

Spatial Characterization of Artisanal Fisheries in Puerto Rico: Geographic Information Systems (GIS) Approach for Assessing the Regional Effort and Landings

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ABSTRACT

Commercial fisheries in Puerto Rico are dominated by small-scale fishing operations that deploy a variety of gear types in multiple, tropical fisheries across the island's diverse oceanic and benthic habitats. While past fishery censuses and targeted studies have evaluated the demographic, economic, and social characteristics of these fisheries, less effort has focused on the spatial dimensions of the fisheries, namely the port fishing ground linkages and the regional distribution of fishery effort. This project conducted over 350 in-person interviews with commercial fishers across coastal municipalities in Puerto Rico, and it collected data on spatial use profiles by species, gear, and effort. The project, completed over five months in 2009, evaluated how fishers in different regions distribute their effort by gear and species, as well as how socio-demographic and economic characteristics are linked to areas fished. The project's spatial findings are expected to provide important insights on the geographic organization of landings and effort and to assist in the identification of key fishing area port linkages.

KEY WORDS: Commercial fishing, Puerto Rico, GIS, benthic habitats, socioeconomics

Caracterización Espacial de la Pesca Artesanal en Puerto Rico: Sistemas de Información Geográfica (SIG) Enfoque para Evaluar el Esfuerzo y Captura Regional

PALABRAS CLAVE: Pesca artesanal, Puerto Rico, SIG, socio-economía

Caractérisation Spatiale de la Pêche Artisanale à Puerto Rico: Systèmes d'Information Géographique (SIG) Approche pour Évaluer l'Effort et Capture Régional

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INTRODUCTION

Puerto Rico has a diverse, small-scale commercial fishery consisting of over 1,100 participants who utilize a variety of gears along the island's four major coastlines and around the smaller islands located off the eastern and western coasts (Matos-Caraballo 2004). The fisheries are organized around fishery centers or fish houses, called villas pesqueras, or along fishing villages and population centers. The fisheries are characteristically small-scale in nature, comprised of owner-operators who utilize small vessels with limited horsepower and who land low quantities on average of a variety of species (Griffiths and Valdés-Pizzini 2002). Fishers from certain ports off the main island, especially those located in the southwest quadrant, have larger vessels and land larger quantities (of mainly deep-water snappers) (Tonioli and Agar 2009), while high liners in ports may land large quantities of mainly queen conch (*Strombus gigas*), but these fishers represent the exception in what is effectively a small-scale fishery.

The island's fishery has been characterized in terms of its economic, social, and cultural dimensions in a variety of snapshot and longitudinal studies. Additionally, the Puerto

Rico Department of Environmental Resources (DNER) has operated a reporting and sampling program, as well as a periodic fishery census (Matos-Caraballo 2004). By contrast, the fishery's spatial dimensions, here defined as the areas utilized by the fishery participants and the combination of biophysical and socioeconomic factors that influence spatial effort, have been largely understudied. Agar et al. (2008) evaluated the spatial dimensions of the region's fish trap fishery and determined the areas targeted by the gear type, and Tonioli and Agar (2009) identified fishing areas associated with southwestern Puerto Rico deep-water snapper fishers in relation to impacts from marine reserves; however, these and other studies only considered particular areas and/or specific gear types.

Conducted as part of a larger costs and returns survey effort, the present study represents among the first to determine the Puerto Rico commercial fishery's spatial dimensions. By utilizing a participatory mapping approach that involved direct and detailed input from the fishers interviewed, the study sought to identify fishing grounds for each of the four major gear types (line, net, trap, and dive gears), and to evaluate the relative importance of gear types by region, fishery, and benthic characteristics. The

study also sought to develop a baseline for effort across regions, such that future research could identify spatial changes and their relationship to fishery abundance, management effects, and socioeconomic conditions.

