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Abstract

The aim of this study was to quantify the bycatch and discard situation in Senegalese artisanal shrimp fishery, along with a brief comparison with industrial fishery, as this is a growing export industry with potential of eco-certification for at least the artisanal part of export, to the benefit of many poor and marginalized fishermen. A field survey was made on artisanal shrimp fishery landings in the Casamance region of Senegal, which showed low but significant discard rates and possible problem of juvenile fish bycatch. Also high rates of small shrimps in target catch were observed, especially downstream the river. Significant differences between these parameters were also found for the two major artisanal fishing gears, drift nets (Félé-félé) and fixed nets (Mujas).

The industrial shrimp fishery was studied indirectly by landing reports from one of the major companies combined with offshore reports in the political zone between Guinea Bissau and Senegal, with results that indicate a recent decrease in discard, yet the general artisanal discard rates are lower and the bycatch rates a lot lower. Artisanal fishery can become a beneficial and ecological sustainable export product but since the artisanal contribution to stock depletion and bycatch extra mortality also are significant, a sustainable management is required to the same extent as for industrial fishery and some management improvements are discussed.

Keywords: Penaeus notialis / Artisanal fishery / Shrimp / Bycatch / Discard / Senegal

Table of Contents

1 Introduction

Discards, the proportion of catch that is returned to the sea, in most case dead, dying or badly damaged, represents a significant part of the world's marine catches and is generally considered a wasteful misuse of marine resources. Although the latest global study made by FAO in 2005 suggests that the overall discard rates have dropped to 8%, mainly because of larger bycatch utilization, tropical shrimp fisheries still have the world's highest rates, mostly varying between 60% and 80% (Kelleher 2005). In the case of Senegalese shrimp fishery, the first global discard study from 1994, often referred to as the Alverson assessment, stated 73% discard (Alverson 1994). Later an updated FAO report from 2005 stated 62% discard (Kelleher 2005), but both of these calculations were based on data gathered before 2000; and many sources state that a lot has changed since then[1]. But these figures only represent the industrially fished shrimps. In Senegal artisanal fishery landings exceed industrial, with their low catch per fisherman compensated by great numbers. During the period of 2004 to 2006 artisanal landings represented 58% of the total shrimp catch (DPCA)[2]. As poor data on bycatch and discard for both industrial and artisanal fishery can lead to biased estimates of fishing effort, mortality and stock status (Whalmsley et al. 2007), the importance of quantifying also the artisanal contribution becomes evident.

Sustainable management of fisheries is socio-economically crucial in developing countries where a greater part of the population is depending on fishery. In Senegal almost 17% of the total labour force, around 600 000 people, has work directly or indirectly related to the fishery, which generates one third of the total export, although it only consists about 2 % of the Gross Domestic Production (SLI 2004). But offshore stocks of fish and shrimps are already showing many signs of overexploitation including falling catch-per-unit effort (CPUE) for all of the six major commercial species, including the studied *Penaeus notialis*, the southern pink shrimp, according to CRODT, the Senegalese oceanographic research centre (Samb et al. 2007).

Also the study was made as an extension to a Life Cycle Assessment (LCA) of Senegalese shrimp products, a quantification of environmental impacts performed by the Swedish Institute of Food and Biotechnology (SIK), on demand from FAO and Swedmar. Therefore the comparative results was also calculated as amount of bycatch and discard associated with a functional unit of 1kg commercially sold shrimps, to congregate with LCA methodology.

[1] Personal contact with K. Kelleher, author of the FAO report 2005, and also confirmed in discussions with company owners and shippers in Dakar harbour in January 2008.
[2] Calculation based on landing figures 2004-2006, provided by the NGO Idée Casamance, retrieved from Ahmet Diarra Diop of the DPCA (Department of Inland Fisheries and Aquaculture), in October 2007.

2 Background

The artisanal shrimp study was conducted at the Casamance River, from where approximately half of the artisanal landings origins (DPM 2007)[3]. Hydrologically it should rather be considered a reversed estuary, with salinity increasing upstream to higher levels than in the ocean. The river itself is 230 km long and 1-10 km wide, but adjacent to this water basin lies over 82 000 ha of shallow water mangrove forest. As tidal changes and the slow outflow of freshwater enables sea water to enter, the evaporation in the vast mangrove forests raises the salinity. In 1969 the estuary was still just slightly hyper saline (approximately 40‰) 80km from the mouth (compared to 36‰ at sea), but continuing draughts have subsequently raised the salinity to a peak around 1986 of 170‰ 220km from the sea (Binett et al. 1995).
The southern pink shrimp *P. notialis* has proven to be very sensitive for right salinity rate for optimum growth rate, but catches actually increased with salinity until a collapse in 1984, when salinity reached critical levels (LeResete 1992).

2.1 Biology background

Industrial shrimp fishery exploits the same stock as the artisanal but in another phase of their lifecycle. The shrimps spawn at sea but their fertilized eggs drifts with currents towards the shore, while metamorphosing through nauplius- and protozoa stage (LeReste et al. 1984). Spawning occurs all season but with two important peaks correlated to the salinity rate in the estuary nursing ground (Le Reste 1992). This is because most juveniles migrate up the river to feed in the protected and nutritious mangrove habitats until they reach mature size, after which they start migrating back to the offshore spawning grounds (Lhomme 1984). Maturation is estimated to occur after 4-5 months at a size that correlates to the commercial calibre 5, a measurement that reaches from 1 (largest, 50 pieces per kg) to 8 (smallest, 120-200 pieces per kg)[4]. All adults with size above calibre 4 are most probably females[5] as the growth rates diverge after maturation. Female fecundity is dependent of number eggs and thus the physical size (Treece 1999). A full lifecycle seldom exceeds 20 months for both sexes (Lhomme 1984).

Today there are two peaks in the artisanal catches, the largest one around October-November right after the rain season (June to September) and a smaller one in February-March, both during a period when the overall salinity is lowered compared to the peak of today's very hyper saline environment[6]. Before 1969 the catch peak was instead at the height of the dry season, when the estuary had the highest salinity (Le Reste 1992). Large seasonal and spatial variations of fish and shrimp biomass has been documented in the nearby Gambia River (Laë et al 2004), but results may not be fully representative since the Gambia estuary functions as a normal salinity gradient estuary, for example most freshwater fish that still can be found in the Gambia river have now disappeared in Casamance (Guillard et al. 2004).

