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# AT-HAULBACK MORTALITY OF ELASMOBRANCHS CAUGTH ON THE PORTUGUESE LONGLINE SWORDFISH FISHERY IN THE INDIAN OCEAN.

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*SUMMARY*

In this study we analyze at-haulback fishing mortality of elasmobranchs caught by Portuguese longliners that target swordfish in the Indian Ocean. Information was collected by an IPIMAR on-board fishery observer that monitored 103 longline sets between May and September 2011, and recorded information on 2910 elasmobranch specimens from 11 different species. At-haulback mortality is species-specific, with some species having high percentages of alive specimens at time of haulback (e.g. manta rays, pelagic stingray and blue shark), while others have higher percentages of dead specimens (e.g. smooth hammerhead, silky shark and bigeye thresher). The most captured elasmobranch species was the blue shark and the odds-ratios of mortality at different sizes and for each sex were estimated with GLM logistic models. Blue shark specimens tended to have decreasing odds of mortality with increasing sizes, and those results are in accordance to what has been previously reported for the Atlantic Ocean. The results presented in this paper can now be integrated in future ecological risk assessment analysis for pelagic elasmobranchs, and can be used to estimate the survival of sharks after being captured and discarded by longline commercial fisheries.

*KEYWORDS: At haulback mortality, by-catch, discards, logistic models, longlines, pelagic elasmobranchs.*

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# 1. Introduction

Ecological Risk Assessment analysis (ERA, also known as Productivity Susceptibility Analysis - PSA), are models useful mainly in data poor situations where other models requiring more detailed data cannot be implemented. Recently, a model of this type was implemented for pelagic elasmobranch species commonly captured as by-catch in pelagic longline fisheries in the Atlantic Ocean by Cortés et al. (2010). With this analysis, both the susceptibility and the productivity of each species are analyzed, in order to rank and compare the most vulnerable and/or susceptible species caught in the fishery. One of the parameters that can be included in the susceptibility component is the probability of survival after capture that can be inferred from the mortality at time of haulback.

Some previous studies have focused on elasmobranch mortality, but most were carried out for coastal species caught in trawl fisheries. Those include the study by Mandelman and Farrington (2007) for the spurdog (*Squalus acanthias*) and the study by Rodríguez-Cabello et al. (2005) for the small-spotted catshark (*Scyliorhinus canicula*). For pelagic elasmobranchs Campana et al. (2009) carried out a comprehensive study for the blue shark (*Prionace glauca*) caught in pelagic longline fisheries in the NW Atlantic (off Canada), and included both the short term mortality (recorded at-haulback) and the longer term mortality (recorded with satellite telemetry). Additionally, a recent ICCAT SCRS Document (Coelho et al., 2011) focused the at-haulback mortality of several elasmobranch species captured as by-catch in pelagic swordfish fisheries in the Atlantic Ocean.

The main aim of this paper was to explore at-haulback fishing mortality (recorded at time of fishing gear retrieval) during pelagic fisheries in the Indian Ocean targeting swordfish and by-catching pelagic sharks. A secondary objective was to compare these results now presented for the Indian Ocean with other results already available for the Atlantic Ocean.

# 2. Material and methods

### *2.1. Data collection*

Data for this study was collected by an IPIMAR fishery observer aboard a Portuguese longliner targeting swordfish in the Indian Ocean. Specifically, data was collected during one mission in the Indian Ocean that occurred between May and September 2011. During that trip, a total of 103 logline fishing sets were carried out (**Figure 1**), capturing 2910 elasmobranch fishes from 11 different species.

For every elasmobranch specimen that was caught, the onboard fishery observer recorded the species, the specimen size (FL – fork length, taken to the lower 1cm size class), the at-haulback condition (alive or dead at time of fishing gear retrieval), the fate (retained or discarded), and the condition if discarded (alive or dead at time of discarding). For each longline fishing set carried out additional information was recorded including the date, location (latitude and longitude) and the number of hooks used in the set.

