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Evaluating the impact of seismic prospecting on artisanal shrimp fisheries

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Abstract

The constant need to discover new hydrocarbon deposits is causing the use of air-guns to become a very widespread method of seismic prospecting. However, there is still disagreement regarding their impact on the marine environment. This uncertainty is particularly severe in the case of shellfish, which account for a substantial share of commercial fisheries and seafood trade in many parts of the world. In this paper we report on the first study to explicitly assess the impact of seismic prospecting on shrimp resources. We measured bottom trawl yields of a nonselective commercial shrimp fishery comprising the Southern white shrimp, *Litopenaeus schmitti*, the Southern brown shrimp, *Farfantepenaeus subtilis*, and the Atlantic Seabob, *Xyphopenaeus kroyeri* (Decapoda: Penaeidae), before and after the use of an array of four synchronized air-guns, each with 635 in^3 of total capacity, 2.000 psi, and peak pressure of 196 dB (re 1 μPa at 1 m). Our results did not detect significant deleterious impact of seismic prospecting on the studied species, suggesting that shrimp stocks are resilient to the disturbance by air-guns under our experimental conditions.

Keywords: Seismic prospecting; Air-guns; Sound pollution; Shrimp trawling yields; Shrimp fisheries

1. Introduction

The use of air-guns is currently the most important method of seismic prospecting for hydrocarbon deposits (Wardle et al., 2001; Gausland, 2003). Their operation consists in the production of high-intensity sounds that are used to generate detailed descriptions of the ocean floor and its

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underlying geological formations (Gausland, 2003). The constant need to discover new oil fields caused this method to be extensively used in many parts of the world. For instance, by 1993, more than 335,000 linear kilometers were prospected this way in the Norwegian continental shelf alone (Anonymous, 1994).

Given their increasing prevalence, the environmental impact of the use of air-guns has received considerable attention in recent years (Falk and Lawrence, 1973; Larson, 1985; Traxler et al., 1993; Sverdrup et al., 1994; Wardle et al., 2001; Gausland, 2003; McCauley et al., 2003). In particular, several studies investigated the impact of seismic prospecting on marine fisheries. For instance, Skalski et al. (1992) found a 52.4% reduction in hook-and-line fishery of rockfish (*Sebastes* spp.) when aggregations were exposed to air-guns with peak pressures above 186 dB re 1 μPa. Engås et al. (1996) showed that intense seismic prospecting (maximum peak value of 253 dB re 1 μPa at 1 m) decreased the abundance and catch rates of cod and haddock in the area adjacent to seismic air-gun activity in Norway. On the other hand, Pickett et al. (1994) showed no effect of seismic surveys on the distribution of tagged bass, even under relatively high source level pressures (202 dB re 1 μPa Hz^{-1} at 1 m). Although more studies are still necessary to reach consensus regarding the impact of air-guns on fish populations of commercial interest, to the best of our knowledge, no study to date assessed the impact of the use of air-guns on shellfish fisheries.

Shellfish account for a substantial share of commercial fisheries in many parts of the world (Dall et al., 1990; Pérez-Farfante and Kensley, 1997), particularly in the West Atlantic (Costa et al., 2003). Therefore, an understanding of the impact of air-guns on commercial catch is important not only for the establishment of environmentally safe prospecting but also to develop sound legal standards for its practice (Dotinga and Elferink, 2000). This study was conducted as part of a larger, formal environmental impact assessment (EIA) effort, required by IBAMA, the Brazilian federal agency for environmental protection, to issue permits for seismic prospecting. In the context of this EIA, which pioneered assessment of seismic prospecting in Brazil, measuring impacts on the ecosystem was important not only for its own sake, but also due to the resulting social and economic impacts on the fisheries, and on the livelihood of fishermen inhabiting the affected area.

2. Methods

2.1. Study site and regional fisheries

Experiments were carried out between March 15 and April 2, 2002 in the Praia de Pratigi, Camamú bay, state of Bahia, Northeastern Brazil (between coordinates 13° 41′ 53.60″S, 38° 57′ 35.50″W and 13° 44′ 15.90″S, 38° 57′ 09.10″W, Fig. 1). Water depth in the experimental area varied from 2 to 15 m. The type of sediment in the ocean floor was quite heterogeneous, often including sandy, rocky and muddy substrates within a nautical mile's distance. Several small fisherman communities exploit shellfish in this area as their main source of income. The most economically important shellfish species in this region are the Southern white shrimp, *Litopenaeus schmitti*, the Southern brown shrimp, *Farfantepenaeus subtilis*, and the Atlantic Seabob, *Xyphopenaeus kroyeri* (Decapoda: Penaeidae).

