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ECOSYSTEMS

Impacts of bycatch from beach seining: a case study of a shrimp fishery in Brazil

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Abstract: It is commonly assumed that beach seining (BS) is more sustainable than bottom trawling because it involves non-motorized operations and limited fishing power. However, no scientific evidence supports this assumption. To address this gap, we evaluated the impact of beach seining, taking a small-scale shrimp fishery in northeast Brazil. Data collected monthly from December 2016 to November 2017 and in literature, were assessed (BS 31,001 individuals, 119 species, 37 families, and 19 orders; BT 6,031 individuals, 58 species, 20 families, and 14 orders). Beach seining demonstrated a lower proportion of bycatch (BS 1:2.3; BT 1:3.2), higher total shrimp catch (BS 87.2 t; BT 65 t), and greater species diversity than bottom trawling catches (BS 119; BT 58). Other aspects were closer associated with bottom trawling, such as the composition of dominant families (Sciaenidae and Pristigasteridae), the proportion of rare species (BS 30%; BT 24%) juveniles (BS 11g; BT 13g), the risk of species extinction, and the composition of ecological guilds. Despite their social significance, both fishing gears showed similar ecological indicators and adverse effects. The findings establish that the ecological concerns related to the impact of bottom trawling are also applicable to beach seine.

Key words: bottom trawl, small-scale fisheries, artisanal fisheries, food security, discard, ecological guild.

INTRODUCTION

Bottom trawl fisheries catch about 4.2 million tonnes/year of bycatch (non-target species), representing nearly 50% of global discard (FAO 2020). This bycatch is often composed of juveniles and vulnerable species (e.g., those with slow growth, low fecundity, and late maturity), such as turtles, sharks, and rays (Hall et al. 2000). As a result, motorised trawling is considered the great villain of biodiversity and sustainability (Thurstan et al. 2010, Rooper et al. 2011, Farriols et al. 2017).

In Brazil, fishery activity is of considerable socioeconomic importance. It employs over 1 million people, providing about US$ 3 billion annually in products and services (MPA 2024, FAO 2010-2015). Trawling is mainly carried out in shallow waters along the entire coast and predominantly targets penaeid shrimps (Costa et al. 2007, Lopes 2008, Silva-Júnior et al. 2019). This fishery comprises three types of fleets (industrial, semi-industrial and artisanal), with differences in vessel size, technology, and catch volume (Dias-Neto 2011, Lira et al. 2021).

The bycatch of trawl fisheries in Brazil is estimated at 487,450 tonnes (453,900 tonnes of shrimp trawling and 33,550 tonnes from non-shrimp trawling), which is nearly 60% of the total annual Brazilian marine catch (842,150 tonnes/ annually) and much higher than the global average (40%) (Davies et al. 2009).

Studies indicate considerable variability in the proportion, diversity, and number of vulnerable and/or threatened species captured as bycatch by these fisheries (Vianna & Almeida 2005, Dias-Neto 2011, Silva-Júnior et al. 2019). However, bycatch data from artisanal fisheries remains scarce in Brazil and elsewhere (Silvano & Begossi 2012, Carvalho et al. 2020).

Artisanal shrimp fishery operations occur throughout the Brazilian coast, especially in the country's northeast region. This fishery has a low level of technology, low storage capacity, and small catches, involving small, motorised and/or non-motorised boats (Dias-Neto 2011, Lira et al. 2021). Due to restrictions regarding motorised trawling in coastal areas (applied independently in each Brazilian state) (Santos 2010), beach seining is an option for ensuring the employment, income, and livelihood of various communities (Nascimento et al. 2020). Such is the case for the shrimp fishery operating in the Lucena region in northeast Brazil.

Beach seining is considered to have a lower ecological impact, despite the lack of studies on many aspects of this modality (Passarone et al. 2019). However, the low operational cost and difficulties in monitoring and regulating beach seining can lead to high fishing efforts with severe consequences in terms of sustainability (FAO 2011).

Artisanal fisheries employ approximately 90% of workers in the fishing industry in developing countries and account for more than half of the catches, mainly destined for human consumption (World Bank 2012). Although the bycatch from these fisheries has no commercial value, it is commonly consumed and constitutes the primary source of protein for many local communities (Tischer 2003, Pinheiro & Martins 2009, Nascimento et al. 2019). Thus, artisanal fisheries play a crucial role in nutrition and food security as well as employment and income, constituting a key industry for achieving the sustainable development goals (SDGs 1, 2 and 14) proposed by the United Nations (2015) and meeting the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries (Westlund & Zelasney 2019).

