Spatial Characterization of Puerto Rican Commercial Fisheries: Gear Usage Across Habitat Classes and Bathymetry Ranges

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SPATIAL CHARACTERIZATION OF PUERTO RICAN COMMERCIAL FISHERIES: GEAR USAGE ACROSS HABITAT CLASSES AND BATHYMETRY RANGES

By

Roberto Koeneke

A THESIS

Submitted to the Faculty of the University of Miami in partial fulfillment of the requirements for the degree of Master of Science

Coral Gables, Florida

May 2011
SPATIAL CHARACTERIZATION OF PUERTO RICAN COMMERCIAL FISHERIES: GEAR USAGE ACROSS HABITAT CLASSES AND BATHYMETRY RANGES

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KOENEKE, ROBERTO (M.S., Marine Affairs and Policy)  
Spatial Characterization of Puerto Rican Commercial Fisheries: Gear Usage Across Habitat Classes and Bathymetry Ranges.  
(May 2011)

Abstract of a thesis at the University of Miami.

Thesis supervised by Professor Maria Estevanez.  
No. of pages in text. (119)

The spatial characterization of Puerto Rican commercial fisheries describing fishing gear use in relation to habitat classes and bathymetry ranges was achieved through the collection and analysis of spatial fisheries data. An extensive field data gathering session was conducted in the entire Puerto Rican territory during the summer months of 2009, from June to October. The field data was digitized and analyzed using geographic information systems (GIS) and computer spreadsheet software, and gear usage charts and graphs, fishing grounds maps, and fishing intensity maps were produced for four gear categories: line, net, dive, and trap gears. Patterns and evidence of likely relationships linking gear usage and benthic habitat, and between gear utilization and water depth ranges, were presented. The importance of the spatial characterization of the commercial fishery for Puerto Rican fisheries management, and other recommendations were given within the concluding chapter.
ACKNOWLEDGMENTS

The completion and success of the thesis was possible through the countless efforts and guidance provided by the thesis committee: Ms. Maria Estevanez, Dr. Liana Talaue-McManus, and Mr. Manoj Shivlani. All of the help with the data encoding and analysis, as well as the content review and other suggestions and comments are deeply appreciated and greatly increased the quality of the thesis. All three committee members made the thesis experience enlightening, fulfilling and memorable.

The opportunity for performing the field work, granted by Juan Agar, from NOAA Fisheries, and Thomas J. Murray and Associates, is greatly esteemed.

Additional help before and during the field work, provided by Flavia Tonioli, from RSMAS, and Daniel Matos-Caballo, from the DRNA in Puerto Rico, made the gathering of information much easier.

The commercial fishers of Puerto Rico, and the people of the island in general, were greatly hospitable, knowledgeable, and helpful. The warmth of many fishing families and communities, their willingness and patience to provide the data for the thesis, are extremely appreciated. The five months of field work were rewarding and enlightening, not only from an academic perspective, but also personally.

Lastly, the unconditional love and support, afforded by the Lord and family members, helped me ultimately fulfill the goal of completing the thesis.
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1.0 Introduction:

Commercial fisheries in the United States Commonwealth of Puerto Rico, are characterized by their small-scale and artisanal nature (Matos-Carballo et al., 2002), even though the island makes considerable landings of commercial conch, lobster, and shrimp at a regional—Caribbean and Latin America—level (Salas et al., 2007). In spite of this, the commercial fisheries in Puerto Rico have been deemed by several researchers and managing agencies to be overfished. LeGore et al. (1997) found that almost all of the fish consumed domestically—approximately 95%, in Puerto Rico, is imported. The study argues that such condition points to the deplorable state of the fisheries and is evidence of the overexploitation of the fisheries. Furthermore, the Caribbean Fishery Management Council (1996) stated that there is much concern not only within the Council, but also among the public, of the scarcity of fishery resources and the importance of protecting commercial species during periods of spawning aggregations. The Puerto Rico Department of Natural Resources and the Environment (DRNA for its acronym in Spanish), in cooperation with the National Marine Fisheries Service (NMFS) of the United States of America, periodically conduct fishery censuses in Puerto Rico, focusing mainly on the demographic composition, fisheries landings, and biostatistics data. The DRNA has published the census results and statistics in several technical agency reports, and context is given to all the data. In particular, the 2002 census report describes the state of the commercial fisheries in which such fisheries are suspected of being overfished (Matos-Carballo et al., 2002).
It is thus evident that Puerto Rican fisheries are consistently monitored and studied. However, when compared to the more prominent USA mainland fisheries, Puerto Rican fisheries have not been as extensively researched and analyzed. Nevertheless, the commercial fisheries in the geographical region to which Puerto Rico belongs, the Caribbean and Latin America, have been increasingly studied over past decades (e.g. Chakalall et al., 2007; Daw, 2008; De Freitas and Tagliani, 2009; Dunn et al., 2010; García-Quijano, 2007). While the Caribbean and Latin America have progressively received research attention, the impacts of small-scale fisheries in the region have not been adequately studied, even though such fisheries account for approximately 95% of the fishing effort in the insular Caribbean (Dunn et al., 2010). Salas et al. (2007) point to the deficiencies in the information gathering processes and body of knowledge regarding small-scale fisheries in the region. Thus, the region’s commercial and artisanal fisheries continue to receive less research effort than the traditional and well-known US mainland commercial fisheries.

Over the past several years, however, Puerto Rican small-scale commercial fisheries have received a growing amount of research interest (e.g. Agar et al., 2008; Aguilar-Perera et al., 2006; Dunn et al., 2010; García-Quijano, 2007; Griffith and Valdés-Pizzini, 2002; Jiménez, n.d.; Tonioli and Agar, 2009). These studies have concentrated on several fishery aspects, including the socioeconomics of the trap fishery, the relationship between marine resource exploitation and wage-labor in small-scale fisheries, and fishing effort within a regional context. In spite of this, little to no attention has been directed towards the spatial characterization of the Puerto Rican commercial fisheries.
Nevertheless, the spatial description of small-scale fisheries has been accomplished in other parts of the world, namely in Brazil (De Freitas and Tagliani, 2009); Nicaragua (Daw, 2008); Florida, United States of America (Chiappone et al., 2004); and New Caledonia, South Pacific (Guillemot et al., 2009).

The spatial distribution of effort and resource use within small-scale fisheries can provide valuable information in the study and management of such fisheries (Aburto et al., 2009; Daw, 2008; De Freitas and Tagliani, 2009; Freire and García-Allut, 2000; Guillemot et al., 2009; Nelson et al., 2009; Riolo, 2006). For example, in order to establish territorial user rights in an artisanal fishery, it is vital to understand the spatial extent of both the stock being exploited and the fishing grounds (Freire and García-Allut, 2000). Furthermore, fisheries spatial information also helps to determine the extension ranges of fishers in a given fishery over time. This helps to establish changes in the distances travelled by the fishers over the course of decades, and may indicate possible overexploitation of resources in a given area (Daw, 2008). In fact, access to the spatial-based fisheries data is imperative for the planning of fisheries management (Anuchiracheeva et al., 2003), and lack of such access may have partially caused the failure of some fishery management regimes (De Freitas and Tagliani, 2009). The spatial description data is considered to be intrinsic to the participants of the fishery, namely the commercial and artisanal fishers. This local ecological knowledge (LEK) possessed by the fishers is obtained through the constant participation in the local fisheries, and, in many cases, is passed down from generation to generation, especially within fishing families and communities (Aguilar-Perera et al., 2006; Anuchiracheeva et al., 2003;
Close and Hall, 2006; Gularte Schafer and Girondi Reis, 2008; Hall et al., 2009; Salas et al., 2007; Schärer et al., 2004; de la Torre-Castro and Lindström, 2010). In some cases, the LEK is acquired by one group or individual fishers from another group of fishers, whenever fishers temporarily migrate from one fishing camp to another, as is the case in Chile’s loco fishery (Aburto et al., 2009).

The local ecological knowledge (LEK), also called traditional ecological knowledge (TEK), serves researchers and fisheries managers several purposes. Such knowledge helps to determine the local names used by local fishers for fishing grounds and important landmarks, previously unknown to scientists (Daw, 2008; De Freitas and Tagliani, 2009; Close and Hall, 2006; Hall et al., 2009). Local knowledge can be incorporated into a fishery study in order to describe the fishery from the fishers’ standpoint (Hall et al., 2009), and allows fishers to recognize that their LEK is treasured (Gularte Schafer and Girondi Reis, 2008). García-Quijano (2007) argues that LEK is vital when attempting to understand complex ecosystems and when large amounts of uncertainty are associated with a given ecosystem. Furthermore, LEK serves fisheries managers in developing and implementing spatial management policies and tools, such as marine reserves and marine protected areas (Aguilar-Perera et al., 2006; Gularte Schafer and Girondi Reis, 2008; Scholz et al., 2004). More importantly, by incorporating LEK and fishermen in the management process, a practice known as co-management, instances of conflict can be reduced and/or avoided (Bennett et al., 2001; Gularte Schafer and Girondi Reis, 2008).
Local ecological knowledge can also be integrated with scientific knowledge (SK), such as landings statistics and socioeconomic data, in order to yield effective management of the fisheries (Gularte Schafer and Girondi Reis, 2008; Hall et al., 2009; Salas et al., 2007; Tonioli and Agar, 2009). However, even though the importance of integrating LEK and SK has been increasingly recognized, LEK is not always included in fisheries analysis and management. The problem arises from the nature of LEK, as it is usually qualitative and in formats not easily utilized by traditional scientific research (Gularte Schafer and Girondi Reis, 2008; Hall et al., 2009). However, not all LEK is grueling to integrate with SK; information such as description of fishing grounds and delineation of conflict areas can be incorporated into formal scientific research with greater ease. Given the challenge of employing spatial LEK in fisheries analysis and management, some researchers and managers have turned to the use of geographic information systems (GIS), in order to effectively utilize such valuable spatial knowledge (Anuchiracheeva et al., 2003; Close and Hall, 2006; De Freitas and Tagliani, 2009; Hall et al., 2009; Scholz et al., 2004; Stanbury and Starr, 1999). The term of geographic information systems (GIS) covers a wide range of definitions. The concept of GIS can be understood as “any computer-based capability for the manipulation of geographical data” (Bernhardsen, 2002), as a collection of spatial-analysis tools, as a system designed for managing geographically-based information and performing queries, as an approach to science, or as a discipline (Clarke, 1999). For purposes of the present thesis, GIS will be considered as a computer-based tool, through which spatial description and analysis of geographically-dependent data is possible.
Historically, geographic information systems (GIS) have not received much attention in the fields of fisheries research and management (Haddad et al., 1996; Rubec, 1996). However, the realm of marine fisheries has been increasingly embracing GIS as a critical tool for a wide variety of analysis and management processes, especially over the last couple of decades (e.g. Daw, 2008; De Freitas and Tagliani, 2009; Close and Hall, 2006; Dunn et al., 2010; Rajitha et al., 2007; Friel and O’Hop, 1996). For example, Dunn et al. (2010) partially used GIS to process data, in order to analyze and describe fishing effort regionally for the wider Caribbean. Also, GIS was employed to perform a density analysis of the American Samoa long-line fishery, in order to further understand the “spatial and temporal fishing dynamics” (Riolo, 2006). In India, Rajitha et al. (2007) found that remote sensing and GIS are crucial tools in aiding the development of sustainable shrimp aquaculture. Other advantages of using GIS deal with the ability to peruse and analyze data at different scales, the ease of use, and the dynamism and adaptability of such system (Riolo, 2006; Stanbury and Starr, 1999). Thus, GIS has proven to be an important tool for recent fisheries research and management, whether at a regional or local scale, and for pelagic and coastal fishery levels.

However, in order for GIS to be effective as a tool, several considerations need to be taken into account.

- Collection of accurate field data according to customary scientific methods,
- Standardization of harvested field data within GIS framework,
- Development of GIS database with corresponding descriptors (e.g. Metadata), and
• Establishment of trends and patterns in the data through frequent and systematic field data collection (especially relevant in when dealing with spatial dynamics)

When collecting and gathering the data, the parties responsible for the study need to take steps to reduce inaccuracies resulting from the methods employed in acquiring the spatial data. This is to say, careful attention needs to be directed at reducing map and seasonal bias (De Freitas and Tagliani, 2009; Guillemot et al., 2009). Then, the compilation of data to be analyzed needs to be manipulated using GIS software to guarantee that the information is standardized and compatible in terms of geospatial projection and map units (Anuchiracheeva et al., 2003; Stanbury and Starr, 1999). Furthermore, the GIS data needs to be organized and easily accessible, usually through the use of a database (De Freitas and Tagliani, 2009; Friel and O’Hop, 1996; Haddad et al., 1996). The relevance of data may decrease over time, and as such, it is important to continually update the GIS data (Anuchiracheeva et al., 2003). Managers and researchers should be careful to “properly identify the need for, plan for, and commit to data collection, acquisition, and quality control”; failure to do so may lead to unsuccessful use of GIS (Haddad et al., 1996). Close and Hall (2006) provide an excellent GIS-based protocol that guides researchers and managers to effectively harvest and utilize LEK for fisheries resource management and planning.

Even though GIS has been increasingly recognized as a valuable tool for fisheries research and management, studies focused in Puerto Rican commercial and artisanal fisheries have rarely used such tool. Limited use has been given to GIS and the spatial analysis of Puerto Rico’s fisheries, as was done within the regional context of the wider
Caribbean (Dunn et al., 2010), and analyzing the trap fishery (Agar et al., 2008).

Nevertheless, those and other studies have produced important spatial findings for the Puerto Rican fisheries managers and researchers. For example, Agar et al. (2008) found that fish traps in Puerto Rico are set in a broad range of different habitats, as well as at different depths, depending on the species targeted. Griffith and Valdés-Pizzini (2002) describe the importance of the Canal de la Mona (Mona Passage) waters for Puerto Rico’s west coast commercial and artisanal fisheries. The wide arrays of habitats and commercially-significant species, as well as varying depths, are given as factors in the large productivity of the Mona Passage waters. In terms of marine fish species assemblages in Southeastern Puerto Rico, García-Quijano (2007) found that fishers identified coral reefs as having a larger number of species than pelagic open waters. Jiménez (n.d.) also found that Queen Conch, an important commercial species in Puerto Rico, is found in larger densities in deeper waters. Furthermore, a few commercially significant fish species aggregate in large quantities to spawn, usually in open waters close to the insular shelf of western Puerto Rico (Caribbean Fishery Management Council, 1996; Ojeda, 2000). Tonioli and Agar (2009) discuss the socioeconomic impacts on the fishing communities of western Puerto Rico from the implementation of MPAs.