METHODOLOGY

The study methodology was implemented in two major stages: The first stage consisted of field data collection, and the second stage included all post-data collection mapping, ground truthing, and (Geographical Information Systems) GIS analysis. The field data collection stage took place from June to November 2009, followed by data entry, verification, and analysis. The mapping and GIS analysis stage overlapped with data entry and analysis, and it was completed by early 2011 (Koeneke 2011).

Field data collection followed a sampling procedure based on a regional, random sample, where a proportional sub-sample was randomly selected for each of the four coasts/quadrants in Puerto Rico (Figure 1). The field team completed a total of 352 in-person interviews, collecting information on socio-demographics, on economic investments and costs, on trip costs and revenues, and on areas and frequency of effort (by gear type and species). Spatial use data were gathered from fishers using a participatory

mapping approach, where participants were first shown a grid map that included main ports, key benthic features, and management areas; after it was determined that fishers could orient themselves, they were asked to identify specific fishing areas by gear type (Figure 2). Fishers were given the opportunity to encircle or shade in fishing areas or were shown the areas they indicated to ensure that these corresponded to their fishing grounds.

Post-data collection mapping activities consisted of spatial data entry, where the fishing grounds by gear types as identified by each respondent were entered into a Geographical Information Systems (GIS) database (Figure 3). Layers comprised of gear types (by total participants and effort frequency) were created to identify fishing grounds as used by the four major gear types, consisting of more than 20 gear subtypes. Effort frequency was calculated by multiplying each cell in the individual gear maps by the corresponding number of total annual trips for each individual fisher. The resulting spreadsheet and GIS operation reflected the number of total possible annual trips for each particular gear type. The individual gears were then grouped by gear category, creating maps describing the pattern of use for each gear category, with the value of each cell revealing the *maximum possible* annual fishing effort, not the *actual* annual fishing effort in the given cell for the specified gear group.