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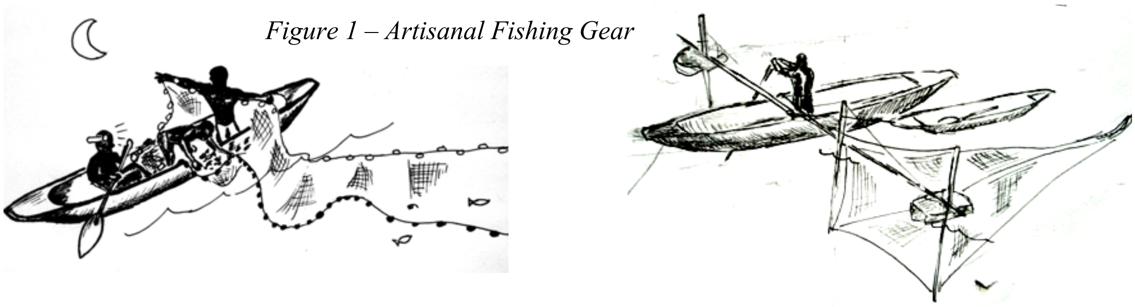
[3] 53% of all artisanal landings comes from Casamance, according to data in DPM (Direction des Pêches Maritimes) annual report of 2005 (published 2007)

[4] Maturation data by LHomme et Garcia (1984), matched by a FAO W/L-relationship (Failler et al. 2006), to the commercial calibres used by industrial and artisanal shrimp trade in Senegal

[5] Sex differentiation data by LHomme and Garcia (1984), matched as above.

[6] Salinity data from 1987-1992 in hold of Idée Casamance, matched with landing data reports from Department of Maritime Fishery (DPM) 2002-2004, confirmed by fisherman interviews December 2007

Figure 1 – Artisanal Fishing Gear



a) Félé-félé, three fishermen fishing at shallow water night time

b) Mujas, one man rigging and collecting on different times during the night depending on tide.

2.2 Exploitation

Artisanal fishery uses three kinds of nets in the estuaries; 1) *Félé-félé,* a type of driftnet that requires active fishing from three men in a canoe, and 2) *Mujas*, a double fixed net that is anchored by a canoe in the middle of the river, thus working as a passive trawl powered by the tidal change, and 3) *Xuus*, a pulled hand net worked by two men wading in the water. Two recent assessments have been made on the different gears in use but the reports differ widely, still both indicate that the handheld Xuus contributes minimally to the total catch (Diadhiou et al 2006 and SRPS 2004). Therefore only the two dominant fishing forms Mujas and Félé-félé were compared by the parameters shrimp size, bycatch species, and weight of bycatch and discard.

The fixed net, the *Mujas,* consist of two poached nets attached to a canoe anchored in the middle of the canal. It is operated by one fisherman working all season with a generally better socioeconomic situation than the Félé-féle fishermen. Also fixed nets anchored only by poles could be found upriver and thus some confusion may occur in literature. The definition of Mujas catch in this report is however how much catch one fisherman using the canoe type of Mujas can yield per day; witch sometimes involves more than one mujas canoe, i.e 2-6 nets. The Félé-félé fishermen on the other hand are often seasonal workers, always working three persons per canoe and around 12 hours each night, whereas Mujas fishermen has an approximate working night of 6 hours, both excluded 1-3 hours of work with reparation of nets daytime. The Félé-félé gear consist a long cotton net, usually150 meters long that is dispatched in more shallow water rendering the net to trail the currents and trap the shrimps when hauled in a folding motion. Both gears use approximately the same mesh size of 12mm[7].

The industrial fleet consist today of around thirty boats, with one company dominating with about 60% of all catches[8]. Most of the boats pull two trawls each on relatively shallow water on the continental shelf, but are restricted to not fish closer than 7 nautical miles outside the coast which is reserved for artisanal fishermen targeting fish (UNEP 2002). The only governmental legislation is a minimal mesh size of 50mm (70mm for fish trawlers) combined with a restricted amount of shrimp licences[9]. All shrimp fishing companies are based in Dakar and no observer programs runs anymore at Senegalese boats documenting discards.

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[7] Based on interviews and observation in Ziguinchor, Banganga and Goudoump by V.Ndiaye , S.Diedhiou and A.Emanuelsson in December 2007, within the Life Cycle Assessment project of Senegalese shrimp products.

[8] Based on landing data from Service Régional des Pêches et de la Surveillance (SRPS) of 2006

[9] Personal contact with Mme Tické Diop Ndiaye, director of Fisheries at DPM (Direction de Pêches Martimes)

3 Method

3.1 Artisanal fishery

The artisanal field study was conducted during a period of three weeks between the 23/11-2007 and 13/12-2007 at the province capital Ziguinchor (eastern landing site) and the village of Banganga. These two locations, separated by 25km, were chosen to represent upriver and downriver conditions of the exploited part of the estuary, where both types of fishing gear were present. Facilities and expertise was provided by IDÉE Casamance[10], a local NGO working with environmental protection. Fishermen were either randomly picked, or selected by contacts already established by IDÉE Casamance. They where instructed to land all bycatch for examination and afterwards the utilization was observed and confirmed by interviews, all leftovers were counted as discard. By this, the catch composition was defined as either *target catch (P.notialis)* or *bycatch*, with bycatch divided into *discards* or *utilized bycatch*. In many other fisheries a fraction of target catch may also be discarded due to restrictions in legislation (Kelleher 2005).