A spatial characterization of Puerto Rico’s small-scale fisheries is of particular importance as it encompasses the entire region, fishery participants and gears, and it systematically (rather than opportunistically) evaluates the fishery’s spatial characteristics in the context of fishery management needs (e.g. areas fished, gear types used, fishery effort, etc.). Thus, the goal of the present thesis project is to spatially characterize the
commercial fishery of Puerto Rico, and to inquire into the relationship between benthic habitat/water depth and fishing gear used by the fishers. Given that several studies of Puerto Rico’s commercial fishery mention the type of gears used in certain habitats (e.g. gillnets in coral reefs), the thesis attempts to determine whether benthic habitat and water depth dictate the type of fishing gear used in the area. The results, including simple tables and graphs based on percentile breakdown of gear usage by water habitat and depth are presented and discussed. The thesis wraps up by providing concluding remarks and management and research recommendations.
Chapter 2.0: Methodology

The research for this thesis was conducted as part of a larger cost and earnings study of the Puerto Rico commercial fishery, which was funded by NOAA Fisheries and headed by Thomas J. Murray & Associates. The field work for both the thesis and the socioeconomic study took place during the summer and fall months of 2009, from the beginning of June to the beginning of November of the same year, throughout the Puerto Rico coastal counties, including the islands of Vieques and Culebra.

Figure 2.1: Coastal Municipalities of Puerto Rico
Whereas the NOAA study primarily focused on the economic investments and costs and returns of the commercial fishery, the thesis concentrated on the spatial characterization of the fishery by gear type and benthic habitat.

The data gathering and analysis procedure of the thesis consisted of the following. Thomas J. Murray & Associates, the consulting firm hired by NOAA to carry out the fieldwork session for the Puerto Rican commercial fisheries socioeconomic study, developed a pilot survey, conducted a pre-test survey session, and further refined the survey questionnaire to be used in the NOAA study (Shivlani, 2011). After the completion of the survey questionnaire, a five-month fieldwork session in Puerto Rico was conducted between the months of June and November of 2009; the session consisted of in-person, field surveys with 350 commercial fishers. Following data collection, the spatial data were digitized, organized, and processed using the ESRI’s ArcGIS 9.3 software package. Maps depicting maximum annual fishing intensity for each gear type were then produced. The spatial data were then summarized and transferred to an Excel worksheet for conducting regression analysis and percentile statistics. The resulting statistics described the percentages of gear type use by habitat and water depth, and the relationship between gear type use and habitat/water depth. Additionally, ESRI’s ArcGIS 10.0 was utilized to perform cluster and geographic distribution analyses. Tables and graphs produced further helped to reveal patterns of spatial use in Puerto Rico’s commercial fisheries.
2.1 Study Area

The island of Puerto Rico is located between Hispaniola to the west and the
United States Virgin Islands (USVI) to the east in the Caribbean Sea. Puerto Rico forms
part of the insular Caribbean, on the western chain of islands called the Greater Antilles,
which constitute the larger Caribbean islands, namely Cuba, Jamaica, Hispaniola, and
Puerto Rico (Griffith and Valdés-Pizzini, 2002). Puerto Rico is the smallest of the islands
in the Greater Antilles, with an approximate area of 8,870 square-kilometers.

Figure 2.2: Location of Puerto Rico
The Commonwealth of Puerto Rico is comprised of one main island, two municipal islands, and a large collection of smaller islands and cays. In total, there are 78 municipalities, of which 42 are coastal, including the island municipalities of Vieques and Culebra, both of which are situated just east of the main island of Puerto Rico. The north coast faces the Atlantic Ocean, while the south coast borders the Caribbean Sea. The Mona Passage (Canal de la Mona) hugs the western coast, while the Vieques Sound borders the east coast. Desecheo Island and Mona Island, both small islands with rich fisheries resources, are located in the Mona Passage, and are administered by the Puerto Rican municipalities of Rincón and Mayagüez, respectively. Puerto Rico, when compared to the US Virgin Islands, contains a considerably large expanse of contiguous coral reef habitats, including related marine environments such as mangroves (Aguilar-Perera et al., 2006). However, even though the island is surrounded by both an ocean and a large sea, scientists have considered the area to have relatively poor fishing grounds when compared to those of the Gulf of Mexico and the continental western Atlantic waters. Griffith and Valdés-Pizzini (2002) describe the reasons why in the following passage:

Caribbean waters are known as oligotrophic: low in nutrients, with generally low biomass yet with a rich biodiversity of fauna and flora, epitomized by the organisms that are associated with coral reefs, sea grass beds, and mangroves on the narrow confines around insular platforms…Absence of large shellfish or finfish populations comparable to those of New England, narrow shelves, strong trade winds, a hurricane season (from June to October), and seasonal fluctuations in the quality and quantity of fish stocks
These environmental factors present in much of the Caribbean have hindered the development of technologically advanced fisheries, with the exception of Puerto Rico. The commercial fishing fleet in the west coast of the island is comparable, in terms of technology and diversity, to those of the Chesapeake Bay fisheries. The benefits of the sociopolitical status of Puerto Rico as a United States Commonwealth makes Puerto Rico an exception to the norm (Griffith and Valdés-Pizzini, 2002).

The island of Puerto Rico has an interesting and unusual status as a Commonwealth nation governed and administrated federally by the United States of America (US). In many ways, Puerto Rico behaves as a nation, while also acting in a manner similar to the states of the US. More clearly, as a territory with an “associate state” status, the island is subject to the laws and regulations of the Federal US government, including environmental laws (Aguilar-Perera et al., 2006). Puerto Rico is also subject to the oversight of the federal agencies, including the National Oceanographic and Atmospheric Administration (NOAA), and its federal fisheries service branch, namely the National Marine Fisheries Service (NMFS). For instance, Puerto Rico’s commercial shallow-water reef fish fisheries are managed by a Fishery Management Plan (FMP), established by the Caribbean Fishery Management Council under the direction of the federal Magnuson-Stevens Act (Caribbean Fishery Management Council, 1996). Additionally, Puerto Rican state agencies, essentially the Department of Agriculture and the Department of Natural Resources and the Environment (DRNA for its acronym in Spanish: Departamento de Recursos Naturales y Ambiente), also regulate and manage the fishery resources in the island. For example, the
DRNA, in cooperation with NMFS, regularly carry out censuses of Puerto Rico’s commercial fisheries (Matos-Carballo et al., 2002). It is within this regulatory context that the NOAA Puerto Rico commercial fisheries costs and earnings socioeconomic study, and thus, the present thesis are performed.

2.2 Survey Instrument and Paper Map

Socioeconomic research studies often rely on questionnaire surveys to gather field information (e.g. Acosta and Valdés-Pizzini, 2005; Christensen and Raakjær, 2006; Guillemot et al., 2009), and a survey instrument was developed and used for the data collected for this thesis. Three separate elements comprised the survey tool, of which the first two pertained to the NOAA socioeconomic study, and the last part concerned the thesis. The first part of the complete questionnaire consisted of the fishery census demographic data. The census data were not limited to the demographic information alone, as it asked for fishing experience and type of fisher—whether the fisher is a crew member, a captain of his/her own vessel, captain in another fisher’s vessel, or any other fisher type. The second section concerned fisher economic data, with questions related to the fishers’ gears, variable costs, fixed costs, and vessel and equipment characterization. The main focus of the economic section was to grasp the costs and earnings per individual fisher associated with all commercial fishing activities. The final part of the survey, which is the primary focus of the thesis, was a paper map of Puerto Rico, Culebra, Vieques, and the outlying islands and large cays (i.e. Mona and Monito, Desecheo, Isla Caja de Muertos).
To obtain spatial data, past fisheries studies have turned to maps to obtain such desired information. For example, Daw (2008) used a household questionnaire and maps in a study of the artisanal lobster fisheries of the Corn Islands in Nicaragua. In Brazil, De Freitas and Tagliani (2009) utilized maps in the data gathering session of their study of artisanal fisheries in the southern region of the country. Fishers provided harvest and use information based on gear used in commercial activities, and the maps provided the basis for spatial data collection.

The paper map of Puerto Rico, shown in Figure 2.3, was designed to include several vital elements to the identification of fishing areas. The main island of Puerto Rico is shown divided into the 41 coastal municipalities.¹ In addition to the coastal municipalities, the islands of Vieques and Culebra, which are also municipalities, were

¹ Guaynabo, another coastal municipality located between San Juan and Bayamón, is not shown on the map
shown on the map. The islands of Mona and Monito, located in the Mona Passage between western Puerto Rico and the Dominican Republic, and Desecheo Island, found off the coast of the Rincón municipality, were also depicted on the map. For the southern and eastern coasts, several small cays and islands were included. To delineate water depth, four main bathymetry contour lines demarcate the 100 meter, 200 meter, 500 meter, and 1000 meter depth marks. The 100 meter bathymetry line was displayed closest to land, and the 1000 meter bathymetry line delineated the outermost contour. Only the benthic habitats and the buoy markers of southwestern Puerto Rico were omitted from the paper maps to avoid visual cluttering.

In order to facilitate the delineation of fishing areas, a grid was created to cover an expanse of area several miles north off of the northern Puerto Rican coast, several miles south off the southern Puerto Rican coast, the Mona Passage off Puerto Rico’s western coast (including the islands of Desecheo, Mona, and Monito), and the Vieques Sound extending east past Vieques and Culebra. Employing a grid system for the survey maps helps to reduce errors and provide an adequate scale (Close and Hall, 2006). The fishnet grid for the thesis survey maps was created in one decimal degree second by one decimal degree second (0° 0’1” by 0° 0”1’ = 0.033333 by 0.033333 decimal degrees) dimensions, allowing the fishermen to detail precise fishing areas. The area of each individual cell was approximately 1.5 square miles.
2.3 Field Work

During the five months of field work, from June 8, 2009 to November 4, 2009, an average of two interviews were conducted per day, resulting in 362 total commercial fishers interviews (Shivlani, 2011). The interviews consisted of both the socio-economic and spatial characterization studies. Out of the 362 total interviews, one fisher began the interview, but terminated it at his own request half-way through it. One other fisher responded the socio-economic survey questions, but chose not to provide the fishing area locations at the end of the interview. As a result, 359 interviews were successful in collecting the spatial data requested for the thesis.

The National Marine Fisheries Service (NMFS), through NOAA, provided both interviewers, Mr. Manoj Shivlani and Mr. Roberto Koeneke, with a randomized list of commercial fishermen of Puerto Rico. The list of all 1,152 commercial fishers was provided to NMFS by the Department of Natural Resources of Puerto Rico (DRNA), and is based on the 2008 Puerto Rico commercial fishery census data (Shivlani, 2011). Basic information was provided in the list, including the last name, first name, nickname, and telephone number, for each fisherman whenever the information was available. That is, not all fishermen in the list were listed by their last and first name, nickname and telephone number, as not all fishermen provided such information in the census. Thus, some fishermen were listed by just their nickname, whereas some listed last and first name and no nickname. The list also provided the *villa pesquera* or fishing community association for each fisherman, identified by a code given to each site by the DRNA, as well as the municipality where the *villa pesquera* or fishing community is located. Each
A commercial fisherman in Puerto Rico is associated to a particular *villa pesquera* (fishing village-cooperative), or a fishing community, which serves as the principal gathering, meeting, and landing location for the commercial fishermen (Griffith and Valdés-Pizzini, 2002).

Within the list, the data were arbitrarily divided into four regions—each pertaining to the four different coasts of the island (north, south, east, and west).

**Figure 2.4: Field Work: Sampling Regions**

The regionalization of the data served the purpose of dividing the data gathering endeavor, and with knowledge that border municipalities could reflect more
characteristics of the neighboring quadrant (Shivlani, 2011). For instance, the fishing communities and benthic habitats of Lajas (of the southern coast) more closely resemble those of Cabo Rojo (of the western coast), than it does other southern coast municipalities. The sampling used for the purpose of both the NOAA and the thesis study, was to be conducted in proportion to regional commercial fisherman population (Agar, 2009). Shivlani (2011) explains the sampling process in great detail:

Due in part to the diversity of gear types and because of fisher participation in multiple fisheries, the regionalization approach was not followed by stratified sampling based on gear or landings. Instead, fisher names were randomly sorted for each region, and the total number of fishers to be surveyed per region was determined based on the regional proportion of total participation across the island. The total number required as part of the study was 350 surveys.

The West coast covers a relatively small geographic area (from Cabo Rojo to Aguadilla); however, it includes the islands of Mona, Monito, and Desecheo, and it is home to the largest number of villas pesqueras in the whole island. The South coast consists of the municipalities from Lajas in the southwest to Patillas in the southeast. The East coast, like the West coast, covers a smaller geographic area (from Maunabo to Fajardo), especially when compared to the South coast. The island municipalities of Vieques and Culebra were also considered part of the East coast for purposes of the study. The Atlantic, or North coast, spans the area from Isabela in the northwest to Luquillo in the northeast.

Villas pesqueras are not evenly distributed along the island. For instance, the west coast is home to 22 villas pesqueras, or roughly 30% of the total number of villas
pesqueras in Puerto Rico. The southern coast is the second most populated in terms of villas pesqueras, with twenty (20) villas pesqueras, amounting to approximately 27% of the total villas in Puerto Rico, with most of such villas situated in the western part of the coast, in the municipalities of Ponce (2), Guánica (3), and Lajas (3). The villas pesqueras of the eastern part of the southern coast, however, were distributed sparsely, with each municipality having an average of one (1) villa pesquera, with the exception of Guayama, which contained three (3).

Table 2.1: Municipalities and Samples by Coast

<table>
<thead>
<tr>
<th>COAST</th>
<th>MUNICIPALITIES</th>
<th>TOTAL NUMBER OF COMMERCIAL FISHERMEN*</th>
<th>SAMPLE NUMBER OF COMMERCIAL FISHERMEN**</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>Cabo Rojo, Mayagüez, Añasco, Rincón, Aguada, Aguadilla</td>
<td>387</td>
<td>118</td>
</tr>
<tr>
<td>South</td>
<td>Lajas, Guánica, Yauco, Guayanilla, Peñuelas, Ponce, Juana Diaz, Santa Isabel, Salinas, Guayama, Arroyo, Patillas</td>
<td>321</td>
<td>98</td>
</tr>
<tr>
<td>East</td>
<td>Maunabo, Yabucoa, Humacao, Naguabo, Ceiba, Fajardo, Culebra, Vieques</td>
<td>216</td>
<td>66</td>
</tr>
<tr>
<td>North</td>
<td>Isabel, Quebradillas, Camuy, Hatillo, Arecibo, Barceloneta, Manatí, Vega Baja, Vega Alta, Dorado, Toa Baja, Cataño, San Juan, Carolina, Loiza, Río Grande, Luquillo</td>
<td>228</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Total: 1152</td>
<td>Total: 351</td>
<td></td>
</tr>
</tbody>
</table>

* According to the master list provided by DRNA
**According to random samples based on master list
The northern coast of Puerto Rico, which is roughly as long as the southern coast, possesses only sixteen (16) villas pesqueras, which makes up approximately 22% of the total villas pesqueras of the island. The eastern coast of the island, which includes the island municipalities of Vieques and Culebra, also has about sixteen (16) villas pesqueras, including one in each of the island municipalities of Vieques and Culebra (Shivlani, 2011).