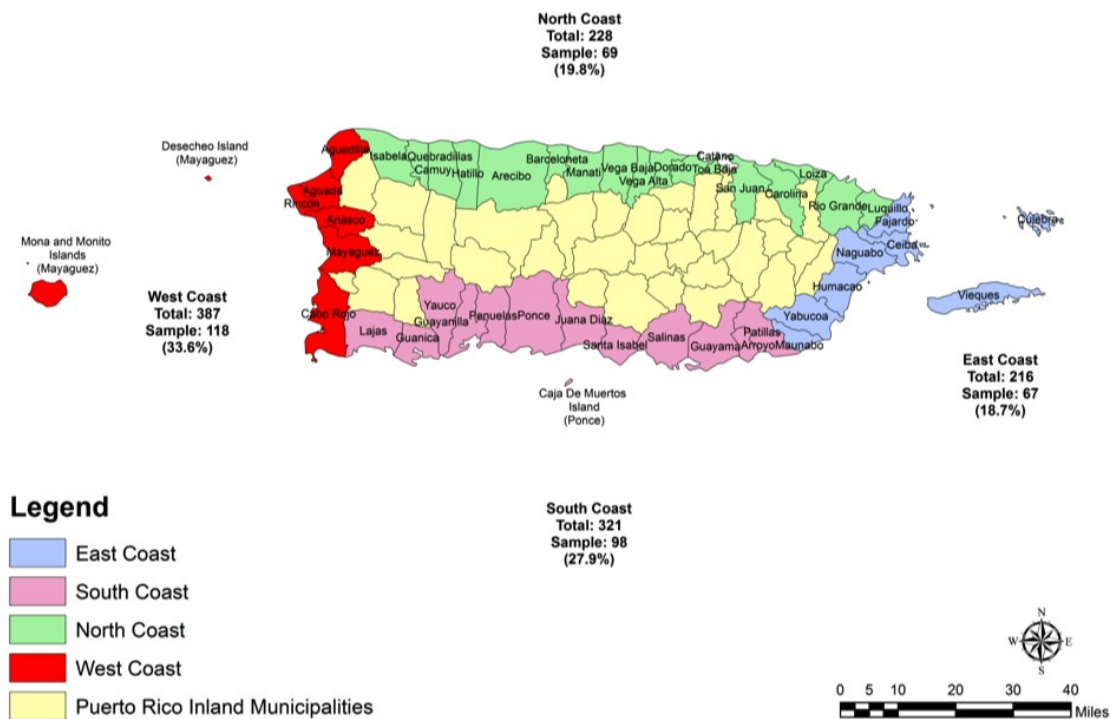


Figure 1. Survey totals by coast

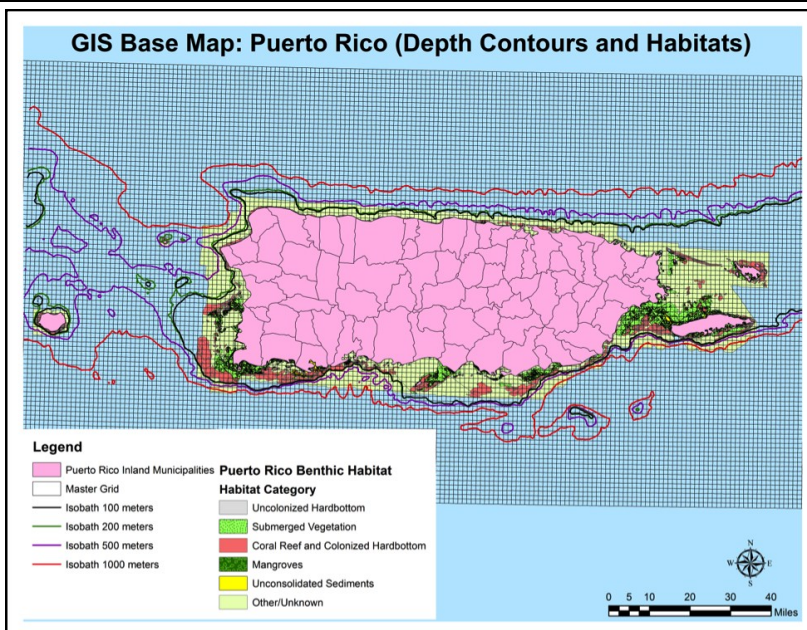


Figure 2. Puerto Rico grid map

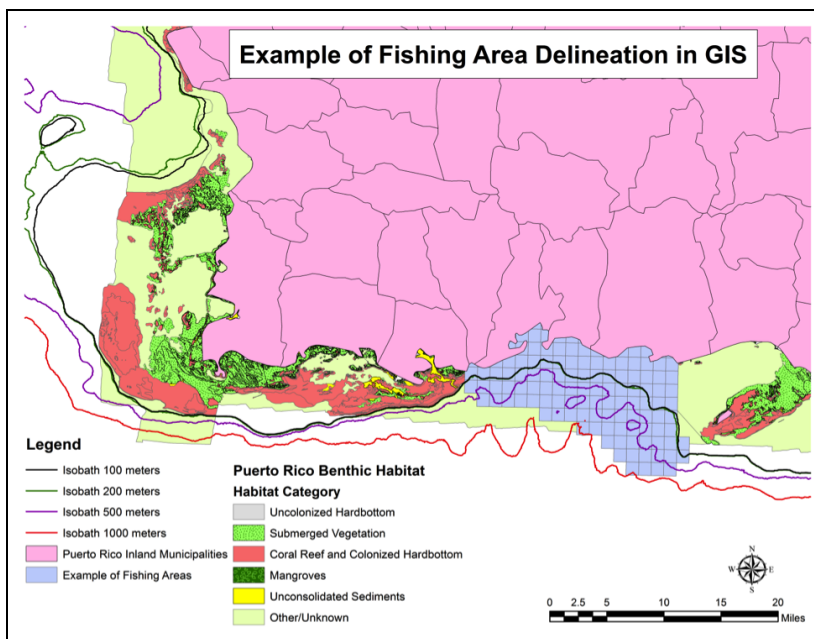


Figure 3. Fishing area layers as created in GIS

Effort frequency levels were compared across gear types to determine whether certain areas (and their underlying benthic characteristics, depth, and proximity or other spatial relationships with adjacent ports) were discretely targeted by particular gears (or not). Further inferences were made concerning effort profiles based on species' abundances across fishery areas, management effects, and socio-cultural and historical patterns.