The primary aim of the present study was to assess the impact of non-motorised artisanal beach seining in northeast Brazil and discuss trade-offs between fishing's economic efficiency and environmental and social costs. Furthermore, an additional objective was to establish metrics that could effectively quantify and scale the various impacts caused by this fishing modality.

MATERIALS AND METHODS

Study area

This study was conducted in the coastal region of the municipality of Lucena located in the state of Paraíba in northeast Brazil (Fig. 1). The region receives large nutrient inputs from the Paraíba do Norte and Miriri Rivers (Assis 1977), which contribute to the formation of a muddy substrate near the coast, favouring the development of penaeid shrimp populations (Santos 2010). The sea average temperature ranges from 21.4 to 29.6°C annually and precipitation is well distributed throughout the year, with maximum rainfall from April to July and an annual average of 1800 mm (Nunes & Rosa 1998, Neves & Neves 2010, Craveiro et al. 2019). Approximately 148 km^2 of Environmental Protection Areas are found near the study area: Barra do Rio Mamanguape National Park (Decree 924/1993, Brasil 1993) and Areia Vermelha State Marine Park (Decree 21.263/2000, Paraíba, 2000).

Data collection

Two distinct sources of data were utilised. The primary source (i) comprised data collected from

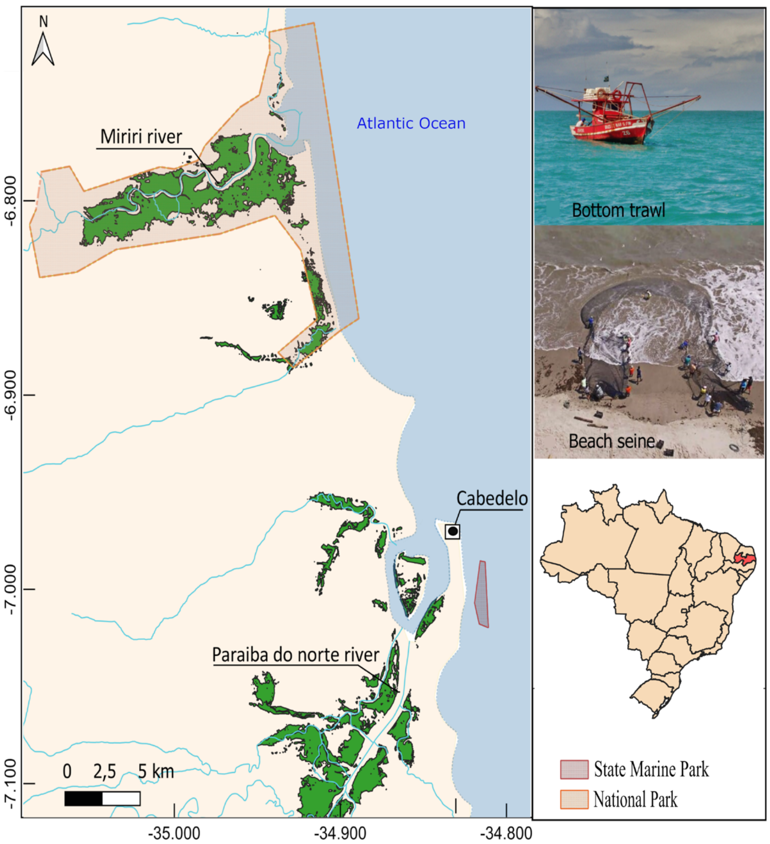

Figure 1. Study area, municipality of Lucena, state of Paraíba, northeast Brazil, highlighting Barra do Rio Mamanguape National Park and Areia Vermelha State Marine Park.

artisanal beach seining (BS) targeting shrimp and the secondary source (ii) was the result of previous studies on artisanal bottom trawling (BT) in the study area.

Primary source

Samples were collected monthly from December 2016 to November 2017, from de commercial catches using a beach seine net (horizontal x vertical dimensions: 120 × 6 m; body mesh: 20 mm, cod-end mesh: 15 mm, length of ropes: about 500 meters). Two seining operations were performed monthly, each lasting 50 min, except for May, when weather conditions made sampling impractical, and June when only one sampling campaign could be performed. The total sampling time was 17.5 hours. The maximum depth in the seining area was 6.0 metres, and the maximum distance from the shore was 500 meters.

The shrimp total weight was measured *in situ*. In this study, we focused on the ichthyofaunal bycatch. Larger samples (> 30 kg) were weighed, and only a random subsample (30 kg) was sent to the laboratory for further analysis. Subsampling was conducted only in February and April. In the laboratory, the specimens were frozen, identified, and measured [total length (TL in cm) and weight (TW in grams)].