Table 2.1 and Figure 2.4 describe the four coasts according to municipalities and commercial fishermen sample numbers. The list was then provided in Microsoft Office Excel format, with each region represented in separate spreadsheets within the same workbook. It was from this final list that the fishermen were contacted prior to beginning the fieldwork; it also guided both interviewers throughout the field session. However, prior to the commencement of the fieldwork, contacting guidelines were developed by NMFS and the research team. Shivlani (2011) outlines the established procedures for contacting the respondents:

The guidelines established for contacting the respondents within the sampling order were as follows:
1. Fisher names from the randomly selected, regional lists would be re-ordered to correspond to the villa pesqueras;
2. The villa pesqueras for each region would be re-ordered in ascending order to correspond to their approximate geographical location along the coasts;
3. Fishers who were most likely to be interviewed, based on a preliminary response rate of 75% (but to be adjusted as a result of actual response rates), would be highlighted to be contacted first by telephone and then by visiting their villa pesquera;
4. Fishers would be contacted a maximum of six (6) times on consecutive or non-consecutive days, in a combination of phone calls and villa pesquera visits, after which the fishers would be removed from the list and replaced by fishers that followed in the random order sample.
The established guidelines presented the interviewers with some difficulties, namely snowball or intercept sampling could not be employed, and the seasonality of the fisheries was not taken into account, which could impact the availability of some fishers. Thus, the data collection effort was increased in order to surpass the limitations. Once in the field, face-to-face interviews and participatory methods were employed, in order to involve and assist the respondent in identifying gear types and fishing grounds (Shivlani, 2011).

During the months from June to November of 2009, the fieldwork session took place, beginning in the west coast, given that such coast accounted for the largest number of fishers in the research sample. Only the surveys for the west coast were performed, until all of the surveys for the coast were completed. The same process was performed for each coast, first on the west coast, then the southern coast, then the north coast, and lastly the east coast. Following the fieldwork guidelines, each fish house was visited a maximum of six times in order to survey the fishers contained within the sample.

The interview process consisted of two parts, namely the NOAA socioeconomic survey, and the thesis spatial survey. The guidelines outlined by Shivlani (2011) were strictly observed, for both the socioeconomic and spatial components of the survey. In terms of the paper map portion of the interview, the fisher was involved in showing the interviewer on the map the exact areas covered when fishing for commercial purposes. When possible, in order to clarify larger areas, fishers were asked to identify landmarks
or provide names of fishing grounds utilized by the individual fisher (e.g. Buoy #6, Tourmaline bank, Bajo de Sico, and Cabo Engaño). In other cases, especially when the fisher engaged in open-water fishing, distances from the coast were asked; for instance, if the fisher engaged in trolling off the north coast, the fisher was asked how many miles from the coast the fisher covered in order to perform the trolling. However, the face-to-face interviews provided an excellent approach to harvesting the necessary spatial information. In fact, in-situ interviews were recommended by De Freitas and Tagliani (2009) to mitigate map bias-induced errors and flaws in the spatial data, that may arise from transcription and data conversion methods employed in the collection and analysis of the data. Notwithstanding the benefits of conducting face-to-face interviews to gather spatial data, such map bias errors are increased when the interviewer records the fishing grounds on the paper map in lieu of the fisher doing so, since issues of spatial scale and map generalization are compounded by the interviewer having to estimate the fishing areas based on what the fisher describes (Close and Hall, 2006). Nevertheless, several fisheries studies resorted to interviews as a vital component of the data gathering effort (e.g. Anuchiracheeva, 2003; Christensen and Raakjær, 2006; Close and Hall, 2006; De Freitas and Tagliani, 2009; Scholz et al., 2004; Tonioli and Agar, 2009).

2.4 Analysis

Following the completion of the field session, the data from the 359 completed paper maps were entered into ESRI’s ArcGIS 9.3 geographic information systems (GIS) software program. Figure 2.5 details the data and actions taken within each specific step in the data encoding process.
The data were digitized by coding the individual fisher’s gear type use by grid cell. Each individual fisher’s coded data delineated the fishing grounds used for each individual gear type used. The digitized individual fisher data were then compiled into individual gear types (e.g. handline, gillnet, SCUBA, fish trap), and into gear categories (lines, nets, dive gears, and traps) using Microsoft Excel. Once the data were aggregated, they were re-imported into GIS and fishing grounds maps for individual gear types and for gear categories were created. Within Excel, the fishing intensity was calculated using the fishing grounds data and the annual trips taken by each fisher for each gear type. Using GIS, the fishing intensity maps were created.
Figure 2.6 illustrates the data analysis process, which consisted of two components: statistical regression tests and frequency analysis. Benthic habitat data and bathymetry data for Puerto Rico were imported into GIS, and projected along with the fishing intensity data. Using the Ordinary Least Squares (OLS) Regression tool from ESRI’s ArcGIS 10.0, the correlation tests were performed. The OLS process produced map layers illustrating the spatial correlation between gear use and benthic habitat and bathymetry, and tables describing the numerical regression values. The frequency analysis was performed within Excel, using the fishing intensity data to produce charts.
and graphs that described the gear use for each habitat type and water depth range.

Appendix A describes the step-by-step processes used to encode the data and to analyze the data within GIS and Excel.
Chapter 3.0: Results

Given the lengthy methods employed in processing and analyzing the data, several layers of results were produced. From the use of geographic information systems (GIS), two types of maps were created. The first type of map displayed the maximum fishing grounds used for each gear based on the number of fisher that visit each cell at any given point during the year. Thus, the first set of maps showed the density of fishers per cell. The second type of map depicted the total annual possible visitation trip frequency for each gear (and gear category) for each cell. Essentially, this set of maps showed the total maximum possible fishing intensity for each cell; however, it is important to note that these maps did not show the actual annual intensity, but rather the total maximum number of trips each cell may receive during the period of one year.

Within the “Results” section, only the maps showing the gear category (i.e. line gears, net gears, dive gears, and traps) are displayed; the rest of the maximum fishing grounds and fishing intensity maps are shown in Appendix B. In addition to producing descriptive habitat and bathymetry gear use maps, GIS was also utilized to evaluate the correlation between gear used and habitat type, as well as the gear type and the depth range. In order to realize the regression analysis, the Ordinary Least Squares (OLS) regression tool from ArcGIS 10.0 was used. Even though large quantities of numerical data were used for the creation of the maps, the maps themselves were highly qualitative and descriptive in nature. Nevertheless, such maps and the data used to generate them provided the vital base for the quantitative analysis of the present thesis.
The regression analysis constituted the first phase of the quantitative data evaluation, taking into account the gear use and total possible annual trip data to test the correlation between two variables at a time. First, the gear types and categories were evaluated against the depth range, setting the total possible annual trips for any given gear type or category as the dependent variable, and the depth range representing the independent variable. Next, the relationship between gear type or category and habitat type was tested, using the gear type or category as the dependent variable, and the benthic habitat class, denoted by the habitat category code, set as the independent variable. The ensuing results of the OLS analysis describes, in quantitative and statistical terms, the weakness or strength of the relationship between the above-mentioned variables.

3.1 Maximum Fishing Grounds and Fishing Intensity Maps

3.1.1 Maximum Fishing Grounds Maps

The maximum fishing grounds maps were created by compiling data for each fisher within ArcGIS 10.0, and grouping the information by gear type. This allowed for the development of individual gear maps for the entire study area, including the information for all fishers that used that particular gear type. For example, all of the Gear 01 areas for each fisher that employed that gear were grouped into a single layer to display the entire composite area where Gear 01 was used. The highest used gears are shown within the Results section, whereas the rest of the density maps are shown under Appendix B.
Figure 3.1 shows the fisher density for the handline gear use throughout Puerto Rico. All fisher density maps contain the four levels of isobaths contours, indicated by different-colored contour lines, each corresponding to a different depth in meters. The Puerto Rico municipalities are shown, with the coastal municipalities where fishers are based displayed in a lighter green. Both Vieques and Culebra are shown off the east coast of the main island, where Vieques is the larger of the two outlying islands. Off the southwest coast, the four main buoys (Buoy 8, Buoy 6, Buoy 4, and Buoy 2), used by many fishers as the outermost limit of their fishing areas, are shown in order from north to south, beginning with Buoy 8 in the north and ending in Buoy 2 just due southwest off Cabo Rojo. The density maps also display the location of the coral reef habitats, as well as seagrass, which constitute the two most prominent benthic habitats outside of the “other/unknown” category. Most importantly, Figure 3.1 illustrates the density of the number of fishers that use the gear, where yellow indicates the lowest density of fishers, and bright red shows where the fisher density was highest.
In the case of handlines, there are five clear areas of high fisher density (14-22 fishers), namely along the western edge of the south coast, in deeper waters off the northwest coast, along the north coast from Dorado to Luquillo, around Culebra island, and along the western and southern coasts of Vieques. Figure 3.1 shows that handlines are used throughout the entire island, even within the Mona Passage, around the Corona del Medio shallow; however, three or less fishers used such gears within the Mona Passage.
Figure 3.2 shows the fishing grounds for the anchored vertical longline gear. Even though the gear was widely used all along the island, the highest density of fishers (20-23 fishers per cell) was located along the north central coast, from the middle of Arecibo east to San Juan, and especially concentrated along Dorado’s coast. Some areas of more moderate density (eight to 12 fishers per cell) were found in the south coast off Ponce, and in the west off Rincón, and between the Bajo de Sico and Corona del Medio within the Mona Passage. The anchored vertical line seemed to be concentrated mainly along the insular shelf drop-off, especially along the north and southern coasts, and it was wide spread in the west coast, and used as far west as the insular shelf of the Dominican
Republic, and around Mona Island. The gear was mostly absent in shallow waters off Juana Díaz, Santa Isabel, Salinas, and Guayama in the southern coast, and along the east coast, with the exception of Culebra.

![Gear 03 (Vertical Line with Buoy) Fishing Grounds Map](image)

**Figure 3.3: Gear 03 (Vertical Line with Buoy) Fishing Grounds Map**

The fishing grounds for vertical longline with buoys was somewhat similar to the anchored vertical longline use density, in that it tends to be used along the insular shelf drop-off. The use of the gear was also widespread in the west, especially along the Mona Channel waters, with the highest concentrations (15 to 18 fishers per cell) found around the Corona del Medio, and near Desecheo Island. The gear was completely absent in the southeastern coast, as well as along most of the east coast. Even in the west, in shallow
waters within insular shelf, from the coral reefs inland, the gear was either not used or sparsely used.

Figure 3.4 displays the spatial density of the fishers using trolling lines. The gear was not used along the entire island, and the use was characterized by pockets of deployment, mainly along the north, east, and southern coasts. The gear was frequently used along the northwestern coast, and within the Mona Passage, especially along the Corona del Medio (six to eight fishers per cell), and along Desecheo Island (eight to 11 fishers per cell). The highest density (eight to ten and ten to 11 fishers per cell) of fishers was found along the Aguadilla, Isabela, and Quebradillas municipalities. Also, a few fishers used the gear in offshore waters along the north coast, from Aguadilla to Loiza, covering a large expanse of water several miles from shore. It is also important to note that the gear was seldom used within shallow insular waters.

Figure 3.5 describes the fishing grounds for the other trolling gear, namely trolling with rods. When compared to the trolling line fisher density map, it is evident that trolling with rods was used over much of the island, and has fewer non-use areas. The gear was mostly absent along the east coast, in the area between the mainland, Vieques, and Culebra. Also, along the wide insular shelf of the southwest, just west of Cabo Rojo and Mayagüez, the trolling rods were not employed.
However, just south of Cabo Rojo, Lajas, and Guánica, a fair amount of fishers (six to eight fishers per cell) use the trolling rods in deeper waters just off the insular shelf. The highest densities of fishers (eight to 14 fishers per cell) are concentrated all along deep waters off the north coast, from Aguadilla to Luquillo. The highest densities within were found from Arecibo to San Juan, just north of the insular shelf drop-off. The fishers trolling with rods in the north coast covered a large expanse of water, spanning the entire north coast, and farther into deep waters, beginning at the insular shelf-drop off to the edge of the grid used for the study, which is roughly 35-45 miles off the northern
shoreline. Similar to trolling lines, the gear was seldom used within inshore waters, with few instances along the southwest, southeast, and off Culebra.

Figure 3.5: Gear 09 (Trolling with Rods) Fishing Grounds Map

Figure 3.6 describes the spatial use of gillnets within Puerto Rico. Unlike most line gears, gillnets were employed mainly within shallower waters within the insular shelf. The use of gillnets was widespread throughout the entire island, as well as around Culebra and Vieques, with the use of the gear being absent only along the northwest coast, as well as off Ponce. The number of fishers per cell for gillnets seemed to be quite uniform along the entire island, with general densities of one to seven fishers per cell. Nevertheless, there were two pockets of high density (13 to 19 fishers per cell), with the
first along the north coast from Barceloneta to San Juan. The other area of high fisher density was found across the island in the southwestern coast, just south of Cabo Rojo, Lajas, and Guánica. Within this area, the highest concentration of fishers using gillnets was found between the shoreline and the coral reef habitat, along the cays of the southwestern coast, especially in Lajas and Guánica. Most of the gillnet use activity seemed to be located around the seagrass beds and the coral reefs, and was largely absent where there are no coral reefs and seagrass, except for the use along the north coast, where the gillnets were present even in waters as deep as 1,000 meters.

Figure 3.6: Gear 12 (Gillnet) Fishing Grounds Map
The fishers using the lobster trammel nets were mainly concentrated along the southern west coast, and the along the western south coast, spanning a continuous area from Peñuelas in the south to Rincón in the west. Lobster trammel nets were seldom used along the rest of the island. Figure 3.7 shows the fisher density distribution for lobster trammel nets, and it is evident that the lobster trammel nets were used primarily in shallow waters, from the insular shelf landward.

