Offshore drilling operations and fishery monitoring programs: a quantitative impact assessment experience in Southern Bahia, Northeast of Brazil.

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Introduction

What should we know about small-scale fishery to infer about impact from drilling operations on shallow waters? What could we consider in drilling activities to define the sources of impact (*i.e.* disturbance) on fisheries catch rates? The current study is an experience on inferential statistics about these concerns. The impact of offshore drilling on small-scale fishing landings were studied in Southern Bahia, NE-Brazil. Disturbances on catch rates were assessed through a fishery monitoring program to comply with the environmental license requirements for *Queiroz Galvão Exploração e Produção* – QGEP oil and gas company. A landing survey was demanded by the Brazilian Environment Institute (IBAMA) to be established in the municipalities of Ilheus, Una, Canavieiras and Belmonte, as a condition for the licensing of offshore drilling activities in the BM-J-2 block south of the state of Bahia. Thus, a Fishery Monitoring Program ("PMDP") was designed and carried out from April 2011 to December 2013. The main objective of the monitoring program was to provide, through the analysis of fish landings data, input for an evaluation of the influence of drilling activity on the local fishing productivity index (or catch rates). An analytical approach based on the before-after control-impact (BACI) design was conducted from the application of the analysis of covariance model fit to the landing data

The study area corresponds to the area of influence related to drilling in Block BM-J-2 Jequitinhonha Basin, off the southern coast of the state of Bahia, which considered the municipalities of Ilhéus, Una, Canavieiras and Belmonte (Figure 1).

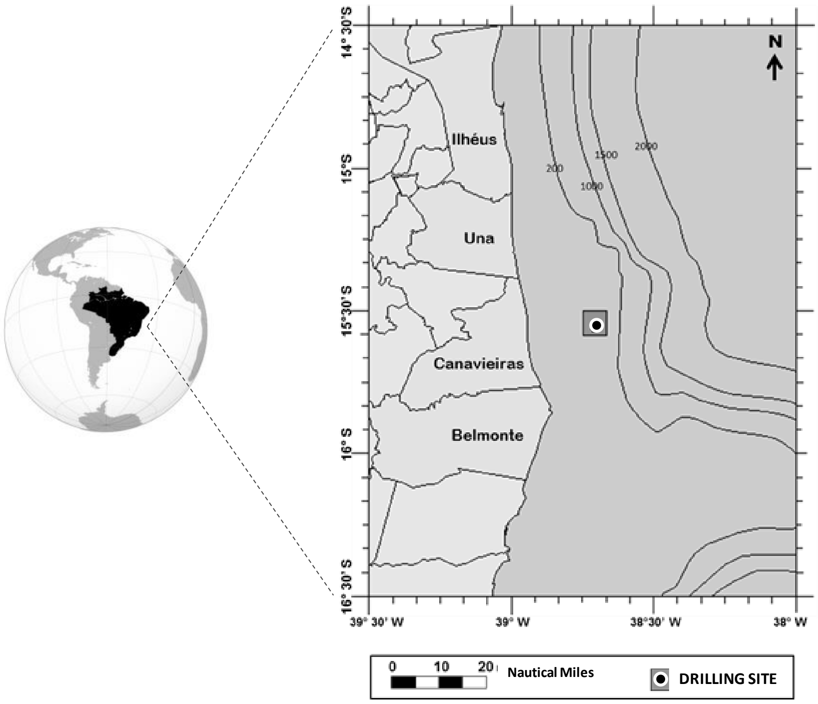

Figure 1: Study area and rig location (drilling site).

Methods

Catch-effort data from small-scale fisheries was collected by randomly sampling the fishing landings, of all motorized fleets on the study area, between April-2011 and December-2013. The samples were stratified by gear and area of capture. The landings sampling design was guided by the technical manuals of the Food and Agriculture Organization – FAO, especially by Stamatopoulos (2002).

Distinct impact assessment scenarios were built according to the spatial scale of drilling activities around the rig location and according to the spatial and temporal distribution of landing samples. The influence of drilling campaigns carried out in 2011 and 2013, from June to September in both years, were analyzed by a general linear model applied under the *before-after control-impact* (BACI) approach. The whole area used routinely by the platform supply vessels in each campaign (year) was considered as the disturbance area (Figure 2).