RESULTS

Effort frequency levels by the four main gear types are main focus of the results; please refer to Koeneke (2011) for a full description of use profiles by the total number of participants and gear subtypes.

Line gears, which were among the most diverse gear type employed in the fishery and which included a variety of vertical, horizontal, and hook configuration subtypes, were deployed across the island (Figure 4). There were three areas of high fishing effort (clusters of cells with more than 4,396 annual possible trips per cell), namely off

the west coast from Bajo de Sico to Corona del Medio, along the insular shelf of the northwestern coast, and the central north coast. The vast majority of the areas with higher line gear fishing effort were located along the insular shelf, and in waters deeper than 100 meters. Line gears were less extensively used all over Puerto Rico in waters shallower than 100 meters, especially in the southwest from Cabo Rojo to Guánica, and along the coasts of the eastern islands of Vieques and Culebra.

The diversity of the line gears, ranging from handlines, vertical lines, and trolling lines, among others, best explained the widespread use of line gears. The gear could be deployed in a variety of habitats and for a number of finfish species. For example, the west coast line fishery, in the areas along Bajo de Sico and Corona del Medio

largely relied on vertical lines, which are used to catch deepwater snapper (chillo) species. Along the north coast, where there is a narrow insular shelf, with deep waters close to the coast, handlines and trolling lines were used to target a variety of snappers or migratory pelagic species, such as tuna and dolphin. Off deeper waters, especially along the north coast, line gear use was prevalent in waters deeper than 1,000 meters, which local fishers targeted during the dolphin migration period. Even in less intensely fished areas, fishers often reported that they fished with handlines or modified line gear while deploying another gear. The accessibility, low cost, and ease of use of line gears made line fishing the most common of all gears in the Puerto Rican fishery.

Like line gears, nets were also used across the entire island (Figure 5). However, unlike lines, nets were most