2.2. Experimental design

Standard seismic prospecting requires accurate planning of the operation of the gun-boat and other support vessels. To that end, seismic *prospecting lines* are previously charted with precision, serving to guide both GPS positioning of hydrophone cables and the navigation of the gun-boat. Eight of such prospecting lines, spaced at least 1400 m from each other, were chosen to establish eight non-overlapping, contiguous *sampling sectors* in this study, as long as they remained within the area commonly used by local fishermen to obtain shrimp. Seven sectors run perpendicularly to the beach and one sector runs parallel to it (Fig. 1). Seven *transects* were established within each sector. The central transect was used by the gun-boat to shoot the air-guns. The remaining six

Fig. 1. Map of the study region showing the position of the experimental sectors. Six parallel hauls were conducted along the length of each sector, both before and after the passage of the gun-boat. See text for details.

transects were used by the fishing boat, a shrimp trawler. They were set three to each side of the central transect, 60–420 m from each other, depending on the sea conditions. The length of a sector corresponded to the distance covered by the trawler in 30 min at standard fishing speed—roughly 1500 m. It is important to note that the air-gun configuration used in our experiments was part of an actual commercial seismic prospecting program and therefore is representative of realistic impact conditions.

The assessment of the impact of seismic prospecting on shrimp catch rates was divided into three phases. On the first phase, starting around 6:00 AM of the first day, all six transects were run by the trawler to determine pre-exposure shrimp density levels. In order to standardize the sampling effort, otter trawls (6.2 m opening between doors during operation, 4.5 cm mesh size) were used in each transect for only 30 min. The trawl was towed by a 12.5 m boat equipped with an 18 hp inboard motor, a setup similar to the ones customarily used by local fishermen. On the second phase (day 2), air-guns were shot along the central transect, during the afternoon. The equipment for seismic prospecting consisted of four synchronized air-guns, each with 635^3 in of total capacity, 2.000 psi, and a peak pressure of 196 dB (re 1 μPa at 1 m), shooting every 12 s. On the third phase (day 3 in the first four sectors, day 4 in the last four sectors), the protocol described for the first phase was repeated to establish post-exposure shrimp density levels (Fig. 2). Phase 3 trawl hauls were conducted at least 31 m (one latitudinal second as read by the GPS) apart from the original transect to minimize the impact of the trawling procedure itself on post-exposure density levels.

Environmental conditions in the study region could vary over time, potentially introducing interference in the comparisons before and after exposure to air-guns, as well as between sectors. We minimized the effect of temporal variation in environmental conditions by conducting all phases in each transect either on consecutive days (transects 1–4), or only a few days apart (transects 5–8, Fig. 2). Trawl hauls were done in the morning, whereas air-gun shooting was done in the afternoon. This procedure maximized the independence between sectors. Environmental variables were measured in each haul, including surface and bottom temperature, surface and bottom salinity, water depth, wind speed and direction, local weather and ocean conditions.

Shrimp abundance was quantified as the weight of shrimp per hour and the number of specimens collected per hour of a mixed catch of the most important species of commercial interest in the Camamú region. Yields from different trawl hauls were placed in individual containers with ice and brought to the lab to be processed.

2.3. Statistical analyses

As expected from organisms with patchy spatial distributions, the data from our experiments were consistent with a negative binomial distribution, potentially causing biases when subjected to parametric statistical tests. Nevertheless, differences in shrimp abundance were compared using *t*-test for paired means given that the distribution of sample means fits the normal distribution (Saville, 1977). To increase the robustness of our conclusions, we also repeated the analyses with log-transformed data on the mass of shrimp per hour using the equation

$$y = \ln(x + 1),$$

where y and x are the transformed and the original values, respectively. Also, we repeated the analyses using a nonparametric statistic, the Mann–Whitney U test (Sokal and Rohlf, 1995). Analysis of covariance was used to compare abundances before and after exposure to air-guns after controlling for environmental variables.