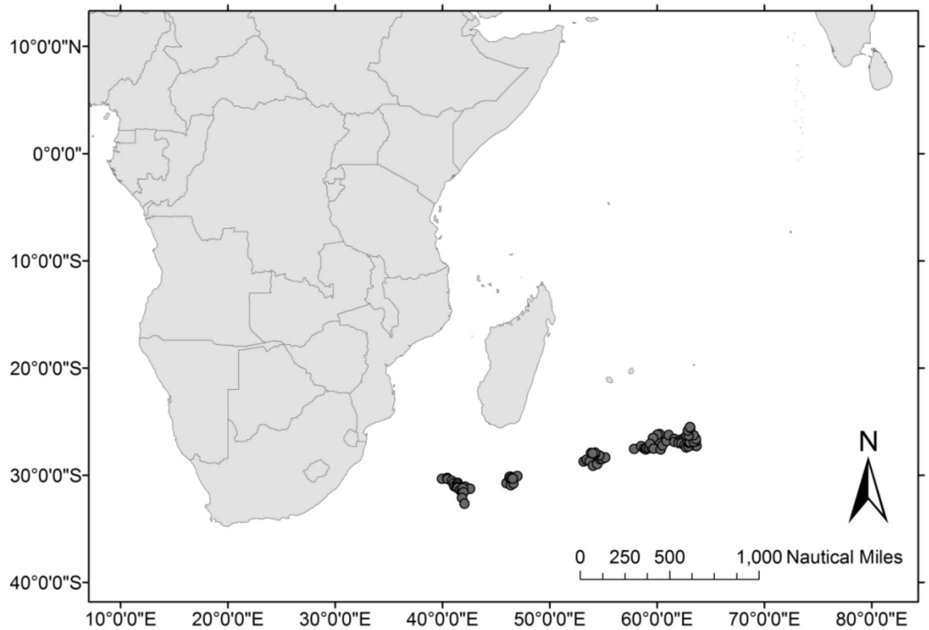


**Figure 1**: Map with the location of the longline fishing sets with information on elasmobranch captures that were analyzed for this study.

### *2.1. Data analysis*

The numbers of alive and dead specimens at time of capture was recorded, and the respective percentages per species calculated. These percentages were compared using the sexes combined, except for the blue shark (*Prionace glauca*) where a sex-specific analysis was carried out. The differences in the mortality ratios between sexes of blue shark were analyzed with a contingency table, and tested with a $Chi^2$ proportion test.

The effect of the size in the odds of mortality for blue shark was determined with a Generalized Linear Model (GLM) with binomial error distribution and logit link function (Logistic Model). For that model, the response variable was coded as a binary variable in which: 1 = specimen dead at-haulback and 0 = specimen alive at-haulback. The explanatory variables used were specimen size (FL in cm) and sex. Explanatory variables were considered at the 10% significance level, determined by the Wald statistic, and by likelihood ratio tests comparing each univariate model with the null model. The GLM assumption of linearity of the continuous explanatory variables (in this case the size) with the linear predictor was assessed with Generalized Additive Models (GAM) plots, and by creating models with the continuous variable transformed with fractional polynomials. After fitting each model, the odds-ratios of each explanatory variable with the respective 90% confidence intervals were calculated.

All statistical analysis was carried out with the R Project for Statistical Computing version 2.13.0 (R Development Core Team, 2011). Most analysis carried out are included in the core R program, except the contingency tables that were created with library “gmodels” (Warnes, 2011), the GAM plots that were created with library “gam” (Hastie, 2011), and the GLMs with fractional polynomials that were created with library “mfp” (Ambler and Benner, 2010).

## 3. Results and Discussion

### *3.1. Species-specific proportions of at-haulback fishing mortality*

During this study a total of 2910 specimens from 11 different species or groups of species were recorded (**Table 1**). The blue shark was the most common of all elasmobranchs (81.1% of the elasmobranch catch in number), followed by the shortfin mako (14.8%). Together, those two species accounted for 95.9% of the elasmobranch catch. Of the 2910 specimens that were caught, information regarding the at-haulback condition (dead/alive) was recorded for most specimens, specifically for 2908 specimens.