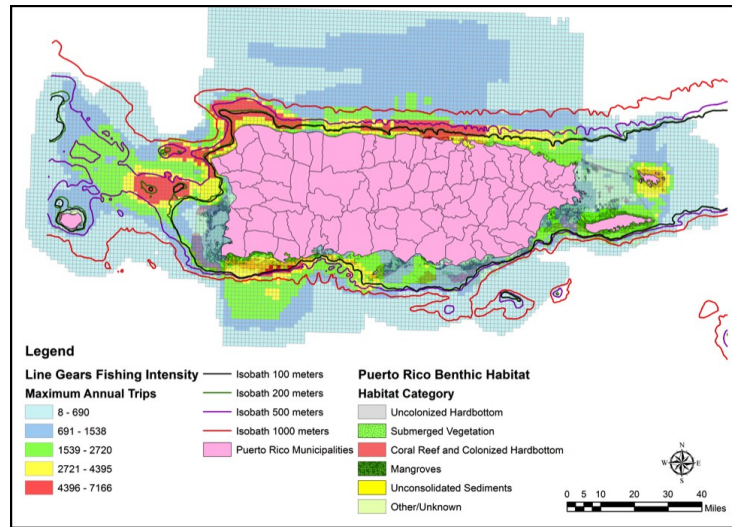


Figure 4. Line gear effort frequency

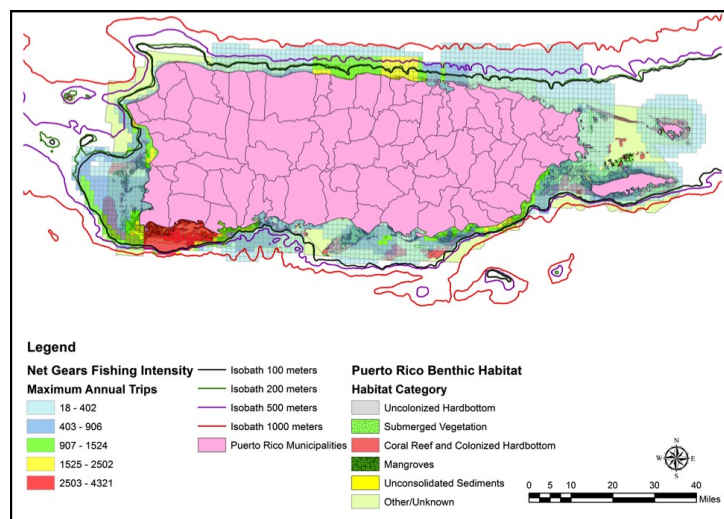


Figure 5. Net gear effort frequency

confined to use within the insular shelf in water shallower than 1,000 meters. The shallow waters off southwestern Puerto Rico, from Cabo Rojo southeast to Guánica, had the highest net use intensity (clusters of cells with more than 2,503 annual trips per cell). Areas of moderate effort were found along the southeastern coast from Guayama northeast to Humacao, off the west coast in Cabo Rojo along the insular shelf drop-off, along the coast of Mayagüez, and along the north coast, from Cataño west to Barceloneta.

As shown in Figure 5, net gear use, although widespread, nevertheless was clustered in areas adjacent to or which contained coral reefs, submerged aquatic vegetation, or mangroves. Acosta and Valdes-Pizzini (2005) reported that net gear use within the south coast of Puerto Rico was common among coral reefs and mangroves, and this study found that the small cays (islands) and wide insular shelf off La Parguera in southwestern Puerto Rico provided the best habitat for the deployment of net gear. It should be noted also that net gears included several subtypes that were often modified for fishing at a variety of depths and for diversity of finfish and invertebrates. For example, lobster trammel nets, which targets spiny lobster (*Panulirus argus*), were a popular net subtype that was set on the benthos; other nets, such as gillnets and other entangling nets were used to target finfish, and these were set in the upper to mid water column. Lobster trammel nets were common along the southwestern coast, where they were deployed in the shallow bottom; by contrast, gillnets were frequently used along the north coast, along the narrow insular shelf.

SCUBA and free diving comprised another important gear (or type of fishing) used over most of Puerto Rico. Unlike net and especially line gears, which could be used at a variety of depths, divers (especially SCUBA divers)

were depth-limited. Thus, narrow insular shelf fishing grounds in the north and northwestern parts of Puerto Rico hosted the lowest dive effort (Figure 6). By contrast, the broad, shallow insular shelf fishing grounds off the southwestern, southern, and eastern coast had moderate to high levels of dive fishing effort. Clusters of cells with 1,753 to 2,785 maximum annual trips per cell were found off Fajardo, Yabucoa, Humacao, and Vieques in the east coast, and from Santa Isabel to Guayanilla along the south coast. Divers also targeted the islands of Vieques and Culebra, off eastern Puerto Rico. However, the highest levels of fishing effort for dive gears (between 2,786 and 4,011 trips) were concentrated along the southwestern insular shelf, from Cabo Rojo to Yauco.

As previously stated, dive fishing was largely limited by depth across the island; but even in shelf-limited areas such as the north coast, dive gears were often deployed closer to the shore as long as divers could harvest high-value species such as conch, lobster, reef fish, and octopus. These species made dive fishing among the most profitable of the gear types and likely explained the popularity of the gear along the island’s shallow waters.