Landings always occurred during nights or early mornings as the Félé-féle driftnets fish all night and land in the morning, and fixed Muja nets follow tide and land sometimes between late evening and early morning. To avoid daily variations in the comparison between the different fishing gears, both types were sampled each day. In total 32 landings where fully examined. The carapace length (back of eye globe to back of head) of 100 randomly sampled shrimps was measured, as well as species composition and weight of shrimp catch and bycatch and discard. A FAO weight-length-relationship for *P. notialis* was applied to the length distribution of shrimps (Failler 2006), and also the sample weight was noted for correction.

$$W = 0.18{L_C}^{2,72}$$

Weight data was then sorted into histograms with columns matching the eight commercial calibres of shrimp. The length distribution data was also complemented with data from the two processing factories in the area. Finally four parameters *Discard ratio, Bycatch ratio, Mean catch* and *Small size ratio* was analysed with a factorial ANOVA (a variance test) with the factors Fishing Method (Fixed net, Driftnet) and Location (Ziguinchor, Banganga) and the interaction between them. The significance level was set to 5%. The Small size ratio was derived from the length distribution as the part of catch that contained the immature calibre size of 8 or smaller, a distinction useful for the LCA study as the smallest shrimps were to be processed differently in the industry.

[10] IDÉE Casamance (Intervenir pour le Développement Ecologique et l'Environnement en Casamance), situated in Ziguinchor (http://www.ideecasamance.org/).

3.2 Industrial fishery

The industrial fleet was studied in Dakar as a reference, mainly by interviews of officials, researcher, shippers and company owners. Hard data results included length distribution of the largest companies' yearly catch from 2005 and 2006, and all records of landed species per boat 2006 from the Senegalese Fishery Department (SDP), in total 140 landings representing fishing trips of approximately 25 days . No recent discard data for Senegalese boats were available due to lack of observer programs, but the European boats (now absent since end of trade agreement in June 2006) was documented by authorities. Also about 2000 trawl hauls from Senegalese boats that where fishing in the political zone between Guinea Bissau and Senegal in 1995 (approximately 5% of the total national shrimp fishing effort) were retrieved and compiled from the archives of the Senegalese Fishery Surveillance Department (DSDP).

But as legislation in the common zone forces fishermen to have at least 30% shrimps in hold and the general Senegalese legislation do not[11], data was considered not truly representative - as legislation demands may induce a higher rate of discard (Pascoe 1997). Boats from the zone landed 32% shrimps 2005 and other shrimp trawlers only 17%. Based on an assumption that the relationship between shrimps and other biomass should be equal in the zone and in the surrounding waters, a model of possible trend in general discard rates was created, as an solved triple equation system that included data from the official landings.

[11] Colonel Mboup, Head of DSPS, Department of Fishery Surveillance

4 Results

4.1. Parameter compare of gear and location

All artisanal parameters; size ratio, mean catch, bycatch rate and discard rate showed significant differences between the two fishing gear in a factorial ANOVA test. Also small-size-rate and mean catch had a significant difference between the locations, but not between the bycatch rate and discard rate. No significant interactions were found between locations and fishing methods. See full test results in appendix 2.

Table 1 – Compared Parameters of Artisanal Fishery

Small Size ratio of Shrimps	Location	Mean	Std. Deviation	Nr. of surveys
Drift net (*Félé-félé*)	Banganga	0.438	0.186	10
	Ziguinchor	0.745	0.107	8
	Average	**0.575**	0.218	18
Fixed net (*Mujas*)	Banganga	0.147	0.110	8
	Ziguinchor	0.404	0.130	7
	Average	**0.267**	0.176	15

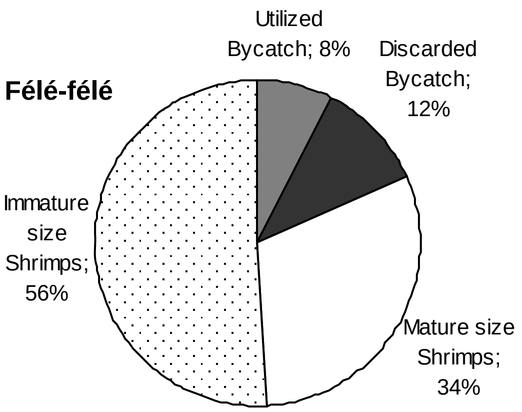
Mean Shrimp catch (kg)	Location	Mean	Std. Deviation	Nr. of surveys
Drift net (*Félé-félé*)	Banganga	13.80	3.32	10
	Ziguinchor	19.21	6.62	7
	Total	**16.03**	5.50	17
Fixed net (*Mujas*)	Banganga	4.13	2.57	8
	Ziguinchor	8.21	2.90	7
	Average	**6.04**	3.37	15

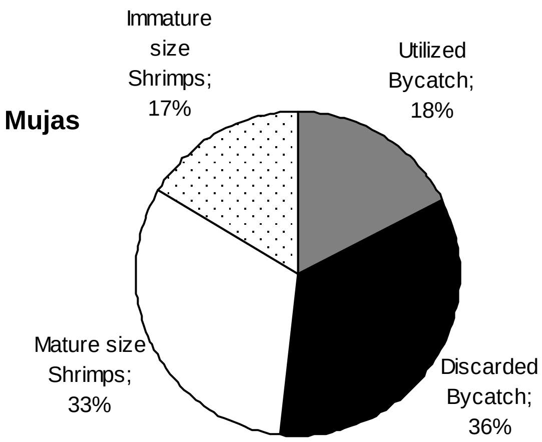
Bycatch ratio	Location	Mean	Std. Deviation	Nr. of surveys
Drift net (*Félé-félé*)	Banganga	0.194	0.106	9
	Ziguinchor	0.207	0.102	7
	Average	**0.200**	0.101	16
Fixed net (*Mujas*)	Banganga	0.637	0.234	7
	Ziguinchor	0.450	0.184	7
	Average	**0.544**	0.225	14

Discard ratio	Location	Mean	Std. Deviation	Nr. of surveys
Drift net (*Félé-félé*)	Banganga	0.173	0.087	4
	Ziguinchor	0.060	0.029	4
	Total	**0.116**	0.085	8
Fixed net (*Mujas*)	Banganga	0.340	0.170	2
	Ziguinchor	0.368	0.230	5
	Average	**0.360**	0.200	7

Fixed nets (*Mujas)* catch larger shrimps but also have both higher discard rate and bycatch rate. Drift nets (*Félé-félé)*, on the other hand, catches smaller shrimps but with lower bycatch and discard. The mean catch for a day's fishing is a lot higher for the driftnets, but since three men are operating one driftnet and only one the fixed net, into account.