Figure 3.7: Gear 13 (Lobster Trammel Nets) Fishing Grounds Map
Areas of five to nine fishers per cell can be found off Rincón and Añasco, as well as south of Cabo Rojo and Lajas. The fishing grounds for fish trammel nets, shown in Figure 3.8, is somewhat different from the lobster trammel net density. Fish trammel nets are employed not only in the southwestern coast, but also along the south central coast, the north central coast, the southeastern coast, the eastern coast, and around Culebra. The highest concentrations of fishers using fish trammel nets (four to six fishers per cell) were located south of Cabo Rojo and Lajas, as well as along the insular shelf drop-off the southwest coast, close to the buoy markers. There were also areas of dense use (two to four fishers per cell) along Juana Díaz, Santa Isabel, and Salinas in the south, and along Patillas, Maunabo, and Yabucoa in the southeast. The fish trammel nets were completely absent north of Mayagüez in the west to Arecibo in the north, off Ponce in the south, and from Cataño to Luquillo in the north. Also, similar to lobster trammel nets, the fish trammel nets tended to be fished in shallow insular waters.
Figure 3.8: Gear 14 (Fish Trammel Nets) Fishing Grounds Map

Figure 3.9 describes the fisher density for the use of SCUBA gear. The use of SCUBA was quite extensive along the entire island except along the north coast, from Quebradillas in the northwest to Manatí in the center of that same coast. In most of Puerto Rico, only about one to eight fishers per cell used SCUBA. Nevertheless, high densities of fishers using SCUBA (20 to 32 fishers per cell) could be found along the insular shelf off the southwest coast, ranging from Mayagüez in the central west coast to Lajas in the southwestern coast.
The use of SCUBA in the southwest covered the entire insular shelf, from the shoreline to the insular shelf drop-off, with the highest concentrations landward of the buoy markers. Along the east coast, there was a high concentration of fishers (eight to 20 fishers per cell) around Culebra.
Figure 3.10: Gear 24 (Fish Traps) Fishing Grounds Map

Fish trap use was fairly prevalent in Puerto Rico, with only the northern coast of Rincón, Aguada, and most of Aguadilla, as well as most of Ponce, showed no signs of fish traps. The rest of the island exhibited high densities of fishers (four to nine fishers per cell), especially along the southwest, south central, north central, northeast, and eastern coasts, and along both Vieques and Culebra. As was the case with gillnet use, trap densities tended to be higher close to coral reefs and seagrass areas, except for the northern coast, where coral reefs are located only within one mile of the coast, and trap use was reported in waters deeper than 100 meters. Even though fish traps presented high fisher densities per cell in many areas (four to nine fishers per cell), densities were
actually low compared to other gears (i.e. SCUBA, gillnets, handlines, trolling gears, and vertical line gears), which showed fisher densities higher than ten fishers per cell.

Fishing ground maps for each gear category were also produced, in order to understand the total density and use for each gear class. Four gear category maps were created to describe the density of fishers for each important gear class: line gears, net gears, dive gears, and traps. The gear category maps contain the same features and elements of the individual gear maps, namely the bathymetry contour lines (by their depth in meters), the four buoys in the southwest, and the Puerto Rican municipalities. The maps also display benthic habitat; however, in addition to showing the coral reef and seagrass habitats, other types of habitat are shown, such as sand, mud, mangroves, and uncolonized bedrock. Additionally, marine reserves are also illustrated on the map, with the main marine reserves around Mona Island and Monito Island, Desecheo Island, and the Canal de Luis Peña Natural Reserve in Culebra. The marine reserves around Mona, Monito, and Desecheo islands prohibit fishing activities within one mile of the coast of such islands. The Canal de Luis Peña Natural Reserve in Culebra is completely closed off to any kind of fishing activities.
The light blue shading denotes the lowest densities, whereas the yellow and red colors indicate the highest concentrations of fishers for each cell. Figure 3.11 illustrates the maximum fishing grounds for line gears. Line gears were used throughout the entire island, in shallow and deep waters alike. However, the highest intensities of line gear use were located in the southwest, just south of Cabo Rojo, Lajas, and Guánica, where concentrations reached 17 to 32 fishers per cell, and along the west and northern coasts. In the west, densities of 33 to 48 could be found around the Corona del Medio and near Desecheo Island. Along the northwestern coast, between Aguadilla, Isabela, and Quebradillas, concentrations of 33 to 48 fishers per cell were also present. The highest
fisher densities (41 to 62 fishers per cell), however, were found along the north coast, from Barceloneta to San Juan, and especially in front of Dorado, in mid-depth waters (deeper than 200 meters, but shallower than 500 meters).

![Net Gears Fishing Grounds Map](image)

**Figure 3.12: Net Gears Fishing Grounds Map**

Net gears, like line gears, were also employed throughout the entire island. However, most of the use was limited to shallower waters, and only in select areas were the nets fished in waters deeper than 500 meters. Areas of high density of fishers, more than 10 fishers per cell, were found in three different pockets around the island. One high density area was in the north coast from Vega Alta to Dorado. Another high density area was in the west, off Mayagüez, and along the southwest, just south of Cabo Rojo, Lajas,
and Guánica. Interestingly, the highest fisher density in the southwest (26 to 31 fishers per cell) was found leeward of the coral reef ecosystems. In many cases, the insular shelf drop-off is the limit to the net use areas.

Figure 3.13: Dive Gears Fishing Grounds Map

Figure 3.13 depicts the areas of dive gears use in Puerto Rico. Diving gears were used throughout the entire main island, with the exception of the northern coast from Quebradillas to Barceloneta. The northern coast, in general, contained low densities of fishers using the dive gears. The eastern, southern, and western coasts possessed higher densities of fishers (9 to 24 fishers per cell); however, the highest concentration was located in the southwestern quadrant, with Cabo Rojo and Lajas containing the most
fishers per cell; approximately 25 to 40 fishers were located within some cells in the southwest. It is important to note that higher concentrations, not only in the southwest, but also along the south coast, especially near Caja de Muertos Island, along Vieques and Culebra, and off Fajardo, tend to be found close or over coral reef and seagrass habitats. Also, in general, diving gears are limited to shallow waters, with the insular shelf drop-off at 200 meters depth being the outermost boundary for gear use. However, the delineation of the 200 meter depth limit for diving could, in fact, have been due to some cells extending into deeper water and respondent error, such that the actual limit for dive use should be shallower (<100 meters).

Finally, Figure 3.14 describes the patterns of use for trap gears, which are comprised of fish traps and lobster traps. Trap gears were present all over Puerto Rico, including Vieques and Culebra, with the exception of two small areas; one of these areas was off Ponce in the south, and the other was off Aguada and most of Aguadilla in the northwest. While most of the density throughout the island tended to not be greater than six fishers per cell, several areas of seven or more fishers per cell using traps were found. In the north coast, Barceloneta exhibited a density of about seven to nine fishers per cell, from the shoreline to the 200 meter depth contour. Also, a few areas along the southwest, off Cabo Rojo and Lajas, near the coralline habitats of the region, also presented fisher densities of about seven to nine fishers per cell. In the east coast, just off Yabucoa and Humacao, south of Culebra, and along the southern and eastern shorelines of Vieques, areas of seven to twelve fishers per cell were found. The highest density of fishers (13 to 18 fishers per cell) was found in the southern coast, from Juana Díaz to Salinas, along
coralline and seagrass habitats. Furthermore, trap gears seemed to also be limited to shallow waters, and rarely, traps were fished in waters deeper than 500 meters (along the north coast). Also, some trap use was found in the shallow waters of the Corona del Medio, in the Mona Passage.

When comparing categories of gears, it was evident that line gears were the most widely used gear on the island, and the gear category exhibits the highest concentrations of fishers per cell, with a maximum of 62 fishers per cell. Dive gears represented the second highest maximum fisher density (up to 40 fishers per cell), with net gears following with the third highest fisher density (with a maximum of 31 fishers per cell).
Trap gears displayed the lowest maximum density among all gear categories, with only up to 18 fishers per cell. In terms of area, line gears were the most widespread, while the other three gear categories appeared to use approximately the same areas, and were also limited to waters no deeper than 500 meters. Only line gears were consistently fished in waters deeper than 1,000 meters.

3.1.2 Fishing Intensity Maps

To better understand the area use by gear category, each cell in the individual gear maps was multiplied by the corresponding number of annual trips for each fisher. Once each cell reflected the number of possible annual visitation trips for each gear, the individual gears were grouped by gear category, just as was done for the gear category fishing ground maps. The resulting maps describe the pattern of use for each gear category, and the value of each cell reflects the maximum possible annual fishing intensity, not necessarily the actual annual fishing intensity in that cell for the given gear type.

The fishing intensity maps are similar to the fishing grounds maps for each gear category, since the maps display Puerto Rico, including Vieques, Culebra, Mona, and Monito, Desecheo, and Caja de Muertos islands, with the main island divided into the different municipalities. Also, the bathymetry-intersect layer, used in the Ordinary Least Squares (OLS) regression analysis, is shown, to indicate the several water depth contours, used in the fisher density maps, but in grid-polygon form. The bathymetry-intersect polygon layer is the bottom-most layer, shown in grid-form with white cells.
Additionally, the benthic habitat categories of uncolonized hardbottom, submerged vegetation (which includes both seagrass and macroalgae), coral reefs and colonized hardbottom, mangroves, unconsolidated sediments (i.e. sand and mud), and other and unknown habitats, are shown in patterns, with hollow backgrounds; however, mangroves are the only habitat category that is shown in color (green) with a green background as well. The benthic habitat layer used for the total possible annual visitation trips maps is the same habitat-intersect layer that was utilized to perform the OLS tests. Such representation of the benthic habitat was used in order to avoid clutter, and to allow the application of a brighter color spectrum to the possible annual visitation trips spatial layer. The grid layer describing the areas of total possible annual visitation trips is displayed with each cell color-coded according to the corresponding one of the five possible fishing intensity categories.

Figure 3.15 shows the line gear total possible annual visitation trips, revealing several trends. First, even though line gears were widely used throughout the island, the highest possible annual visitation trips took place along the north coast, off the west coast, along the western half of the south coast, and to a lesser extent, around Culebra. Also, a considerable number of possible trips took place in deep, offshore waters along the north coast, and along the south coast, especially in the southwestern corner of Cabo Rojo, Lajas, and Guánica. Over 4,000 trips may take place each year on the seaward edge of the coral reefs off Lajas and Guánica, along the insular shelf drop off. Within the Mona Passage in the west, the area between Bajo de Sico and Corona del Medio also may receive over 4,400 trips annually. The same intensity was found from Desecheo Island to
Rincón, and northward along the coast, following the insular shelf from Rincón to Hatillo. The last area of heavy possible intensity was found along the north coast, from Barceloneta to San Juan, in waters shallower than 500 meters.

Figure 3.15: Line Gears Fishing Intensity Map

Figure 3.16 corresponds to the total possible annual trips for all net gears. Similar to the net gear fishing grounds map, the maximum fishing intensity (2,503 to 4,321 possible annual trips) was found in the southwestern corner, just south of Cabo Rojo, Lajas, and Guánica, all the way from the shoreline to the insular shelf edge. Also, a few areas of lesser possible fishing intensity (1,525 to 2,502 possible annual trips), were found off Rincón and Mayagüez in the west, Patillas and Maunabo in the southeast, and
Barceloneta, Vega Alta, and Dorado in the north. Zones of medium possible annual net gear fishing trips were located along the insular shelf of the shallow off the southwest (along the southwestern buoys), along the southeast from Salinas to Humacao, along the western coast from Mayagüez to Rincón, and off Manatí and Vega Baja in the north coast. In contrast to the net gear fisher density map, even though the area surrounding Culebra contained a moderate fisher density per cell, within the total possible annual visitation trips map, the waters around Culebra received the lowest possible amount of possible fishing intensity. The same situation applied to the waters east of Fajardo and Ceiba, and the area north of Rio Grande and Loiza.

Figure 3.16: Net Gears Fishing Intensity Map
Figure 3.17 illustrates the maximum possible fishing intensity for dive gears. Relatively standard intensities were evident throughout most of the island. Most areas, except for the north coast and off Guayama, Arroyo, and Patillas, showed intensities of the second or higher levels. Areas of moderate intensity (1,753 to 2,785 possible annual visitation trips) occurred from Peñuelas to Santa Isabel in the south coast, off Yabucoa and Humacao in the southeast, around Vieques and west of Culebra, and east of Fajardo. The waters around Culebra experienced some moderately high fishing intensity, where most cells received from 2,786 trips to a possible maximum of 4,011 trips per year. Nevertheless, the areas with the highest fishing intensity, where each cell may experience anywhere from 4,011 trips to 6,568 trips annually, covered the southwestern corner, from just south of Mayagüez, along the southwestern coast to Yauco, all of which contain large expanses of seagrass and coral reefs.

The last fishing intensity map, which corresponds to the trap gears, is represented in Figure 3.18. The traps were deployed to varying degrees, even within the same coasts. For instance, along the north coast, off the coast of Isabela, there are cells that received the lowest level of intensity (12 to 228 trips), while other cells experienced higher possible number of trips annually, (229 to 462 trips). The waters along Quebradillas, Camuy, and Hatillo all had the lowest level of intensity; whereas, on the eastern part of the northern coast, from San Juan to Luquillo, each cell experienced a moderate level of intensity (463 to 816 possible annual trips).
The east coast fishing intensity tended to be low, with no more than 228 possible annual trips. However, both Vieques and Culebra, experienced a moderate to high moderate amount of possible fishing intensity (463 to 816, and 817 to 1,440 possible annual trips, respectively). Moderate to low levels of possible intensity was found off the southwestern coast, from western Cabo Rojo to Guánica. Similar to the trap gears fisher density map, the highest concentration of possible annual visitation trips (from 817 to 2,268) was found along the southern coast, from Juana Díaz to Salinas, especially around the seagrass beds and coral reefs near the Caja de Muertos Island.
In terms of comparing the different categories of gears, the line gears experience the highest possible intensity per cell (a maximum of 7,166 possible annual trips), followed by dive gears (a maximum of 6,568 possible annual trips), net gears (4,321 maximum possible annual trips), and trap gears (a maximum of 2,268 possible annual trips). These results are quite similar to the fisher density maps, which followed the same order; but in terms of fisher density, the gears with the highest densities were line and dive gears, and the gears with the lowest fisher densities were net and trap gears, respectively.