The final, major gear type evaluated were traps, comprised of fish traps and lobster pots (“cajones”). Trap use was widespread throughout Puerto Rico, but effort varied considerably between and within coasts (Figure 7). Moderate trap gear fishing effort (clusters of cells with 463 to 816 maximum annual trips per cell) was identified along all four coasts: Cabo Rojo in the west; Manatí, Barceloneta, Arecibo, Dorado, Toa Baja, and from Carolina to Luquillo in the north; Culebra and Vieques in the east; and Lajas, Guánica, Juana Díaz, Santa Isabel, Salinas, and Guayama in the south. However, the highest maximum fishing effort for trap gears was concentrated along the southern coast, from Juana Díaz to Guayama, within the insular shelf. Clusters of cells with 1,441 to 2,268 maxi-

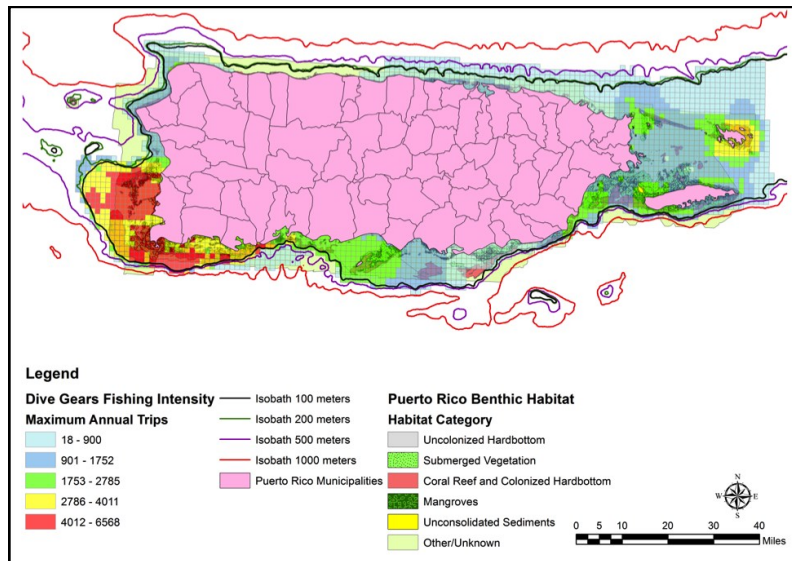


Figure 6. Dive gear effort frequency

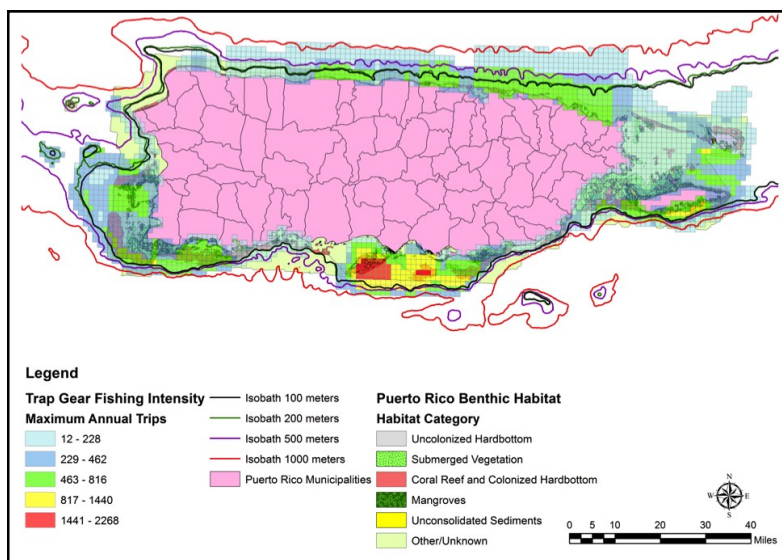


Figure 7. Trap gear effort frequency

mum annual trips per cell were found along the seagrass beds of Caja de Muertos Island and along the reef off Salinas in southeastern Puerto Rico.