Figure 2 –Generalized artisanal catch composition with maturation rate included





Catch composition generalized by gear (50% location 1, 50% location 2) with target catch divided with mature size (≥calibre 5) definition instead of small size (≥calibre 7)

4.2 Bycatch species

Table 3 – The 5 most frequent bycatch species in Ziguinchor landings

Félé-félé	Prop.inCatch	Mean weight g
Calinectes spp – Swimming Crabs	50.5%	23.4
Eucinostomus melanopterus – Flagfin Mojarra	22.1%	11.7
Liza spp – Fam. Mullets (Mugilidae)	6.4%	21.0
Etmalosa fibriata – Bonga Shad	5.7%	8.5
Elops lacerate – West African Lady Fish	4.6%	43.8
Total	*89.3%*	

Mujas	Prop.inCatch	Mean weight g
Etmalosa fibriata – Bonga Shad	31.9%	21.2
Calinectes spp – Swimming Crabs	27.0%	28.7
Pseudolithus elongatus – Bobo Croaker	12.5%	26.6
Elops lacerata – West African Lady Fish	11.1%	45.9
Brachydeuterus auritus – Big Eye grunt	5.5%	12.0
Total	*88.1%*	

See full list in Appendix

Swimming crabs, *Calinectes,* dominated the Félé-féle catches and was observed as second most frequent in Mujas. This is the overall the most frequent bycatch, and it is utilized mostly as flavouring powder or stews if large enough. Large discards of *Calinectes* were however observed, especially at Mujas landings late at night when no local women were collecting or buying them, a phenomenon that applies to most edible species of smaller size.

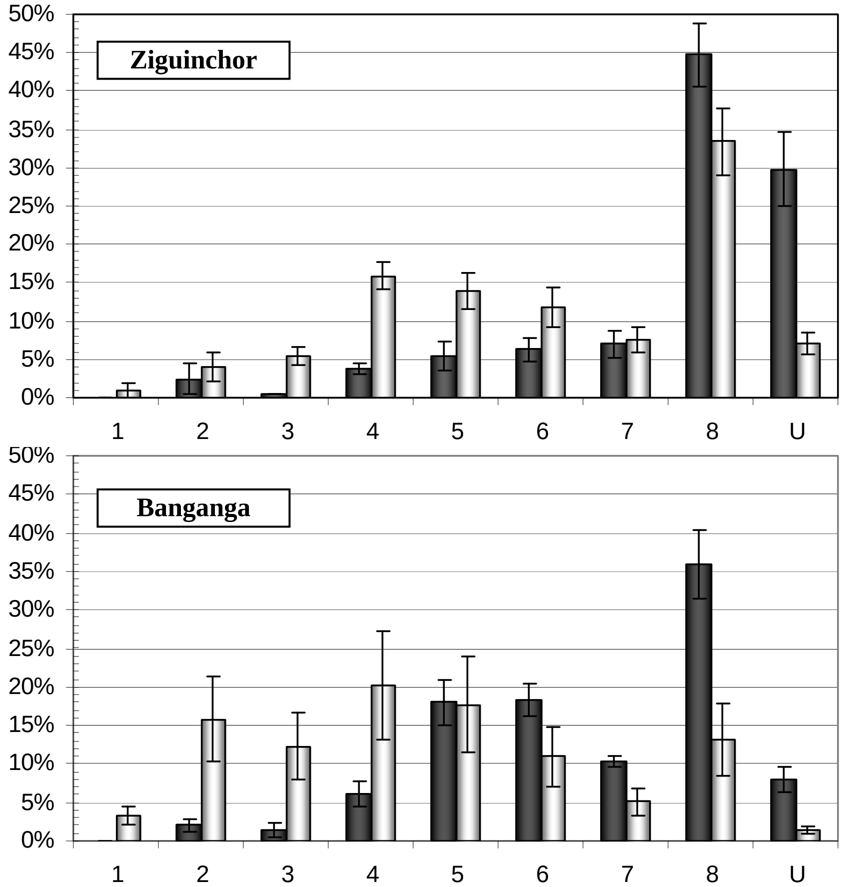
Bonga Shads, *Etmalose fibriata* were also found frequently in both gears topping the Mujas (31.9%) and rendering fourth place in Félé-félé catches (5.7%). This clupeid feeding phytoplanctonical is of commercial importance when caught at larger size, a maximum size of 45cm and a high rate of spawning due to a minimum population doubling time less than 15 months (Fishbase 2008). It was however never observed at larger size, as most individuals measured about 10 cm or smaller. Size also varied between gears with Mujas catching the larger ones (mean weight 21g compared to 8g). It is usually fried or cooked but often discarded during night.

The Flagfin mojarra, *Eucinostomus melanopterus* was the most frequent bycatch besides crabs for the Félé-félé fishing (22.1%), but almost absent in Mujas landings (1.3%). This is a coastal omnivore that enters estuaries and is found over sand and muddy bottoms with maximum size of 30 cm and a lower resilience factors than *E. fibriata* due to longer population doubling time of 1.4 - 4.4 years. It is marketed as fresh but not highly esteemed (Fishbase 2008). Depending on size it was found both discarded and utilized occasionally.

As the third most frequent species in Mujas, the Bobo Croaker, *Pseudotolitus elongatus* was also caught at an essentially smaller size than the maximum size 47 cm. As a typical fish and shrimp predator that is also caught offshore as it spawns at depths up to 100m during the rainy season (Fishbase 2008). Other species that drop below 10% frequency but as well should be noticed are different species of mullets *Mugiliae,* the *Elops lacerata* which can grow to 100 cm and the *Brachydeuterus auritus,* Big Eye grunt 30cm (Fishbase 2008), see full list in appendix.