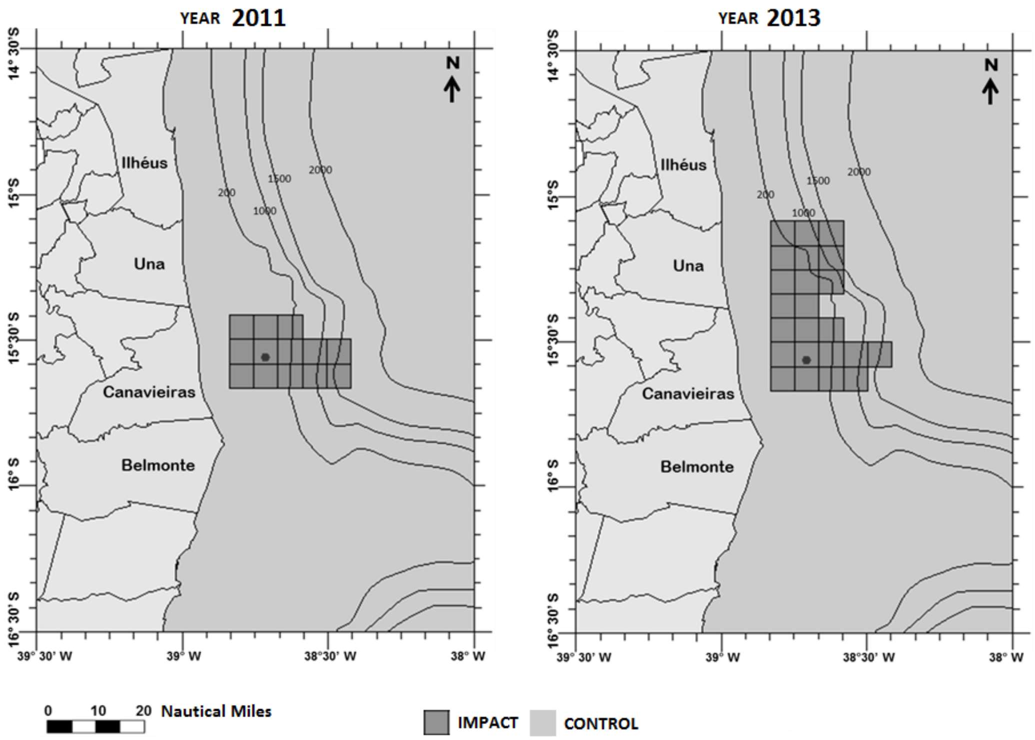

Figure 2: Spatial distribution of the impact area defined by the operations of platform supply vessels (PSV) in each year (2011 and 2013); and respective outside control area.

Models were performed by the application of analysis of covariance (ANCOVA) considering the total catch per landing (kg) as the response variate, the fishing effort as the covariate, and "period" (before or after the drilling operations) and "sites" (control area or impact area) as the factors. As the fishery monitoring is an observational study, several areas of capture with different distances from the drilling site were sampled. This analysis approach aims to detect some kind of disturbance (impact) through differences in the patterns of temporal variation of data populations (Green, 1993; Underwood, 1991, 1992 and 1994; Stewart-Oaten *et al*., 1986; Underwood, 1991; Martin *et al*, 2012).

Set all scenarios for impact assessment, landing samples were analyzed according to BACI method. Thus, catch and effort data for fisheries selected for evaluation were organized through monthly groups as demonstrated in Figure 3.