Within the gear subtypes, fish traps tended to be deployed island-wide, but lobster pots were mostly set along the four municipalities in the south-central to southeastern coast, from Juana Diaz east to Salinas. Target species also affected areas targeted, especially in the Corona del Medio and Bajo del Sico for deepwater snappers, and along the south-central coast for lobster. Also, a combination of depth and benthic habitats also determined areas fished, with trap use being limited to waters along and within the insular shelf, as well as concentrated use observed near reefs and seagrass beds. Agar et al. (2008) found that trap gears in Puerto Rico are deployed within the insular shelf, as well as along the shelf drop-off. Acosta (1994) described how some fishers deploy traps along the coral reefs due to their fishing effectiveness as a passive gear in those ecosystems. However, traditional and social factors may also have affected (or at least reinforced) the areas in which traps (especially fish traps) were used. For example, trap fishers from south-central Puerto Rico explained that trap fishing represented a regional tradition, practiced by several generations; however, the practice was also greatly facilitated by the availability of wide insular shelf and relatively low fishing pressure. Along the east coast, trap fishers reported having reduced effort in the trap fishery. The main reason for the decline in trap use was due to high rates of trap poaching and theft. As a result, some fishers had deployed subsurface lines and buoys to avoid detection, moved their traps in areas where the fishers could monitor the traps, or had largely abandoned using traps.

DISCUSSION

The spatial characterization of fishery effort by a variety of gear types showed that small-scale fishers utilize most gear types (and subtypes) across Puerto Rico, but that there are specific areas – defined by habitat, species, socioeconomics, culture, or a combination of factors – that attract higher levels of use by particular gear types. Thus, while line gears were used across the island, these were most prolifically used in their vertical configuration (“calas”) off western Puerto Rico in the deepwater snapper fishery and the off northern Puerto Rico in the offshore pelagic fishery. Similarly, nets and dive gear were also common around Puerto Rico, but both gears were largely depth-limited. In the case of diving, it remained an important gear type along all coastlines where it could be used to target high value species, especially conch and lobster. Traps were the least frequently used gear, both in terms of the number of participants and in effort intensity; this was due in part to the perceived threat of trap poaching and theft and the high costs and low profitability of the gear type (see Agar et al. 2008, for an economic description of the US Caribbean fish trap fishery). Nevertheless, fish traps still comprised an important gear along the south-central and southeastern coast, where fishers continued the diminishing practice of fish trapping along the region’s broad and shallow insular shelf.

The results also demonstrated that depth more than species or even habitat regulated the gear types used across Puerto Rico. Thus, while fishers used nets, SCUBA, free diving, and traps to target lobster, nets and dive gears were limited by the depth at which they could harvest lobster. Similarly, the absence of a broad insular shelf along the northern coast led to the dominance of line gear and gear subtypes (ex., handlines, troll lines, rod and reels, etc.) and

prioritized the harvest of offshore pelagic species. Conversely, a diversity of accessible shallow and deep-water habitats along the western and southwestern coasts facilitated the use of a variety of gears (by the largest population of commercial fishers in Puerto Rico).

The spatial characterization identified several fishing grounds-ports linkages that denoted important regional differences, even within the same coasts. The west coast fishery had both nearshore and offshore components, where the former was targeted for a variety of finfish and invertebrates and the latter was targeted for mainly deepwater snapper. The north coast ports linked to extensive fishery grounds, due to the nature of the trolling fishery and because of the narrow shelf. The south coast fishery was characterized by the availability of a broad shelf along much of its length, favoring the use of multiple gears that was largely targeted closer to shore than in other coasts. Finally, the east coast fishery focused extensively on shallow habitats located in proximity of the region's main ports where fishers targeted a variety of reef fish, conch, and lobster.

The study findings have important management implications, in that the spatial characterization demonstrated that there exist only a few singular relationships between gear types and target species and gear types and benthic habitats. Instead, the characterization showed that gear types were used throughout the island for a number of different species and across a variety of habitats. Related results also determined that fishers often use more than one gear over the same habitat during the same trip. For example, participants often related that they use multiple gears on a single trip, such that crew may deploy different gear over the same habitat. Thus, a gear-based management approach that seeks to reduce or eliminate the gear in favor of fishery abundance expectations may simply result in the fishery shifting to the other gear types. Similarly, gear-based efforts may disproportionately affect certain areas more than others, where alternate gears cannot be deployed due to depth or other key characteristics. Finally, gear-based management may have effects on the culture and traditions of certain areas, where gears have been utilized for generations and play a role in the region's identity.

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