4.3 Weight distribution of target catch, P. notialis

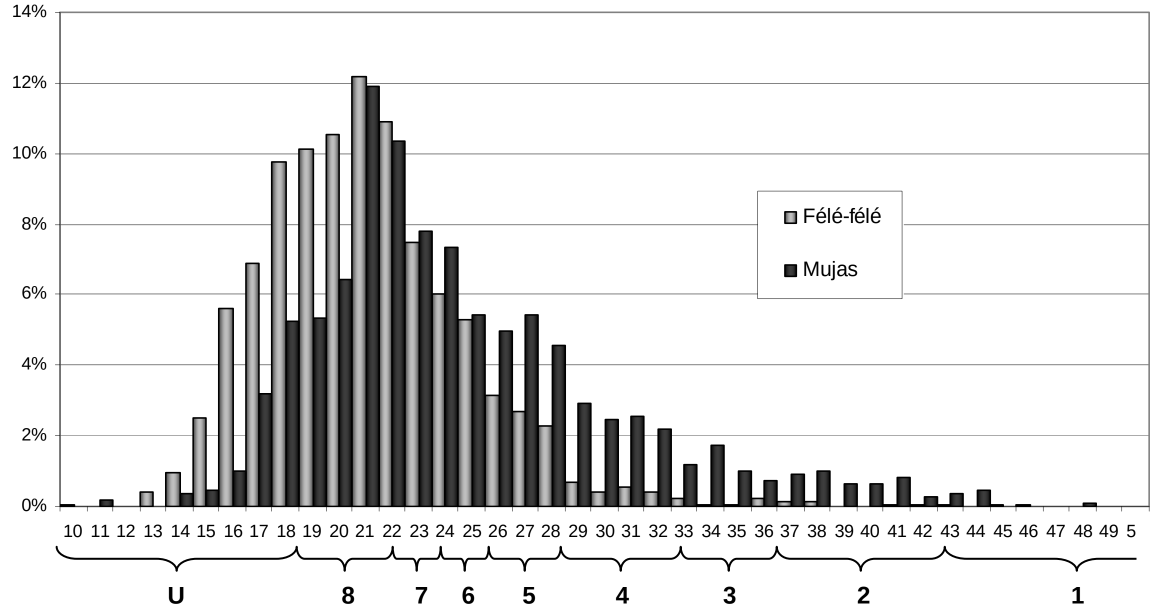
Figure 4 – Weight distribution of Shrimp Catch in Ziguinchor and Banganga



Weight distribution in percentage of catch over 9 commercial calibres including a category U of undersized **1) Mujas, the fixed net (White)** *and* **2) Félé-félé, the driftnet (Black***). Surveys made in Ziguinchor (downriver) and Banganga (upriver) landing sites in December 2007. Standard error indicated with bars.*

Vast geographical differences were observed between the size composition of the Ziguinchor landings (closest to the sea) and the Banganga landings (up river). Both fishing gears catches smaller shrimps in Ziguinchor with a remarkable rate of 74% immature (of calibre 8 and lower) for the driftnets. By the legal definition of maximum 200 individuals per kg, none of the examined driftnet samples would have been approved at this location.

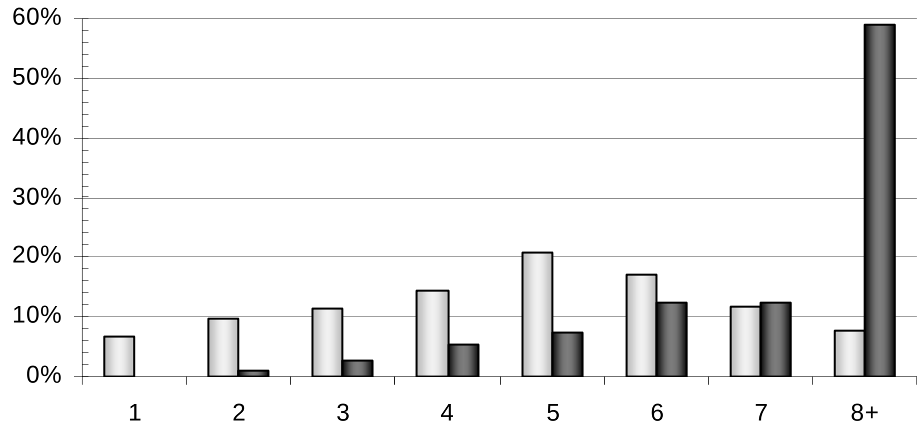
Figure 5 – Length distribution between gears



Carapace length distribution of sampled shrimps, note that the commercial calibres are not equidistant in there range

4.4 Industrial fishery as a reference

Figure 6 – Calibre distribution by Artisanal and Industrial company production



Industrial (white) *trawling distribution from 2005-2006 by a major company representing 60% of all industrial catches, compared with one out of three* ***artisanal (black****) distributor factories active in Casamance in Nov 2005.*

Table 7 – Industrial and Artisanal statistics summarized

	Discard		***Bycatch***		***Small size***	
	Ratio	kg per kg mixed catch	Ratio	kg per kg mixed catch	Ratio	kg per kg mixed catch
Industrial						
-SDP (Company1)2006	-	-	**>83%**	>4.9	**8%**	0.09
*- Calc Tot 2005**	(25%)	(0.33)	(62+25=87%)	(1.6)	-	-
- Zone 2005	**44%**	0.79	**87%**	6.7	-	-
- European 2005	**59%**	1.44	-	-	-	-
- FAO ≈2000	**62%**	1.63	-	-	-	-
- FAO ≈1990	**73%**	2.70	-	-	-	-
Artisanal						
Félé-félé 2007	**12 ±3% SE**	0.13	**20±3 %SE**	0.25	**57±5 %SE**	1.34
Mujas 2007	**35 ±8% SE**	0.55	**54±6 %SE**	1.19	**28±5 %SE**	0.38

The industrial discard rates in the political zone and for the European boats are both much higher than the artisanal. However, the legislation compensating model (see appendix) indicate that this may be an over estimation. Results also show bycatch rates that are higher for the industrial fishery, but also with essentially lower small size ratio, as also illustrated in Table 5.

5 Discussion

5.1 General artisanal results and ANOVA test

All landing data show large standard deviations, representing the large daily differences of biomass caught in both types of nets. Although significant differences between the gears have been documented, the numerical values should not be accounted for as representative within the two digits accuracy for the whole fishery. Practical limitations set the time frame to three weeks field work whereas ideally more data points would be recommended for future studies. By this also the compensation for seasonal variations was not possible to include, although the quota between different gears was assumed to be more constant.