Secondary source

The study conducted by Nunes & Rosa (1998) was used to compare BS and BT operations. The paper describes BT in the municipality of Lucena from September 1994 to September 1995 (17 sampling campaigns) after the banning of this activity imposed by ordinance N° 833/1990 of the Brazilian environmental agency Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA 1990).

This legislation was created to resolve conflicts between adjacent communities for fishing areas, as fleets moved into the area during the closed season in other states, thereby reducing beach seine catches. Sampling was conducted out during seventeen trawling operations, each lasting 30 min (total 8.5 h), with a net measuring 14.0 m in length (body mesh: 25 mm), similar to that used in the commercial fishery.

Data analysis

The two fishing modalities (BS and BT) were compared concerning the following attributes:

Proportion (fishes to shrimp) and bycatch composition

The proportion of ichthyofauna and bycatch was calculated monthly and for the entire period (one year). The bycatch composition was described, for both fisheries in terms of the number of specimens, species richness, and taxonomic composition. The average weight of individuals caught by BS was based on our samples, while the average weight of specimens caught by BT was based on data by Nunes & Rosa (1998) (total number of individuals/total biomass caught). In addition, a chi-square test was applied to analyse shrimp proportion between fishing methods. The analysis used the R environment (R Core Team 2020).

Risk of species extinction

The conservation status of the species was determined based on the Red List of the International Union for Conservation of Nature (IUCN) through a regional assessment conducted by the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio 2018). The seven categories within this classification were 1- critically endangered (CR), 2- endangered (EN), 3- vulnerable (VU), 4- nearly threatened (NT), 5- least concern (LC), 6- data deficient (DD), and 7- not assessed (NA).

Feeding mode functional group and estuarine use functional group

The ichthyofauna was also evaluated according to the functional groups [feeding mode functional group (FMFG) and estuarine use functional group (EUFG)] proposed by Elliot et al. (2007). Based on the FMFG, species were classified as zooplanktivores (ZP), detritivores (DV), herbivores (HV), omnivores (OV), piscivores (PV), and zoobenthivores (ZB). Using the EUFG, species were classified as marine migrant (MM), marine straggler (MS), or estuarine (ES). Whenever possible, regional literature was prioritised in the categorisation of the species. Species without habitat use and feeding strategy information were classified as “not assessed” (NA).

Estimated total catch of shrimp and bycatch

The estimated shrimp catch by beach seine (SCBS) was based on a study by Nascimento (2020), who monitored five of the eight nets operating in the local fishery, observing a catch of 54.5 tonnes. The estimated bycatch was calculated using the SCBS value and the shrimp-to-bycatch proportion obtained here. The shrimp catch by bottom trawling (SCBT) was estimated using official reports from MMA(1995) (landings per state) and based on the estimation by Moura (2005) (proportion of catches from each municipality). The BT bycatch was estimated using the SCBT value and shrimp-to-bycatch proportion obtained by Nunes & Rosa (1998).

RESULTS

The proportion of shrimp to fish caught by BS was 1:2.3 [1:12.51 ±22.34 kg (mean± SD)].

[199 kg of shrimp [18.15 ±30.44 kg (mean± SD)] and 462 kg of fish [42.01 ±24.81 kg (mean± SD)]. This ratio was 1:3.2 for BT (Nunes & Rosa 1998), corresponding to 0.9 kg of extra bycatch caught by BT for each kilogram of shrimp caught. In both studies, monthly variations were found in the proportion of shrimp and bycatch. The chi-squared test results indicate no significant differences observed in the proportions of shrimp and bycatch between the fishing modalities ($p > 0.05$). The lowest shrimp catch values were found in February for BS and January for BT, whereas the highest shrimp catches were recorded in August for both fisheries (Fig. 2).

A total of 31,001 individuals, 119 species, 37 families, and 19 orders were caught in the BS modality, whereas the catch using the BT modality comprised 6,031 individuals, 58 species, 20 families, and 14 orders (Supplementary Material - Table SI). Sciaenidae was the most highly represented family in both fisheries. The most abundant species were relatively distinct: BS = *Opisthonema oglinum* (21%), *Cetengraulis edentulus* (16%), and *Pellona harroweri* (13%); BT = *P. harroweri* (21%), *Larimus breviceps* (11%), and *Stellifer stellifer* (11%). Forty-four species were caught by both fisheries. The estimated mean weight of the individuals caught by BS and BT was similar (BS = 10.83 g (SD ±22.86); BT= 12.77 g).