Figure 3.18: Trap Gears Fishing Intensity Map
3.2 Ordinary Least Squares Regression Analysis Results

The first part of the data analysis concerns with a GIS-based regression function, which describes the relationship between the gear type used (i.e. handline, gillnet, lobster trap) and the depth ranges (i.e. 0-100 meters, 101-200 meters), as well as the relationship between the gear type used and the benthic habitat (i.e. uncolonized hardbottom, seagrass). When utilizing ESRI’s ArcGIS 10.0 to perform the regression analysis, the Ordinary Least Squares (OLS) function from the Spatial Statistics toolbox produces two sets of information:

- The numerical regression values, and
- New map layer displaying the spatial correlation and standard deviation values

The first set of data pertains to the statistical results of the regression function, displayed on a separate pop-up window. The results window of the OLS is separated into three main subsections, namely the Summary of OLS Results, OLS Diagnostics, and Notes on Interpretation. For purposes of the present thesis, the OLS Diagnostics section provided the most relevant results, given that the most basic, yet vital, statistical results were presented within such section. For instance, the number of observations, the number of variables, the degrees of freedom, the multiple R-squared, and the adjusted R-squared results were all summarized in the OLS Diagnostics section. Furthermore, within the above mentioned statistical descriptors, the multiple R-squared results were compiled and organized in the following four tables below.
Table 3.1: OLS Results: Depth: Individual Gears

<table>
<thead>
<tr>
<th>Gear Type</th>
<th>Multiple R-Squared</th>
<th>Adjusted Multiple R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gear 01-Handline</td>
<td>0.133784</td>
<td>0.133740</td>
</tr>
<tr>
<td>Gear 02-Anchored vertical line</td>
<td>0.081278</td>
<td>0.081232</td>
</tr>
<tr>
<td>Gear 03-Vertical line with buoy</td>
<td>0.040237</td>
<td>0.040188</td>
</tr>
<tr>
<td>Gear 04-Other vertical line</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 05-Horizontal longline</td>
<td>0.069107</td>
<td>0.069060</td>
</tr>
<tr>
<td>Gear 06-Shark longline</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 07-Other longline</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 08-Trolling line</td>
<td>0.025708</td>
<td>0.025658</td>
</tr>
<tr>
<td>Gear 09-Trolling rods</td>
<td>0.012317</td>
<td>0.012266</td>
</tr>
<tr>
<td>Gear 10-Rod and reel</td>
<td>0.023016</td>
<td>0.022967</td>
</tr>
<tr>
<td>Gear 11-Other line gear</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 12-Gillnet</td>
<td>0.074558</td>
<td>0.074511</td>
</tr>
<tr>
<td>Gear 13-Lobster trammel net</td>
<td>0.026867</td>
<td>0.026817</td>
</tr>
<tr>
<td>Gear 14-Fish trammel net</td>
<td>0.058691</td>
<td>0.058644</td>
</tr>
<tr>
<td>Gear 15-Bait cast net</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 16-Shrimp cast net</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 17-Beach seine</td>
<td>0.027203</td>
<td>0.027154</td>
</tr>
<tr>
<td>Gear 18-Wahoo seine</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 19-Ornamental fishery nets</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 20-Other net gears</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 21-SCUBA diving</td>
<td>0.137156</td>
<td>0.137113</td>
</tr>
<tr>
<td>Gear 22-Skin diving</td>
<td>0.080462</td>
<td>0.080415</td>
</tr>
<tr>
<td>Gear 23-Other diving</td>
<td>0.009611</td>
<td>0.009561</td>
</tr>
<tr>
<td>Gear 24-Fish traps</td>
<td>0.138089</td>
<td>0.138045</td>
</tr>
<tr>
<td>Gear 25-Deep water snapper fish traps</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 26-Lobster traps</td>
<td>0.033562</td>
<td>0.033513</td>
</tr>
</tbody>
</table>

This table presents the results of the Multiple-R Square and the Adjusted Multiple-R Square from the Ordinary Least Squares regression results displayed in the OLS results window. The Multiple-R Square is represented as a decimal number; however, when multiplied by 100, it represents the multiple regression coefficient percentage. Thus, a Multiple-R Squared result of 0.133784 can be interpreted as
approximately thirteen percent (13.3784%). The Adjusted Multiple R-Squared values account for any variability that may arise when calculating Multiple R-Squared with more than one independent variable. In the present thesis, only one independent variable was utilized when calculating each Ordinary Least Squares regression test; thus, even though the Adjusted Multiple R-Squared were given in each table, the Multiple R-Squared values were the focus of the OLS analyses results. When performing the OLS test on the depth ranges, the bathymetry contour was the only independent variable used. The Contour column from the bathymetry-intersect layer contained the bathymetry value for each cell, expressed as a depth range. For example, one cell may have a Contour value of negative one-hundred (-100), which represents the 0-100 meter depth range. The neighboring cell may have a Contour value of negative two-hundred (-200), which means that the depth in the cell ranges from 101 meters to 200 meters. Whereas, when the OLS test was applied to the benthic habitat, the coded habitat values were used as the only independent variable. The Habitat Code column in the attribute table of the habitat-intersect layer contained the six habitat categories (aggregation of all habitat types of a given category, i.e. submerged vegetation, coral reefs and colonized hardbottom) numerically coded for each cell. For example, a cell close to the shoreline may have a Habitat Code value of one (1), which means that the benthic habitat present in the cell is uncolonized hardbottom. However, the neighboring cell may have a Habitat Code value of four (4), denoting that mangroves are the habitat covering the given cell. Thus, even though there were six categories of habitat, and five different depth ranges, those categories were the only two independent variables used in the OLS regression tests.
Table 3.1 represents the relationships between the individual gear type used and the depth ranges. The gears with the highest Multiple R-Squared percentages are Gear 24 (13.8089%), Gear 21 (13.7156%), and Gear 01 (13.3784%), respectively. All other gear types produced Multiple-R Squared values of less than ten percent (10%), with Gear 10 (2.3016%), Gear 09 (1.2317%), and Gear 23 (0.9611%), each representing the lowest three Multiple R-Squared results.

Table 3.2: OLS Results: Depth: Gear Categories

<table>
<thead>
<tr>
<th>Gear Category</th>
<th>Multiple R-Squared</th>
<th>Adjusted Multiple R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Gears</td>
<td>0.091725</td>
<td>0.091679</td>
</tr>
<tr>
<td>Net Gears</td>
<td>0.076474</td>
<td>0.076427</td>
</tr>
<tr>
<td>Diving Gears*</td>
<td>0.147248</td>
<td>0.147205</td>
</tr>
<tr>
<td>Traps</td>
<td>0.120321</td>
<td>0.120276</td>
</tr>
<tr>
<td>Diving Gears (All)**</td>
<td>0.149854</td>
<td>0.149811</td>
</tr>
</tbody>
</table>

*Excludes Gear 23
**Includes Gear 23

Table 3.2 describes the relationship values that exist between the gear categories (aggregation of all gears of a given category, i.e. line gears, net gears). Overall, diving gears (whether including Gear 23 or not) represent the strongest relationships among all gear categories, with a Multiple R-Squared value close to 15%. Net gears, on the other hand, depict the gear category with the weakest relationship to depth ranges, with a Multiple-R Squared value of approximately 8%.

Whereas the Multiple-R Squared results for the OLS test for individual gears and depth ranges did not vary considerably, the habitat category and individual gear OLS test Multiple-R Squared values are extremely diverse. Table 3.3 shows the habitat category and individual gear OLS test results. The highest three Multiple R-Squared results were
represented by Gear 01 (34.4209%), Gear 24 (27.3504%), and Gear 21 (21.0151%), respectively. In contrast, the lowest three Multiple-R Squared values were described by Gear 23 (3.1794%), Gear 03 (0.4452%), and Gear 09 (0.1027%). The range from the highest Multiple-R Squared value to the lowest is 34.3182%. Thus, there is a difference of about twenty-one percent (21.4704%) in the variability between the Multiple-R Squared results for the habitat-individual gear OLS test and the bathymetry-individual gear OLS analysis.

Table 3.3: OLS Results: Habitat: Individual Gears

<table>
<thead>
<tr>
<th>Gear Type</th>
<th>Multiple R-Squared</th>
<th>Adjusted Multiple R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gear 01-Handline</td>
<td>0.344209</td>
<td>0.343996</td>
</tr>
<tr>
<td>Gear 02-Anchored vertical line</td>
<td>0.171088</td>
<td>0.171046</td>
</tr>
<tr>
<td>Gear 03-Vertical line with buoy</td>
<td>0.004452</td>
<td>0.004401</td>
</tr>
<tr>
<td>Gear 04-Other vertical line</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 05-Horizontal longline</td>
<td>0.175494</td>
<td>0.175452</td>
</tr>
<tr>
<td>Gear 06-Shark longline</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 07-Other longline</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 08-Trolling line</td>
<td>0.065323</td>
<td>0.065276</td>
</tr>
<tr>
<td>Gear 09-Trolling rod</td>
<td>0.001027</td>
<td>0.000976</td>
</tr>
<tr>
<td>Gear 10-Rod and reel</td>
<td>0.108630</td>
<td>0.108584</td>
</tr>
<tr>
<td>Gear 11-Other line gear</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 12-Gillnet</td>
<td>0.143253</td>
<td>0.143209</td>
</tr>
<tr>
<td>Gear 13-Lobster trammel net</td>
<td>0.040666</td>
<td>0.040618</td>
</tr>
<tr>
<td>Gear 14-Fish trammel net</td>
<td>0.105874</td>
<td>0.105828</td>
</tr>
<tr>
<td>Gear 15-Bait cast net</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 16-Shrimp cast net</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 17-Beach seine</td>
<td>0.056573</td>
<td>0.056526</td>
</tr>
<tr>
<td>Gear 18-Wahoo seine</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 19-Ornamental fishery net</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 20-Other net gear</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Gear 21-SCUBA diving</td>
<td>0.210151</td>
<td>0.210111</td>
</tr>
<tr>
<td>Gear 22-Skin diving</td>
<td>0.175144</td>
<td>0.175102</td>
</tr>
</tbody>
</table>
Table 3.4 displays the results for the OLS regression analysis of the habitat category and gear category relationship. This table is similar to Table 3 that it presents the Multiple-R Squared values for the OLS performed on the gear categories, instead of the individual gear types. The strongest Multiple R-Squared value is represented by the trap gears (24.5365%), and the net gears contain the weakest Multiple R-Squared value (13.9483%).

**Table 3.4: OLS Results: Habitat: Gear Categories**

<table>
<thead>
<tr>
<th>Gear Category</th>
<th>Multiple R-Squared</th>
<th>Adjusted Multiple R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Gears</td>
<td>0.206419</td>
<td>0.206379</td>
</tr>
<tr>
<td>Net Gears</td>
<td>0.139483</td>
<td>0.139440</td>
</tr>
<tr>
<td>Diving Gears*</td>
<td>0.237297</td>
<td>0.237259</td>
</tr>
<tr>
<td>Traps</td>
<td>0.245365</td>
<td>0.245327</td>
</tr>
<tr>
<td>Diving Gears (All)**</td>
<td>0.245032</td>
<td>0.244993</td>
</tr>
</tbody>
</table>

*Excludes Gear 23
**Includes Gear 23

### 3.3 Fishing Intensity by Gear Category Graphs

The total possible gear type annual trips for each habitat class bar graph, shown in Figure 24, show potential gear-habitat use patterns. Supporting the spatial-use maps and information, line gears are the most used gear among all categories, followed by dive gears, net gears, and trap gears. The habitat that receives the most use is the other/unknown, with coral reefs habitats and submerged vegetation being the second and
third habitat classes, respectively, that hosted high use. Trip totals for all cells of a particular habitat exceeded a million trips only in only four instances, out of a possible 24, corresponding to line and dive gears for both coral reefs and other/unknown habitats. In terms of line gears only, the other/unknown habitat category receives a disproportionate amount of use when compared to the other habitat types. For both net and dive gears, the use is much more evenly distributed among all habitats, and each gear is used in both coral reef ecosystems and other/unknown habitats equally. Trap gears are used more frequently in other/unknown habitats followed by coral reef and colonized hardbottom habitats. Overall, the uncolonized hardbottom habitat class experiences the least amount of gear use, followed by mangroves and unconsolidated sediments.

3.3.1 Habitat Graphs

![Graph of Total Possible Gear Category Annual Trips per Habitat](image)

**Figure 3.19:** Total Possible Annual Trips per Habitat (Gear Category)
The results presented in Figure 3.20 corroborate the patterns described in Figure 3.19; however, the use is expressed as a proportion instead of number of total possible annual trips for all cells of a given habitat. The other/unknown, coral reef and colonized hardbottom, and the submerged vegetation habitat classes receive the most use, whereas unconsolidated statements, mangroves, and uncolonized hardbottom receive the least use, respectively. The use patterns for trap gears are easier to discern when viewed as percentages. The other/unknown habitat category accounts for over half of the use for trap gears, and coral reef habitats experience over 30% of the trap gear use, and submerged vegetation habitats explain 10% of the total trap use.
Figure 3.21: Line Gears Habitat Use (Percentage)

Figure 3.22: Net Gears Habitat Use (Percentage)
Figures 3.21 to 3.24 describe the percentage breakdown of habitat use for each individual gear class, and provide numerical values for such percentages. As is evident from the line gears and net gears piecharts, the other/unknown habitat class accounts for over three fourths of the entire habitat use, and for net gears that number is just above one third of the habitat use. In terms of net gears, however, coral reef and submerged vegetation area uses correspond to approximately 50% of the total habitat use.

**Dive Gears Habitat Use (Percentage)**

In terms of dive gears and trap gears, the other/unknown habitat category also describes the highest use of any habitat class. However, for dive gears, the use of coral reef and colonized hardbottom habitats corresponds to the same percentage as the use of other/unknown habitat, with 38% each.
For net gears, the proportion of use between both the coral reef and other/unknown habitat classes are similar to those of trap gears; nevertheless, the other/unknown habitats account for 38% of the use, while the coralline habitats correspond to 36%.

### 3.3.2 Depth Range Graphs

The total possible annual gear category trips per depth range bar graph, depicted in Figure 3.25, is quite revealing. First, even though line gears are used widely among all different depth ranges, the gear class is not used frequently in waters that range from more than 100 to 200 meters in depth. Also, waters that are deeper than 500 meters, but shallower than 1,000 meters, received the highest number of trips per year for all cells of a given depth range, accounting for approximately 3.25 million trips annually. Dive, net,
and trap gears all are used disproportionately in shallow waters, no deeper than 100 meters. However, some diving, net, and trap use was reported in waters deeper than 100 meters, but shallower than 1,000 meters, covering three different depth ranges (101-200 meters; 201-500 meters; and 501-1000 meters). Overall, only line gears were found to be employed in deep waters, deeper than 1,000 meters, and all gears showed the lowest level of use in waters that range from 100 meters to 200 meters. Dive gear use was higher than line gear use in shallow waters (from 0-100 meters) with approximately 2.7 million trips annually, compared to just over 2.5 million trips for line gears in shallow water.