As mean shrimp catch and the Length/Weight distribution was completely examined, the bycatch related statistics suffered from communication problems in the more remote Banganga village, where fishermen at different times kept or sold fish during night to an extent that these data points had to be excluded in the ANOVA test. Therefore the variance test of Discard at first generated no significant result for the whole model, but with the interaction excluded (after shown irrelevant in all other tests) the corrected model became significant.

5.2 Species composition of Bycatch

When bycatches were analyzed a few species of high salinity tolerant species dominated both landing types. The exact species composition should in no way be held representative for the whole fishery, as reports and interviews speak about large seasonal and geographical variations. Also only the Ziguinchor site was sampled while Banganga was excluded by the same reason as mentioned above. Sadly, as some spatial differences were observed also here. For example, an abundance of juvenile catfish, *Arius sp*. which is one of the species the national oceanographic research instate (CRODT) has recently studied offshore, with falling CPUE for.

Otherwise the most of the species has no reliable catch studies to rely on, but most of the species are found at larger size on local markets. However, as almost all fish species were caught at considerably smaller size than full maturity would suggest - the catch is not easily sold to a good prize. A recruitment overfishing on these bycatch species of may not be overseen and a precautionary approach by minimizing bycatch is recommende.

5.3 Size distribution of target catch, P. notialis

The industrial size distribution gave a small size ratio of 8% to be compared with the artisanal fishery rates (57% Félé-félé and 28% Mujas). The size difference implies that every kg shrimps caught by artisanal fishermen consists of almost the double amount of individuals, i.e. double the mortality counted in individuals per time unit and population size. But the industrial fishery on the other hand catches almost twice the amount of mature sized shrimps that are potential spawners. Ideally the harvest should contain only the middle sized shrimps leaving the small to grow and the largest to reproduce. A comparison of the different stock impact of mixed catches are hard to estimate without additive growth parameters, but a suggestion based on potential spawner biomass removed suggest roughly equal shares, see appendix 5.

As the weight distribution of commercial calibres gave benefits in comparison to commercial data, biologically they may lead to some confusion as the calibre definition not is equidistant with regard to either weight or length. For example the observed sink in calibre 7 is not a biological relevant variation, as the calibres are not equidistantly defined. The sink here is caused by smallest range by definition, see appendix 1. Also the data given by artisanal process plant may not be representative for the whole fishery as its based on only three day of processing and other sources indicate that other factories process larger shrimps, however the available data matches results from the field survey very well.

5.4The industrial fishery as reference

Data collected of all official landings 2007 suggested a minimum offshore bycatch rate of 83% with eventual discards not included, which is far beyond comparable values of artisanal fishery (20% Félé-félé, 54% Mujas). In a fishery where many of the larger demersal fish species are threatened this is a remarkably high rate, that independent of the rate of utilization makes the artisanal fishery far more selective in targeting shrimps while causing less extra mortality to other different species. Data compilation of reports from fishery surveillance department suggests 44% discard in the political zone with different legislation, to be compared with 59% for European ships during the same time.

Also the outcome of the general discard model (25%) is essentially lower then all previous estimates. But the critical assumption is the one of equal rates of shrimps in the zone and in general, however when this parameter is disturbed with 10% the model gives discard rates of either 17% if more shrimps in general then in zone alt. 32% if zone contains more shrimps then in general, which is more likely it geographically contains the main spawning ground of the southern stock.

However the assumption of equal rates of shrimps might be a too rough model. Therefore these figures may not represent the actual national discard rate, but rather suggest that the figure could actually be lower then the compiled 44%. Anyway, a trend of decreasing discards is evident. It could be explained by various reasons, such as increased value of different fish species due to overfishing, global competition on the shrimp market and higher fuel prizes. Also an illegal market has emerged, where catch and bycatch are sold to small artisanal canoes, a phenomenon referred to as transhipment. The extent and impact of transhipment is difficult to estimate as there is an interest in keeping it secret among those who are involved, since it is illegal by legislation.

5.5 Management improvements suggested

By regarding the significant artisanal yearly catch and relating it to bycatches and general stock status for both shrimps and fish, it is obvious that a sustainable management strategy is required also for the artisanal fishery.

The risk of juvenile fish bycatch must be taken into account as it could affect also other stocks and a larger study of on sight landings would be recommended. By precautionary approach some disturbance could be avoided by fishermen themselves if they sort back unwanted catch directly from the canoes. The Félé-félé for example could easily return small fish when they are fishing without killing or damaging most part of the catch. Compared to the trawl bycatch there are no quick ascending, no stress in a densely packed moving pouches and small enough catch per haul to minimize the handling time. Thus, survival chances should be good. The Mujas on the other hand could probably be optimized for minimizing bycatch in a way resembling large bycatch reducing device's (BRD) of commercial trawlers, witch either sort by size or behavioural patterns shrimps (Eayrs 2007). For example inserting a fish eye or parts with square mesh grid would be considerably easy for the fishermen and to a low cost. As no big animals have to be excluded all rigid and costly frontal sorting grids would not be needed.

Also the artisanal fishery should minimize the fishing of small sized shrimps that only contributes with a marginal kg price when sold, for both biological and socio economical reasons. One way could be not allowing fishing in the outer part of the river with the highest frequency of small sized shrimps, at least not with the Félé-félé driftnet which gives a very high proportion of small shrimps. If government would enforce current legislation this would probably also be the consequence. Also one could study the effects of an increased mesh size for both types of gear. With enforcing of the minimum sizes there would be little economical incitement for continues usage of the smaller mesh since the only difference then would be less small fish of negligible economical value.

The artisanal shrimp fishery has the possibility of becoming ecologically sustainable product for other reasons compared to industrially caught shrimp; the artisanal fishery is very energy efficient whereas the other consumes large amounts of diesel per kg and have less mechanical seafloor disturbance then bottom trawled shrimps (Ziegler et al 2008). But finally there must be a possibility of scientific based effort regulation for the combined stock output where also the artisanal effort can be adjusted and limited if needed. Practically this could be a limited amount of legislations, fishing stops during certain periods or individual quotas per fisherman. Ideally large studies and monitoring of the combined industrial and artisanal fishery should be conducted which include the bycatch situation. But possibly only with accuracy related a risk based stock assessment and a controlled precautionary approach, as this fishery as well as many other small fisheries in developing countries is characterized by stock data deficiency (Hobday 2007).