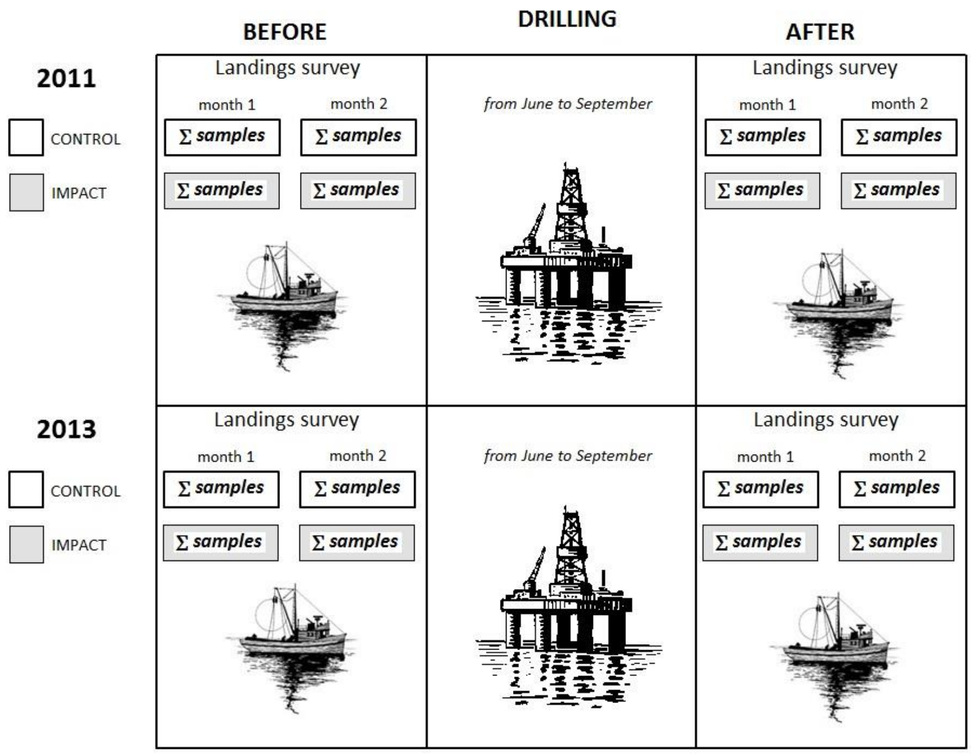

Figure 3: Balanced sampling design for application of analysis of covariance (ANCOVA) under before-after control-impact (BACI) approach. The data set was aggregated spatially and temporally according to the period (before or after the drilling operations in each year) and the area (control or impact).

The initial model applied to the evaluation of drilling impact on catch rates of fisheries selected in their respective scenario analysis was defined as follows:

$$Y_{ij} = \mu + \beta(X + \bar{X}) + \alpha_i + \tau_j + interactions + \varepsilon$$

where,

Y_{ij} = catch in kg aggregate monthly in the area I and period j, as the dependent variable;
μ = population mean (the dependent variable) common to all observations;
β = slope of the covariate effort (days at sea);
X = sea days, added monthly as a covariate on the fishing effort in the area ie period j;
$\bar{X}$= average fishing effort on sea days, for all observations;
α_i = effect of the area where the fishery factor was performed ("control" or "impact");
τ_j = effect of factor period which the fishery was made ("before" or "after" the drilling);
interactions = interactions between the interacting components covariate "X" factors "α" and "τ" to homogeneity test slope of the regression lines (parallelism); and among the factors ("area * period") to test about the impact hypothesis of drilling activity on catches ("control-impact before-after");
ε= random error assumed N (0, σ2).

Given the conclusive model for each case evaluation, the validation was performed by analysis of residues versus the estimated values (Huitema, 2011). The normality of the common waste was assessed using the Lilliefors test (Legendre and Legendre, 1998). The presence or absence of autocorrelation here was investigated by use of the Durbin-Watson test (Chatterjee and Price, 1991).

Results

The total number of samples obtained during the study period was 7,812 individual landings for all the municipalities. The number of samples was different due to the size of fleets and respective "time-at-sea" per trip for each location. Thus, larger sample numbers were observed in Ilheus (3146) and Canavieiras (2648), followed by Belmonte (1609) and Una (409). The fishing gears sampled on the whole area were handline, gillnet, trawl, longline and trap fishing. Regarding the individual capture values per landing, a positive skewness distribution was verified. It means that lower capture values (per trip) are usually more frequent than the values of high catches among artisanal fisheries landings. Most landings occurred for the class of up to 100 kg per trip, representing 60.2% of all landings recorded from April 2011 to December 2013.

Handline and gillnet were, respectively, the fishing gears which better provided information spread out over the fishing grounds and months of the year. However, the size of samples by unit of space and time was examined in order to select the best case to accomplish a balanced experiment. Due to the effect-size and the power of the analysis to detect an impact (Underwood and Chapman, 2003), the handline fishing was the selected case for the statistical modelling.

The dispersion of individual values capture and handline fishing effort has not shown a marked pattern of linearity between these variables (Figure 4A). This lack of linearity was somewhat expected, since some fishing data are usually vulnerable to various sources of environmental variation. The aggregation of data blocks at monthly sums for each area (control or impact) and time (before or after) resulted in a satisfactory linear relationship for applying the ANCOVA model (Figure 4B), since grouping the data blocks promotes homogeneity of variance.