Both fishing modalities caught similar proportions within each IUCN category: least concern (BS = 85%; BT = 89%), data deficient (BS = 10%; BT = 7%), and near threatened (BS = 4%; BT = 2%). Only one species in the endangered category (*Pogonias cromis*; BT) was caught (Fig. 3).

Regarding the FMFG, species richness was similar between the two modalities. Zoobenthivores (BS = 58%; BT = 58%), piscivores (BS = 25%; BT = 24%) and zooplanktivores (BS =

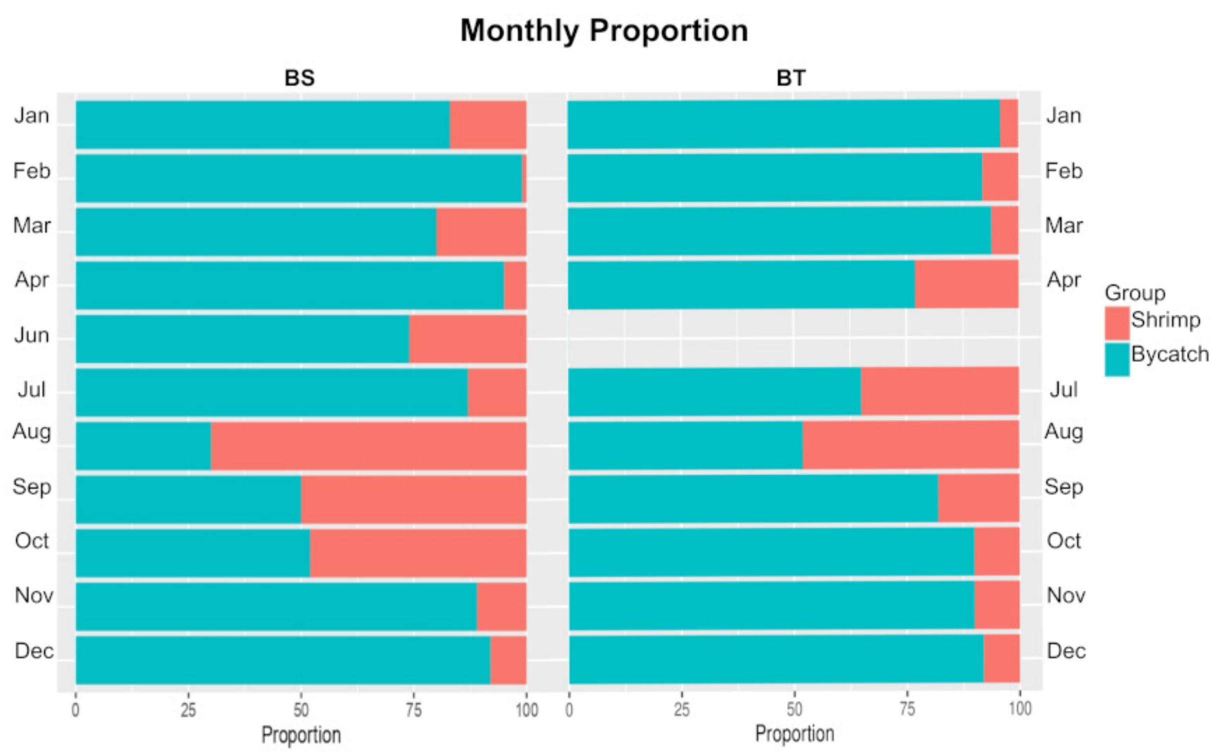

Figure 2. Monthly proportion of shrimp and bycatch caught by beach seining (BS) from December 2016 to November 2017 and bottom trawling (BT) from September 1994 to September 1995 (Nunes & Rosa 1998) in Lucena, state of Paraíba, northeast Brazil.

12%; BT = 16%) were predominant (Fig. 4). Species richness was also similar when considering the EUFG, in which marine migrants as the most representative category (BS = 53%; BT = 61%), followed by marine strangler (BS = 35%; BT = 29%) and estuarine (BS = 12%; BT = 11%) (Fig. 5).

Based on the data from Nascimento et al. (2020), the estimated shrimp weight in the total BS catch was 87.2 tonnes in 2016 and the bycatch estimated based on the proportion reported by the authors was 200 tonnes. Using data from 1990, these figures were 65.6 tonnes of shrimp and 210 tonnes of bycatch in the total BT catch (Fig. 6).