6 Conclusions

Bycatches and discards in artisanal shrimp fishery has been shown significant for the two major fishing gear, and they differ in terms of 1)size distribution of target catch, 2) mean catch, 3) bycatch rate and 4) discard rate. The fixed nets, *Mujas* catches larger shrimps with higher catch per working hour, but also with higher bycatch rates and discard rates. The *Félé-félé* driftnet is more selective but requires more working labour and catches essentially smaller shrimps. Also large spatial difference has been observed between upriver and downriver condition, especially in terms of small sized shrimps captured as they enter the estuary.

The artisanal bycatch species was dominated by few mostly juvenile fish species and swimming crabs, *Callinectes sp*. Contribution to juvenile overfishing could not be overlooked, although the total impact requires a much larger study. Industrial shrimp fishery however has a lot higher bycatches by weight percentage. Discards are generally lower for the artisanal fishery, but as the offshore discard rates have dropped due to higher bycatch utilization, the worst artisanal gear could in this sense have a comparable discard rate. Industrial fishery also catches far larger shrimps then the artisanal in general.

As the artisanal contribution to target stock depletion and bycatch extra mortality has been shown significant, sustainable management is required for artisanal fishery just as for the industrial fishery. Artisanal fishery still has a good potential of becoming a beneficial and ecological sustainable export product but a possibility of a scientifically based effort regulation is required and by a precautionary approach all bycatches and discards should be reduced and the catch of small shrimps minimized.

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8 Appendix

Appendix 1 – Commercial shrimp calibres

Commercial definition		**Weight g**			**Length mm**		
Calibre	Max nr/kg	Min	Max	Range	Min	Max	Range
1	20	50,00	>50		43,02	>43,02	
2	30	33,33	50,00	16,67	37,07	43,02	5,96
3	40	25,00	33,33	8,33	33,35	37,07	3,72
4	60	16,67	25,00	8,33	28,73	33,35	4,62
5	80	12,50	16,67	4,17	25,84	28,73	2,88
6	100	10,00	12,50	2,50	23,81	25,84	2,04
7	120	8,33	10,00	**1,67**	22,27	23,81	**1,54**
8	200	5,00	8,33	3,33	18,45	22,27	3,81
Undersized	>200	0	5,00	5,00	0	18,45	18,45

Literature limits	*Roxo-Bissagos, January (Southern stock, Casamance)*		*St Louis, September (Northern Stock)*	
(Lhomme and Garcia 1981)	L_C (mm)	Calibre	L_C (mm)	Calibre
Maturation Female	27,5	5	24	6
Maturation Male	26	5	21,5	8
Max length Female	41	2	41	2
Max length Male	30	4	20	4

Appendix 2 – Full ANOVA test results

Smallsize rato

Levene's Test of Equality of Error Variances

F	df1	df2	Sig.
1,814	3	29	0,167

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.439	3	0.480	24.072	0.000
Intercept	6.103	1	6.103	306.231	0.000
Fishing Method	0.810	1	0.810	40.659	0.000
Location	0.646	1	0.646	32.392	0.000
Fishing Method * Location	0.005	1	0.005	0.256	0.616
Error	0.578	29	0.020		
Total	8.254	33			
Corrected Total	2.017	32			

Mean Shrimp Catch (kg)

Levene's Test of Equality of Error Variances

F	df1	df2	Sig.
3,384	3	28	0,032

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	979.39	3	326.462	19.901	0.000
Intercept	4 027.6	1	4 027.6	245.525	0.000
Fishing Method	836.98	1	836.98	51.023	0.000
Location	176.85	1	176.85	10.781	0.003
Fishing Method * Location	3.438	1	3.438	0.210	0.651
Error	459.31	28	16.404		
Total	5 556.5	32			
Corrected Total	1 438.7	31			

Bycatch ratio

Levene's Test of Equality of Error Variances

F	df1	df2	Sig.
2.129	3	26	0.121

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.010	3	0.337	12.794	0.000
Intercept	4.115	1	4.115	156.345	0.000
Fishing Method	0.874	1	0.874	33.229	0.000
Location	0.057	1	0.057	2.178	0.152
Fishing Method * Location	0.075	1	0.075	2.852	0.103
Error	0.684	26	0.026		
Total	5.597	30			
Corrected Total	1.694	29			

Discard ratio, Test 1

Levene's Test of Equality of Error Variances

F	df1	df2	Sig.
4.213	3	11	0.033

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.248	3	0.083	3,433	0.056
Intercept	0.737	1	0.737	30.579	0.000
Fishing Method	0.188	1	0.188	7.817	0.017
Location	0.006	1	0.006	0.247	0.629
Fishing Method * Location	0.016	1	0.016	0.682	0.426
Error	0.265	11	0.024		
Total	1.307	15			
Corrected Total	0.513	14			

Discard ratio, Test 2 (No interactions tested)

Levene's Test of Equality of Error Variances

F	df1	df2	Sig.
4.213	3	11	0.033

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.232	2	0.116	4.939	0,027
Intercept	0.846	1	0.846	36.054	0,000
Location	0.010	1	0.010	0.425	0,527
Fishing Method	0.232	1	0.232	9.876	0,008
Error	0.282	12	0.023		
Total	1.307	15			
Corrected Total	0.513	14			