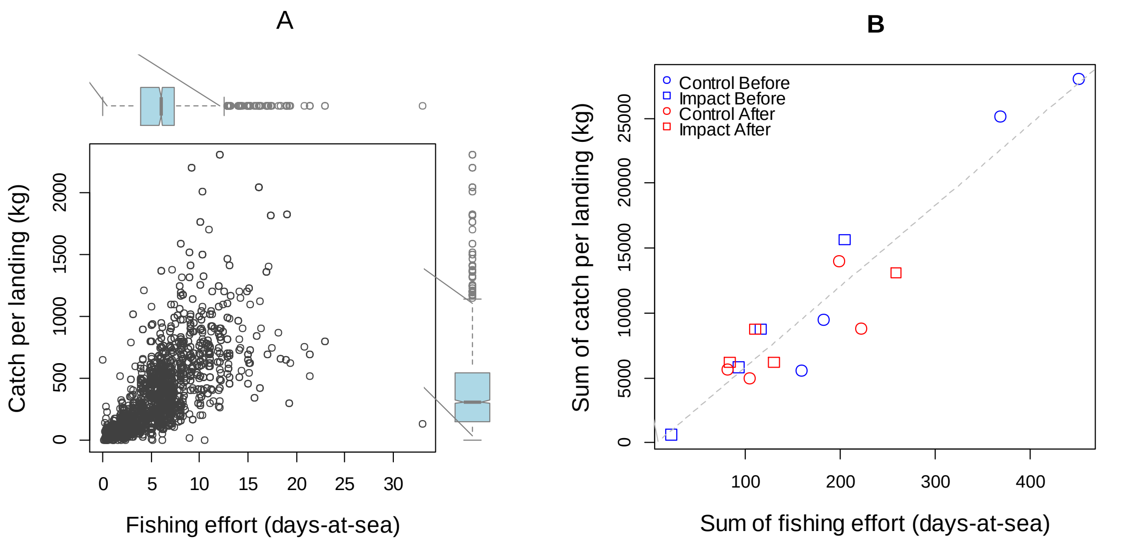

Figure 4: (A) Relationship between the individual values per trip catches (kg) and fishing effort (days at sea) by handline landing in southern Bahia between April 2011 and December 2013; boxplot of the distribution of their catch values (box on the right) and fishing effort (upper box). (B) Scatterplot between the categorized data capture (kg) and fishing effort (days at sea) aggregated monthly for all landings of handline fishing by period (before or after) and area (control or impact).

The homogeneity of variance test was pursued for each factor separately. The regression lines were parallel only for the area factor (p = 0 463), and not for the time factor (p = 0.027). Thus, after model simplification, the minimal model obtained kept the interaction between the covariate and the time factor (p = 0.015), preventing the progression of ANCOVA model since the assumption of homogeneous regression slopes was not met for this factor. However, the interaction between the area and period factors showed no significant effect in explaining variations on the handline catches (p = 0.306). This indicates that there was no evidence of drilling impact on handline fishing catches in this case. The Durbin-Watson test did not indicate the presence of autocorrelation for this minimal model (dw = 3.13; p = 0.967; dw> dU). Finally, the Lilliefors test indicated that the waste is actually normal (p = 0.589) Thus, the model was then validated.

Conclusions

The final model showed that the drilling operations in 2011 and 2013, here analyzed, were not a significant source of variation on handline fishing catches in Southern Bahia. There was no interaction between the factors "period" and "area" for this fishery gear. The results produced by the fishery monitoring program, and from respective impact assessment based on the quantitative approaches, were effective. They also provided useful information for a range of stakeholders in different instances, and at various levels of decision making.

The analysis of covariance model was showed as an appropriate tool for impact researches, as it allowed the evaluation of the effects of the *factors* corrected by the effect of *covariate* (Huitema, 2011); which increases the test power and hence the validity of the conclusions from the results (Stewart-Oaten et al., 1986; Underwood, 1991; Stewart-Oaten, 1996; Underwood and Chapman, 2003).

The construction of distinct impact scenarios of analysis, through the use of auxiliary information about the whole drilling operation, helped to reach the goal of improvement of the power of the test and the minimizing of the error type II (Green, 1993; Underwood and Chapman, 2003).

An intrinsic advantage of BACI approach is that it provides a balanced sampling design; which promotes a reducing of noise effects caused by environmental stochasticity, characteristic in fisheries data (Petrere, 1986). Besides, considering the observational nature of fishery landing surveys, the spatial and temporal distribution analysis of landing samples was the start point for the purpose of evaluation impact with greater power (Osenberg *et. al.* 1994).

In shorts, the applied analysis based on ANCOVA and BACI was a suitable alternative to a quantitative approach for description of "what happened" about the drilling impacts on handline fisheries. Given the need for information that can be useful for the decision-making processes, the design of a fishery monitoring program and its respective analysis outcomes (*i.e.* reports) could be more problem-driven. For this purpose, the guidelines for environmental license could be improved by defining what questions you really have to answer from fishery data set demanded to comply with the requirements.

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