**Table 1:** Descriptive statistics of specimens caught and analyzed for this study in the Indian Ocean. “N” refers to the total catch, “n_state” to the sample that was recorded for at-haulback fishing mortality, and “n_size” to the sample that was recorded for size. Size refers to fork length (FL) in centimeters, with values for the minimum (Min), the maximum (Max), the mean size (Mean) and the standard deviation of the mean (SD).

| Species Code | Species / Family | Sample | | | Size (FL, cm) | | | |
|---|---|---|---|---|---|---|---|---|
| | | N | $n_{\_state}$ | $n_{\_size}$ | Min | Max | Mean | SD |
| BSH | *Prionace glauca* | 2360 | 2358 | 2334 | 98 | 299 | 222.3 | 29.4 |
| SMA | *Isurus oxyrinchus* | 430 | 430 | 422 | 81 | 323 | 181.3 | 35.9 |
| FAL | *Carcharhinus falciformis* | 31 | 31 | 31 | 77 | 239 | 121.8 | 51.6 |
| SPZ | *Sphyrna zygaena* | 25 | 25 | 24 | 116 | 262 | 240.1 | 28.2 |
| BTH | *Alopias superciliosus* | 19 | 19 | 17 | 109 | 296 | 210.1 | 46.6 |
| PLS | *Dasyatis violacea* | 16 | 16 | 0 | | | | |
| JAM | Mobulidae | 14 | 14 | 0 | | | | |
| LMA | *Isurus paucus* | 7 | 7 | 7 | 73 | 172 | 129.7 | 40.0 |
| PSK | *Pseudocarcharias kamoharai* | 5 | 5 | 5 | 84 | 99 | 90.6 | 6.5 |
| GAC | *Galeocerdo cuvier* | 2 | 2 | 2 | 186 | 219 | 202.5 | 23.3 |
| OCS | *Carcharhinus longimanus* | 1 | 1 | 1 | 63 | 63 | 63.0 | |

The condition at time of haulback seems to be species-specific, with significant differences in the proportions between the different species (**Figure 2**).

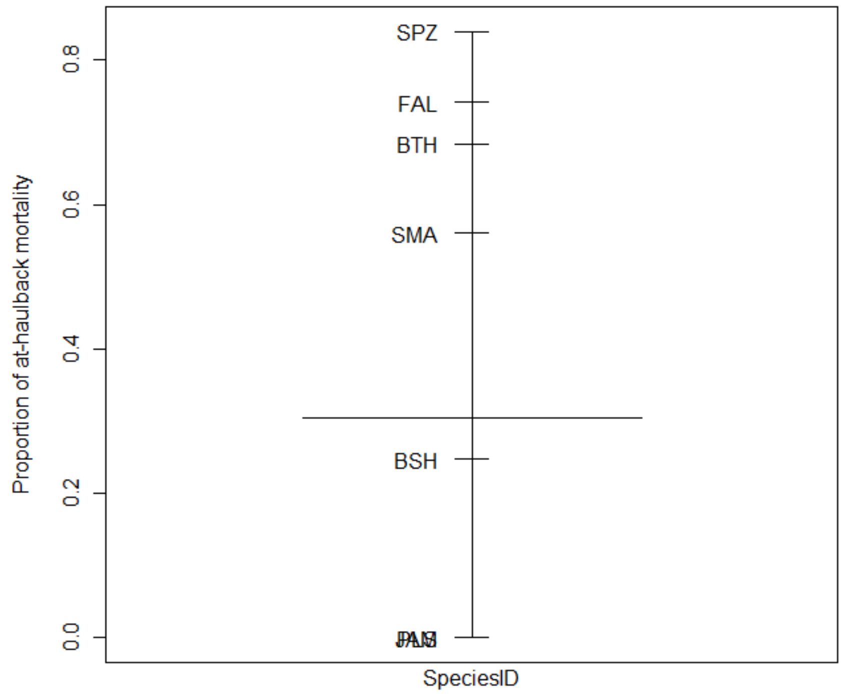


**Figure 2**: Design plot with the proportions of at-haulback mortality of the most captured elasmobranch species (only species with sample size (n) > 10 are plotted). The horizontal line refers to the overall proportion of at-haulback mortality across all species. BSH - *Prionace glauca*; BTH - *Alopias superciliosus*; FAL - *Carcharhinus falciformis*; JAM - family Myliobatidae; PLS - *Dasyatis violacea*; SMA - *Isurus oxyrinchus* and SPZ - *Sphyrna zygaena*. (Note: JAM and PLS have proportions of at-haulback mortality equal to 0 and the species legends appear overlapped in the graphic).