DISCUSSION

The catch proportions observed for both modalities (BS = 2.3: 1; BT = 3.2: 1) were similar to those reported for artisanal shrimp fisheries in other states of northeast Brazil (e.g., 5: 1 in Piaui and 3.28: 1 in Ceará) (Braga et al. 2001, Dias-Neto 2011) and lower than those reported for industrial fisheries in the southeast region between the states of Rio de Janeiro and São Paulo (10.5: 1) (Vianna & Almeida 2005) and the northern region between the states of Pará and Amapá (4.1: 1) (Paiva et al. 2009). High bycatch ratios were also reported in other developing countries, e.g., Sri Lanka (11: 1), India (4: 1), Venezuela (9: 1), Kuwait (15: 1), and Ghana, where these ratios range from 9: 1 at night to 23: 1 in daytime catches (Alverson et al. 1994, Ye et al. 2000, Pramod & Pitcher 2006, CMFRI 2006, Marcano 2006). According to Alverson et al. (1994), shrimp trawling in Brazil captures an average of 9.3 kg of bycatch for each kg of shrimp (9.3: 1) (Davies et al. 2009). However, the proportion varies among the different types of fisheries, as shown above.

Species richness was greater with the BS modality (119 species) compared to BT for the same locality (58 species) (Nunes & Rosa 1998) and also greater than that reported for artisanal fisheries in other states of northeast Brazil, e.g., Pernambuco (51 species), Ceará (97 species), Sergipe (89 species), and Bahia (33 species) (Braga et al. 2001, Pinto-Nascimento et al. 2007, Barreto et al. 2018, Silva-Júnior et al. 2019). The

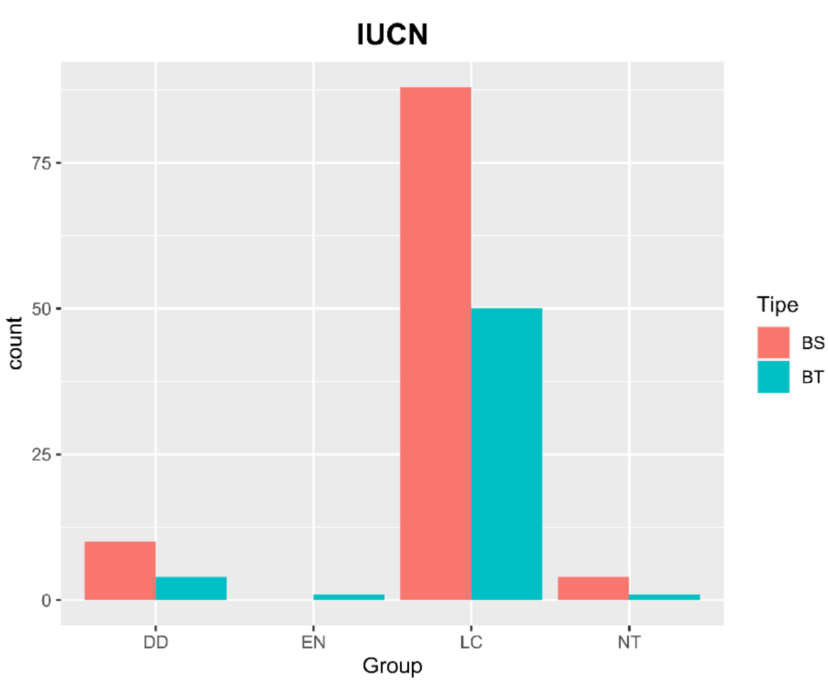

Figure 3. Catch composition of species groups caught by beach seining from December 2016 to November 2017 and bottom trawling from September 1994 to September 1995 (Nunes & Rosa 1998) in Lucena, state of Paraíba, northeast Brazil. Based on IUCN data deficient (DD), least concern (LC), near threatened (NT), and endangered (EN).

number of species caught by BS was also higher than that reported for industrial fishing in Brazil (e.g., 91 species between the states of Rio de Janeiro and São Paulo, 69 species between the states of Pará and Amapá, and 88 species in the state of Rio Grande do Sul) (Haimovici & Mendonça 1996, Vianna & Almeida 2005, Lima et al. 2021). High diversity caught by beach seining has also been reported in other countries, such as South Africa (119 species), Australia (71 species), and Colombia (59 species) (Gray et al. 2001, Beckley & Fennessy 1996, Plazas-Gómez et al. 2018).

