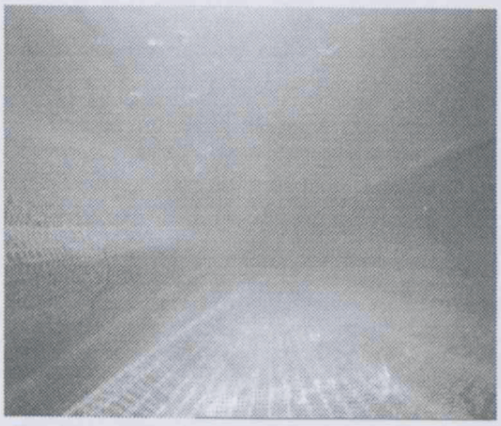


Figure 2.12 Small turtle clamped against the filter grid and lowering downwards along the meshes and escaped swimming (2004-11).

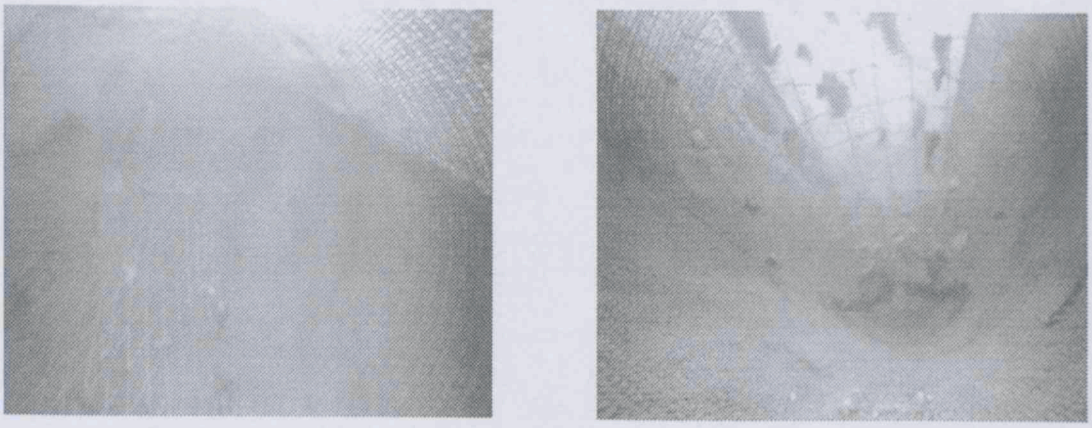


Figure 2.13 Overview 400 meshes excluder (2004-11b) with and without a chain weight on the junction of the filter grid and separation pa