For the pelagic stingray and the manta rays all specimens were captured alive at time of haulback, and were then discarded also alive. For those two species the specimens tended to be discarded without being brought aboard the vessels, so there is little information available regarding the sizes and the sex of the specimens. Within the sharks, specimens from species such as the smooth hammerhead and the silky shark tended to be captured already dead, while for species such as the blue shark most specimens were captured still alive (**Table 2**).

**Table 2:** Percentage of dead specimens at time of haulback for each species recorded, both for the Indian (IO) and the Atlantic Oceans (AO), with indication of the sample size (n) used for the analysis. Only species with samples sizes (n) > 10 are presented in this table. Data for the Atlantic Ocean taken from Coelho et al. (2011).

| Species Code | Species / Family | At-haulback condition IO | | At-haulback condition AO | |
|---|---|---|---|---|---|
| | | n | % Dead | n | % Dead |
| BSH | *Prionace glauca* | 2358 | 24.7 | 22887 | 12.7 |
| SMA | *Isurus oxyrinchus* | 430 | 56.0 | 1004 | 32.8 |
| FAL | *Carcharhinus falciformis* | 31 | 74.2 | 296 | 55.1 |
| SPZ | *Sphyrna zygaena* | 25 | 84.0 | 338 | 70.1 |
| BTH | *Alopias superciliosus* | 19 | 68.4 | 849 | 48.6 |
| PLS | *Dasyatis violacea* | 16 | 0.0 | 351 | 1.1 |
| JAM | Mobulidae | 14 | 0.0 | 130 | 1.5 |

### *3.2. Effects of size and sex in the odds of mortality of blue shark*

For the blue shark, the proportion of dead females at time of haulback was 20.4% while the proportion of dead males was higher (25.5%). Those differences were statistically different ($Chi^2$ proportion test: $Chi^2 = 4.01$; df = 1; p-value = 0.045), even thought the significance is only marginal given that the p-value is very close to 0.05. The size of the blue shark also seems to have an effect in terms of the odds of mortality, with mortality decreasing as specimen size increases (**Figure 3**).

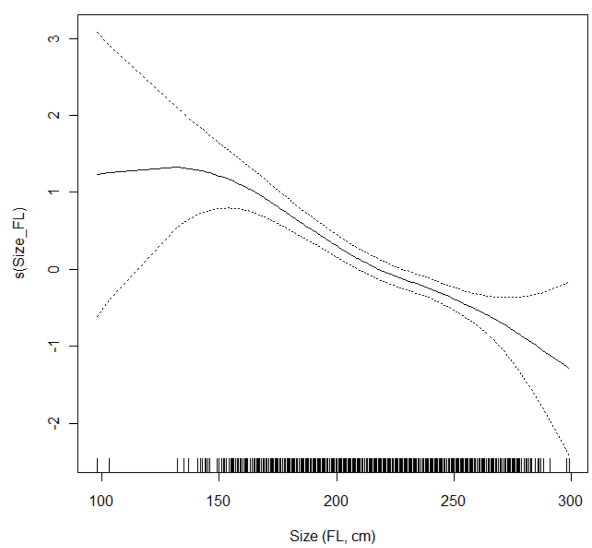


**Figure 3**: GAM plot representing at-haulback mortality of blue shark in the Indian Ocean in terms of specimen size (FL). The solid line represents the model while the dotted lines represent the confidence bands. The vertical bars in the bottom represent the sample.

The results of the logistic model using sex and size as explanatory variables are presented in **Table 3**. Size is significant at the 1% level, while sex is only significant at the 10% level. In terms of the odds ratios calculated with this model, it was possible to estimate that for each 10 cm FL increase in the size of the sharks, the odds of being dead at time of haulback decreased 14.3%, with 90% confidence intervals varying between 11.9% and 16.6% (**Table 4**). In terms of sex of the specimens, the odds of a male being dead at time of haulback are 30.7% higher than those of females, with 90% confidence intervals varying between 3.3% and 65.3% (**Table 4**).