3. Results

When combined across sectors, a total of 92 trawl hauls (from the 96 planned) were conducted, 46 before and 46 after the use of air-guns. (Some of the hauls could not be conducted due to adverse sea conditions.) *X. kroyeri* was by far the most abundant species, whereas *L. schmitti* was quite uncommon. Moreover, most hauls were

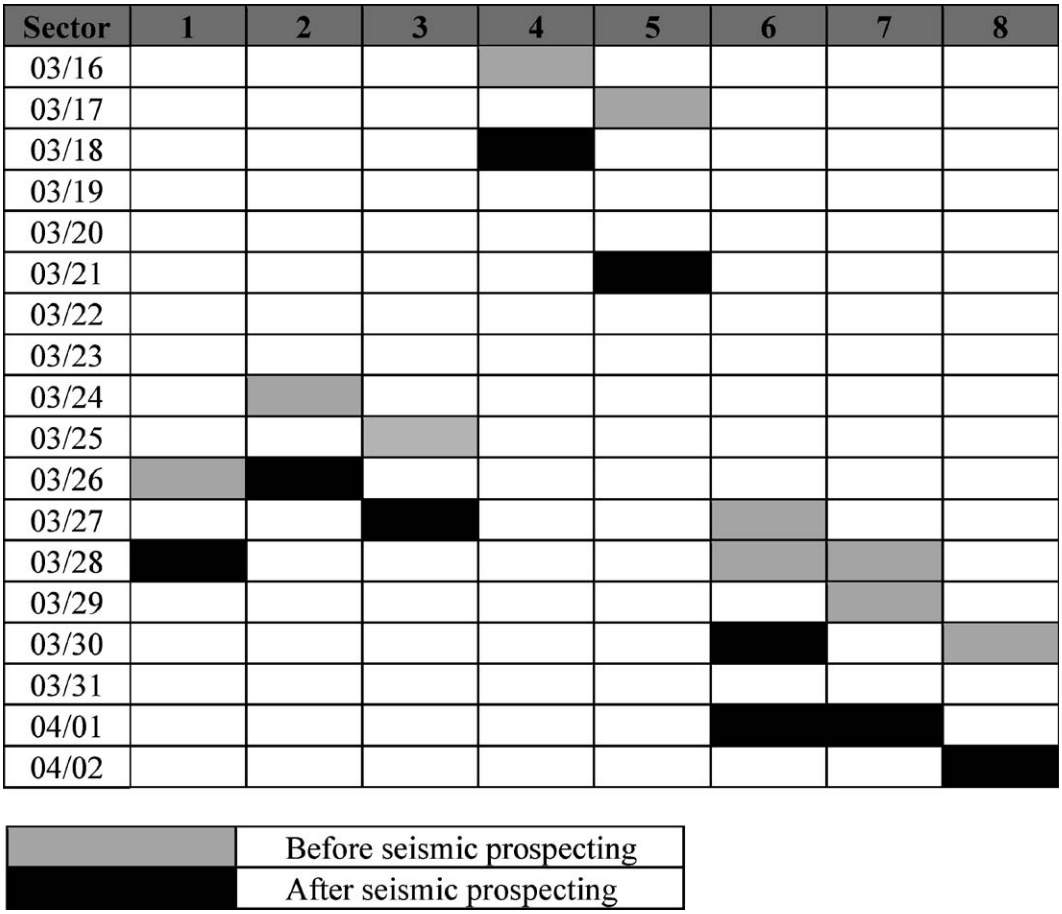

Fig. 2. Diagram describing the temporal order of trawl hauls. Columns 1–8 describe the dates when trawl hauls were conducted in each sector. (Column numbers represent the corresponding sectors depicted in Fig. 1.) For instance, in sector 1, hauls were conducted on March 26 and 28, before and after seismic prospecting in the sector, respectively. In some sectors (e.g. 6 and 7), sea conditions prevented hauls to be conducted on consecutive days as originally planned.

monospecific, prompting us to weigh all species together, performing the analysis for the total catch. Even if that represents a loss of biological information, results are still useful to assess socioeconomic impacts to the fisheries resulting from changes in total shrimp catch, which is ultimately the variable of interest to local fishermen.

No statistically significant decrease in density was detected after exposure to air-guns using both parametric and nonparametric tests (Table 1). This conclusion was confirmed by an analysis of covariance using wind speed and bottom temperature as covariates, given that those were the only environmental variables that differed significantly between phases 1 and 3 and also correlated significantly with shrimp catch (Table 2). A comparison of catch rates after air-gun use according to distance from the source (the central line of the sector) also showed no significant differences (Table 3).