Three reasons may explain the relatively high fish species richness found for BS. Firstly, the net employed had a large size (120 m) and smaller mesh (body: 20 mm, cod end: 15 mm) compared to a motorised trawling net, leading to less selectivity. Secondly, the BS fishing area includes both the surf (two metres in depth) and deeper (six metres) zones, which increases the number of habitats exploited and, thus, the number of species collected. Indeed, high species richness (i.e., up to 165 species) is commonly reported for surf zones, since species use this habitat as feeding grounds, refuge from predators, spawning sites, and nursery grounds (Olds et al. 2017). Lastly, the adjacent ecosystems may have recovered after the ban on BT. A similar trend was observed in the boreal Northwest Atlantic, where the ban on trawling and gillnetting led to significant changes in biological communities, benefitting fishing communities, fishery production, and the biodiversity conservation (Kincaid & Rose 2017).

The families Sciaenidae and Pristigasteridae were the most representative in the catches of both fishing modalities and individuals had a similar average weight (BS = 10.83 g; BT = 12.77 g), which may indicate that both types of gear catch a similar proportion of juveniles. High catches of Sciaenidae are common in BT fisheries in northeast Brazil (Santos 2008, Barreto et al. 2018, Silva-Júnior et al. 2019). Species of this family are distributed in shallow waters of the continental shelf near the mouths of large rivers, mangroves, saline lagoons, estuaries, and bays over mud, sand, or gravel at depths ranging from 1 to 25 metres (Menezes 1980). The most abundant species in the area (*O. oglinum, C. edentulus, P.*

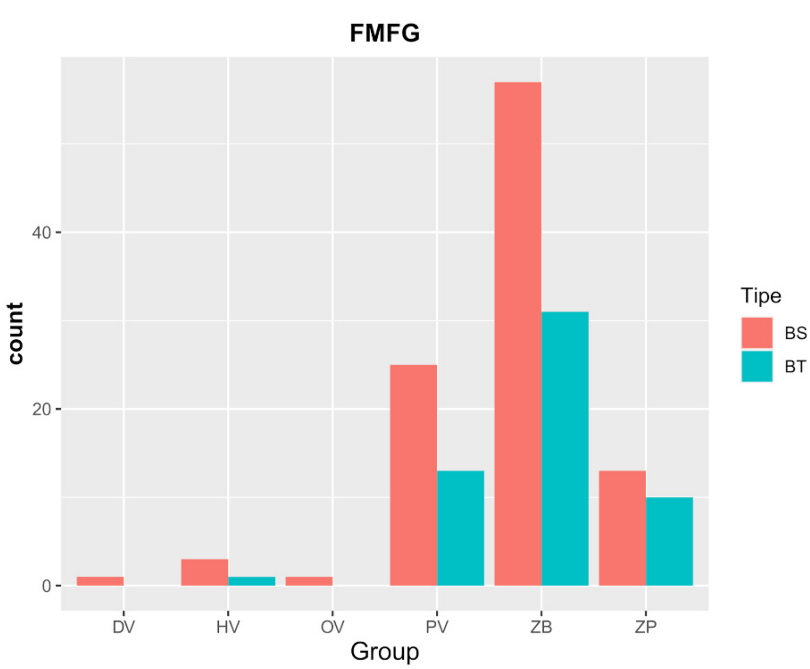

Figure 4. Catch composition of species groups caught by beach seining from December 2016 to November 2017 and bottom trawling from September 1994 to September 1995 (Nunes & Rosa 1998) in Lucena, state of Paraíba, northeast Brazil. Based on feeding mode functional group (FMFG), proposed by Elliot et al. (2007): detritivore (DV), herbivore (HV), omnivore (OV), piscivore (PV), zoobentivore (ZB) and zooplanktivore (ZP).

harroweri, L. breviceps, and *S. Stellifer*) exhibit an "r-strategist" behaviour: small body size, high reproductive capacity, fast growth, and early sexual maturation (Passarone et al. 2019, Santos et al. 2021, 2022, 2023).

The two modalities had similar proportions regarding the composition of the feeding and estuarine use functional groups. The most frequent feeding groups were zoobenthivores (BS = 58%; BT = 58%), piscivores (BS = 25%; BT = 24%), and zooplanktivores (BS = 12%; BT = 16%). A high biomass of zoobenthivores was also reported in the state of Pernambuco (Ferreira et al. 2019) near the study area and may be associated with the high biomass of benthic organisms in muddy areas near the mouths of rivers (Stegmann et al. 2019). Moreover, the position of these species in the water column makes this group more vulnerable to trawling (Silva-Júnior et al. 2013).