**Figure 3.25: Total Possible Annual Trips per Depth Range (Gear Category)**

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2 It is likely that error resulted from respondents giving the wrong areas or using cells that were at the drop off that showed gear use in deeper waters. In some areas of Puerto Rico, the bathymetry values drop significantly within short distances. Thus, some cells in the paper map contained two or three water depth contour lines, resulting in some gears showing use in deeper waters, when in reality, the actual depth limit for that gear may have been the shallowest depth represented within the cell.
Figure 3.26 shows that waters that range from 501-1000 meters in depth accounted for approximately 30% of the total line gear use, whereas the other depth ranges corresponded to between 20% and 25% each, with the exception of the 101-200 meters bathymetry range, which described less than five percent of total use. The disproportionate use of the other gear categories in waters shallower than 100 meters was also evident; the 0-100 meter depth range accounts for over sixty percent for dive, net, and trap gear use. All other bathymetry ranges corresponded to less than twenty percent for each gear category, with the exception of line gears. Overall, the second shallowest depth range (101-200 meters) accounted for less than five percent of the use for all gear categories, and waters deeper than 1,000 meters corresponded to negligible use for net and trap gears, and no use for dive gears.
Figures 3.27-3.30 break down the percentage of use for each individual gear category. The pie charts illustrate the high gear use for the shallow water depth range of 0-100 meters for net, dive, and trap gears. For line gears, the use was much more evenly distributed among the bathymetry ranges, with most ranges, except for the 101-200 meters range, accounting for approximately one fourth to one third of the use. Both net and trap gears attributed between 13% and 17% to the 201-500 meters and 501-1000 meters ranges.
meters bathymetry ranges each. However, diving gears were almost exclusively limited to the shallow waters (0-100 meters), with the other depth ranges accounting for less than ten percent.
Chapter 4.0: Discussion

The fishing grounds and possible annual intensity fishing maps, the regression values of the relationships between gear and benthic habitat and between gear and bathymetry range use, and the charts and graphs describing the patterns of gear use for both habitat and water depth provide essential information detailing the spatial gear usage within the Puerto Rico commercial fisheries. The results provided an in-depth insight into the complexities that exist within the multi-species and multi-gear fisheries of the island, by increasing the understanding of the relationships between gear and two important geo-environmental variables, namely benthic habitat and water depth. However, the results also shed light on the limitations of the methods employed in carrying out the field work of the present thesis, dealing mainly with the map used for the data gathering session. The thesis provides spatial distribution of gear in the context of very coarse (and sparse) independent spatial data such as depth and habitat type. In reality, fishers choose the gear type on the basis of target species, whose habitats are depth correlated. Thus, in the wake of limited depth and habitat data, and catch data that could not be accessed during the time of analyses, the spatial distribution of gear use and use intensity provides preliminary measures of extent of fishing grounds, and fishing intensity. The discussion presents explanations for all of the results stemming from the analysis, taken within the context of the literature review presented in the first chapter of the current thesis.
4.1 Line Gears Use

Both the fisher density and the possible fishing intensity maps present quite interesting finds. However, certain questions also arise from glancing at the maps. The line gears fisher density map describes high density areas along the northern coast and in offshore waters off the west coast. Even though the highest concentration of fishers are found along the west coast (Shivlani, 2011), the north coast holds the highest densities of line fishers, quite close to the coast—within the short insular shelf that runs along the northern coast (Griffith and Valdés-Pizzini, 2002). Also, the north coast experiences large amounts of possible annual fishing intensity along the coast, mainly along the northwest, and from Barceloneta to San Juan, and, to a lesser extent, off Arecibo and the northeast. Additionally, offshore waters off the entire northern coast details a modest amount of line gear use, several miles off the insular shelf drop-off. By taking a closer look at the fisher density and possible fishing intensity maps, most of the use of line gears that takes place in waters deeper than 1,000 meters off the north and south coasts can be attributed to trolling gears. Vertical line gears are mainly responsible for the fishing that takes place within the Mona Passage, which contains a wide variety of depths, and is usually shallower than 1,000 meters along the insular shelf that connects Puerto Rico with the Dominican Republic, and the islands of Mona, Monito, and Desecheo; however, some trolling does take place within the Mona Passage.

The correlation values from the regression results are not significant across for any gear category for neither the depth range nor the habitat categories analyses, since the Multiple-R Squared values are not statistically relevant. In fact, the highest correlation
factor for the depth range tests is just under fifteen percent (14.7248%) for dive gears, and the strongest relationship between gear use and benthic habitat corresponds to trap gears, at approximately twenty-five percent (24.5365%). Line gears have the second lowest correlation factors for both water depth and benthic habitat; thus, by relying only on the regression analysis, it cannot be inferred that line gears, or any gear for that matter, are strictly determined by either bathymetric ranges or benthic habitat. Nevertheless, other studies have shown that fishers rely on water depth when demarcating and using fishing areas (Daw, 2008; Anuchiracheeva, 2003; Griffith and Valdés-Pizzini, 2002).

In terms of water depth, both the bar and pie graphs that depict percentage breakdowns per bathymetric ranges, it is evident that line gear use is fairly evenly distributed among the different depths, with the only exception being the 101-200 meter depth range, which accounts for only about two percent (2%) of the use. However, when comparing the total area of the different bathymetry ranges, it is noticeable that the 101-200 meter depth range is significantly smaller in area than the rest of the bathymetry ranges, by a margin of almost two thousand (2000) miles to the next smallest depth range area. Thus, the low use of line gears within the 101-200 meter bathymetry range may be attributed not to fisher preference for that given depth range, but rather to the small area, within the 101-200 meter depth range, available for fishers to use. Table 6 details the rest of the areas for each depth range used in the analysis.
Table 4.1: Area Measurements by Bathymetry Range

<table>
<thead>
<tr>
<th>Depth Range (meters)</th>
<th>Total Area (in miles$^2$)</th>
<th>Area (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>3426.10</td>
<td>11.29</td>
</tr>
<tr>
<td>101-200</td>
<td>937.30</td>
<td>3.09</td>
</tr>
<tr>
<td>201-500</td>
<td>2897.16</td>
<td>9.54</td>
</tr>
<tr>
<td>501-1000</td>
<td>3862.29</td>
<td>12.72</td>
</tr>
<tr>
<td>Deeper than 1000</td>
<td>19236.75</td>
<td>63.36</td>
</tr>
<tr>
<td><strong>Total Area</strong></td>
<td><strong>30359.60</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

The same process employed to create the bathymetry area table, Table 4.1, was replicated to produce the habitat area table, Table 4.2, and the habitat area by water depth table, Table 4.3, which are both shown below. The other/unknown habitat class, as well as the coral reefs and submerged vegetation habitat categories are the habitats that cover the largest expanses, with the other three categories, uncolonized hardbottom, mangroves, and unconsolidated sediments, each covering less than 35 miles.

Table 4.2: Area Measurements by Habitat Category

<table>
<thead>
<tr>
<th>Habitat Class</th>
<th>Total Area (in miles$^2$)</th>
<th>Area (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncolonized Hardbottom</td>
<td>0.34</td>
<td>0.01</td>
</tr>
<tr>
<td>Submerged Vegetation</td>
<td>340.53</td>
<td>14.40</td>
</tr>
<tr>
<td>Coral Reef and Colonized Hardbottom</td>
<td>356.93</td>
<td>15.10</td>
</tr>
<tr>
<td>Mangroves</td>
<td>34.28</td>
<td>1.45</td>
</tr>
<tr>
<td>Unconsolidated Statements</td>
<td>23.06</td>
<td>0.98</td>
</tr>
<tr>
<td>Other/Unknown</td>
<td>1609.32</td>
<td>68.06</td>
</tr>
<tr>
<td><strong>Total Area</strong></td>
<td><strong>2364.45</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

In terms of habitat area by depth range, the 501-1000 meter bathymetric range contains approximately one-fourth of the total habitat cover, the 201-500 meter depth range accounts for just over twenty-two percent (22.26%) of the total benthic habitat area, the
two shallower depth ranges comprise approximately 20% of the habitat cover each, and
the deepest water range contains the least amount of habitat cover—just under fourteen
percent (13.77%).

Line gears are used, in the majority of cases, within the other/unknown habitat
areas. The next significant habitat category were line gears are employed, are coral reefs,
with approximately 12% of the use, while each of the other categories receive less than
five percent of the usage. The percentage use of the line gears within the above
mentioned habitat classes may, in fact, be due to the large expanses that both habitats
cover, and the relatively smaller presence of the other habitats. Given that 74% of the line
gear use takes place in waters deeper than 200 meters, and approximately sixty percent
(60.66%) of the benthic habitat coverage are located in such waters, the possibility of a
relationship existing between the line gears and the deep water habitats is plausible.
Several fishers of southeastern Puerto Rico, interviewed by García- Quijano (2007), claim
that open pelagic waters have the least amount of species. However, small-scale fishers in
the Wider Caribbean area are known to target sizeable pelagic fish species that travel
through offshore waters within the region (Chakalall et al., 2007).

The analysis results seem to indicate that line gear usage is not necessarily
dependent upon benthic habitat type, or water depth. Instead, another factor may be
responsible for such widespread usage of line gears over all habitats and depth ranges.
Line gears usage may then be fish species-dependent, targeting the specific species across
the wide variety of habitats and depth ranges. Tonioli and Agar (2009), conducted a study
on a seasonal closure area off the western coast of Puerto Rico, the Bajo de Sico, in
which they found that the fishers interviewed for the research resorted to using several line gears, such as longline and hook-and-line, in the area. The reason for resorting to those specific was to target specific fish, namely the snapper and grouper species. Similarly, the line gear usage patterns found within the present thesis raises evidence target species may be a more important variable than water depth and habitat, and may corroborate those findings of Tonioli and Agar (2009).

Table 4.3: Area Measurements of Habitat by Depth Range

<table>
<thead>
<tr>
<th>Depth Range (in meters)</th>
<th>Total Area (in miles²)</th>
<th>Area (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>459.43</td>
<td>19.43</td>
</tr>
<tr>
<td>101-200</td>
<td>470.72</td>
<td>19.91</td>
</tr>
<tr>
<td>201-500</td>
<td>526.23</td>
<td>22.26</td>
</tr>
<tr>
<td>501-1000</td>
<td>582.40</td>
<td>24.63</td>
</tr>
<tr>
<td>Deeper than 1000</td>
<td>325.66</td>
<td>13.77</td>
</tr>
<tr>
<td><strong>Total Area</strong></td>
<td><strong>2364.45</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Most academic literature mentions habitat within the context of ecosystem-based management and environmental protection, as well as the use of certain fish species, mainly reef fish, of several habitat types, such as coral reefs, seagrass, and mangroves (Aguilar-Perera and Appeldoorn, 2008; CFMC, 1996; Chiappone et al., 2004; Freire and García-Allut, 2000; Jiménez, n.d.; Nelson et al., 2009; Ojeda, 2000; Pomeroy et al., 2010; Salas et al., 2007). However, few academic studies have discussed the use of habitats by fishers (Agar et al., 2008; Scholz et al., 2004). In fact, the Scholz et al. (2004) study, which was conducted with fishers in California, describes the importance of not only benthic habitats, but also of physical oceanography, as influential factors for the location of fish species targeted by fishers. While the analysis results presented in the current
thesis do not indicate a strong relationship between line gear use and benthic habitat and between line gear use and water depth, the data do not indicate the opposite either. In light of the findings of the literature review, the possibilities of habitat and water depth dictating line gear use cannot be dismissed.

### 4.2 Net Gears Use

The fisher density and possible fishing intensity maps indicate that most of the net gear use in Puerto Rico takes place within relatively shallow waters (500 meters or shallower), and mainly within the southwestern quadrant, and along the north coast (off Vega Alta and Dorado). The area along the north coast contains coral reefs, seagrass beds, and other/unknown habitats along the shoreline to the 200 meter water depth contour line. The waters off Cabo Rojo and Lajas, in the southwest, contain large amounts of coral reefs and seagrass beds within a few miles of the 200 meter bathymetry contour. When compared to the rest of the gear types, net gears have the lowest correlation factors for habitat class and bathymetry, 7.65% and 13.95% respectively. While the regression values indicate no relationship exists between gear use and habitat type and water depth, the percentage breakdown detailed in the pie charts describes a firm trend. In addition to being used in the most prevalent habitat type, other/unknown, one-third of the net gear use occurs within coral reef areas. Also, over two-thirds of the net gear usage takes place in the shallows—waters no deeper than 100 meters.

Net gears do, in fact, tend to be employed on or near coral reefs, given that nets are passive gears that are well built for fishing within coralline habitats (Acosta, 1994).
Also, depending on the type of net, whether gillnet or trammel net, different habitats may be targeted; however, reefs, seagrass beds, sandy flats, and mangroves tend to experience the highest net usage. The net gear use varies according to the coast as well, with use in the north coast taking place mainly within estuaries and mangroves, while the reefs and mangroves of the southern coast account for most of the net usage in that coast (Acosta and Valdés-Pizzini, 2005). Water depth around coral reefs is vital for effective net gear usage, namely shallow waters near the coral reef habitats allow the nets to fish a greater portion of the water column (Parrish, 1982). Thus, academic literature presents evidence that both water depth and benthic habitat are important factors in the spatial deployment of net gears in Puerto Rico. Even though the net gear correlation factors for both water depth and habitat type were the lowest among all gear categories, strong relationships between net gear usage and coral reefs and submerged vegetation habitats, as well as water depth, are highly plausible. In fact, the percentages of net gear use within coral reefs and submerged vegetation, as well as inside shallow waters (0-100 meters), substantiate the findings of the academic literature dealing net gear usage in coral reef and seagrass habitats of Puerto Rico. It is unclear whether net gears are employed to target certain species; however, demersal species, which are endemic to coral reef habitats, are often caught using net gears (Parrish, 1982). It is likely that a combination of factors contributes to the decision of employing net gears within a given area, mainly shallow waters and coral reef and seagrass habitats.
4.3 Dive Gears Use

Commercial diving is quite prevalent throughout the entire island, with the exception of waters along five municipalities of the northern coast. There are two centers of high dive use, namely the southwestern quadrant and around Culebra. Both of these areas are rich in seagrass and coral reef habitats, and both have large expanses of shallow water and wide insular shelves. In terms of the regression analyses results (though not significant), dive gears present the strongest correlation between gear use and water depth. Coral reefs and other/unknown habitats account for 38% of the dive gear use each, and submerged vegetation experiences 16% of the total dive gear usage. Regarding the water depth gear use, dive gears present the highest use of shallow water (0-100 meters) of any gear category, with 82%. Thus, when compared to the other gear classes, dive gears tend to have higher affinities for specific habitats, such as coral reefs and submerged vegetation, and for shallow waters.

The academic literature reviewed for the present thesis does not focus on the use of diving gears with respect to water depth nor habitat class. Also, with the exception of the Puerto Rico commercial fishery census reports, no other mention of commercial divers targeting a specific species or group of species was found for Puerto Rican commercial fisheries. However, the findings of the current thesis do point to the highly plausible relationship between dive gears and shallow waters, and among dive gears and coral reef and submerged vegetation habitats. Given that the results of the analysis cannot be corroborated by the literature referred to throughout the thesis, the findings should be treated as preliminary and could serve as a base or benchmark for future research.
4.4 Trap Gears Use

The employment of trap gears is common throughout much of Puerto Rico, with only areas of Rincón, Aguada, and Aguadilla, as well as off the coast of Ponce, with no fish or lobster trap usage. The possible annual fishing intensity map for traps, when compared to the other possible annual fishing visitation gear use maps, depicts fairly uniform usage, with many areas of moderate intensity, and few areas with low usage. The area with the highest use centers on the seagrass beds and coral reefs east of Caja de Muertos Island and off Santa Isabel and Salinas. Also, the water depth limit for the high possible intensity tends to be the 500 meter contour. Over half of the trap gear use takes place on the other/unknown habitats, and about one-third of the usage is accounted for in the reef systems. Submerged vegetation comprises the third largest use habitat, with approximately 10% of the total trap use. In terms of water depth, close to two-thirds of the gear use is limited to the shallowest waters (0-100 meters), while the 201-500 meter and the 501-1000 meter together account for about a third of the trap usage. The correlation values for trap gears was the highest among all gears for the habitat regression test, and was the second highest result for the gear-bathymetry relationship. Thus, the results suggest a strong relationship between trap gear use and shallow water, as well as among trap usage and coral reefs and, to a lesser extent, submerged vegetation habitats.