Appendix 3 – Species composition of Ziguinchor bycatch

Scientific name	Local/working name	**Mujas**	7 landings		**Félé-félé**	8 landings	
		nr	kg	% of weight	nr	kg	% of weight
Arius spp	Cong, Catfish	12	0,37	0,8%	1	0,01	0,0%
Brachydeuterus auritus	Degerbop	213	2,56	5,5%	7	0,31	1,0%
Calinectes spp	Niankar, Crab	436	12,49	27,0%	662	15,5	50,5%
Cynoglossus spp	Sole	4	0,07	0,2%	6	0,8	2,6%
Drepane africana	Tampandar	4	0,4	0,9%	4	0,18	0,6%
Elops lacerata	Lak, Ladyfish	112	5,15	11,1%	32	1,4	4,6%
Etmalosa fibriata	Cobo, Bonga Shad	695	14,72	31,9%	208	1,76	5,7%
Eucinostomus melanopterus	Fatomatanding	18	0,58	1,3%	583	6,8	22,1%
Galeoides decadactylus	Tiekem	14	0,5	1,1%	8	0,11	0,4%
Hemiraphus brasiliensis	Soun-Soun, Half beak	0	0	0,0%	5	0,05	0,2%
Ilicha africana	Rimbol	7	0,48	1,0%	0	0	0,0%
Lagocephalus laevigatus	Smooth puffer	2	0,12	0,3%	0	0	0,0%
Liza spp	Thiap	43	2,81	6,1%	94	1,97	6,4%
Mugil spp	Mulet	1	0,03	0,1%	0	0	0,0%
Murex spp	Shell	0	0	0,0%	1	0,01	0,0%
Penaeus monodon	Tigershrimp	0	0	0,0%	3	0,1	0,3%
Polydactylus quadrofilis	Capitaine	0	0	0,0%	2	0,02	0,1%
Psettias sebae	Thiagarac, African Moony	1	0,05	0,1%	0	0	0,0%
Psettodes belcheri	Mbang,Turbot	0	0	0,0%	1	0,2	0,7%
Pseudolithus elongatus	Dioto	216	5,76	12,5%	13	0,92	3,0%
Psudolithus typus	Ngouka	0	0	0,0%	0	0	0,0%
Sarotherodon melano	Wass,Tilapia	0	0	0,0%	25	0,56	1,8%
Spyraena spp	Baracuda	0	0	0,0%	0	0	0,0%
X	Other	5	0,1	0,2%	1	0,01	0,0%
			46,19			30,71	

General Senegalese data available 2005:
Proportion of landed target catch T_L=17,45%, landed bycatch B_L=1-T_S, and thus the ratio k=B_L/T_L
No data available for discards and thus the real proportions of T, B and D. Legislation does not have a minimum rate of target catch that could cause extra discard.

Zone of Guinea Bissau/Senegal data available 2005:
On board target catch T_z=13,09%, bycatch rate B_z=43,23% and discard rate D_z=43,68%, (without the discard this makes up a comparable landed target catch T_{LZ}=32,2% of landed weight). Legislation demand minimum 30% target catch.

By assuming 1) that it's the same rate *p* of shrimps in the zone as in general, one can solve an equation system for T, B and D for an approximation of general bycatch and discard.

1) $$\frac{T}{T+B+D} = p = \frac{T_Z}{T_Z + B_Z}$$ (Assumption of same rate p of shrimps in unsorted catch)

2) $$T + B + D = 1$$ (Catch defined as T, target catch, B, landed by-catch and D, discard)

3) $$B = kT$$ (Same proportion of shrimps T and landed bycatch B as observed in official records)

2) & 3) $$T = \frac{1-D}{1+k}$$

$$B = kT = k\frac{1-D}{1+k}$$

1) $$D = T(\frac{1}{p} - 1) - B$$

$$D = \left(\frac{1-D}{1+k}\right)a - k\left(\frac{1-D}{1+k}\right) \qquad a = \left(\frac{1}{p} - 1\right)$$

$$D = \frac{\frac{a-k}{1+k}}{1+\frac{a-k}{1+k}} = 24{,}98\% \qquad T = \frac{1-D}{1+k} = 13{,}09\% \qquad B = k\frac{1-D}{1+k} = 61{,}93\%$$

If zone contains more shrimps then in general				Same rates		If zone contains less shrimps then general *(unlikely)*			
p*0,8		p*0,9		p		p*1,1		p*1,2	
D=	0,399826	D=	0,324804	D=	0,249782	D=	0,17476	D=	0,099739
T=	0,104717	T=	0,117807	T=	0,130896	T=	0,143986	T=	0,157075
B=	0,495457	B=	0,557389	B=	0,619322	B=	0,681254	B=	0,743186

	Zone data		Estimation
Discarded bycatch (D)	44%	→	25%
Utilized Bycatch (B)	43%	→	62%
Target catch (T), *P.notialis*	13%	→	13%

Appendix 4 - Discard observer program on EU-ships (obs, not only P. notialis)

2004	No discard data, only landings

2005		Landed/kg	Discard/kg	D.rate
	Jan	352982	24750	6.6%
	Feb	96045	54334	36.1%
	Mar	190151	117084	38.1%
	Apr	78937	72375	47.8%
	May	546779	615185	52.9%
	Jun	217996	143510	39.7%
	Jul	192646	184195	48.9%
	Aug	216550	187373	46.4%
	Sep	29947	44296	59.7%
	Oct	121040	290492	70.6%
	Nov	104453	516407	83.2%
	Dec	97616	540126	84.7%
	TOT	**2245142**	**2790127**	**55.4%**

2006	Jan	13089	6390	32.8%
	Feb	16741	18490	52.5%
	Mar	22854	26587	53.8%
	Apr	17561	22807	56.5%
	May	31838	66827	67.7%
	Jun	15623	13265	45.9%
	TOT	**117706**	**154366**	**56.7%**
	End of fishing agreement			

Appendix 5 – Model of spawner biomass removed

Spawner biomass removed	Total Catch T (tonnes)	Weight quota of spawners q (calibre>=5)	Spawners (tonnes) S=T*q	Future Spawners (tonnes) F=(T-S)*m	Future Spawners after Growth (tonnes) G=F*g	Effective Spawner biomass removed (tonnes)	Including compensation factor 2) and 3)
Artisanal	1000	0,331	331	134	353	684	650
Industrial	1000	0,630	630	74	195	825	866
Artisanal (2006)	1386	0,331	459	185	489	949	901
Industrial (2006)	1070	0,630	674	79	209	883	927

Adjustable parameters	**1) Mortality factor m**, approximated as probability of finding mature size in mixed artisanal catch distribution	0,2	**2) Density dependency** If neglected - possible overestimation of Artisanal effect	0,95	**3) Fecundity difference compensation** If neglected - possible underestimation of Industrial effect	1,05	

Growth parameter g	Representative CL (mm)	Weight (g)
Immature size	21	7,11
Mature size	30	18,75
	g	2,64

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