Regarding the estuarine use functional group, marine migrant (BS = 53%; BT = 61%), marine straggler (BS = 35%; BT = 29%) and estuarine (BS = 12%; BT = 11%) species were predominant. Such similarities in composition may be explained by the proximity of the sampling areas (approximate distance of 800 m) and similar depths (BS = up to 6.0 m; BT = 2.0 to 6.5 m). It is therefore reasonable to presume that these species move between areas seeking shelter and food. Consequently, both modalities would have similar impacts on species that use the coastal area for breeding, shelter, and feeding. Despite the crucial role of connected coastal habitats in the life cycle of several species, management actions are usually restricted to adjacent coastal habitats (Olds et al. 2017, Pelage et al. 2021a, b).

In both modalities, most species caught were categorised as "least concern" (BS = 85%; BT=89%). *Pogonias cromis*, an endangered species that uses coastal areas as its preferential habitat, was caught by BT, but not found in the most recent catches by BS. *Hyporhamphus unifasciatus, Lutjanus jocu, Gymnura micrura* (caught by BS), and *Bagre bagre* (caught by BS and BT) were categorised as "near threatened". Except for *H. unifasciatus*, these species are highly vulnerable due to their intrinsic characteristics of slow growth,extensive longevity, and low

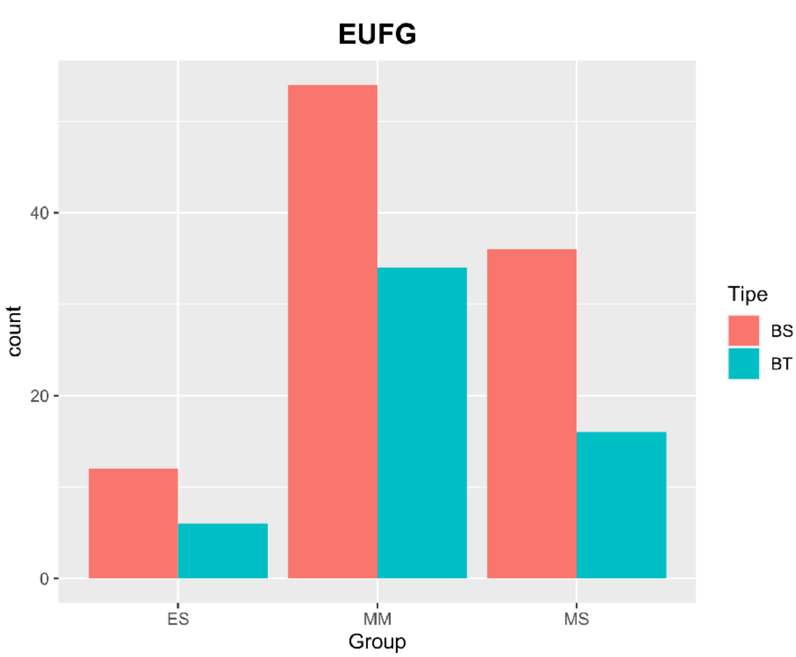

Figure 5. Catch composition of species groups caught by beach seining from December 2016 to November 2017 and bottom trawling from September 1994 to September 1995 (Nunes & Rosa 1998) in Lucena, state of Paraíba, northeast Brazil. Based on the estuarine use functional group (EUFG) proposed by Elliot et al. (2007): estuarine (ES), marine migrant (MM), and marine straggler (MS).

reproductive rate and should be prioritised for conservation and management actions (Rezende & Ferreira 2004, Bornatowski et al. 2012, Pinheiro-Sousa et al. 2015). *H. unifasciatus and L. jocu* are commercially important and the latter has been overexploited locally since the 2000s (Frédou et al. 2009a, b). Many species were categorised as "data "deficient (BS = *Gymnothorax funebris, Aetobatus narinari, Mugil curema, Mugil curvidens, Pseudobatos percellens* and *Sphoeroides testudineus*; BS and BT = *Menticirrhus americanus, Menticirrhus littoralis, Ophioscion punctatissimus,* and *Bagre marinus*). According to Ordinance 43/2014 of Ministério de Meio Ambiente [Environmental Ministry] (MMA 2014), this category is considered as a priority for research on conservation status.

The estimated catch of the target species was about 25% higher in the BS modality (shrimp: BS = 87 tonnes; BT = 65 tonnes), whereas bycatch estimates were similar (BS = 200 tonnes; BT = 210 tonnes). Therefore, BS could be a more profitable option, as it leads to a higher catch of the target species and has lower operational costs related to vessel acquisition, maintenance, and fuel. Conversely, BS requires more manual labour, as approximately twelve people are needed for each fishing operation. However, most of these people are members of low-income coastal communities and work in exchange for bycatch, lowering operating costs.