**Table 3:** Parameters of the GLM (logistic model) using size and sex as explanatory variables for the mortality of blue shark in the Indian Ocean.

| Parameter | Parameter estimation | | | |
|---|---|---|---|---|
| | Estimate | SE | Wald Stat. | p-value |
| Intercept | 2.044 | 0.387 | 5.281 | 1.28E-07 |
| Size | -0.015 | 0.002 | -9.263 | < 2E-16 |
| Sex_M | 0.268 | 0.143 | 1.874 | 0.061 |

**Table 4:** Odds ratios for the parameters of the logistic regression using size and sex as explanatory variables for the mortality of blue shark. The odds-ratios for size are calculated for each 10 cm FL increase in size, and the odds-ratios for sex are calculated for males compared to females. The 90% confidence intervals are presented.

| Parameter | Odds-Ratios | | |
|---|---|---|---|
| | Estimate | Lower 90% | Upper 90% |
| Size_10cmFL | 0.857 | 0.834 | 0.881 |
| Sex_M | 1.307 | 1.033 | 1.653 |

### *3.3. Comparison of results between the Indian and the Atlantic Ocean*

When comparing the results now presented for the Indian Ocean to results previously obtained for the Atlantic Ocean (Coelho et al., 2011), the relative proportions between the different species were relatively similar. However, most species tended to have higher proportions of dead specimens at time of haulback in the Indian Ocean than in the Atlantic Ocean (**Table 2**).

Like in the Atlantic Ocean, species such as the Manta rays (family Myliobatidae) and the pelagic stingray are mainly captured alive, while some shark species (such as the hammerheads) are mainly captured already dead. Therefore, eventual conservation measures with mandatory discarding practices of particular species, such as the ones recently implemented in the Atlantic Ocean by ICCAT (for *Alopias* spp., *Sphyrna* spp.

and *Carcharhinus longimanus*), as well as in the Indian ocean by IOTC (for *Alopias* spp.), will have specific efficiencies depending on the species itself.

The present study is only considering the short term mortality that results from the actual capture process. Some specimens may be discarded still alive but with severe internal trauma that may result in longer term mortality. For measuring such effects the use of pop-up tags (satellite telemetry) would be needed, given that those tags allow tracking the sharks' vertical and horizontal movements for several weeks after being discarded. Therefore, the values presented in this paper should be regarded as the minimum mortality values due to the fishing process, and those values may actually increase due to longer term mortality that was not accounted for in this study. A recent study by Campana et al. (2009) using satellite telemetry tags looked into blue shark long-term survivorship after being discarded in the Atlantic Ocean, and concluded that all blue sharks discarded in healthy conditions survived, while 33% of those that were badly injured (or gut hooked) died. Further, Campana et al. (2009) also concluded that 95% of the mortality occurred within 11 days after being released.

Similar decreasing odds of mortality with increasing sizes of blue shark had been previously recorded for the Atlantic Ocean by Campana et al. (2009) and Coelho et al. (2011). Both previous studies also used logistic GLMs to assess the survival status of blue sharks at the time of fishing gear retrieval. For the present study, only two possible covariates were explored, specifically the size and sex of the specimens. This was because the dataset available for the Indian Ocean is still limited, and with data from only one fishing trip. As more data from fishery observers becomes available, other covariates will be explored such as the effects of the year, season or quarter of the year, vessel identity, location and temperature. Some potentially important variables that were not recorded and that might be important are the time that each specimen spent in the longline after capture (using hook timers) and the length and material of the gangion line.

This paper presents important new information on the impacts of the longline fishery on oceanic elasmobranch populations. These results can now be incorporated into future stock assessment models of elasmobranch species in the Indian Ocean, including Ecological Risk Assessment analysis. These results can also be used to estimate the survival of sharks after being captured and discarded by the commercial fisheries. Moreover, these results can also provide preliminary insights on the efficiency of eventual recommendations for mandatory discards of some vulnerable elasmobranch species, such as some of the measures already implemented by different RFMOs.

## 4. Acknowledgments

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