Several studies within the academic literature have investigated the relationship between trap use and ecosystem characteristics. In terms of benthic habitat, sand flats have proven to be environments where the trap use is effective; mainly due to the refuge the traps provide the species within a mainly barren seascape (Parrish, 1982). Given the
passive quality of traps as gears, they are considered as useful gears effective at fishing within the diverse coral reef systems (Acosta, 1994). Trap usage is widespread to a large variety of habitats, and at varying depths; however, the decision of where to place the traps is sometimes contingent on the target species. Furthermore, traps are not limited by bathymetry; some traps are set in shallow waters, while others may be deployed along the beril, or insular shelf drop-off (Agar et al., 2008). Thus, the findings of the current thesis agree with the academic literature research performed on trap usage in Puerto Rico.

4.5 Overall Gear Usage and Further Discussion

The spatial characterization of any given fishery is essential for fisheries and ecosystem management by providing the following:

1. A spatial representation of use;

2. Port-fishing ground linkages;

3. Areas of within group and inter-group use conflicts;

4. Gear impact areas (ex., sensitive habitats being affected by gear use);

5. The identification of important fishing grounds and fishery aggregation sites;

6. An aid in marine spatial planning (ex., marine protected areas).

Such information may influence the decision to implement, or not, spatial management instruments (Daw, 2008). Furthermore, if it is determined that a given fishery experiences great fishing density, such as Puerto Rico’s commercial small-scale fisheries, it is then
vital for fishery managers to investigate whether or not overfishing is occurring (Dunn et al., 2010). Thus, the integration of the spatial description of use of any fishery into the management decision-making is crucial for the effective administration of the fishery resources, and for the reduction of conflict surrounding the use of such resources (Guillemot et al., 2009; Aburto et al., 2009; Salas et al., 2007). The spatial characterization results, generated within the present thesis in the fisher density and possible annual fishing intensity maps, contribute indispensable preliminary findings regarding the spatial distribution of gear use in Puerto Rico. The maps created as part of the thesis delineate key environmental and physical features (i.e. bathymetry contours, benthic habitats), and further detail how gear usage is allocated among different water depths and habitats. In essence, the outcomes of the thesis analyses provide the base for future research.

However, the maximum fishing grounds and possible annual fishing intensity maps also raise several questions. For instance, how is it possible that, in certain areas, SCUBA diving takes place in waters deeper than 100 meters? Along the north coast, from Vega Baja to Fajardo, SCUBA fisher densities are found along the insular shelf drop-off delineating the 500 meter bathymetry contour. The fact that SCUBA and certain net gear usage were reported by the fishers in waters deeper than 100 meters seems quite unlikely, due to the maximum depth that divers can reach using SCUBA.

Therefore, a possible explanation for such unusual results may be attributed to map bias and map generalization. Essentially, map bias encompasses the different types of data errors that result in the data gathering process. Such errors may arise during the
identification of fishing areas by the fishers on hard-copy paper maps (Close and Hall, 2006). Given that method of collecting the spatial data was exclusively through the use of paper maps, map bias might in fact be responsible for the errors described for the SCUBA and net gear use. During the interview process, the majority of fishers claimed to not own any kind of global positioning system (GPS), nor were most of them familiar with a gridded paper map detailing four different levels of bathymetric contours. Close and Hall (2006) agree the fact that many fishers are not acquainted with using nor completely understanding topographic maps. Thus, when asking the fishers to point on the map to delineate the area of usage for each gear used by the interviewee, many would show the location of usage without asking the interviewer any questions. However, only a few interviewees would ask questions as to which contour line referred to which depth.

Also, the majority of fishers named certain fishing areas, such as Bajo de Sico and Corona del Medio (within the Mona Passage), Isla Caja de Muertos (off Ponce), and Cayo de la Margarita (off La Parguera, Lajas). While the map delineated many environmental and physical features, none of the features were named or labeled, in order to avoid cluttering the map. Thus, the issue of map generalization, which refers to the degree that key features are omitted from the map, employed to deal with scale and visual clutter, seems to have affected some of the responses by the interviewees. In the case of the SCUBA and net gear usage, the fact that the water depth was not labeled on the contours may have led the fishers to interpret the water as being shallower in certain areas than it really was. Additionally, the benthic habitats were not displayed on the paper maps. Therefore, fishers that in fact rely on the specific habitats may have estimated the
distance between areas based on their location relative to the coastline or nearby islands. For instance, dive gear usage delineation within the eastern coast, in the area from Fajardo to Culebra, may be partial since the coral reef tract that spans from Fajardo’s coast to Culebra was not shown. Instead, several fishers indicated that they fished along the beril (insular shelf drop-off), which, in this case, instead of referring to the insular shelf, may have referred to the reef tract, which may define a beril that is shallower than 100 meters and was not indicated on the map. The issue may also have been the scale of the map used; a much larger and detailed map could have been used to gather more precise information.

Nevertheless, map generalization is not limited to shallow, insular waters. Line fishers, especially along the northern coast, specified trolling gear use along offshore waters. Given the nature of the open expanses of offshore waters, and because land is not visible and no other reference points exist, large “unreferenced areas” impede the precise delineation of fishing areas (Close and Hall, 2006). Many trolling fishers indicated how far from shore they usually fished. The lateral boundaries were indicated by the respective municipality; for example, the fisher might indicate that he or she fishes up to 30 miles from the shore, from Arecibo to San Juan. Thus, the outermost boundaries of each municipality were used as the east-west boundaries of the fishing area. In order to avoid the errors arising from “unreferenced areas,” Close and Hall (2006) encourage the use of travel times and map grids. While the map grid was implemented during the development of the paper maps, travel times were not provided by the fishers in reference to the distance. However, many trolling fishers did provide the maximum distance from
shore travelled, which was recorded on the maps and later drawn to scale within the geographic information systems (GIS) program. Furthermore, even though face-to-face interviews were conducted, as is recommended by De Freitas and Tagliani (2009), the errors associated with map bias and map generalization were not completely prevented.

Since both map bias and map generalization errors were present, up to a certain extent, in the fisher density and possible annual fishing intensity maps, the Ordinary Least Squares (OLS) regression values were likely affected by such issues. Also, the size of each individual cell within the grid is approximately 1.55 squared-miles, and several habitat features are smaller in area than the size of the cells. Thus, since the OLS analysis, executed using GIS, was performed cell-by-cell, the map bias and generalization errors may have been compounded to artificially weaken the correlation factor between gear usage and water depth, and among gear use and benthic habitat type. The extent to which the OLS results were negatively affected is not known, further research is warranted. However, the correlation values determined as part of the analysis, when taken within the context of the gear usage bar and pie graphs, provide strong evidence that water depth and habitat type may indeed dictate the use of certain gear types.

Dive gears show a strong affinity for shallow waters, coral reef and seagrass habitats. Trap and net gears follow a similar pattern of use to dive gears; nevertheless, net and trap usage is not strictly limited to shallow waters, given that close to one-third of the use of such gears takes place in waters deeper than 100 meters, but shallower than 500 meters. Again, these results are corroborated findings from Agar et al. (2008), which describe the use of trap gears in deeper waters along the insular shelf. In contrast, line
gear usage does not present a strong relationship with the benthic habitat and bathymetric range variables. The large variety that exists within the line gear class, made up of 11 different gear types, may explain the widespread use among different water depths, and across all habitat classes. However, it may well be that line gear usage tends to target specific species, rather than target several species present at a given habitat or depth range. While the other gear categories contain less variety of individual gears (net gears: nine gear types; dive gears: three gear types; trap gears: two gear types), the relationship between gear use and the environmental and physical variables may be stronger than with line gear usage not because of the relative lack of gear diversity, but rather by the species groups targeted. Line gears may target pelagic species more than do the other gears; meanwhile, the other gear categories may target less mobile and demersal species, which, according to Parrish (1982), are more prevalent among coral reef habitats. Thus, even though benthic habitat and water depth influence the deployment of net, dive, and trap gears more than line gears, there remains a strong likelihood that target species are also strong spatial gear-distribution factors.

Therefore, although the analysis identified slight degrees of errors stemming from map bias and generalization, the overall outcomes present promising evidence of the spatial distribution and characterization of gear use within Puerto Rican commercial and small-scale fisheries. Several clear patterns of gear use dependency on benthic habitat and water depth are described by combining all three sets of results, namely the fisher density and possible annual fishing intensity maps, the correlation results from the regression analysis, and the frequency distribution graphs. Only when all three series of
results are grouped and analyzed collectively can a holistic understanding of the spatial distribution of gear usage be determined. Importantly, the findings uncovered within the current thesis should be considered preliminary, and further research is needed to better understand the spatial relationships between the marine environment and the gears employed within such areas.
Chapter 5.0: Conclusion and Recommendations

The findings provided in the current thesis, even though preliminary in several respects, contribute greatly to spatially characterizing the Puerto Rican small-scale fisheries, which have received scant attention within the existing academic literature. While several studies have explored various fisheries aspect in Puerto Rico and the Caribbean, little research has been dedicated, at least in part, to understanding the spatial distribution of fishing activities in Puerto Rico (e.g. Agar et al., 2008; Dunn et al., 2010; Griffith and Valdés-Pizzini, 2002; Tonioli and Agar, 2009). The present thesis is the first study devoted entirely to investigating the gear usage dependency on benthic habitat and bathymetry. Also, the findings generated by the current thesis corroborate the results from the academic literature. Furthermore, the data generated within the present study can serve as a benchmark for future research, and as the basis for developing a regional geographic information systems (GIS) database for Puerto Rican fisheries. Some academic papers stress the need to develop a GIS-based databank for easier dissemination and analysis of related fisheries data, and to aid fisheries and environmental management decisions (De Freitas and Tagliani, 2009; Nelson et al., 2009). Thus, the spatial characterization of the commercial Puerto Rican fisheries developed within the current thesis provides the foundation for such needed database in Puerto Rico.

Also, the products of the study provide support to the body of academic knowledge surrounding the use of GIS for the gathering and integration of local knowledge (LK) with scientific and academic knowledge (SK) (Close and Hall, 2006; De Freitas and Tagliani, 2009; Hall et al., 2009; Scholz et al., 2004). The methods and data
collection process employed in Puerto Rico was simple and highly effective in obtaining the necessary spatial LK possessed by the local fishers. Even in light of the limitations derived from utilizing a generalized paper map of Puerto Rico for the data gathering, namely map bias and generalization, the study was able to capture and spatially characterize the usage of gear categories among benthic habitats and bathymetric contours. Essentially, GIS was the ideal tool for processing the fishers’ LK and producing information that is compatible with the existing SK. By converting the fishing areas described by the local fishers into spatially-referenced computer maps, and by organizing the derived quantitative data into tables and graphs, the resulting information is available in a format that is practical for fisheries management and further academic research.

While GIS proved to be an excellent tool for the transformation of LK into an academically usable format, it is important to recognize the role of the Puerto Rico fishers in providing such ecological and resource use knowledge. Fishers in other geographic areas, such as Brazil and Thailand, are recognized to hold essential knowledge regarding not only the fisheries resources, but also the ecology of the local environment (Anuchiracheeva et al., 2003; De Freitas and Tagliani, 2009; Hall et al., 2009). Fisheries managers should strive to incorporate the LK of fishers, in order to facilitate the administration of such resources, including the spatial management of fisheries (Scholz et al., 2004). García-Quijano (2007) found that fishers’ LK is vital for managing uncertainty and complexity within the ecosystems of the local environment in southeastern Puerto Rico.
Throughout the course of the data gathering session of the present thesis, the fishers interviewed provided the desired spatial information; however, several fishers detailed seasonal variations in the availability of certain fish species, the best areas of where to employ a given gear type, decadal variations in the activity of fishes and fishing, the behavior of marine species, and socio-political issues regarding the local fisheries. For instance, several line fishers know the best months when the targeted pelagic species migrate through their fishing areas. Other line fishers described the methods for fishing at night, and what moon phases yield the best opportunities for good fishing sessions. Many divers provided anecdotal information as to the changes in the local coral reef structures that have occurred over time. Numerous trap fishers indicated the presence of trap theft, which some suspect can be attributed to some commercial divers, which may point to possible conflict between two commercial fisher groups. Trap theft has also been documented in other parts of the Caribbean, for example, in the Nicaraguan spiny lobster fishery (Daw, 2008). Large groups of fishers have pointed to the need of regulating seafood imports, which some say undercuts the local fishing activities. Furthermore, several commercial fishers have expressed concern over the nonexistent regulation of the recreational fisheries, with some fishers making anecdotal claims that recreational anglers catch large amounts and sell the catch in order to offset the trip costs. Thus, local fishers not only possess vital local spatial and environmental knowledge, but also vital socioeconomic, political, and anthropological insights. As such, further research should aim to continually gather and integrate the local knowledge of fishers within Puerto Rico and elsewhere.
In Puerto Rico, the usage of three gear types, namely the trap, dive, and net gears, are dependent to some degree on the benthic habitat and bathymetry of the fishing area. The limited habitat discrimination of coral reefs should be highlighted in that the mapping of gear-based fishing grounds and gear use intensity show a heavy use of reef based resources by trap, net, and dive gears. As such, there is a need to finely resolve coral and coral associated habitats, as well as determine targeted coralline fishery resources for effective management. Nevertheless, groups of target species may also factor into the fisher’s decision of where to deploy the gear. Line gears, as a gear class, show the highest level of diversity of use, with weaker relationships between usage and the specific features of the marine environment. Thus, it is highly possible that line gear utilization depends to a higher extent on the specific target species. For instance, trolling gears tend to target migrating pelagic species, which explains the line gear use in offshore waters of the south and north coasts of Puerto Rico. Deep water snappers and groupers, found in the waters of the Mona Passage, are targeted by the vertical line fishery of the west coast, accounting for the widespread line gear use within the passage. Therefore, line gear usage may rely much less on the benthic habitat and specific water depth, and more so on the specific species targeted. Since pelagic species migrate, the use of line gear may not be as spatially limited as the usage of the other three gear categories, which are more passive in nature. Given the relatively low mobility of the gears, and of the species groups that nets, traps, and divers target, which are mainly reef and demersal fish, the type of habitat and the depth of the water may limit the extent to which the gear may be used. The patterns of gear use by habitat and bathymetry described within the results
provide the foundation for subsequent catch data analysis. The delineation of fishing grounds and intensity by gear type or category can be linked to catch and landings data to further understand the dynamics and the spatial structure of Puerto Rican commercial fisheries.