In a data-poor context, this study may have some setbacks related mainly to the temporal difference between the two types of gear and the availability of common and detailed data (monthly or per set for motorized fishing), which limits the use of comparable attributes and tests. Given the temporal differences between the conducted studies, it is important to acknowledge that direct extrapolation or data comparison should be cautiously approached . Nonetheless, our findings reveal that, despite being a manual fishing method, BS also exerts

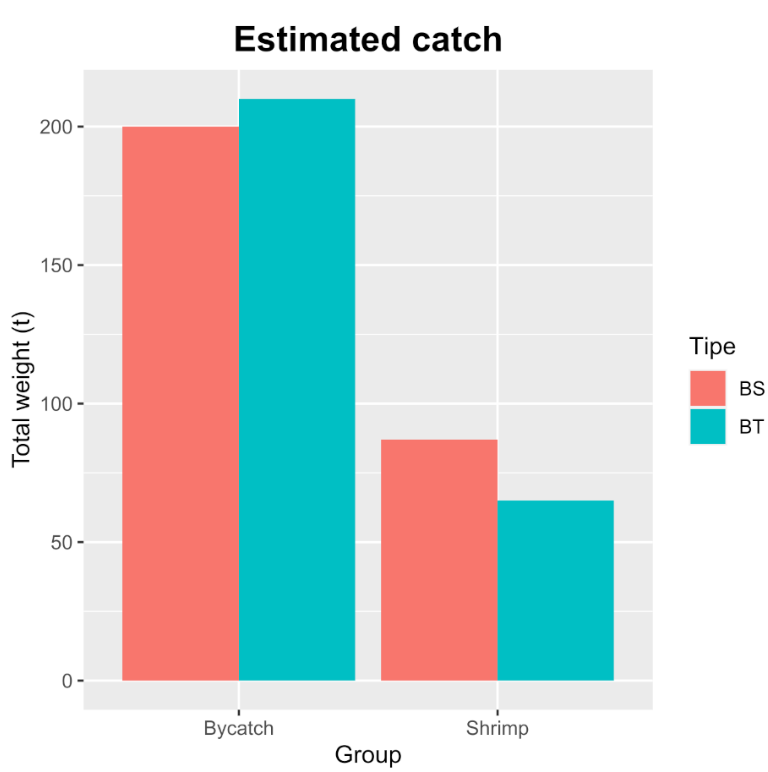

Figure 6. Estimate catch of shrimp and bycatch (t) by beach seining and bottom trawling (Nunes & Rosa 1998) in Lucena, state of Paraíba, northeast Brazil.

significant environmental impacts that cannot be ignored.

Properly comparing the two fishing modalities requires the consideration of the three dimensions of sustainability (ecological, economic, and social) to design management policies in line with the local situation. As highlighted in this study, the ecological concerns raised for BT, such as the high proportion of bycatch, harvesting of vulnerable species, high catches of juveniles, and high ichthyofaunal diversity, are also valid for BS. Indeed, both modalities run the risk of growth overfishing (stock depletion due to harvesting young fish before reaching a reasonable size), especially for vulnerable species. Thus, BS has a considerable ecological impact, despite not causing the fuel pollution and substrate impact inherent to the BT modality.

However, BS has advantages over BT. In addition to fishers' participation, BS also involves the local population in the operational activities, wherein they receive the bycatch in exchange. This ensures that the entire bycatch is utilised for consumption within the local community, thus contributing to enhanced food security and minimizing one of the major environmental concerns, the ecosystem imbalance that could be caused by bycatch discard. Thus, BS may be a better practice for achieving food security goals, except where the BT fleet operates close to shore. Furthermore, donations or low sales prices have also been reported for this modality (Tischer 2003). Additionally, there is no evidence of an increase in fishing efforts over the years for this region (Nascimento et al. 2019), which is likely due to the lack of incentive for the involvement of younger generations as they often encounter infrastructure challenges and financial instability.

It is essential to recognise the social, political, and economic aspects in both cases and address factors that place fishers and other actors involved in the value chain in situations of vulnerability (Nascimento et al. 2019, Lira et al. 2021), such as i) the low level of education notably due to the distance from schools; ii) the lack of infrastructure for fish storage and processing, which leads to the loss of part of the production and decreases the quality of the product; iii) the inequality in the power relationships between fishers and intermediaries, which prevents a fair negotiation of the price; iv) the decrease in the value of small-scale fishing products due to increasing competition from shrimp farming; and v) environmental problems, such as deforestation and the pollution of mangroves caused by shrimp farming and other activities. Hence, the social aspect of this fishery and many other small-scale fisheries in developing countries should not be overlooked.

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SUPPLEMENTARY MATERIAL

Table SI.

How to cite

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