4. Discussion

Our experiments failed to detect a statistically significant deleterious effect of seismic prospecting on shrimp fishing yields. To the best of our

Table 1
Results from experiments assessing the impact of air-guns on the average catch of shrimp by artisanal trawlers

Variable (unit)	N	Average before air-gun shooting (SE)	Average after air-gun shooting (SE)	p_1	p_2
Mass (kg/h)	92	0.91 (0.083)	0.79 (0.084)	0.475	0.496
Number of specimens (n/h)	92	297 (34.50)	281 (35.03)	0.819	0.482
ln (mass)	92	0.570 (0.040)	0.482 (0.046)	0.317	0.496
ln (number of specimens)	92	4.61 (0.22)	3.93 (0.27)	0.232	0.481
Total length *F. subtilis*	1333	6.6 (0.045)	6.6 (0.050)	0.933	0.813
Carapace length *F. subtilis*	1333	2.5 (0.019)	2.5 (0.020)	0.150	0.153
Total length *X. kroyeri*	1726	5.1 (0.025)	5.2 (0.0295)	0.110	0.055
Carapace length *X. kroyeri*	1726	2.0 (0,011)	2.00 (0.012)	0.838	0.706

Probabilities are based on the t-test for paired means (p_1) and the Mann–Whitney test (p_2).

Table 2
ANCOVA of experiments assessing the impact of air-guns on the average catch of shrimp by artisanal trawlers after controlling for environmental variables

Variable (unit)	N	Adjusted average before (SE)	Adjusted average after (SE)	p
Mass (kg/h)	92	0.886 (0.118)	0.812 (0.121)	0.670
Number of specimens (n/h)	92	275.83 (48.69)	302.08 (49.69)	0.713
ln (Mass)	92	0.563 (0.062)	0.489 (0.063)	0.421
ln (Number of specimens)	92	4.637 (0.351)	3.917 (0.358)	0.165

Average wind speed and bottom temperature were used as covariates. Wilks $\lambda = 0.927$, $F_{(4,87)} = 1.695$, $p = 0.158$.

Table 3
Mean catches of shrimp, and associated standard errors, by artisanal trawlers at various distances from the source after air-gun shooting

Variable (Unit)	N	Closest hauls (148 m)	Mid-distance hauls (496 m)	Farthest hauls (680 m)	p_1	p_2
Mass (kg/h)	46	0.58 (0.185)	0.78 (0.190)	1.03 (0.242)	0.307	0.675
Number of specimens (n/h)	46	182 (62.77)	288 (82.32)	379 (106.80)	0.267	0.533
ln (mass)	46	0.362 (0.107)	0.492 (0.112)	0.601 (0.125)	0.343	0.675
ln (number of specimens)	46	3.48 (0.60)	4.01 (0.69)	4.36 (0.71)	0.641	0.533

"Closest hauls" are those following transect lines 3 and 4; mid-distance hauls followed lines 2 and 5, and farthest hauls followed lines 1 and 6. Distances are averages of actual trawling distances from the central transect of each sector (see text for details). Probabilities are based on one-way analysis of variance (p_1) and the Kruskal–Wallis test (p_2).

knowledge, this is the first such test ever conducted on shrimp. Given that sampling sectors were contiguous in space, and sampling was done on consecutive days, these results suggest that shrimp populations did not move elsewhere when exposed to the disturbance of air-guns. If shrimps were indeed driven off prospecting grounds, such an effect was short-lived and spatially narrow, not affecting actual fishing yields. Even though shrimp have more limited dispersal capacities, this observation contrasts sharply with studies on migratory fish species such as cod and haddock, where seismic prospecting has been demonstrated to cause severe decreases in their abundance and catch rates in the area adjacent to seismic air-gun activity (Engås et al., 1996).

One important limitation of the present study is that we are unable to detect immediate effects, given that samples were collected 12–36 h after air-gun use. This experimental design may have precluded recognition of air-gun mortality within the stocks as they could have been quickly replenished with recruits from neighboring sites. However, no obvious changes in catch rates were observed during our study. Also, in a companion set of experiments designed to assess acute effects of exposure to air-guns on shrimp, Ostrensky et al. (2002) placed individuals of *L. schmitti*, *F. subtilis*, and *X. kroyeri* in cages that were placed at varying distances from the transect of the air-guns. No mortality was observed even when air-guns were shot at very close distances from the caged shrimp, in conditions even more severe than in the present study. A detailed study of their gonads, branchiae and hepatopancreas showed negligible histopathological damage that could be associated with exposure to the pressure wave from air-guns. Therefore, one can infer that the ecological impacts of the air-guns on shrimp populations, whatever they might be, seem not distinguishable from, nor add significantly to, fishing impacts themselves.

Future studies under more severe conditions are necessary to determine to what extent crustaceans are resilient to the types of pressures caused by seismic prospecting. Nevertheless, our results indicate that the use of air-guns for seismic prospecting—in the experimental conditions present in our study—does not cause a short-term decrease in artisanal shrimp fisheries. Moreover, seismic prospecting is a brief, non-repetitive disturbance, which suggests that long-term effects are also unlikely.

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