Also, regional variations in gear use seem to be linked to the geographic and environmental differences among them. For example, the southwestern quadrant is a highly productive area for all kinds of gear, especially dive and net gears, possibly due to the large insular shelf area with shallow water and abundance of coral reef and seagrass habitats. The northern coast, in contrast, experiences more line gear usage than any other gear class, likely due to the narrow insular shelf with small productive habitats (e.g. coral reefs and seagrass beds), and deep open water near the shoreline, where many pelagic species migrate through. Nevertheless, future research is warranted for investigating the relationships between gear usage and marine resources. Furthermore, the gear use data is a snapshot in time, and gear use patterns may change over time given the economics of gear deployment and the availability of fishery resources and their profitability. However, the intensive data gathered can provide a reference point and monitoring data (e.g. every 5 years) by sampling gears across fishers to determine how gear numbers and use may fluctuate over time. Gear data indicates fishing effort; and therefore, needs be analyzed along with catch data.
Policy, management, and research recommendations:

- Collect and organize available spatial, socioeconomic, and ecological information into an open-access and publicly accessible database, as suggested by Nelson et al. (2009)

- Research further the relationship between gear use, benthic habitat, and bathymetry

- Continue to collect and process local ecological knowledge from local fishers, through the use of paper maps that include vital landmarks and names of important places identified by fishers

- Conduct studies aimed at understanding the other socioeconomic, political, and cultural issues present in the fishing communities (i.e. management of recreational fishing sector, effectiveness of commercial fishing regulations, conflicts between commercial fisher groups, trap theft)

- Continue integration of fisher ecological knowledge with academic knowledge, as well as the incorporation of local fishers in the management of fisheries and local marine resources
Works Cited


Caribbean Fisheries Management Council (CFMC). (1996). Regulatory Amendment to the Fishery Management Plan for the reef fish fishery of Puerto Rico and the United States Virgin Islands concerning red hind spawning aggregation closures including a regulatory impact review and an environmental assessment.


Appendix A: Detailed Description of Data Encoding and Data Analysis

Prior to creating the layer files for each individual fisher, the base layers of Puerto Rico were imported into the map file. The following base layers were loaded and displayed prior to the digitization of the spatial data from the fieldwork:

- Puerto Rico (divided into the 78 municipalities), including Mona and Monito islands, and Desecheo
- Coastal municipalities (41, excluding Guaynabo), including Vieques and Culebra
- Four contour lines (100 meter, 200 meter, 500 meter, and 1,000 meter isobaths)
- Benthic habitats (divided into categories: e.g. coral reefs, mangroves, mud, sand)
- Small islands and cays (southern Puerto Rico)
- Small islands and cays (eastern Puerto Rico)
- Master grid (same grid used in the paper maps)
- Southwester buoys (Buoys 2, 4, 6, and 8; off Cabo Rojo’s coast)
- Marine reserves and protected areas (including buffers around Mona, Monito, and Desecheo)

In order to create individual layers for each fisher, an empty layer was created by copying the master grid layer, since the attribute table of the grid layer contains all of the cells within the grid already coded so that each cell in the attribute table matches the correct cell in the grid. This allowed for the input of new data in the layer without having to resort to ArcCatalog to create a new, empty layer, and populate it with the master grid data for each of the 359 individual fisher layers. The attribute table of the new layer was
then prepared, and a column was created and coded for each particular gear that the fisher in question possessed. For example, if fisher 001 owned and operated a vertical anchored long-line and SCUBA gear, then a column would be created for each gear, and coded accordingly. There are 26 gears in total, and each gear has its own code. In the example, the attribute table would then have two new columns, one for Gear 02 and one for Gear 21. Line gears are coded from 01 to 11, net gears were coded from 12 to 20, diving gears represent 21 to 23 in the code, and traps were coded from 24 to 26. The coding system was employed to provide uniformity to the data, and to reduce possible spelling mistakes and inconsistencies for all 359 survey maps.

Once the new layer and the attribute table were coded and prepared, an individual fisher’s data were input into the new layer by using the Editor tool, selecting the new layer, and highlighting and selecting each individual cell in the grid to match the fishing ground delineated by the fisher in the paper map. For fishers that had more than one gear, the Editor tool highlighting process was repeated for each separate gear, until the file contained the separate gear data for the individual fisher layer file. The Editor method was employed until all 359 fisher layer files were complete.

The data was then aggregated by gear type into single gear-type layer files. That is, all of the Gear 01 data was input into a new empty master grid file, resulting in the layer having an attribute table populated with the grid information and only the Gear 01 data for all fishers that used Gear 01. This process was repeated for all 26 gears, which produced 26 separate layers with the aggregate data for each individual gear. The gear data was then exported to a Microsoft Excel workbook, in which the data for each gear
type was displayed in its own spreadsheet. Thus, the workbook contained 26 different
spreadsheets, each representing one gear type. The data was then combined and
multiplied with another data set, containing the number of annual trips taken by each
individual fisher per gear. The data for each individual gear was then added using the
summation (SUM) function in Excel, producing total number of annual visitation trips for
each gear type for each cell within the grid. These totals actually represent the total
possible annual visitation trips per gear type for each individual cell. Thus, each gear-
type spreadsheet contained the total possible visitation data per individual gear type for
each cell. This data was then imported back into ArcGIS, and each gear layer contained
the total possible annual fishing visitation data.

Additional steps had to be performed prior to any spatial statistical analysis.
Specifically, an Intersect function was performed by inputting the mater grid layer and
the benthic habitat layer. The Intersect resulted in a new layer consisting of the overlap
between the grid and the marine habitats, with an attribute table containing both the grid
cells data (cell ID and cell index ID) as well as the benthic habitat data (e.g. habitat
description), in addition to the area expressed in square meters. In order to prepare the
bathymetry layer for the Intersect function, the Editor tool was employed to “close-off”
each corresponding contour line (e.g. 100 meter line with the matching 100 meter line),
essentially creating closed contour lines. In order to convert the contour lines into
polygons, the Polyline-to-Polygon Convert tool from the ET GeoWizard toolbox was
used, producing one layer with separate polygons for each bathymetry constant, enabling
the selection of all bathymetry polygons by a simple Query function from the layer
properties window. The new bathymetry polygon layer was then intersected with the master grid layer using the Intersect tool, resulting in a new layer showing the bathymetry polygons within the appropriate cells from the grid, and complete with the spatial data from the master grid, the bathymetry, and the area (again expressed in square meters).

In preparation for the spatial statistical analysis, the total annual fishing visitation table for Gear 01, from the Excel workbook, was joined to the master grid via the Join Attributes function. Then, the habitat-intersect layer was also incorporated into the master grid layer using the Join Attributes function, and using the ET_Index (an individual number code for each individual cell in the grid, generated by ArcGIS) as the common feature for the joining operation. The master grid, the individual gear annual visitation trip tables, the habitat-intersect layer, and the bathymetry-intercept layer are all divided into individual cells with a corresponding code, listed under the ET_Index column of the attribute tables. Given that the same grid, and thus the same ET_Index for each individual cell, was used for all layers and tables, the ET_Index was the ideal ID-index attribute for the Join Attributes operation. Having joined both the Gear 01 table and the habitat-intersect layer to the master grid, the data from the master grid layer was exported by employing the Export Data option from the File tab, and a new individual gear grid layer was created from the Export function. The Export Data function allowed for the creation of a new individual gear grid layer, with the joined data already incorporated, and any values that showed up as “<Null>” on the attribute table of the original master grid layer were automatically converted to zeroes (0), wherever the column contained numerical values.
Having prepared the individual gear grid layer for analysis, a simple regression test, using the Ordinary Least Squares regression tool from the Spatial Analyst toolbox, was performed for each gear to determine if a relationship exists between gear used and benthic habitat. This resulted in a new map layer with each cell color-coded by the standard deviation of the regression performed. Also, a window displaying the statistical results, summary, and notes of the regression analysis shows up after performing the regression, from which the Multiple-R Squared values were recorded on a table in a new Excel Sheet dedicated exclusively to the OLS results. Once the OLS results were recorded, the window was closed in order to view the created regression layer. It is important to note that after each regression layer was produced, the exported individual gear grid was removed, and the habitat-intersect layer and the given annual visitation gear table had to be un-joined from the original master grid, in order to be able to reuse the master grid layer for the same purpose. The exact same process was performed for each individual gear type, from Gear 01 to Gear 26. Gear 04, Gear 06, Gear 07, Gear 11, Gear 15, Gear 16, Gear 18, Gear 19, Gear 20, Gear 23, and Gear 25 were not statistically tested using the Ordinary Least Squares regression tool, since less than ten fishers use each of these gears. Most of the excluded gears were fished by only one or two fishers, thereby rendering the regression test useless for those gears. The exact same layer preparation and regression analysis process was followed for the four gear categories (i.e. lines, nets, diving gears, and traps), again excluding Gear 06, Gear 07, Gear 11, Gear 15, Gear 16, Gear 18, Gear 19, Gear 20, Gear 23, and Gear 25 from the regression test.
Furthermore, a similar layer preparation process was performed for the regression analysis for gear-type and depth. The original master grid was cleared of any previously-joined layers and tables, and any other exported gear grids were removed from the Layer View window. Then, the total annual fishing visitation table for Gear 01 was joined to the master grid utilizing the Join Attributes function, and choosing the ET_Index as the common feature to join the layer and the table. Having incorporated the Gear 01 data into the master grid layer, the bathymetry-intersect layer was then joined to the master grid by employing the Join Attributes function, and again, using the ET-Index as the common join attribute. The master grid was then exported via the Export Data tool. Once the newly-exported individual grid layer was added to the map, the attribute table of the new layer was opened and the Select by Attributes function was employed to select all of the records in which the Contour column had a value of zero (0). This selection described all of the cells outside the bathymetry-intersect polygons, and represents waters deeper than 1,000 meters. Having selected such records, the top row of the Contour column, where the name of the column is displayed, was highlighted by right-clicking it and a drop-down menu appeared next to the column. The Field Calculator tool was selected from the menu, and the Contour attribute was made to equal negative two-thousand (-2000), in order to assign a valid numerical value to the waters deeper than 1000 meters.

Once all of the zero (0) records in the Contour column were changed to negative two-thousand (-2000), the individual gear grid was ready for the Ordinary Least Squares regression analysis. The same OLS process that was applied to the individual gear grid with the habitat-intersect layer data, was applied to the individual gear grid with the
bathymetry-intersect information. Gear 06, Gear 07, Gear 11, Gear 15, Gear 16, Gear 18, Gear 19, Gear 20, Gear 23, and Gear 25 were all excluded from the regression test, since less than ten fishers utilized each gear. Furthermore, the same grid layer preparation and OLS method was utilized for testing the regression for categories of gears and depth; thus, individual gears were grouped according to the category (lines, nets, diving gear, and traps), and excluding Gear 06, Gear 07, Gear 11, Gear 15, Gear 16, Gear 18, Gear 19, Gear 20, Gear 23, and Gear 25 from the analysis. The Multiple-R Square from the individual gear and gear category regression analyses were recorded in the OLS results Excel table.

Following the initial regression analysis, and having un-joined all of the layers, the Gear 01 total annual fishing visitation table and the habitat-intersect layer were again joined (using the Join Attributes function) to the master grid layer. Once joined, the attribute table of the master grid layer was opened, and a Count Sum function was performed, which produced a Sum Output table summarizing the number of possible annual fishing visitation trips for all cells per given habitat type. A new Excel sheet was created, with a column for gear type, and separate columns for each habitat type. The data from the Sum Output table was copied and pasted in the corresponding gear type row, under each habitat type column. Again, it is important to note that in order to reuse the master grid layer, after each Sum Output table was produced, the layers were un-joined. The entire process of joining layers and producing the Sum Output tables was repeated for each gear type. Additionally, the same process was duplicated for each gear type; however, instead of joining the habitat-intersect to the master grid layer, the bathymetry-
intersect layer was joined. As with the habitat-intersect procedure, it was repeated for each gear, until all 26 gear Sum Output tables were produced and transcribed onto a new Excel sheet with the gear type column, and the bathymetry category columns (e.g. 0-100 meters, 101-200 meters, 201-500 meters, 501-1,000 meters, and More than 1,000 meters).

Once all of the Sum Output data was in corresponding column and row, for all gears and for each habitat type and bathymetry range, a total column was added to the habitat spreadsheet, as well as for the bathymetry spreadsheet. The total number of trips per gear for all habitat types was calculated in the new total column, using Excel summation (SUM) function; the same procedure was used for calculating the totals for the bathymetry data. Additionally, in each respective spreadsheet, new columns with the same category headings were created, and percentages for each category was calculated by dividing the number of trips for each habitat category for one gear by the total number of trips for that given gear, and multiplying the quotient by 100. This process was executed for each gear type and for each habitat category. A total percentage column was then created and all percentages for each gear were summed using the summation (SUM) function in Excel, to verify that the percentages did, in fact, add to 100. Again, the same exact method was employed to display and calculate the percentages for the depth ranges and gear type. Using the raw trip numbers, as well as the percentages, bar graphs were created for the purpose of illustrating possible trends in the data. However, in order to better display the data, and due to visual space constraints, the gear types were grouped according to gear category (line gears, net gears, diving gears, and traps), without excluding any gears, as was done with the spatial statistical analysis of the GIS-portion of
the analysis. Even though the spatial data was analyzed following two long, yet simple, procedures, the ensuing results shed light on the complex patterns of gear use, and of the intricate relationships between habitat type, water depth, and gear type utilized in Puerto Rico’s commercial fisheries.
Appendix B: Fishing Grounds and Additional Maps

Fishing grounds maps for all other gears not displayed within the “Results” section are illustrated within the present section. However, only gears that were fished by five or more fishers are shown due to confidentiality concerns.

Figure B.1: Benthic Habitat of Puerto Rico Map

Legend

Puerto Rico Benthic Habitat

Habitat Category
- Uncolonized Hardbottom
- Submerged Vegetation
- Coral Reef and Colonized Hardbottom
- Mangroves
- Unconsolidated Sediments
- Other/Unknown
- Puerto Rico Municipalities

N

0 10 20 30 40 50 60 70 80 Miles
Figure B.2: Puerto Rico Benthic Habitat: NE Coast
Figure B.3: Puerto Rico Benthic Habitat: SE Coast
Figure B.4: Puerto Rico Benthic Habitat: SW Coast
Figure B.5: Puerto Rico Benthic Habitat: NW Coast
Figure B.6: Gear 05 (Horizontal Longline) Fishing Grounds Map
Figure B.7: Gear 10 (Rod and Reel) Fishing Grounds Map
Figure B.8: Gear 17 (Beach Seine) Fishing Grounds Map
Figure B.9: Gear 22 (Skin Diving) Fishing Grounds Map
Figure B.10: Gear 23 (Other Diving: Ornamental Fishery) Fishing Grounds Map
Figure B.11: Gear 26 (Lobster Trap) Fishing Grounds Map